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ENGINEERING GEOLOGIC FACTORS OF THE MARBLE AREA GUNNISON COUNTY, COLORADO

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INTRODUCTION

This reconnaissance engineering geology study of the Marble Area in Gunnison County, Colorado by the Colorado Geological Survey delineates several geologic factors which could adversely affect future development in the area. The area presents timely problems concerning the interaction between future development demands, geological and engineering factors, economic feasibility and land use decisions in the public and private sector. Development pressures derive from several sources. Colorado has a strong and growing demand for recreational areas. This area affords unparalleled natural beauty. Precipitation patterns, as well as the variety and steepness of slopes, appear generally favorable for skiing. A large block of privately-owned land is available for development of base facilities adjacent to Forest Service lands which might be available for ski area expansion and recreational use. On the other hand, several geologic factors provide development and engineering problems. Both Slate and Carbonate Creeks historically produce frequent and damaging floods and mudflows. Previous published maps of the U.S. Geological Survey indicate large areas of landslides. The soft, weak bedrock of the area combine with steep terrain and high moisture content to cause general slope stability problems. Delineating and evaluating these significant favorable and unfavorable conditions constitutes the problem. The cost of planning and engineering solutions to geologic problems, and the carrying capacity of the land, must be carefully balanced against economic considerations if a sound and viable plan of development is to be devised for the area. This report describes some of the adverse geologic conditions of the area, and evaluates some of the hazards in terms of possible area development.

Under the legislative charge to the Colorado Geological Survey to "determine areas of geologic hazard that could affect the safety of or cause economic loss to the citizens of Colorado," and "to evaluate the physical features of Colorado with reference to present and potential human and animal use," an extensive reconnaissance investigation of the Marble area has been performed by staff members of the Colorado Geological Survey. The investigation, to date, has consisted of a study of the available historical and geologic records of the Marble area, photogeologic evaluations, and reconnaissance field work in the area. The investigation to the present time has included 12 man-days of field work. Approximately 20 days of office time were spent in detailed photogeologic studies, literature research, interpretation of the collected data, and preparation of the report.

LOCATION AND BRIEF HISTORICAL SKETCH

The area covered in this report is located on the Crystal River in northern Gunnison County, Colorado. With the exception of private lands, the area is entirely within the White River National Forest. The approximate boundary of Forest Service land is indicated on plate 1. The Maroon Bells-Snowmass Wilderness Area is adjacent to the northeast. The area between private lands and the Wilderness Area is classified as "undeveloped" on the U.S. Forest Service inventory map of Colorado. Primary interest of this study is focused on the watersheds of Slate

Creek and Carbonate Creek. Both creeks are south-flowing tributaries of the Crystal River in the vicinity of the old Marble townsite. The area of interest also includes some lands adjacent to the Crystal River which are in other drainage basins.

Access to Marble is by way of Colorado Highway 82 from Glenwood Springs to the vicinity of Carbondale, then via Colorado Highway 133 to the vicinity of Placita. From the junction south of Placita, Marble is reached by following a gravel road approximately 6 miles east along the Crystal River.

The name of this community is derived from the marble producing and processing industry which operated with varying degrees of success between 1880 and 1941. Production was from high quality marble deposits which are located on Yule Creek approximately three miles southeast of the townsite. The marble deposits consist of metamorphosed Leadville Limestone which occurs on the southwest flank of the Treasure Mountain Dome. The town and its marble industry reached maximum development immediately before the start of World War I when Marble attained a population of about 1500. The marble works, and with it the town, declined between the World Wars and finally closed after the mud flood of 1941. After 1941, the town rapidly dwindled to the extent that it was considered essentially a ghost town. Since the demise of the marble industry, the area has reverted to a ranching economy with some business related to summer residents and tourists.

GENERAL GEOLOGIC AND GEOMORPHIC SETTING

The area encompassed in this report is entirely within the Marble 7½ minute topographic quadrangle map. It is located in the Elk Mountains of Western Colorado, approximately 35 airline miles south of Glenwood Springs. The area of primary interest consists of the combined watersheds of Slate Creek and Carbonate Creek. This basin forms a southwest-facing bowl having an area of approximately 4000 acres. The Slate Creek drainage, which consists of only about 600 acres, exerts a significant influence on the area because it heads in the rapidly wasting Gallo Bluff area which feeds the Slate Creek mudflows. It seems quite probable that in the geologic past, Slate and Carbonate Creeks were part of the same stream system which contributed to the early growth of the major mudflow fan. The Slate-Carbonate drainage basin descends from an elevation in excess of 12,000 feet at the basin rim to approximately 7,950 feet on the Crystal River near Marble. A portion of the area upstream from the mouth of Carbonate Creek is drained by small tributaries of Lost Trail Creek. An area on the north side of Crystal River and west of Slate Creek is drained by several small intermittent streams which are direct tributaries of the Crystal River. The area south of the Crystal River is drained by Yule Creek, Raspberry Creek, Milton Creek and several short direct tributaries of the Crystal River. ESSA precipitation charts indicate an annual rainfall of approximately 30 inches, with the major rainfall occurring during the peak thunderstorm season of July and August. All mud floods which we have been able to fix in time have occurred in July or August.

Bedrock geology of the area is complex, but the area is underlain for the most part by strata of the Mancos Shale and Mesa Verde Formation, both of Cretaceous age. Structurally, these strata occur along the northwest-trending axis of the broad Treasure Mountain Dome which lies to the southeast. The Mancos Shale underlies most of the area, with Mesa Verde strata cropping out high on Gallo Bluff and in a narrow band south of the Crystal River. The Mesa Verde also probably subcrops beneath the extensive talus debris north of the Crystal River in the vicinity of the landing strip. There is intensive minor faulting and shattering of the Cretaceous strata in Gallo Bluff - a condition which presumably extends under the landslide, colluvial, mudflow, and other surficial deposits which mask the bedrock surface over most of the area between Gallo Bluff and the main mass of Treasure Mountain Dome east of Marble. Porphyritic intrusive rocks occur within the area, on both sides of the Crystal River west of Marble in the vicinity of the landing strip. These outcrops consist of the adjacent synclinal limbs of the Raspberry Creek Phacolith. Other intrusive igneous rocks occur in the upper reaches of Carbonate Creek, along with Pennsylvanian sedimentary strata. These rocks have been thrust over Cretaceous beds along the Elk Range Thrust Zone. Igneous rocks of minor importance occur as occasional dikes cutting the Cretaceous strata.

Surficial deposits of the area, with which much of the report is concerned, are also complex but are much younger, being of Pleistocene and Recent age. These deposits consist of residual soils formed on Mancos Shale, talus and other colluvial soils, landslide and mudflow deposits, and older morainal material which occurs as discontinuous deposits mostly on the higher slopes.

Geomorphic evolution of the area has been affected by rock type and structure, by multiple glaciation during Pleistocene time, and finally by intensive fluvial action and vigorous mass wasting. The vigorous fluvial and mass wasting processes which have dramatically modified the area since the last glaciation are continuing, and are closely related to the geologic hazard conditions outlined in the ensuing report.

SOURCES OF DATA

Photogeologic Studies

Photogeologic studies utilized five different sets of stereoscopic aerial photographs, taken at intervals between 1945 and 1971. Scale of the various sets of photographs varies between 1:70,000 and 1:12,000. In addition to stereoscopic study, single frame oblique photos taken by the U.S. Forest Service were examined. Black and white Polaroid photographs and 35 mm. color slides were taken to depict and document field observations. Some of these photos are included in the report, and others which are considered a part of the report are available for inspection at the office of the Colorado Geological Survey. Comparison of the aerial photographs of different vintages afforded considerable insight into ongoing geologic processes such as the frequent mudflows which have occurred on Slate and Carbonate Creeks.

Geologic Literature

The earliest available geologic study covering the Marble area is contained in Chapter IV of the Annual Report of the U.S. Geological Survey for the year 1876. This report entitled, "Geology of the Northwestern Portion of the Elk Range," was written by W. H. Holmes of the Hayden Expedition. The Holmes report consists of a geologic reconnaissance traverse along Rock Creek (Rock Creek is the older name for the Crystal River). The report includes observations in the Marble area and adjacent areas along the Crystal River. Most recent and detailed published geologic literature of the area is the U.S. Geological Survey geologic map of the Marble 7½ minute quadrangle, by Gaskill and Godwin, 1966. Other geological reports which were useful in filling in the regional geologic setting include U.S. Geological Survey Bulletin 884, (J. W. Vanderwilt, 1937), entitled, "Geology and Mineral Deposits of the Snowmass Mountain Area, Gunnison County, Colorado," and several recent USGS quadrangle maps of areas adjacent to the Marble quadrangle.

Miscellaneous Sources

A reconnaissance geologic and soils investigation covering portions of private lands in the Marble area, dated September 9, 1970, was studied. This report was prepared by R. C. Hepworth of Chen & Associates, soils consultants for Marble Ski Area, Inc., Larkspur, Colorado. John Rold, W. P. Rogers and R. H. Pearl of the Colorado Geological Survey spent a day in the field with Mr. Hepworth, engineering geologist and soils engineer with Chen & Associates, and Mr. Weixelman of the development firm. Certain aspects of the Marble region were also discussed with Ron Russell and Cliff Hunt of the Division of Watershed Management, U.S. Forest Service. Hydrologic and soils reports by Hunt and by Nishamura of the U.S. Forest Service were also examined. Some of the problems of the area were discussed with Mr. Dave Gaskill, who mapped the Marble quadrangle for the U.S. Geological Survey, and with Mr. Peter Wingle of the U.S. Forest Service, Recreation Planning and Administration Branch.

Historical Records

Several sources were drawn upon for historical data of the Marble area. Most useful was the excellent and thoroughly-researched volume entitled, "Marble, Colorado: City of Stone" by Vandenbusche and Myers (Golden Bell Press, 1970). Other useful but less formal historical information is contained in, "Ghost Towns of the Colorado Rockies" by R. L. Brown (Caxton Printers, Ltd., 1969); "Crystal River Saga" by Teresa V. Francis (private printing, 1969); and "History of Marble, Colorado" by Ruby Isler (Reminder Publishing Co., 1964). Additional historical information was gained by conversations with long-time residents of the area.

ACKNOWLEDGMENTS

Land owners of the area were very courteous in giving us free use of trails, furnishing gate keys and other details which aided our field studies of the area. The U.S. Geological Survey lent us two sets of aerial photographs, and Mr. Peter Wingle of the U.S. Forest Service lent us his set of low altitude oblique photographs of the Marble area.

DESCRIPTION OF AREAS OF POTENTIAL GEOLOGIC HAZARD

Introduction

Major areas of known or suspected geologic hazard are listed and described below and shown on plate 1. The number in parentheses after each topic indicates the corresponding index number on plate 1. Some of the features mapped and discussed are based primarily on photogeologic studies, but nearly all were field checked by reconnaissance methods.

In describing these potential hazard areas, our intent is to bring attention to factors which we believe will have a significant impact on area development. Some impacts will be essentially economic - involving the cost of designing and implementing engineering solutions to unfavorable geologic conditions vs. the potential value of the land reclaimed. Other possible impacts involve situations in which engineering solutions or general construction activities attending development could affect adjacent lands or the Crystal River.

The specific areas designated and described in this report are those which our reconnaissance investigation indicated should be carefully evaluated both for engineering and economic feasibility, and for possible deleterious impacts within the area or on adjacent lands. We do not consider this a complete inventory of potential geologic problems of the area studied, nor do we believe that the problems described are necessarily insoluble. However, we do believe that any development of the area should proceed only with caution and with full knowledge of geologic conditions within the entire area of intended development and its environs.

This investigation is not intended to be either comprehensive or final. Our intent is to focus attention on some of the typical engineering geology problems that can be expected in extensive development of an area such as Marble, where much of the terrain is precipitous and geologic processes are complex and vigorous. The specific areas upon which we have focused our field investigations are either areas of known, but potentially serious geologic phenomena - such as the mud floods that have occurred periodically on Slate and Carbonate Creeks during historic times - or major features which were discovered during photogeologic and field studies of the area. We believe that before extensive construction is undertaken in the area, much more extensive and detailed engineering geology studies would be advisable.

