AVALANCHE STUDIES IN THE SAN JUAN MOUNTAINS OF SOUTHWESTERN COLORADO[1/]

568-73

By

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In May, 1971, the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, was awarded a contract by the Bureau of Reclamation, U. S. Department of the Interior, to begin a three year study of the causes of snow avalanches in the San Juan Mountains of southwestern Colorado and to begin developing a forecast model to predict avalanche occurrence. In addition, the project is designed to evaluate the possibilities of increased avalanche activity which could result from winter cloud seeding activities of the Bureau of Reclamation's Project Skywater. At present, seeding by the pilot project is not directed at the area of this study. It is hoped that a practical capability to forecast avalanches will become an important part of operational control of seeding activities, and that when a high avalanche hazard is forecast, seeding of the area will be suspended until the snow slides have been controlled or the snowpack has stabilized.

The study area mainly relates to the hazard presented by U. S. Highway 550 between Coal Bank Hill and Ouray (36 miles) and Colorado Highway 110 between Silverton and Gladstone (9 miles). Approximately one hundred avalanches cross these two highways with varying frequency.

Traffic patterns observed indicate that much travel on both roads stems from the mining activities in the area: an estimated 300 workers from Silverton, Ouray, Durango, and Montrose use Highway 550 daily; ore trucks travel an estimated 30 round trips on Highway 110 and 20 round trips on Highway 550 between Silverton and Ouray daily. Additional travel is by citizens of Silverton to market centers north and south, highway maintenance crews, a scheduled bus service, mail delivery, and general commercial and private travel between Grand Junction and Durango.

Winter traffic on that portion of Highway 550 under study has increased considerably during the past two years. This is a direct result of the continuing development of the ski areas at Purgatory and Telluride as well as the rising public interest in wintertime outdoor activities such as cross-country skiing and snowmobiling.

Several slide paths run out within the city limits of Silverton though at this time no structures are located such that any but an exceptional slide would effect them. Three mine building complexes in the study area are prone to damage by slides of a more frequent nature.

Basically, the project has undertaken the study of the problem of avalanche initiation by analysis of the complex relationships which exist among terrain, climate and snow stratigraphy.

The terrain onto which snow is deposited influences the snow stability in many ways. In terms of surface characteristics only, the maximum instability will probably develop on smooth, grassy slopes while maximum stability will be found on heavily forested slopes. Surface features, such as boulders and forest cover, which are higher than the mean thickness of the snow cover act as an anchor; an avalanche will normally not occur until such time as snow depth exceeds the mean height of such closely spaced surface irregularities. Widely spaced or isolated obstacles have little stabilizing effect.

It is generally considered that a basic correlation between slope angle and avalanche frequency does exist. While they do occur, avalanches are rare on slopes greater than 60° and less than 25°.

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A strong relationship exists between the amount and type of snow cover that develops within a particular slide path and the orientation of the ridge system associated with the slide path. The orientation of the ridge with respect to the wind direction during a given storm will determine to a considerable degree the precipitation pattern of that storm in terms of the local topography.

With the aid of U.S.G.S. maps, the orientation of both the slide paths and associated ridge systems, as well as mean angles of the slide paths, have been established for the study area.

Meteorological/climatological processes contribute to the development of an avalanche potential virtually from the time the individual snow crystal is formed in the atmosphere until it has been destroyed by either melt or evaporation. Crystal morphology and degree of crystal riming play a role in the initial stability of a snow deposit; both are determined largely by the temperature and degree of supersaturation with respect to ice of the air mass in which the snow crystal is formed and through which it passes during its fall to earth.

Following deposition, the flux of heat and water vapor between a snow deposit and the atmosphere results in metamorphic changes which greatly modify the initial properties of the mass. Snow is a mixture of ice, air, water vapor and sometimes, liquid water. The percentage composition is highly variable. The thermal properties of each of these constituents varies widely and the relative contribution of each to heat transfer and subsequent metamorphism depends upon the structure, texture and proximity to the melting point of the deposit, upon the presence or absence of temperature gradients and upon the slope of these gradients.

