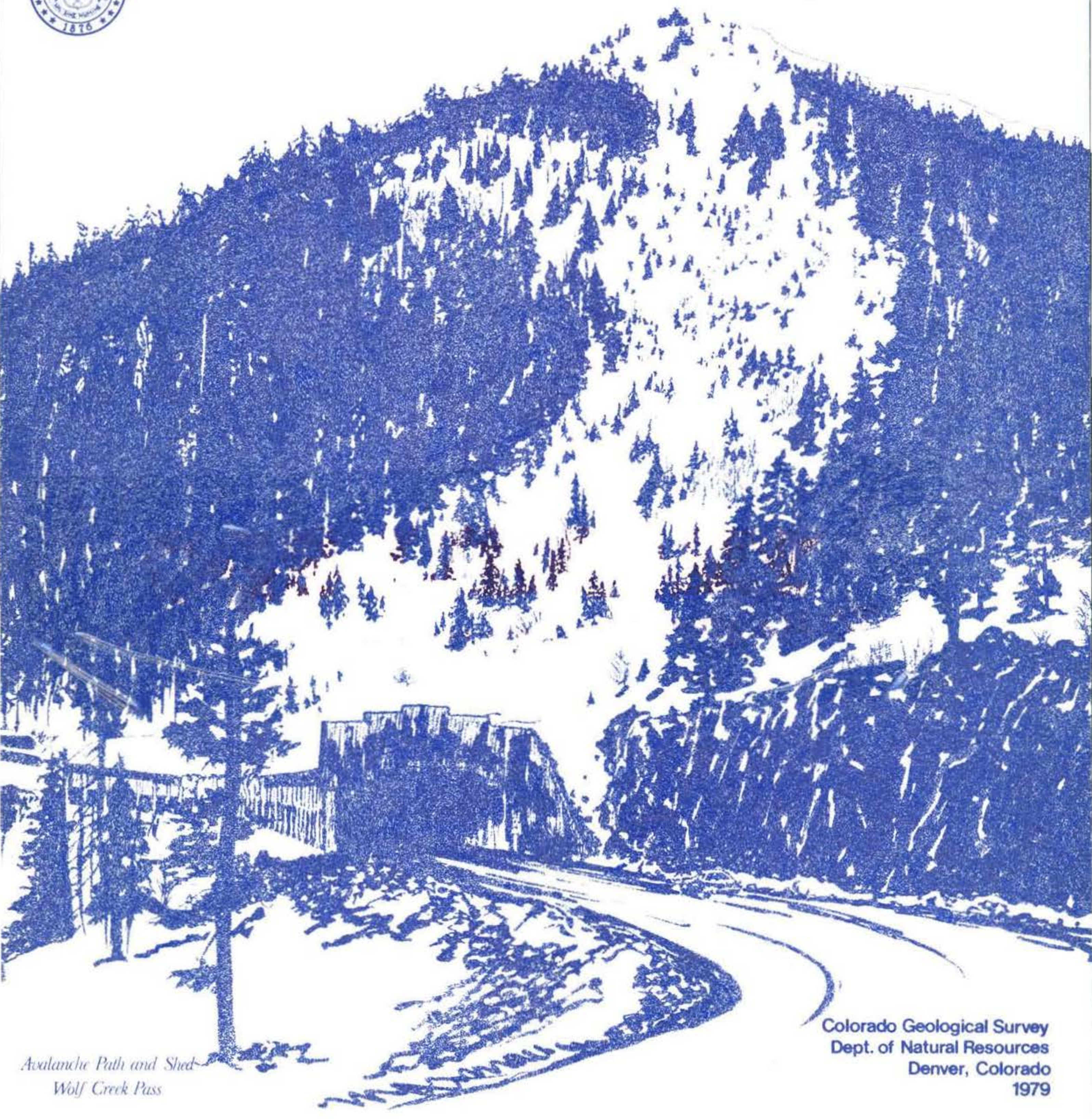
Special Publication 7

Colorado Snow-Avalanche Area Studies and Guidelines for Avalanche-Hazard Planning

by Arthur I. Mears



Avalanche Path and Shed-
Wolf Creek Pass

Colorado Geological Survey
Dept. of Natural Resources
Denver, Colorado
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FOREWORD

Thousands of snow avalanches fall from the steep mountain slopes of Colorado each year. Most of these occur in remote mountain areas where man is not affected and, as a result, go unnoticed. Avalanches become a hazard when man and his works are exposed to them. Two general types of avalanche hazards can be distinguished. The first type affects travelers in mountainous areas who initiate or are reached by small avalanches (snowslides) occurring during periods of unstable snowpack which exist many times during a typical winter. The second type of hazard affects permanent facilities or persons occupying areas reached only by occasional large avalanches.

We feel that the first type of hazard is not amenable to mapping. This hazard exists many times during a winter season primarily in response to rapid changes in snowpack stability induced by weather changes. The majority of victims initiate small slides which can occur on almost any steep slope and often run less than 100 ft (30 m). It is not possible to include all of these areas of potential hazard without resorting to an overly generalized approach to mapping that would not distinguish between the vast number of potential danger areas and some areas that are completely safe. To protect themselves, users of the back country should learn the techniques of avalanche avoidance and survival.

The second type of hazard can be effectively delineated on maps. Mapping the hazard is essential in areas of development or potential development because planning for safe locations of permanent facilities requires knowledge of the magnitude and characteristics of the rare, very large avalanche event. Such avalanche events have seldom been observed and recorded in Colorado, primarily because of the relatively short existence of many mountain settlements. Consequently, the magnitude of the rare avalanche event usually must be determined by indirect observational and analytical techniques.

The reliability of the various avalanche-analysis techniques depends on knowledge about possible snowpack conditions, avalanche dynamics, and terrain elements. Man can respond to knowledge gained about potential avalanche size by zoning of land exposed to the identified hazard or through special engineering to mitigate the hazard. These topics are discussed in the text of this report.

Part 1 of this report is a general introduction to the phenomenon of snow avalanches and their effects on human activities. Part 1 discusses the general concepts of avalanches, their destructive effects, and principles of mapping hazard areas. It also explores the various options available to government officials, planners, and citizens concerned with mitigation of related hazards through education, land-use controls, and engineered defense structures. Part 1 is intended to be a general reference for government officials, planners, and other professionals who are inexperienced in avalanche technology and who have need for such information. The bibliography provides additional references for the reader desiring a more complete and technical discussion of the topics covered.

Part 2 and its appendix are a summary of the 15 area mapping projects that were released in 1975 as open-file reports. The maps, at the reduced scale of 1:50,000, are included with this report in the appendix. Descriptive data for individual avalanche paths are also given in the appendix tables. The text of part 2 describes the mapping technique used and limitations of the method. These data are presented to make this body of information on some Colorado avalanche areas generally available. The basic data of the area reports may be useful to persons performing more detailed studies to refine avalanche-zone boundaries and/or to design avalanche-hazard mitigation measures.

PART I

AVALANCHE HAZARDS AND LAND-USE PLANNING

Failure of snow slopes

Avalanches begin as a result of two distinct failure processes that depend on the mechanical properties of the snowpack. The snowpack properties, in turn, depend on antecedent meteorological conditions. For a comprehensive discussion of the factors that cause avalanches, the reader is referred to Perla and Martinelli (1976).

Loose-snow avalanches

In one process, failure begins near the snow surface when a small volume, usually less than $1 m^3$ ($35 ft^3$), of snow slips out of place and flows downslope. Avalanches that form in this way are called loose-snow avalanches, a term that refers to the cohesionless state of the snow <u>before</u> avalanche release. Loose-snow avalanches are usually small, and although they may be a hazard to mountain travelers on steep slopes, they seldom are large enough to endanger structures in valley bottoms. However, in rare instances, large avalanches will result from similar point failures of wet, loose snow. These avalanches can endanger man-made structures. It is possible that some avalanches attributed to this process actually result from the fracture of a wet-snow slab rather than failure of cohesionless snow.

Small-scale loose-snow avalanches can occur almost continually during and after storms and where the slope angle exceeds approximately 50 degrees (Perla and Martinelli, 1976). Because of this continual sluffing, the snow is gradually redistributed on less steep slopes. Although most loose-snow avalanches do not constitute a significant hazard, they sometimes trigger the more dangerous slab avalanches by dynamic* loading of adjacent slopes.

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*Terms marked with an asterisk are defined in the glossary; an asterisk appears only the first time the term is used.

Slab avalanches

The second failure process is brittle fracture of snow slabs. Snow slabs commonly form in the Colorado mountains as a result of a wide variety of weather conditions (Perla and Martinelli, 1976). Such slabs may be described as visco-elastic* materials. Under gravitational stress, visco-elastic materials are capable of both gradual viscous* deformation (creep) and storage of a finite amount of elastic-strain energy*. If, under a given set of conditions in the snow pack, viscous deformation can respond rapidly enough and the accumulation of significant amounts of elastic strain energy is prevented, only creep will occur. Alternatively, if the stresses within the mass accumulate more rapidly than viscous deformation can accommodate through creep, elastic-strain energy builds up and brittle fracture of the snow slab is possible. The balance between slow-creep deformation and elastic-energy accumulation in the snow slab determines whether stresses are dissipated harmlessly as creep, or whether fracture of the slab occurs, resulting in avalanche release. The snowpack may also slide on the ground (glide) if the friction between the snow and ground is sufficiently small. Creep and glide can exert great pressures on objects located on steep, snow-covered slopes. Glide is a relatively unimportant factor for rough surfaces in cold climates such as those that prevail in the high Colorado Rockies; it is a far more significant problem in the maritime climate of the Swiss Alps. In Colorado, the snowpack deforms primarily by creep.

When snow is forced to deform at a rate in excess of the maximum possible creep rate, sudden brittle fracturing of the slab occurs. The increased creep rate may result from increased loading by wind or snow storms, decreased strength due to modification of the internal structure of the slab, or development of stress concentrations* in areas of surface irregularities. The released strain energy is quickly transferred to fracture surfaces at the crown, flanks, downslope slab boundary or stauchwall, and the bed of the slab (Figure 1). All of these surfaces must fail in order for the slab to become detached from the adjacent stable snow. These fracture surfaces propagate very rapidly and often connect areas of weakness or stress* concentrations within the slab.

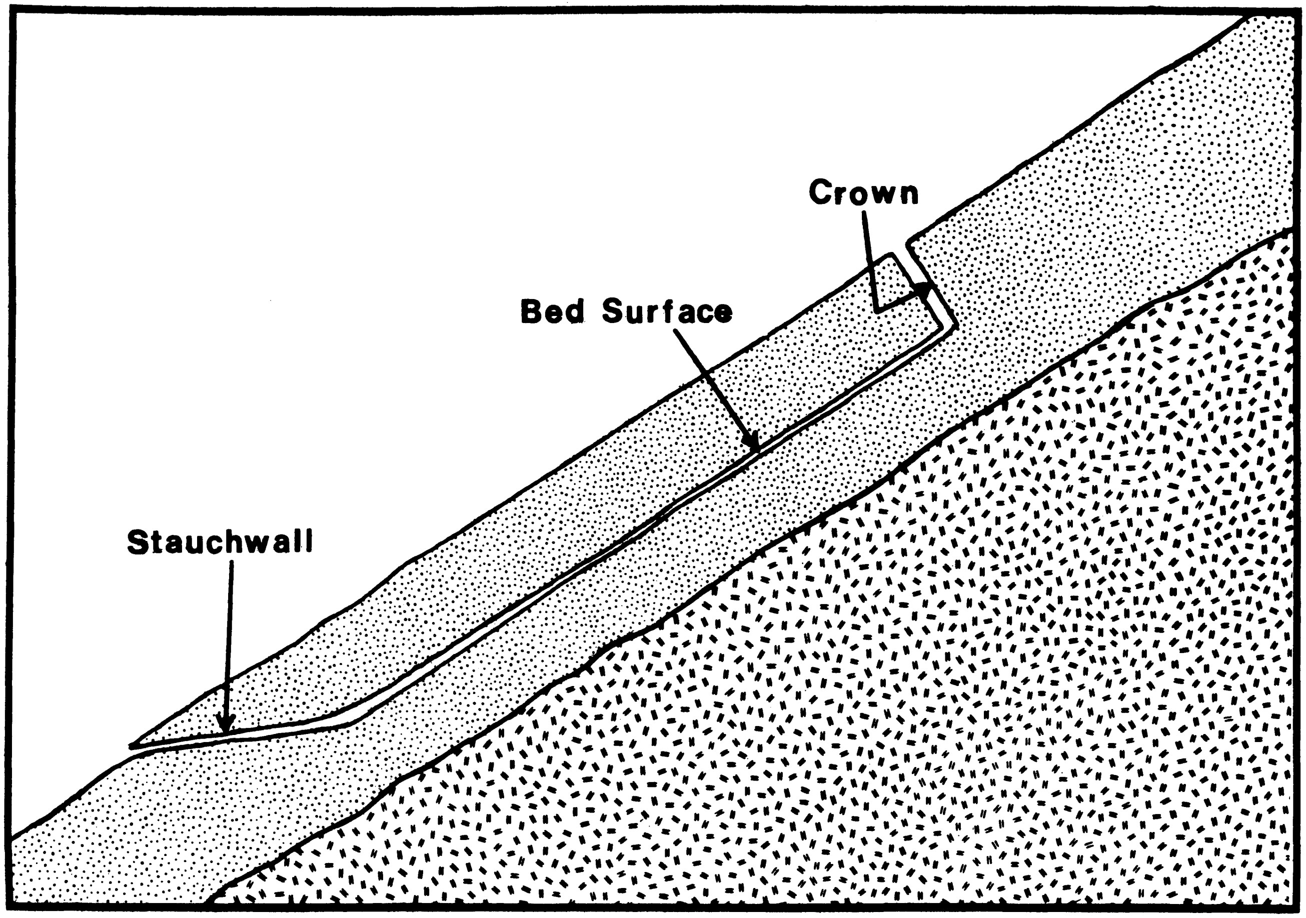

Figure 1. *The fracture surfaces in an inclined snow slab are the crown, bed, stauchwall, and flanks. In this illustration the flanks are in the plane of drawing.*

The characteristics of such slabs are discussed by Perla and Martinelli (1976). The slabs can vary widely in thickness, density, hardness, strength, and wetness. Although the slab strength and wetness are difficult to measure and measurements may be subjective, some data are available for slab thickness and density. Slabs are known to vary in thickness from a few inches to more than 15 ft (5 m) and to vary in density between roughly 10 percent and 40 percent of water density. The less dense slabs are known as soft slabs and usually are mechanically weaker than hard slabs of higher density. After fracture of a slab and release of an avalanche, soft slabs tend to disintegrate quickly into a formless, fluid-like mixture of snow particles and air, whereas the denser hard slabs are composed of strongly bonded snow that further fractures into jagged blocks capable of remaining intact for the duration of the avalanche. Field evidence obtained in a limited number of cases suggests that the strength of slabs strongly influences the velocity and destructive range of large avalanches (Mears, unpubl. data).

The bed-surface inclinations of most large slab avalanches lie within the 30- to 45-degree range (Perla and Martinelli, 1976). There are isolated examples of areas where slab avalanches begin outside of this range, however. It is possible that less steep slopes (in the 30-degree range, for example) are more apt to have thicker, more massive releases of snow because a greater weight of snow is necessary to stress the slab to the breaking point. A morphological study of 67 large Colorado avalanche paths (Bovis and Mears, 1976) suggests that larger avalanches may begin on slopes in the 30- to 35-degree range. A well known example of a massive slab avalanche released from slopes in the 28- to 35-degree range occurred in 1962 at Gordon Gulch near Twin Lakes, Colorado (Frutiger, 1975).

As used in this section, the terms "loose-snow" and "slab" avalanche refer to the properties of the snowpack prior to avalanche release. They should not be used to describe the properties of moving avalanches. The subject of avalanches in motion is discussed in the next section.

AVALANCHE DYNAMICS

The theoretical basis of avalanche dynamics most commonly used for avalanche analysis in Europe and North America was first derived by Voellmy (1964). Little additional research on the flow of snow has been done since that time, even in Switzerland where severe land-use problems in avalanche paths exist. In the United States this subject has been ignored until recently, when we have begun to experience increasing pressures to develop potential avalanche zones with permanent structures. Consequently, the technical or engineering approaches to dynamic analysis of avalanches has closely followed Voellmy's earlier fluid-mechanics model for avalanche movement. Although it is generally agreed that not all avalanches behave as fluids, or can be adequately modeled by fluid mechanics, such an approach provides a workable approximation and is certainly preferable to subjective ones. In time, more data will be collected, measurements will improve, and perhaps new experiments will be carried out that will affirm, modify, or negate the present model. In the meantime, realizing that the results from the present approach are only approximate, land-use decisions should be based on what we consider to be the state of the art for avalanche analysis. This is a common procedure in science and engineering and, if allowed to operate, will gradually provide improved models on which more confident estimates of the extent of avalanche hazards can be made.

Few measurements of avalanche velocity, dynamic pressures, densities, flow dimensions, or length of travel (runout distance) have been made on actual avalanches. Such data are obviously difficult to obtain. Efforts to obtain such data are presently being made by the U.S. Forest Service, the National Research Council of Canada, and the center for Snow Studies in France.

Rather than advocating a particular model for avalanche dynamics, the present discussion summarizes existing information and presents certain basic ideas about the forces operating in an avalanche related to properties of the snowpack.

Driving force and motion resistance

After fracture and release, the snow slab accelerates downslope as an avalanche. The rigid slab is broken up by sliding, tumbling, and bounding movements of fragments. If it travels far enough or is broken up into sufficiently small particles, the motion develops into a flow. Two opposing sets of forces affect an avalanche. The driving force, F, is the component of its weight acting acting parallel to the slope; the resisting force, R, is composed of several forces that act to oppose F (Figure 2).

Regardless of details about the forces, an avalanche in motion will accelerate as long as F exceeds R because there will be a net force difference and thus an acceleration acting in the downslope direction. The first condition, F exceeding R, occurs in the upper part of the path (starting zone) because of the steep terrain that results in a large driving force, F. In turn, additional unstable snow is incorporated into the avalanche and, because more snow is entrained than deposited, the flow mass increases. For dynamic analysis of avalanches, the starting zone is usually defined as the area within the avalanche path where slopes exceed approximately 30 degrees. An area thus defined usually exceeds the area of the initial snow slab released.

Constant velocity is achieved when F equals R. This condition occurs in the track, which is the transition between the starting zone and the bottom of the avalanche path (Figure 3). However, even in the track, velocity must continually change in response to topographic irregularities, entrainment of additional snow, and deposition. Normally, however, maximum or terminal velocity is attained in the track.

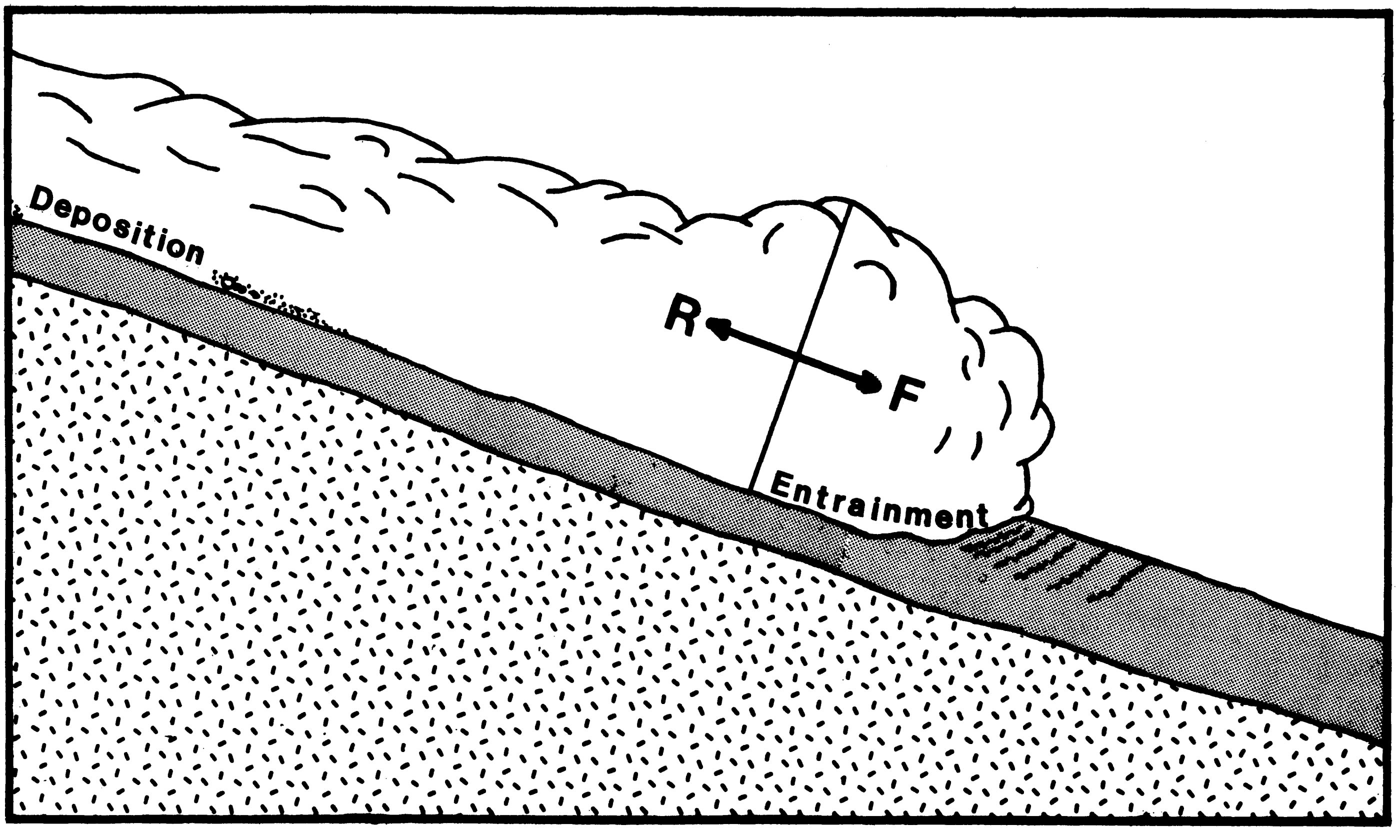

Figure 2. *The driving force, F, and the resisting forces, R, act on a moving avalanche to determine its acceleration and final or maximum velocity. The relative importance and total magnitude of the resistance forces depend on the type of avalanche.*

Deceleration occurs when R exceeds F. This occurs in the runout zone, where the gradient is reduced, and as a result, the driving force, F, is also reduced. Furthermore, the underlying snowpack is stable, the kinetic energy* is dissipated, and avalanche material is deposited. The distribution of the avalanche deposits defines the maximum limits of the runout zone for a particular event. These limits probably depend more on avalanche velocity than on ground roughness in the runout area. The various parts of avalanche paths are illustrated in Figure 3.

The preceding discussion applies to all avalanches regardless of size. Avalanches begin in a starting zone and stop in a runout zone. In a given path, the type and amount of snow released determines the balance between forces, the velocity, the amount of snow entrained, and the location and extent of the runout zone. Thus, a given avalanche path can produce avalanches of various sizes; the

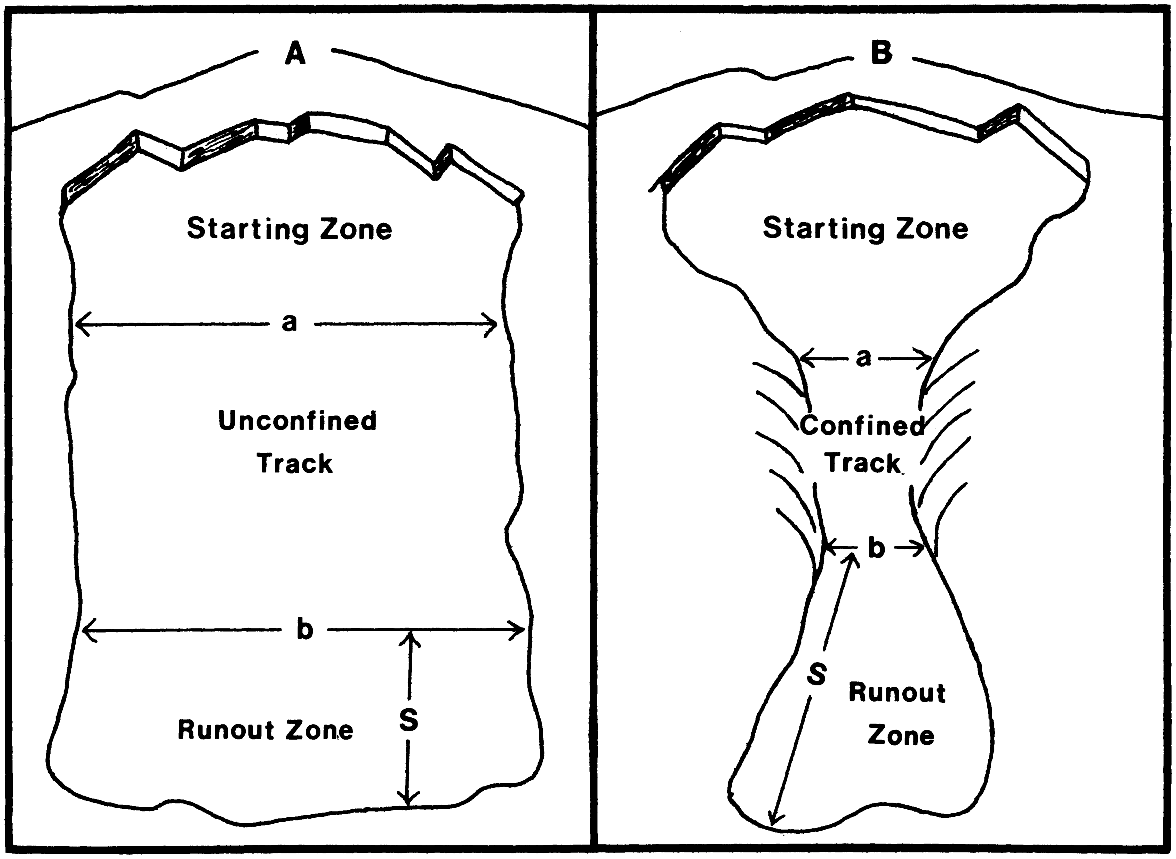

Figure 3. *An unconfined avalanche path (A) and a confined path (B). In path (A) the runout distance, S, is not affected by the width of the starting zone because concentration of discharge does not occur at (a) and (b). In path (B) all the released snow is forced through the confined track at (a) and (b). Therefore, velocity is increased and the runout distance depends on the size of the starting zone. (Mears, 1976a).*

largest avalanches occur least frequently and are potentially the most destructive. Smaller avalanches can occur yearly, or many times in a given year, and are usually easier to predict.

