REPORT GD-1

GLACIOLOGICAL DATA

this issue:

AVALANCHES

World Data Center A
for
Glaciology

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Marilyn J. Shartran, Editor
Glaciological Data
World Data Center A: Glaciology
Institute of Arctic and Alpine Research
University of Colorado
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DESCRIPTION OF DATA CENTERS

WDC-A, Glaciology is one of three international data centers serving the field of glaciology under the guidance of the International Council of Scientific Unions Panel on World Data Centres. It is part of the World Data Center System created by the scientific community in order to promote worldwide exchange and dissemination of geophysical information and data. WDC-A endeavors to be promptly responsive to inquiries of the scientific community and to provide data and bibliographic services in exchange for copies of publications or data by the participating scientists.

The addresses of the three WDCs for Glaciology and of a related Permanent Service are:

World Data Center A
INSTAAR
University of Colorado
Boulder, Colorado, U.S.A. 80309

World Data Center B
Molodezhnaya 3
Moscow 117 296, USSR

World Data Center C
Scott Polar Research Institute
Lensfield Road
Cambridge, CB2 1ER, England

Permanent Service on the Fluctuations of Glaciers
Section on Hydrology and Glaciology
Research Institute on Hydraulics and Soil Mechanics
Federal Institute of Technology
Voltastrasse 24
8044 Zürich, Switzerland

The World Data Centers follow the guidelines established by the International Council of Scientific Unions _Third Consolidated Guide to International Data Exchange through the World Data Centres_, 1973. The following description from the Guide details the form of the data accepted by the WDCs.

General. WDCs are prepared to accept raw, analyzed, or published data, including photographs. It is suggested that researchers submitting data to the WDCs do so in a form which will be intelligible to other users. Researchers should be aware that the WDCs are prepared to organize and store data which may be too detailed or bulky for inclusion in published works. It is understood that such data which are submitted to the WDCs will be made available according to guidelines set down by the ICSU Panel on WDCs in the _Guide to International Data Exchange_. Such material will be available to researchers as copies from the WDC at cost, or if it is not practical to copy the material, it can be consulted at the WDC. In all cases the person receiving the data will be expected to respect the usual rights, including acknowledgment, of the original investigator.

Fluctuations of Glaciers. The Permanent Service will be responsible for receiving data on the fluctuations of glaciers and will also receive such data as are generated by the International Hydrological Decade Project on Variations of Existing Glaciers. The types of data which should be sent to the Permanent Service are detailed in UNESCO/IASH (1969) _Variations of Existing Glaciers: A Guide to International Practices for Their Measurement_. These data should be sent through national correspondents in time to be included in the regular reports of the Permanent Service every 4 years (1964-68, 1968-72, etc.).

Projects of the International Hydrological Decade. In addition to the above, the International Hydrological Decade, 1965-74, sponsors an _Inventory of Seasonal and Perennial Snow and Ice Masses_, as well as a project on the _Combined Heat, Ice and Water Balances at Selected Glacier Basins_. Until such time as technical secretariats are established for these projects, data should be channeled through the World Data Centers.

In order that the WDCs may serve as information centers, researchers and institutions are requested:

To send WDCs reprints of all published papers and public reports which contain glaciological data or data analysis; one copy should be sent to each WDC or, alternatively, three copies to one WDC for distribution to the other WDCs.

To notify WDCs of changes in operations involving international glaciological projects, including termination of previously existing stations or major experiments, commencement of new experiments, and important changes in mode of operation.

FOREWORD

In October 1976, responsibility for the operation of World Data Center A: Glaciology was assumed by the Institute of Arctic and Alpine Research, University of Colorado, in conjunction with the Environmental Data Service, National Oceanic and Atmospheric Administration, Boulder. At that time, it was decided that publication of Glaciological Notes in an accession bulletin format would be superceded by a new publication through which WDC-A: Glaciology would seek to provide timely information on data availability to the international user community via an alternative format.

Glaciological Data, to be issued 3-4 times per year, will comprise a systematic bibliography and related data information on a selected theme. Our first issue deals with avalanches; number 2 is in preparation on arctic sea ice. These bibliographies will be as complete as we can at present make them, drawing on available computer-retrieval systems as well as printed bibliographies and holdings in the collection. In addition to the bibliographic information, we plan to include short contributions relating to the collection and dissemination of data for the particular topic of that issue. It is anticipated that a cycle of themes covering glaciology will last approximately two years.

Glaciology, as defined by the ICSU Guide to International Data Exchange through the World Data Centres, 1973, deals with the occurrence, properties, processes and effects of all forms of snow and ice in the atmosphere-earth-ocean system and with aspects of their past occurrence and effects. Already, experiences with potential suppliers of data to WDC-A and, therefore, our user community, suggest that "glaciology" is narrowly interpreted by many scientists as the study of mountain glaciers. The term cryosphere is a more descriptive indication of the scope of the ICSU-sponsored activities, but such a change in designation would perhaps cause further confusion even if it were feasible.

The scope of glaciology spans an immense range of organizations concerned with data collection, monitoring, and research. In the United States, for example, snow cover is reported by the National Weather Service, NOAA, and mapped from satellites by the National Environmental Satellite Service, NOAA; snow depth and moisture content are measured by the Soil Conservation Service; sea ice, by the U.S. Navy and NASA, and so on. A similar situation prevails in most countries. A first task of WDC-A: Glaciology, in conjunction with WDC-B (Moscow), WDC-C (Cambridge) and the Permanent Services, is to identify and locate data sources of this type on a worldwide scale and then to collate information on the holdings, format and availability of these records. With present resources, it is anticipated that a first role of WDC-A should be to coordinate such information and act as a clearinghouse. Subsequently, based on this information and input from the user community, the shape of future activities in archiving quantitative data types can be evaluated.

We cordially invite your participation in the building of World Data Center A: Glaciology by the submission of pertinent materials and personal visits to use the facilities. Marilyn Shartran, Assistant Director, who is in charge of the day-to-day activities of the center, will appreciate suggestions for improving our user services. To assist our initial planning we request responses to the enclosed inquiry form. Scientific input to the center by the Institute of Arctic and Alpine Research will be forthcoming from its Director, Dr. Jack D. Ives (currently on leave), as well as faculty J.T. Andrews, R.G. Barry and N. Caine and research associates.

Roger G. Barry
Acting Director
Institute of Arctic and Alpine Research

PREFACE

The articles and related material contributed to this issue are intended to provide perspectives on data problems and data applications in the context of avalanches. Thus, Dr. E. LaChapelle deals with the fundamental question of terminology and R.L. and B. Armstrong discuss particular field problems. Illustrative accounts of federal programs in the United States and Switzerland are provided by Dr. M. Martinelli, Jr. and Dr. H. Frutiger, respectively. Dr. M. Plam has contributed an overview of activities in avalanche investigations in the USSR, and Dr. Helgi Björnsson comments on avalanche research in Iceland. These summaries of research may serve as examples to others doing related research in other areas of the world. For example, the Swiss experience in mapping and zoning in relation to avalanche hazard may serve as a basis for similar work in other mountain areas. We welcome comments and suggestions for future contributions along these lines, especially from countries/individuals endeavoring to develop programs in related areas of glaciology.

We would like to express our appreciation to all of the contributors who have readily cooperated to bring about this first issue of Glaciological Data, particularly in view of the limited notice they were given as a result of our imposed schedule of publication. We would also like to thank P. Harvill and G. Manzanares who assisted in the bibliographic compilation.

Contributions from those who have donated material to the Data Center since October 1976 are gratefully acknowledged.

Marilyn J. Shartran
Editor

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An Informal, Annotated Glossary of Avalanche Terms

Edward R. LaChapelle
University of Washington
Seattle, Washington, U.S.A.

An avalanche is a large mass in motion down a mountainside or over a precipice. Formally (Webster) it may be snow, rock, earth or mud. In practice, the term avalanche as used in English-speaking countries is reserved almost exclusively for the snow avalanche unless qualified by additional description, such as "avalanche of rock." The more general term commonly used in the United States is slide, which may mean any of the substances mentioned above unless specifically qualified, as in snowslide. The term slide is taken to mean snowslide when used in a context where the meaning is unequivocal. Snowslide and avalanche may be used interchangeably to describe the same phenomenon, the difference being only in the respective Anglo-Saxon and French roots. Uninformed users of the terms may introduce their own distinctions, as in the case of a motorist on a mountain pass who found his way blocked by snow which had avalanched onto the highway. When asked why he had ignored broadcast warnings of this likelihood, he replied, "I heard on the radio there was danger of snowslides. If I had known you were going to have avalanches, I wouldn't have come."

Avalanches can fall only when snow exists on an inclined surface, usually a mountainside. Among avalanche workers this layer of snow is often referred to as the snow cover, a direct translation of "Schneedecke", from German, a language in which much of the widely used avalanche terminology originated and was disseminated by early Swiss leadership in this field. In the United States hydrologists like to call the same layer of snow the snowpack. The two terms are synonymous.

Avalanches normally recur from time to time (the mean length of time between occurrences is the return interval) in the same mountain locality, called the avalanche path. This path consists of three parts. The release zone is the area at the top of the path where the avalanche starts; it usually involves the breakaway zone for slab avalanches (see below) and is characterized by accelerating motion. The track is the middle part of the path where steady-state velocity usually prevails unless modified by local terrain variations. There is little or no deposition of avalanched snow in the track. Below the track is the runout zone, usually less steep than the release zone and track, where avalanche motion decelerates and deposition takes place. This latter part of the path is sometimes called the deposition zone. These distinctions of path parts are more than of academic interest. A prime rule for safe travel in avalanche terrain is "stay out of the release zones," hence it pays to make the physical as well as the linguistic distinction.

Avalanches come in all sizes ranging from the very small, called sluffs (a spelling corruption of "sloughs"), which by definition do not run more than 50 meters, to the very large which may involve millions of tons of snow and can devastate whole mountainsides. Casual usage sometimes terms the latter kind climax avalanches, although scientific workers are careful to apply this term only to avalanches of any size which result from a sequence of meteorological causes rather than a single snowstorm. In the latter case, direct-action avalanches are observed.

The two usages for "climax" may be synonymous, but are not necessarily so. If avalanches occur in only the top layers of snow and slide on an underlying snow surface, they are called *surface avalanches*. If they involve the whole snow cover and slide on the ground, they are called *full-depth avalanches*. Avalanches on open slopes are called *unconfined avalanches*. If parts or all of their track lies in gullies or ravines, they are *channelled*.

Two basic types of avalanches are recognized according to conditions prevailing at the point of origin. The *loose snow avalanche* originates at a point and propagates downhill by dislodging successively larger numbers of poorly-cohering snow grains, typically gaining in width as it falls. The behavior of avalanching loose snow is analogous to that of dry sand. On the other hand, when cohesion among snow grains increases, large areas of the release zone may break away all at once in the form of a *slab avalanche*. A distinct, cohesive layer of snow cover then slides on a clearly-defined *gliding surface*, often facilitated by the presence of a weak or cohesionless snow layer called the *lubricating* layer. The division between the sliding slab and the stable snow above and to the sides is called the *fracture line*. These terms for slab avalanche features are direct translations from the German equivalents. More recently, a different nomenclature has been introduced in the United States which follows long-standing usage for analogous features in soil mechanics. The gliding surface in this usage is called the *bed surface*, the top fracture line the *crown surface*, and the side fracture lines the *flank surfaces*. A separate term is not introduced for the lubricating layer. In both terminologies, the surface of compression failure at the downhill edge of the slab is termed the *stauchwall*, a German avalanche label which apparently has no equivalent in English-language soil mechanics and for which no convenient translation exists. Slab avalanches are distinguished as *hard* or *soft* according to whether the slab snow has enough cohesion to remain in coherent lumps as it falls or breaks into a cohesionless mass similar to loose snow. While the exact terminology may vary, again the physical distinction of different avalanche types is very important. Most large and dangerous avalanches, and most involving accidents whether large or small, are slab avalanches. The reason a mountain traveler is exhorted to stay out of the release zones is because disturbances of the snow here may provide the *trigger* to initiate fracturing of a slab.

Avalanches are further classified as *wet* or *dry* according to whether or not liquid water is present in the snow at the point of origin. Knowledge on this point may be obscure. The deposition of avalanche debris in the runout zone, on the other hand, has a distinctly different character according to whether liquid water is present or absent there, and the difference can be easily recognized. When avalanches fall over long paths, they sometimes may originate in dry snow but experience sufficient melt in descent that they form deposits as wet snow. Dry snow falling at appreciable velocities conveys some of the snow particles into the air to form a *dust cloud*, an example of *mixed motion*. If the dust cloud predominates, such avalanches are sometimes called *powder snow avalanches*, or simply *powder avalanches*. If a sufficiently dense aerosol is formed by the snow particles entrained in the air, the dust cloud may behave as an atmospheric turbidity current, rushing ahead of the sliding snow at high velocity and occasionally inflicting heavy damage through *wind blast*.