In mountainous regions, climate and terrain interact to produce a distinct topoclimate which in turn establishes the local snow structure. Variations in slope orientation, angle and altitude combine to influence avalanche potential. Slopes facing the noon sun and inclined so that the sun's rays are essentially normal to the surface receive maximum solar energy. Depending upon the intensity of insolation, enhanced sintering may stabilize these slopes, surface crusts resulting from diurnal freeze-thaw cycles may form, or, if the temperatures are high enough, free water may be produced in sufficient quantities to destroy the intergranular bonding with a consequent reduction in strength. North-facing slopes and those which are topographically shaded much of the time receive relatively little direct short-wave radiation. These areas are characterized by lower surface temperatures which inhibit sintering and favor the formation of cohesionless snow deposits or depth hoar.

When the project was initiated, only a limited amount of climatological data was available for the study area. Until Western Scientific Services, Inc. installed precipitation gauges on a transect across Molas and Red Mountain Passes in 1971, the only data available was from valley floor stations in Silverton, Telluride, Ouray, and Durango. Extrapolation of temperature and precipitation data from these stations to the elevations of the avalanche initiation zones is a questionable procedure.

It was recognized that an avalanche prediction model would rely heavily upon data gathered from accurate, reliable instruments installed on carefully selected sites. Therefore, fixed instrumentation is utilized to measure meteorological parameters, determine snowpack depth, density, and stratigraphy and to detect avalanche events.

A snow study site is located near Molas Pass, 10,575 ft (3225 m), with a standard instrument shelter containing a hygrothermograph and means for measuring snowfall for storm intervals as well as seasonal totals. A comparable station exists adjacent to the INSTAAR Project Headquarters in the town of Silverton, 9,280 ft (2830 m). The primary snow study site is located at Red Mountain Pass. Instrumentation located at this site includes a standard shelter with hygrothermograph, recording precipitation gauge, wind speed and direction system, snow settlement gauge, net radiometer, and an isotopic snow density profiler. This latter instrument produces density profiles for the snowpack at 1.0 cm intervals. This is accomplished by measurement of the relative attenuation of gamma radiation passing through the snow at each interval.

South of Red Mountain Pass the Rainbow meteorological site occupies a unique location directly above the starting zones of a series of avalanches which frequently cross the highway below.

Wind speed and direction are recorded at three sites in the vicinity of Red Mountain Pass, two ridgetop, including the Rainbow site, and one forest. The ridge top system at 12,325 ft (3759 m) transfers speed and direction data by telemetry through 7,500 ft (2288 m) of buried cable to an analog strip chart recorder located in the High Altitude Research Station at Red Mountain Pass. The location of these various instrumentation sites can be seen in Figure 1. A detailed description of the instrumentation utilized by this project can be found in the Project Interim Report for Period August 1971 July 1972 INSTAAR Publication No. 14 06 7155.

Meteorological conditions continue to effect the snow by determining the eventual stratigraphic pattern of the pack on the ground. Metamorphism, which is essentially an alteration of texture, structure and degree of crystallinity within the snow deposit, results from the basic thermodynamic instability of snow under most natural environmental conditions. There are at least four types of metamorphism. Two of these result primarily from vapor diffusion processes, one results largely from overburden pressure and the fourth from significant amounts of free water. They have been termed equi-temperature, temperature-gradient, pressure and melt metamorphism, respectively. In equi-temperature metamorphism, crystallographic slopes are destroyed and rounded grains are produced as an end product; in temperature-gradient metamorphism, crystallographic slopes are developed and intergranular bonds are destroyed. From the standpoint of avalanche research, it is important whether or not intergranular bonds are being created or destroyed, and the actual number and spacing of bonds. During much of each winter, equi-temperature, temperature-gradient, and pressure metamorphism are proceeding simultaneously within the snowpack which implies that at any given level in the pack, bond growth and dissoluation are in a constant state of flux. With the onset of melt metamorphism, the other processes are largely eliminated.

In order to monitor these processes within the snowpack, snowpits are dug at intervals of approximately ten days in the study plots at Molas and Red Mountain Pass. Data relating to the strength, density, crystal type and temperature gradient within the snowpack are obtained. Daily values are available at Red Mountain Pass for stratigraphic density (isotopic profiler) and temperature gradients from fixed thermistors within the snowpack.

The initial objective of the project was to set up a research procedure capable of adequately observing and recording phenomenon associated with these relationships among the local terrain, climate and snow structure. It was felt that the next logical step would be to attempt to determine the relative contribution of each factor and to isolate those processes which contribute most directly to avalanche initiation.