Resisting forces, R_1, and snow type

The most important factors contributing to the resisting forces within an avalanche are:

R_1, sliding friction at the bottom of the avalanche,
R_2, internal shear resistance due to collisions between snow particles,

R_3, turbulent friction,
R_4, shear with surrounding air, and
R_5, frontal drag.

The net force available to accelerate the avalanche results from the summation of all driving and resisting forces and can be expressed in the following equation:

$$\text{acceleration} = \frac{F - (R_1 + R_2 + R_3 + R_4 + R_5)}{\text{avalanche mass}}$$

Within the avalanche, the resisting forces vary in relative importance, depending on the type of avalanche snow. The type of snow in the avalanche depends, as discussed earlier, on the characteristics of the slab prior to avalanche release and the type of snow encountered and entrained in the track.

In dry-snow avalanches, the strength and density of the dry slab probably determine the relative importance of the resisting forces. In the release of a hard, strong slab the majority of the avalanche mass is composed of relatively large snow blocks probably 4 to 40 in. (10 to 100 cm) in length. These blocks roll, slide, bound, collide with one another, but because of their large size and high, free-fall velocities, they never become suspended in a turbulent flow well above ground level. Instead, the mass moves near the surface as a cascade of discrete fragments and resistance to movement is primarily from forces R_1 and R^2. In this case, forces R_3, R_4, and R_5 do not contribute much resistence to movement because the avalanching snow does not behave as a fluid.

After a soft-slab release, disintigration of the slab and air entrainment are very rapid, and much of the mass is suspended well above the ground level. As a result, resisting forces R_1 and R_2 are less important because the avalanche exhibits the properties of a fluid. As air entrainment and flow height increase, velocity also increases, and resisting forces R_3, R_4, and R_5 are primarily responsible for resistance to acceleration. In some cases, a large mass of flowing snow is whirled into suspension and held well above ground level by turbulence. This is known as powder a avalanche. The denser mass that remains close to the ground is called a flowing avalanche. Powder avalanches, because of their great flow depths and high velocities, can travel long distances in the runout zone and are very difficult to stop or deflect. In the majority of cases, soft-slab releases develop into a combination of flowing and powder-avalanche types. An example is diagrammed in Figure 4.

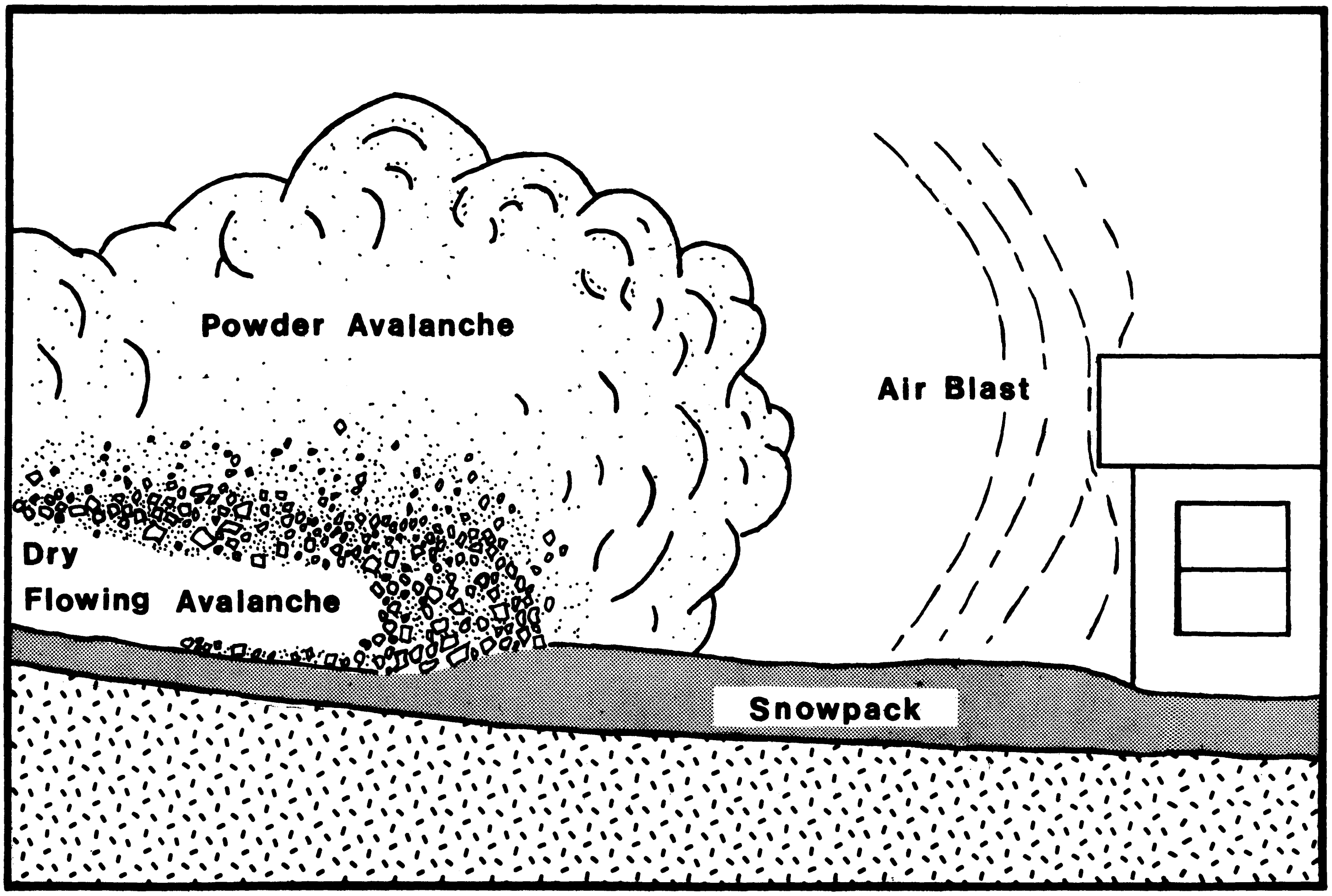

Figure 4. *The release of a dry slab usually results in a mixed flowing and powder avalanche. The amount of air entrainment and mass transported well above the ground as a powder avalanche depends on initial slab strength and path roughness and steepness. In large avalanches the powder-avalanche component can separate from denser, slower moving flowing avalanches and reach the runout zone first. Powder avalanches are sometimes preceeded by an air blast.*

If an avalanche path is long, steep, or broken up by cliffs, both hard and soft slabs can evolve into powder avalanches because the blocks of snow have more opportunity to become fractured into small fragments.

Avalanches resulting from the release of wet slabs usually disintegrate quickly into a pasty mass or slurry which moves at relatively low velocities and

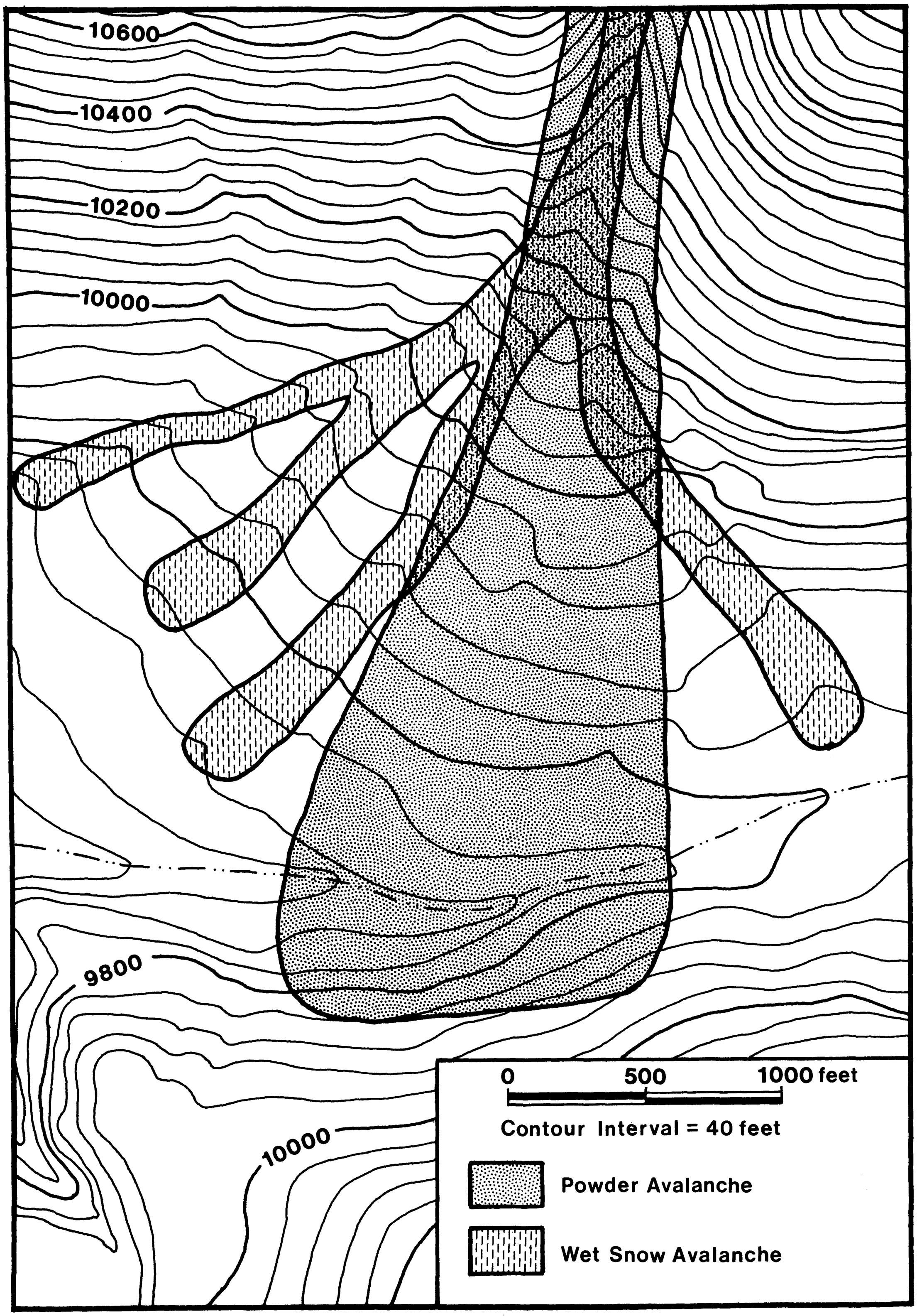

Figure 5. *Different types of avalanches can affect different parts of the runout zone in this debris fan. Slow moving wet snow avalanches follow gullies and are deflected by small ridges. Powder avalanches advance across the fan in the direction attained in the channeled track. (Mears, 1976a).*

follows gullies or other terrain features faithfully (Figure 5). Because of the small amount of air entrainment in wet-snow avalanches, their flow does not achieve great heights. Resisting forces R_1 and R_2 are much more important than R_3, R_4, and R_5. However, in spite of relatively low velocities, and because of their high densities, wet-snow avalanches can be very damaging.

Table 1 gives typical values for the velocities of small, medium, and large avalanches. The values, which are only estimates, are based on the opinions of avalanche-dynamics researchers in Europe and North America.

TABLE 1

Typical Avalanche Velocities--mph (kph)

Type of Avalanche	Small	Medium	Large
Wet-flowing	up to 25 (40)	25 to 50 (40 to 80)	50 to 75 (80 to 120)
Dry-flowing	up to 25 (40)	25 to 75 (40 to 120)	75 to 125 (120 to 200)
Powder	up to 50 (80)	50 to 125 (80 to 200)	125 to 200 (200 to 322)

The dynamic pressures caused by an avalanche are of practical concern when building is planned in or near avalanche paths. However, these pressures have seldom been measured, primarily because of difficulties associated with instrumentation of very large avalanches which are of the most interest for land-use planning. Measurements that have been made are usually over a very small area, so it is not known if the recorded data accurately represent potential pressures over much larger areas such as the walls of a building. Furthermore, the pressure (a force per unit area) depends on the size and shape of the object, as well as the type, velocity, and density of the flowing snow. The pressures given in Table 2 assume that the impacted objects are rigid solids. Powder-avalanche pressures are stagnation pressures* and do not consider drag or shape coefficients*. Flowing-avalanche pressures assume the flow is deflected through 90 degrees. For a more comprehensive discussion of avalanche impact see Mears (1976a).

TABLE 2

Typical Avalanche Dynamic Pressures--lbs/ft^2 (kg/m^2)

Type of Avalanche	Small	Medium	Large
Wet-flowing	to 1000 (4880)	1000 to 4000 (4880 to 19,520)	4000 to 10,000 (19,520 to 48,800)
Dry-flowing	to 500 (2440)	500 to 5000 (2440 to 24,400)	5000 to 15,000 (24,412 to 73,236)
Powder	to 100 (488)	100 to 600 (488 to 2928)	600 to 1500 (2929 to 7323)

As Table 2 suggests, the denser flowing avalanches have much higher pressure potentials than the much more diffuse powder avalanches. Observations indicate that in the runout zones, denser flowing avalanches are much more limited in areal extent. Powder avalanches, on the other hand, tend to affect much larger areas in the runout zones (Figure 5).

Air blast sometimes accompanies fast moving, dry-flowing and powder avalanches. Air blast may extend the destructive range of these avalanches, but pressures probably do not exceed 100 lbs/ft^2 (488 kg/m^2) with 50 to 75 lbs/ft^2 of air blast and its applicability to avalanche-hazard planning, see Mears (1976a, p. 92).

TERRAIN, MAGNITUDE/FREQUENCY RELATIONSHIPS, AND HAZARD ANALYSIS

General

A detailed discussion of avalanche terrain and its relationship to snow accumulation, avalanche formation, and avalanche size is beyond the scope of this report. For more comprehensive treatments see Mears (1976a) and Perla and Martinelli (1976). This section provides a brief discussion of avalanche terrain and its relationship to avalanche-magnitude/frequency relationships.

Confined and unconfined paths

Avalanche paths may be distinguished on the basis of how the released snow is channelized down the mountainside. In a confined path (Figure 3), all of the snow released and entrained in the starting zone is forced through the narrow channelized track regardless of the mass released. Therefore, the volume of snow passing through a given cross section of the channel during a specified time period depends on the volume of snow released from the starting zone. For a given snowpack depth (an assumed maximum or design depth) the volume is proportional to the area. In confined paths, it is necessary to determine the area of the starting zone in order to calculate the velocity and discharge* of snow and, as an end result, the runout distance (Mears, 1976a).

In unconfined paths (Figure 3), the snow is released across an open slope and does not converge into a gully. The avalanche is the same width over the entire path. Thus flow depth, discharge, and velocity do not depend on starting-zone area and runout distances becomes a function of snow type and track steepness rather than the area of the starting zone.

Starting-zone characteristics

With optimum conditions that result in a snowpack sufficient for release of a large avalanche, avalanche size is limited by topographic boundaries. Although weather and snowpack conditions fluctuate widely over a long time period, the terrain remains constant, thus providing a means by which potential maximum avalanche size may be estimated. The potential for large avalanches is greater if the starting zone is not broken up by sharp ridges that inhibit formation and release of a single large slab. Furthermore, moderate instead of steep terrain may favor less frequent but larger releases of snow. An excellent sample of this occurred at Twin Lakes, Colorado, during January, 1962 (Frutiger, 1975). In this case much of the snow was released from slopes of only 29 to 30 degrees. Although steep slopes produce frequent, more commonly observed slides, extensive slopes of approximately 30 degrees may be more important for the assessment of major avalanches that are of the most interest for planning development of mountain areas.

Magnitude/frequency relationships in the runout zone

As defined earlier, the runout zone is that part of the path where avalanches decelerate and stop. Although not fully understood, there is for any given path some relationship between the size and length of the runout zone, and the frequency or probability of an avalanche. This is called the magnitude/frequency relationship, a frequently used concept in flood-plain determinations. The relationship is usually expressed as the return period (or annual probability) of an avalanche that will travel some specified distance into the runout zone.

There is no definable upper limit to avalanche size. One can always imagine an event slightly larger (and less likely) than the largest of record. Nonetheless, a practical upper size limit exists at which the probability of an occurrence of such an avalanche is similar to that of other risks we normally take in our daily activities. In this country we have defined the "100-year" event, or 1-percent-probability event, as a benchmark hazard level for water flooding and, in some areas such as Vail, Colorado, for design avalanches*. This concept will be discussed more fully later.

Figure 5 is a schematic drawing (not based on detailed analysis) of the runout zone of large, rare avalanches that start in the confined avalanche path called Spring Gulch at Ophir, Colorado (Ives and others, 1976). The powder-avalanche runout zone extends 2500 ft (762 m) from the mouth of Spring Gulch across the fan and a considerable distance up the opposite valley wall. In the past, powder and dry-flowing avalanches have destroyed mature conifers at the end of the runout zone on the opposite side of the valley. Different types of avalanches (wet-flowing, dry-flowing, and powder) have taken different paths across the runout zone. Wet-snow avalanches move more slowly and are deflected by ridges and gullies.

Therefore they are likely to be split into fingers that follow shallow distributary channels on the fan. The channels maintain flow depth and can cause long runout distances in widely divergent directions. High-velocity dry-snow and powder avalanches are not deflected by surface irregularities on the fan surface because of their great flow depths (Figure 4). They advance across the fan in the direction dictated by the main gully, gradually widening as they do. Although a detailed study of the dynamics of the Spring Gulch avalanche path has not been made, it would seem appropriate to designate the entire fan as a potential-hazard area until more detailed studies are completed (see Plate 9).

Another exceptionally large and well documented avalanche occurred February, 1976, three miles north of Crested Butte, Colorado, in the valley of the Slate River. This was a very large mixed dry-flowing and powder avalanche that released from a large, smooth slope and ran out at least 2200 ft (671 m) across the valley bottom. The runout zone was nearly level for the first 1000 ft (305 m) and gradually climbed 150 ft (46 m) as it ascended a series of benches during the next 1200 ft (366 m) (Mears, 1976b). Several lodgepole-pine trees more than 100 years old were destroyed by powder-avalanche impact in the runout zone of this avalanche. This suggests, from the observed event, that an avalanche of this magnitude probably had not occurred at this location for approximately a century.

These are common examples of "design-magnitude" avalanches in large avalanche paths. If development were to be planned in or near these runout zones it would be advisable to plan and design for avalanches of approximately the magnitude of those that have been observed or well documented. Small avalanche paths have much smaller design-avalanche runout zones. Well known examples exist at Vail, Colorado (Plate 15), where numerous small snowslides fall only 200 to 500 ft (61 to 152 m) on steep valley walls and even during severe conditions may run only 100 to 300 ft (30 to 90 m) on gradients of 5 to 15 degrees in the runout zone. Nevertheless, these small flowing avalanches may produce formidable dynamic pressures as indicated in Table 2 and may constitute significant hazards because the runout zones are being developed with residential and commercial buildings.

It is evident that hazard depends both on the magnitude/frequency relationship and also on man's use of the runout zone. For example, placing a public facility that concentrates large numbers of people for long periods of time within a runout zone creates considerably more hazard than that caused by occasional exposure to avalanches of cross-country skiers at the same location. The relationship of avalanching to weather conditions does not change, but the hazard depends on both avalanche magnitude/frequency relationships and total exposure time of people and facilities. The permanent facility is a constant fixed target.

Delineation of Hazard Zones

Although the limits of hazard may appear obvious in the Spring Gulch and Slate River examples described above, these are exceptionally well documented cases. Because of their long return periods, design avalanches are rarely observed, especially in areas that have been inhabited only a few years or decades. Therefore, in most cases we are obliged to use various indirect methods to determine expectable avalanche size.

There are two common methods of hazard-zone analysis: observational and analytical. Observational methods involve assessing avalanche size from traces of destruction in forested runout zones. Starting zones, tracks, and runout zones may sometimes be clearly distinguished in forested areas. Study of damage to trees may provide indications of the limits of past large avalanches. In some cases estimates of return periods can be made by detailed tree-ring study. However, such observational studies do not provide good data in sparsely timbered avalanche paths. Furthermore, they do not provide reliable information about dynamic pressures which is also necessary to evaluate hazard potential. It is necessary to employ the avalanche-dynamics analytical methods even though such techniques are simplistic. Because of the uncertainty inherent in the use of any single method, it is best if several independent methods, some observational and some analytical, can be employed to the study of any given avalanche path. The various analytical techniques should take into account vegetation damage, terrain, and analytical calculations (Mears, 1976a; Mears, 1977). Thus the best available interpretations may be derived and land-use decisions and zoning can be based on this information.

AVALANCHE-HAZARD ZONING

Two types of zones exist. The first depends on the dynamics of the design avalanche which was defined in the preceding section. This zone is defined in terms of the magnitude/frequency relationship, types of avalanches possible, discharges, pressures, and velocities. These zones of intensity represent natural conditions which man may choose to alter by avalanche defenses. The problem, as mentioned in the previous section, is in defining these zones through use of the best available information and analytical methods.

When man arrives and defines the hazards adequately a second and distinctly different problem occurs. He must now decide what degree of hazard is acceptable. In heavily developed areas the criterion for acceptable hazard in an avalanche zone is usually a government decision rather than a private one. In Switzerland the final decisions about land use in hazard zones are usually made by local government(s). In Colorado final decisions are also usually made by local town and county governments.

Avalanche-zoning plans emerge as a result of these government decisions. It has been generally recognized that for permanent habitation there exists a part of the avalanche path in which the hazard is unacceptably high. In such areas avalanches may occur frequently or produce very high dynamic pressures. On the outer fringe of a design-avalanche path, occurrence may be so rare that the probability of injury or structural damage can be considered negligible and the slight risk may be accepted. Between these two zones there exists a moderate-hazard transition zone.

It has proven most useful to define these zones in terms of avalanche frequency and dynamic pressure, thus defining a magnitude/frequency distribution in the runout zone. The first comprehensive avalanche-zoning plans defined in these terms developed in Switzerland (Frutiger, 1970) and have been revised during the past few years (U.S. Forest Service, 1975). The Swiss government recommends that the following zone definitions be applied by its local governments:

Red (high-hazard) zone. This zone includes terrain exposed to frequent and/or large, powerful avalanches that satisfy either of the following:

1. Any avalanche with a return period of less than 30 years.
2. Any avalanche with a dynamic pressure of 615 lbs/ft^2 (3.0 t/m^2) or more, and with a return period of up to 300 years.

New buildings are not generally permitted in the red zone.

Blue (moderate-hazard) zone. This zone includes avalanches that are either smaller or less frequent:

1. Avalanches with dynamic pressures of less than 615

lbs/ft^2 (3.0 t/m^2) or more and a return period of 30 to 300 years. The specification of return periods as long as 300 years is strongly questioned by some Swiss scientists who think that it is not practical to define avalanches with such small probabilities. The 300-year period is approximately equal to the oldest records of avalanches in Switzerland. Private homes are permitted in the blue zone if they are designed to resist expectable avalanche forces or are otherwise protected by avalanche defenses.

Yellow (very low-hazard) zone. This optional zone is not always used. It defines avalanches that are very rare or defines areas subject to the blast of low-density snow or air from powder avalanches.

1. A powder avalanche with dynamic pressures of 62 lbs/ft^2 (0.3 t/m^2) or less having a periodicity of more than 30 years.
2. Extremely rare flowing avalanches with return periods of more than 300 years.

Swiss avalanche-zoning guidelines suggest that buildings constructed according to standard Swiss construction criteria would probably not be damaged by powder avalanches within this zone. This is not necessarily true of buildings constructed conforming to the Uniform Building Code Standards, widely used in the United States.

White Zone. White zones are considered to be hazard-free. Specifically, this means that the zone is beyond the limit of the design avalanche as defined in Switzerland. It does not mean that it is outside of the range of all avalanches possible.

The Town of Vail, Colorado, has defined hazard zones in terms of avalanche dynamics (Figure 6). Avalanche-hazard-zone definitions will be explicitly specified in the town comprehensive plan which is presently being developed. In the past, new buildings were reviewed on an individual basis and were permitted in hazard zones if the hazard zones corresponded to the Vail definition of "moderate hazard". Construction was permitted within moderate-hazard zones only if specially designed avalanche defenses were constructed according to design criteria developed in a detailed avalanche-dynamics study. Vail hazard-zone definitions differ from that of the Swiss moderate-hazard zone because the Vail definitions are for an area affected by avalanches with return period of up to "one or two centuries" and more than 25 years. This modification to the Swiss definition recognizes the uncertainty of specifying very long return periods in an area of short observational records. A powder-avalanche blast zone is also defined in areas where it is applicable.