A snow cover on a mountainside is subjected to gravitational forces which cause slow deformations as well as the violent fall of avalanches. Compression of the visco-elastic snow perpendicular to the slope under its own weight is called settlement. Internal deformation parallel to the slope is creep, while displacement of the entire snow cover along the ground surface is glide. On an irregular mountainside, or where snow depth varies, or both, these deformations vary in time and space, therby inducing stresses in the snow cover. Elastically stored strain energy in the snow may be released to propagate fracturing in the form of a slab avalanche fall, or the formation of glide cracks if the snow layers remain in place. Under certain conditions favorable for glide, the snow cover may then slowly accelerate, the cracks widen and an increasingly rapid transition is made to avalanche velocities. Japanese investigators have termed this phenomena the trans-avalanche, a condensation of the phrase "transition avalanche."

A Note on Procedures and Problems in Avalanche Data Collection

Richard and Betsy Armstrong
Institute of Arctic and Alpine Research
Snow and Avalanche Project, San Juan Mountains
Silverton, Colorado, U.S.A.

Data from several areas of study contribute to the better understanding of the avalanche phenomenon. The following briefly summarizes some data collection procedures for predicting avalanche events; monitoring frequency, type and magnitude of events; recording the effect of their occurrence, such as personal injury and damage to property; and studying avalanche dynamics, such as measurement of velocity, impact force and runout distance. Within the area of avalanche event forecasting, research is generally divided into two types. The first involves monitoring those factors which contribute to avalanche formation. These data involve both snow cover and meteorological parameters. The second type involves the documentation of the avalanche event itself.

First we will discuss the factors contributing to avalanche formation. Generally, the application of snow cover data for predicting avalanche occurrence involves more of a "hind-casting" technique rather than actual forecasting. For example, following an avalanche cycle, an observer may note certain stratigraphic conditions in the snow pit of a study site which he feels may have contributed to the preceding avalanche activity. Conditions associated with slab type avalanches generally involve layers of cohesionless, often low density snow which, in the release zone, may have provided inadequate support or poor interface adhesion for higher density, cohesive layers above. Examples would include wind slabs above layers deposited in the absence of strong winds; cohesive, well-sintered layers above recrystallized, temperature-gradient layers; well-rimed crystals or graupel above lightly or unrimed crystals; warm dense layers above colder, lower density layers; and poor adhesion between a melt-freeze crust and a cohesive slab above. As an observer gains experience in snow structure analysis, he may acquire a technique of pattern recognition which will allow him to anticipate conditions which lead to avalanche release and thus incorporate snow structure data into an actual avalanche forecast. While various avalanche forecasters may have achieved a significant level of competence in this area, no formalized incorporation of snow structure data into either a statistical or physical avalanche prediction model has been accomplished to date. The effective application of snow structure data to existing numerical prediction models could greatly enhance their accuracy (Armstrong, 1976).

Recent advances have been made in continuous monitoring of acoustic emissions accompanying the downslope deformation of a snow cover (St. Lawrence and Bradley, in press; Sommerfeld, in press). Correlations between specific acoustic signals and snow stability would significantly improve avalanche prediction methods. Considerable technology is currently available to acquire acoustic data from within a snowpack in the form of sophisticated geophones. Signals are continuously recorded on magnetic tape systems and combined with pulse height analysis of resulting data. Considerable problems exist, however, in efforts to quantify, analyze and apply these data.

Limited agreement does exist on the numerous meteorological parameters which contribute to avalanche release. Those parameters which are generally accepted in the United States, such as new snow crystal type, precipitation rates and amounts, wind speed and direction and air temperature patterns, are listed in the Avalanche Handbook (Perla and Martinelli, 1976). Among observers, however, there is little agreement on how these meteorological parameters are analyzed or how their importance is weighed with respect to a specific avalanche forecast. The lack of agreement may be due to the varied backgrounds and experiences of individual observers, as well as the wide variety of climates where avalanche activity occurs. While the type and sophistication of instrumentation involved varies, it is common to record precipitation, temperature and wind speed and direction data on a continuous basis, with accurate time references allowing precise event chronology. Such detailed data regarding the various independent meteorological variables are relatively easy to acquire and exist for numerous avalanche study sites.

The dependent variable, the avalanche event itself, rarely receives such detailed attention. In many locations, avalanche event records are often incomplete and data may reach research personnel as second- or third-hand information via ski-patrol or highway maintenance personnel. A further drawback is that ski patrols are concerned with relatively small areas and highway personnel are primarily concerned with avalanches which reach or cross the maintained road. Avalanches which may have run full-track but stop short of the road, or avalanches which run outside the ski area boundary are often not recorded.

The logistical support required to provide comprehensive and uninterrupted avalanche event data collection over a large area is costly in both time and personnel. Optimum efficiency has been achieved by the Swiss observer network (Frutiger, 1977) but such a system can only work in mountainous areas with high population density. This type of observer may be able to report on his entire area of responsibility from two or three vantage points. In other parts of the world, such as North America, observations must be made over wide areas of uninhabited terrain to support, for example, efforts to predict avalanches affecting highways. The Institute of Arctic and Alpine Research (INSTAAR) has been involved in such an effort in the San Juan Mountains of southwestern Colorado, with 222 avalanche paths being monitored along 72 km of highway (Armstrong and Ives, 1976). Even when this type of observer system is effective, it can only guarantee "after-the-fact" data with the time of event being correct at best to the nearest few hours, and often simply within a given 12-hour period. This is in sharp contrast to the level of precision considered essential to the collection of meteorological data and presents obvious problems when one attempts to correlate the timing of avalanche releases with prevailing weather conditions.

Recent attempts to improve avalanche forecasting by means of statistical methods have included studies by Judson and Erickson (1973); Bois, Obled and Good (1975); Salway (in press); and Bovis (1977). The work done by Bovis was undertaken in conjunction with INSTAAR snow and avalanche studies in the San Juan Mountains of southwestern Colorado. Bovis applied discriminant analysis to the forecast problem and his results may be considered the most sophisticated and perhaps the most successful technique developed to date. Previous models have provided only a "yes" or "no" prediction of avalanche occurrence. The approach of Bovis, however, allows the forecast to be stated in probability terms by providing the relative distance of a discriminant score from the discriminant index. This numerical model is also the first to predict magnitude as well as type (wet, dry, slab or loose) of release. Tested against a four-year sample of observed avalanche events, this method has demonstrated an accuracy of 88 percent for prediction of dry snow events and 82 percent for wet events (Armstrong and Ives, 1976).

The classification of avalanche type may be based on either genetic or morphological parameters. Many suggestions for standardized systems have been provided, such as those found in six papers on avalanche classification presented at the IUGG-IASH International Symposium on Scientific Aspects of Snow and Ice Avalanches, Davos, Switzerland, 1965 (Union de Géodésie et Géophysique Internationale, 1966). Standard procedures have been developed for individual countries. For example, the Westwide Data Network system devised by the U.S. Forest Service, Alpine Snow and Avalanche Project, is widely applied in the western United States. A worldwide standard will soon be available in the form of an International Avalanche Atlas to be published by the International Commission on Snow and Ice (ICSI) and UNESCO. While this long-awaited standard will be a welcome contribution, it unfortunately will not touch on the problem of avalanche size. An objective technique for recording avalanche magnitude should be based on either debris volume or theoretical impact force. Problems associated with either approach have so far precluded any widely accepted size standard.

The size classification which first came into use in the United States was based on the observer's estimate of threat to life and property. The system was proposed by M.M. Atwater and appeared in the first U.S. Forest Service avalanche handbook in 1961 (U.S. Forest Service, 1961). Since that time, another system has superceded this one and is based on assigning an index number (2 through 5) to describe subjectively the volume of snow transported down a given avalanche path with respect to the size of the path. (A size 1 is an avalanche of sluff running less than 45 m slope distance, approximately 20 m vertical, regardless of its other dimensions such as width, fracture line, etc.) Significant problems exist with this method of measuring avalanche size. For example, a size 3 avalanche event on a very large path would actually involve a much greater volume of snow than the same event on a very small path. Yet both events would be recorded with the same index number. Such subjective systems are of value only among those persons familiar with the characteristics of the specific avalanche paths involved. It would not be feasible for a researcher in the Rocky Mountains, for example, to attempt to communicate size information to a researcher in the Swiss Alps based on such a system.

Data regarding damage to structures and injuries or deaths resulting from avalanches are gathered by a standard method in the United States by the Forest Service. In Switzerland (Frutiger, 1977), as well as in other countries with avalanche problems, significant efforts are directed toward comprehensive avalanche damage records. In addition, the Swiss strive to compile all available data regarding maximum avalanche runout distances. Such data, extremely important to land use planning in areas threatened by avalanches, are available in the United States only for a very few locations, and for relatively short periods of time.

In the effort to document the maximum runout of specific avalanche paths, the Swiss are greatly assisted by historical information which may span four or five centuries. Little historical information is available in the United States, and where it can be found, the record rarely exists for more than 100 years. Therefore, efforts to reconstruct the history of individual avalanche paths in the United States depend primarily on geomorphic and dendrochronologic evidence (Potter, 1969;

Smith, 1973; Burrows, 1976; Mears, 1976) in addition to the historical approach, interviews with local residents and newspaper and chronicle research (Armstrong, 1976, in press), or by utilizing all of the above methods combined with remote sensing techniques (Ives et al, 1976).

Data collection in the area of avalanche dynamics has been restricted due to problems associated with directly monitoring such a transient yet destructive phenomenon. Numerous theoretical descriptions of avalanche dynamics have been developed as well as efforts to predict avalanche velocity and impact forces (Sommerhalder, 1966; Voellmy, 1955; Salm, 1966), but only a few actual measurements such as those accomplished by Roch (1962) and Schaerer (1973, 1975) have been made. Due to the continued pressure to develop mountain recreation areas, the problem of defining areas threatened by avalanches is receiving increasing attention. Accurate methods to predict avalanche runout distance depend heavily upon accurate velocity data. Efforts to provide more of this type of information are being undertaken by several research groups.

As is evident from the article by H. Frutiger contained in this issue of Glaciological Data, the need to compile information on areas affected by avalanche activity and the detailed mapping of such areas has long been recognized, if not always readily implemented. In North America, the first avalanche atlas was produced by the U.S. Forest Service for use by the Colorado Department of Highways (Frutiger, 1964) and is still being used for avalanche control, highway design and highway maintenance. Similar atlases were developed for the Washington State Highway Department by the Geophysics Program and Department of Civil Engineering, University of Washington (LaChapelle, 1971). The Colorado Geological Survey (Mears, 1975) has produced avalanche zone maps for fourteen critical areas in Colorado. These maps subdivide avalanche paths into "high" and "moderate" zones based on expected frequency and impact pressures. Avalanches in the moderate zone possess estimated recurrence intervals in excess of 25 years and will produce impact pressures of less than 5 tons/m^2.

Another attempt to take a further step in the evolution of the avalanche atlas in the United States is found in an avalanche atlas of San Juan County, Colorado (Miller et al, 1976) produced by INSTAAR at the request of the San Juan County Commissioners. This atlas includes the mapping of all avalanche paths affecting U.S. Highway 550 and Colorado Highway 110 in San Juan County on 1:24,000 scale maps of the U.S. Geological Survey. It contains outlines of the paths on aerial photographs and pertinent dimensional data, as well as terrain and vegetation parameters for the starting, track and runout zone of each path. This atlas is also a catalog of observed avalanche activity within these paths from 1875 to 1975.

Mapping techniques have probably advanced to the point where further refinement required for more detailed studies will depend on the availability of maps with a larger scale than the 1:24,000 scale USGS maps which have been used in the above studies.

It should be apparent from the preceding brief overview that avalanche data collection and the analysis of these data for the purpose of developing better methods to predict avalanche occurrence, runout distance and impact force are highly complex problems. Numerous university and government research organizations throughout the world are working on these problems, often seeking to solve the same problem simultaneously. It would appear that one key to the advancement of avalanche studies would be a continued emphasis on frequent communication among such groups, whether it be between individual researchers or through formal workshops or symposia, such as the three meetings held in North America over the past five years.* The next formal opportunity to exchange research concepts will be at an avalanche symposium organized by the International Glaciological Society and the U.S. Forest Service to be held in 1979 in Fort Collins, Colorado, U.S.A.

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Avalanche Activities at the Rocky Mountain Forest and Range Experiment Station 1977

M. Martinelli, Jr.
U.S. Forest Service
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado, U.S.A.

Avalanche activities at the Rocky Mountain Station involve both operational and research efforts. Operational programs include the Westwide avalanche and mountain weather reporting network, the Colorado avalanche warning services, the compilation and publication of avalanche accident statistics and case studies, and participation in the biannual U.S. Forest Service National Avalanche School. Research programs are now concentrating on the development of a Computer Assisted Avalanche Prediction System (CAAPS), the acoustic monitoring of the snowpack in avalanche starting zones, the correlation between mass flux of blowing snow and the stability of avalanche prone snowcovers, the improvement of quantitative precipitation forecasts for mountainous terrain, and improvement of existing avalanche dynamics techniques for predicting the runout distance and impact force of avalanches, as well as the development of new techniques for making these predictions.