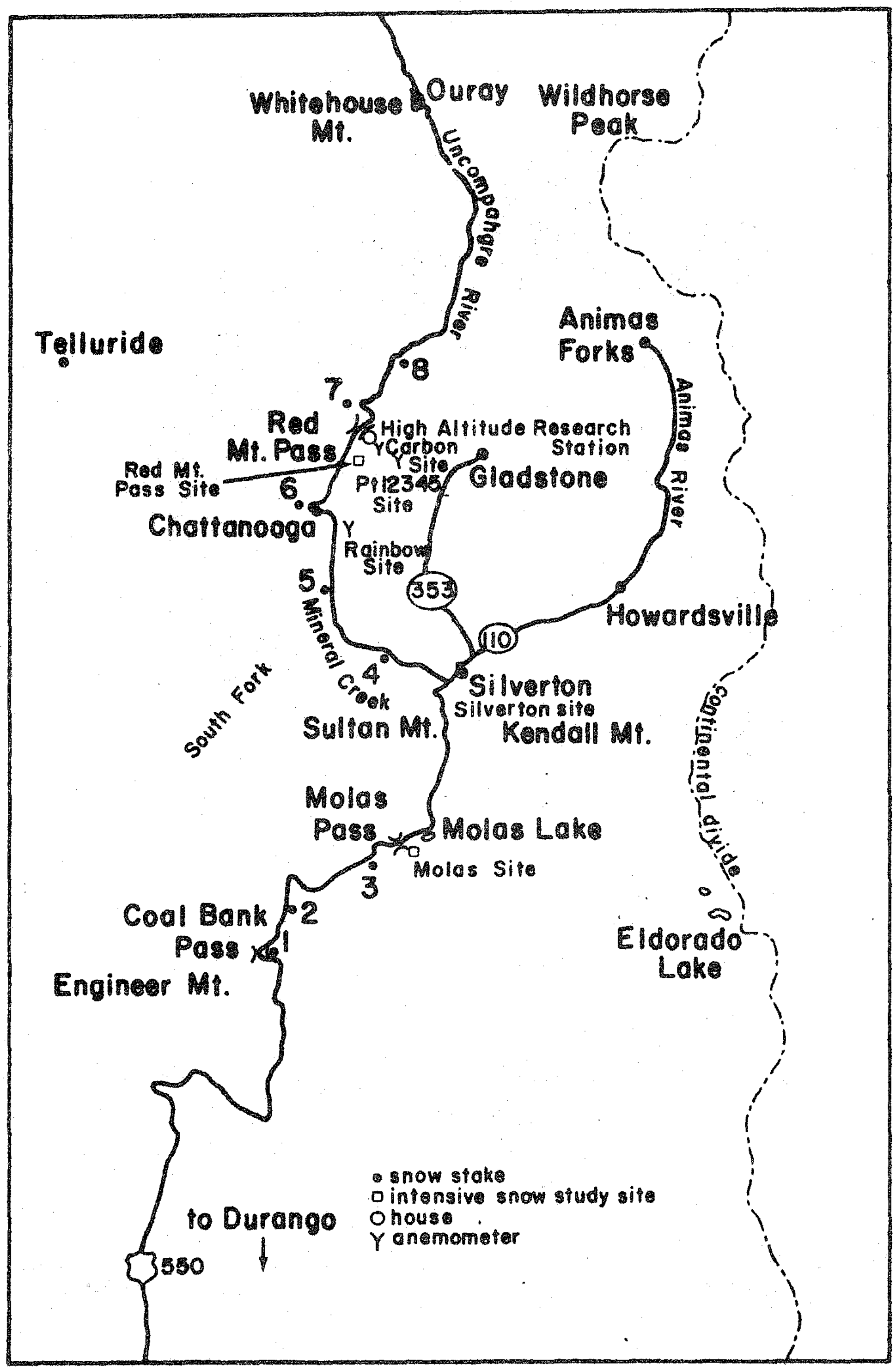
Following the first winter's research, all members of the project felt that the structure of the local snowpack differed to a considerable degree from continental areas which had been previously studied, such as Berthoud Pass, Colorado; Alta, Utah; Goose Lake and Bridger Bowl, Montana; and Jackson, Wyoming. The low latitude, high altitude of the study area was considered to be a possible source for a somewhat unique situation. In general, the local snowpack was experiencing phenomenon throughout the winter which the above mentioned areas only experienced in the late winter or early spring.

Generally, this condition is caused by extreme nocturnal radiation cooling which maintains temperature gradients within the snowpack, along with the physical changes in the snow associated with such a gradient. During the day, however, relatively large amounts of solar radiation cause melting just below the surface to produce freeze-thaw crusts. The resulting stratigraphy is highly complex.

