A HISTORY OF AVALANCHE HAZARD AND AVALANCHE RESEARCH IN THE SAN JUAN MOUNTAINS, SOUTHWESTERN COLORADO, USA

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ABSTRACT:

The San Juan Mountains' recorded avalanche history began simultaneously with mineral exploration in the 1870s. Development of mines and transportation systems and huge influxes of miners and associated personnel, railroad workers, packers, cooks, etc., placed humans and structures in the paths of avalanches. A century later, in the late 1960s, the Bureau of Reclamation funded an operational winter cloud-seeding program for the San Juan Mountains, bringing renewed attention to avalanche hazard. In response to citizen requests, the Bureau of Reclamation funded an avalanche research project through the University of Colorado Institute of Arctic and Alpine Research (INSTAAR), known as the San Juan Avalanche Project. This paper summarizes some of the diverse research projects undertaken by the San Juan Avalanche Project from 1971 through 1987. Research included basic observations and data collection of weather, snow cover and avalanche activity along U.S. 550 and Colorado 110; automated avalanche occurrence detection; physical and mechanical properties of snow and specific snow metamorphism studies; conventional and numerical avalanche forecasting; exploring alternative methods of avalanche control; avalanche zoning (path identification, mapping, runout distance and impact pressure estimates) and historical studies to determine locations and frequency of major avalanche occurrences. We describe the process by which this long-running research project was initiated, the key players responsible for both the field operations and the scientific guidance supporting the research, the additional agencies that provided funding for the various research tasks, and selected publications that resulted from this project.

KEYWORDS: avalanche monitoring, forecasting, control, history, zoning, snow metamorphism

1. BACKGROUND AND INTRODUCTION

In May of 1971 the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, Boulder, was awarded a contract by the Bureau of Reclamation, Office of Atmospheric Water Resources (U.S. Department of Interior). Initial funding was provided for three years in support of the study to learn the causes of snow avalanches along Highway 550 between Coal Bank Hill and Ouray and other secondary roads in the San Juan Mountains and to develop a forecast model to predict their occurrence. The San Juan Avalanche Project (SJAP) was a part of the Bureau of Reclamation's proposed "Project Skywater", which was a winter cloud seeding pilot study. The developers of Project Skywater predicted a precipitation enhancement potential of from 10 to 30 percent. If such results were to be obtained, the impact on avalanche activity would be significant as more than 100 avalanches paths cross Highway 550 alone (Miller et al. 1976; Armstrong and Armstrong, 1977) . Thus the justification for the initial request for proposals from the Bureau of Reclamation for this study.

The principal investigators for the first year of the SJAP were Drs. Jack D. Ives, Director, Institute of Arctic and Alpine Research, (INSTAAR), J. Christopher Harrison, Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, and Donald L. Alford, INSTAAR. Alford acted as field project director during the first year of the project and Richard L. Armstrong served as field project director and principal investigator during the remaining 16 years of the project.

Continuous funding for the SJAP throughout its 17 year history was provided by the Bureau of Reclamation. The program managers, Archie Kahan, Olin Foehner and John Lease, were consistently supportive, maintained a close association with our work and played productive and creative roles throughout the project. At various times throughout the project additional

funding was also provided by the U.S. Army Research Office, NASA, the Colorado and Washington Departments of Transportation, the U.S. Geological Survey, the State of Colorado and San Juan, Ouray and San Miguel counties.

Other key personnel during the first years of the project included:

Scientific Consultants: Dr. Edward R. LaChapelle, University of Washington and the U.S. Forest Service, Dr. Malcolm Mellor and Dr. Wilfred Weeks, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire. These three scientists together represented world renowned expertise in snow and ice physics and avalanche science and the SJAP benefited enormously from their participation.

Initial Field Team: Primary participants, Richard Armstrong, Don Bachman, Rod Newcomb, Betsy Armstrong and John Clark.