Operational Activities

The Westwide network consists of about 40 observing stations in the western United States and Alaska that take daily avalanche, snowcover, and weather data on standardized forms. A copy of these data are sent to the Experiment Station monthly where they are checked for consistency and accuracy and then are stored for quick computer retrieval. Twenty-five years of data are now available for a few of the sites and over 10 years for most of the rest. It is felt that these records constitute the beginning of an avalanche cadastre which will become more useful and valuable as the length of the record grows. Publications by Judson (1970) and Williams (1972) give more details on the network.

The Colorado avalanche warning service is a real time alert issued to the public when dangerous avalanche conditions develop. It is a joint effort of the National Weather Service and the U.S. Forest Service. Forest Service personnel determine when a warning should be issued from Weather Service forecasts and from weather, snowcover, and avalanche data telephoned to the Experiment Station daily from numerous observers scattered throughout the mountains. The warnings are issued over the National Weather Service Colorado Weather Wire, which is a teletype circuit that reaches most newspapers, radio, and television stations. Warnings are geared primarily to backcountry areas where no systematic avalanche control is undertaken. They are issued only when danger is considered high and are withdrawn when danger subsides. For more on the Avalanche Warning Program see Judson (1976 and 1975) and Williams (in press a).

Details on all avalanche accidents are sent to the Experiment Station by Forest Service personnel throughout the western United States, Alaska, and by many other individuals. These data, in the form of case studies, have been published by Gallagher (1967) and Williams (1975a) and as accident statistics by Williams (1975b and in press b).

Avalanche workers at the station also take part in the biannual National Avalanche School conducted by the Forest Service for federal, state and private persons concerned with avalanche safety and control. The school consists of three parts. The first part is a five day series of lectures, discussions, and workshops presented to 150 to 200 students every other fall at some indoor facility. The second part is a series of field seminars for small groups held during the winter, usually at one or more of the large avalanche prone ski areas. The third part is a series of visits by highly experienced avalanche workers to individual field locations to discuss the specific avalanche problems at that location with local control specialists. Since 1971 there have been four schools with over 800 students.

Research Activities

Evaluating snowcover stability requires careful consideration of many interacting factors and has usually been carried out by experienced observers in a highly subjective and individualistic manner. Attempts to use regression or stochastic techniques have given mixed results with the latter appearing to be the more successful. In order to introduce more objectivity and to learn more about the relative importance of the factors that can contribute to avalanches, a simulation model of snowpack stability is being developed. It will first simulate the development of the snowpack layer by layer, then will combine this with additional data on the amount and intensity of wind loading, response of the snowpack to explosive control or natural triggers and other factors to estimate the likelihood of avalanches.

Additional studies of the stability of the mountain snowpack are being carried out using simple geophones to monitor the sound emitted by the pack in steep terrain. Promising preliminary results indicate an increase in sound emissions around 87 Hz as instability develops. These studies are being carried out at Berthoud Pass, Colorado, by Station personnel, and in central Montana by scientists from Montana State University under a cooperative agreement with the Station. Recent articles by McNair and Wolfe (in press), Sommerfeld (in press), St. Lawrence and Williams (1976), and Lang (1976) discuss various aspects of this work.

As mentioned above, wind loading of avalanche starting zones is an important factor contributing to avalanches. To learn more about this phenomenon, a snow particle counter is being operated upwind of an avalanche starting zone known to receive large amounts of blowing snow. The accumulated mass flux of blowing snow into the site is being compared to the accumulation of snow in the avalanche starting zone and to avalanche activity in the path. Mass flux data from the sensor is being telemetered about 95 airline km to the Avalanche Warning Center in Fort Collins. Information on the snow particle counter appears in Schmidt and Sommerfeld (1969), Schmidt and Holub (1971), and Schmidt (1971).

Under a cooperative agreement with the Atmospheric Science Department at Colorado State University, a quantitative precipitation forecasting scheme has been developed and is now being tested. This scheme uses the predicted moisture field, winds aloft, and upper air temperatures from the Limited-Area Fine Mesh (LFM) Model of the National Weather Service to give estimates to the orographic component of precipitation at 10 km intervals for western Colorado on either a storm-by-storm or seasonal basis. Owen Rhea developed the scheme and has described it in two papers, Rhea and Grant (1974) and Rhea (1975).

Field data are being collected on the size of fracture lines, snow properties, and the location and distribution of debris following moderate to large avalanches. These data are part of a study to improve techniques for predicting the runout distance and impact forces of avalanches. The field data will be used to improve the selection of the proper friction coefficients needed to use the avalanche dynamics equation developed more than 20 years ago by the Swiss scientist A. Voellmy. The field data will also be used to test and improve a numerical model of avalanche dynamics based on the "marker-and-cell" method often used in fluid flow problems. It is hoped that the new model will allow greater freedom in describing snow conditions, terrain configurations and related problems than was possible with the Voellmy equations. Publications on this study will be forthcoming in the next year or so.

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Avalanche Damage and Avalanche Protection in Switzerland*

H. Frutiger
Swiss Federal Institute for Snow and Avalanche Research
Davos, Switzerland

Avalanche Cadastral Surveys and Avalanche Damage

In 1872, Johann Coaz, a pioneer in the field of avalanche protection in Switzerland, initiated the first avalanche maps. At that time, he commissioned his district forestry division to undertake the compilation of avalanche statistics. After the office of the Swiss Federal Forest Inspectorate (FFI) was created in 1874, the individual cantons were invited in January 1878 to compile the necessary data. The result of this first effort was "Statistics and Structural Control of Avalanches in the Swiss Alps," which Coaz ultimately published in 1910. This specialized document provided a Forest Cover and Avalanche Map of Switzerland at a scale of 1:100,000 and was produced by Swiss Forestry personnel under the direction of the Federal Forest Inspectorate. It had been previously published in 1907 at a scale of 1:250,000. This effort was apparently neglected, and unfortunately today no copy of the original publication can be located. Four decades elapsed until Switzerland again began to document catastrophic avalanche events in 1951. At that time, the effort to develop a body of avalanche event statistics was renewed. The office of the FFI, supported by a federal government decision to expedite the further development of avalanche defense structures, provided guidelines which, among other things, stated: "The tabulation of avalanche event statistics and their continuous updating is strongly recommended to the forestry divisions of the cantons."

Unfortunately, this request was not given the attention it deserved in all cantons. The serious consequences of this omission will be discussed later in conjunction with efforts regarding avalanche control measures. The Federal Institute for Snow and Avalanche Research (SLF), through continued suggestions, was providing assistance toward developing a Swiss Avalanche Cadastral Survey and the appropriate preliminary work was to be completed by 1955. The survey was to contain data regarding the type, size and frequency of each avalanche within a specific area, for example, along the length of an inhabited valley. From this work, it was anticipated that reliable information regarding avalanche conditions in populated areas, along transportation routes, and for back-country areas of frequent winter tourist activity would result. Such studies would also be well suited to further statistical evaluation, such as a better understanding of the relationships between avalanche activity and elevation, orientation and other factors specific to a given site.

Unfortunately, personnel at the Institute (SLF) were not in the position to be involved in work on the survey when it was initially undertaken. On this account, it was decided at a conference of canton forestry officials in 1962 that the canton

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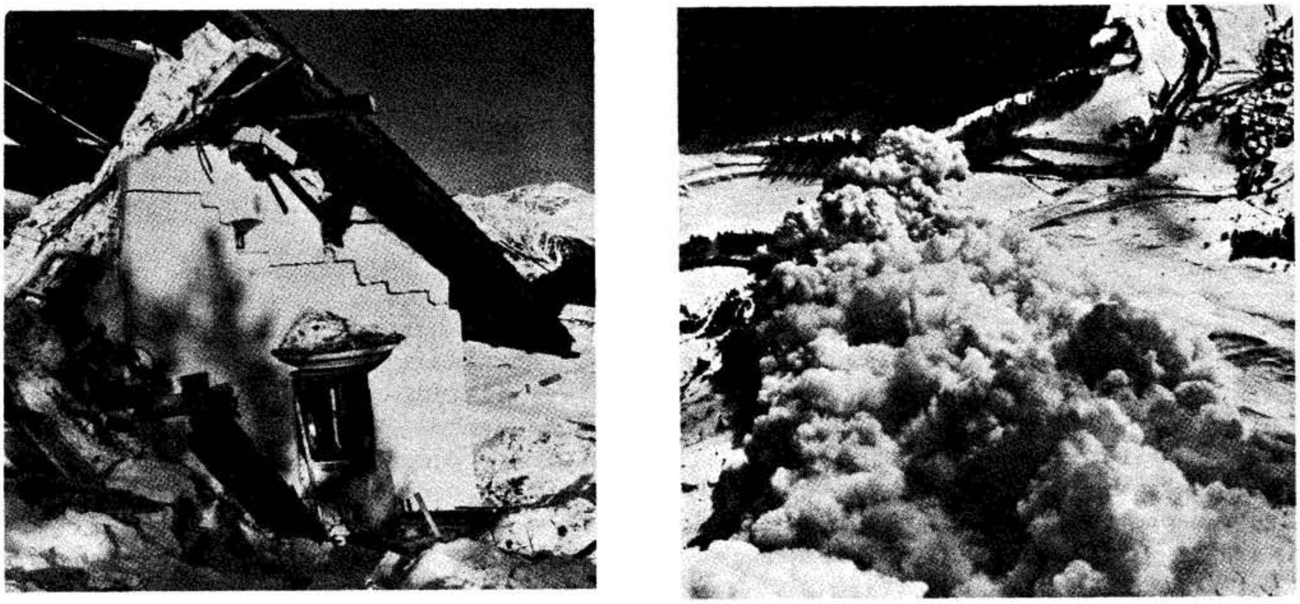

Figure 1. In the case of powder avalanches, the greatest damage results from the powerful dust cloud pressure wave. The primary destructive force of a wet avalanche, however, results simply from the enormous weight of the moving snow mass. Left: Results of an avalanche on January 26, 1968, near Davos. Right: Powder avalanche near the town of Lavin in the Engadin.

forest services should work together as much as possible for this purpose. In particular, the Institute (SLF) was to be concerned with the basic project design and serve as data center while the task of preparing the surveys would be carried out in the cantons.

How then was a modern avalanche cadastral survey to be produced, and which elements should be considered most essential? On a general map with a scale of 1:50,000, a region may be divided into individual observer districts, for example, a single inhabited valley (figure 2). All avalanche paths within a certain area are recorded on this map by a simple line or by an outline and are given a number. For each individual avalanche path, the characteristic features are noted and compiled. Also, attempts are made to establish the maximum run-out distances of each avalanche by questioning local residents and by researching newspapers, chronicles and local historical studies. A local observer is required in each district and has the responsibility of recording each avalanche event in the survey. In addition to the routine entries, special forms are provided for additional data such as photographs, sketches and diagrams, comments regarding weather conditions and in the case of damage, statements regarding type and extent. Such supplementary data serve to support the survey with as much testimonial information as possible.

If the Swiss avalanche cadastral survey has not yet reached the level of development which was initially envisioned, at least since 1949 the Snow and Avalanche Research Institute has published a regular Winter Report which gives a good picture of the most significant avalanche occurrences during each winter. The Institute, since the winter of 1936-1937, has documented with as much detail as possible all avalanche events causing human injury or death. Also, all avalanches

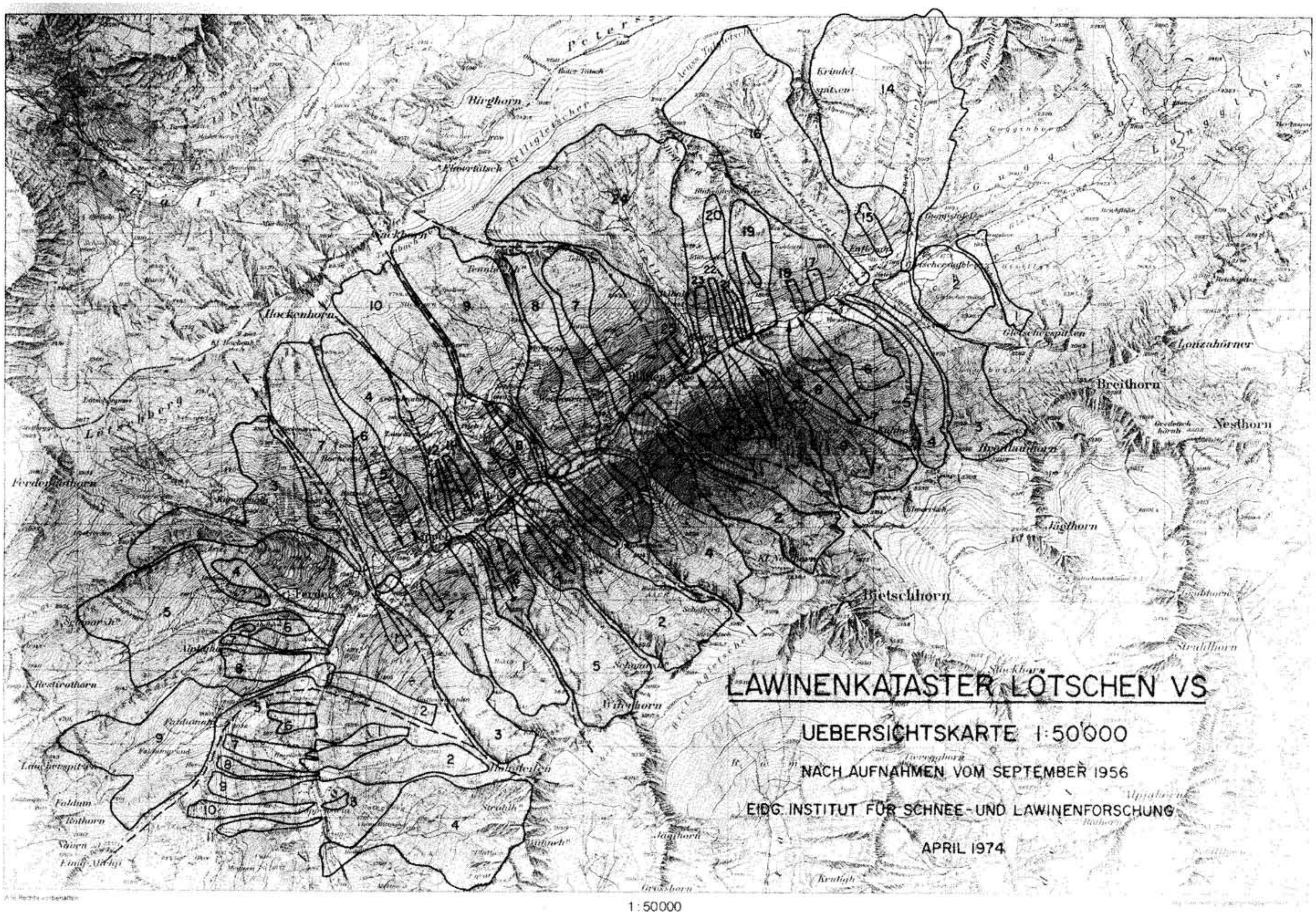

Figure 2. Outline map of the avalanche cadaster for the Loetschen Valley at a scale of 1:50,000