Therefore, during the second winter's research, considerable emphasis was given to the study of snow stratigraphy. This was accomplished by concentrating a major portion of project time and manpower on acquiring snow pit data. These snow pits are divided into three categories according to location and purpose. One series is located within the study sites at Molas and Red Mountain Pass. These areas are by definition level sites. The second type of pit is located on a test slope. This test slope possesses angle and orientation which can be related to that of actual slide paths, but which in itself is relatively free of hazard to the observer. The majority of this work is done on Carbon Mountain, located adjacent to the Red Mountain Pass snow study site. Carbon Mountain affords elevations comparable to those of actual avalanche release zones in the immediate area.

The third type of snowpit is associated with the actual fracture line of the avalanche, whether naturally or artificially released. This type of investigation provides

Figure 1



Ouray
Whitehouse Mt.
Wildhorse Peak
Uncompahgre River
Telluride
Animas Forks
Animas River
8
7
Red Mt. Pass
High Altitude Research Station
Carbon Site
Red Mt. Pass Site
Pt12345 Site
Gladstone
6
Chattanooga
Rainbow Site
353
5
Mineral Creek
110
Howardsville
4
Silverton
Silverton site
South Fork
Sultan Mt.
Kendall Mt.
Continental divide
Molas Pass
Molas Lake
Molas Site
3
Coal Bank Pass
2
1
Engineer Mt.
Eldorado Lake
snow stake
intensive snow study site
house
anemometer
to Durango
550

