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Avalanche Conditions and Avalanche Research in the United States

with recommendations for future work

SNOW, ICE AND PERMAFROST RESEARCH ESTABLISHMENT

Corps of Engineers, U. S. Army

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AVALANCHE CONDITIONS AND AVALANCHE RESEARCH IN THE UNITED STATES

with recommendations for future work

by Alfred Fuchs

This report is based on a visit to most of the important avalanche areas and research stations of the western United States during the period February 15 through March 21, 1955. The work was done under SIPRE Project 22.2-8.

Manuscript received May 23, 1955.

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ABSTRACT

Most of the important avalanche areas and research stations of the western United States were visited during the period February 15 through March 21, 1955. The avalanche defense measures and research work are discussed. Suggestions are made for improving methods of predicting avalanche danger and for control by explosives. For some avalanches, other defense measures (snow fences, barriers, reforestation) are proposed. The work and equipment of the research and observation stations are appraised, and in some cases improvements suggested. A research program suited to the existing facilities is outlined.

CONTENTS

INTRODUCTION AND SUMMARY

Under SIPRE project 22.2-8 (Study of avalanches), I have visited most of the practically important avalanche areas of the western states during the period February 15 through March 21, 1955. The object of this paper is to report my impressions, to discuss the avalanche defense measures and the avalanche research work already done, and finally to make some proposals for further work on the basis of my knowledge of similar work in Europe. Many of the statements made in this report about control measures and changes in the research stations must be considered as preliminary and subject to review after I have seen the areas without snow.

Thanks to the friendly and patient introduction by the local observers, and on the basis of the publications and reports, I have obtained a good insight into the situation. I see the following main problems of avalanche research in the United States:

1. Avalanche forecasting: In order to protect highways and winter sports areas against avalanche accidents, it is necessary to survey and predict the increase and decrease of the avalanche hazard. The research has already made a promising start. The goal of this work is to obtain more and more knowledge about the relations between the development of the snow cover and the formation of avalanches and to gradually supplement the practical experiences of the observer by data measured under well defined conditions. Thus the countermeasures will become more and more effective and will be applied at just the right time.

2. Avalanche control by explosives: In several places this work is done routinely with good results. It is important to develop this method further. Most of the avalanches should be released several times during bigger storms in order to bring down smaller avalanches which either will stop in upper parts of the slidepaths, or will be stopped easier by mounds or dams, or can be removed more easily from the highways. Therefore, it is necessary to have a gun or other device which allows blind firing. It would be important also to have a easily movable gun which can be carried by a ski lift. The effect of explosives on the snow cover should be studied under defined conditions.

3. Snow fences and wind baffles as avalanche defense structures: In many avalanche areas, snow fences would be very effective by causing more sedimentation in specified places and preventing erosion. Snow fences on windward slopes could diminish the quantity and the shape of the deposited snow on the leeward slope, and thus would diminish the size of the avalanches or facilitate defense measures (reforestation, construction). The formation of cornices can be prevented by fences or wind baffles. Systematic tests with fences and wind baffles should be made on slopes and crests, perhaps together with model tests in a wind tunnel.

4. Barriers: Perhaps some of the avalanches menacing an important highway must be controlled by barriers. The theory and practice of this kind of structure is quite well known. Their applicability to conditions in this country has to be studied.

5. Reforestation: Some fracture areas and windward slopes could be reforested. The growing trees have to be protected against avalanches, creeping, and slow sliding of the snow cover. There is, however, a chance that trees which are very resistant to avalanches could be planted without protection by expensive barriers. These trees, planted in different patterns, should be observed both in an avalanche path where no other control is used and where the avalanche is controlled by explosives.

6. Basic research: Some basic research should be done, as far as it is possible without laboratory facilities. In connection with the avalanche problem, the formation of slab and depth hoar in relation to the exposure of the slopes and the climate could be studied, and the relations between the development of the snow cover and the formation of the avalanches could be further clarified.

In this country much has already been done in the investigation of avalanche formation. The precipitation intensity and other avalanche contributory factors have been discerned and their interrelation has been analyzed for many storms. New instruments have been invented. The technique of avalanche control by explosives has been worked out very well.

But I do not believe that there will be much more progress if the work is continued as in the past. The test conditions I have seen were in most cases rather poorly defined.

In my opinion the problems mentioned above can be solved only under much better defined conditions. I also think that none of the existing research stations are suitable for this research work in their present form.

I do not criticize the work already done without realizing the difficulties with which the research workers have had to contend. They have had to begin research without being able to choose a suitable location, and have had to carry out other duties as well.

In this report, I propose some fundamental changes and a program fitted to the existing equipment and personnel. But it would be best to formulate the program and choose the means only with regard to the problems.

As the first step, I recommend improving the test conditions (new installation of test fields and instruments) and beginning a few simple practical research projects.

It is expected that the results of the proposed research program, with the changes in instrumentation, will reveal some fundamental laws even for such a complicated structure as snow. Once research facilities have been improved and experience in the study of snow gained, it will be possible to enlarge the research and tackle other outstanding problems.

Figure 1. North slope of Arrowhead Mountain with the two Barne slides (two gullies without trees). (Photograph by A. Fuchs.)

Figure 2. Gainor Slide, Stevens Pass, Washington. The slide breaks off on the slope left of the gully and goes through the gully towards the observer over the debris cone in the foreground. (Photograph by A. Fuchs.)

CHAPTER I

MAIN AVALANCHE PROBLEMS IN THE UNITED STATES, REPRESENTED BY SEVERAL EXAMPLES

In the following examples, taken from different climates, I will describe the methods of avalanche control work that I have seen applied and the methods that I would recommend in addition. But I emphasize expressly that all the following recommendations are made with reservations, since I have not studied the avalanche areas when they were free of snow. The following suggestions are only mentioned as examples in order to give an outline of the avalanche problems in this country.