Map detail and hazard zones

The maps discussed above require a detailed topographic base map and/or extensive on-site field investigations. The example shown in Figure 6 from the Town of Vail is at a scale of 1:4,800 (1 in. equals 400 ft; 1 cm equals 48 m). The original mapping was done on a topographic base with 2-ft contours. The accuracy level of these maps correspond to the maximum practical level of accuracy obtainable from detailed analysis of a large avalanche path. Such detailed maps are rarely available in the United States unless prepared for a particular site or project. The scale most commonly available in mountain regions is 1:24,000 (1 in. equals 2000 ft; 1 cm equals 240 m) with 40-ft contours. They do not provide sufficient detail for site-specific hazard evaluation and planning. Detailed avalanche-hazard maps are sometimes shown on high-quality aerial photographs, usually at a scale of 1:10,000 or larger. Photographs have some advantages over maps in that they commonly show individual trees, boulders, and various works of man. These provide good reference points for hazard-area delineations. Because of the lack of detailed maps of many parts of the United States, it is necessary for all detailed avalanche studies that careful field study of the starting zones, tracks, and runout zones be undertaken.

Although detailed topogaphic maps (or photo-maps) are necessary, there is an upper limit to the practical accuracy of avalanche-hazard-area mapping. Even after detailed studies have been completed, there will still be some uncertainty about the limits and dynamics of avalanches that should be expected. Because of this uncertainty, it is misleading to present runout-zone details on maps of scales much larger than 1 in. equals 200 ft (1:2400) unless the overall dimensions of the avalanche path are very small. Regardless of the details of a study, additional precision usually cannot be shown on a scale much larger than that shown on Figure 6.

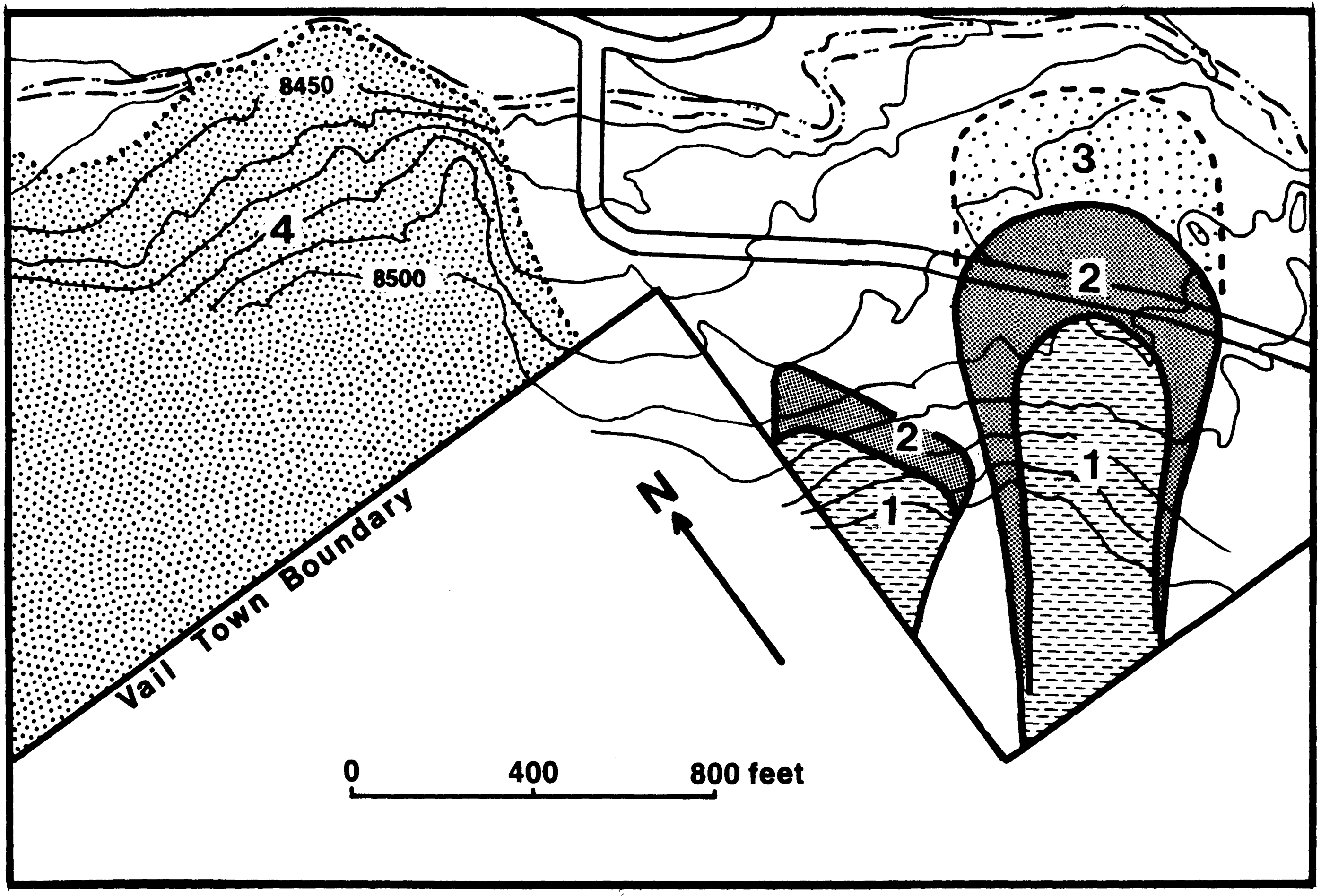

Figure 6. *Example of detailed avalanche-hazard mapping at Vail, Colorado. Hazard zones 1, 2, and 3 were determined by detailed studies of the avalanche paths and vegetation damage and avalanche-dynamics calculations. Zone 1 is high-hazard where dynamic pressures exceed 600 lbs/ft^2 (123 kg/m^2) and estimated return periods are less than 25 years. Zone 2 is moderate-hazard where pressures are less than 600 lbs/ft^2 (123 kg/m^2) and return periods are 25 to 100 years. Zone 3 is affected by power-avalanche air blast pressures up to 65 lbs/ft^2 (13 kg/m^2). Zone 4 is designated as an "avalanche-influence zone--more detailed studies required." Influence zones correspond approximately to the mapped limits provided by reconnaissance mapping shown on Plate 15.*

More generalized avalanche-planning maps have been prepared by the Colorado Geological Survey for several other selected areas in Colorado. Examples (Plates 1-15) appear in this publication. These maps were initially prepared on 1:24,000-scale U.S. Geological Survey topographic base maps. They are similar to Swiss 1:25,000-scale avalanche planning maps in that they show three zones of hazard intensity. The definition of the high, moderate, and no-hazard zones are given and discussed in Part 2 of this report. Delineation of intensity zones serves a useful purpose as land-use planners can often determine if property is located clearly in one hazard zone or another. Borderline cases cannot be determined from map inspection and usually require additional study. If property is clearly located in one hazard zone or another, the owner or prospective buyer can be advised of the condition. With such information about hazard intensity, informed land-use decisions and recommendations can be made. The maps included in this publication are intended for general land-use planning purposes only. No attempt is made to warn the winter-recreational backcountry users of the hazard which, as stated in the introduction, fluctuates widely in response to weather conditions and may be localized.

Other avalanche maps of various parts of Colorado have been prepared since 1964 by the U.S. Forest Service, U.S. Geological Survey, Colorado State University, and the University of Colorado Institute of Arctic and Alpine Research. These maps differ significantly in usability as well as method of investigation and apparent mapping objectives, although most were prepared at a scale of 1:24,000. Some of these maps have the warning of winter users of the backcountry as their stated purpose. For reasons discussed earlier in this report we do not believe that this is a practical objective. However, for completeness and convenience of users of this report, we are listing all known mapping of Colorado avalanche areas as a separate section of the bibliography.

In general we recommend that the following factors be considered and evaluated in preparing avalanche-hazard maps for land-use-planning purposes:

1. The maximum extent of the runout zone should be related to the size of the starting zone and elevation and climate of the mountain area.
2. The geometry and length of the runout zone should take into consideration all types of avalanches considered possible over a long period (Figure 5).
3. The dynamics and sequences of slab releases from the starting zone or zones and how they may combine should be considered as all of these factors strongly affect potential avalanche size. This is especially important in paths with complex or multiple starting zones.

4. Vegetation damage, a good indicator of past events, does not necessarily show the size of an avalanche that should be anticipated. In some cases damage may have been caused by other geologic processes. Topography and potential avalanche velocity at various points in a path are better indicators of runout extent(s). Vegetation damage should be used whenever possible to estimate avalanche frequency.

AVALANCHE DEFENSES

Building in avalanche paths should be avoided whenever possible; the most desirable defense is to locate objects outside of avalanche paths. As mountain populations increase and less desirable sites are considered for development, it may not always be feasible to avoid moderate-hazard avalanche zones. When this is the case, strictly enforced zoning, as discussed in the preceding section, appears to be the best solution. Very high land values, such as those at Vail, Colorado, sometimes dictate that some degee of hazard will be accepted.

At locations where avalanche hazards cannot be avoided and permanent facilities already exist or are planned, avalanche defenses should be employed to mitigate the hazard. The wide variety of structural avalanche defenses may be classified into four groups: (1) supporting structures in the starting zone; (2) deflecting, retarding, and catching structures in the track and runout zone; (3) direct-protection structures in the track and runout zone; and (4) snow fences and wind baffles (Perla and Martinelli, 1976). Details of supporting-structure design are given in the Swiss Federal Institute for Snow and Avalanche Research (SFISAR) guidelines (1962) and in Frutiger and Martinelli (1966). Design details for deflecting, retarding, catching, and direct-protection structures are given in Mears (1976a).

Artificial release of avalanches by explosives or artillery is not considered to be an acceptable avalanche-defense alternative for areas of potential human occupancy because it is unreliable as a long-term fail-safe method. This technique is commonly used, with varying degrees of effectiveness, in ski areas and on highways where avalanche paths can be evacuated prior to control attempts and where avalanches will not cause structural damage. Obviously, artificial release should not be used as a control method above permanent structures intended for occupancy.

Supporting structures in the starting zone

Supporting structures are built in the starting zone and are intended to reduce or eliminate avalanche release. The structures provide points or lines of anchorage for snow slabs and, when properly designed, prevent large-scale avalanche release. Design of supporting structures has evolved during the past few decades primarily through the research and experience of the SFISAR. Modern support structures are usually steel and are high enough to project above the design snowpack. In Switzerland, structures in areas of heavy snowfall are more than 13 ft (4 m) high (Figure 7).

Figure 7. *Supporting structures anchor the snowpack to the mountainside and prevent large avalanche releases. They must resist the large pressures caused by creep and glide of the snowpack and must be high enough to support the design snowpack. (Davos, Switzerland).*

Construction of supporting structures in the starting zone usually begins in the steep upper part where avalanches occur most often. This prevents the smaller slides that may trigger larger avalanches at lower elevations. These subsequent larger avalanches are capable of reaching developed areas. By construction over a period of years, entire starting zones with slopes of 30 to 50 degrees may be anchored by supporting structures. The structures must be designed to resist the great pressures caused by creep and glide of the snowpack.

In some parts of Switzerland, large glide pressures have destroyed supporting structures and plowed the soil away (Frutiger, pers. comm.). Small slides may release between rows of structures and subject lower structures to dynamic loading.

Swiss supporting-structure projects are heavily subsidized by the Federal Government and usually include reforestation* of the starting zones wherever possible. In some cases the Swiss Federal Government will pay for as much as 80 percent of the total cost if the structures conform to its guidelines. Supporting structures are very expensive to install and maintain.

Supporting structures may be desirable where starting zones are relatively small and accessible, and the objects to be protected are numerous and valuable. Such structures may be the only remaining alternative if advance hazard planning has not occurred and works of man needing protection are already located in avalanche-hazard zones. However, the expense of such construction would be high and the environmental and aesthetic impact of them on mountains might be undesirable in many areas.

Deflecting, retarding, and catching structures

These structures alter the dynamics of flowing avalanches by slowing, stopping, or changing the direction of the flow. In general they are not effective against high-velocity powder avalanches with great flow depth.

Deflecting dikes are designed to change the direction of an avalanche and in doing so make some areas safe that were previously endangered. It has been determined through practical experience that these structures are most effective if they deflect the avalanche through as small an angle as possible. If the deflection angle is too large, the structure will tend to be overtopped by the fast moving snow. It can be generally stated that they should not be placed at an angle exceeding 20 to 30 degrees to the flow direction. In fact, the design height and necessary deflection angle are functions of avalanche velocity, flow height, snowpack depth, and avalanche discharge, all of which are quantities that need to be determined prior to design of the structure (Mears, 1976a).

Earth mounds in the runout zone are an example of avalanche-retarding structures. They are placed in unconfined reaches of the avalanche track or runout zone to split avalanches and widen the flow. This reduces the average flow depth, increases friction effects, and decreases the runout distance (Figure 8). In order to be most effective, mounds should be higher than the flow depth of the avalanche, and they usually work best if they are located on slopes of less than 20 degrees where large avalanches may begin to slow naturally (in the runout zone).

Figure 8. *Earth mounds in the runout zone split avalanches into several channels, cause cross currents, increase flow width, and shorten the runout distance. They are most effective on slopes of less than 20 degrees where avalanches slow naturally. (Davos, Switzerland).*

Catching dams (Figure 9) are built perpendicular to avalanche flow direction and are intended to stop the moving snow. Clearly, these structures must be very high in order to stop a large, fast moving avalanche and they must have a sufficient volume behind the dams to store the avalanche debris, even that of a major avalanche event.

Figure 9. *This large dam is designed to stop a large flowing avalanche and hold the avalanche debris. It is not intended to stop large powder avalanches. (Innsbruck, Austria).*

Direct-protection structures

Direct-protection structures are built to protect individual structures in an avalanche path. Various direct-protection structures have been used in the Alps, some of which have been adapted for use in the United States. These include: (1) splitting wedges on the uphill sides of buildings; (2) ramp roofs; and (3) reinforced walls. Examples of these structures are given in Figures 10, 11, and 12. Direct-protection structures have been most commonly used in the United States because they can be constructed on the actual site being protected and sometimes can be incorporated into the design of the building itself. Recent examples exist at Vail, Colorado. The design of the Vail structures utilize calculated dynamic properties of the design avalanches.

Historically, structures built to resist avalanche forces were not designed based on avalanche-dynamics parameters. For example, the size of a catching dam might be determined by the amount of material available at the dam site rather than calculated avalanche size or velocity. Subjective design of this type should be discouraged because it may provide a false sense of security and underdesign can increase the hazard in some cases. In recent years direct-protection structures in Switzerland and Austria have been built only after careful study of the avalanche path and calculation of the avalanche dynamics.

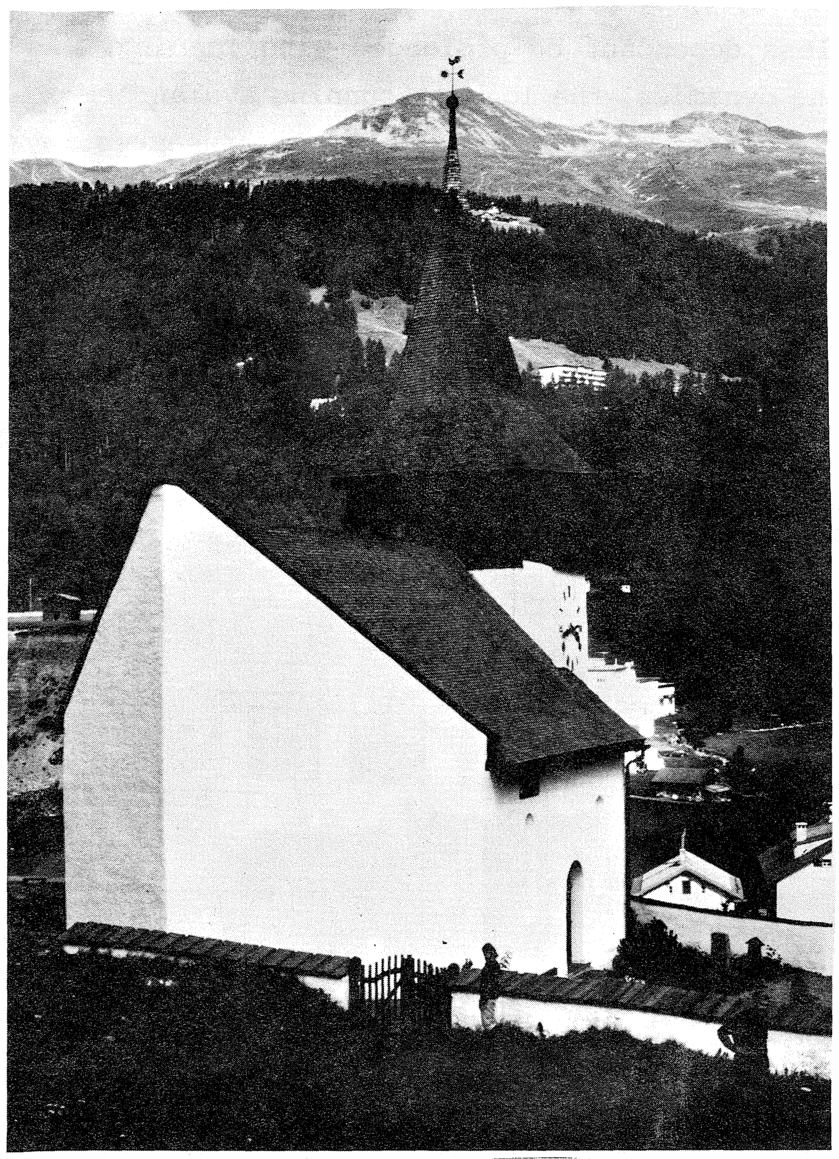

Figure 10. *This splitting wedge has diverted avalanches and protected the church for more than 200 years. Modern splitting wedge design is based on the criteria developed from the dynamics of the design avalanche. (Davos, Switzerland).*

Snow fences and wind baffles

Snow fences and wind baffles are designed to alter the deposition pattern of snow starting zones by disturbing the natural flow of wind as it enters the starting zone. They may reduce cornice buildup or decrease the volume of snow accumulation in the starting zone. In order for these structures to be effective, it is necessary that the design avalanche being defended against be the result of wind loading of the starting zone. Thus, although they may prove effective against frequent avalanches, they may prove far less effective against extensive soft-slab buildup which is less dependent on prolonged wind loading. As discussed in the section on avalanche dynamics, the longest-running avalanches probably result from the release of soft slabs, suggesting that wind structures may not be effective against some design avalanches.

Figure 11. *A modern example of a direct-protection structure is this ramp roof. Design must consider the dynamic force generated by the avalanche and the weight of snow deposited on the roof. (Davos, Switzerland).*

Figure 12. *This thick, reinforced wall is designed to resist the normal and vertical uplift components of avalanche thrust. (Davos, Switzerland)*.

CONCLUSIONS

Knowledge about avalanche phenomena is slowly improving with time and study. Some of the general ideas presented in this report are being actively researched by the U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station. One objective of this research is to provide verification and additional quantification of existing equations describing the movement of avalanches.

However, we now have few technical tools at our disposal to carefully describe avalanche behavior. The engineering approaches to avalanche mitigation are largely untested and often not understood by those who are called on to use them. In view of the uncertainties that prevail, a conservative approach to analysis is certainly warranted, keeping in mind that future research and practical experience may reveal today's moderate-hazard zones to be tomorrow's high-hazard zones.

The avalanche-hazard discussion presented in this report presents a conservative approach and, if used in future land-use planning, should help to avoid some of the problems that have historically been associated with human occupation of areas affected by avalanches.

PART 2

SNOW-AVALANCHE-HAZARD MAPS AND PATH DESCRIPTIONS FOR SELECTED AREAS OF COLORADO

As part of the responsiblity of the Colorado Geological Survey under H.B. 1041 (C.R.S. 1973, 24-65.1-101, et seq.) and where the need seemed most urgent, we identified avalanche hazards in several areas of the state. The intent of those studies was to select and map those areas of present or expected intensive development activity where avalanche hazards were known to exist. Final selection of the study areas were made after consultation with the U.S. Forest Service, State agencies, local governments, and knowledgeable citizens.

The hazards mapping was initially done on 1:24,000-scale U.S. Geological Survey topographic base maps. For each study area an open-file report was prepared and made available as a separate booklet.

The original area studies are by no means comprehensive. Additional area studies must be made as development pressures and patterns emerge. In addition, areas within San Juan County that would have been included were deleted because of studies underway by the University of Colorado, Institute of Arctic and Alpine Research (INSTAAR). The report on avalanche mapping of San Juan County was published subsequently by INSTAAR (Miller and others, 1976).

The maps contained in this report are for potential development areas only. No attempt is made to map potential back-country hazards which vary considerably in response to the amount of recreational use. Most of the avalanches which might affect the skier, snowshoer, or snowmobiler are too plentiful and much too small to be mapped at 1:24,000. They are often small snowslides triggered by the victims. It is strongly recommended that users of the back country educate themselves or attend avalanche schools to learn techniques of avalanche avoidance and survival and heed all official avalanche warnings.

The ensuing text includes a description of hazard zone rationale, mapping techniques and criteria and descriptive data for each avalanche path of the area maps (Plates 1-5).

HAZARD ZONES

High-hazard zone: Avalanches within this zone have return periods of 25 years or less and will produce impact pressures of 500lb/ft^2 (2440 kg/m^2) or more. The hazard zone is characterized by either either high frequency, high impact pressure, or both high frequency and high pressure.

Moderate-hazard zone: Avalanches within this zone will occur at return periods in excess of 25 years and will have impact pressures of less than 1000 ft/lb^2 (4900 kg/m^2). Avalanche frequency and impact pressures increase toward the outer limits of this zone. When large avalanches occur and run to the outer boundaries of this zone they can be very destructive in spite of their reduced probability and pressures. This zone is characterized by return periods of more than 25 years and lower pressures.

No hazard: Areas not designated as hazardous can be considered free of avalanches with return periods of up to one or two centuries. However, there is some probability that unpredictable large avalanches may occur and surpass the moderate-hazard-zone boundaries. Such avalanches have a probability small enough to be disregarded for planning purposes, and may be considered as an acceptable risk. Estimates of return periods cannot be made for these areas.

Air blast from powder avalanches may also extend beyond the moderate-hazard zone. However, resulting pressures would usually be less than 50 lb/ft^2 (245 kg/m^2) but may occasionally reach 100 lb/ft (490 kg/m^2).

Small avalanche areas: These areas are not wide enough to be accurately displayed at the mapping scale of 1:24,000 so they are indicated as arrows. Although they appear small at this scale, they can be very destructive.

PREPARATION OF THE HAZARD MAPS

Accurate determination of avalanche frequency and impact pressure cannot be made without very long records of weather, snow accumulation, snow accumulation intensity, avalanche occurrence, extent of past avalanches, and measurement of impact pressures. Ideally the length of these records should be considerably longer than the return period it is necessary to predict. For example, it may be necessary to have two or three centuries of detailed records to be able to calculate the "100-year avalanche" extent. However in the United States long, detailed records of this type have not been kept.

In the absence of a long and detailed historical record of Colorado avalanches, other techniques were used to prepare these maps. They were prepared from studies of maps, terrain analysis, steroscopic aerial-photograph study, and field reconnaissance. Frequency estimates were obtained from historical records where available, personal interviews with long-time residents, highway department records, and qualitative studies of vegetation indicators. More detailed dynamic-analyses were made of selected paths in each of the study areas. These analyses made use of the Swiss equations for avalanche motion and other dynamic-analysis techniques developed especially for this study. The results of these more detailed studies were applied to other avalanche paths in areas that are similar in size, shape, orientation, and elevation.

From these studies and our experience gained in more detailed studies of many other Colorado avalanche paths, qualitative estimates of extents, frequencies, and impact pressures were made.

MAPPING ACCURACY AND LIMITATIONS

It is important to recognize that the techniques of avalanche dynamics and terrain analysis on which these maps are based are not exact. As a result, our analyses and interpretations are subject to some undefinable degree of uncertainty. Furthermore, as mentioned previously in the no-hazard zone description, there is some small probability that the avalanche paths mapped will exceed even the boundaries indicated. It is also possible that we have not delineated all hazard areas within each map, or that future hazard could increase through forest fire, timber cutting, construction operations, or similar land uses.

These uncertainties point to a need for a continuing effort, especially on the part of the local residents and government officials, to carefully report, observe, and document avalanche events. In this way the hazard maps can constantly be improved as new information becomes available. Specific responsibility for this should rest with a certain individual or local-government entity.

Regardless of the quality of avalanche information, the map accuracy cannot exceed that of the U.S. Geological Survey base map upon which it is drawn. The base map used conforms to U.S. map accuracy standards, which means not more than 10 percent of the well defined points on the base map (such as buildings) are in error by more than 1/50 inch, and not more than 10 percent of the elevations are in error by more than one-half the contour interval. The greater mapping accuracy needed for the more detailed studies cannot be gained by enlarging a given map. The inherent errors in such enlarged maps increases in proportion to the amount of enlargement. In general, a specifically compiled map of the area should be provided which meets the needs and specifications of the investigator undertaking the detailed analysis.

RECOMMENDED USE OF THESE MAPS

Land-use recommendations in avalanche-hazard zones discussed herein are modeled after the Swiss avalanche-zoning plans and regulations. Swiss plans and regulations evolved after study and debate at both scientific and the various government levels over the past two or three decades.

Legal Identification of Hazard Zones: Property located within the high- and medium-hazard zones should be so designated and recorded on all legal property descriptions. This would inform potential buyers of a hazard before purchase.