Although the information contained in this report is pertinent to any present or proposed planning for the area, we believe that it will be equally applicable to possible development during the foreseeable future - the problems implicit in safe and economically feasible development in areas of active mud floods, snow avalanches, or landslide masses will be essentially the same whether the development takes place today or 50 years in the future. It is our hope that the data of this report will contribute toward feasible development and sound land use practices for the entire Marble area.

Area East of Carbonate Creek on Slopes of Mt. Daly (1)

General Slope Stability

The entire area east of Carbonate Creek and north of Beaver Lake consists of steep to moderately steep slopes underlain by northwest-dipping Mancos Shale. The surface is mantled by residual and colluvial soils, landslide deposits, and glacial debris - all of highly variable thickness. Several small and medium sized active landslides are present along Carbonate Creek. These appear to have been caused by oversteepening of slopes by erosion as the channel of Carbonate Creek has rapidly entrenched itself across the area. The active or recently active landslides are designated 1a, 1b, and 1c. Two other much larger slide masses, designated 1d, and 1e, do not appear to be active at the present time. The larger landslides are not directly related to stream erosion as are most of the others.

These active and ancient slide masses indicate the marginal stability of slopes on this part of Mt. Daly. Any redistribution of stresses by excavation, increased erosion, placement of fill material or structures, or surface drainage changes, carries the risk of initiating new slides or reactivating old ones. These critical geologic and soil engineering factors must be recognized and taken into account in any development activity. Numerous seeps and slough areas aggravate the general slope stability problems of the area. Seeps are especially numerous in the vicinity of the very large older slide mass (1e). Before any sizeable concentration of buildings or other heavy structures is constructed on these slopes, foundation investigations should include evaluation of possible extensive slab slides which could develop on surfaces of weakness parallel to the slope such as the contact between mantle and shale bedrock. The usual analysis of the bearing capacity of individual shallow foundations would not preclude the possibility of deeper failure initiated by loading from a multiplicity of individual structures.

Road Construction

The Mancos Shale has posed serious stability problems in many Western Slope areas of Colorado. On nearby McClure Pass, south of Placita on Colorado Highway 133, a series of landslides has seriously affected the highway. Most of the slopes in this part of Mt. Daly are in the range of 30% to 60%. Stability of any cut slopes, which will have the effect of steepening existing slopes and "daylighting" weak surficial layers, will pose serious long range stability problems. The possibility of encountering swelling soils and seepage areas makes the stability of cut slopes even more of a problem. Although these conditions may not initiate massive sliding in construction of local roads, construction activity will cause intermittent and piecemeal sliding and sloughing of soil and unstable rock onto the roadway. The high maintenance and inconvenience of these processes can be expected to continue for years.

Scarp Slope East of Beaver Lake (1f)

Another potential problem area is the steep, barren scarp slope (generally consisting of 40% to 60% slopes) to the northeast of Beaver Lake and adjacent to the Crystal River. Development of such an area even in competent rock such as granite would be difficult. On this slope of fractured and rapidly wasting shale, development would appear to be very impractical. Although proper foundations might be obtained by careful geology and engineering, the problems of access and of erosion appear prohibitive. As in other areas of Mancos Shale, founding of homesites and other small structures may be difficult if the shales encountered have the expected swelling characteristics.

General Environmental Considerations of Mt. Daly Area

This area is part of the Carbonate Creek watershed which is well known for the serious mud avalanches and flash floods which it produces. Construction of roads, clearings for building sites or ski runs, excavation for utility lines, and similar construction activities are bound to increase peak flood runoff and sediment supply, both of which will intensify the existing problems of flooding and destructive mudflows. This will increase the hazard of flooding and erosion problems on the slopes of Mt. Daly as well as to existing homesites in the town of Marble. Reconnaissance studies by the U.S. Forest Service indicate that the revegetation potential of the shale-derived Mt. Daly soils is very limited, so the problems associated with excessive runoff and erosion and site grading would not be easily or quickly solved. In general, we believe this area is best suited for low density development, and with the least possible disturbance of the precarious slopes and natural vegetation cover.

Major Mudflow Fan Area (2)

General

This major feature is very evident on both topographic maps and aerial photographs because it has the classical form of an alluvial fan, (figure 1, plate 2, plate 3). It is called a mudflow fan in this report because it appears to be built almost entirely by a succession of mudflows with only minor and local reworking by running water. At the present time, Carbonate Creek is routed along the east margin of the older fan and Slate Creek runs along its west margin. It is virtually certain that in the geologic past both have contributed to the deposition of the older fan which is more than a mile wide, and estimated to be at least 175 feet thick near the Marble townsite. Deposition of this fan has deflected the course of the Crystal River southward, and mudflows have periodically dammed the river. Beaver Lake is a man-made enlargement of ponding caused by mudflows on Carbonate Creek. More detailed features of the main mudflow fan will be discussed separately below. Plate 3 is a detailed topographic map of the mudflow fan area.

Slate Creek Mudflow (2a)

Slate Creek enters the area near the apex of the major fan, and follows an entrenched course along its western edge (plate 1). This is a highly erosive channel, and the banks are oversteepened to the extent of being potentially very unstable, (figure 2). In the lower reaches, starting about 2,000 feet north of the Crystal River, the channel emerges from its entrenched course and numerous very recent mudflows have come down the deep channel and spread out over the gentler slopes north of the river. Detailed topographic maps and aerial photos show four well-defined modern distributary channels across the flood area (plate 3). The area involved in very recent mud flooding is approximately 2,000 feet in length and 500 feet in average width. Studies of aerial photographs of different ages show many changes of topography and vegetation caused by mud floods between 1945 and 1970, and local residents describe at least three mudflow events since 1965. We consider the entire area of contemporary mud flooding on lower Slate Creek to be unsuitable for viable residential or commercial development unless and until a workable, economical and environmentally acceptable solution to the problem of frequent mud floods is devised and implemented. Some of the factors which we believe will affect the engineering of possible control structures and the cost of their construction and maintenance will be discussed in a later section of this report. Figures 2, 3, 4, 5, 6, 7 and 8 depict the general appearance and condition of the Slate Creek mudflow terrain.

Carbonate Creek Mudflows (2b)

Carbonate Creek descends from a steep and sizeable drainage basin (approximately 3,500 acres) on the slopes of Mt. Daly and Elk Mountain, and follows a deeply entrenched and actively eroding channel adjacent to and east of the major mudflow fan. Just north of the Marble townsite, Carbonate Creek emerges from the steep-walled canyon it has cut into the Mancos Shale, and flows in a normal channel through the town to its confluence with the Crystal River. The area between the mouth of the canyon and the Crystal River has a history of similar but much larger mud floods than those described on Slate Creek (figure 9, and plate 1). The area affected by periodic recent mud floods from Carbonate Creek covers approximately twice the area of the Slate Creek flows (2b, plate 1). The most recent catastrophic mud floods on Carbonate Creek occurred in 1936, 1941 and 1945, and smaller floods are reported nearly every year. This area of active mudflow hazard is within the townsite of Marble; however, we believe that construction activities related to recreational, residential, or other development anywhere within the watershed of Carbonate Creek could profoundly increase the threat of mud and water flooding in the lower reaches of Carbonate Creek. In addition, it is possible that a major landslide from the slopes of Mt. Daly or the steep shale bluffs west of Carbonate Creek could divert the creek to another course over the older mudflow fan. Photogeologic studies and limited field inspection of the steep basin rim between the north end of Gallo Bluff and Mt. Daly indicate active as well as old mudflows and potential debris avalanches which are additional reasons for carefully evaluating the water and mud flood potential of the entire drainage basin as a part of any proposed construction or development.

Older Mudflow Area (2c)

A third area for caution in possible area development is the central part of the mudflow fan area, which is not currently traversed by active flood channels of either of the major streams. This is somewhat deceptive since (as will be described later) Slate Creek was diverted from this area to its present course in historic times by residents of Marble.

The generalized terrain of this area is that of a very steep alluvial fan with its apex near the foot of Gallo Bluff. In detail, the surface looks rather chaotic with numerous ridges, old channels, and poorly drained areas. The material exposed at the surface and on the sides of the old channels is predominantly a jumbled and ill-sorted mixture of materials including shale and sandstone fragments of all sizes, with a matrix of clay formed from weathered Mancos Shale. The irregular topographic surface is an expression of the multiplicity of channels, bars, and lobes formed by many earlier flows of viscous mud that make up the major fan feature. Plate 3 is a tracing of a detailed topographic map of the area which is quite instructive concerning the location and topographic expression of distributary channels, slope of the mudflow surface, and other critical aspects of the fan area.

Some of the larger and more extensive channels represent former through-flowing channels of Slate Creek as it shifted from one temporary position to another in building the mudflow fan. One major former channel in particular (2d, plate 1) has in the very recent past crossed the older fan and discharged mudflows into the Marble townsite from the northwest. According to local reports, this channel was artificially plugged and diverted to its present course by Marble residents to prevent Slate Creek mudflows from entering the town. From our field and photo inspections, it appears that the diversion is indeed man-made, which serves to show how temporary and easily diverted the channel location is at any given time. In our opinion, the re-entry of Slate Creek into this former channel is only one large landslide or mudflow away - provided the landslide is of the required size and location, or the flood of the necessary volume, viscosity, and erosive energy. The detailed topographic map (plate 3) shows a dozen or more temporary distributary channels in the area between the present Slate Creek channel and the one that was occupied before the diversion. Several of the smaller distributary channels terminate in a lobe indicating that the final event consisted of mud that was viscous enough to pile up and obstruct the channel rather than continue flowing.

Because of the conditions and history above described, we consider it highly probable that future erosion, landsliding, mudflow, or other natural alterations of the existing channel will continue to bring about shifting of floods among the various older channels. Shifting of distributary channels is the normal course of events on alluvial or mudflow fans. However, the exact timing, location, or nature of the event which brings about the channel change is not predictable. Because of the high degree of unpredictability, and the high energy and large sediment volume of alpine-type mudflows, we feel that control structures with any possibility of success would be expensive to build and maintain, and that their long-range effectiveness would be problematical.

Nature of Mudflows in the Marble Area

Because they are usually short-lived events and are seldom observed in their entirety even by geologists and hydrologists who are called upon to interpret and control them, we believe there is a tendency to underestimate the seriousness of mudflow phenomena and the difficulty of effectively controlling them. In order to adequately convey the actual nature of alpine-type mudflows, we will cite some eyewitness accounts, and describe our opinion as to how the flows form, become channeled, and spread out over the lower slopes with disrupting and destructive effects. We will also outline our opinions concerning probable difficulties in designing workable control structures.

The earliest eyewitness account of a mudflow in the Crystal River area, and the only one which describes events on the upper slopes where they probably initially form, is contained in an account by W. D. Holmes, geologist with the Hayden expedition in 1874. Holmes described the events as follows:

> "On the 29th (of August, 1874), a rain-storm had set in, and everything was wet, thoroughly saturated. Muddy torrents poured down the upper slopes and dashed over the cliffs into the valley. Avalanches of wet earth, carrying many rocks and trees, formed near the summits and came roaring down, discharging great masses of debris into the river and tearing out such gorges in the alluvial bottoms as to make travel almost impossible."

The following account by Mrs. Charles Orlosky, long-time resident of Marble, describes her experiences during the July 31, 1945 mud flood on Carbonate Creek in Marble:

> "It was raining so hard, the noise on the roof made it difficult to hear; however, I did hear an odd roaring sound about 7:00 P.M. but didn't mention it to my husband right away. We soon realized, however, that Carbonate Creek was flooding again and quickly moved our car. While Charlie was moving another man's car from the flood, I was in our shed getting his saddle and pack outfit. While lugging these out, the wall of mud, rocks and debris which had been running past our house, broke my way and pinned my leg to the gatepost. Although I was being covered up, I didn't have time to be scared. My main concern was to free my leg, which I did after considerable struggling. My leg was badly bruised, with dirt ground in, and my clothes were pretty well torn off. I shall never forget the tremendous noise of the flood, and of houses breaking up like cardboard boxes, and the sight of houses floating like boats and bumping other houses," (quotation from: "Marble, Colorado: City of Stone," Vandenbusche, 1970.)