In the individual cases the technical problems are quite similar to those in the Alps. However, in the highly populated European Alps, many farms and villages are menaced by avalanches, while in the United States, the purpose of avalanche control is limited to protecting traffic routes and skiers in winter sports areas. For this reason, defense constructions in the fracture areas of the avalanches have not yet been used in this country, but with minor exceptions only avalanche control by explosives has been applied.

In most of my proposals in the following examples the ultimate goal of the countermeasures is a lasting defense in the form of snow fences, barriers, or reforested timber. This is not always the only way. Some of the avalanches can well be controlled from a distance by explosives. The technique could be developed into a routine well suited to the local conditions, and the prediction of the avalanche hazard could be perfected. The first type of defense solves the problem permanently. The second type requires continual observation of snow conditions and repeated artificial release of avalanches. The final decision between the two ways must be made from the economic standpoint. For instance, if one or more of the avalanches along a highway can only be controlled by gunfire , because the fracture areas are above the timberline and defense constructions would be too expensive, then it might be more efficient for the highway maintenance crew to control other avalanches by gun also, rather than by defense constructions.

Stevens Pass ski area (Washington):

Around the ski trails, the avalanches are controlled by hand-placed explosives. This work could be done much easier and without risk for the crew by a light gun or rocket launcher transportable by the ski lift(discussed later).

Barne slides (Arrowhead Mountain, Stevens Pass):

Figure 1 shows the north slope of the Arrowhead Mountain on the east side of the Stevens Pass. Avalanches break off occasionally from the two gullies and cover the road. Apparently the avalanches occur because there is more wind-deposited snow in the gullies. The timber is scattered around the gullies, but very heavy in the vicinity. I see two possibilities of avalanche defense here. The slope could be reforested successfully if the ground is fertile enough. In the meantime some defense constructions could prevent avalanches, if necessary. The other way would be permanent control by shooting.

Gainor slide, Stevens Pass:

About 7 mi. east of the pass a narrow side valley comes from the north. It has formed a large debris cone, crossed by the highway (Fig. 2.). After heavy storms and in the spring, a big avalanche breaks off the western slope (left slope in Fig. 2) and flows over the road, sometimes covering a large area very deeply. Figures 2 and 3 show many young trees in the fracture area. These trees apparently are growing in spite of the fact that big avalanches cover them and bend them down to the ground. Therefore I think that reforestation could be tried.

Here and in many other places it would be very important to have a method of reforestation which allows avalanche control by explosives while the trees are growing. It does not seem to be impossible, if the right kinds of trees are used (for instance pinus flexilis, abies lasiocarpa, which are tough enough to stand up again

Figure 3. Gainor Slide. View from east to Avalanche slope. (Photograph by A. **Fuchs.**)

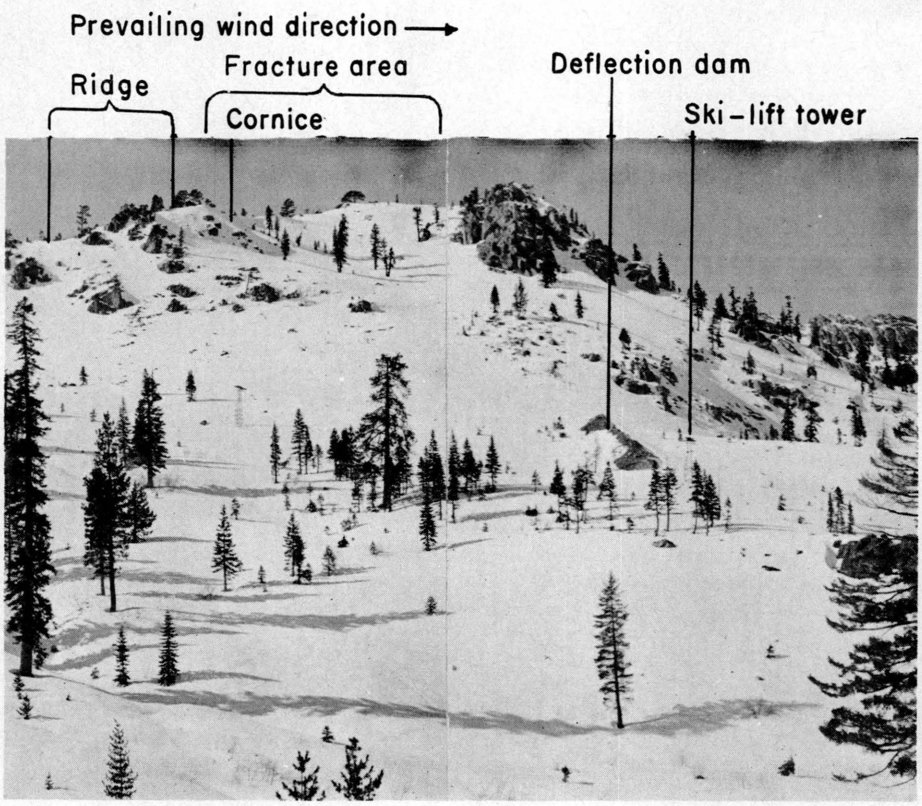

Figure 4. Winter-sports area, Squaw Valley, California. One tower of the main ski lift was damaged by a slab avalanche some years ago. Later, a deflection dam was built to protect the tower. (Photograph by A. Fuchs.)

Figure 5. Winter-sports area, Squaw Valley, California.

Convex slope to left of top terminal of upper ski lift. Prevailing wind direction is over the ridge towards the observer. Thus, more snow is deposited in the area near the upper borderline of the shadow, causing slab avalanches. (Photograph by A. Fuchs.)

in summer after being bent down by the avalanches).