Building Within Hazard Zones: If property falls within high-hazard zones, then the hazard, in terms of frequency and impact pressure, is probably too great to allow permanent residences. Although buildings can be designed to withstand the expected pressures within this zone, the people one wishes to protect may not always be inside when the avalanche occurs. Thus, avalanche frequency within this zone becomes an important consideration.

Lesser hazard exists within the moderate-hazard zone. Building in this zone might be permitted provided that certain precautions are taken. These precautions should include careful engineering and design regarding:

1. the location of buildings,
2. building type, arrangement, and proportion, and
3. building stability and strength.

The lesser avalanche frequency within this zone substantially reduces the probability of encounter with persons who may be outside the building and as such this is probably not an important consideration.

Specific hazard zones cannot be defined within the "small avalanche areas" because of the small scale of the base maps. Property within these areas must have detailed studies to delineate the hazard.

The probability of avalanches occurring which extend beyond the moderate-hazard zone is small enough to be disregarded for planning purposes.

MORE DETAILED STUDIES OF AVALANCHE-HAZARD ZONES

Avalanche-hazard maps prepared on a scale of 1:24,000 give some indication of avalanche frequencies and impact pressures, but they do not provide the necessary design criteria for building within hazard zones. If building is planned within the hazard zones it is strongly recommended that detailed studies be conducted by qualified experts. It is recommended that these studies be designed to provide information about:

1. the areal extent of the runout zone,
2. the impact pressure distribution within the runout zone,
3. the type of avalanche reaching various parts of the runout zone,
4. avalanche frequency,
5. avalanche discharge, and
6. avalanche flow depth.

This information should be summarized on a map with a scale of 1:12,000 or larger, with accurate topographic details. The report should also present the necessary explanatory text, data tabulation, and other essentials for further work or governmental review. The information obtained through such studies should enable the architect and structural engineer to design buildings which can safely withstand avalanche forces.

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GLOSSARY

Design avalanche: The magnitude or size avalanche that must be considered in locating and designing facilities.

Discharge: The volume of fluid passing through a given area in a specified time period.

Dynamic: Referring to the study of masses in motion.

Kinetic energy: Energy developed by a moving mass.

Reforestation: Refers to the planting of trees in the starting zone to reduce the possibility of avalanche release.

Stagnation Pressure: A reference pressure consisting of that pressure developed by moving fluid (such as a powder avalanche) upon an object that is submerged in the flow.

Shape Coefficient: A coefficient (usually between 0.4 and 1.5) by which stagnation pressure must be multiplied to find the pressure on an object of a particular shape that is submerged in the flow.

Strain energy: The energy stored in a deformed substance that is released when the force causing the deformation is removed.

Stress concentration: Localized high values of stress that develop at areas of irregularities or discontinuities within a substance under stress.

Stress: The amount of force acting over some specified area (i.e. force/area).

Visco-elastic: Property of a substance that can flow like a fluid and undergo recoverable deformation as well.

Viscous: The property of some fluids to deform at a rate proportional to the applied stress.

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Appendix

Avalanche paths on these maps are described in terms of their topographic settings, which in turn give some indication of potential avalanche size. It must be remembered that potential size also depends on variations of weather and snowpack conditions which vary greatly across large geographic regions, and with elevation. The results of this variability have been qualitatively evaluated for these maps though observations of the cumulative destructive effects of avalanches that have occurred over a long time period. This technique was described briefly in the section on preparation of hazard maps.

Total Vertical Drop: This is the maximum elevation difference in a given path. It may be a good indication of path size when the track is wide and unconfined although for narrow, confined tracks the starting zone area is a better measure.

Starting Zone Area: An estimate of starting zone area is obtained from existing topograhic maps. It is an upper limit of the area that could be involved in a single, large avalanche release, and such areas are bounded on the top and sides by distinct topographic features such as ridges. The size of the starting zone is the most important topographic factor in determining the size, velocity, impact pressure, and runout distance of confined avalanches.

Track Gradient: Track gradient is important in determining the velocity of dense, flowing avalanches. As defense construction in a runout zone is primarily effective against the dense flowing portion of an avalanche, track gradient becomes an important consideration. Powder-avalanche velocity is probably not strongly affected by track gradient.

Runout Zone: The length of this zone was scaled from topographic maps and the width is indicated on the hazard maps. It is assumed that runout zones begin where the slope inclination becomes less than 30 percent (17 degrees) because it is on slopes of this or lesser inclination that defense structures become most effective and avalanches will probably begin to slow naturally. Another criterion for the definition of runout zones is the top of alluvial fans below gullies. It is at this point that confined avalanches can begin to widen and decelerate.

ENGLISH METRIC CONVERSIONS

1 ft equals .3048 m

1 acre equals .4040 hectares

ASPEN AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 1

Group A:

This is a group of small paths with vertical drops of 600 to 1100 ft and small starting zones, generally less than 2 acres. The starting zones are small clearings in the forest. Avalanches will stop abruptly on low gradient slopes on the valley bottom.

Path 1 (McFarlane Gulch, or Independence Basin):

Total vertical drop: 2900 ft
Starting zone: About 50 acres in open bowl below timberline
Track: Gradient 33 percent; confined to narrow channel although fast moving powder avalanches overtop the edge of the track at bends of the track.
Runout zone: Gradient 12 percent; length 1200 ft.

Group B:

Small avalanche paths with vertical relief of 500 to 700 feet and starting zones in timber, that are probably less than 1 acre. Avalanches do not involve sufficient mass to cause long runouts.

Path 2:

Total vertical drop: 2200 ft
Starting zone: 10 acres, below timberline
Track: Gradient 40 percent; confined to channel.
Runout zone: Gradient 16 percent; length 800 ft.

Group C:

Small paths with vertical drops of 400 to 900 ft. Starting zones are small open spots in timber of less than 5 acres. Long runouts are not likely because of small mass of avalanches.

Path 3:

Total vertical drop: 2900 ft
Starting zone: About 30 acres on open slope below timberline
Track: Gradient 38 percent; confined to channel.
Runout zone: Gradient 10 percent; length 1000 ft.

Path 4:

Total vertical drop: 2100 ft
Starting zone: 10 acres, open hollow below timberline
Track: Gradient 43 percent; confined to channel.
Runout zone: Gradient 13 percent; length 600 ft.

Note: Paths 2, 4, and especially 3 are easily accessible from Aspen Mountain Ski Area (Ajax), and therefore might be thought to be controllable by protective skiing. It must be recognized that this procedure, along with explosive control, would not be reliable in event of severe weather conditions, and development within the indicated runout zones should not be planned considering these as control measures.

Group D:

Small to moderate sized paths with vertical drops of 800 to 600 ft. Most have very small starting zones (less than 2 acres) and therefore stop quickly in the runout zone. Paths D-a and D-b have starting zones of 5 to 10 acres and travel somewhat farther in the runout zones.

Group E:

In spite of their number, these paths are all grouped together because of their similar physiographic setting. The southwest exposure and moderate elevations (generally 9000 to 10,000 ft in the starting zones) will make many of these paths snow-free for long time periods during many winters. Nevertheless, under severe conditions, avalanches are possible which will flow the entire length of these tracks, and average 60 to 70-percent inclination. These avalanches will be confined mostly to the gullies and will not involve much mass.

Path E-a can produce larger avalanches than other paths within Group E because it starts in a very large (50 acres) bowl which can easily collect snow approaching from several directions. However, the topography is so steep and rugged in this starting zone that avalanches should not be expected to be as large as those of McFarlane Gulch (Path 1), which has a starting zone of about the same size.

Group F:

These avalanche paths have vertical drops of 600 to 1600 ft, although, because of their small (usually less than 2 acres) starting zones will not involve much snow. Avalanches will stop in the valley of Castle Creek. However, the northern paths of Group F are likely to run more frequently because they can collect snow in the lee (east side) of Aspen Mountain. They too will be small, and will stop quickly before they reach the Aspen town boundary as shown on the U.S. Geological Survey topographic map.

Group G:

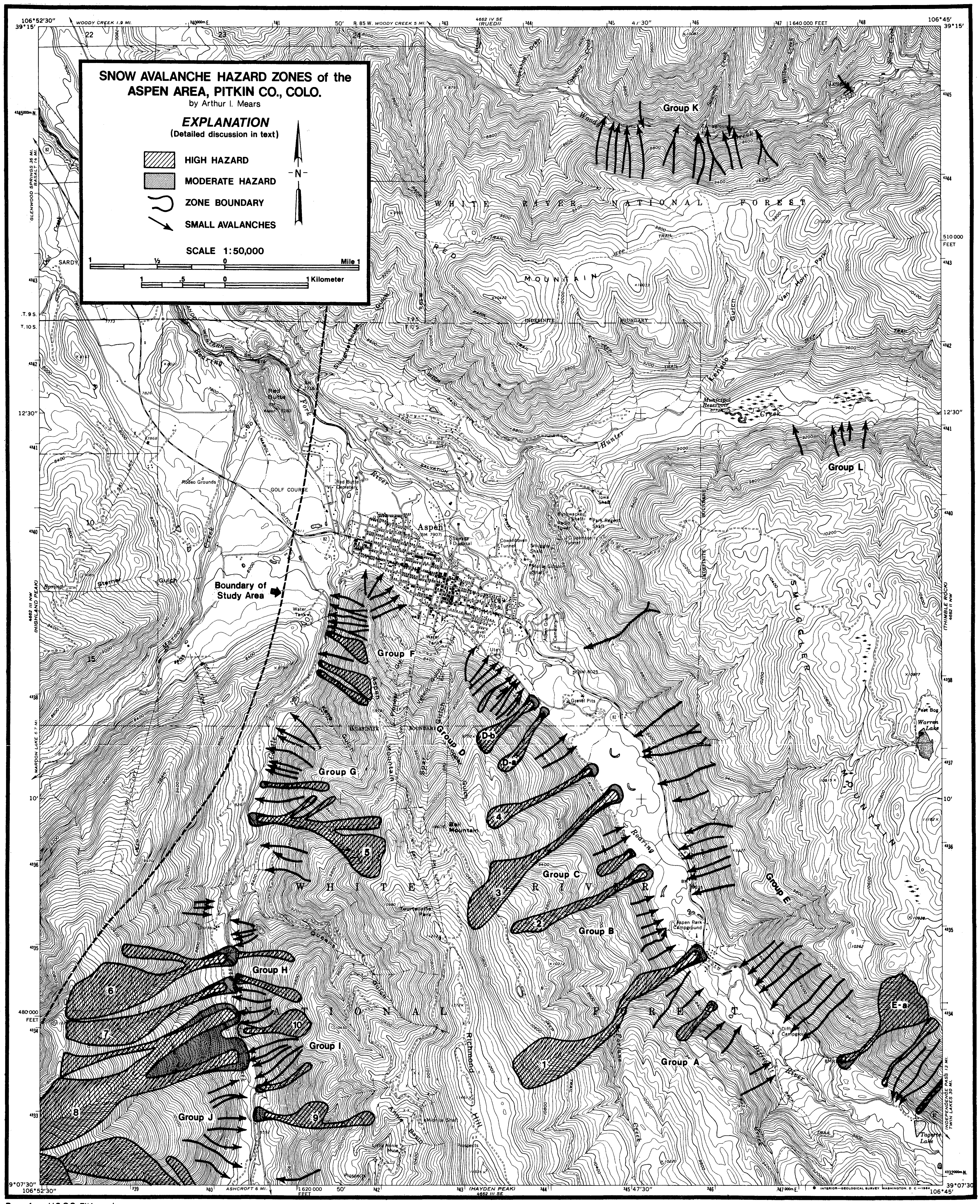
These are actually a southern continuation of Group F with vertical drops of 600 to 1500 ft. The small starting zones cause these avalanches to stop before reaching Castle Creek.

Path 5:

Total vertical drop: 2400 ft
Starting zone: About 10 to 20 acres, open areas in timber
Track: Gradient 3 percent; confined to channel.
Runout zone: Gradient 20 percent; length 1000 ft.

Group H:

These are small paths with vertical drops of 800 to 1500 ft and starting zones of less than 5 acres. Avalanches stop in Castle Creek.



Base from U.S.G.S. 7½' quad. map

PLATE 1

Group I:

This is a continuation of Group H, and the same description applies.

Path 6:

Total vertical drop: 3100 ft
Starting zone: About 30 to 50 acres; consists of many open spots below timberline.
Track: Gradient 42 percent; confined to channel.
Runout zone: Gradient 18 percent; length 1600 ft.

Path 7:

Total vertical drop: 3100 ft
Starting zone: About 20 to 30 acres below timberline in open areas
Track: Gradient 42 percent; confined to channel.
Runout zone: Gradient 22 percent; length 1300 ft.

Path 8 (Highland Bowl):

Total vertical drop: 3900 ft
Starting zone: About 120 acres, mostly above timberline.
Track: Gradient 37 percent; broad, open slope.
Runout zone: There is no extensive section less steep than 30 percent. Avalanche can run to Castle Creek.

Path 9:

Total vertical drop: 2800 ft
Starting zones (2): About 5 acres in forest and about 15 acres of open slope below timberline; both can probably release at one time
Track: Gradient 39 percent; confined to channel.
Runout zone: Gradient 25 percent; length 900 ft.

Path 10:

Total vertical drop: 1600 ft
Starting zone: About 10 to 20 acres in open spots in timber
Track: Gradient 53 percent; confined to gully.
Runout zone: Gradient 40 percent; length 500 ft.

CAMP BIRD AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 2

Path 1 (Squaw Gulch):

Total vertical drop: 2800 ft
Starting zones: 50 acres in main bowl
Track: Gradient 47 percent; channeled.
Runout zone: Can reach Canyon Creek but is not within limits of this map.

Path 2 (Lewis Creek):

Total vertical drop: 3600 ft
Starting zones: 4 major locations with areas 30, 15, 5, and 5 acres. It is doubtful that they will release simultaneously.
Track: Gradient 46 percent; channeled.
Runout zone: Hits opposite (north) side of Canyon Creek valley.

Path 3 (Thistledown Creek):

Total vertical drop: 3600 ft
Starting zones: 5 major locations with areas of 20, 30, 30, 5, and 30 acres. It is likely that the lowest elevation starting zone could be triggered by avalanching from higher starting zones.
Track: Gradient 46 percent; channeled.
Runout zone: Hits north side of Canyon Creek valley.

Path 4:

Total vertical drop: 2500 ft
Starting zone: 40 acres
Track: Gradient 76 percent.
Runout zone: Hits north side of Canyon Creek valley.

Path 5 (Fall Creek):

Total vertical drop: 3800 ft
Starting zones: 5 major locations with areas of 60, 15, 10, 10, and 15 acres. It is likely that the lower 2 starting zones could be triggered by avalanching from the upper, 60-acre starting zone
Track: Gradient 53 percent; channeled.
Runout zone: Hits north side of Canyon Creek valley.

Path 6:

Total vertical drop: 2200 ft
Starting zone: Two separate locations of 10 and 10 acres. They probably run separately.
Track: Gradient 110 percent; channeled; some avalanches fall over cliff.
Runout zone: Hits north side of Canyon Creek valley.

Path 7 (Senator Gulch):

Total vertical drop: 2500 ft
Starting zone: 6 separate locations of 15, 30, 5, 5, 15, and 10 acres. They probably run separately.
Track: Gradient 44 percent; channeled.
Runout zone: Hits south side of Canyon Creek valley.

Path 8:

Total vertical drop: 2800 ft
Starting zone: 30 acres
Track: Gradient 74 percent; confined to broad gully.
Runout zone: Hits north side of canyon.

Path 9:

Total vertical drop: 2000 ft
Starting zone: 20 acres
Track: Gradient 52 percent; channeled.
Runout zone: Hits north side of canyon.

Path 10 (Waterhole Slide):

Total vertical drop: 2900 ft
Starting zone: 30 acres
Track: Gradient 67 percent; channeled.
Runout zone: Hits north side of canyon.

Path 11:

Total vertical drop: 2200 ft
Starting zones: Two locations of 5 and 10 acres. Avalanches from the upper starting zone can trigger the lower starting zone.
Track: Gradient 50 percent; channeled.
Runout zone: Hits south side of canyon; meets and overlaps runout of Path 12.

Path 12:

Total vertical drop: 1400 ft
Starting zone: 5 acres; below timberline
Track: Gradient 90 percent; unconfined; falls over cliff.
Runout zone: Hits north side of valley meets and overlaps runout of Path 11.

Path 13:

Total vertical drop: 2800 ft
Starting zone: Two locations of 20 and 5 acres. They probably run separately.
Track: Gradient 50 percent; channeled.
Runout zone: Meets and overlaps runout of Path 14.

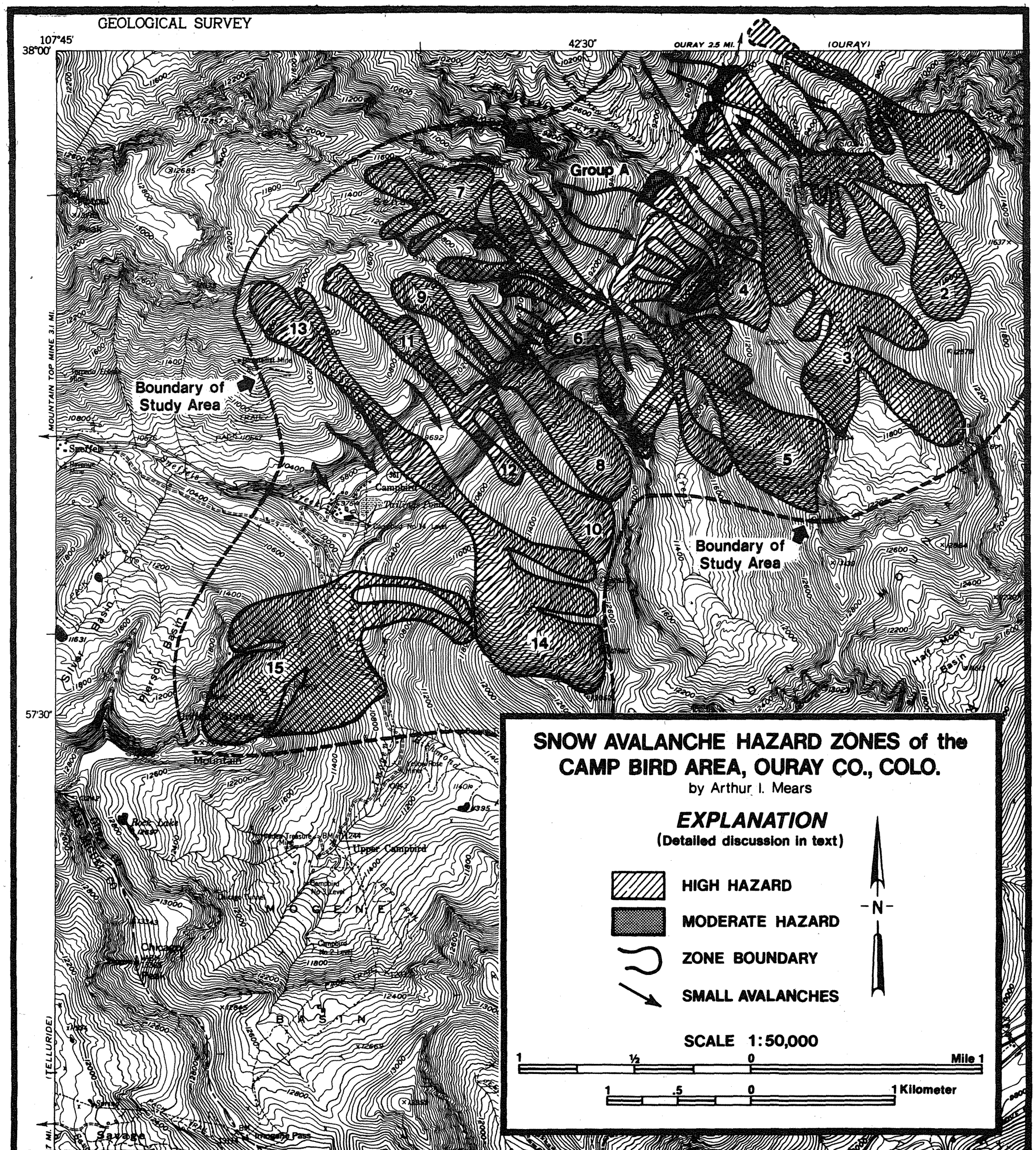
Path 14:

Total vertical drop: 3300 ft
Starting zones: Three separate locations of 30, 15, and 15 acres. They probably run separately.
Track: Gradient 52 percent; unconfined.
Runout zone: Meets and overlaps runout of Path 13.

Path 15:

Total vertical drop: 2800 ft
Starting zones: Three separate locations on the east side of United States Mountain of 20, 20, and 15 acres. They probably run separately.
Track: Unconfined east slope of United States Mountain; gradient 50 percent to 70 percent.
Runout zone: Hits east side of the valley of Imogene Creek.

In addition to the large avalanche paths described in this vicinity there also exist numerous smaller paths as indicated on the map. These smaller paths, although involving less snow, can also be dangerous and make road maintenance difficult.



Base from U.S.G.S. 7½′ quad. map

PLATE 2

CRESTED BUTTE AREA (GOTHIC)

INDIVIDUAL PATH DESCRIPTIONS - see Plate 3

Path 1:

Total vertical drop: 2200 ft
Starting zone: 20 acres; above timberline
Track: Gradient 44 percent; unconfined.
Runout zone: Gradient 0 percent; length 900 ft.

Path 2:

Total vertical drop: 2600 ft
Starting zone: 30 acres; above timberline
Track: Gradient 52 percent; unconfined.
Runout zone: Gradient 18 percent; length 1100 ft.

Path 3:

Total vertical drop: 2800 ft
Starting zone: Three separate areas can contribute to avalanches, however will probably not release simultaneously. The starting zone areas are, from north to south, 12 acres, and 30 acres respectively.
Track: The portion of the track common to all three starting zones has a 50-percent gradient and is unconfined.
Runout zone: Gradient 17 percent; length 1200 ft.

Path 4 (east face of Gothic Mountain):

This path is large and complex and can start at numerous small, steep areas. The four major areas are outlined. The track is broken by steep terrain in its upper portion which can cause dry-snow avalanches to become dangerous, long running powder avalanches. The runout zone is continuous for about one mile laterally and part of it extends into Gothic.
Total vertical drop: 3100 ft
Runout zone: Typical gradient is 10 percent to 15 percent; length about 1500 ft

Path 5:

Total vertical drop: 1400 ft
Starting zone: 40 acres
Track: Gradient 45 percent; unconfined.
Runout zone: Gradient 0 to 10 percent; length 500 ft.

Path 6:

Total vertical drop: 1800 ft
Starting zone: 10 ares
Track: Gradient 50 percent; channeled.
Runout zone: Gradient percent; length of 500 ft.

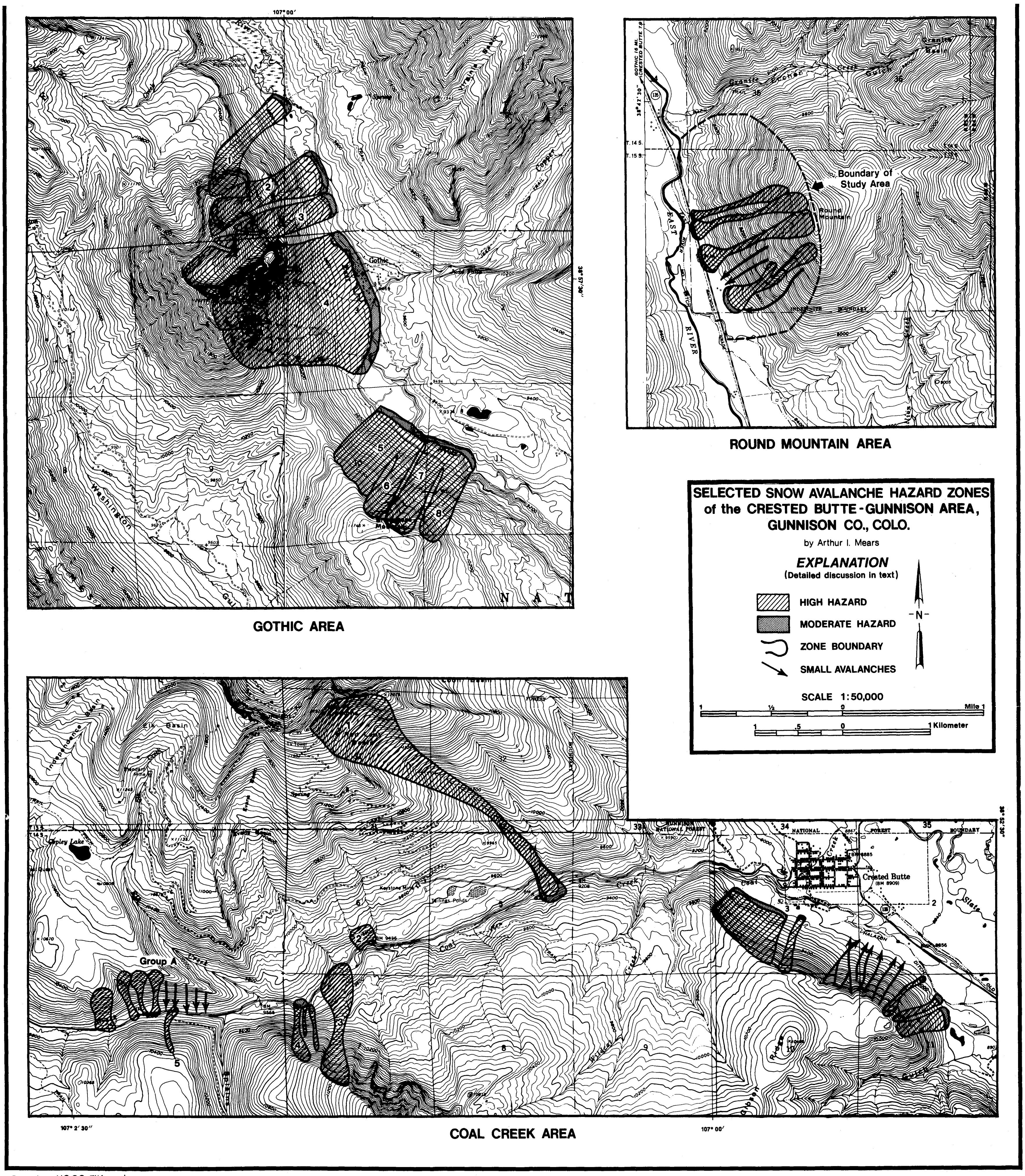
Path 7:

Total vertical drop: 1800 ft
Starting zone: 30 acres
Track: Gradient 43 percent; unconfined.
Runout zone: No runout zone; stops in East River.