From evaluating eyewitness accounts, and studying the nature and distribution of the mud flood deposits, we have reconstructed the following probable sequence of events:

(1) With torrential or "cloudburst" type rainstorm, either area-wide or only in the steep upper reaches of the watershed, rapid water runoff occurs, generally accompanied by debris avalanching on the upper slopes. The water and debris attain high velocities and tend to become somewhat channeled, incorporating the coarse lag deposits which accumulate at very steep angles of repose in the steep intermittent stream beds of the lower parts of the high slopes.

(2) The mixing of storm runoff, soil, and rock debris forms a viscous slurry of the approximate consistency of wet concrete mix. When these mud avalanches reach the level of the mudflow fan, they generally become more definitely channeled, and follow one of the distributary channels across the steep part of the fan. A rather high velocity is maintained by the channeling effect, the steep gradient, and the pressure of the moving mass from above and behind. When this stream of mud reaches the lower slopes, it spreads out, loses velocity, deposits much of its coarse load, and may be in part discharged into the Crystal River.

Some Hydrologic and Engineering Geology Implications of Mud Floods

(1) One of the factors to be considered is the high kinetic energy of the very dense and high velocity stream of mud and/or flood water. This gives it the tremendous capacity for erosion, deposition and destruction that are earmarks of alpine mudflows. It should also be noted that the regime of these occasional mudflows has no particular relationship to the normal stream flow, and any control measures must take this into account. Debris samples taken from the well-observed Wrightwood, California mudflows of 1941 had a bulk density of 2.4 and

a water content of only 25% to 30% by weight (Sharp and Nobles, 1953, p. 552). The same authors cite typical surge front velocities in the range of 1 to 14.5 ft./sec., and an average velocity of 9.4 ft./sec. The gradient of these flows varies from approximately 9 degrees within the contained canyon section to less than 1 degree at its outermost limits. It should also be noted that the initial high kinetic energy is probably attained on the steep upper slopes of the watershed, and that control measures taken in the lower areas may be ineffective or shortlived, or both.

(2) Because of the above described conditions, we are virtually certain that conventional velocity dissipating ponds or other structures on the existing stream channels will be completely ineffectual in watersheds subject to voluminous mudflows as well as normal stream flooding. If there are any doubts concerning the volume and composition of mudflow debris, the very recent deposits on lower Slate Creek should be inspected (figures 3, 5, 6, 7, 8). The bulk of this debris is of boulder size with a matrix of fine material, and on the top surface of the flow near the apex of the mudflow sheet, there are numerous blocks of Mesa Verde sandstone as large as five feet on a side (figure 3). This not only shows the great energy and competence of the mud floods, but also indicates that much of the coarse debris has come from the upper cliffs of Gallo Bluff, where the massive beds of sandstone crop out. Again, we wish to stress our opinion that because of the particular characteristics of alpine-type mudflows, any conventional "flood control" approach to controlling them or minimizing their impact will almost certainly be doomed to failure. Even defensive or control measures that

are technically feasible may well be unacceptable in terms of economics and/or environmental impacts.

Problems Related to Mudflow Control and Construction on Mudflow Debris

General

There are several problems that we would anticipate in achieving economical and environmentally acceptable control for mudflows in the Marble area, and still others related to safe and feasible development of the area after the mudflow problems are solved.

Recognition of the recent geologic history and probable future course of natural events on the entire mudflow fan is basic to solution of the many problems related to possible defensive or control measures. Data of this report shows that Slate Creek has in historic and very recent times occupied a dozen or more temporary channels between the town of Marble and its present course, and accompanying mudflows have spread out over an area of 200 acres or more. Since all of this area is potentially within the reach of the Slate Creek mudflows, it is not developable until a workable, economical, and acceptable solution to the mud flooding problem is devised and implemented.

It should also be recognized that the area is composed almost entirely of old mudflow debris which can in all probability be remobilized by addition of water - whether from rainfall, snowmelt, lawn irrigation, septic tank effluent, sewer line leaks, or other sources. In laboratory experiments, debris from the Wrightwood, California mudflows flowed readily on a 7 degree slope (approximately 12.5% slope) when mixed with 16% by weight of water (Sharp and Nobles, 1953, p. 552).

The areas mantled with Slate Creek mudflows have an average depositional slope of 12.5%, which would suggest that any construction or natural processes that would steepen the existing slopes and significantly increase the moisture content will tend to produce instability. The combination of poorly developed surface drainage and potentially unstable soils indicates that if intensive residential or commercial development is proposed, extreme care should be exercised in road construction, homesite clearings, and trench excavations for utilities. Such potential problems are intensified by the occurrence of the most intense thunderstorm activity during the construction season.

Strict Channelization as Possible Solution

There are two obvious types of solutions to the most immediate problem of controlling the mudflows on Slate Creek. The simplest solution would be to securely plug off and protect the older channel diversion point, and to channelize the creek near its present course, with an adequate cross-section, and protected banks constructed at a stable slope. This would be the most economical in terms of land requirements, and would probably be aesthetically the most acceptable in the area above the Crystal River flood plain.

The shortcomings of this solution would be the accompanying aesthetic and hydrologic degradation of the Crystal River and its flood plain west of Marble. If the Slate Creek mudflows were to be "straight-piped" to the Crystal River or its flood plain in the general manner described above, there would be several unfavorable impacts. These would include visual degradation of the flood plain and the general Marble area, which would appear quite serious since the discharge point would be located adjacent to the main road near the entrance to the area. Hydrologic degradation would include both temporary and long-term obstruction of the flood plain by debris that would, in the normal course of events, be deposited mostly in areas above the Crystal River flood plain. Unfavorable side effects would include occasional damming, and a general condition of backwater upstream from the discharge point during flood flows of the Crystal River. Direct discharge of the mudflow debris in or near the river would greatly increase the sediment supply which could be expected to affect game fish, and the general stream aesthetics in the downstream direction. If such a solution is proposed, it would almost certainly require approval from the U.S. Forest Service, Colorado Division of Game, Fish and Parks, Colorado Water Pollution Control Commission, and other interested agencies.

Debris Dams as Possible Solution

An alternative solution would consist of somewhat similar channelization of Slate Creek, but with addition of debris dams or catchment basins which would be designed to intercept and hold a large part of the flood debris within retaining structures adjacent to the channel. There are several complications with such a possible solution which has been tested in parts of California and the Wasatch Front area of Utah. The mudflow events (not ordinary flood waters) are the basic problem, and the solid matter ("sediment") content of these probably constitutes 70 to 75% of the mass, and nearly all of the volume. The "sediment" volume is, therefore, roughly equal to the total flow of a mud flood event. Although we have made no estimate of sediment production in the Slate Creek drainage basin, it must be extremely high judging from the rapid backwasting of Gallo Bluff and the sizeable and frequent debris sheets deposited in the lower reaches of Slate Creek.

Environmental and Economic Problems Associated with Debris Dams

Some of the specific problems inplicit in the above include: (1) Land requirements for debris basins large enough to even temporarily alleviate the problem will be quite high, and the basins, whether empty or full, will have unfavorable aesthetic impacts. (2) If the system is to remain effective, the basins will have to be cleaned out after each major mud flood event. If this isn't done, the system will either overflow and divert to new channels, or revert to the "straightpipe" method described earlier which had very unfavorable impacts and possible legal complications in the river flood plain area. (3) If the required frequent clean-out of debris is performed, the operation will be very expensive, and there will be serious problems in disposal of the debris in a safe, economical, and environmentally acceptable manner. As described earlier, the mudflow debris is not suitable for road base or fill material unless placed as an engineered fill. If it is placed as a dumped fill, it could be expected to readily become unstable upon wetting, and create the old problem at a new location.

If a catchment basin solution is proposed for such an area, the details and long-term cost of maintenance and debris disposal as well as original construction should be carefully worked out so that necessary funding can be arranged and the responsibility for the system clearly understood. Experience with this sort of control system in California and Utah has been generally disappointing in the long term because of inadequate basin size and/or lack of necessary clean-out when required.

GALLO BLUFF-ELK MOUNTAIN AREA (3)

Area of Active Rockfall and Potential Large Landslides (3a)

Gallo Bluff is a steep and barren cliff that rises abruptly above and to the north of the apex of the major mudflow fan, (figures 1, 10, 12, 13, 14, 15, 16). The cliffs are composed of strongly faulted, jointed, and fractured Cretaceous rocks. The lower part is shale and sandy shale of the Mancos formation, and the upper part consists of alternating shale and sandstone beds of the Mesa Verde formation. The rapid rate of weathering, erosion, and back-wasting has prevented development of vegetative cover, and provides superabundant debris for the Slate Creek mudflows. Gallo Bluff is entirely within the watershed of Slate Creek. Erosion of the cliffs is so active that one can see and hear minor rockfalls constantly while in the vicinity of the bluff. Several factors conspire to produce the rapid erosion of the cliffs. Both sandstone and shale are strongly jointed, (figures 13, 14, 15, 16, 17), including vertical joints which are both parallel and at approximate right angles to the retreating cliffline. In addition, the shale air-slakes rapidly, providing an easily activated clay matrix for mudflows. Numerous spring seeps between sandstone and shale units saturate and soften the weathered shale and rock debris (figure 12). The weathered shale is removed by minor sloughing and sliding as well as by sheet and rill wash.

The above described processes produces a general "Grand Canyon" type of topography with waste slopes of shaley debris alternating with nearly vertical ledges of broken sandy shale or sandstone (figure 13). The average slope of the highest part of the cliff is approximately 36 degrees, or 75%. At this location, the bluff has 1,400 ft. of vertical rise in 1,900 ft. horizontal distance.

The more resistant sandy layers frequently are undercut by the rapidly wasting shale beds, and the sandstone ledges in many cases consist of stacks of loose, joint-bounded blocks which are precariously unstable when undercut by erosion (figures 12, 14, 15, 16). This situation gives rise to the constant minor rockfalls which can be precipitated by a gust of wind or another falling rock. Evidence of larger scale instability in the cliffs can be seen in the weathered and open joints which, in many cases, form fissures several tens of feet back of the cliff face (figures 13, 17). These are especially prominent in projecting points in the cliff which form between adjacent gullies. Such gullies or re-entrants in the cliffline tend to follow minor faults which are oriented at approximate right angles to the cliffline. The precipitous gullies on Gallo Bluff, and also those in the Carbonate Creek watershed that lie between the north end of the bluff and Elk Mountain, are locally choked with coarse rock rubble at a precarious angle of repose. The currency and active nature of cliff retreat is shown by still-green trees that can be seen along with rubble in the steep gullies (figure 12).

Avalanches and Potential Debris Slides on Elk Mountain (3b)

The area extending north from the barren cliffs of Gallo Bluff to the vicinity of Elk Mountain is similar in structure and composition to Gallo Bluff. Slopes are nearly as steep but the area is covered with small timber and brush which indicates somewhat less active mass wasting. In general, there is a fairly stable cover of a few tens of feet of unconsolidated colluvial soils overlying the Cretaceous shale and sandstone beds. This area is within the Carbonate Creek drainage basin and is drained by numerous precipitous ravines which have cut through the coarse colluvial soils, and flow on the exposed shale and sandstone bedrock.

The upper slopes of the Elk Mountain area contain numerous springs and extensive seepage areas that emerge between fractured sandstone beds and underlying shale strata. Outflow from the springs and seeps maintains a streamflow in the ravines through most of the year. The ravines contain numerous reaches that are choked with lag deposits of coarse sandstone rubble lying at a precarious angle of repose. This combination of conditions which includes abundant groundwater seepage into relatively thick colluvial soils overlying bedrock on steeply inclined contacts, and daylighting of the soil cover by numerous deeply incised ravines, all add up to a classical situation for debris avalanche production.

The east-facing slope of Elk Mountain also contains three large and active snow avalanche paths which are marked by "pushed" and stunted brush cover, and scattered rock debris. The southernmost of these (3c) has quite evidently discharged to a point immediately adjacent to the mountain meadow described in the previous section. This is illustrated in the photograph of figure 11.