which have caused significant damage to property have been documented since 1951, although such data are admittedly incomplete. Of course, in the case of regional or national avalanche catastrophes, it is often simply not possible to document each of the hundreds of avalanche events that occur.

Of special interest are the recreation-related avalanche accidents which have greatly increased due to the enormous growth in the popularity of skiing since World War II. During the years between 1900 and 1945, an average of 12 persons per year died in avalanches, but from 1946 to 1976 this average increased to 18 persons. Those persons killed by extraordinary avalanche occurrences, the so-called "catastrophe victims," are not included in these average figures. If one were to count these victims as well, the number of persons killed by avalanches in the Swiss Alps since 1900 would total 1388. These avalanche accident statistics differentiate between catastrophe and work-related victims and recreation-related victims. The first group comprises that type of accident which, as a rule, occurs during periods of widespread avalanche danger, when avalanches reach villages, highways, roads, mountain construction sites and work areas in forests and pasture lands, involving, for example, timber workers and farmers. On the other hand, the danger which threatens the tourist (skier, ski-tourer, mountaineer) is quite localized. For example, a tourist could be caught in an avalanche in a specific location, i.e. a steep slope with a cornice above, when no general hazard exists.

Through this distinction, interesting relationships between the type of accident and snow cover conditions appear (figure 3). The long-term average of avalanche deaths per winter is 23, of which 12 are the catastrophe and work-related type and 11 are recreation-related. The winter of 1966-1967 was a heavy snowfall winter with the average snow depth being 123% of normal. The number of work-related fatalities was high while recreation-related deaths were few. The reverse situation occurred during the 1968-1969 winter, a very light snow winter (85% normal snow depth), when there were no work-related fatalities but an unusually high number of recreation-related accidents, resulting in 22 deaths. This paradoxical picture presented by the numerous recreation-related deaths can be explained by the respective snow cover conditions during the two winters, 1966-1967 and 1968-1969. During the winter of 1968-1969, a thin snow cover, which was exposed to long periods of clear cold weather, became strongly metamorphosed. The snow layers became coarse-grained (granulated), and lost cohesive strength and load-bearing capacity which resulted in a dangerous base for skiing. The other example, 1966-1967, involved a winter when a deep, strong snow cover with good load-bearing capacity developed during continuous periods of snowfall which were not interrupted by any significant periods of dry weather. Moreover, the opportunity to go out skiing during stormy periods was limited compared to fair weather.

In the 31 winters since 1946, approximately 4400 avalanche accidents and damage reports have been compiled in various levels of detail. Analysis of such data allows a better understanding of the relationships among the conditions of snow cover, weather factors, and avalanche danger. Precautionary measures and rescue methods can then be examined and, if necessary, be altered and improved. The documentation of snow and weather conditions and of circumstances surrounding avalanche accidents also serves to provide "expert opinions" in possible legal judgements and as evidence in lawsuits.

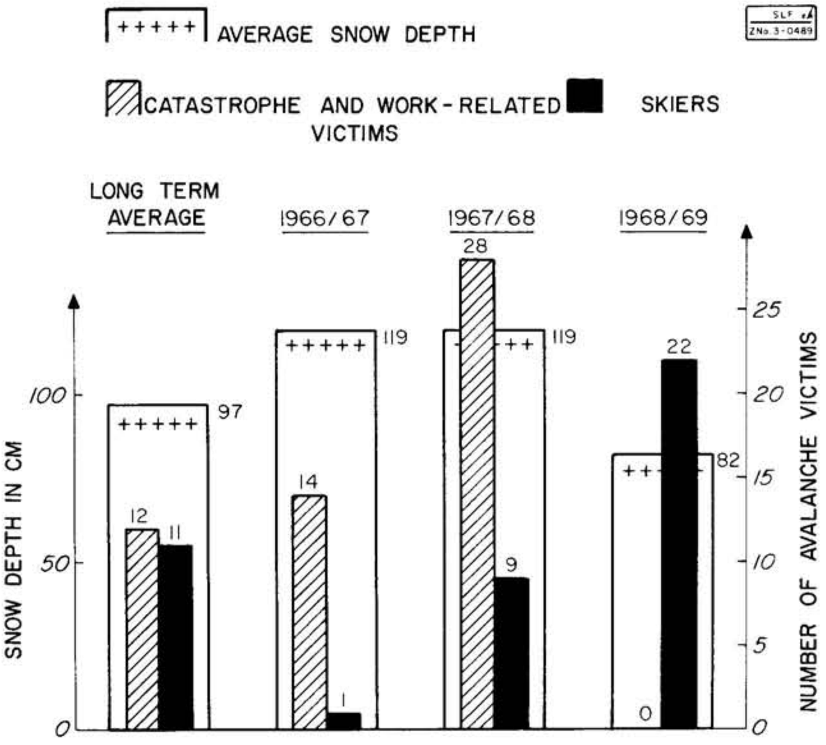

Figure 3. Relationship between catastrophe and work-related avalanche victims and recreation-related victims as a function of the winter snow depth. The individual and long-term average snow depths are for the months of December-March for elevations above 1800 m.

The sequence of major avalanche disasters during the 100-year period from 1875 to 1975 is listed in Table 1. These major disasters are primarily the result of heavy and deep snowfalls. As a rule, these individual major disasters are limited to specific regions but may, over the course of a winter, occur one after another at various locations so that finally the entire area of the Swiss Alps has been affected. This was the case during the winter of 1950-1951, the worst avalanche winter of the last 100 years. Very heavy snowfalls occurred on the north slopes of the Alps from 18-25 January and on the south slopes from 4-14 February. The "lightest" winter was that of 1948-1949, when only 8 avalanche accidents were recorded, 4 of which were highway burials. The only avalanche death was a ski-tourer caught in a slab avalanche. In comparison, the high number of avalanche deaths during the winter of 1969-1970 was less a result of the severity of the winter than of a disastrous accident. On 24 February, 30 persons were killed simultaneously by the Bächital Avalanche near the town of Reckingen. Tables 1 and 2 also give some idea of how often such catastrophes occur. According to H. W. Courvoisier [7] (SLF), a small or large catastrophe situation occurs in the Swiss Alps on the average of every seventh year. These data do not include isolated situations where only one single village or valley is affected. If one focuses on a specific area, for example the one which experienced the catastrophic avalanche of April 1975, the average recurrence interval for major avalanche disasters appears to be every 25 years.

The most recent regional avalanche catastrophe occurred from 3-7 April 1975 with the hardest hit area being Bedretto, upper Leventina, upper Blenio, the Urseren

Table 1. Avalanche catastrophes from 1875-1975* in the Swiss Alps. In some cases, the numbers in the table must be considered only minimal values because the total extent of the damage was not known.

Winter	Number of avalanches causing damage	People		Animals Killed	Buildings Destroyed		Forest destroyed in m^3 of timber
		Injured	Killed		Houses	Out-buildings	
1887/88	1094	84	49	665	86	764	82,100
1916/17	?	?	39	?	min. 200		min.82,000
1934/35	?	?	36	?		?	min.25,000
1944/45	min.500	56	39	?	min. 300		40,000
1950/51	1300	234	98	884	187	1302	170,000
1953/54	325	159	33	228	63	571	10,300
1967/68	421	106	37	23	97	307	25,400
1969/70	254	120	56	3	21	77	41,000
1974/75	1022	127	27	172	72	233	146,000

? : not known

min. : minimum number - the total extent of damage was not known

*None were reported during the 1875-1887 period.

Table 2. Avalanche catastrophes during the time period 1808-1975 that significantly affected large areas of the Swiss Alps [7]

Year	Date	Area Affected
1808	Early December	Central and north-central Switzerland
1817	End February - early March	Northern Ticino, Gotthard, Lower Engadin, central Switzerland
1848	Mid-March	Visp Valley, Gotthard
1851	3-23 to 4-4	Northern Ticino, Gotthard
1863	1-5 to 1-13	Ticino, Misox, Bergell
1888	2-12 to 2-23	North slopes of Alps, upper Engadin
1888	3-20 to 4-2	South slopes of Alps and ridge top areas
1892	Early February	North slopes of Alps - near ridge tops
1895	1-13 to 1-17	South slopes of Alps not including Bergell, Puschlav and Münstertal
1916	12-5 to 12-16	South slopes of Alps, Visp Valley, Gotthard, upper Engadin
1917	4-17 to 4-22	Ridge top areas of north and south Alps
1919	12-23 to 12-26	North slopes of Alps east of Lütschinen Valley, northern Switzerland
1923	12-23 to 12-29	Wallis, north slope of Alps, north and central Switzerland
1925	2-11 to 2-15	Southern Alps and adjoining ridge tops
1931	End February - early March	Upper Wallis, north slopes of Alps east of the Lütschinen Valley, northwest Ticino
1935	1-5 to 1-6	Hasli Valley, central Switzerland
	1-27 to 2-7	Central Switzerland, Glarner Alps, St. Galler Oberland, north Switzerland
	2-14 to 2-17	Upper Wallis, Gotthard, central Switzerland, lower Engadin
	2-23 to 3-3	Lower Wallis, central Switzerland, lower Engadin
1945	1-19 to 2-13	Upper Wallis, north slopes of Alps, especially central Switzerland
	3-5 to 3-9	North slopes of Alps east of Lütschinen Valley
1951	1-15 to 1-21	Upper Wallis, north slopes east of Kandertal, north and central Switzerland, lower, middle Engadin
	2-4 to 2-12	South slopes of Alps, Gotthard
1954	1-9 to 1-12	North slopes of Alps, especially the vor-Alps
1968	1-24 to 1-27	North slopes of Alps, north and central Switzerland, upper and lower Engadin
1975	4-3 to 4-7	Southern Alps, Gotthard, central Switzerland, upper Engadin

Valley, Cadi, Vals and Rheinwald. This situation was the result of an extraordinarily heavy and severe snowstorm. Record snowfall was measured in Ritom, Andermatt, Sedrun and Disentis, with daily new snow depths averaging between 56 and 62 cm for four days. The avalanches were correspondingly large and widespread. In spite of the large number of avalanches, 1022, causing damage in a relatively small area, the number of injuries to humans remained an amazingly low 27. This relatively fortunate consequence of such major avalanche activity may be attributed to the population and governmental authorities' familiarity with most of the possible locations of avalanche activity, based on the special avalanche maps and zoning plans. Also, operational agencies such as the avalanche warning service and police services successfully and with proper advance timing brought about appropriate road closures and evacuations and thereby were able to minimize an otherwise highly critical situation, thus avoiding fatalities.

Avalanche Hazard Maps and Zoning Plans

In the preceding section, the appeal of the FFI in the guidelines of the Federal Department of Interior of 17 June 1952 was mentioned as well as the fact that the response to the appeal was not always satisfactory. The appeal was repeated again on 7 July 1959. At that time the FFI turned once again to the governmental bodies of the mountain cantons and expressed their demands in the following words: "The guidelines of our department of 17 June 1952 regarding reforestation and structural control of avalanches in areas of avalanche danger contained specific directives intended to prevent structural damage and human injury in the future due to avalanches. The production of avalanche zoning plans [4] and cadastral surveys is essential if in the future the loss of life and property is to be prevented. The Federal government cannot subsidize resettlement or those measures required to protect buildings from avalanches when the choice of the construction site was made without consideration of the avalanche zoning plan, or, where none exists, the warnings of those familiar with the area were disregarded. Experience has taught that the avalanche disasters of 1951 and 1954 were too soon forgotten and that today construction is again taking place, with irresponsible negligence, in areas of avalanche danger. Those persons concerned must alone be responsible for the consequences of their carelessness because the Federal government, according to the guidelines set forth, will not provide funds for protective measures in such cases."