Path 8:

Total vertical drop: 1700 ft
Starting zone: 12 acres
Track: Gradient 40 percent; unconfined.
Runout zone: No runout zone; stops at East River.

Note: Paths 5 through 8 are a major hazard on the road to Gothic. In some paths avalanches may reach the road annually, or more than once in a winter. They may reach the road during or after most large storms.



Base from U.S.G.S. 7½′ quad map

PLATE 3

CRESTED BUTTE AREA (COAL CREEK)

INDIVIDUAL PATH DESCRIPTIONS - see Plate 3

The following text describes characteristics of individual avalanche paths.

Path 1 (Red Lady Basin):

Total vertical drop: 3100 ft
Starting zone: Steep basin on east and southeast walls of Mt. Emmons, about 75 acres.
Track: Deeply entrenched channel; gradient 22 percent.
Runout zone: Reaches main road and Coal Creek.

Path 2:

Total vertical drop: 300 ft
Starting zone: 2 acres
Track: Gradient 50 percent; unconfined.
Runout zone: Crosses road; stops in valley bottom.

Path 3:

Total vertical drop: 1900 ft
Starting zone: Bowl shaped depression below timberline; about 20 acres.
Track: Open, unconfined slope; gradient 38 percent.
Runout zone: Gradient 22 percent; length 900 ft; (on exceptional occasions will reach road).

Path 4:

Total vertical drop: 1400 ft
Starting zone: Shallow bowl below timberline, about 10 acres
Track: Open slope/shallow gully; gradient 58 percent.
Runout zone: No transition above Coal Creek; (on exceptional occasions will reach road).

Path 5:

Total vertical drop: 800 ft
Starting zone: Open spots in timber, about 5 acres
Track: Runs in shallow gully; gradient 46 percent.
Runout zone: No transition above creek; (exceptional avalanches will reach road).

Group A:

These are mostly open slopes with some moderately channelled avalanches with small starting zones. Although volumes of individual releases may be small, there are no gently sloping runout zones above the road. Consequently, even moderate sized avalanches can reach the road. This area may be particularly susceptible to wet snow avalanches because of the south-facing exposure.

FRISCO AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 4

Group A:

These are small paths with vertical drops of 1000 to 1400 ft and starting zone areas of 5 acres or less. The runout zones are 20 to 25 percent and about 1000 ft long.

Path 1:

Total vertical drop: 1600 ft
Starting zone: 10 acres
Track: Gradient 70 percent; unconfined.
Runout zone: Gradient 30 percent; length 700 ft.

Path 2:

Total vertical drop: 1300 ft
Starting zone: Less than 5 acres, undefined
Track: Gradient 75 percent; unconfined.
Runout zone: Gradient 40 percent; length 700 ft.

Path 3:

Total vertical drop: 1200 ft
Starting zone: Less than 5 acres, undefined
Track: Gradient 70 percent; runs in shallow gully.
Runout zone: Gradient 18 percent; length 900 ft.

Path 4:

Total vertical drop: 1600 ft
Starting zone: 10 to 15 acres
Track: Gradient 50 percent; confined to shallow gully.
Runout zone: Gradient 23 percent; length 1400 ft.

Path 5:

Total vertical drop: 700 ft
Starting zone: 1 to 2 acres
Track: Gradient 70 percent
Runout zone: Gradient 20 percent; length 250 ft.

Path 6:

Total vertical drop: 2300 ft
Starting zone: Open spots in timber, 20 to 30 acres
Track: Gradient 60 percent; confined to channel.
Runout zone: Gradient 22 percent; length 1000 ft.

Path 7:

Total vertical drop: 2900 ft
Starting zone: Above timberline broken up by ridges, single releases probably less than 20 acres.
Track: Gradient 60 to 70 percent; confined to channel.
Runout zone: Gradient 30 percent; length 1000 ft.

Path 8:

Total vertical drop: 3300 ft
Starting zone: Above timberline, broken by ridge, single releases probably less than 20 acres.
Track: Gradient 70 percent; confined to channel.
Runout zone: Gradient 20 percent; length 600 ft.

Path 9:

Total vertical drop: 3200 ft
Starting zone: Above timberline, broken up by ridges, single releases probably less than 20 acres.
Track: Gradient 60 percent; confined to channel.
Runout zone: Gradient 25 percent; length 300 ft.

Path 10:

Total vertical drop: 3200 ft
Starting zone: Above timberline, broken up by ridges, single releases probably less than 30 acres.
Track: Gradient 55 percent; confined to channel.
Runout zone: Track reaches to valley bottom with no extended zone of gentle gradient.

Path 11:

Total vertical drop: 3200 ft
Starting zone: Above timberline; broken up by ridges; single releases probably less than 20 acres.
Track: Gradient 60 percent; confined to channel.
Runout zone: Track reaches to valley bottom with no extended zone of gentle gradient.

Path 12:

Total vertical drop: 2900 ft
Starting zone: Above timberline; broken up by ridge; single releases probably less than 20 acres.
Track: Gradient 67 percent; confined to channel.
Runout zone: Track reaches to valley bottom with no extended zone of gentle gradient.

Group B:

These are small paths with vertical drops of 700 to 1400 feet with starting zones below timberline and areas of 5 acres or less. Runout is flat floodplain of flat floodplain of Tenmile Creek.

Path 13:

Total vertical drop: 2300 ft
Starting zone: Above timberline; steep irregular slope broken up by cliffs and ridges. Single releases are probably less than 10 acres.
Track: Gradient 80 percent; unconfined slope.
Runout zone: Gradient 30 percent; length 300 ft.

Path 14:

Total vertical drop: 3100 ft
Starting zone: Above timberline; about 100 acres.
Track: Gradent 40 percent; confined to channel.
Runout zone: Gradient 19 percent; length 1700 ft.

Path 15:

Total vertical drop: 2900 ft
Starting zone: Above timberline; about 40 acres.
Track: Gradient 45 percent; confined to channel.
Runout zone: Gradient 20 percent; length 1400 ft.

Path 16:

Total vertical drop: 2800 ft
Starting zone: Above timberline; about 60 acres.
Track: Gradient 40 percent; confined to channel.
Runout zone: Gradient 20 percent; length 1200 ft.

Path 17:

Total vertical drop: 2400 ft
Starting zone: Above timberline 50 to 60 acres.
Track: Gradient 40 percent; confined to two parallel channels.
Runout zone: Gradient 17 percent; length 1500 ft.

Path 18:

Total vertical drop: 2400 ft
Starting zone: Above timberline, 50 to 60 acres.
Track: Gradient 35 percent; confined to channel.
Runout zone: Gradient 22 percent; length 1300 ft.

Group C:

This is a group of small, unconfined slope avalanches descending 500 to 700 ft to Highway 91.

Path 19 (Graveline Gulch):

Total vertical drop: 2000 ft
Starting zone: 30 to 40 acres above timberline.
Track: Gradient 40 percent; confined to channel.
Runout zone: Gradient 20 percent; length 900 ft.

Base from U.S.G.S. 7½' quad. map

PLATE 4

HENSON CREEK AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 5

Path 1:

Total vertical drop: 2600 ft.
Starting zone: 70 acres; bowl above timberline.
Track: Gradient 65 percent; confined to channel.
Runout zone: Runs up opposite valley wall crossing the main road.

Path 2:

Total vertical drop: 2300 ft
Starting zone: 10 acres above timberline.
Track: Gradient 70 percent over broken terrain.
Runout zone: Reaches opposite valley wall crossing the main road.

Path 3:

Total vertical drop: 2200 ft
Starting zone: 15 acres above timberline.
Track: Gradient 85 percent; over broken terrain with cliffs.
Runout zone: Joins with runout zone of Path 6; reaches opposite valley wall crossing the main road;

Path 4:

Total vertical drop: 2200 ft
Starting zone: 70 acres in bowl above timberline.
Track: Gradient 45 percent; confined to gully; joins Paths 5 and 6 at 600 ft and reaches the main road.

Path 5:

Total vertical drop; 2700 ft
Starting zone: 70 acres, above timberline.
Track: Gradient 36 percent; runs in gully.
Runout zone: Same as Path 4.

Path 6:

Total vertical drop: 2300 ft
Starting zone: 40 acres, above timberline.
Track: Gradient 45 percent; runs in channel in lower part.
Runout zone: same as Path 4.

Path 7:

Total vertical drop: 2800 ft
Starting zone: 50 acres, trough-shaped basin above timberline.
Track: Gradient 53 percent; confined to channel.
Runout zone: Gradient 25 percent; reaches opposite valley wall.

Path 8:

Total vertical drop: 2700 ft
Starting zone: 40 acres, unconfined slope above timberline.
Track: Gradient 53 percent; unconfined.
Runout zone: Gradient 25 percent; reaches opposite valley wall.

Path 8a:

Total vertical drop: 3400 ft
Starting zone: 110 acres, steep unconfined slope.
Track(s): Two separate tracks reach same runout zone--
north track: Gradient 42 percent; channeled.
south track: Gradient 44 percent; channeled.
Runout zone: Gradient 18 percent; length 1110 ft; reaches runnout of path 12.

Path 9 (lower Boulder Gulch):

Total vertical drop: 2100 ft
Starting zones (2): North portion 30 acres; south portion 25 acres, steep slopes broken by cliffs.
Track: Gradient 30 percent; confined to channel.
Runout zone: Gradient 20 percent; length 1200 ft; reaches runout of path 3.

Path 10:

Total vertical drop: 1800 ft
Starting zone: 15 acres, unconfined slope.
Track: Gradient 65 percent; unconfined slope.
Runout zone: Merges with runout zone of Path 7; Gradient about -5 percent; length about 500 ft.

Path 11:

Total vertical drop: 2300 ft
Starting zone: 20 acres, unconfined slope.
Track: Gradient 70 percent; unconfined slope.
Runout zone: Merges with runout zone of Path 8; gradient 15 percent; length 800 ft.

Path 12:

Total vertical drop: 2500 ft
Starting zone: 10 acres
Track: Gradient 64 percent; shallow gully on upper part; unconfined on lower part.
Runout zone: Gradient 13 percent; length 900 ft.

Path 13:

Total vertical drop: 2300 ft
Starting zone: 20 acres
Track: Gradient 54 percent; unconfined slope.
Runout zone: Gradient 20 percent; length 1400 ft; reaches runout zones of Path 18 and 19.

Path 14:

Total vertical drop: 2600 ft
Starting zone: 25 acres, bowl above timberline.
Track: Gradient 52 percent; confined to channel.
Runout zone: Gradient 19 percent; length 1400 ft.

Path 15:

Total vertical drop: 2300 ft
Starting zone: 15 acres at timberline
Track: Gradient 48 percent; confined to channel.
Runout zone: Gradient 20 percent; length 1300 ft.

Path 16:

Total vertical drop: 2000 ft
Starting zone: 45 acres, two bowls above timberline.
Track: Gradient 50 percent; confined to channel.
Runout zone: Runs into gorge of North Henson Creek; climbs adverse slope; gradient -20 percent, length 500 ft.

Path 17:

Total vertical drop: 1200 ft
Starting zone: 20 acres, below timberline.
Track: Gradient 73 percent; unconfined slope.
Runout zone: Runs into gorge of North Henson Creek.

Path 18:

Total vertical drop: 1000 ft
Starting zone: Unconfined slope and bowl below timberline, about 20 acres.
Track: Gradient 65 percent; unconfined slope.
Runout zone: Gradient 0 percent; length 500 ft; runs into runout zone of Path 13.

Path 19:

Total vertical drop: 1100 ft
Starting zone: 10 acres, below timberline.
Track: Gradient 55 percent; unconfined slope.
Runout zone: Gradient 10 percent; length 700 ft; runs into runout zone of Path 13 and 14.

Group A:

Small paths with vertical drops of 1000 to 1900 ft and small starting zones. Because of small volumes of individual avalanches, they will stop shortly after reaching slopes of 30 percent or less.

Group B:

Small paths with vertical drops of 500 to 600 ft. Individual avalanches will will not have sufficient energy to reach Henson Creek.

Path 20:

Total vertical drop: 800 ft
Unconfined slope avalanche with starting zone and track combined, gradient 60 percent.
Runout zone: Reaches Henson Creek and intersects runout zone of Path 22.

Path 21:

Total vertical drop: 1600 ft
Starting zone: 15 acres
Track: Gradient 63 percent; unconfined slope.
Runout zone: Reaches Henson Creek, and intersects part of runout zone of Path 22.

Path 22:

Total vertical drop: 1000 ft
Unconfined slope avalanche with starting zone and track combined; gradient 75 percent.
Runout zone: Reaches Henson Creek; intersects runout zone of Path 20 and 21.

Path 22a (Lee Smelter Gulch):

Total vertical drop: 3000 ft
Starting zones: Three trough-shaped basins above timberline, each with about 10 to 20 acres and which probably release separately.
Track: Gradient 36 percent; channeled.
Runout zone: Gradient 27 percent; length 900 ft.

Copper Gulch Group (Paths 23, 24, 25, and 26) all share a complex but common runout zone.

Path 23:

Total vertical drop: 2200 ft
Starting zone: 30 acres
Track: Gradient 57 percent; confined to channel.
Runout zone: same as Path 26.

Path 24:

Total vertical drop: 3100 ft
Starting zone: 40 acres
Track: Gradient 45 percent; confined to channel.
Runout zone: same as Path 26.

Path 25:

Total vertical drop: 3400 ft
Starting zone: 80 acres
Track: Gradient 36 percent; confined to channel.
Runout zone: same as Path 26.

Path 26:

Total vertical drop: 3000 ft
Starting zone: 30 acres
Track: Gradient 40 percent; confined to channel.
Runout zone: Alluvial fan of Copper Gulch; Gradient 15 percent; length 1500 ft; crosses Henson Creek. This is runout zone for Paths 23, 24, 25 and 26, all of which can run separately.

Path 27:

Total vertical drop: 1700 ft
Starting zone: 25 acres
Track: Gradient 67 percent; unconfined slope.
Runout zone: Runs into Henson Creek and joins eastern part of Copper Gulch runout zone.

Path 28:

Total vertical drop: 1000 ft
Starting zone and track are combined; gradient 60 percent; unconfined slope.
Runout zone: Runs into Henson Creek and main road without zone of gentle gradient.

Path 29 (Big Casino Gulch):

Total vertical drop: 3200 ft
Starting zone: 80 acres into two parallel basins above timberline, both can release at once.
Track: Gradient 45 percent; confined to channel.
Runout zone: No runout zone; hits Henson Creek, main road, and opposite valley wall directly without transition of gentle gradient.

Path 30:

Total vertical drop: 1900 ft
Starting zone: 15 acres
Track: Gradient 55 percent; confined to channel.
Runout zone: Hits Henson Creek; joins runout of Path 31.

Path 31:

Total vertical drop: 2500 ft
Starting zone: 35 acres
Track: Gradient 53 percent; confined to track.
Runout zone: Hits Henson Creek and main road without zone of gentle gradient.

Path 32:

Total vertical drop: 1200 ft
Starting zone: 15 acres
Track: Gradient 65 percent; confined to channel.
Runout zone: Hits Henson Creek, and access road without zone of gentle gradient.

Path 33:

Total vertical drop: 1500 ft
Starting zone: 15 acres
Track: Gradient 60 percent; confined to channel.
Runout zone: Hits Henson Creek and access road without zone of gentle gradient.

Path 34:

Total vertical drop: 1600 ft
Starting zone: 15 acres
Track: Gradient 65 percent; confined to multiple shallow channels.
Runout zone: Gradient 30 percent; length 600 ft.

Path 35:

Total vertical drop: 2800 ft
Starting zone: 25 acres
Track: Gradient 55 percent; confined to channel.
Runout zone: Hits Henson Creek and main road without zone of gentle gradient.

Path 36:

Total vertical drop: 2500 ft
Starting zone: 20 acres
Track: Gradient 55 percent; confined to channel.
Runout zone: Hits Henson Creek and main road without zone of gentle gradient.

Path 36a (Owl Gulch):

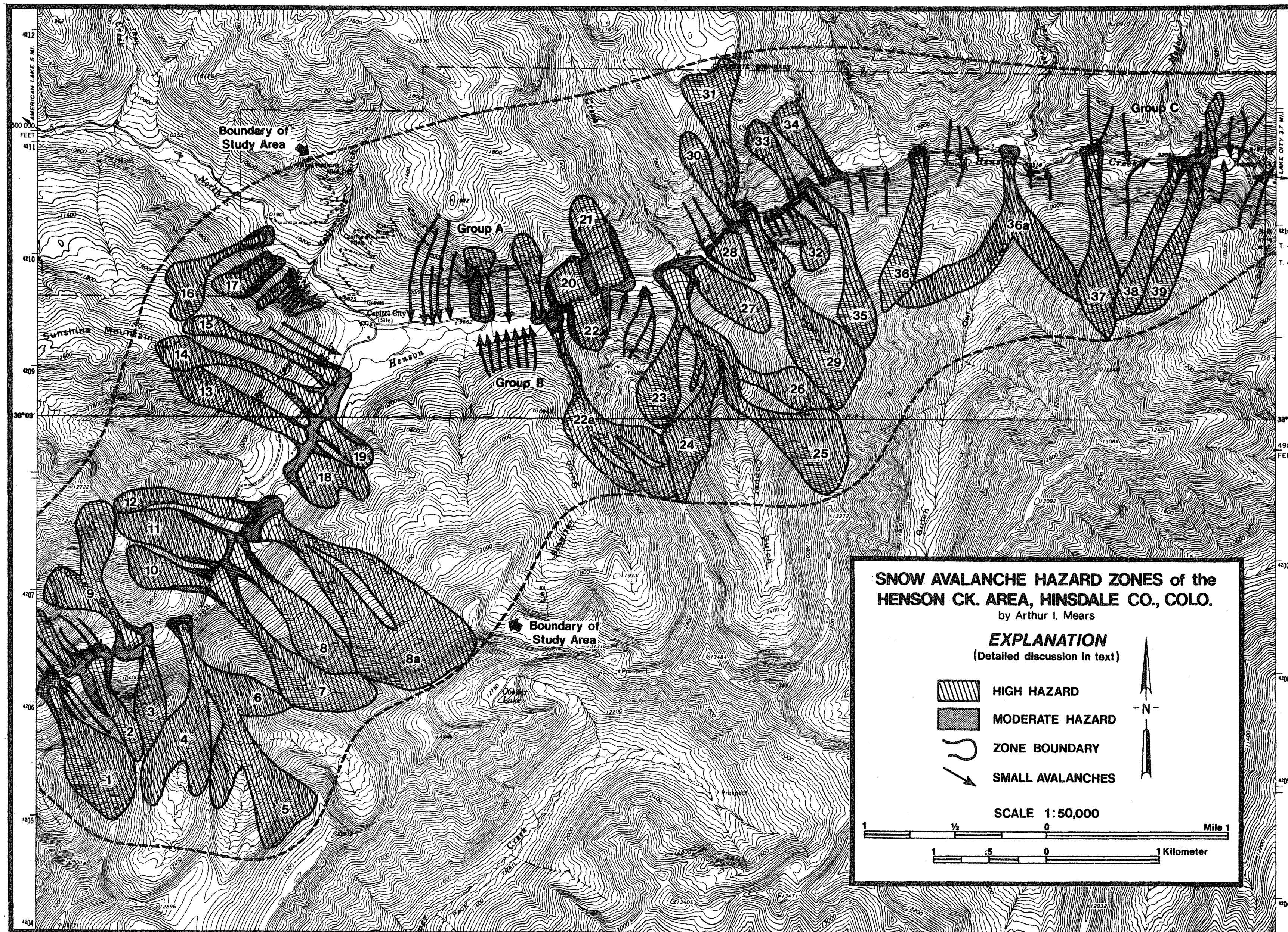
Many avalanche paths exist on the walls of Owl Gulch. Those mapped may reach Henson Creek.
Total vertical drop: 2300 ft
Starting zones: two, on west and east sides of Owl Gulch; west part has an area of 20 acres, east part has an area of about 30 acres.
Track: Confined to steep channel with gradient of 30 percent in lower Owl Gulch.
Runout zone: Gradient 30 percent; length 900 ft.

Path 37:

Total vertical drop: 3000 ft
Starting zone: 30 acres
Track: Gradient 52 percent; confined to channel.
Runout zone: Hits Henson Creek and main road without zone of gentle gradient.

Path 38:

Total vertical drop: 2800 ft
Starting zone: 20 acres
Track: Gradient 56 percent; confined to channel.
Runout zone: Hits Henson Creek and main road without zone of gentle gradient.



Base from U.S.G.S. 7½' quad. map

PLATE 5

Path 39:

Total vertical drop: 2800 ft
Starting zone: 20 acres
Track: Gradient 57 percent; confined to channel.
Runout zone: Hits Henson Creek and main road without zone of gentle gradient.

Group C:

These paths have vertical drops of 1100 ft or less and small (less than 5 acre) starting zones. They reach the main road because of their steep gradients.

INDEPENDENCE PASS AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 6

Note: The runout zones of paths 1 through 10 coalesce, forming an almost continuous band of high hazard for about 8000 ft along Highway 82. These runout zones will not be described separately, but they are shown on the accompanying map.

Path 1:

Total vertical drop: 1800 ft
Starting zone: 40 acres
Track: Gradient 53 percent; unconfined.

Path 2:

Total vertical drop: 1900 ft
Starting zone: 30 acres
Track: Gradient 53 percent; unconfined.

Path 3:

Total vertical drop: 3400 ft
Starting zone: 100 acres
Track: Gradient 41 percent; channeled.

Path 4:

Total vertical drop: 2000 ft
Starting zone: 20 acres
Track: Gradient 50 percent; channeled.

Path 5:

Total vertical drop: 1700 ft
Starting zone: 15 acres
Track: Gradient 47 percent; unconfined.

Path 6:

Total vertical drop: 1800 ft
Starting zone(s): 2 branches; east branch 10 acres, west branch 20 acres.
Track: Gradient 40 percent; channeled.

Path 7:

Total vertical drop; 3000 ft
Starting zone: 60 acres
Track: Gradient 44 percent; channeled.

Path 8:

Total vertical drop: 2400 ft
Starting zone: 50 acres
Track: Gradient 48 percent; channeled.

Path 9:

Total vertical drop: 2600 ft
Starting zone: 40 acres
Track: Gradient 50 percent; unconfined.

Path 10:

Total vertical drop: 1800 ft
Starting zone: 10 acres
Track: Gradient 54 percent; channeled.

Path 11:

Total vertical drop: 3000 ft
Starting zone: Entire cirque wall; single releases are probably less than 80 acres.
Track: Gradient 29 percent; channeled.
Runout zone: Gradient 12 percent; length 1200 ft.

Path 12:

Total vertical drop: 1000 ft
Starting zone: 10 acres
Track: Gradient 46 percent; unconfined.
Runout zone: Gradient 8 percent; length 1000 ft.

Path 13:

Total vertical drop: 2400 ft
Starting zone: 20 acres
Track: Gradient 54 percent; channeled.
Runout zone: Gradient 5 percent; length 800 ft.

Path 14:

Total vertical drop: 2600 ft
Starting zone: 35 acres
Track: Gradient 48 percent; channeled.
Runout zone: Gradient 12 percent; length 1000 ft.

Path 14:

Total vertical drop: 2200 ft
Starting zone: 50 acres
Track: Gradient 46 percent; channeled.
Runout zone: Reaches path on opposite side of valley.

Group A:

The avalanche paths comprising this group reach Highway 82 quite often because the road is cut through the avalanche tracks. This part of the road would probably be one of the most hazardous sections during winter. Paths have vertical drops of 900 to 2600 ft and starting zones of generally less than 20 acres.

Path 16:

Total vertical drop: 600 ft
Starting zone: 5 acres
Track: Gradient 57 percent; unconfined; crosses road in two places.
Runout zone: Gradient 20 percent; length 700 ft.

Group B:

Highway 82 crosses the tracks of these avalanche paths, consequently, they probably reach Route 82 quite often. Total vertical drops average about 700 ft.

Path 17:

Total vertical drop: 1000 ft
Starting zone: 20 acres
Track: Gradient 65 percent; broad, unconfined slope.
Runout zone: Gradient 22 percent; length 900 ft.

Path 18:

Total vertical drop: 1000 ft
Starting zone: 5 acres
Track: Gradient 50 percent; unconfined.
Runout zone: Gradient 12 percent; length 600 ft.