I think that it would be possible to stop the avalanche on the debris cone by deflection dams and mounds before it flows across the highway, if it is released repeatedly by blind firing during the storms, before it grows large.

Squaw Valley winter-sports area (California):

Several years ago a tower of the main chairlift was damaged by an avalanche which broke off in a small bowl on the leeward side of a ridge (Fig. 4). In consequence a deflection dam was built to protect the tower. This dam does not have quite the right shape and position: the end toward the lift-tower is rounded too smoothly and is too far from the tower. It seems to me that the avalanche could flow together again in the space between the end of the dam and the tower.

Probably this avalanche could be controlled by snow fences on the plateau behind the ridge. They would hinder the transport of drift snow into the bowl. From the material of the dam, a mound could be built closer to the tower.

The avalanche which comes from the east ridge of Squaw Peak on the end of the valley (Fig. 5) threatens the terminal of the main lift. The slab breaks off on the convex NE-slope, on which drift snow is deposited by winds coming from west and southwest. A deflection dam was built to protect the terminal, but is probably too low for big avalanches. In my opinion two things should be done: the dam should be raised (if loose material is available in the vicinity) and the avalanche should be controlled, either by blasting (if necessary, during the storm) or by snow fences beyond the ridge. A final decision can be made after a visit in summer.

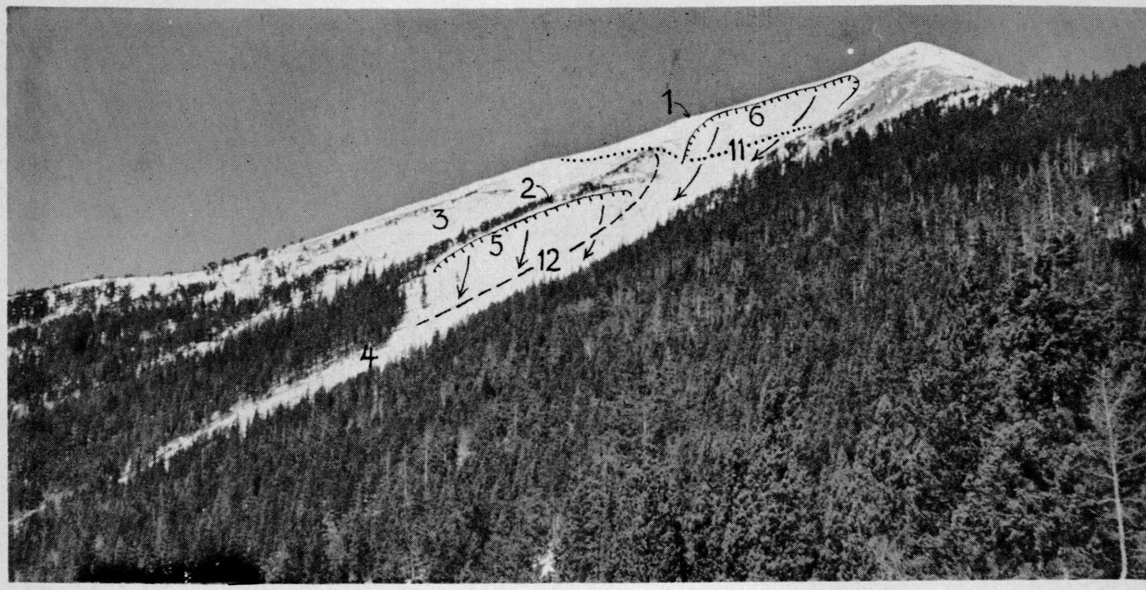

Figure 6. Upper part of Stanley Park slide, Berthoud Pass. For explanation of numbers, see text. (Photograph by E. LaChapelle.)

Alta winter-sports area (Utah):

In the ski area of Alta, the center of avalanche research in the United States, avalanche control is accomplished by routine use of artillery, hand-placed explosives, and skiing. I was there during a period of big avalanches and I would like to express my opinion about these events.

For several days the road was closed by many avalanches of different size. I think that some of the snow masses on the road would have been much smaller if smaller avalanches had been released by blind firing at intervals during the snow fall.

If a light gun could be transported by chair lift to the Collins Basin or by weasel to the Albion Basin, avalanche control could be accomplished just as effectively and much faster than by hand-placed explosives, without endangering the patrol.

Stanley Peak slide (Berthoud Pass, Colorado):

This avalanche comes from Stanley Peak to the south and crosses the two legs of the switchback of the highway over Berthoud Pass (see Figs. 6, 7, 8).

The prevailing winds come from westerly directions during and between storms. Blowing across the SW-ridge (1) of Stanley Peak, they deposit much snow on the leeward side of the ridge. Therefore, and because of the strongly marked formation of depth hoar, large slab avalanches occur which break off along the lines (5) and (6). The gully (4) comes down from the fracture area. But the avalanche does not always use this path alone. It sometimes jumps out of the gully to the east near (8) and takes the two paths (9) and (10) through the timber. Thus the upper leg of the switchback is crossed at three places side-by-side. The slope between the two legs of the road in the slidepath is without trees (see Fig. 7 and 8). The lower leg is just barely crossed by the avalanche in a large front. It seems that the avalanche never comes in the form of a dust avalanche.

At present the avalanche is controlled by artillery fire.