Old Landslide Terrain Below Gallo Bluff (3d)

A large area of old landslides extends from the base of Gallo Bluff south to the mudflow fan, and east to an area of Mancos Shale bedrock near the west bank of the main channel of Carbonate Creek. A large part of this was delineated on the USGS Geologic Map by Gaskill and Godwin, and additional areas of landslide debris and terrain were mapped by photogeologic study and field reconnaissance during our investigations. The surface of this area lacks the uniform general slope of the major mudflow fan, and instead is characterized by a hummocky, poorly drained surface and occasional sizeable closed depression features which form boggy areas or ponds. This feature appears to be older than the main mudflow fan and, except for the probable landslide scarp (3e), shows no indications of large fairly recent movements. Relative to possible construction in the area of the old landslides, we have the same general observations made concerning the mudflow fan areas. Much of the area is poorly drained, there is locally very steep topography, and the material is primarily disintegrated and broken shale which could be easily mobilized by addition of water and disturbance from construction activities.

A more serious implication of the extensive old landslide debris below Gallo Bluff is that it suggests large scale and catastrophic rock-fall or debris avalanche events may occur periodically in the history of the bluff. If this is the case, the area for a considerable distance in front would be subject to severe devastation. Large scale events of this sort probably explain the large area of landslide terrain described above. We believe that the present extent of landslide materials is a combination of original very large landslides from the bluff, followed by subsequent movement of part of the originally displaced mass by less spectacular sliding at lower topographic levels. This is our interpretation of the scarp (3e) described above which appears to be more recent than the main landslide. On the strength of the above geologic evidence, we strongly suggest that if this area is to be developed, a wide setback should be observed from the base of Gallo Bluff, and that any construction in the area of the old landslide terrain should proceed only after thorough engineering geology and soils engineering studies.

Area South of Crystal River and Opposite the Mudflow Fan (4)

Gaskill's geologic map indicates that the area south of the Crystal River in the vicinity of Marble is composed of the same Cretaceous shales and sandstones that were described on Gallo Bluff (plate 2). Slopes of this area are in the range of 40% to 100%. Both photographic and field observation indicate that the western part of this slope is an area of long standing and still active snow avalanching (4a, plate 1; figures 1, 4, 14). There are seven avalanche tracks across the area, and photo studies indicate that the accumulation areas have enlarged by erosion considerably since 1945. At the foot of each avalanche chute, there is a talus of fresh rock debris. In view of the steepness, the nature of the bedrock and the active avalanching and rockfall, these areas do not appear to be suitable for development.

The central part of the area south of Crystal River (which is directly opposite the old marble works) is also very steep except for a large and fairly recent landslide mass (4b, plate 1) which has locally deflected the course of the river northward. There are also large accumulation areas and avalanche tracks above the landslide mass. These avalanches do not at the present time appear to be as active as those to the west, but the historic record describes many damaging avalanches which affected the marble works until a protective dike of waste marble was built. We feel that this part of the area also has many serious problems which would have to be resolved before construction of any kind is advisable.

The eastern part of the area south of Crystal River looks somewhat more favorable, but there are still several reasons for carefully considering any construction in the area. The geologic map (plate 2), indicates strongly dipping Mancos shale beds with vertical jointing. These facts together with the generally steep slopes are enough to indicate the need for careful geologic and engineering studies and extreme caution. The lower part of this area is on the Crystal River flood plain, and just opposite the confluence with Carbonate Creek (4c, plate 1). Possible hazards from flooding and mudflows should be carefully evaluated before construction on this part of the site is planned.

Area of Unstable Talus and Landslides, North of Landing Strip (5)

This is a sizable, roughly triangle-shaped area north of the landing strip and opposite the confluence of Raspberry Creek and the Crystal River. It was mapped as talus by Gaskill (1966), and as active talus by Hepworth (1971). Our initial photo studies showed scarp and ridge features that are not typical of a talus slope, since both active and inactive taluses generally consist of an equilibrium slope of smooth curvature. Because of its anamalous appearance, further field and photogeologic studies were made of the area.

Field examinations showed that most of the rubble slope consisted of igneous rock debris which was typical of the Raspberry Creek Phacolith intrusion. The source of the rock debris is an erosionally detached portion of the Phacolith that lies just upslope from the area discussed. This rock is strongly jointed in three directions, and the regional dip is downslope toward a synclinal axis which is just south of the Crystal River.

In detail, the surface of the rubble slope consists of sharp curvilinear ridges, scarps, and elongate depression features. These, typically, have relief of several tens of feet, and lengths of many hundreds of feet. The ridge features are roughly parallel to the contour of the slope, and the scarps occur both parallel and at low to moderate angles to the contours. The generalized slope of the area is in the range of 40% to 60%, but is much steeper locally on the scarp and ridge features described above. These local topographic features, in general, do not show on the 7½' quadrangle map because of the overall steepness of the slope and the 40 foot contour interval. The larger scarps of this area can be seen on all of the various sets of aerial photographs used, but the complex of ridges could be seen well only on the very low altitude aerial photos.

Our geologic interpretation of the history and development of this slope assumes that in the past, it has probably been a simple talus slope. However, at the present time (and for some time in the past), the slope has experienced much more active movement than the normal accretion and creep of an active talus. It is our impression that the debris slope is currently undergoing a very accelerated type of mass movement similar to the movement of rock glaciers. Active rock glaciers (or rock streams as they are sometimes called) are common in the surrounding Crystal River area at slightly higher elevations.

The sharp transverse ridges which extend parallel to the slope contour, or bend convexly in the downslope direction, and the coarse blocky rock debris of which the slope is composed are all very similar to rock glaciers of the area. The slope in question differs from the usual rock glaciers in that the rock debris is on an open slope rather than being contained between valley walls. In addition, the scarps and narrow depression features are not typical of rock glaciers we have seen.

The scarps and elongate depression features have the appearance of landslide scarps and tension features associated with landslide displacements. We believe the talus is actually a mantle over numerous underlying landslide surfaces. Figures 18 and 19 illustrate the general appearance of the linear depression features.

According to our geologic interpretation, it seems probable that a talus of coarse rock debris formed on the glacially oversteepened north side of the Crystal River valley in this area. Influenced by the steep angle of repose of the coarse rock debris, and perhaps aided by seasonal presence of intersticial ice, the talus assumed more rapid movement similar to a rock glacier. In addition to the movements within the mass, we believe that slow landslide movements have taken place at the contact between the talus and the steep glaciated surface upon which it was deposited, or along south-dipping bedding surfaces of the underlying rock. The probability of such sliding occurring is increased by several conditions, including (1) a very steep original slope caused by previous glaciation; (2) abundant water on the surface from underlying morainal material and subcropping Mesa Verde sandstone beds; and, (3) south-dipping and erosionally detached bodies of intrusive igneous rocks on the upper slope. We believe that the above described combination of movement within the mass of rock debris, concurrent with basal slippage and landsliding has produced the observed topographic forms - the sinuous transverse ridges by movement within the talus, and the elongate depressions and linear scarps as a result of tension and downslope displacements of portions of the talus. Field observations suggest that these movements are rather slow, but continuing (figure 19).

We consider the entire slope in this area to be unstable and unsuitable for construction. We strongly advise that construction or removal of material be completely avoided in the area adjacent to the main road since this constitutes the critical toe of the unstable mass. As long as this is observed, the flat areas past the toe of the slope are probably moderately safe.

Hermit's Hideaway Area (6)

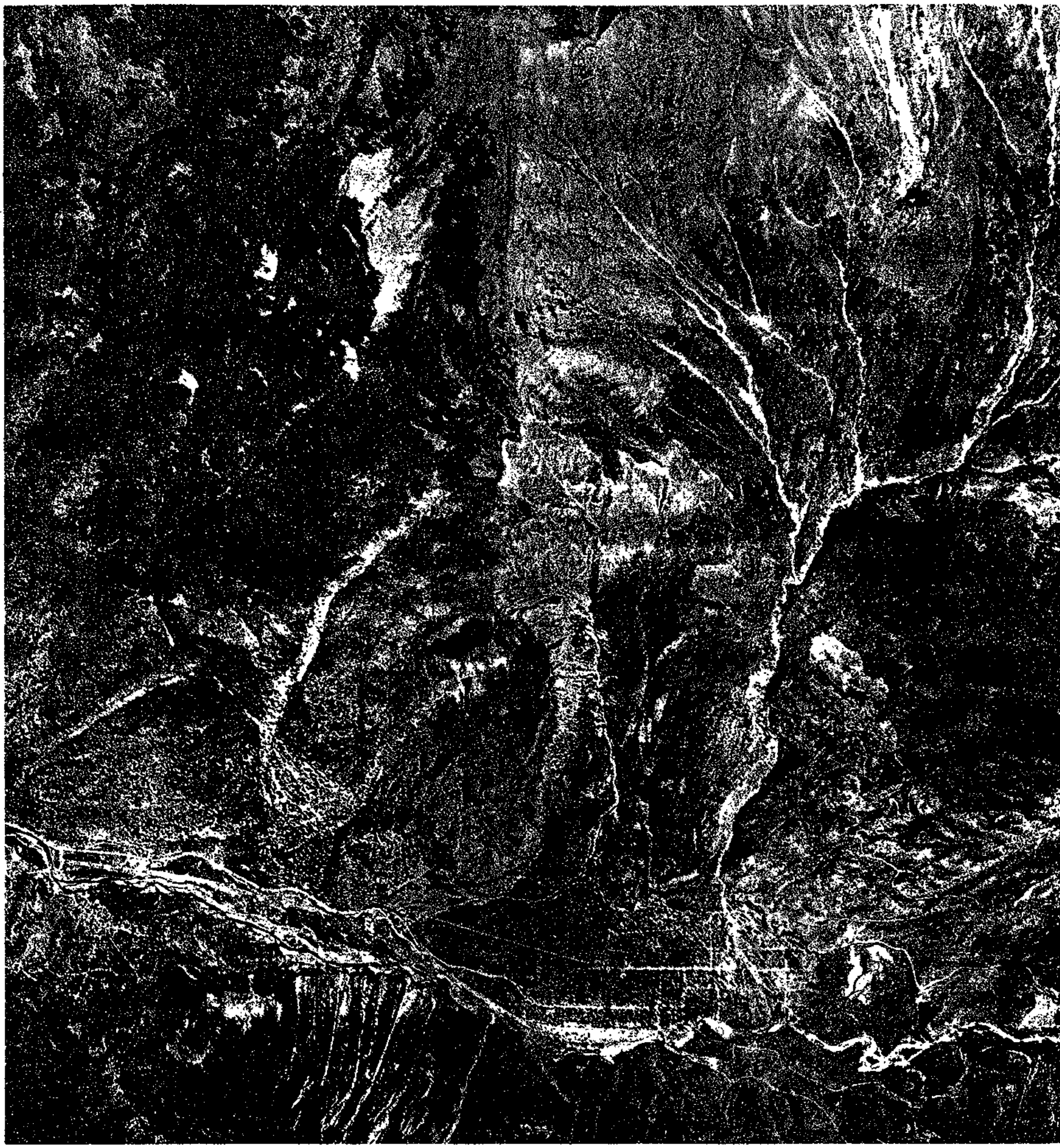
This area is located on the alluvial deposits at the mouth of the combined Milton Creek and Raspberry Creek watershed, and adjacent to the flood plain of the Crystal River. According to our understanding, there is an older subdivision in this area, and it is currently slated for single family dwellings on one-half to one-third acre sites.

The combined Milton-Raspberry watershed has a drainage area of approximately 4,700 acres, which is considerably larger than the troublesome Carbonate-Slate watershed. Like the Carbonate-Slate system, this drainage basin has extremely steep gradients and superabundant sediment supply in the steep upper reaches of the watershed. The danger from mud floods is probably not serious since much of the debris consists of coarse intrusive igneous rock, but the possibility of serious flooding and erosion problems in the Hideaway area during rapid storm runoff must be carefully evaluated and taken into account in planning for this tract.

Other conditions of the Hideaway area which should be evaluated in possible area development include: (1) rather shallow water table conditions; (2) very granular soil (probably deficient in soil colloids); (3) very high percolation rates; (4) very high density of proposed housing units; (5) plans for using shallow ground water for domestic supply. This combination of conditions suggest to us a definite possible pollution hazard, involving inadequate natural leaching fields and possible contamination of shallow ground water, and waters of the Crystal River. We strongly recommend that the area receive careful study to determine the feasibility of septic tank systems, and the proper density for such units.