Additional field personnel at various times throughout the project: William Isherwood, Len Miller, William McClelland, Thomas Carroll, Juris Krisjansons, Imants Virsnieks, Ronald Lindsay, Gail Davidson, Leland Dexter, Tim Lane and Jerry Roberts. There were certainly other participants who provided expertise, labor, or both, to this project who are not listed here and we apologize for not mentioning each and every one of them.

Close and productive working relationships were maintained with the Colorado Department of Transportation and in particular Noel Peterson, S.R. “Tuffy” Foster and Ray Ledford as well as with the San Juan County Sheriff’s Office, in particular, Sheriff Virgil Mason and Deputy John “Scotty” Jackson.

2. SELECTED RESEARCH PROJECTS

2.1 Avalanche event monitoring

Avalanche activity was monitored immediately following storms within the study area adjacent to the highway system by way of direct observations from road patrols. In addition, certain avalanche paths with a record of frequent activity were monitored with trip wire/clock installations in order to obtain the exact timing of the avalanche release. A new method of avalanche detection using both seismic and infrasonic sensor arrays was applied during the first two years of the project. This experiment was supervised by Dr. J. Christopher Harrison, Director of the Cooperative Institute for Research in Environmental Sciences (CIRES) University of Colorado and his graduate student, William Isherwood. Both of these systems were tested in the region of the Muleshoe curve at Chattanooga, typically during artillery control. Weak high frequency signals from the seismic sensors were detected for both the explosive charges and the moving avalanches while no clear signals were detected by the infrasonic microphones. All types of recorded avalanche activity were transmitted to the U.S. Forest Service West Wide Avalanche Data Network Project in Ft. Collins Colorado.

2.2 Avalanche cause determination and avalanche forecasting

Prior to about 1970, much emphasis was placed on the primary meteorological variables contributing to avalanche release with a lesser emphasis on the details of snow stratigraphy. This approach was succinctly summarized in the well-known “contributory factors” described by avalanche research pioneer Montgomery Atwater as early as the 1950’s. These contributory factors provided certain parameter threshold values favorable for producing significant avalanche activity. These threshold values were useful only as rough rules of thumb and were typically not applicable to individual situations in forecasting. As snow and avalanche climates varied, so did the rules. This became immediately apparent to Ed LaChapelle when he began his work in the San Juan Mountains. In the second annual report of the SJAP, LaChapelle identified what he termed a radiation snow climate resulting from the predominantly low latitude, high altitude continental climate. Thus a substantial amount of solar energy is available to east through south to west facing slopes even during mid-winter, increasing rapidly as spring approaches. At the same time, the combination of high altitude and frequent low humidity leads to intensive nocturnal radiation cooling on all exposures. These conditions lead to widespread temperature-gradient metamorphism and the formation of depth hoar within the snow cover. “Radiation recrystallization”, described by LaChapelle

(1970) was frequently observed in the surface layers on all but north-facing slopes. These conditions contributed to a snow cover with low mechanical strength and a strong stratigraphic differentiation. The moderate snowfalls and radiation snow climate of the San Juan Mountains combine to produce a snow cover which in most avalanche release zones and for most of the winter can be described as conditionally unstable. By conditionally unstable, it was meant that at any given time while the snow cover is at sub-freezing temperatures, it may be only marginally unstable with respect to spontaneous slab release through internal causes, but it remains highly susceptible to either load-induced or thaw-induced avalanche release throughout the winter. These conditions differed significantly from the maritime and intermountain snow climates (Armstrong and Armstrong, 1987) where much of the previous avalanche research had been undertaken. Thus it became an important task of the SJAP field team to dig snow pits and extract essential snow properties such as density, crystal type and size, hardness, temperature and wetness representative of a comprehensive sample of aspects and elevations throughout the study area. This specific emphasis on snow structure, along with weather factors, was a significant departure from previous methods to determine the causes of and prediction of avalanches. In addition to study site snow pits, at both level and slope locations, the SJAP generated one of the most comprehensive collections of fracture line profiles available at the time. Although all personnel were involved in the fracture line profile work, the vast majority of these data were collected by Rod Newcomb.