Figure 2

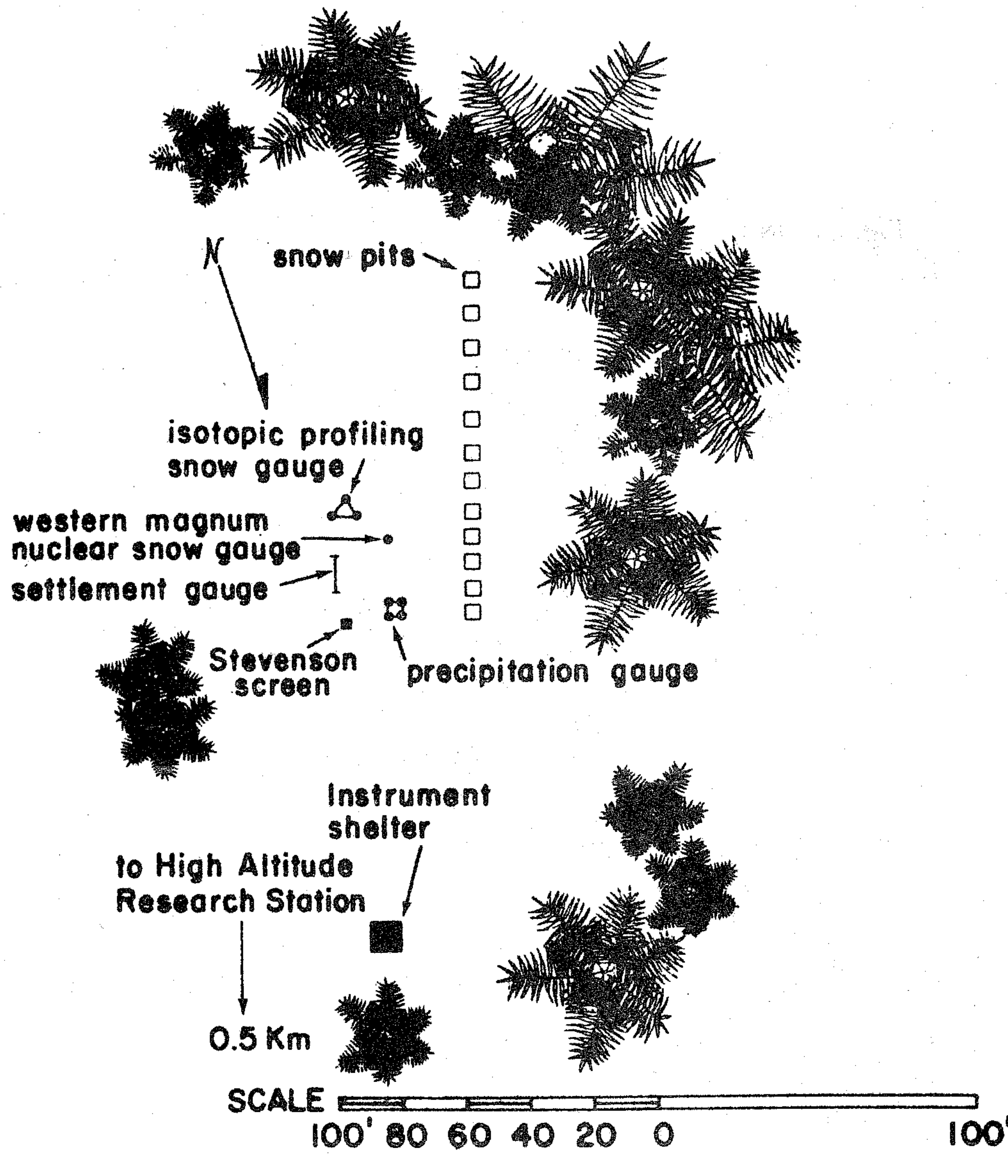


Figure 2: A sketch map of the Red Mountain Pass snow study site showing the location of the various instruments in use during the winter of 1971-72 and of the snow pits. The scale is approximate.

data which is the closest approximation to the idealized research objective, that of determining the actual physical and mechanical properties of the snowpack at the zone of failure. These studies are made as soon as possible after the avalanche has released. However, such considerations as safety to the field crew as well as the amount of time and effort which may be expended in arriving at such a fracture line several thousand feet above the road dictate that this type of investigation will be relatively infrequent compared to the work done on the test slopes.

While the precise emphasis of next winter's research will depend heavily on detailed data analysis during the coming summer, specific studies related to snow stratigraphy will certainly continue. In particular, an effort will be made to learn more about the processes associated with temperature gradients. A limited body of field and laboratory evidence suggests that the vapor transfer and recrystallization process associated with depth hoar formation is initiated when temperature gradients exceed 0.1^{o} per centimeter but few data are available relating the magnitude of this gradient to snow density and crystal type. One phase of next winter's research will attempt to relate the rate of recrystallization and the ultimate size of the ensuing crystal to density and crystal type of the original snow. Fixed thermocouple arrays will be used to determine the temperature gradients in the natural snow cover at selected sites representing various elevations and slope orientations. The crystal structure of the surface snow layers will be investigated daily at these sites and regular snow pit profiles will be obtained at approximately ten day intervals. In addition to this field work, laboratory experiments will be performed in the cold-lab located at Red Mountain Pass. Snow samples will be exposed to a varied spectrum of artificially imposed temperature gradients. The density, mechanical characteristics, and crystal types of these samples will be observed periodically. Crystal type evolution will be recorded with photomicrographic apparatus. The basic purpose of the above study is to observe the role of recrystalization in causing poor layer bonding which can lead to avalanche initiation. Dr. E. R. LaChapelle, consultant to the project, will determine the methodology and direct the experimental procedure of this work.

The overall objective of the San Juan Avalanche Project is to determine the dominant, and hopefully, reasonably predictable, processes which contribute most directly to the initiation of avalanches, to establish empirical relationships among these processes, and finally to expose these relationships to some form of statistical evaluation.

Due to the relationship which exists between any given period of avalanche activity and a complex and often prolonged series of meteorological events, there appears no practical way to determine the effect of any single cloud-seeding event on the subsequent avalanche patterns. The results of seeding or not seeding a storm in November could not be predicted in terms of how the particular stratigraphic layer within the snowpack composed of that precipitation event would react to an avalanche cycle two or three months later. However, public safety within the study area could be inhanced by providing accurate stability evaluations based on the meteorological events as they actually occur, whether or not they were influenced by cloud seeding.

Such stability evaluations are a part of the daily "in house" avalanche forecast which is produced daily by this project. It is the responsibility of the observer at Red Mountain Pass to formulate this forecast based on his knowledge of the stratigraphic properties of the snowpack as it exists throughout the study area, the meteorological events currently effecting the snowcover, and knowledge gained from the weather forecast as provided by staff meteorologists of E. G. and G. in Durango. It is also the duty of the daily observer to evaluate the forecast made the day before in terms of actual events occurring since that time.