Conclusion

In most areas, the normal geologic processes of erosion, and mass downhill movement of surficial materials occurs quite slowly in terms of calendar years. However, the Marble area is quite different; rapid erosion, mudflows, landslides, and flooding present extreme problems. It should be remembered that such normal geologic processes become "geologic hazards" only when they interact with man and his works. History of Marble is replete with examples of man's frustration in the struggle with natural processes of the environment. As this area faces increasing pressure for development as a residential and recreational center, it would be well to remember past history, and to recognize the geologic capability of the land in arriving at land use decisions in the private sector as well as at all levels of government.



Easily identifiable features recognizable from photograph on facing page are shown in line drawing below. Symbols not self-explanatory are listed below.

ALS indicates areas believed to be active landslides.

Landslide Scarps are shown by heavy lines with teeth indicating direction of down-slope movement.

Heavy Arrows indicate snow avalanche chutes, and Diagonal Pattern shows identifiable landing areas.

SMF indicates area of small mudflows at base of Gallo Bluff.

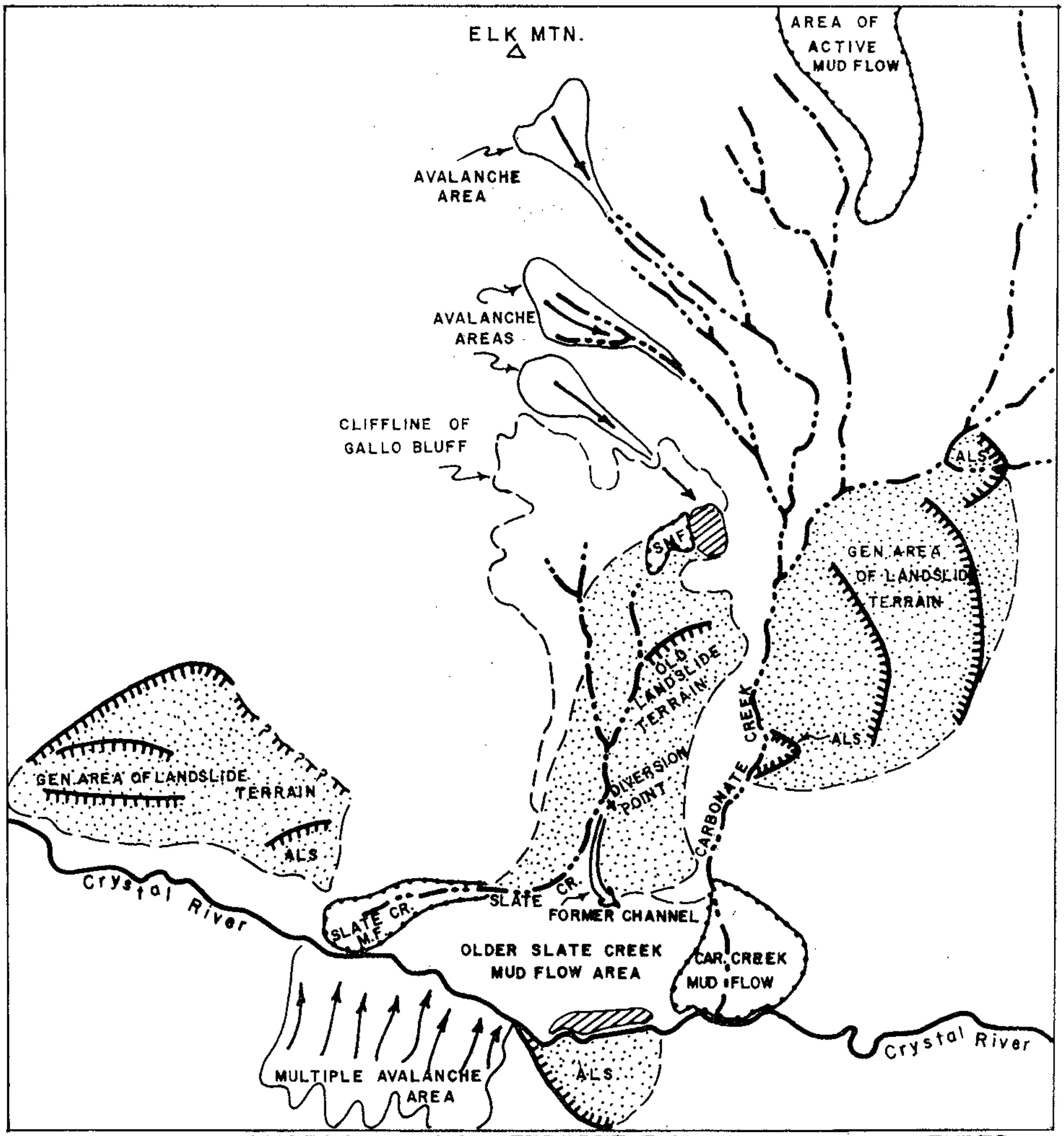


FIGURE 1. PHOTOGEOLOGIC INTERPRETATION OF MAJOR FEATURES

Figure 2. Entrenched portion of Slate Creek channel, showing steepness of banks and mudflow material in channel sides.

Figure 3. Large blocks of Mesa Verde Sandstone in recent mudflow debris of Slate Creek, twelve year old boy in foreground. Recency of deposit indicated by fine debris on top of blocks.

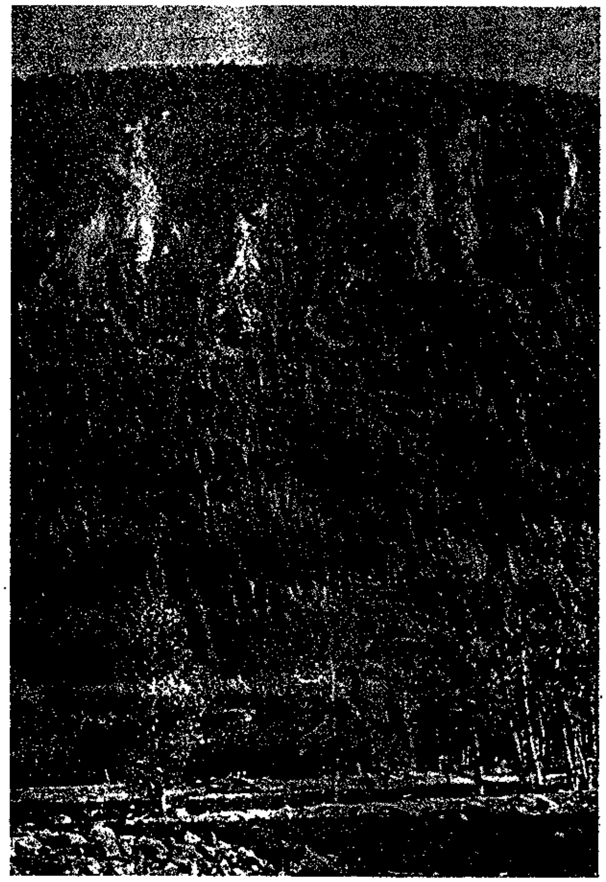


Figure 4. Lower part of Slate Creek mudflow area in foreground, avalanche and rockfall area south of the Crystal River in background.

Figure 5. Edge of very recent mudflow debris sheet in Slate Creek area.

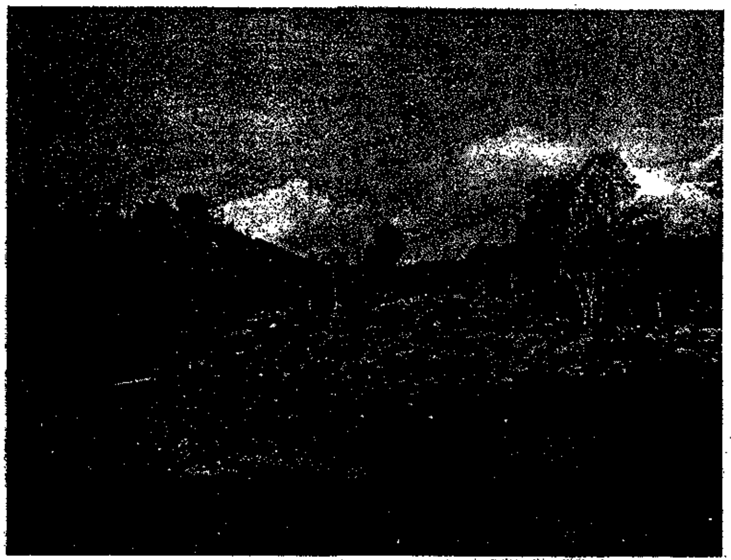


Figure 6. Looking up (northeast) along recent mudflow plain of Slate Creek.

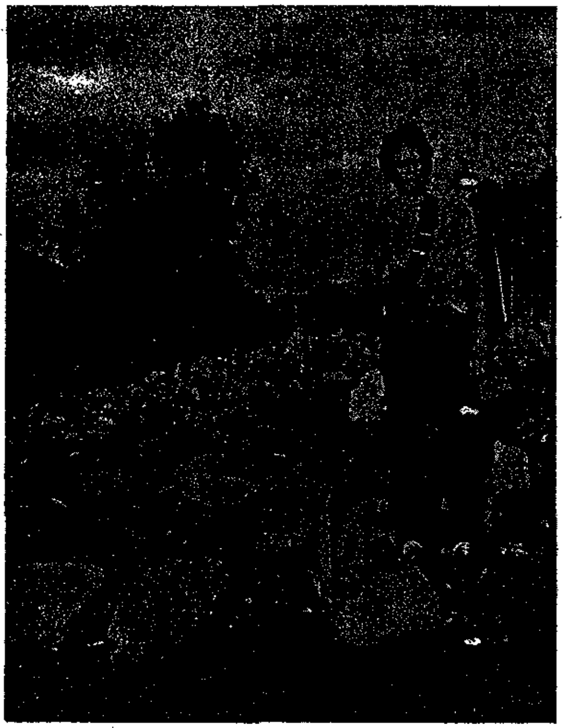


Figure 7. Rock-strewn surface of upper part of Slate Creek mudflow plain in subdivided area. Stake indicates a lot corner.

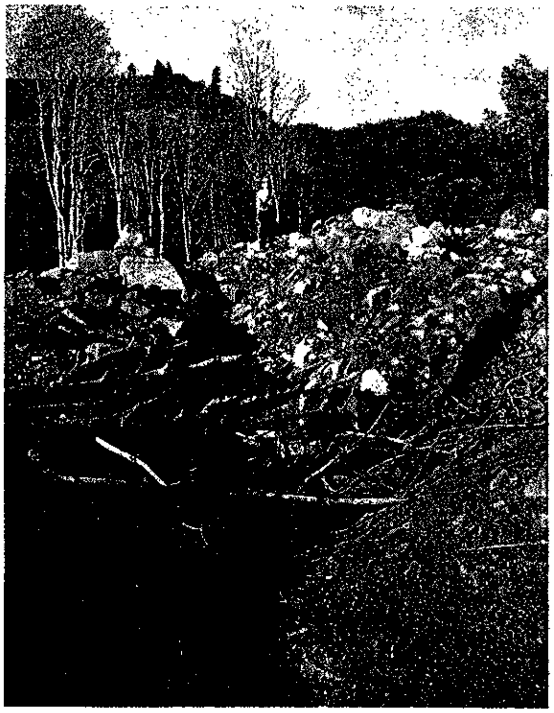


Figure 8. Abandoned channel and mudflow debris in subdivided land of recent Slate Creek mudflows. Boy is standing by the same lot corner shown in figure 7.

Figure 9. Top of park bandstand in town of Marble, lower part was buried by coarse mudflow debris of 1945 mudflood on Carbonate Creek.

Figure 10. Large unvegetated scar in background is Gallo Bluff. Bare scarp in right center is Mancos Shale on the west bank of Carbonate Creek. Town of Marble in right foreground.