As far as I could see the snow conditions and the features of the slope from afar, the following preliminary statements can be made about the control:

The average total depth of snow fall is only 200 in. (that is about 80 in. settled snow). It should not be too difficult, first, to force the snow to accumulate

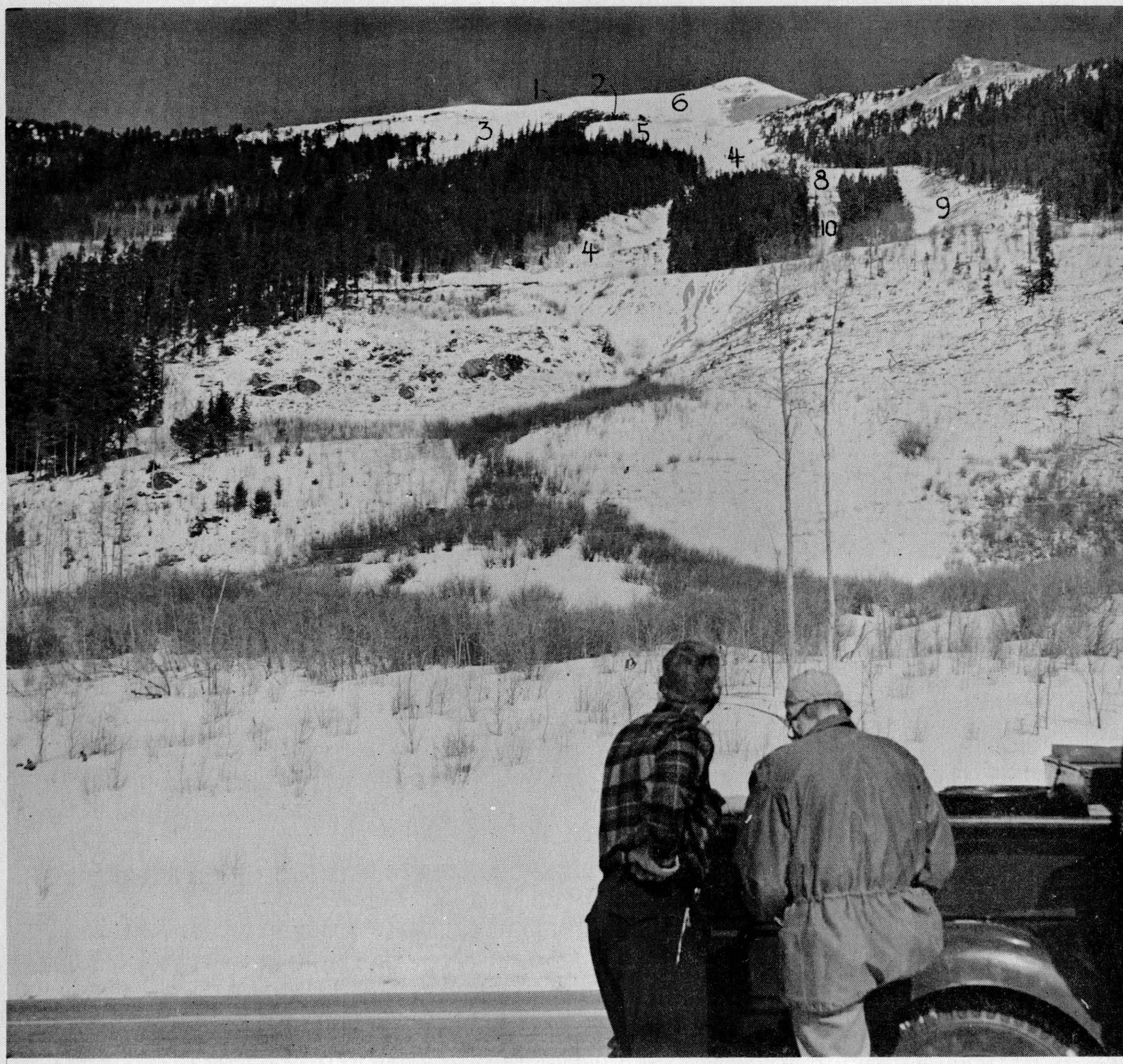

Figure 7. Looking up Stanley Park slidepath from lower leg of road leading to Berthoud Pass. (Photograph by E. LaChapelle .)

on areas where it cannot break off and, second, to prevent erosion and resedimentation on other areas. Usually the wind is stronger between than during storms, so we have to consider erosion and resedimentation. However sometimes bigger storms with 30 in. new snow occur with more or less wind.

The first step should be to try to prevent the erosion of snow by snow fences on the windward side (the slope beyond ridge (1)). The arrangement and the size of the fences depend on the size and features of the area. These fences will also hinder transportation of snow during storms from the windward to the leeward side.

The vicinity of ridge (2) , which is timbered only on the west side by a narrow strip of trees, presents a special problem. On the east side (leeward) , much snow is accumulated in the form of an elongated cushion along which slab avalanches break off. It is not yet evident if this excess of snow is deposited in the eddy zone caused by the whole strip of timber or if the snow is picked up in area (3) and blown through the narrow and scattered timber during snow drifting. This question should be answered by observations on the spot during a storm and during a snowdrift period before any fences (in the timber and on the west side) are built.

Figure 8. Looking down Stanley Park slidepath from upper leg of road leading to Berthoud Pass. (Photograph by E. LaChapelle.)

With effective fences, not much excess snow will be deposited in areas (5) and (6) and the avalanches released by gunfire will not be so big.

Moreover a deflection dam could be made on the east side of the gully near location (8) (if there is enough material) in order to hinder the avalanche along paths (9) and (10). Also, these paths should be reforested.

In order to obtain a durable protection against snow drift, other areas west of the line (12) and below the timberline (11) should be reforested.

If the avalanche is confined to path (4) only, the road could probably be shifted towards the slope in a gentle curve and then protected by a shed.

Figures 7 and 8 show that the avalanche tends to stop in the flat area north of the lower leg of the road. I am sure that earth mounds here would protect the road.

If all these measures can be carried out, and if it is possible to shoot during storms and snow-drift periods, the avalanches will not be large and the highway will never be blocked.

Figure 9. Bethel Mountain slide, looking from road to Loveland Pass. (Photograph by E. LaChapelle.)