Avalanche forecasting within the SJAP was undertaken using both the conventional or subjective approach based on the experience of the forecaster as well as through the development of one of the earliest applications of a numerical model. Conventional forecasting was based, in general, on the approaches of the time, best described in the *Avalanche Handbook* written by R. I. Perla and M. Martinelli and published by the U.S. Forest Service as well as publications by LaChapelle (1966, 1970). One interesting experiment undertaken by the SJAP within the scope of conventional forecasting was the attempt to determine the role of field experience in the accurate determination of avalanche hazard. Project participants ranged from those with many years of forecasting and control experience to those with limited or interrupted experience, to those with a strong background in meteorology but no experience in avalanche forecasting. Results of the experiment indicated that, as one might expect, those personnel with greater direct experience with avalanche forecasting demonstrated a higher accuracy but results also indicated that these experienced personnel had some difficulty verbalizing just exactly what method or procedure they had used to arrive at the more accurate forecasts. The conclusion was that the difficulties in the systematic codification of these skills and their written transmission in support of the education of a person new to the field constituted a significant and continuing problem within the field of avalanche forecasting.

The numerical method was based on the statistical analysis of the relationship between avalanche occurrence and contributing snow cover and weather variables. This method could only be applied after sufficient snow, weather and avalanche data had been collected. At the end of the third year of the project the results from the initial effort to generate numerical forecasts using linear discriminant functions were published by then University of Colorado graduate student Michael Bovis (Bovis, 1977).

2.3 Snow metamorphism

Snow metamorphism was monitored at snow pits systematically obtained at both level and slope study sites at consistent time intervals. In addition, stratigraphic density changes were monitored by both a profiling and fixed isotopic gauge (radiation attenuated with increasing density). Density and strain rates were also measured using a settlement gauge where changes in electrical resistance indicated the rate of downward vertical movement over time of platters initially placed on the snow surface and clipped into a nichrome wire circuit. Using this method, settlement rates for depth hoar, fine-grained, and wet snow were clearly characterized. The relationship between strain rate and density for both equi-temperature (equilibrium) and temperature gradient (kinetic) snow was also demonstrated (Armstrong, R., 1977, 1980, 1985). Snow metamorphism was also systematically monitored within layers of new snow under natural conditions at a study site in the town of Silverton as well as under

controlled conditions in a cold laboratory. Results showing the rate and extent of temperature-gradient (kinetic) metamorphism as a function of vapor pressure gradient were described (Armstrong, R., 1980, 1985). Additional studies involving methods to model snowpack evolution were undertaken by Dexter (1987).

The SJAP afforded the somewhat unique opportunity to advance the understanding of wet snow avalanches because much of the previous avalanche research had been undertaken at alpine ski areas which typically ceased operation before the final phases of the wet snow avalanche season. Thus limited attention had been given to this type of release. The SJAP maintained observations throughout the wet snow avalanche season which could continue into June in the higher elevation north-facing starting zones. Relationships were established between mean daily air temperature, the penetration of the zero degree Celsius isotherm into the snow cover and the distribution of liquid water in the snow cover (Carroll, 1977) and the potential for the release of wet slab avalanches. It was also noted that, all other conditions being equal, the probability of large wet slab releases increased in winters with exceptionally thick depth hoar layers at the base of the snow cover (Armstrong et al. 1974).

2.4 Alternate methods of avalanche control

As a result of concerns regarding the diminishing availability of military weapons and ammunition for avalanche control. funding was provided by Washington and Colorado Departments of Transportation to investigate alternate methods of avalanche control. Within the SJAP, two techniques were extensively tested over several winters. The first method involved the remote ignition of a mixture of oxygen and acetylene within canisters placed in avalanche starting zones. At ignition the expanding gasses forced the movable lid of the canister upwards into the base of the overlying snow cover. The jargon term used for these devices was “thumpers”. When correctly placed, this method proved reasonably effective in the release of slab avalanches in the relatively shallow and structurally weak snow cover of the San Juans.