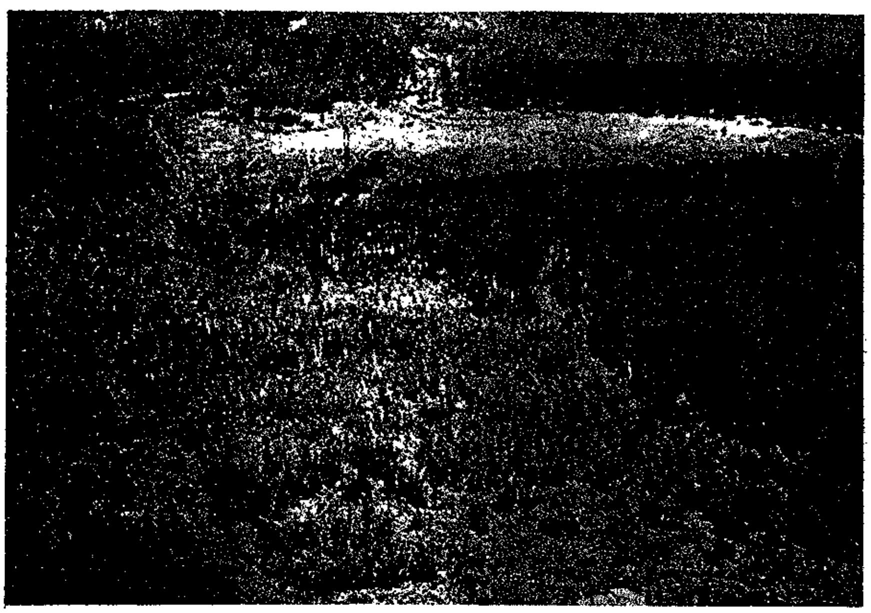


Figure 11. Area below north end of Gallo Bluff. Stunted and pushed timber on left side is result of airborne snow avalanches from Elk Mtn. Small mudflows have moved through larger timber on the right to the edge of the clearing in background.

Figure 12. Typical gully on face of Gallo Bluff. In background, loose overhanging sandstone blocks can be seen. Dark color just below center is from water seepage. In lower center, note loose rock rubble and recently fallen tree.

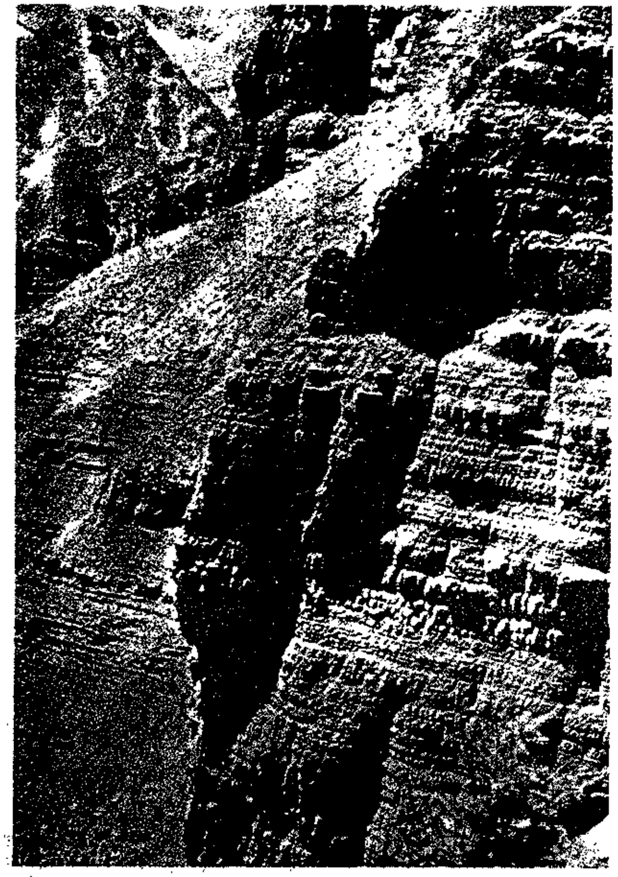


Figure 13. Typical appearance of middle part of Gallo Bluff. More resistant sandy beds stand near-vertical with numerous open and weathered joints back of cliff face.

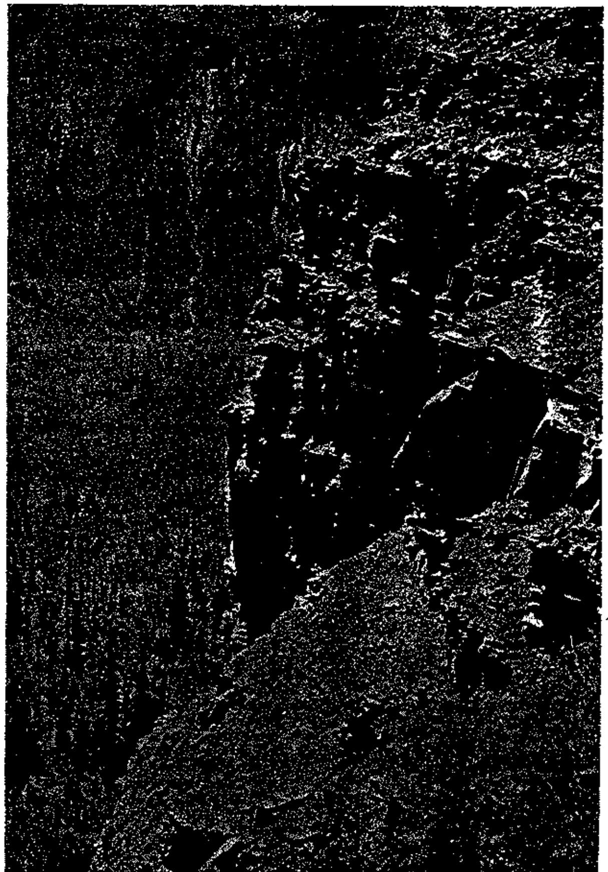


Figure 14. Interbedded shale and sandstone in middle part of Gallo Bluff. Avalanche scars south of Crystal River in background.

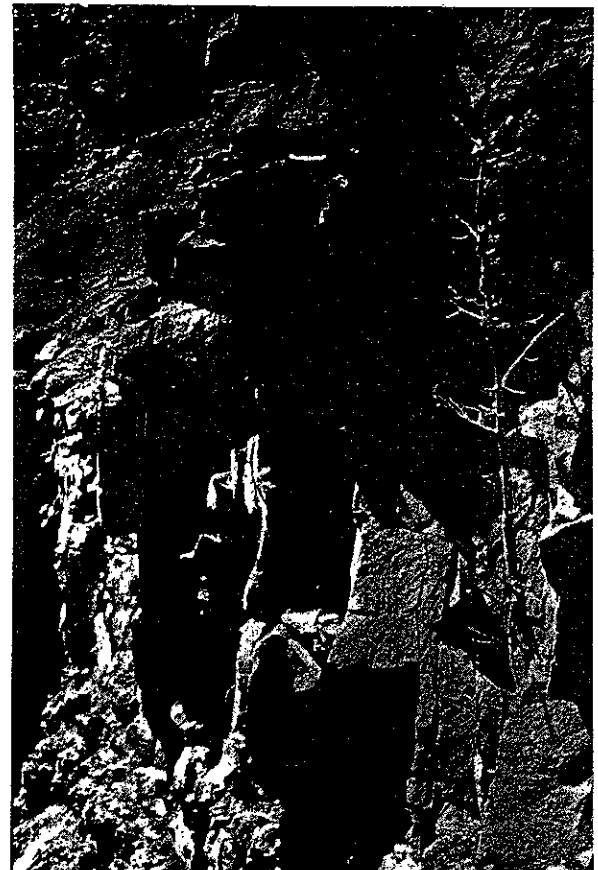


Figure 15. Fractured and loose blocks of Mesa Verde Sandstone in upper part of cliff of Gallo Bluff.

Figure 16. Overhanging ledges of broken and fractured Mesa Verde Sandstone in upper part of Gallo Bluff.

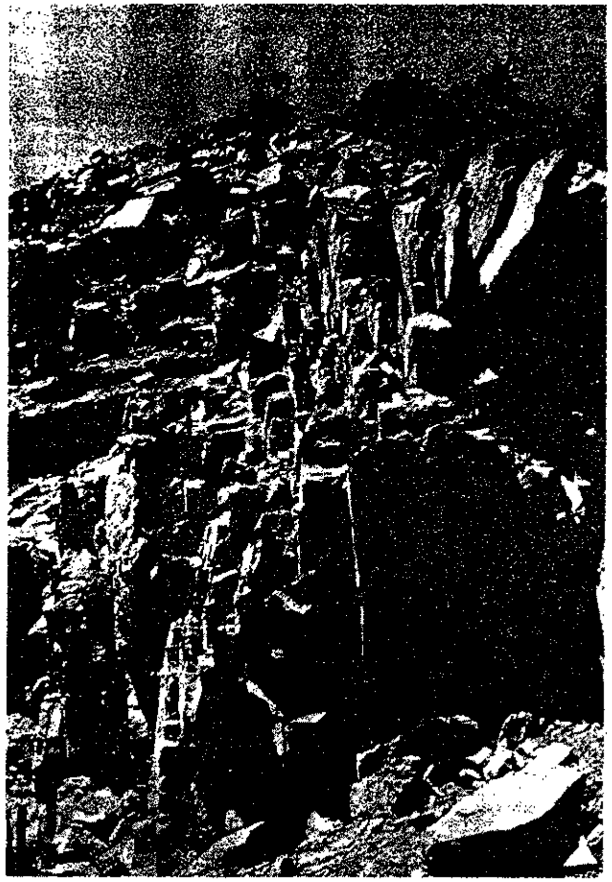


Figure 17. Strongly jointed Mesa Verde Sandstone on ridge just above Gallo Bluff.

Figure 18. Corrugated surface of coarse talus produced by landslide movements within the talus (area 5 of text).

Figure 19. Same general area as above but showing tilting of trees indicating recent movements.

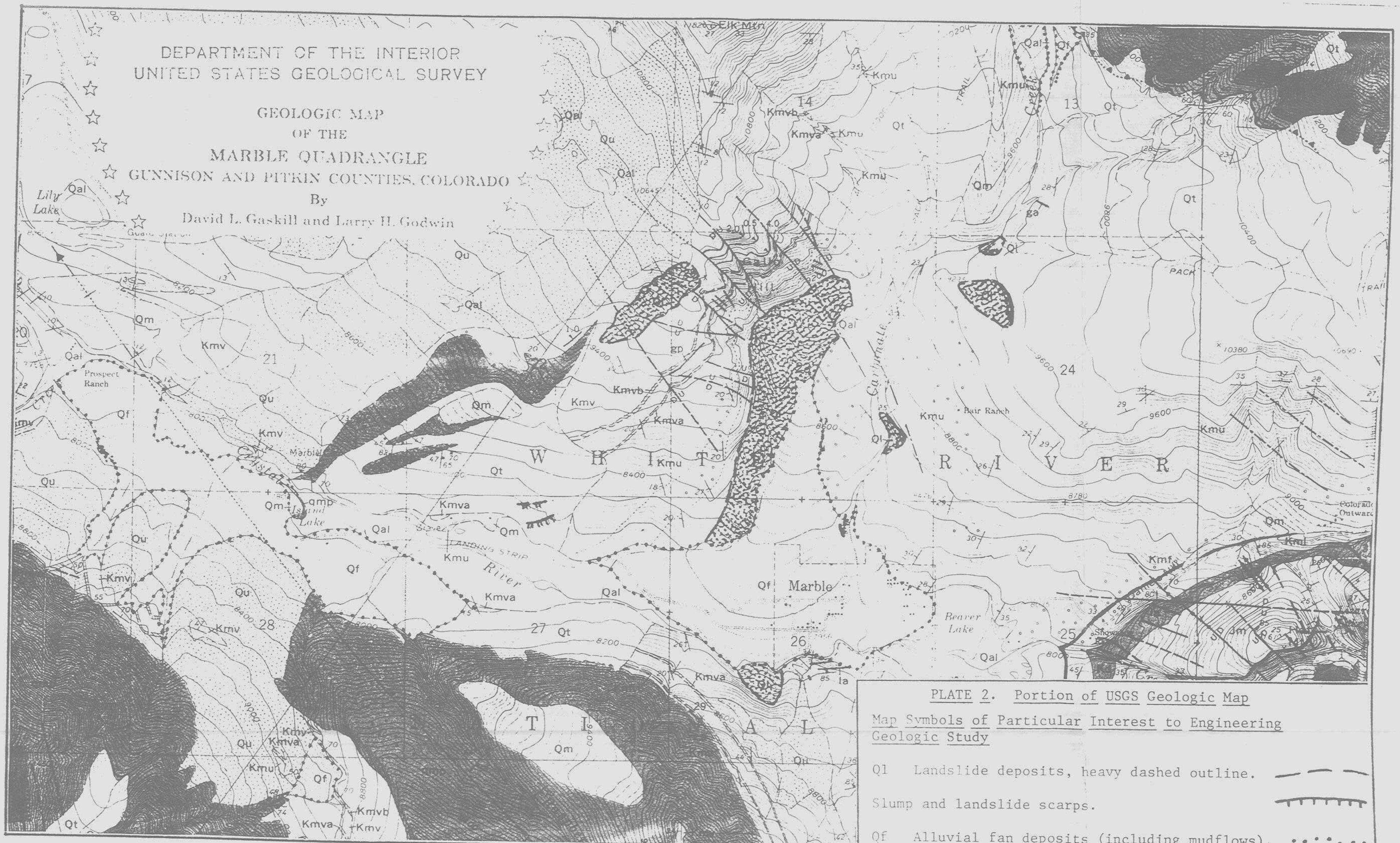


PLATE 2. Portion of USGS Geologic Map

Map Symbols of Particular Interest to Engineering Geologic Study

Ql Landslide deposits, heavy dashed outline.