After the planned study of the avalanche area in summer, I will be able to estimate the possibilities of building defense structures in the fracture areas. With such barriers, and with reforestation, the whole problem could be solved.

Floral Park, Berthoud Pass:

The avalanche slope is covered by timber too scattered to prevent the fracture or stop the avalanche. The fracture area is located near the timberline. Above the timber the slope is bare most of the time because of the strong winds. The avalanche is controlled by artillery fire.

Probably no avalanches would occur if the timber were more compact, and it is obvious to propose some planting of new trees in the clearings. Perhaps, near the timberline, some single barriers, or nets hooked to trees, or baffles in areas open to the wind may prevent the fracture of a slab.

Bethel Mountain slide (Loveland Pass, Colorado):

Like the Stanley Peak slide, this avalanche (Figs. 9, 10) is caused by excess snow drifted into a large bowl. Snow fences on the windward side should cut snow-drifting. But the question arises: how much of the south slope must be controlled by fences in order to prevent erosion and hinder accumulation on the leeward slope? The large fracture area is above the timberline, so the only control method besides heavy barriers seems to be artillery fire. If the avalanche can be kept small (by firing during the storms and prevention of snow drifting onto the slope) the road probably could be protected by earth mounds.

The uniformly shaped south slope seems to be right for experiments with snow fences and perhaps with windbaffles too (see Fig. 10 and Ch. III, section B3c).

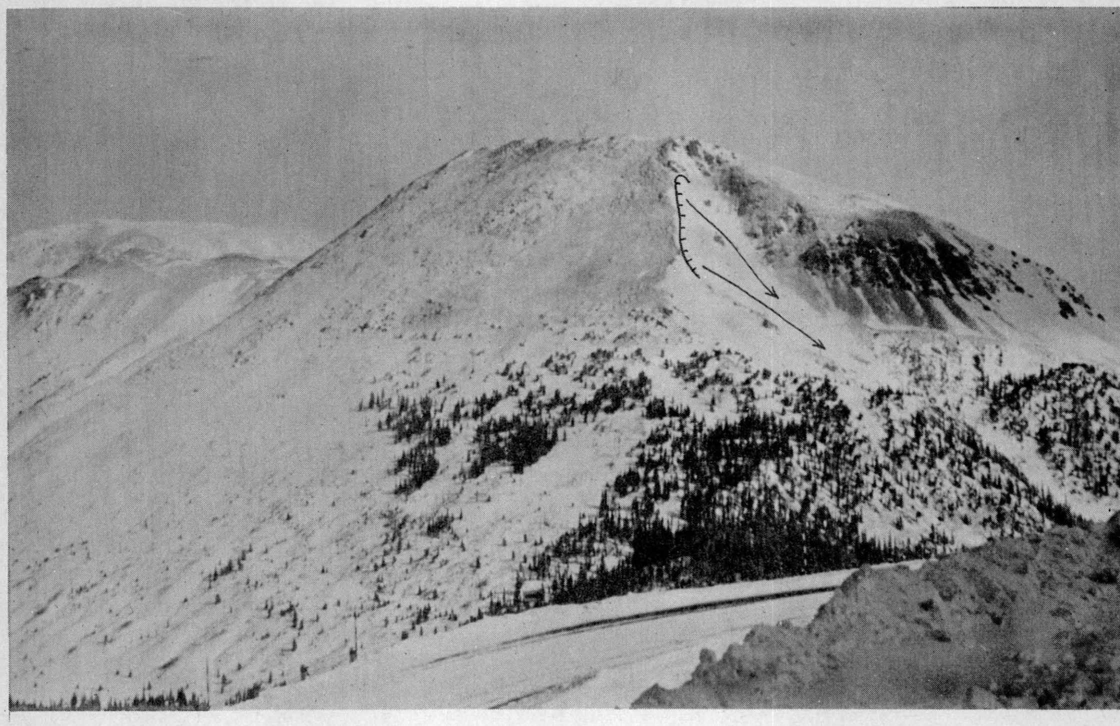

Figure 10. Bethel Mountain as seen from near summit of Loveland Pass. The uniform SSW-slope on the left side of the ridge facing the observer is without snow most of the time (the picture shows a thin new snow cover). The winds blowing across this slope transport the snow onto the slope to the right of the ridge, where the Bethel Mountain slide breaks off. The SSW-slope would be very suitable for tests with snow fences in order to prevent erosion and transportation onto the leeward slope (see text). (Photograph by E. LaChapelle.)

Seven Sisters slides (Loveland Pass):

As Figure 12 shows, there is very strong wind action in this area also. The snow is blown from exposed ridges and slopes and redeposited in bowls and gullies. The streamlines of the wind are conspicuous in the picture.

In the Seven Sisters slidepaths, some experiments were made with avalanche defense structures last winter (see Fig. 11: fences in slidepaths #2, 3, and 6; wind-baffles in #7). I think that these were not correctly placed for experiments because the slide areas are targets of gunfire.

There are three possible ways to control these avalanches: 1). Development of a good snow-information and avalanche-warning system. Continued control by gun fire, if necessary during storms and snow-drift periods. No defense construction. 2). Snow fences and if possible reforestation to prevent drifting into the gullies. In this way the snow depth in the gullies will be lessened and the avalanches released by fire will cover the road less deeply. 3). Snow fences together with defense structures (for instance terraces, barriers, nets) and reforestation too if possible in the fracture areas. I am sure that the whole slope could be controlled by these structures, because the average snow depth is not great (80 in). Further details will be proposed after a summer inspection.

On this slope some preliminary work should be done. I would recommend a good contour map of the whole slope between road and ridge to a scale 1:500. On this map all the pertinent data can be plotted (Morphology; roughness of the surface; nature of soil; vegetation; snow depths; streamlines of the wind; fracture lines and slidepaths).