Path 19:

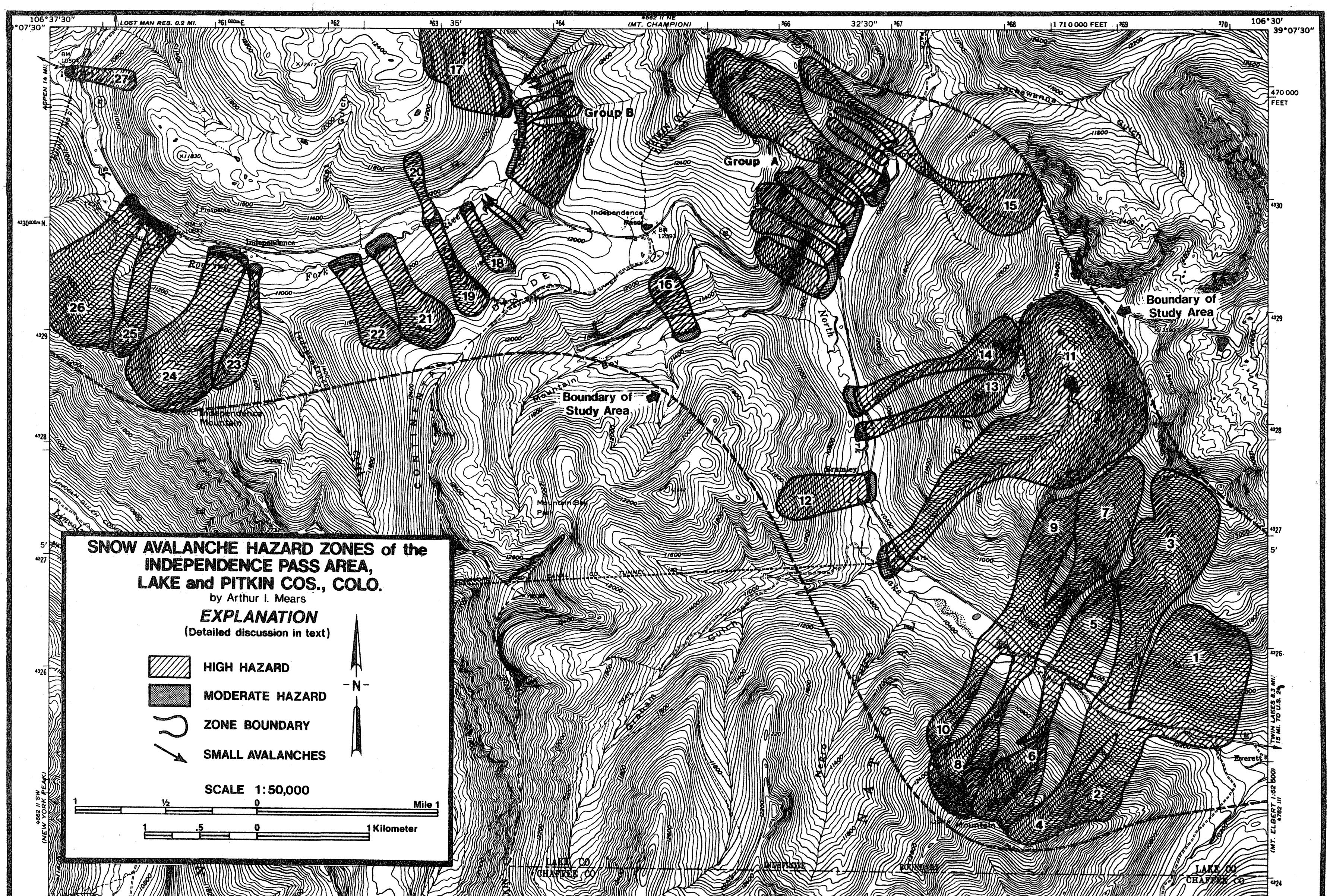
Total vertical drop: 1200 ft
Starting zone: 20 acres
Track: Gradient 47 percent; channeled.
Runout zone: Gradient 15 percent; length 800 ft.

Path 20:

Total vertical drop: 900 ft
Starting zone: 5 acres
Track: Gradient 60 percent; unconfined.
Runout zone: Gradient 13 percent; length 600 ft.

Path 21:

Total vertical drop: 1300 ft
Starting zone: 40 acres
Track: Gradient 43 percent; unconfined.
Runout zone: Gradient 20 percent; length 1200 ft.



Base from U.S.G.S. 7½′ quad. map

PLATE 6

Path 22:

Total vertical drop: 1200 ft
Starting zone: 20 acres
Track: Gradient 50 percent; unconfined.
Runout zone: Gradient 25 percent; length 1100 ft.

Path 23:

Total vertical drop: 1500 ft
Starting zone: 10 acres
Track: Gradient 44 percent; unconfined.
Runout zone: Gradient 20 percent; length 1000 ft.

Path 24:

Total vertical drop: 1600 ft
Starting zone: 50 acres
Track: Gradient 31 percent; unconfined.
Runout zone: Gradient 23 percent; length 1700 ft.

Path 25:

Total vertical drop: 1600 ft
Starting zone: 15 acres
Track: Gradient 41 percent; unconfined.
Runout zone: Gradient 0 percent; length 700 ft.

Path 26:

Total vertical drop: 1700 ft
Starting zone: 80 acres
Track: Gradient 37 percent; unconfined.
Runout zone: Gradient 0 percent; length 800 ft.

Path 27:

Total vertical drop: 800 ft
Starting zone: 5 acres
Track: Gradient 56 percent; channeled.
Runout zone: Gradient 26 percent; length 1000 ft.

MARBLE AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 7

Path 1:

Total vertical drop: 3300 ft
Starting zone: 50 acres, shallow bowl below timberline.
Track: Gradient 70 percent; confined to shallow channel.
Runout zone: Gradient 21 percent; length 1500 ft.

Group A:

Small paths with vertical drops of 1000 ft to 1500 ft and small starting zones of 1 to 3 acres. Steep overall path gradients of 70 to 80 percent enable small slides to reach the Crystal River.

Paths 2 through 7 all start on the northeast facing slope immediately south and west of Marble. They can all cross the Crystal River and some of them damaged the old marble-processing plant in the past. The starting zones of these paths are oriented so they collect snow through accumulation in the lee of the ridge and can maintain a deep snowpack throughout most winters.

Path 2:

Total vertical drop: 1600 ft
Starting zone: 10 acres, below timberline.
Track: Gradient 65 percent; confined to channel.
Runout zone: Gradient -8 percent; length 500 ft.

Path 3:

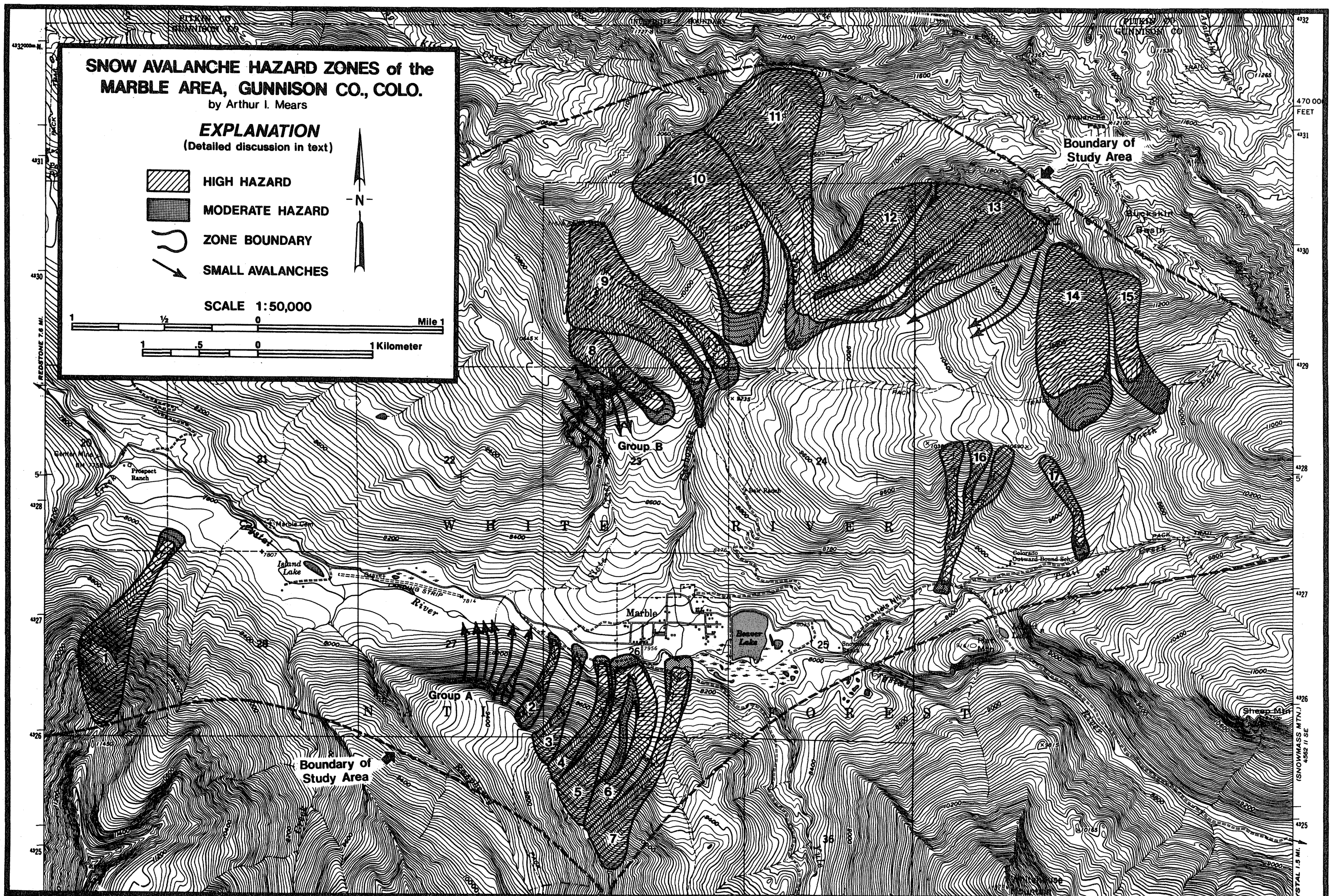
Total vertical drop: 2100 ft
Starting zone: 15 acres
Track: Gradient 65 percent; confined to channel.
Runout zone: Gradient -8 percent; length 600 ft.

Path 4:

Total vertical drop: 2300 ft
Starting zone: 10 acres
Track: Gradient 68 percent; confined to channel.
Runout zone: Gradient 15 percent; length 1000 ft; crosses flat bench about 200 ft long.

Path 5:

Total vertical drop: 2600 ft
Starting zone: 30 acres
Track: Gradient 60 percent; confined to shallow channel.
Runout zone: Gradient 7 percent; length 800 ft, crosses Crystal River and reaches Marble.



Base from U.S.G.S. 7½′ quad. map

PLATE 7

Path 6:

Total vertical drop: 2600 ft
Starting zone: 15 acres
Track(s): Splits into two tracks, one of which joins path 5; average gradients are about 55 percent.
Runout zone: same as path 5.

Path 7:

Total vertical drop: 2900 ft
Starting zone: 30 acres
Track: Gradient 44 percent; lower track is unconfined and average only 30 percent for a stretch 3000 ft long.
Runout zone: Gradient 10 percent; length 700 ft.

Group B:

These paths start on the steep slopes of Gallo Hill and fall 800 to 1600 ft before stopping in Slate Creek. They can become small powder avalanches because of the steep (100 percent) terrain.

Path 8:

Total vertical drop: 2000 ft
Starting zone: 20 acres
Track: Gradient 65 percent; lower part falls over steep cliffs of Gallo Hill.
Runout zone: Gradient 20 percent; length 900 ft.

Path 9:

Total vertical drop: 3000 ft
Starging zone: 90 acres
Track(s): Gradient 40 percent; splits into two branches.
Runout zones: Two runout zones, both with average gradients of 25 percent lengths 2000 ft; both stop in Carbonate Creek.

Path 10:

Total vertical drop: 2600 ft
Starting zone: 80 acres
Track: Gradient 47 percent; unconfined slope.
Runout zone: Gradient 25 percent; length 3200 ft; it is confined on east by ridge.

Path 11:

Total vertical drop: 2800 ft
Starting zone: 150 acres
Track: Gradient 58 percent; broad, unconfined slope.
Runout zone: Gradient 13 percent; length 4100 ft; confined laterally by valley walls.

Path 12:

Total vertical drop: 2300 ft
Starting zone: 30 acres
Track: Gradient 50 percent; two parallel channels.
Runout zone: Gradient 25 percent; length 1800 ft, hits west side of Carbonate Creek.

Path 13:

Total vertical drop: 3000 ft
Starting zone: 70 acres
Track: Gradient 50 percent to 55 percent; two parallel channels.
Runout zone: Gradient 24 percent; length 3400 ft.

Path 14:

Total vertical drop: 2400 ft
Starting zone: 60 acres
Track: Gradient 50 percent; unconfined.
Runout zone: Gradient 25 percent; length 1600 ft.

Path 15:

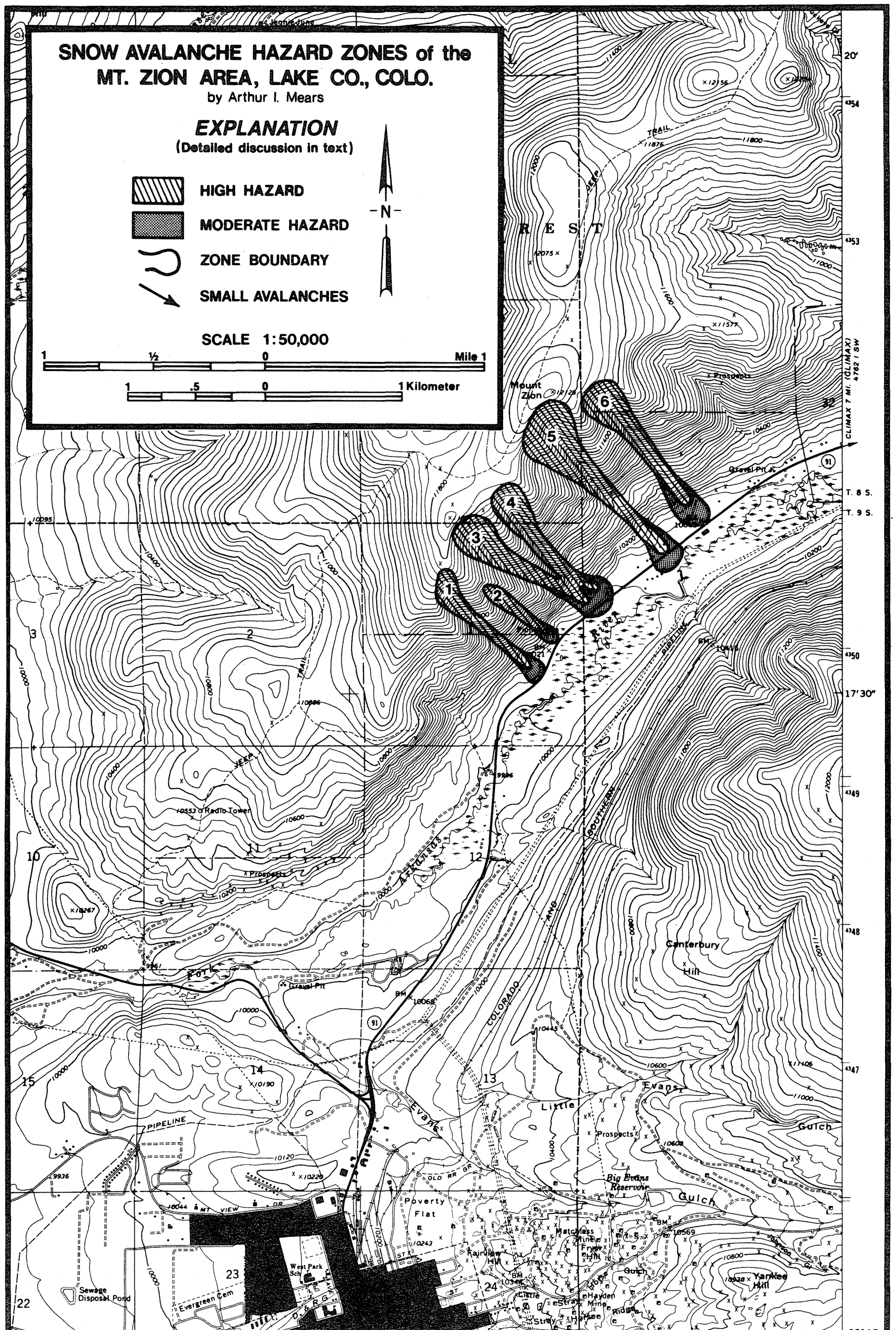
Total vertical drop: 2100 ft
Starting zone: 20 acres
Track: Gradient 47 percent; unconfined.
Runout zone: No runout zone (encounters steep opposite valley wall).

Path 16:

Total vertical drop: 2000 ft
Starting zones: 3 separate zones, each about 10 acres.
Tracks: Gradient 48 percent; all three tracks confined to channels.
Runout zone: Gradient 22 percent; length 1100 ft.

Path 17:

Total vertical drop: 1500 ft
Starting zone: 10 acres
Track: Gradient 57 percent; confined to channel.
Runout zone: Gradient 28 percent; length 1300 ft.



Base from U.S.G.S. 7½′ quad. map

PLATE 8

MT. ZION AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 8

Path 1:

Total vertical drop: 1600 ft
Starting zone: At timberline, about 10 acres.
Track: Gradient 55 percent; confined to channel.
Runout zone: Gradient 20 percent; length 700 ft.

Path 2:

Total vertical drop: 1200 ft
Starting zone: Below timberline, 5 acres.
Track: Gradient 60 percent; confined to shallow channel.
Runout zone: Gradient 30 percent; length 400 ft.

Path 3:

Total vertical drop: 1800 ft
Starting zone: 15 acres, at timberline.
Track: Gradient 48 percent; confined to deep channel.
Runout zone: same as path 4.

Path 4:

Total vertical drop; 1800 ft
Starting zone: At timberline, 15 acres.
Track: Gradient 53 percent
Runout zone: Gradient 32 percent; length 1000 ft (merges with runout zone of Path 3).

Path 5:

Total vertical drop: 2000 ft
Starting zone: above timberline, 20 acres
Track: Gradient 45 percent; confined to deep channel
Runout zone: Gradient 12 percent; length 1200 ft

Path 6:

Total vertical drop: 1900 ft
Starting zone: At timberline, 15 acres.
Track: Gradient 46 percent; confined to deep channel.
Runout zone: Gradient 12 percent; length 800 ft.

OPHIR AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 9

Group A (Needles Group):

These are small paths with steep rugged starting zones of less than 10 acres. Large accumulations of snow and large avalanches are not likely because of the general steepness of the paths (70 to 75 percent). However, as these paths are steep in the runout zone, avalanches probably can reach the road at fairly frequent (5 to 10 year) return periods.

Path 1:

Total vertical drop: 2600 ft
Starting zone: 20 acres
Track: Gradient 70 percent; confined to gully.
Runout zone: Gradient 26 percent; length 1500 ft.

Path 2:

Total vertical drop: 2800 ft
Starting zone: 40 acres
Track: Gradient 58 percent; confined to gully.
Runout zone: Gradient 15 percent; length 2000 ft.

Path 3:

Total vertical drop: 2800 ft
Starting zone: 60 acres
Track: Gradient 58 percent; confined to channel.
Runout zone: Gradient 16 percent; length 1900 ft.

Path 4:

Total vertical drop: 3000 ft
Starting zone: 45 acres
Track: Gradient 54 percent; confined to channel.
Runout zone: Gradient 9 percent; length 1800 ft.

Path 5:

Total vertical drop: 3200 ft
Starting zone: 30 acres
Track: Gradient 56 percent; confined to two parallel gullies.
Runout zone: Gradient 13 percent; length 1600 ft.

Group B:

These are small open-slope avalanches between Paths 5 and 6. They have small (less than 5 acres) starting zones, but steep tracks of 50 to 70 percent. They may cross the north town boundary of Ophir as either wet, dry, or powder avalanches.

Path 6 (Staatsburgh Basin):

Total vertical drop: 3700 ft
Starting zone: 75 acres

The gently sloping floor (23 percent; length 1200 ft) of Staatsburg Basin serves as the upper track for avalanches. Small to medium sized avalanches remain in the upper basin but large avalanches completely cross the basin, descend the steep slope below it, and converge with the runout zone of Spring Gulch (Path 7).

Path 7 (Spring Gulch):

Total vertical drop: 3700 ft
Starting zone: As much as 110 acres, complex with west, east and south orientations
Track: Gradient 39 percent; confined to deep channel.
Runout zone: Gradient 16 percent; length 2700 ft.

Note: This avalanches has reached Ophir at least 4 times in the last 80 years, and has moved buildings as much as 200 ft (pers. comm. R. Belisle, 1974).

Group C:

These are small channeled avalanches between Paths 7 and 8. Their starting zones are less than 5 acres, but due to their steep (60 percent) tracks, some my reach the Ophir Pass road.

Path 8:

Total vertical drop: 3400 ft
Starting zone: 45 acres
Track: Gradient 45 percent; confined to shallow, broad channel.
Runout zone: Gradient 24 percent; length 2100 ft.

Path 9:

Total vertical drop: 3400 ft
Starting zone: 45 acres
Track: Gradient 46 percent; confined to channel.
Runout zone: Gradient 25 percent; length 2400 ft.

Path 10:

Total vertical drop: 3300 ft
Starting zone: 80 acres
Track: Gradient 44 percent; confined to two parallel, shallow channels.
Runout zone: Gradient 17 percent; length 2300 ft.

Path 11:

Total vertical drop: 3200 ft
Starting zone: 115 acres
Track: Gradient 39 percent; confined to deep channel.
Runout zone: Same as for Path 12 (Chapman Gulch).

Path 12 (Chapman Gulch):

Total vertical drop: 3200 ft
Starting zone: 120 acres
Track: Gradient 40 percent; confined to channel.
Runout zone: Gradient 17 percent; length 3200 ft.

Path 13:

Total vertical drop: 2400 ft
Starting zone: 80 acres, above and below timberline.
Track: Gradient 38 percent; confined to channel.
Runout zone: Gradient 22 percent; length 1700 ft.

Group D:

These are small open slope avalanches which probably cannot reach beyond the south Ophir town limits.

Path 14:

Total vertical drop: 2200 ft
Starting zone: 30 acres, above and below timberline.
Track: Gradient 52 percent; runs in shallow channel.
Runout zone: Gradient 5 percent; length 800 ft.

Path 15:

Total vertical drop: 3000 ft
Starting zone: 65 acres
Track: Gradient 52 percent; runs in shallow channel.
Runout zone: Gradient 16 percent; length greater than 1000 ft.

Path 16:

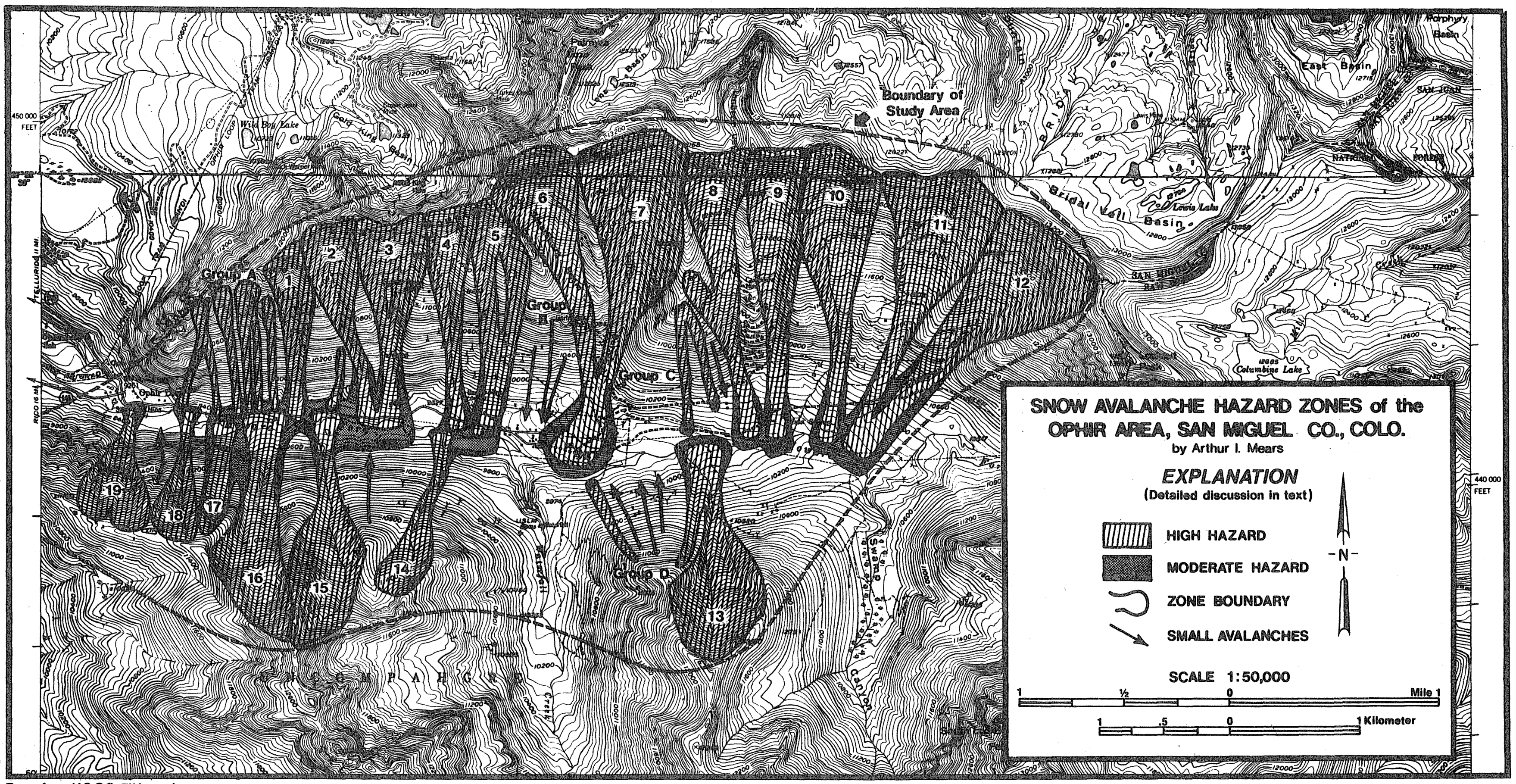
Total vertical drop: 3200 ft
Starting zone: 90 acres
Track: Gradient 64 percent; runs on open slope.
Runout zone: Gradient 20 percent; length over 1000 ft; reaches runout zones of paths of the Needles Group (Group A).