On 6 March 1928, the federal forest inspector, Dr. F. Fankhauser, gave a lecture on avalanches and avalanche defenses in which he stated: "When during the coming years property in locations of known danger is sold at high prices to 'foreigners' (those strange to the place) as homesites and these people then build in good faith, so that in some individual cases millions of Swiss francs are required in order to undo the initial mistakes, as far as possible, by building defense structures, so it should serve as a lesson for the future and motivate the community authorities to deny construction permits in areas of known danger." These words of warning have in the past 50 years become a reality as can be seen in the following example.

A new area was to be opened and developed as a ski resort. Therefore, at the end of 1972, an authorized planning commission was to provide an expert opinion on the skiing potential and required protective measures against avalanches on the ski runs. All facilities associated with the ski area such as access roads, ski lifts, parking lots, residences and related recreational facilities including the central facilities with the usual retail stores were methodically planned. By the winter of 1974-1975, the access road, access chair lift and three ski area lifts were in operation. In addition, the first seasonal residents had already built their vacation homes. Then came the heavy snowfall from 3-7 April 1975, causing an exceptional avalanche which swept away three new vacation homes which fortunately were not yet occupied, knocked down the chairlift over a distance of 300 m, and destroyed a barn which had been remodeled into a vacation home in which seven persons were staying. Five people were killed and the others were injured but were removed safely. The avalanche penetrated an area which was then considered the potential residential area and central shopping area of this developing ski resort.

The reaction to this incident was peculiar. The canton police, Division of Public Safety, wrote: "In fact no one could have foretold that an avalanche could penetrate into this area where the house stood and where at no time in human memory had such an event been noted." In a newspaper it was stated: "Farmers often speak of 'Fate.' This avalanche should simply never have occurred, at least not with such magnitude." It was, nevertheless, quite simple to learn enough about previous avalanche activity in this area to subsequently produce a hazard map with little trouble. It was learned that this same avalanche occurred on 15 December 1961, the only difference being that on that date the avalanche ran even farther! It was also learned that on 15 February 1925, another avalanche actually reached the exact spot where one of the winter sports buildings was to be constructed. In this case, the tendency to disregard avalanche danger had quite literally reduced planning to a shambles.

On 16 April 1961, the legal section of the Federal Department of the Interior stated: "The development of avalanche zoning maps shall be the concern of the individual mountain cantons or, respectively, the local municipalities with avalanche danger." In addition, the opinion regarding the various legal aspects of the avalanche zoning maps indicated that it was the primary duty of the municipal governments to provide for the safety of all residents. At a minimum, the municipal council was to arrange for the services of those experts who would be capable of producing hazard maps. The forestry agencies of the cantons are, as a rule, best qualified to be of assistance to the municipalities in this matter. The SLF Institute, in 1962, conducted a course for those persons working with avalanche zoning plans. Additional courses were held in 1967, 1970 and 1972. Although these courses were primarily attended by forestry personnel, there were also participants from private planning agencies as well as interested parties from foreign countries.

There are occasional instances when municipal governments hesitate to prohibit construction at a site endangered by avalanches because such a decision will cause the construction company (developer) to sue for compensation, based on the assumption that not issuing a building permit would be construed as expropriation. Now that it has become more common to speak of avalanche zoning plans, the withdrawal of danger zones from construction is causing fewer problems for planning groups. Laws applying to public bodies regarding restrictions on private property were not created through the avalanche zoning plans but rather existed long before, although unfortunately they are not well-known. Therefore, the current official opinion is that the municipal governments in specific well-defined cases have general police powers "to be required to provide for public safety" and that power is quite sufficient to deny building permits. However, local planners would not be allowed, without an explicit legal basis, to bring about a general construction ban over large areas.

Now the legal foundations are available and are found in two federal ordinances. The executive order of 1 October 1965 regarding police powers in federal forest lands states in Article 32, Section 2: "The cantons are responsible for seeing that no buildings are erected in areas of avalanche danger. For this purpose avalanche zoning plans will be developed. The government will not provide any type of protection for new buildings which are constructed without consideration for the zoning plan; or, where no zoning plan exists, where warnings or design criteria advice is ignored." And in a federal decision regarding urgent measures with respect to planning for efficient use of space, it states in Article 1: "The cantons shall designate without delay those areas where settlement and construction should be provisionally restricted or prohibited entirely for reasons relating to protecting fragile landscape, for preservation of adequate recreation areas or for protection from natural hazards."

The avalanche zoning plan will indicate potential avalanche danger for all parcels of land. The basic document also provides a plan for surveying individual parcels of land and establishing boundaries. The technical basis for the avalanche zoning plan is the avalanche hazard map. Since topography is critical to the avalanche phenomenon, the maps must include contour lines. The 1:10,000 scale maps produced by the Swiss Land Registry Survey serve this purpose very well. The boundaries of avalanche areas as shown on the avalanche hazard map may then be transferred to other maps with other scales (figure 4).

The avalanche hazard map is a complete inventory of all land areas threatened by avalanches and is developed with the aid of the important and fundamental information contained in the cadastral survey. This survey, however, often only includes avalanches which have occurred in the last 50 or 100 years, and may not include the potential avalanches which may only occur every 300 years. In practice, it is customary to divide the levels of hazard on the maps according to 4 colors: red, blue, yellow and white. The red areas are exposed to frequent or large avalanche events. By large avalanches it is meant that a site may be exposed to pressure forces of 3.0 $tons/m^2$ or more. An area of frequent hazard is one where the particular avalanche will, on the average, occur one or more times in 30 years. The blue zone includes areas where avalanche activity can occur without doubt, but where such activity does not equal the size and frequency of the red zone specifications. The yellow zone designation is given to areas where the effect of avalanche activity is limited to the dust cloud or air-blast effect of a powder avalanche. Areas absolutely free of avalanche hazard are designated as white zones. In 1975, the Swiss Federal Forest Inspectorate provided guidelines with regard to avalanche hazard and the construction of individual buildings, the development of transportation systems and municipal planning for use by those involved in developing avalanche hazard maps and avalanche zoning plans [8].

Structural Control of Avalanches

As has already been mentioned above, certain "operational methods" exist which can provide comprehensive protection from avalanches. What alternatives are included in these methods? They are primarily concerned with avoiding areas of avalanche danger by using avalanche zoning plans; avalanche warnings and bulletins; ski run, road and railway closures; the artificial release of avalanches and evacuation. However, buildings and equipment permanently located cannot be protected in such a fashion. For this purpose, avalanche defense structures are necessary.

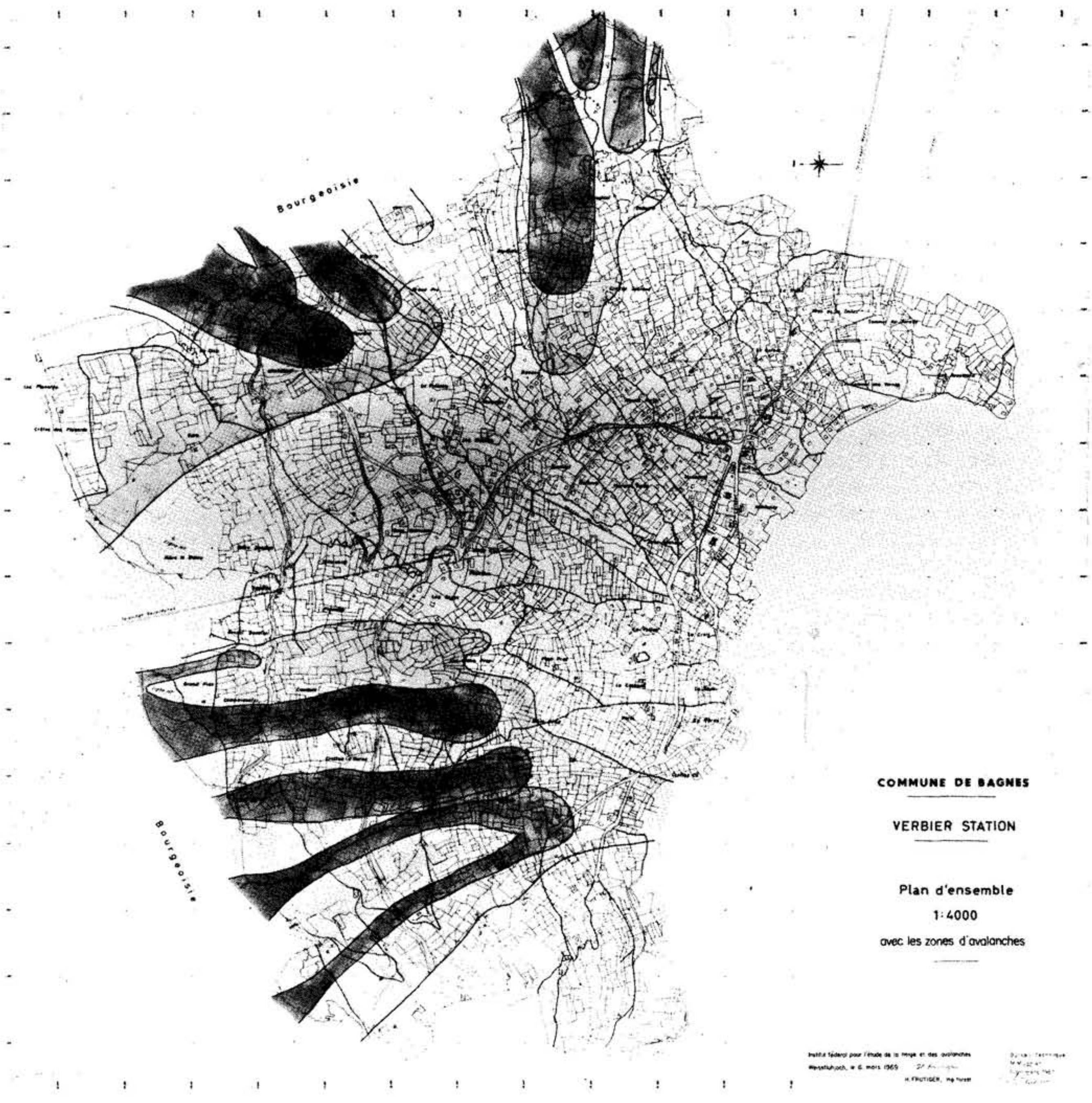

Figure 4. Avalanche zoning map for Verbier. The heavily shaded areas are those with the highest danger; the lighter areas are less dangerous.

Problems associated with mountain torrents indirectly led to large avalanche structures in the release zones. In order to reforest those slopes which were steep and bare (denuded) and whose water source was fast-moving mountain streams, it was necessary to build structures to prevent avalanches. It is then, in historical context, easy to understand why the forest engineer, rather than the construction engineer, became engaged in the structural control of avalanches. On 21 June 1871, the decision was made at the federal level to provide funds to build structures against mountain floods and for reforestation in high mountains. This was the first federal assistance in the battle against avalanches. The forest was considered the best and least expensive method to protect against avalanches. It must be stressed, however, that the forest can only serve this protective function in the avalanche release zone. Once the avalanche is allowed to come into motion, the forest may be destroyed.

It was on 24 March 1876, when the federal government became responsible for the forest police in high mountain areas, that the original financial basis for avalanche defense structures was established. Without this type of legislation, the primarily poor municipal governments in the mountains could never afford such protective structures. Current legislation allows an 80 percent subsidy to be provided by the federal government. In the anniversary publication "A Hundred Years of Forest Protection" [6], the federal contribution to the financing of reforestation and the structural control of avalanches from 1960 to 1974 is described in detail. This amount has varied from year to year between 7.0 and 24.1 million Swiss francs.* The average cost per year has been 13.3 million francs.

It is truly quite impressive that structural avalanche control is now 100 years old. This, however, is valid only for modern structures in the release zone, for protection structures in the track and run-out zone are actually quite older and go back as far as the earliest settlements in alpine regions. Typical of the earliest structures are those which cause the avalanche either to pass over, or deflect it away from the protected structure. Numerous barns, alpine huts and mountain residences, as well as churches, are protected in this fashion. These techniques are widespread and have many names such as splitting wedges, avalanche breakers, triangles, arrows, avalanche blocks, protective walls, splitting spear, snow ridge, as they were described by J. Coaz in his publication "Statistics and Structural Control of Avalanches" in 1910.

Also, special shelters have been used for many years. In the village of Saas-Grund there are "avalanche vaults" which are more than 100 years old. These are cellars with heavy masonry walls where the residents can take refuge during periods of avalanche danger. Such protective shelters have been built in more recent times in the villages of Gadmen and Husen (Meintal, Uri). Special shelters were, and still are, constructed alongside roads and foot paths to provide an escape from avalanches. Of special importance are the avalanche galleries (snow sheds). A drawing by H.C. Escher in 1811 shows that the Saumweg through the Cardinell on the

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*As of March 1977, the Swiss franc equals approximately 0.4 U.S. dollars.