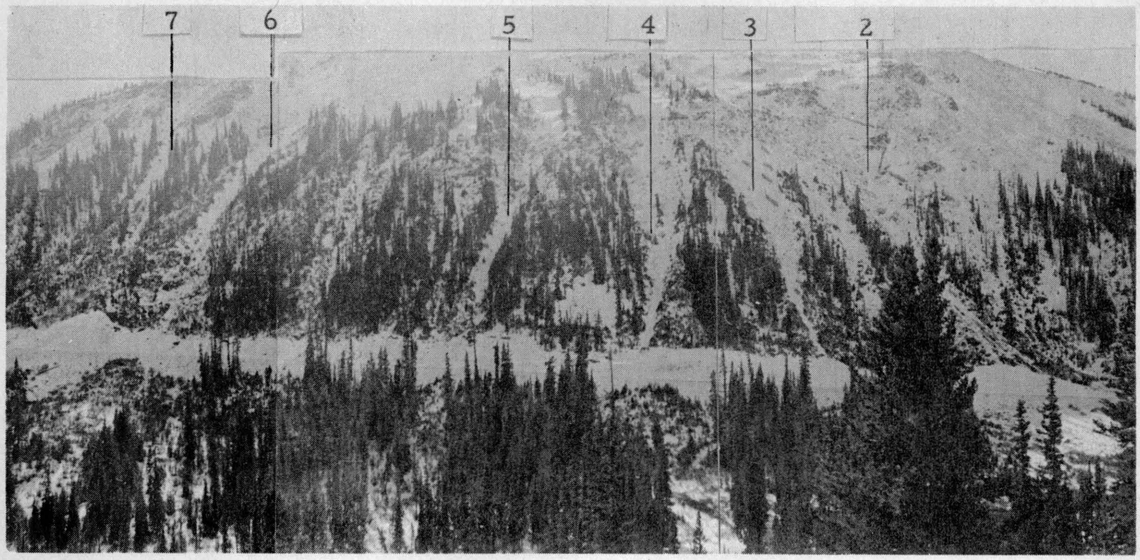

Figure 11. Area of the Seven Sisters slides, Loveland Pass, Colorado. Early in the winter 1954/1955. Numbers indicate slidepaths. (Photograph supplied by M. M. Atwater.)

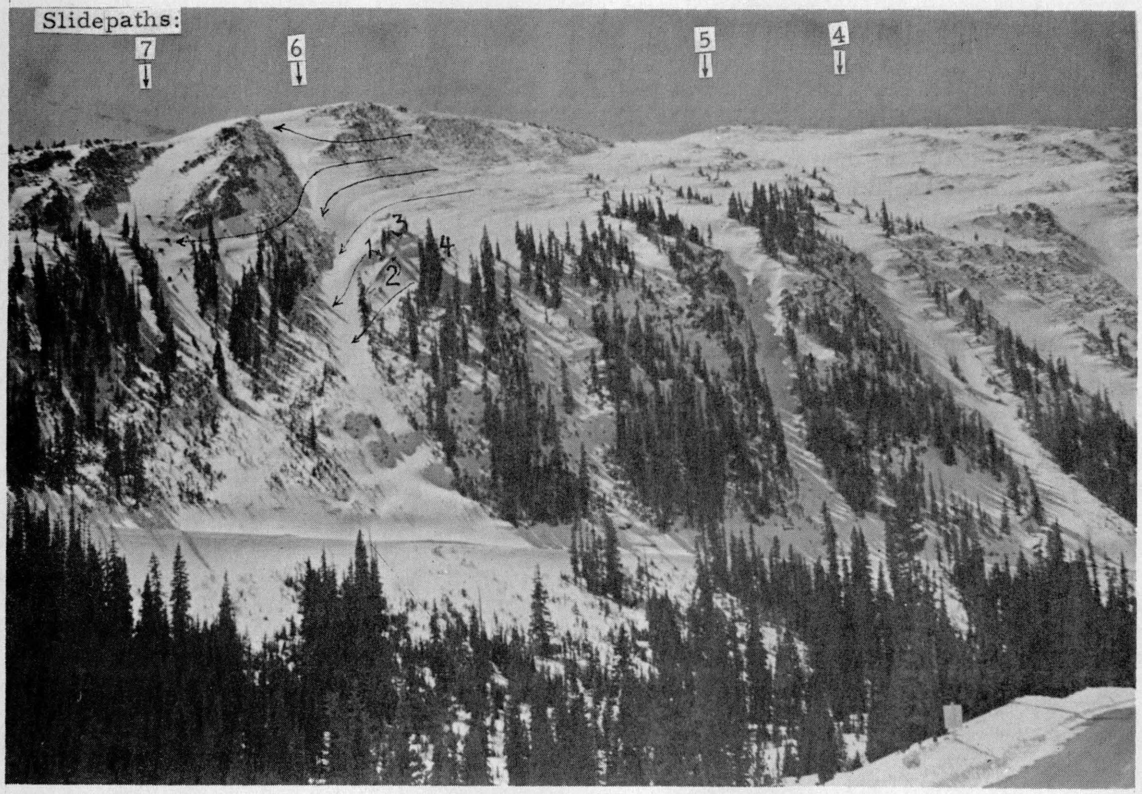

Figure 12. Seven Sisters slidepaths on east side of Loveland Pass. Photo taken after a snow-drifting period. The distribution and surface of the snow shows the direction and relative velocity of the wind on all parts of the slope (see text). (Photograph by E. LaChapelle.)