Path 17:

Total vertical drop: 2000 ft
Starting zone: 15 acres below timberline.
Track: Gradient 63 percent; open slope.
Runout zone: Gradient 12 percent; length 600 ft.

Path 18:

Total vertical drop: 2000 ft
Starting zone: 30 acres, below timberline.
Track: Gradient 70 percent; confined to gully.
Runout zone: Gradient 7 percent; length 600 ft.



Base from U.S.G.S. 7½′ quad. map

PLATE 9

Path 19:

Total vertical drop: 2000 ft
Starting zones: two basins below timberline; east basin 25 acres; west basin 15 acres.
Track: Gradient 71 percent; runs in shallow gully.
Runout zone: Gradient 11 percent; length 700 ft.

RICO AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 10

Path 1 (Peterson Slide):

Total vertical drop; 1800 ft
Starting zone: Unforested east and south facing slope below timberline, 20 acres.
Track: Gradient 54 percent; confined to gully.
Runout zone: No zone of moderate gradient, hits highway 145 without transition.

Path 2:

Total vertical drop: 1300 ft
Starting zone: Steep, east-facing cliffs of Sandstone Mountain.
Track: Gradient 90 percent; broad unconfined slope.
Runout zone: No zone of moderate gradient, hits highway 145 without transition.

Group A:

Paths in this group have vertical drops of 500 to 1000 ft, small starting zones, and track gradients of 60 to 70 percent. Under extreme conditions they will reach highway 145.

Path 3:

Total vertical drop: 2000 ft
Starting zone: Unforested south-eastern facing slope below timberline, about 30 acres
Track: Gradient 41 percent; confined to gully.
Runout zone: Gradient 23 percent; length 1300 ft; covers debris fan of Aztec Gulch.

Path 4:

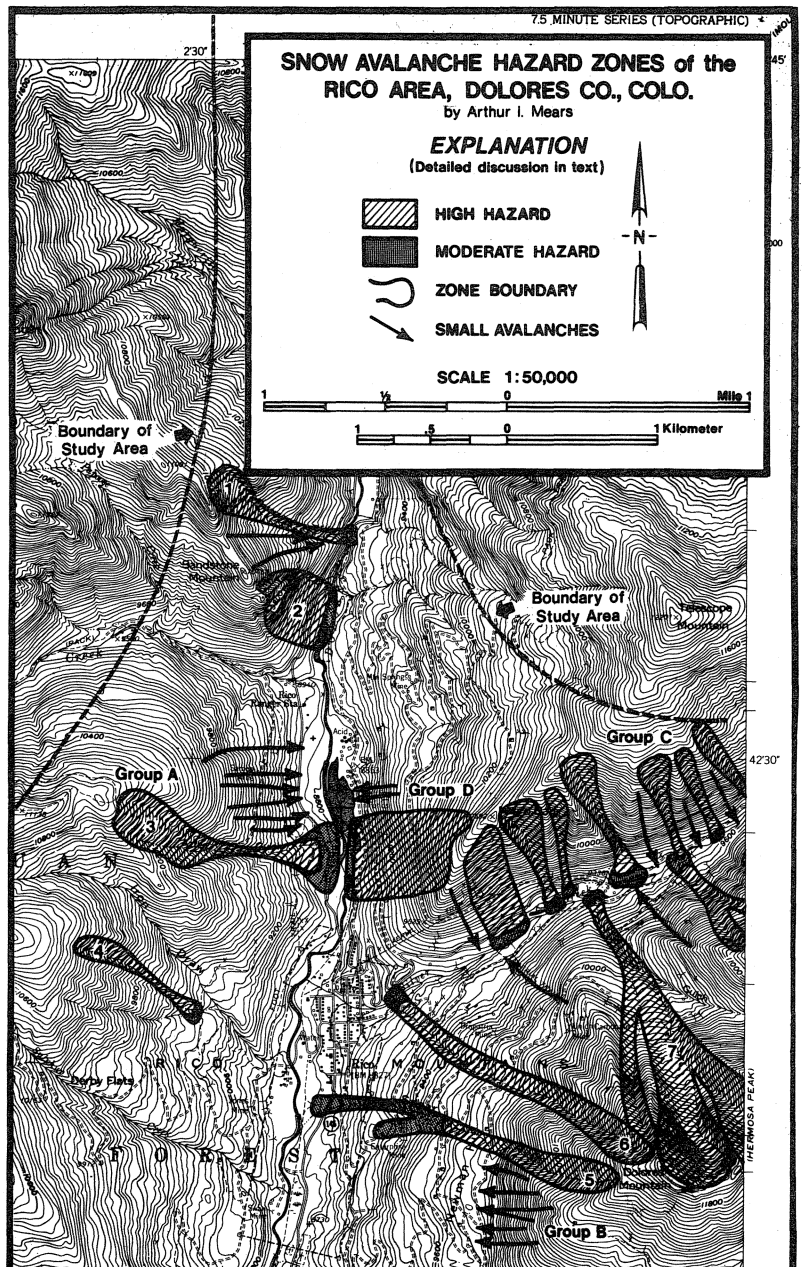
Total vertical drop: 1400 ft
Starting zone: Unforested area below timberline, about 10 acres
Track: Gradient 46 percent; confined to gully.
Runout zone: Gradient 29 percent; length 700 ft.

Group B:

Paths in this group have vertical drops of 600 to 1100 ft, and stop on the Newman Hill area.

Path 5 (Spear Slide):

Total vertical drop: 2800 ft
Starting zone: Bowl on west side Dolores Mountain, about 20 acres
Track: Gradient varies considerably from 59 percent on upper part to 32 percent across Newman Hill.
Runout zone: Small to moderate avalanches stop on Newman Hill; large avalanches can reach Rico.



Base from U.S.G.S. 7½′ quad. map

PLATE 10

Path 6:

Total vertical drop: 3000 ft
Starting zone: About 20 acres, above and below timberline
Track: Gradient varies from 53 percent on upper part to 33 percent across Newman Hill.
Runout zone: Moderate to small sized avalanches stop on Newman Hill, large avalanches run to Silver Creek.

Path 7 (Allyn Gulch):

Total vertical drop: 2800 ft
Starting zones: Composed of three distinct starting zones:
a. About 10 acres on north side of Dolores Mountain
b. About 40 acres on north bowl of Dolores Mountain
c. About 30 acres on northeast bowl of Dolores Mountain
Track: Confined to Allyn Gulch in lower part, gradient, 31 percent.
Runout zone: Runs to Silver Creek.

Group C:

These avalanche paths are on the south side of Telescope Mountain, have vertical drops of 800 to 1500 ft, and can run to Silver Creek.

Group D:

These avalanche paths are on the west side of Telescope Mountain, have vertical drops of 600 to 1200 ft, track gradients of 60 to 70 percent, and can reach the flood plain of the Dolores River. Some can reach the settling ponds. Debris flows also occur on these slopes.

ROSE CABIN AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 11

Path 1:

Total vertical drop: 2000 ft
Starting zone: 20 acres; above timberline.
Track: Gradient 75 percent; unconfined.
Runout zone: Crosses Henson Creek.

Note: Path 2 through 8 constitute a continuous band of high hazard for almost one mile along Henson Creek as their runout zones coalesce. Although the high hazard zone, as defined in this mapping project, is affected by avalanches with return periods of less than 25 years, the actual return periods of these avalanches may be considerably less than 25 years even at the valley bottom. Since these runout zones do coalesce they are not described separately.

Path 2:

Total vertical drop: 2200 ft
Starting zone: 40 acres, above timberline.
Track: Gradient 60 percent; channeled.

Path 3 (Schafer Basin):

Total vertical drop: 2600 ft
Starting zone: Complete cirque wall; more than 100 acres.
Track: Gradient 40 percent; channeled.

Path 4:

Total vertical drop: 1700 ft
Starting zone: 10 acres; above timberline.
Track: Gradient 75 percent; unconfined.

Path 5:

Total vertical drop: 2100 ft
Starting zone: 15 acres; above timberline.
Track: Gradient 78 percent; unconfined.

Path 6:

Total vertical drop: 2400 ft
Starting zone: 15 acres; above timberline.
Track: Gradient 75 percent; unconfined.

Path 7:

Consists of three parts which probably release separately but all reach the same runout zone. The areas of the three starting zones are, from east to west, 20, 30, and 60 acres respectively.

Path 8:

Total vertical drop: 2100 ft
Starting zone: 10 acres; above timberline.
Track: Gradient 75 percent; channeled.

Note: Paths 9 through 12 constitute a continuous band of hazard almost one-half mile long along the Henson Creek road. Avalanche frequencies within the runout zone are probably similar to those of paths 2 through 8. Return periods are probably much less than 25 years.

Path 9:

Total vertical drop: 2200 ft
Starting zone: 40 acres, above timberline.
Track: Gradient 65 percent; channeled.

Path 10:

Total vertical drop: 1800 ft
Starting zone: 30 acres, above timberline.
Track: Gradient 75 percent; unconfined.

Path 11:

Total vertical drop: 2000 ft
Starting zone: 20 acres, above timberline.
Track: Gradient 38 percent; channeled.

Path 12:

Total vertical drop: 2100 ft
Starting zone: 15 acres, above timberline.
Track: Gradient 72 percent; unconfined.

Path 13:

Total vertical drop: 2300 ft
Starting zone: 30 acres, above timberline.
Track: Gradient 67 percent; unconfined.
Runout zone: Gradient 8 percent; length 1000 ft.

Path 14:

Total vertical drop: 2300 ft
Starting zone: 30 acres, above timberline.
Track: Gradient 75 percent; unconfined.
Runout zone: Gradient 5 percent; length 800 ft.

Path 15:

Total vertical drop: 1800 ft
Starting zone: 15 acres
Track: Gradient 52 percent; unconfined.
Runout zone: None; hits west side of Schafer Gulch without transition.

Path 16:

Total vertical drop: 1500 ft
Starting zone: 40 acres; above timberline.
Track: Broad unconfined slope; gradient 60 percent.
Runout zone: Gradient 0 percent; length 400 ft.

Path 17:

Total vertical drop: 2000 ft
Starting zone: 60 acres; above timberline.
Track: Broad, unconfined slope; entire path is about 3000 ft wide.
Runout zone: Reaches bottom of Schafer Gulch without transition.

Path 18 (Hurricane Basin):

All of Hurricane Basin can be reached by avalanches falling from the cirque walls. Because of the elevation and exposure to wind and snow, it must be considered a high hazard zone.

Path 19 (Seigal Mountain):

Avalanche paths here are similar in topography to those of Hurricane Basin and can reach the upper part of Schafer Gulch.

Total vertical drop: 1600 ft
Starting zones: West portion about 30 acres; east portion 20 acres.
Tracks: Gradient of west portion 36 percent; unconfined.
Gradient of east portion 40 percent; unconfined.
Runout zone: Upper Schafer Gulch.

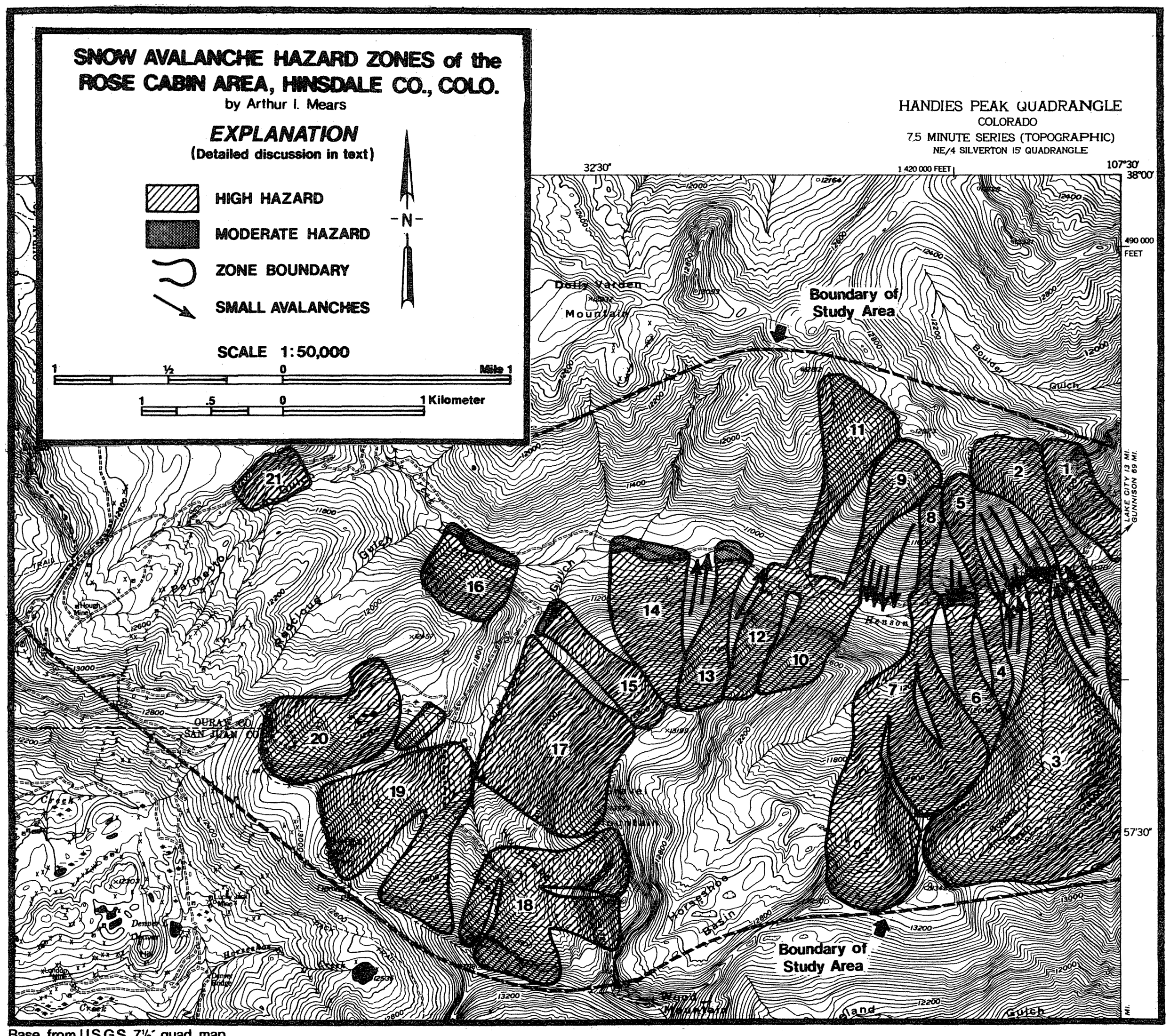
Path 20:

Avalanches can occur around most of this cirque and can reach most of the cirque floor.

Redcloud and Palmetto Gulches are apparently free of avalanche hazard except for a short section along the Engineer Pass road (Path 21).

Path 21:

This is an unconfined slope avalanche crossing about 1500 feet of the Engineer Pass road.


SNOW AVALANCHE HAZARD ZONES of the
ROSE CABIN AREA, HINSDALE CO., COLO.
by Arthur I. Mears
EXPLANATION
(Detailed discussion in text)
HIGH HAZARD
MODERATE HAZARD
ZONE BOUNDARY
SMALL AVALANCHES
-N-
SCALE 1:50,000
1 ½ 0 Mile 1
1 .5 0 1 Kilometer
HANDIES PEAK QUADRANGLE
COLORADO
7.5 MINUTE SERIES (TOPOGRAPHIC)
NE/4 SILVERTON 15' QUADRANGLE
32'30"
1 420 000 FEET
107°30'
38°00'
490 000
FEET
57'30"
Boundary of
Study Area
Boundary of
Study Area
Dolly Varden
Mountain
Boulder
Gulch
LAKE CITY 13 MI.
GUNNISON 69 MI.
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20
21
Henson
Horseshoe
Basin
OURAY CO
SAN JUAN CO
Wood
Mountain
Gulch
Base from U.S.G.S. 7½' quad. map

PLATE 11

SHERMAN AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 12

Group A:

Consists of several narrow paths through the forest with vertical drops of about 2000 ft. Relatively small volumes of avalanches in these paths do not permit long runouts.

Path 1:

Total vertical drop: 2900 ft
Starting zone: 20 acres, above timberline.
Track: Gradient 56 percent; channeled.
Runut zone: Gradient 12 percent; length 1000 ft.

Path 2:

Total vertical drop: 3300 ft
Starting zone: 40 acres, above timberline.
Track: Gradient 51 percent; channeled.
Runout zone: Gradient 18 percent; 1800 ft.

Path 3:

Total vertical drop: 3800 ft
Starting zone: 70 acres, above timberline.
Track: Gradient 62 percent; channeled.
Runout zone: Gradient 19 percent; length 1600 ft.

Path 4:

Total vertical drop: 4000 ft
Starting zone: 50 acres, above timberline.
Track: Gradient 55 percent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition.

Path 5:

Total vertical drop: 2200 ft
Starting zone: 10 acres, above timberline.
Track: Gradient 65 precent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition.

Path 6:

Total vertical drop: 3600 ft
Starting zone: 40 acres, above timberline.
Track: Gradient 57 percent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition.

Path 7:

Total vertical drop: 3100 ft
Starting zone: 20 acres, above timberline.
Track: Gradient 52 percent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition; meets and overlaps runout zone of path 8.

Path 8:

Total vertical drop: 3400 ft
Starting zone; 50 acres; above timberline.
Track: Gradient 53 percent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition; meets and overlaps runout zone of path 7.

Path 9:

Total vertical drop: 3100 ft
Starting zone: 50 acres, above timberline.
Track: Gradient 47 percent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition; meets and overlaps runout zone of path 10.

Path 10:

Total vertical drop: 1900 ft
Starting zone: 15 acres, above timberline.
Track: Gradient 45 percent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition; meets and overlaps runout zone of path 9.

Path 11:

Total vertical drop: 3200 ft
Starting zone: 80 acres, above timberline.
Track: Gradient 47 percent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition; meets and overlaps runout zone of path 12.

Path 12:

Total vertical drop: 2700 ft
Starting zone: 50 acres, above timberline.
Track: Gradient 54 percent; channeled.
Runout zone: None; hits Lake Fork of Gunnison without transition; meets and overlaps runout zone of path 11.

Path 13:

Total vertical drop: 2600 ft
Starting zone: 30 acres, above timberline.
Track: Gradient 50 percent; unconfined.
Runout zone: Gradient 20 percent; length 300 ft; meets and overlaps runout zone of path 14.

Path 14:

Total vertical drop: 2000 ft
Starting zone: 30 acres above timberline.
Track: Gradient 65 percent; unconfined.
Runout zone: None; hits Lake Fork of Gunnison without transition; meets and overlaps runout zone of path 13.

Note: The runout zones of paths 9 through 14 coalesce for a distance of about 2500 ft along the Shelf Road.

Path 15:

Total vertical drop: 3200 ft
Starting zone: Large and complex, completely above timberline; avalanches with various orientations can all reach the valley bottom.
Track: Follows two branches of Campbell Creek; average gradient varies from 30 to 50 percent and is channeled in most of the reaches.
Runout zone: None; hits Lake Fork of Gunnison without transition.

Path 16:

Total vertical drop: 2400 ft
Starting zone: 20 acres above timberline.
Track: Splits into two branches, confined in one, unconfined in other.
Runout zone: Southern branch has no runout zone; Northern branch, 25 percent gradient; length 250 ft.

Path 17:

Total vertical drop: 2000 ft
Starting zone: Not well defined, consists of upper part of track, about 10 acres.
Track: Gradient 60 percent; unconfined.
Runout zone: Gradient 30 percent; length 300 ft.

Path 18:

Total vertical drop: 1900 ft
Starting zone: 10 acres above timberline.
Track: Gradient 70 percent; channeled.
Runout zone: Gradient 6 percent; length 500 ft.

Path 19:

Total vertical drop: 2600 ft
Starting zone: 20 acres above timberline.
Track: Gradient 60 percent; channeled.
Runout zone: Gradient 0 percent; length 800 ft.

Path 20:

Total vertical drop: 1700 ft
Starting zone: 15 acres above timberline.

Tracks: This path has two distinct, unconfined tracks; gradients of both are about 50 percent.
Runout zones: Both run out onto zero gradients and extend 800 to 1000 ft.

Path 21:

Total vertical drop: 2600 ft
Starting zone: 60 acres; above timberline.
Track: Gradient 52 percent; unconfined.
Runout zone: Gradient 17 percent; length 1200 ft; in part meets and overlaps runout of path 22.

Path 22:

Total vertical drop: 1800 ft
Starting zone: 10 acres above timberline.
Track: Gradient 53 percent; channeled.
Runout zone: Gradient 17 percent; meets and overlaps runout zone of path 21.

Path 23:

Total vertical drop: 2700 ft
Starting zone: 30 acres above timberline.
Track: Gradient 48 percent; channeled.
Runout zone: Gradient 20 percent; length 1200 ft.

Path 24:

Total vertical drop: 2100 ft
Starting zone: 10 acres above timberline.
Tracks: Splits into two tracks; east track is channeled with gradient of 59 percent; west track is unconfined with gradient of 67 percent.
Runout zone: Meets and overlaps runout of path 25.

Path 25:

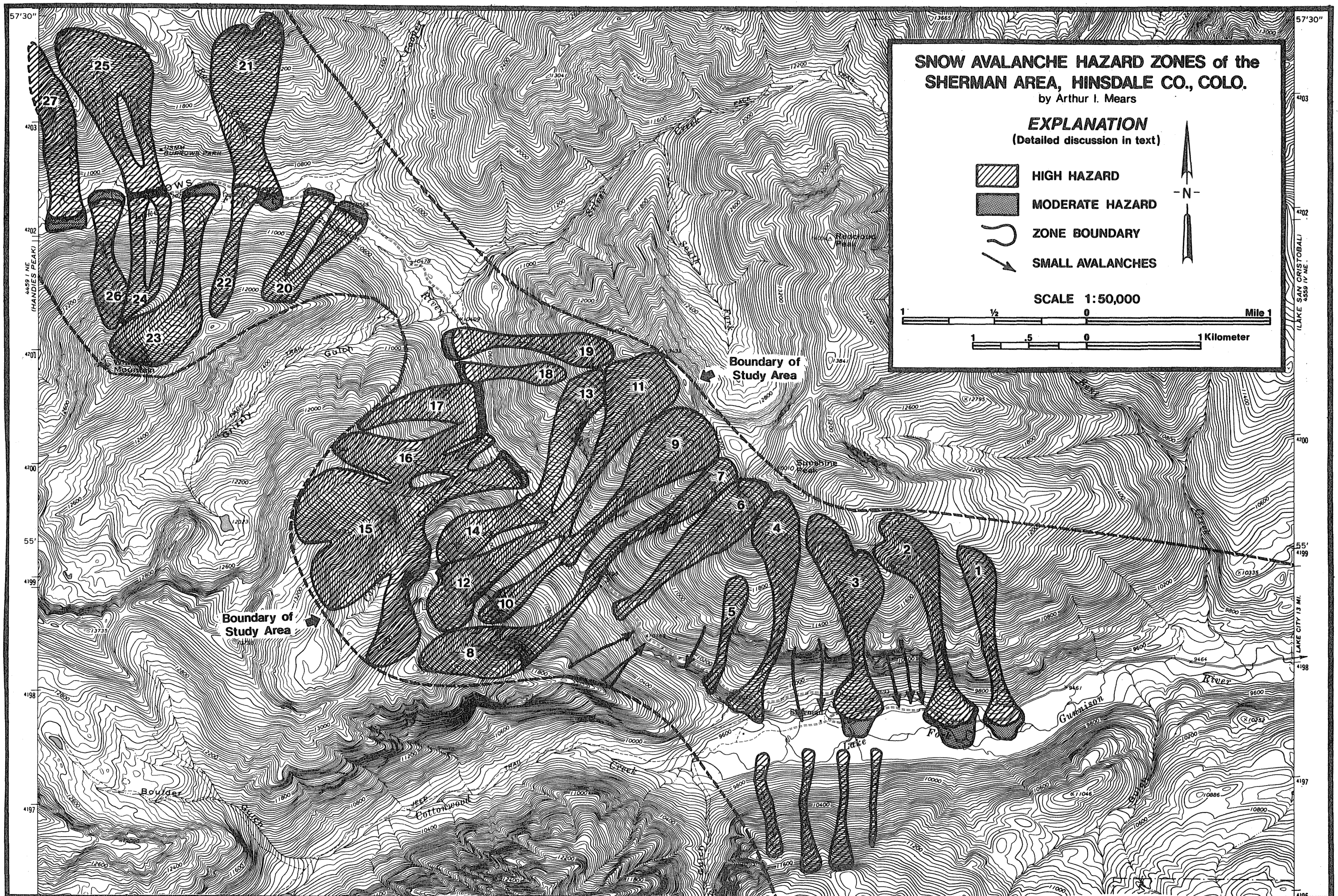
Total vertical drop: 2500 ft
Starting zone: 60 acres above timberline.
Tracks: Follows two separate channels, both with gradient of about 50 percent.
Runout zone: Gradient 20 percent; length 1500 ft.