The second method involved the placement of large rubber bladders on the ground at the anticipated location of cornice formation. (These devices were originally designed to occupy large empty spaces in partially filled railway freight cars and other cargo containers.) These bags were inflated by a compressor, again from a remote location, essentially levering and displacing the cornice out onto the starting zone below. Although avalanches were successfully triggered using this method, problems resulted from the need for precise placement of these devices as well as pressure losses resulting in under-inflation as well as the obvious consequences of their inadvertent over-inflation.

2.5 Historical Studies of Avalanche Occurrence and Frequency

With funding from NASA, the State of Colorado (H.B. 1041), and the counties of San Juan and Ouray, we undertook studies to identify and map the locations of avalanche activity in San Juan and Ouray counties. This work involved researching the historical record by using primary sources: newspapers dating back to the early 1880s, both in original form and on microfiche, county records of mining claims, and interviews with county residents who had direct experience with the impacts of avalanche activity on transportation, work related activities, and daily lives. We also reviewed secondary sources, e.g. books and reports, although these sources weren’t as accurate as the original source materials.

After accumulating these data, we mapped the sites on U.S.G.S. 1:24,000 scale maps covering the two counties, field-checked many of the sites to determine accuracy of the historical data, and incorporated the maps into two historical studies, *A Century of Struggle against Snow* (for San Juan County), (Armstrong, B.,1976) and *Avalanche Hazard in Ouray County, Colorado*, (Armstrong, B. 1977).

An additional historical study for San Miguel County, *Avalanche Hazard Areas in the Telluride Mining District, Colorado*, was completed in cooperation with the U.S.G.S. and included searching the literature for primary and secondary sources, field checking, and publication as a U.S.G.S. map for the Telluride quadrangle (Armstrong and Carrara, 1981). The San Juan historical studies and mapping

projects contributed to the knowledge base of the county planning commissions and were used to determine avalanche zoning laws.

2.6 Avalanche mapping

The San Juan Avalanche Project updated and enhanced the only published atlas of avalanche paths affecting U.S. Highway 550 (Frutiger, 1964) with two publications that mapped avalanche activity along this highway, on Colorado Highway 110, and within the town of Silverton (Miller, et al. 1976; Armstrong and Armstrong, 1977). Incorporating historical data from the historical studies (Armstrong, B.,1976, 1977) and avalanche frequency data from the C.D.O.T., avalanche paths were outlined for their maximum runout on U.S.G.S. 1:24,000 scale maps. The atlases were published as INSTAAR Occasional Papers.

In a paper published by the Western Snow Conference, avalanche hazard on U.S. Highway 550 was analyzed using avalanche frequency data, the avalanche maps, and a model devised by Peter Schaerer to assess hazard on Canadian highways (Schaerer, 1974; Armstrong, B., 1981).

With funding from NASA, we undertook a mapping project on a coarser scale then the maps described above but covering the entire San Juan Mountains area. INSTAAR also investigated the avalanche potential for the townsite of Ophir in San Miguel County, and created a larger scale avalanche map for this area.

3. CONCLUSION

During the lifetime of the SJAP project, personnel provided significant and influential expertise to a wide community concerned with avalanche problems. Beyond the annual reports produced for the U.S. Bureau of Reclamation and other funding agencies mentioned above, the project generated 23 journal articles and conference proceedings articles and made substantial and continued contributions to the U.S. Forest Service National Avalanche School as well as other local and regional avalanche training courses. Two Doctoral Dissertations and one Masters Thesis resulted from the project. In addition, project personnel also served as authors of the 1990 National Research Council/ National Academy of Sciences publication *Snow Avalanche Hazards and Mitigation in the United States* (Voight et al. 1990).

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