The INSTAAR project is unique in the sense that it is the only large scale avalanche research project ever undertaken in the United States which does not possess some type of avalanche control responsibility. Most previous studies have been associated with ski areas and operated on the principle that whenever an uncertainty existed regarding the stability of the snow within the area, control measures were undertaken to initiate artificial release of avalanches by explosives. While several of the avalanche paths being observed by this project are subject to artillery control by the Colorado Department of Highways, we are nevertheless offered the unique opportunity to study numerous slide paths which are allowed to release naturally. In the study of this natural type of avalanche event, it is hoped that our research will contribute to the basic body of knowledge regarding the release mechanism of avalanches. This would seem most appropriate at this time due to the increasing need to develop methodology for comprehensive or "back country" forecasting as opposed to localized forecasting within the relatively confined limits of a ski area. In order to provide for the general safety of increasing numbers of people becoming involved in back-country winter recreational activities, a better understanding of the phenomenon leading to the initiation of natural avalanches becomes a primary concern.

Avalanche Zone Mapping

As a part of the avalanche research currently being conducted, INSTAAR is cooperating with the San Juan Regional Planning Commission in an effort to develop an Avalanche Zoning Plan for San Juan County as well as the town of Silverton. Input by INSTAAR regarding regional planning is direct as the author is an elected member of the planning commission.

Legal efforts to protect the public from the natural hazard of avalanche occurrance are only in the very early stages of development in the United States. Within the borough of Juneau, Alaska, the creation of an avalanche zoning plan is underway, but the author is not currently aware of an example of a completed project of this type within the United States. Work currently underway in this country is based primarily on the knowledge and experience provided by zoning plans which exist in Switzerland.

The first task to be undertaken is to identify the zones of hazard. This is a relatively easy process in terms of the avalanche path itself, especially where the lateral boundaries of the slide path are well defined by a trim line in the vegetation. Such areas are most often associated with steep slopes and not the logical location for consistent human activity or building construction. The difficulty lies in identifying the extent of the hazardous area beyond the break in slope. It is within this run-out zone that potential or existing human activity will logically occur. It is necessary to attempt to determine not only how far a certain avalanche could possibly run within a given track, but also how often this might occur and with what force this moving avalanche would come into contact with existing structures. Not only must the effects of the moving snow be determined, but also that of the air blast which preceeds certain high velocity dry-snow avalanches and is capable of producing damage equal to or greater than the moving snow mass itself.

In Swiss experience, it became obvious that an unquestionable separation of safe and dangerous areas can not be achieved. It is necessary to describe a zone of transition between the areas proven to experience constant avalanching and areas proven to be safe. This zone of transition could not be considered safe from avalanche danger; however, the danger represented is so small that there is not justification for prohibiting construction. Therefore, it became common practice to determine three zones. As represented on maps, these were white areas which were without danger, red zones where construction was not permitted, and blue zones where occasional construction was permitted. However, within this blue zone building permits were issued with the understanding that the type and form of the building could be specified, as well as necessary reinforced construction or evacuation of the inhabitants in case of avalanche danger.

The second and most difficult part of implementing an avalanche zoning plan relates to the actual enforcement of the zoning code. The problems which occur are no different than those confronting any effort to establish restrictive zoning in regard to land use. The opposition states that the zoning board is acting in an unconstitutional manner in preventing private landowners from using their land in the manner they wish and in taking property without due process of law or compensation.

Unfortunately, there is no area of law now annotated concerning avalanches in the United States. In Switzerland, this problem is dealt with in the following legal statement: "The fact that a person might be willing to chance a dangerous situation will according to existing law, not justify any action by the police. Buildings in danger from avalanches, however, extend beyond the private interests of the builder, owner and renter and become a matter of public concern."* While this is certainly not a totally unambiguous legal statement, it does express the "spirit" or attitude of Swiss law concerning avalanche zoning.

* Frutiger, Hans. THE AVALANCHE ZONING PLAN. Alta Avalanche Study Center translation No. 11 July, 1970.

By the time this report is published, San Juan County will possess the only legal document relating to avalanche zoning in the United States. This ordinance soon to be acted upon by the city as well as the county government was drafted by Dr. E. R. LaChapelle. As yet, no mapping has been done and the existing ordinance will simply be incorporated into the existing building codes. Basically, the ordinance states that in all areas of San Juan County for which an avalanche zoning plan has not been enacted, the burden of proof is placed on the permit applicant to demonstrate that his proposed construction is safe, either because it is located at a site free from snow avalanche hazard or is adequately protected from avalanche danger by reason of external avalanche defenses or internal structural provisions.