Alberta slide (Wolf Creek Pass, Colorado):

This slide has two branches with two fracture areas. The two paths join just on the highway. Figure 13 shows one of them. The other comes from a bowl which lies behind ridge (1) and goes along gully (2). The top of the mountain is without timber although it seems to be below the regional timberline: so the snow can drift onto the leeward slopes and accumulate there (see fracture plane (4) of a slab avalanche in Fig. 13). As well as I could see the slope from the road and the whole area by aerial photos and stereoscope, I would recommend snow fences along the ridge and on the windward side. Further measures cannot be proposed yet. The trees seem to be growing very well (see the young trees in the slidepath): Perhaps the top of the mountain and the slidepaths can be reforested. But I cannot yet say what kind of measures are needed to protect the young trees.

Figure 13. Alberta slidepath on east side of Wolf Creek Pass.
(Photograph by E. LaChapelle. Fracture plane (4) has been darkened by pencil.)

Silverton avalanche areas along Highway No. 550, Colorado:

I have little information about snow and avalanche conditions in this area. Therefore I will not make any recommendations until I have studied the slidepaths when snow free. The captions of Figures 14 - 17 give some indications.

Figure 14. Slidepaths above Silverton-Durango road on Sultan Mountain. (Photograph by E. LaChapelle.)
It is very difficult to recommend preventive measures without studying the features of the slopes and the ground. Perhaps some of the avalanches within the limits of the round, timbered mountain could be controlled by reforestation.

Figure 15. Battleship slidepath between Silverton and Red Mountain Pass. Photo taken from highway. (Photograph by E. LaChapelle.) This slide sometimes comes into the opposite slope and over the road. Barriers probably would be too expensive, so avalanche control by gunfire seems most applicable.

Figure 16. Highway Silverton-Red Mountain Pass, Colorado.
View from the road of Bullion King (to south). An 8000-ft stretch of highway gets many small slides from the east and one big slide from the west. A compact timber on both sides of the valley would be the best protection. But one cannot yet see if trees would grow everywhere. (Photograph by A. Fuchs.)

Figure 17. Slidepaths on Bullion King Mountain between Silverton and Red Mountain Pass. (Photograph by E. LaChapelle.)
Probably most of the ground on this slope is bedrock. The possibilities of avalanche protection, except control by explosives, cannot be estimated yet.

CHAPTER II

REMARKS ON PREVIOUS AVALANCHE RESEARCH IN THE UNITED STATES

A. General Remarks

We must distinguish between investigations on the development of the snow cover in relation to avalanche occurrenceand practical tests with defense construction and explosives.

The first type of investigation has brought quite good results over the course of the last few years.* A number of avalanche contributory factors were discerned by means of an excellent, practical knowledge of snow and avalanche conditions. Then an attempt was made to measure and record these factors (for instance by precipitation intensity gage, settlement gage) and to clarify the interaction by analysis of many storms. Actually pretty good relations have been found, and thus one hopes to obtain gradually better means of predicting the avalanche hazard.

But I do not think that much more progress will be made by using the same methods, because they have one main defect: in most of the cases the test conditions are not as well defined as they could be. Thus the picture becomes unnecessarily vague.

In each of the three climatic regions discussed here, I am sure that the factors which contribute to avalanches could be recognized much more clearly if the test conditions were better defined and some instruments were improved.

The experiments with wind baffles, snow fences, and posts in the Seven Sisters slide area and on the cliff near Berthoud Pass were made at the wrong place. Such tests cannot be made on a slope which requires avalanche control by explosives. Also, the first step in such experiments must be a study of the pertinent conditions. One must begin with well defined simple cases. The following example illustrates what I mean: Two snow fences ((1) and (2) in Fig. 12) were built on the west side of slidepath 6 of the Seven Sisters. The direction of the fences is oblique to the dip of the slope. A study of the features of the slope and the streamlines would have shown that, first, the wind velocity is relatively low there because of the shoulder (3) and the trees (4) and, second, the wind streams obliquely downward (see arrows). This can be seen very clearly on the snow cover after a drifting period. Thus the fences were placed nearly parallel to the wind. Moreover the fence (1) is in the region sheltered by the shoulder.

B. Critique on Some Equipment of the Observation Stations

In the following pages I shall criticize some equipment and methods, which seem to me inadequate or insufficient for scientific work. Proposed changes are discussed in Chapter III.

1. Alta, Utah.

The test field (Fig. 18) lies on a slope which is inclined about 9° south. No horizontal area can be found in the vicinity of the station. The field is surrounded on three sides by scattered timber; it is open to the prevailing winds. The trees in the vicinity probably cause some inhomogenity in the deposition of snow. The snow

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* See:

Avalanche Handbook, Washington, D. C.: U. S. Department of Agriculture, Forest Service (1953)

Atwater, M. M; La Chapelle, E. E.; Stillman, R. M.; and Foto, F. M.: Avalanche research, a progress report. Part I-II, Appalachia (Dec. 1954; June 1955).

Borland, W. M.: Investigation of snow conditions causing avalanches. Interim reports (Jan. 1952; Feb. 1954; July, 1954). Unpublished mss.

cover creeps, affecting the measurements of settlement and thickness of the layers.

The experimental precipitation gage (Fig. 19; for detailed description see the report Avalanche Research 1955) should automatically record the precipitation intensity. In my opinion this apparatus has several defects: The stub (1) with its throat (2) always faces the wind because the whole snow collector is turned round the axis (3) by the wind vane (4). This apparatus can collect snow only if the wind is not too weak. During a storm I observed it for a time: when the wind was weak (during most storms the wind velocity varies between lulls and gusts) very little or no snow entered the throat. During this storm a little snow cushion was deposited in the stub, which reduced the intake port. If the stub faced a stand of the frame it was partially sheltered. Therefore, I think that the registered values give only a very rough measure, including many sources of error. Storms can be recorded entirely erroneously if the wind conditions are not favorable for the instrument.