Slump and landslide scarps.

Qf Alluvial fan deposits (including mudflows).

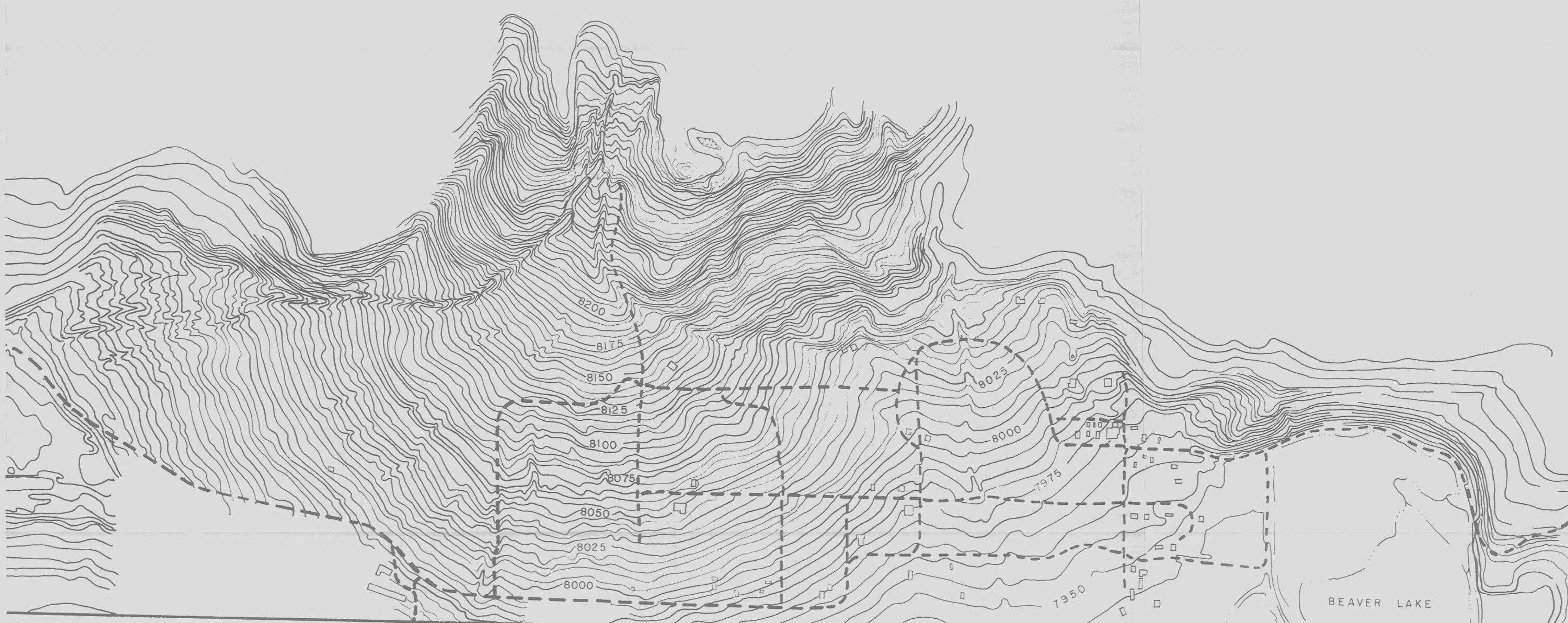
PLATE 3. DETAILED TOPOGRAPHIC MAP OF MUDFLOW FAN AREA

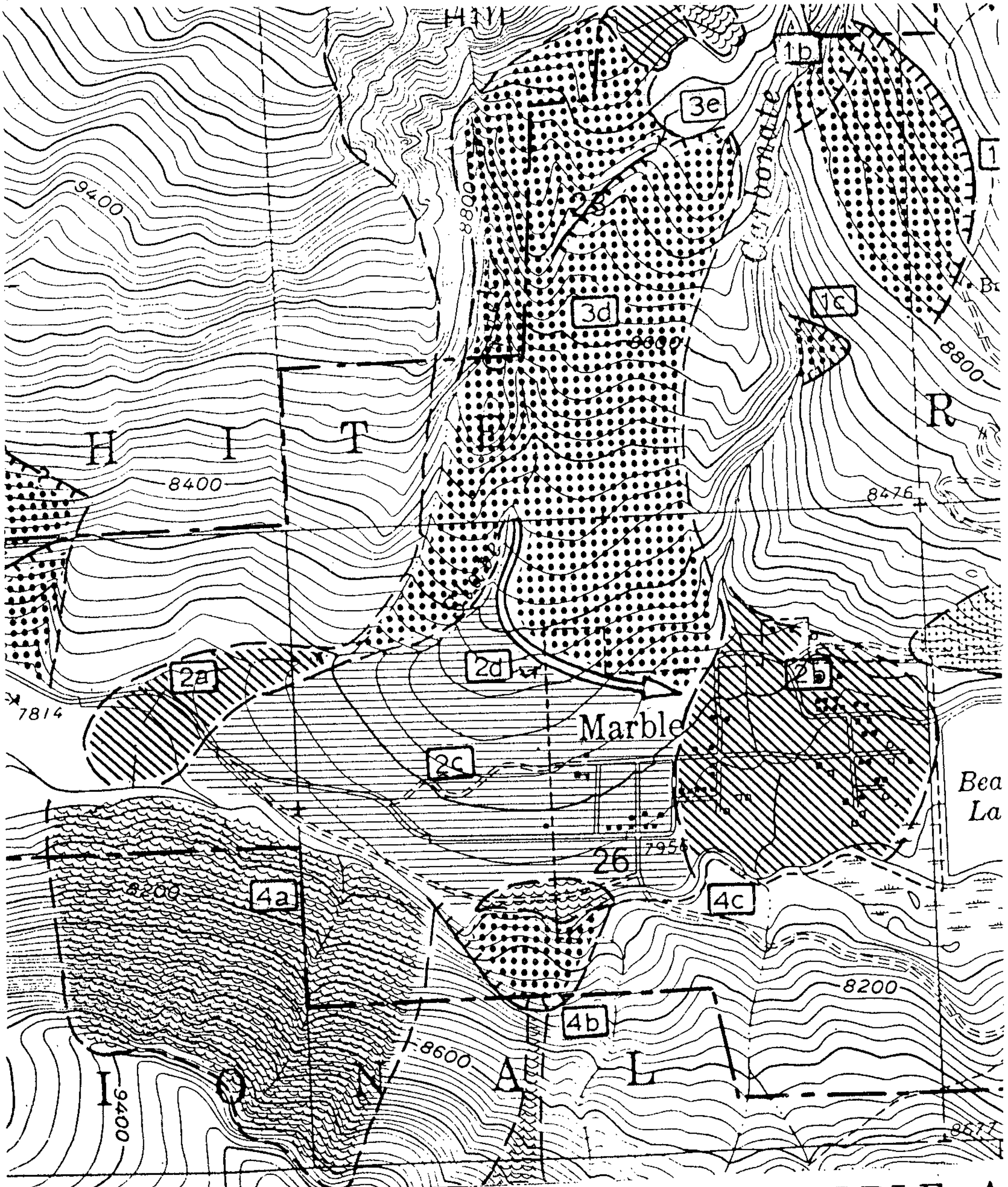
Topographic map prepared from base by Merrick and Co., Consulting Engineers-Denver, Colo.; compiled from aerial photography of 10/29/68. Original maps prepared for Ketchum, Konkel, Barrett, Nickel, Austin; Consulting Engineers-Denver, Colorado.

Scale one inch equal : 500 ft.

Contour interval 5 ft.

Drafting by Al Campbell





ENGINEERING GEOLOGIC MAP, MARBLE A

COLORADO GEOLOGICAL SURVEY

PLATE 1. ENGINEERING GEOLOGIC MAP, MARBLE AREA

W. P ROGERS

OPEN-FILE REPORT 78-11
Plate 2 of 2

GEOLOGIC HAZARDS
UPPER CRYSTAL RIVER AREA
GUNNISON COUNTY, COLORADO

by WALTER R. JUNGE
1978

Colorado Geological Survey
Department of Natural Resources
State of Colorado
John W. Rold, Director

GENERAL DESCRIPTION

The upper Crystal River area is likely to experience increased growth related to future expansion of recreational activities and nearby coal mining. To aid in the planning for this anticipated growth, geologic conditions in the area were studied and mapped in accordance with House Bill 1041 (C.R.S. 1973, 24-65.1-101, et seq.) to determine areas of geologic hazard that could cause an economic loss or affect the safety of the citizens of Colorado. The mapped units used in this study conform to the terms and definitions given in Colorado House Bill 1041 and in the Colorado Geological Survey's "Guidelines and Criteria for Identification and Land Use Controls in Geologic Hazard and Mineral Resource Areas" (Rogers and others, 1974). As defined in House Bill 1041, a geologic hazard means "a geologic phenomenon which is so adverse to past, current, or foreseeable construction or land use as to constitute a significant hazard to public health and safety or to property." These geologic hazards may be intensified or decreased by human activity. Regardless of the intensity, the hazards should be recognized and considered prior to any land-use changes.

Previous studies in the Crystal River area include geologic mapping of the Marble quadrangle by Gaskill and Godwin (1966), an analysis of engineering geologic factors in the Marble area by Rogers and Rold (1972), and mapping of geologic hazards in the Marble Ski Area by Robinson and others (1972). Additionally, environmental and engineering geology factors in the general area were described by Olander and others (1974) and snow avalanche hazards were evaluated by Mears (1975). These studies were reviewed and, where applicable, incorporated into the present study.

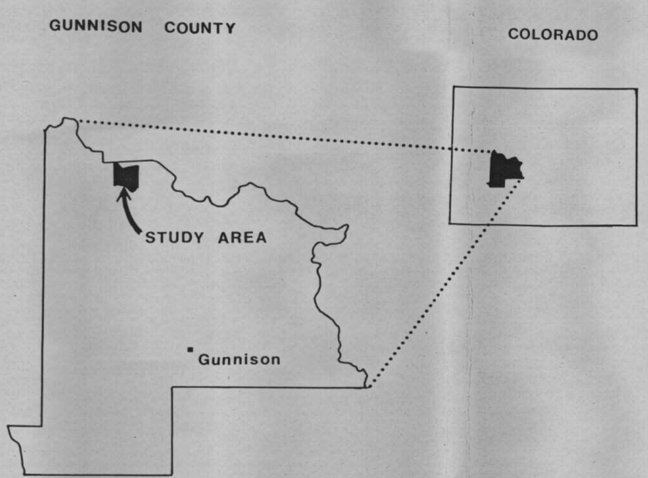
SUGGESTIONS TO MAP USERS

The upper Crystal River area is that part of the Crystal River valley in the 7.5-minute Marble quadrangle and includes the Yule Creek, Lost Trail Creek, Carbonate Creek, and Slate Creek drainages. Potentially hazardous geologic conditions in this area are related to normal dynamic processes such as transportation and deposition of material by water (fluvial processes) and by mass wasting (gravity related processes). These processes have been very active in the past and will be active in the future. The geologic hazards map at a scale of 1:24,000 shows only the most severe geologic condition in a specific area. Additional geologic conditions that could affect a particular development activity may be present locally.