Splügen Pass was already protected by galleries. The first roads over alpine passes, such as the Simplon, Bernard and Splügen, as well as the highest alpine pass, the Stilfserjoch, all of which were constructed between 1800 and 1824, had been furnished at numerous points with such protective structures. Even today, these excellent products of the stone masons' art can be seen on the Splügen Pass. After construction of the trans-alpine railway was completed at the end of the last century, there was no immediate need to provide additional structures. A "renaissance" for such construction developed in the 1950's with the effort to provide a Swiss national highway network. The Federal Department of Interior commission for the planning of the highway network wrote in their final report in 1959: "The primary intent in improving routes through the Alps is to keep the main north-south highways open all year round." And in a September 1963 report regarding winter highway connections with the Gotthard Tunnel, it was stated about winter highway networks: "This shall be a highway connection which will be maintained and open 24 hours daily. Closures in normal winters should be no longer than 2 hours; closures of an entire day should not occur any more often than once in 4 or 5 years." As a consequence, several avalanche galleries have been constructed during the last 20 years. The design and contruction of these galleries benefited greatly from modern snow and avalanche research.

The structural control of avalanches in the starting zone is clearly divided into two periods of development. From 1868 until about 1930, the structures which supported the snow cover were predominately constructed of materials available at the site. These included the terracing of slopes as well as berms of natural earth material and the construction of walls, both backfilled and free-standing, made from dry masonry. These massive structures had the disadvantage of often being covered by the snowpack by early winter, thereby greatly reducing their effect against the so-called surface avalanches. Following the avalanche winter of 1950-1951, a new construction material came into use. Now, in addition to the previously used wood and iron, pre-stressed concrete, light-weight metal alloys and cable-nets are being used, and some attempts are being made to utilize synthetic materials. These newer structures which are made from individual pre-fabricated parts are collectively known as "articulated" structures. Included in this type of structure are "snow-bridges," snow-rakes and snow-nets (figure 5).

During the winter of 1936-1937, instrumentation was installed for the first time on the Weissfluhjoch (Davos) which measured the pressure of the snow cover on the slope against a supporting structure. Based on this type of pressure measurement as well as theoretical investigations, R. Haefeli [1] published, in 1939, an equation for the calculation of such snow pressure, which, in principle, retains its validity to the present day. The newer articulated supporting structures exhibit substantially greater susceptibility to snow pressures (creep and glide) than their massive predecessors. Over the course of the years, especially following heavy snow winters, the weak points of the construction became apparent. The various interactions which occur between the supporting structures and the snow cover are therefore investigated through field observations so that the builder can continually adjust construction requirements according to actual wintertime observations as well as experimental and theoretical snow research. Today those involved in the construction of supporting structures have an extensive body of data resulting from research, as well as practical knowledge which is contained in guidelines of the Federal Forest Inspectorate for supporting structures [2,3].

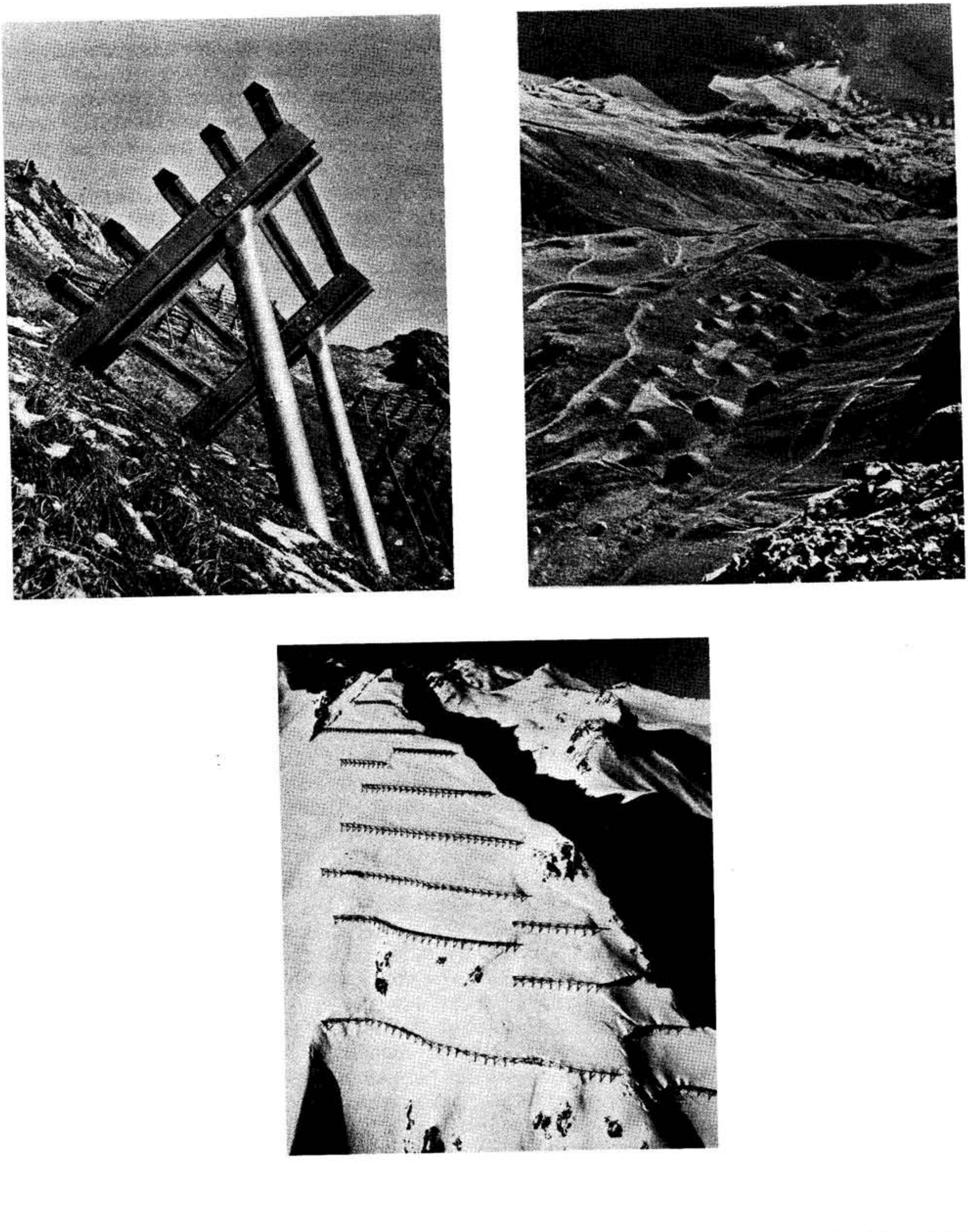

Figure 5. Left: Supporting structure in the starting zone; snow bridge made of light metal alloy on the Mattstock above the town of Amden. Right: Breaking or retarding structures in the Dorftäli avalanche track zone near Davos; the mounds and the dam are constructed simply by piling up local soil and rock (photo by H. Frutiger). Bottom: Supporting structures in the starting zone of the Schiatobel avalanche near Davos (photo by Institute SLF).

The following numbers will provide an example of the enormous loads which must be supported by these structures. On a 45° slope with a snow cover which is perhaps 5.0 m thick (measured vertically), conditions are quite extreme. In order to support such a snow cover, a snow bridge at least 3.5 m high must be constructed approximately perpendicular to the slope. Based on the snow pressure calculations, a load of at least 8 tons per running meter results. The structures are made of single sections 4 m in length spaced 2 m apart. For each 6 m length of structures, there are two support pilings (figure 6). Therefore, each support must withstand a load of 24 tons. Theoretically, the resultant forces of the snow pressure affect only one-half the height of the structure. As can be seen in figure 6, the large forces which especially affect the upper portions of the bridge are counterbalanced by special anchor systems which fasten the structure to the ground.

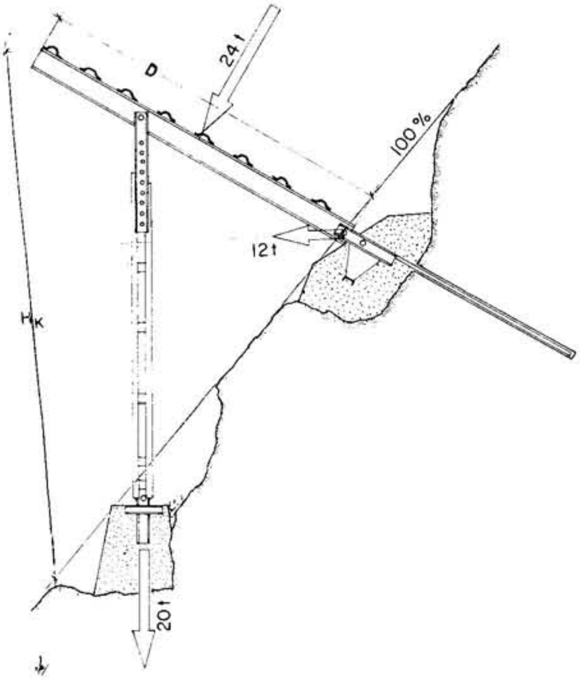

Figure 6. A cross-section of a steel snow bridge, including the calculated forces exerted by a snowcover 5 m in depth

In the case of the above example, a new row of structures must be located every 22 m, measured along the fall line of the slope, in order that the collective length of structures per hectare is 643 m. For the most part, such avalanche structures are in remote areas with difficult access and there are generally only about 100 days per year that can be used for construction at some of the higher sites. It is therefore not surprising that such construction in release zones is a very expensive undertaking. Today, costs are figured at approximately 1000 francs per running meter for finished supporting structures. In the example described above, the cost would be 643,000 francs per hectare. Generally, most of the relatively small release zones are still several hectares in size so that the cost estimates quickly exceed the million franc level.

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Soviet Avalanche Research

Misha Plam
Institute of Arctic and Alpine Research
Boulder, Colorado, U.S.A.

Avalanche research in the USSR can be divided into four periods. The first stage, 1930-1940, began with the study of avalanches in the European parts of the USSR in the Caucasus and in the Khibinskiy Mountains of the Kol'skiy Peninsula with only a small number of published results. The second period, 1950-1960, was characterized by expanded studies in the same mountain regions following World War II, by the same research groups, resulting in a considerable number of publications. The third period, 1960-1965, was marked by a sharp geographic expansion of investigations in the mountain regions of the entire Soviet Union. The fourth period, 1965-1975, resulted in an intensification of studies in the theoretical areas, an extensive use of physics, mathematics, and mechanics and the development of engineering measures for avalanche defense.

1930-1940

The first Soviet studies were begun in the 1930's in the Caucasus in connection with protecting roads in mountain passes from avalanches, and in the Khibinskiy Mountains in connection with the construction of the large apatite mine where minerals were being extracted for farming.

In 1932, the Zakavkazskiy Institute of Structures in Tbilisi entered into a project for avalanche defense structures. For this purpose, scientists at the institute conducted theoretical studies of the rate of movement and shock force of small natural avalanches as well as studies of the mechanical properties of snow. As a result, a foundation was established for designing snow sheds. Results of the studies are discussed by G. Saatchan in 1936 [1].

Also in 1932, at the Teberdinsk National Park in the Caucasus, G. Tushinskiy began studying snow metamorphism and geomorphological and geobotanical signs of avalanche danger on the basis of which he developed a geomorphological classification of avalanches [2].

Beginning in 1933, avalanche observations were carried out in the Khibinskiy Mountains for the apatite mine. The first avalanche service in the USSR was organized at this mine which is still in operation at present and has the longest history of avalanche observation. M. Anisimov summarized these observations where primary attention is focused on forecasting periods of avalanche danger [3].

1950-1960

Avalanche studies which had been interrupted by the war were renewed in the 1950's. A new group of researchers appeared in the Caucasus under the direction of G. Sulakvelidze, continuing the work begun by Saatchan. Investigations were primarily devoted to the study of snow physics, the mechanics of snow avalanches, and the avalanche cycle of the Great Caucasus. The studies of this group led to the creation of the High Mountain Geophysics Institute in 1961 in Nal'chik with a mountain research station in Terskol (Priel'brus') [4].

In the Khibinskiy Mountains, V. Akkuratov perfected a method of avalanche forecasting and proposed a genetic classification of avalanches. He also developed a method of artificial release of avalanches by means of mortar bombardment [5].

Avalanche studies were begun in the mountains of Central Asia in connection with the construction of uranium mines, when, for the first time, the Hydrometeorological Service of the USSR became involved with avalanche research. Special avalanche stations were built serving the mines and their access roads, and a special snow avalanche laboratory was organized at the Central Asian Regional Hydrometeorological Research Institute, Tashkent, providing methodological direction for the avalanche stations and design institutes [6].

1960-1965

In the 1960's interest in avalanche research sharply increased as a result of new development in high altitude regions. New highways and railroads were designed in the mountains of Siberia, the Far East, and in the expanding industrial mining areas of central Asia, and the first ski resorts were constructed in the central Caucasus-Priel'brus' (Cheget) and in the western Caucasus-Dombai.