Path 26:

Total vertical drop: 2300 ft
Starting zone: 15 acres above timberline.
Track: Gradient 60 percent; channeled.
Runout zone: Gradient 10 percent; length 800 ft.

Path 27:

Total vertical drop: 2600 ft
Starting zone: 40 acres
Track: Gradient 53 percent; channeled.
Runout zone: Gradient 13%; length 1500 ft.



Base from U.S.G.S. 7½' quad. map

PLATE 12

SILVER PLUME AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 13

Group A:

This pair of avalanche paths have small starting zones of 5 acres or less and steep tracks of 70 to 80 percent. Because of the steep, rugged slopes, and small starting zones, avalanches will not involve much snow. However, there is no runout zone above the highway, and avalanches can reach it occasionally.

Path 1 (Snowdrift Gulch):

Total vertical drop: 2100 ft
Starting zone: About 5 acres in shallow gully.
Track: Gradient 62 percent; confined to gully.
Runout zone: Gradient 25 percent; length 400 ft. An avalanche reached the north part of town in about 1922 (Personal communication, George Rowe).

Path 2 (Cherokee Gulch):

Total vertical drop: 2200 ft
Starting zones: Top of three gullies which converge at about 10,200 ft elevation. Area about 5 to 10 acres.
Track: Gradient 40 percent; condined to gully.
Runout zone: Gradient 40 percent; length 1000 ft.

Path 3 (Williham Gulch):

Total vertical drop: 2600 ft
Starting zone: About 10 acres, at timberline.
Track: Gradient 44 percent; top runs in shallow channel, bottom on open slope.
Runout zone: Gradient 40 percent; length 500 ft. Has previously run almost to the school (Personal communication, George Rowe).

Path 4 (lower Brown's Gulch):

Total vertical drop: 200 ft
Starting zone: 10 acres below timberline.
Track: Gradient 53 percent; confined to channel.
Runout zone: Gradient 30 percent; length 400 ft.

Path 5:

Total vertical drop: 1900 ft
Starting zone: 5 acres in shallow gully
Track: Gradient 58 percent; runs in gully.
Runout zone: Joins in runout zone of Path 6 (described below).

Path 6 (Pinkerton Gulch):

Total vertical drop; 2600 ft
Starting zone: 30 acres in bowl above timberline.

Track: Gradient 50 percent; confined to gully.
Runout zone: Gradient 28 percent; length 1000 ft, can cross Interstate Highway 70. Lower part of runout has been oversteepened by excavation.

Path 7 (Cloud Gulch):

Total vertical drop: 2900 ft
Starting zone: 60 acres, above timberline.
Track: Gradient 46 percent; confined to gully.
Runout zone: Gradient 20 percent; length 1000 ft; reaches runout zone of Path 14.

Path 8 (Thompson Gulch):

Total vertical drop: 2300 ft
Starting zone: Two separate starting zones of about 10 to 15 acres each.
Track: Gradient 36 percent; confined to gully.
Runout zone: Gradient 20 percent; length 600 ft.

Path 9:

Total vertical drop: 1400 ft
Starting zone: 5 to 10 acres, below timberline.
Track: Gradient 57 percent; on unconfined slope.
Runout zone: Gradient 40 percent; length 600 ft.

Path 10:

Total vertical drop: 2000 ft
Starting zone: 5 acres, below timberline.
Track: Gradient 60 percent; confined to channel.
Runout zone: Gradient 30 percent; length 800 ft.

Path 11:

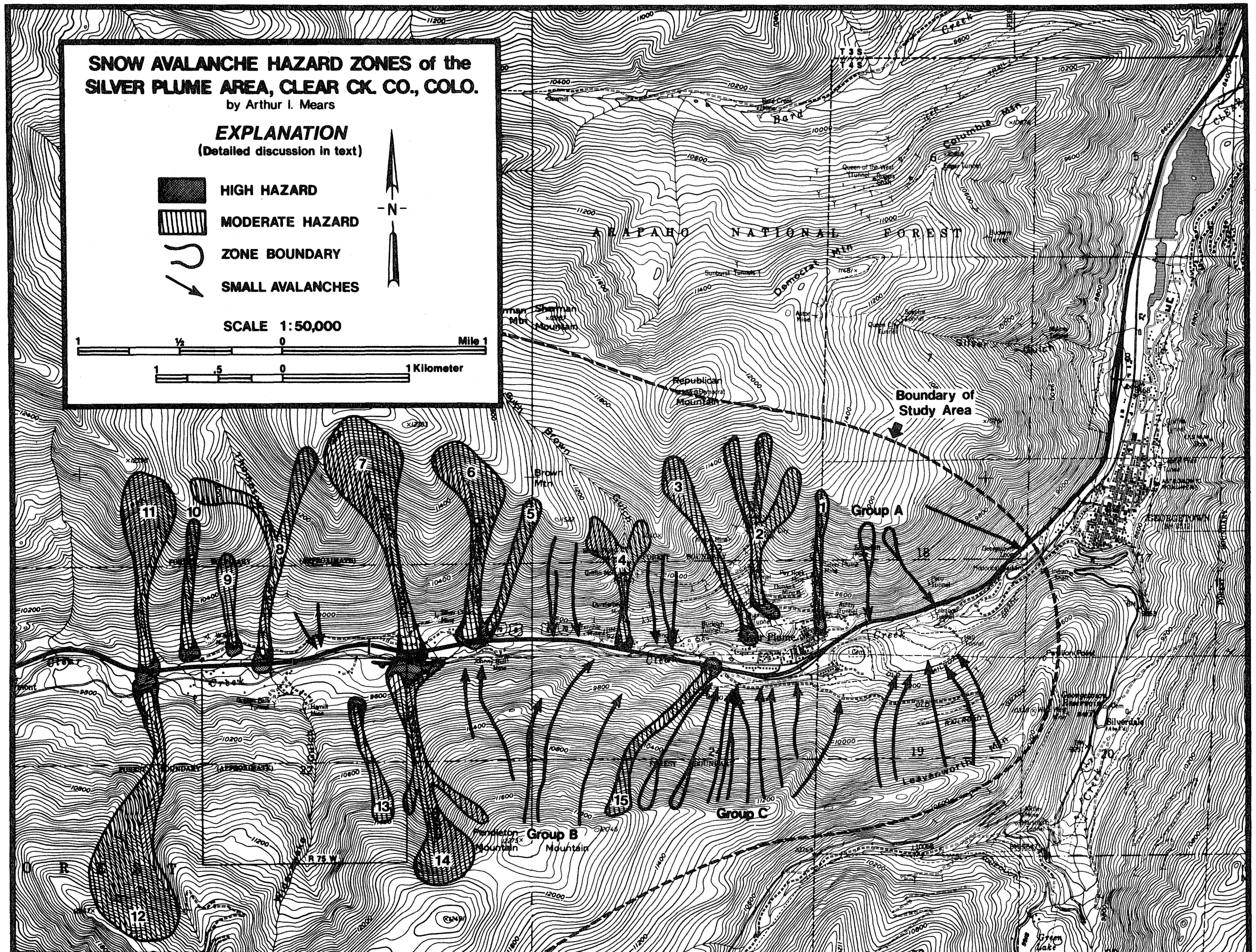
Total vertical drop: 2600 ft
Starting zone: 40 acres, above timberline.
Track: Gradient 45 percent; confined to channel.
Runout zone: Gradient 27 percent; length 900 ft; can reach Interstate Highway 70.

Path 12 (Ganley Gulch):

Total vertical drop: 2600 ft
Starting zone: 60 acres, above timberline.
Track: Gradient 33 percent; confined to channel.
Runout zone: Gradient 22 percent; length 900 ft; crosses access road and runs to Clear Creek.

Path 13:

Total vertical drop: 1700 ft
Starting zone: 10 acres, below timberline.
Track: Gradient 52 percent; runs in shallow channel.
Runout zone: Gradient 40 percent; length 500 ft.



Base from U.S.G.S. 7½' quad. map

PLATE 13

Path 14 (Deadman Gulch):

Total vertical drop: 2800 ft
Starting zone: 40 acres, above timberline.
Track: Gradient 43 percent; confined to channel.
Runout zone: Gradient 30 percent; length 1000 ft; wet slides will sometimes be deflected to northwest part of runout zone.

Group B:

Paths in this group have vertical drops of 1400 to 2000 ft, but do not involve sufficient snow to reach populated areas at the valley bottom.

Path 15:

Total vertical drop: 2600 ft
Starting zone: 10 acres at timberline.
Track: Gradient 57 percent; runs in gully.
Runout zone: Gradient 30 percent; length 800 ft.

Group C:

Paths in this group release from north side of the ridge connecting Pendleton and Leavenworth mountains. They have small starting zones of less then 5 acres (usually less than 2 acres) and fall 1000 to 2000 ft. They do not involve sufficient volume to reach populated parts of the valley.

TWIN LAKES AREA

INDIVIDUAL PRONS - see Plate 14

Path 1 (Gordon Gulch):

Total vertical drop: 3500 ft
Starting zone: Smooth slope above timberline, single releases as large as 150 acres possible
Track: Gradient 37 percent (20 degrees); confined to broad channel
Runout zone: Ave. gradient 15 percent; length 2800 ft. Small avalanches are deflected by a moraine and follow Gordon Creek, large avalanches which flow to east of the creek and fall over steep incline to Colorado Highway 82 are 700 ft wide at this point, and run 1000 ft or more beyond road onto a flat valley bottom.

Path 2:

Total vertical drop: 2800 ft
Starting zone: at timberline, about 10 acres.
Track: Gradient 56 percent; channelized.
Runout zone: Gradient 23 percent; length 800 ft, about 400 ft wide at Highway 82.

Path 3 (S. E. side of Parry Peak):

Total vertical drop: 3400 ft
Starting zone: 30 acres above timberline.
Track: Gradient 69 percent; confined to deep channel.
Runout zone: Gradient 31 percent; length 1800 ft, about 600 ft wide at Highway 82.

Path 4:

Total vertical drop: 2400 ft
Starting zone: open spots in timber, 15 to 20 acres.
Track: Gradient 60 percent; confined to channel.
Runout zone: Gradient 30 percent; length 700 ft.

Path 5:

Total vertical drop: 1500 ft
Starting zone: open spots in timber, 5 to 10 acres.
Track: Gradient 73 percent; flows in shallow channel.
Runout zone: Gradient 27 percent; length 600 ft.

Path 6 (Smith Gulch):

Total vertical drop: 3200 ft
Starting zone: Rugged basin above timberline, mostly S-W facing, single release probably less than 80 acres.
Track: Gradient 36 percent; confined to deep channel.
Runout zone: Gradient 19 percent; length 1500 ft.

Path 7:

Total vertical drop: 2300 ft
Starting zone: Two shallow gullies above timberline; less than 20 acres.
Track: Gradient 64 percent; confined to channel.
Runout zone: Gradient 30 percent; length 1000 ft.

Path 8 (Last Chance):

Total vertical drop: 2900 ft
Starting zone: Rugged basin above timberline; about 40 acres.
Track: Gradient 47 percent; confined to channel.
Runout zone: can reach Highway 82; gradient 26 percent; length 1300 ft (small eastern spur of Path 8 has same runout).

Path 9:

Total vertical drop: 1700 ft
Starting zone: small open spots in timber; about 10 acres.
Track: Gradient 73 percent; runs in broad, shallow channel.
Runout zone: Gradient 40 percent; length 800 ft.

Path 10:

Total vertical drop: 1900 ft
Starting zone: open spots in timber; about 10 acres.
Track: Gradient 61 percent; runs in shallow gully.
Runout zone: Gradient 40 percent; length 900 ft.

Path 11 (Hayden Gulch):

Total vertical drop: about 2400 ft
Starting zones: Complex, west branch is rugged cliff area of about 30 acres above timberline, east branch is broad open slope of about 40 acres.
Track: Gradient 31 percent; confined to deep, narrow gully.
Runout: Crosses Highway 82 (width here 300 ft); gradient 18 percent; length 1500 ft.

Path 12:

Total vertical drop: 1900 ft
Starting zone: Open spots in timber; about 10 acres.
Track: Gradient 69 percent; open slope.
Runout zone: Gradient 27 percent; length 600 ft.

Path 13:

Total vertical drop: 2200 ft
Starting zone: about 10 acres above timberline.
Track: Gradient 67 percent; runs in shallow gully.
Runout zone: Gradient 22 percent; length 800 ft.

Path 14:

Total vertical drop: 2600 ft
Starting zone: about 40 acres above timberline.
Track: Gradient 53 percent.
Runout zone: Gradient 27 percent, length 1500 ft.

Path 15:

Total vertical drop: 3100 ft
Starting zone: About 30 acres in main path and 5 to 10 acres in adjacent gully to west; both areas are above timberline.
Track: Gradient 54 percent; confined to gully.
Runout zone: Gradient 23 percent; length 2100 ft.

Path 16:

Total vertical drop: 2100 ft
Starting zone: About 20 acres above timberline.
Track: Gradient 57 percent; confined to channel.
Runout zone: Gradient 24 percent; length 1000 ft.

Path 17:

Total vertical drop: 1900 ft
Starting zone: Bowl below timberline; 10 to 15 acres.
Track: Gradient 52 percent; confined to channel
Runout zone: Merges with runout zone of Path 18; features of combined zones described below.

Path 18:

Total vertical drop: 2800 ft
Starting zone: 40 acres in bowl above timberline.
Track: Gradient 50 percent; confined to deep, narrow channel.
Runout zone: combined with Path 17. Gradient 20 percent; length 1500 ft.

Path 19:

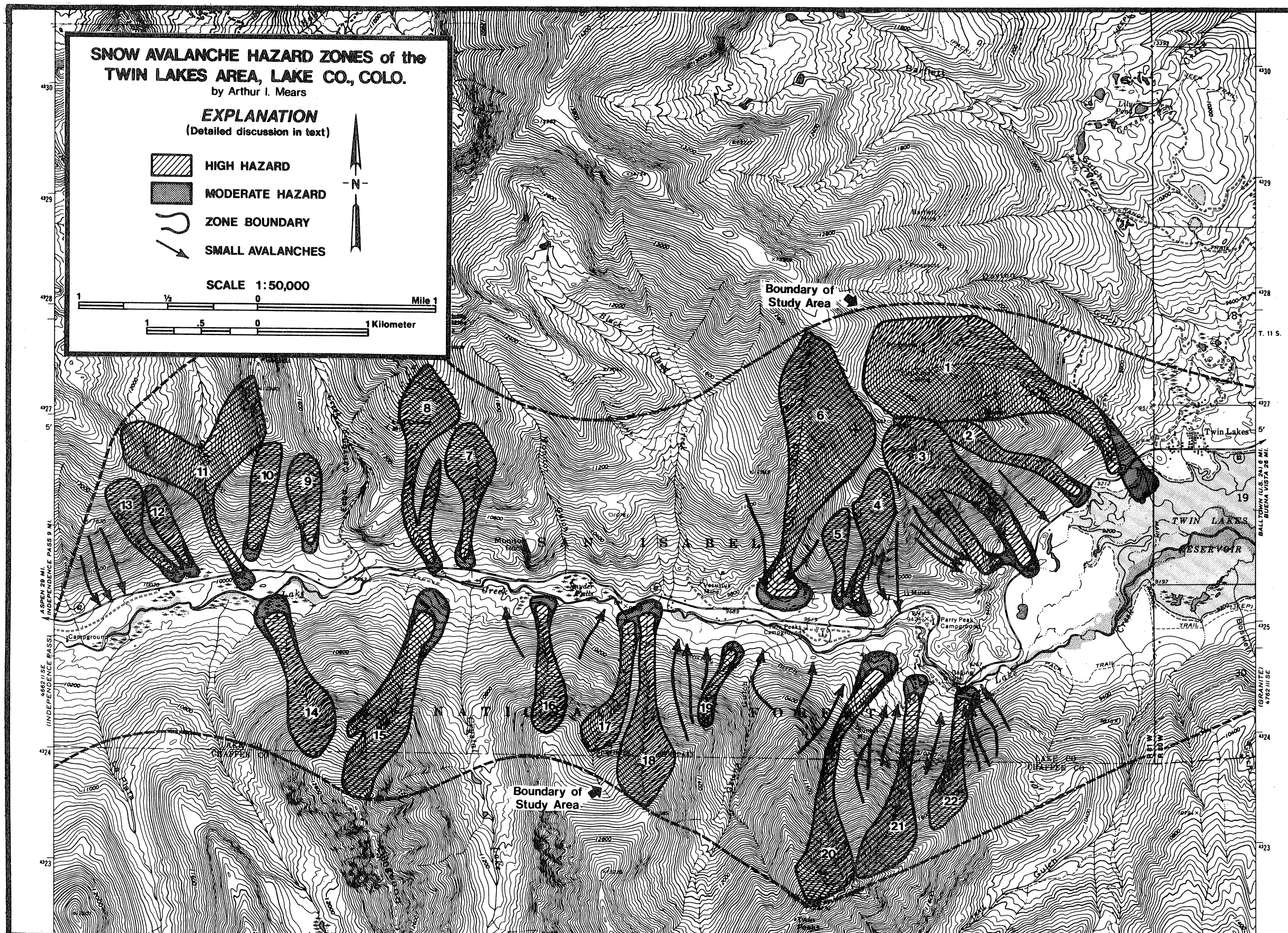
Total vertical drop: 1400 ft
Starting zone: Open spots in timber; 5 acres.
Track: gradient 60 percent; confined to channel.
Runout zone: gradient 25 percent; length 900 ft.

Path 20 (Sunset Gulch):

Total vertical drop: 3600 ft
Starting zone: Steep basin above timberline; 50-60 acres.
Track: Gradient 50 percent; confined to deep channel.
Runout zone: Gradient 17 percent; length 2000 ft.

Path 21:

Total vertical drop: 3600 ft



Base from U.S.G.S. 7½' quad. map

PLATE 14

Starting zone: Steep basin above timberline; 40 acres.
Track: Gradient 60 percent; confined to deep channel.
Runout zone: Gradient 21 percent; length 1900 ft.

Path 22:

Total vertical drop: 2500 ft
Starting zone: Above and below timberline; about 20 acres.
Track: Gradient 67 percent; confined to deep channel.
Runout zone: Gradient 30 percent; length 1600 ft.

VAIL AREA

INDIVIDUAL PATH DESCRIPTIONS - see Plate 15

Path 1 (Vail Meadows):

Total vertical drop: 2600 ft
Starting zone: 50 acres, shallow bowl timberline.
Track: Gradient 41 percent; confined to channel at top; open slope near bottom.
Runout zone: Path hits 100-ft-high hill directly, part of the avalanche flow is deflected east of the hill, part goes over the top, and most of the flow is deflected west of the hill.

Path 2:

Total vertical drop: 1800 ft
Starting zone: 5 to 10 acres, open spots in timber.
Track: Gradient 38 percent; runs in shallow gully.
Runout zone: Gradient 22 percent; length about 900 ft.

Path 3 (King Arthur):

Total vertical drop: 2400 ft
Starting zone: Two sections consisting of upper basin and west side of upper track; total area is 40 acres.
Track: Upper track confined to channel, gradient 50 percent. Lower track runs on upen slope over cliff; gradient 32 percent.
Runout zone: Gradient 8 percent; length about 1000 ft.

Path 4 (Old Muddy):

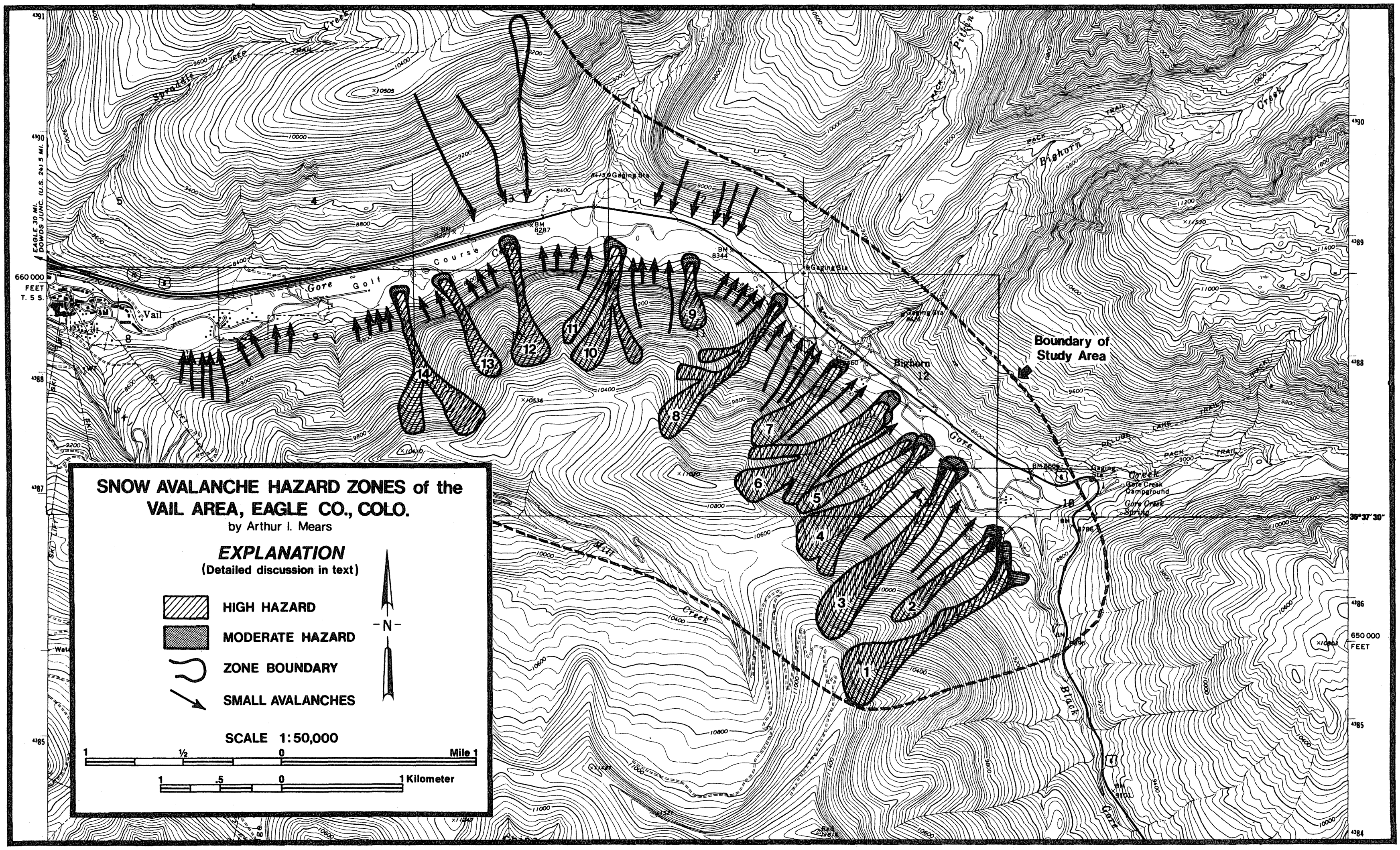
Total vertical drop: 1900 ft
Starting zone: 35 acres, open spots in timber.
Track: Gradient 43 percent; confined to gully, falls over small cliff at bottom.
Runout zone: Gradient 10 percent; length about 800 ft.

Path 5:

Total vertical drop: 1800 ft
Starting zone: 6 acres, open spot in timber.
Track: Gradient 54 percent; runs in shallow channel.
Runout zone: Gradient 15 percent; length about 500 ft.

Path 6:

Total vertical drop: 2500 ft
Starting zone: Total area, 30 acres. Consists of three sections which, under extreme conditions, could all release at once.
Track: Gradient 50 percent; mostly unconfined.
Runout zone: Gradient 10 percent; length 800 ft; reaches Gore Creek.



Base from U.S.G.S. 7½′ quad. map

PLATE 15

Path 7:

Total vertical drop: 2000 ft
Starting zone: 15 acres, open spots in timber.
Track: Gradient 63 percent; open slope; falls over several cliffs.
Runout zone: Gradient 30 percent; length 500 ft.

Note:

Several small avalanches in this area can develop into powder avalanches as they fall over cliffs in the avalanche tracks.

Path 8 (Waterfall):

Total vertical drop: 2400 ft
Starting zone: Total area, 25 acres; consists of three main parts which could release at one time.
Track: Gradient 52 percent; falls over steep cliff at bottom.
Runout zone: Gradient 20 percent; length about 700 ft.

Path 9 (Terray):

Total vertical drop; 1300 ft
Starting zone: about 10 acres
Track: Gradient 70 percent; confined to channel.
Runout zone: Gradient 30 percent; length about 500 ft.

Path 10 (Gilkey):

Total vertical drop: 1800 ft
Starting zone: Total area about 15 acres. Consists of two parts, which might release at one time.
Track: Gradient 60 percent; falls over cliff at bottom/
Runout zone: Gradient 28 percent.

Path 11 (Sidewinder):

Total vertical drop: 1800 ft
Starting zone: about 5 acres
Track: Gradient 60 percent, falls over cliff at bottom.
Runout zone: Gradient 20 percent, length about 600 ft.

Path 12 (Frontage):

Total vertical drop: 1900 ft
Starting zone: 20 acres in bowl
Track: Gradient 55 percent; runs in channel; falls over cliff at bottom.
Runout zone: Gradient 25 percent; length 500 ft.

Path 13 (Gore):

Total vertical drop: 1900 ft
Starting zone: 10 acres
Track: Gradient 65 percent; runs in shallow channel; falls over cliff at bottom.
Runout zone: Gradient 25 percent; length 500 ft.