Three conditions that have not been shown on the map are expansive soils, high ground-water levels, and shallow bedrock. These conditions affect the feasibility or design of building foundations and on-lot sewage disposal systems. Each of these conditions should be carefully evaluated for all construction activity by on-site geotechnical investigations.

In using this map, the reader should consult the accompanying Explanation of Map Units and the Geologic Hazards Assessment for Common Land Uses. These explanations define the geologic hazards, describe the conditions affecting those hazards, and estimate the degree of hazard for a specific land use. The degree of hazard will vary depending on the particular land use. Landslides, for example, may be a serious constraint to high-density residential development, whereas recreational areas may be only slightly affected. The map and accompanying descriptions and explanations are not intended as a detailed analysis of a particular site or land use and should not be used in place of detailed field investigations of specific areas. We recommend that the map serve as a basis for further, detailed investigations so that the safety and feasibility of specific projects can be adequately evaluated.

INDEX



Drafting by: RAYMOND LOKKEN

EXPLANATION OF MAP UNITS

ls — Landslide Area: an area formed by the moderate to rapid downward and outward movement of rock and/or soil where a surface of failure or zone of weakness separates the landslide from more stable underlying material. Landslide areas include earthflows, translational slides, rotational slides, and debris slides. Man-caused disturbance of these landslide areas could initiate additional instability and mass movement of part or all of the slide mass. This movement could damage or destroy structures and possibly could affect adjacent downslope areas.

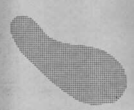
mf — Mudflow Area: an area subject to the rapid downslope movement of wet, viscous masses of fine-grained material following mobilization of the material by intense rainfall or snowmelt runoff. Mobilization usually includes the erosion and transport of poorly consolidated surficial materials that have accumulated in drainage channels and slide slopes. Physiographic features associated with the mapped mudflow areas indicate very recent activity and potential danger for any structures.

df — Debris-Flow Area: a triangular-shaped area formed by the accumulation of water-transported rock, soil, and vegetation debris. Debris accumulation usually occurs at the confluence of a tributary stream with a larger drainage and generally is associated with rapid flows caused by intense rainfall or rapid snowmelt runoff. These flows may cause severe damage to or destruction of man-made structures.

rf — Rockfall Area: an area subject to rapid but intermittent rolling, sliding, or free-falling of detached bedrock of any size from a cliff or very steep slope. Rockfall most commonly occurs in sparsely vegetated areas having jointed bedrock cliffs and represents a serious hazard for residential or commercial development.

us — Unstable Slope: a slope where mass movement has occurred but where recent movement is not apparent or certain. The slope generally is characterized by landslide or soil-creep physiography and may be susceptible to landslide, earthflow, mudflow, or accelerated-creep processes, especially if disturbed.

pus — Potentially Unstable Slope: a slope that currently is in equilibrium and where past or present mass movement of the soil or rock is not apparent. Physical attributes, such as composition of surficial and bedrock materials or slope inclination and aspect, are similar to nearby areas that have failed. A potentially unstable slope may be susceptible to mass-movement failures if disturbed.



Snow-Avalanche Area: an area subject to the rapid downslope movement of snow, ice, and associated rock and vegetation debris. These areas include the avalanche starting zone, track, and runout zone and usually are very hazardous areas for most types of construction.

MAP SYMBOLS

Map unit contact

Snow avalanche: narrow avalanche paths that may be very destructive.

Recent landslide scarp: hachures point in the direction of landslide movement.

NOTE

The entire upper Crystal River area generally is susceptible to a number of geologic conditions that could influence the feasibility or design of building foundations or on-lot septic systems. These conditions include high ground-water levels, expansive soils, and shallow bedrock. Construction anywhere in the area should be undertaken only after detailed geotechnical investigations have determined the specific hazards present and the methods necessary to minimize or abate any adverse conditions.

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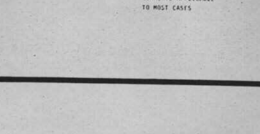
GEOLOGIC HAZARDS ASSESSMENT FOR COMMON LAND USES

Geologic Hazard	Land-Use Activity: Residential Development — High Density	Residential Development — Low Density	Commercial / Industrial Development	Roads	Utilities	On-Lot Effluent Disposal	Ranching	Open Space / Recreation
Landslide (ls)	4 ABCG HAZARD MITIGATION TYPICALLY IS PROHIBITIVELY EXPENSIVE	4 ABCG FEASIBLE ONLY WITH ELABORATE AND EXPENSIVE MITIGATION MEASURES	4 ABCG USUALLY REQUIRES ELABORATE AND EXPENSIVE MITIGATION MEASURES	4 ABCG NOT FEASIBLE WITHOUT CAREFUL PLANNING AND DESIGN; HIGH MAINTENANCE COSTS	3 ABCG NOT FEASIBLE WITHOUT CAREFUL PLANNING AND DESIGN; VERY HIGH MAINTENANCE COSTS	4 AC USUALLY NOT FEASIBLE; EFFLUENT (WATER) MAY REACTIVATE LANDSLIDE	1 CD USUALLY MINOR PROBLEMS EXCEPT FOR BUILDINGS AND IRRIGATION DITCHES	2 AD COMMONLY FEASIBLE; BUILDING SITES SHOULD BE CAREFULLY SELECTED
Unstable Slope (us)	4 ABCG HAZARD MITIGATION USUALLY IS NECESSARY AND MAY BE PROHIBITIVELY EXPENSIVE	4 ABCG NOT FEASIBLE WITHOUT CAREFUL PLANNING AND DESIGN	4 ABCG NOT FEASIBLE WITHOUT CAREFUL PLANNING AND DESIGN	4 ABCG HAZARD MITIGATION MAY BE NECESSARY AND EXPENSIVE; HIGH MAINTENANCE COSTS	3 ABCG MAY BE FEASIBLE WITH CAREFUL PLANNING AND DESIGN	4 AC NOT FEASIBLE WITHOUT CAREFUL PLANNING AND DESIGN; LANDSLIDES MAY BE REACTIVATED	1 CD USUALLY MINOR PROBLEMS EXCEPT WHERE DITCH LEAKAGE CAUSES MASS WASTING	2 AD COMMONLY FEASIBLE; MAINTENANCE COSTS LIKELY
Potentially Unstable Slope (pus)	3 BCEG NOT FEASIBLE WITHOUT CAREFUL PLANNING AND DESIGN; MITIGATION MAY BE EXPENSIVE	3 BCEG MAY BE FEASIBLE WITH CAREFUL PLANNING AND DESIGN	3 BCEG HAZARD MITIGATION MAY BE NECESSARY AND EXPENSIVE; HIGH MAINTENANCE COSTS LIKELY	3 ABCEG MAY BE FEASIBLE WITH CAREFUL PLANNING AND DESIGN	2 BCEG HAZARD CAN BE MINIMIZED WITH CAREFUL PLANNING AND DESIGN	3 AC MAY BE FEASIBLE WITH CAREFUL PLANNING AND DESIGN	1 CDE USUALLY MINOR PROBLEMS EXCEPT IN AREAS OF INTENSE GRAZING ON STEEP SLOPES	1 DE TYPICALLY NO DIFFICULTIES
Rockfall (rf)	4 ABD FEASIBLE ONLY WITH ELABORATE AND EXPENSIVE MITIGATION; HIGH MAINTENANCE COSTS	4 ABD HAZARD MITIGATION IS NECESSARY AND MAY BE PROHIBITIVELY EXPENSIVE	3 ABD HAZARD MITIGATION IS NECESSARY AND MAY BE EXPENSIVE	4 AB HAZARD MITIGATION IS NECESSARY; MAINTENANCE COST USUALLY VERY HIGH	3 AB USUALLY FEASIBLE; HIGH MAINTENANCE COSTS	1 USUALLY FEW OR MINOR PROBLEMS	1 USUALLY FEW OR MINOR PROBLEMS; BUILDING SITES SHOULD BE CAREFULLY SELECTED	3 AD COMMONLY FEASIBLE; BUILDING SITES SHOULD BE CAREFULLY SELECTED
Mudflow (mf); Debris Flow (df)	4 CDEFG FEASIBLE ONLY WITH ELABORATE AND EXPENSIVE MITIGATION; HIGH MAINTENANCE COSTS	4 CDEFG FEASIBLE ONLY WITH ELABORATE AND EXPENSIVE MITIGATION; HIGH MAINTENANCE COSTS	3 CDEFG NOT FEASIBLE WITHOUT CAREFUL PLANNING AND DESIGN; MITIGATION MAY BE EXPENSIVE	4 CDFG FEASIBLE ONLY WITH ELABORATE AND EXPENSIVE MITIGATION; HIGH MAINTENANCE COSTS	3 CEFG MAY BE FEASIBLE WITH CAREFUL PLANNING AND DESIGN	1 USUALLY FEW OR MINOR PROBLEMS	2 CEF USUALLY FEW OR MINOR PROBLEMS; BUILDING SITES SHOULD BE CAREFULLY SELECTED	3 CDEF MAY BE FEASIBLE WITH CAREFUL PLANNING AND DESIGN; HIGH PERIODIC MAINTENANCE COSTS
Physiographic Flood Plain (pfp)	4 FG SEVERE HAZARD AREA; HYDROLOGIC FLOOD PLAIN DETERMINATION NECESSARY	4 FG SEVERE HAZARD AREA; HYDROLOGIC FLOOD PLAIN DETERMINATION NECESSARY	4 FG SEVERE HAZARD AREA; HYDROLOGIC FLOOD PLAIN DETERMINATION NECESSARY	3 FG HAZARD MITIGATION DIFFICULT AND EXPENSIVE; DAMAGE-PRONE AREA	3 F HAZARD MITIGATION DIFFICULT AND EXPENSIVE; DAMAGE-PRONE AREA	4 C COMMONLY NOT FEASIBLE; SEVERE POLLUTION OF NEAR-SURFACE GROUND WATER	2 F COMMONLY FEASIBLE; PERIODIC MAINTENANCE COSTS	3 F COMMONLY FEASIBLE; HIGH, PERIODIC MAINTENANCE COSTS
Snow Avalanche	4 A MAY NOT BE FEASIBLE; MITIGATION MEASURES VERY EXPENSIVE	4 A MAY NOT BE FEASIBLE; MITIGATION MEASURES VERY EXPENSIVE	4 A MAY NOT BE FEASIBLE; MITIGATION MEASURES VERY EXPENSIVE	3 A NOT FEASIBLE WITHOUT CAREFUL PLANNING AND DESIGN; HIGH MAINTENANCE COSTS	2 A COMMONLY FEASIBLE WITH SUBSURFACE PLACEMENT	1 A COMMONLY FEASIBLE	1 A COMMONLY FEASIBLE	4 A SEASONAL HIGH RISK; HAZARD MITIGATION TYPICALLY IS VERY EXPENSIVE

Explanation of Chart Symbols

Key



Degree of Hazard

4 HIGH: DETAILED GEOTECHNICAL STUDIES NECESSARY TO DETERMINE IF AREA IS COMPATIBLE WITH PROPOSED LAND USE
3 MODERATE: DETAILED GEOTECHNICAL STUDIES NECESSARY DURING PLANNING STAGES
2 LOW: GEOTECHNICAL STUDIES MAY BE NECESSARY DURING PLANNING STAGES
1 VERY LOW: GEOTECHNICAL STUDIES COMMONLY NOT NECESSARY

Conditions Affecting Hazard

A HAZARD ESPECIALLY SEVERE ON STEEP SLOPES
B OVERSTEEPENING OR CUTTING OF SLOPES CAN INCREASE HAZARD
C ARTIFICIAL OR NATURAL INCREASE IN GROUND MOISTURE CAN INCREASE HAZARD
D REMOVAL OF NATURAL VEGETATION CAN INCREASE HAZARD
E HAZARD MAY DECREASE AS SLOPE DECREASES
F HAZARD RELATED DIRECTLY TO METEOROLOGICAL EVENTS
G DISTURBANCE OF NATURAL DRAINAGE SYSTEM CAN INCREASE HAZARD

Base from U.S. Geological Survey
Marble qudrangle (7½-minute)

Explanation of Map is Plate 2

Colorado Geological Survey OF-78-11

GEOLOGIC HAZARDS UPPER CRYSTAL RIVER AREA GUNNISON COUNTY, COLORADO

Plate 1 of 2

by WALTER R. JUNGE

1978