Meetings in 1963 and 1965 were organized to coordinate the activities of organizations engaged in Soviet avalanche research [4,7]. K. Losev's monograph, Avalanches of the USSR, appeared at this time, in which the author examined the extent of avalanche danger in the USSR, providing the first small-scale schematic map dividing the mountain regions according to factors of avalanche formation, and offering an analytical representation of avalanche forecasting [8].

The Snow Avalanche Problem Laboratory was formed in 1964 at the Geography Department of Moscow State University with two mountain research stations in the Caucasus and the Khibinskiy Mountains. This laboratory is the largest institution involved in avalanche research in the USSR. In 1969, under the direction of G. Tushinskiy and V. Kravtsova, an avalanche map of the Soviet Union was compiled with a scale of 1:7,500,000 [9, 10]. Detailed map studies for the creation of models of large-scale maps (1:25,000) utilizing aerial photography (black-and-white, color, and multispectral) as well as field interpretation preceded the formulation of this map. Analytical methods were developed for the creation of small-scale maps of 1:100,000 and 1:300,000 where direct avalanche observations based on relief analysis, snow cover condition, and vegetation are not present [11].

Detailed geographic methods of investigation were begun at the Snow Avalanche Problem Laboratory. For example, in the dissertation of S. Myagkov, runout debris were studied using modern techniques of soil stratigraphy to determine the maximum runout zone and the frequency of release [12].

A special branch was organized in 1965 by Professor A. Dyunin at the Novosibirsk Engineering Institute for Railroad Transportation for the study of avalanches. This group conducted field studies primarily in Siberia, the Far East, and in Sakhalin. They developed engineering methods for railroad avalanche defense, and constructed a special laboratory model for studying avalanche impact [13].

In examining the publications during this period, one notes that from 1956 to 1965 60 articles were published, whereas from 1965 to 1966, 104 were published; that is, in a two-year period, one and a half times as many were published as in the preceding 10-year period. The following years yielded a still greater number of papers.

1965-1975

At the present time, avalanche studies in the USSR are carried on by about 200 people who have published close to 650 articles from 1956-1973. Theoretical studies in the area of snow avalanche mechanics during the early part of this period were in a formative stage with repect to unity of direction and solution of practical problems of avalanche defense. In 1965, with the appearance of S. Grigoryan's group at the Institute of Mechanics, Moscow State University, theoretical studies changed significantly for the better. A survey of the studies of this group was presented at a conference in Grindelwald in 1974 by Professor Grigoryan [14]; however, most of the works to which he referred in his paper remain unknown to the English reader since they have never been translated. It is planned to elucidate these works in greater detail and to provide a full translation of them in the future. The five major institutes involved in avalanche research are cited in Appendix I.

Appendix I

Soviet Institutions Involved in Avalanche Projects

1. Problemnaya Laborotoriya Snezhnykh Lavin Moskovskogo Gosudarstvennogo Universiteta
   (Snow Avalanche Problem Laboratory, Moscow State University)
   Moscow 117234, USSR
   S. Myagkov (Director), Prof. G. Tushinskiy, Prof. K. Voytkovskiy

2. Institut Mekhaniki Moskovskogo Gosudarstvennogo Universiteta
   (Institute of Mechanics, Moscow State University)
   Moscow 117234, USSR
   Prof. S. Grigoryan (Deputy Director), Prof. Yu. Yakimov

3. Vysokogornyy Geofizicheskiy Institut (VGI)
   (High Mountain Geophysics Institute)
   Nal'chik, USSR
   M. Dolov (Director)

4. Snedneaziatskiy Regionalnyy Naucno-issledovatel'skiy Gidrometeorologicheskiy Institut (SARNIGMI)
   (Central Asian Regional Hydrometeorological Research Institute)
   Tashkent, USSR
   Yu. Moskalëv (Director, Avalanche Laboratory)

5. Novosibirskiy Institut Inzhenerov Zheleznodorozhnogo Transporta (NIIZhT)
   (Novosibirsk Engineering Institute for Railroad Transportation)
   Novosibirsk, USSR
   Prof. A. Dyunin (Chairman of department)

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Snow Avalanche Studies in Iceland

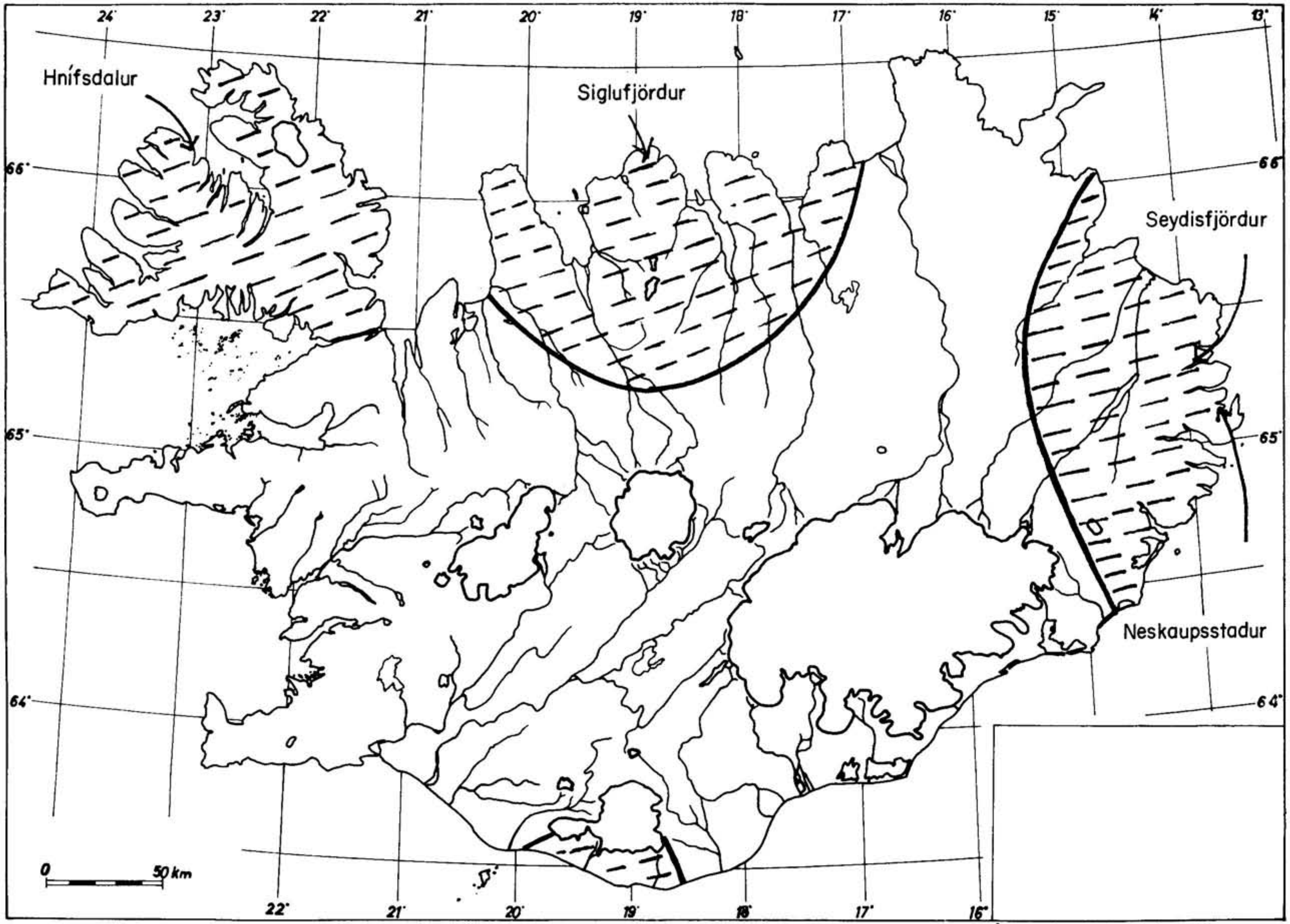
Helgi Björnsson
Science Institute
University of Iceland
Reykjavík, Iceland

Throughout the 1100 years of Icelandic history, snow avalanches have caused more fatalities than any other single natural hazard, accounting for about 600 deaths. The Icelandic record of snow avalanches is one of the longest records available. Ólafur Jónsson's (1957) pioneer work lists all reported avalanches from about 1100 A.D. to 1957. Jónsson (1971) extends the record for the period 1957-1971 and Sigurjón Rist (1975) covers the period 1972-1975. This work is primarily a literature study of annals, newspapers, articles, etc., and reports avalanches which have caused damage to inhabited areas. Rist (1971) analyzes this material for distribution of avalanches in Iceland and the risk to life and property. Figure 1 shows the position of the four main avalanche areas in Iceland.

Table 1 gives the number of people killed by avalanches in the four main avalanche areas. The table is quite accurate for the mid-northern part of Iceland since 1600 A.D. and for eastern Iceland and the northwestern peninsula after 1800 A.D. The mid-northern part of the country has always been the most densely populated of the avalanche areas. It is interesting that the number of fatalities has been quite constant in this area since 1600 A.D. The population in eastern Iceland has never been more than half of the northern Iceland population. The low number of avalanche victims in the 18th century is partly due to epidemics that reduced the Icelandic population and restricted all activities, including traveling. In the 17th century the population had increased, and traveling from farms to the coastal fishing stations was common. The high number of fatalities occurred in the 19th century at the time of increased sheep farming and the growth of fishing villages after 1880. The winters between 1880 and 1920 had high amounts of snow, and as a result, about 110 people were killed by avalanches.

Table 1. Recorded deaths by avalanches in Iceland.

Period	1601-1700	1701-1800	1801-1900	1901-1975	1601-1975	
Avalanche Area						%
Mid-northern Iceland	40	32	44	35	151	34
Eastern Iceland	22	19	72	22	135	30
Northwestern peninsula	22	3	30	49	104	23
Mýrdalur, southern Iceland	0	4	6	3	43	3
Other places	16	1	21	5	43	10
Total	100	59	173	114	446	100



Útgef.: Ríkisútgáfa námsbóka

Figure 1. Main avalanche areas in Iceland

The highest number of fatal accidents has been in the fishing villages: 24 people at Seydisfjördur and Hédinsfjördur in 1910 and 12 at Neskaupstadur in 1974.

The accident in Neskaupstadur in 1974 initiated increased activity in avalanche studies in Iceland. Up to that time all work on the topic had been carried out by volunteers. Now, systematic mapping of avalanches is done by the National Energy Authority (by Sigurjón Rist), the Electricity Board, the Road Authority, and the Post and Telegraphic Office. One fishing village, Neskaupstadur, has already started a detailed program on snow surveys, meteorological observations and avalanche forecasting. The Science Institute, University of Iceland, is studying the value of existing information on weather and avalanches for avalanche forecasting and zoning of avalanche hazard areas.

Recently the Government organized a committee for coordinating and planning systematic avalanche studies in Iceland. The committee has proposed that avalanche study centers should be established in the avalanche areas with headquarters at the Meteorological Office in Reykjavik. The organization plan has not yet been finalized.

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A Report on the Avalanche Workshop, Banff, Alberta, November 1976

Ronald I. Perla
Environment Canada
Calgary, Alberta
Canada

Over 120 avalanche specialists from Canada, U.S.A., Norway, Chile, Japan, and Italy met in Banff, Alberta, on 1-4 November 1976, to discuss current problems in avalanche control, forecasting, and rescue. The workshop was jointly sponsored by the National Research Council of Canada, Environment Canada, British Columbia Department of Highways, Parks Canada, and the University of Calgary. Presentation of 35 papers served to initiate vigorous discussions which were allowed to drift according to the spirit of the group, but which were refocused at appropriate times by the masterful chairmanship of Peter Schaerer.

The theme of the opening session was avalanche control. Due to the lack of participants from the central European countries, the coverage of this topic was uneven, with the greatest interest centering on artificial release of avalanches, and with only brief mention of defense structures. Lengthy debate was addressed to the question of the appropriate amount of explosives for artificial release. Also, some rather exotic methods of releasing avalanches were suggested. In light of the explosive accidents at Mammouth Mountain, California, there was serious concern for establishing safe techniques for handling and storing explosives.

The second session dealt with the problem of avalanche forecasting, with several papers reviewing the current status of numerical prediction of avalanches. Participants were in general agreement that numerical models have a long way to go before catching up with "seat-of-the-pants" forecasting. A few participants expressed the belief that deep slab avalanches are triggered by "sudden temperature changes," rising or falling, but this idea was strongly challenged and the ensuing debate left most questions unanswered. For the first time at any avalanche workshop in North America, government meteorologists from weather offices in Canada and the U.S.A. turned out in force, and by their active participation in formal presentations and discussions demonstrated that their respective organizations have a deep interest in the avalanche problem.

The final session, devoted to safety and rescue, included some of the more heated discussions. It was mentioned that technology is close to developing a rescue transceiver with directional capabilities. However, concern was shown for the proliferation of rescue gadgets, especially when new devices are incompatible with presently accepted units. Managers of helicopter skiing operations presented their views on how to contend with serious problems in the back-country. The session also included presentations on avalanche problems in mountaineering, an important topic badly neglected at previous workshops.

After the Banff presentations, the participants traveled to Rogers Pass to inspect Canada's foremost avalanche defense program.

The proceedings of the Banff Avalanche Workshop will be published by the National Research Council, Ottawa, and should be available early in 1978.

BOOK REVIEWS

AVALANCHE RELEASE AND SNOW CHARACTERISTICS: SAN JUAN MOUNTAINS, COLORADO. Edited by Richard L. Armstrong and Jack D. Ives. Institute of Arctic and Alpine Research. Occasional Paper no. 19, 1976. 256 pp. 7 plates. $7.50.*

This report deals with a four-year study designed to develop methodology for forecasting avalanches in a mountain area characterized by moderately high altitude (2.8 - 4.3 km), high local relief (1.3 - 2.0 km), continental montane climate, comparatively low latitude (37°N), and fairly sparse vegetation (treeline about 3.6 km). In an introductory chapter (21 pp), Armstrong and Ives outline the geography, climate and history of this thinly settled region, and describe the research plans and procedures. The nature and causes of avalanches in the region are discussed by LaChapelle and Armstrong (18 pp), with emphasis on snow characteristics and records of avalanche events. Avalanche forecasting methods tried during the project are outlined by Armstrong and LaChapelle (25 pp), and the results of experimental forecasts are reviewed. Armstrong covers the subject of wet snow avalanches (15 pp), and checks occurrence against air and snow temperatures, slope orientation, time of day, and a parameter intended to represent snow properties. Statistical analysis is treated by Bovis (26 pp + appendices). Development of a discriminant function model is described, the input data are explained and results are given with details listed in appendices. Armstrong deals with the use of gamma ray transmission for recording vertical profiles of snow density (13 pp), and mentions some of the operational problems that were encountered. Harrison describes seismic and infrasonic experiments intended to detect avalanche release (8 pp). Low frequency sonic recorders (0.3 - 0.05 Hz) did not detect avalanche releases; seismic signals from avalanches were generally weak and overridden by "noise," especially from highway traffic. The general appendices of the report (104 pp) cover a winter summary, meteorological and avalanche summaries, an example of data from a local avalanche atlas, and snow profiles at avalanche fracture lines.

The report, which is illustrated by excellent photographs, provides under single cover a complete, concise description of a major investigation. It is a rare pleasure to be presented with so much detailed information in an organized and properly digested form.

Malcolm Mellor
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755 U.S.A.

*Available from: INSTAAR, University of Colorado, Boulder, Colorado 80309 U.S.A. Orders by mail add $.65 handling.

AVALANCHE HANDBOOK. By Ronald I. Perla and M. Martinelli, Jr. U.S. Department of Agriculture, Forest Service. Agriculture Handbook 489, July 1976. 238 pp. $3.95*

The intent of this handbook is a general survey of avalanche characteristics, hazards and control procedure, based on North American experience. It is intended for anyone with an interest in snow, particularly anyone who might encounter unstable snowpacks during work or recreation in the mountains. In keeping with this market, the treatment offered is intentionally neither rigorous nor quantitative.

The volume opens with a short history of the more disastrous avalanches that have occurred in North America during the last century. This serves as an introduction to the rest of the book which covers three broad areas of avalanche work. The conditions which lead to avalanche activity are treated in Chapters 2 and 3. The first of these treats basic meteorology, especially as it relates to snowfall and airflows over mountainous terrain, and the second reviews the physical changes of metamorphism and melt that occur in a snowpack on the ground surface. The mid-part of the book concerns avalanches themselves. Chapter 4 treats the mechanics of failure in the snow cover and of the flow motion in avalanches, as well as the problems of identifying avalanche paths. This is followed, in Chapter 5, by a discussion of avalanche forecasting, including the use of meteorological data and the physical testing of the snow pack on the ground. The last 3 chapters make up almost half of the volume and are all concerned with the control of, and response to, avalanche hazards. This involves a chapter on protection and control procedures in ski areas which includes a relatively long discussion of the use of explosives. A further chapter treats the protection of residential areas and highways, particularly by the use of protective structures and land use zoning. Finally, Chapter 8 offers a summary of search and rescue procedures. The book closes with 5 appendices, including one on the recording of snowpit observations, one on the International Avalanche Classification and one on avalanche reporting.

Throughout, Avalanche Handbook is illustrated by photographs and diagrams; not all of the former are well reproduced or clear but the latter are generally simple and readily understood. In addition, each chapter concludes with a selection of references for further reading with a short comment on each entry. This should greatly assist the reader who is interested in obtaining more information on specific topics.

Given its stated purpose and market, this is a most useful volume. The authors have provided a valuable summary of North American knowledge on avalanches and presented it in a comprehensible way. Anyone with a broad interest in snow and mountain environments should be aware of this book, if only to be able to recommend it to the neophyte.

Nel Caine
Institute of Arctic and Alpine Research
Boulder, Colorado 80309 U.S.A.

*Available from Superintendent of Documents, U.S. Government Printing Office, Washinton, D.C. 20402 U.S.A.

AVALANCHES: A SELECTED BIBLIOGRAPHY, 1950-77

This bibliography has been compiled from several different sources, including the following: Glaciological Notes; Journal of Glaciology; CRREL, Bibliography on Cold Regions Sciences and Technology; Library Catalog of the Scott Polar Research Institute; American Geographical Society, Catalog of the Glaciology Collection; Arctic Bibliography; U.S. Government Reports Announcements; Meteorological and Geoastrophysical Abstracts; Bibliography and Index of Geology; Monthly Catalog of U.S. Government Publications; Library of Congress Catalog - Books: Subjects; Selected Water Resources Abstracts; plus several other miscellaneous bibliographies. During the compilation we discovered that only one-third to one-half of the citations were duplicated among the above sources, indicating the need for this more comprehensive literature survey.

Because of the large body of avalanche literature, it was decided to include only the non-Russian citations in this issue. A bibliography containing approximately 600 Russian citations (including English translations) is currently being compiled and will be published in a future issue of Glaciological Data.

In the bibliography, we assume that the language of publication is English unless otherwise stated. Because we do not have all of the original material in hand, we cannot be certain of the completeness of each citation, although every effort possible has been made to ensure accuracy. Where keywords or phrases were provided by the sources, we have included them as guides to subject content. Since we realize that the usefulness of a bibliography lies in the availability of the original documents, we have marked each item owned by the World Data Center with an "*". Photocopies of any of these documents can be provided upon request at $0.10/page ($1.00 min.) to institutions and individuals. Lengthy publications are available on interlibrary loan to other libraries. We urge you to acquire items not owned by the WDC through your regular library channels or from the publishing agency or author. However, if these methods are unsuccessful, please feel free to call or write the WDC for assistance.

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Marilyn J. Shartran

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3. IN-SITU INVESTIGATIONS OF THE TEMPERATURE DEPENDENCE OF THE CREEP OF LOW DENSITY SNOW, by D.M. McClung
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[snow fences, avalanche countermeasures]

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[snow mechanics, avalanche triggering, avalanche pressure]

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[snow physics, avalanche mechanics, measuring instruments]

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[snow as a material, structure, various conditions causing stability and instability]

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[the methods used in Germany for protecting roads from snowdrifts and avalanches are described]

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[avalanche engineering, avalanche countermeasures]

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[information is given on (1) mass balance studies on Storglaciären which include accumulation, ablation, balance, and the retreat of glacier fronts, (2) variations of the extent of Swedish glaciers, (3) changes in surface profiles on Storglaciären, and (4) a remarkable avalanche in Tarfala]

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[letter from G. Seligman criticizing proposed new nomenclature for avalanches, and reply by M. Oechslin]

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[basic knowledge for ski mountaineers]

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[discussion of avalanche in Austria on 28 January 1956]

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3. METEOROLOGICAL CONDITIONS OF AVALANCHE FORMATION IN THE KHIBINY by V.N. Akkouratov, p. 35-42.
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38. AVALANCHE FORECASTING: A MODERN SYNTHESIS by E. LaChapelle, p. 350-56.
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6. PERMANENT SUPPORTING STRUCTURES by W. Schwarz, p. 56-73.
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ABBREVIATIONS USED IN BIBLIOGRAPHY

AGU Trans. - American Geophysical Union. Transactions.

AIDJEX Bull. - AIDJEX Bulletin (Arctic Ice Dynamics Joint Experiment)

ASCE. Highway Div. J. - American Society of Civil Engineers. Highway Division, Journal.

A.T.A. Assoc. Tec. dell'Auto. - A.T.A. Associaziane Tecnica dell'Automobile.

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Allg. Forstztg. - Allgemeine Forstzeitung.

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Amer. Alp. J. - American Alpine Journal.

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Ann. Meteorol. - Annalen der Meteorologie.

Annu. Eng. Geol. Soils Eng. Symp. Proc. - Annual Engineering Geology and Soils Engineering Symposium, Proceedings.

Arct. Alp. Res. - Arctic and Alpine Research.

Assoc. Amer. Geogr. Ann. - Association of American Geographers, Annals.

Bündnerwald, Bünd. Forstvereins und der SELVA. - Bündnerwald. Zeitschrift des Bündnerischen Forstvereins und der SELVA, Genossenschaft der Bündnerischen Holzproduzenten.

CRREL - Cold Regions Research and Engineering Laboratory.
- -RR - Research Report
- -TL - Translation
- -TR - Technical Report
- -Mono - Cold Regions Science and Engineering Monograph

Can. Electron. Eng. - Canadian Electronics Engineering.

Can. Geotech. J. - Canadian Geotechnical Journal.

Colo. Geol. Surv. Bull. - Colorado Geological Survey. Bulletin.

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-Mitt. - Mitteilungen, Bern. (supplement to Zeitschriften des Schweizerischen Forstvereins)
-Winterber. - Schnee und Lawinen in den Schweizeralpen. Winterberichte. (Winter Report)

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Geogr. Ber. - Geographische Berichte. (Geographische Gesellschaft in der Deutschen Demokratischen Republik)

Geogr. Mag. - Geographical Magazine.

Geol. Bauwes. - Geologie und Bauwesen. Vienna.

Geol. Soc. Am. - Geological Society of America.
-Bull. - Bulletin
-Spec. Pap. - Special Paper

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Hydrol. Sci. Bull. - Hydrological Sciences Bulletin. Supercedes IASH Bull.

IASH - International Association of Scientific Hydrology.
-Bull. - Bulletin. Superceded by Hydrological Sciences Bulletin
-Publ. - Publication

Inst. Snow Ice Stud. Rpt. - Institute of Snow and Ice Studies. Report.

Int. J. Non-Linear Mech. - International Journal of Non-Linear Mechanics.

Int. Sci. Tech. - International Science and Technology.

J. Geol. - Journal of Geology.

J. Geophys. Res. - Journal of Geophysical Research.

J. Glaciol. - Journal of Glaciology.

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Mitt. Forst. Bundes-Versuchsanst. Mariabrunn - Mitteilungen der Forstlichen Bundes-Versuchsanstalt Mariabrunn.

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N.Z. J. Geol. Geophys. - New Zealand Journal of Geology and Geophysics.

Nat. Hist. - Natural History.

Natl. Geogr. Mag. - National Geographic Magazine.

Natl. Res. Counc., Can. - National Research Council of Canada.
- -Assoc. Comm. Geotech. Res. - Associate Committee on Geotechnical Research.
  - -Tech. Mem. - Technical Memorandum
- -Assoc. Comm. Soil Snow Mech. - Associate Committee on Soil and Snow Mechanics
  - -Tech. Mem. - Technical Memorandum
- -Div. Bldg. Res. - Division of Building Research
  - -Tech. Pap. - Technical Paper
- -Div. Mech. Eng. - Divison of Mechanical Engineering
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Neve Intl. - Neve International.

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Oesterr. Ing.-Z. - Oesterreichische Ingenieur- Zeitschrift.

Phys. Unserer Zeit. - Physik in Unserer Zeit.

Rev. Gén. Routes Aérodromes - Revue Général des Routes et des Aérodromes. Paris.

Rev. Geogr. Alp. - Revue de geographie alpine.

Roy. Soc. London, Proc., A. - Royal Society of London, Proceedings, Series A.

SIPRE - U.S. Army Snow Ice and Permafrost Research Establishment (now CRREL)
-SR - Special Report
-RR - Research Report
-TL - Translation

Schweiz. Bauztg. - Schweizerische Bauzeitung. Revue Polytechnique Suisse. Zürich.

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Str. Verkehr - Strasse und Verkehr.

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- -Agri. Info. Bull. - Agriculture Information Bulletin
- -Alta Aval. Study Ctr. - Alta Avalanche Study Center, Wasatch National Forest
  - -Misc. Rpt. - Miscellaneous Report
  - -Rpt. - Report
  - -Transl. - Translation
- -Pac. NW For. Range Exper. Sta. - Pacific Northwest Forest and Range Experiment Station, Portland, Oregon
  - -Res. Pap. - Research Paper
- -Rcky. Mt. For. Range Exper. Sta. - Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado
  - -Gen. Tech. Rpt. - General Technical Report
  - -Pap. - Paper
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ERRATUM

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