The settlement gage (Fig. 20; for detailed description see Atwater et al., 1955) is the first instrument which allows an automatic recording of the settlement of the new snow and the old snow layer. Small sources of error are introduced by the creep of the snow cover—the same effect as on the test field of Stevens Pass, but not so large.

The anemometer and wind vane are mounted upon arms fastened on a pole of a power line. I am sure both instruments are too close to the pole, in the region of disturbance by the pole. It seems to me, also, that they are not high enough above the ground.

The instrument shelter is located too close to the station. In addition it is in the area of reflection of a tree and is next to the edge of the cornice which grows around the house during the winter. This is just the place where flow conditions are most unpredictable.

It seems to me that the recorder should be kept running continuously. The weather and the settlement, for instance, is interesting between as well as during the different storms.

2. Stevens Pass, Washington.

The test field (Fig. 22) is located in a clearing of the timber a few yards behind the station. Its ground is slightly inclined. The timber around the field causes a very inhomogeneous deposition of the snow both in depth and probably also in

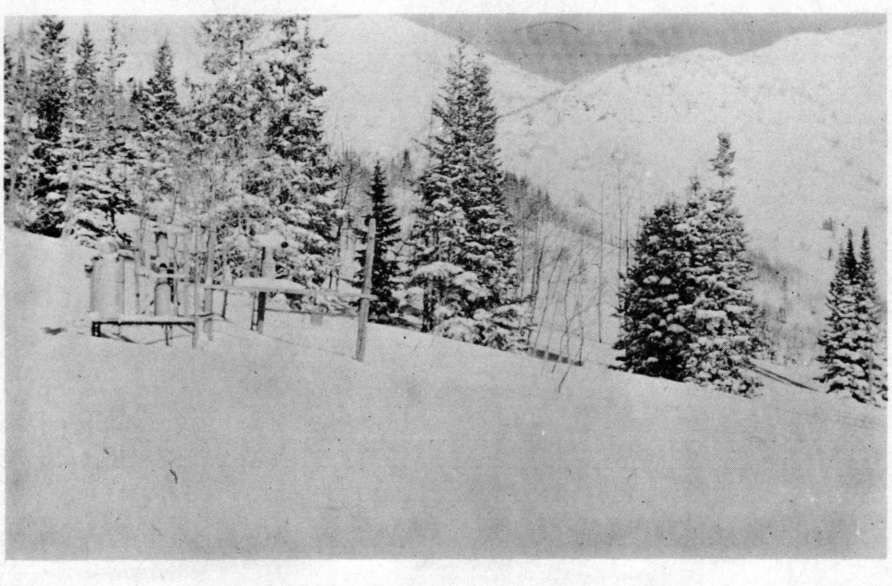

Figure 18. Test field, Alta research Station. (Photograph by A. Fuchs.)

Figure 19. Alta Test Field. Precipitation intensity gage. (Photograph by A. Fuchs.) For explanation of numbers see text.

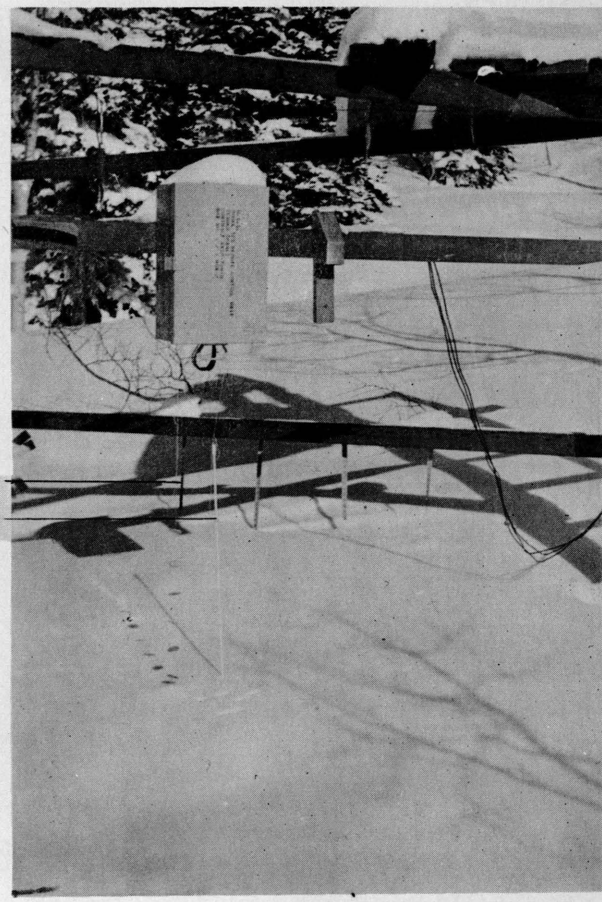

Figure 20. Settlement gage, Alta test field. (Photograph by A. Fuchs.) (1) New-snow settlement gage (disks on a cord). (2) Old-snow settlement gage (plate with rod). Many things around the measuring area (beams, platform, poles, trees) disturb snow deposition.

structure. I participated in a profile test: the snow depth in the pit was about 2 ft less than the snow depth shown by the gage. I have seen unevennesses of 3 ft. This inhomogenity must affect all the values. For instance, the new snow sticks with their boards are moved from one place to another after each measurement: therefore the conditions of deposition are different each time. The depths of the new snow can not be compared with the snow depth of the whole snow cover, because the amount of snow deposited where the gage is situated may be different. When the wind blows from another direction, all the conditions of sedimentation change due to the heterogeneous environment.

The instrument shelter rests upon a solid platform on a framework, (see Fig. 22) a very poor location. I believe that the instruments inside have their own climate depending on wind and radiation.

The measurements of the settlement are much distorted by the creeping of the snow cover (see Fig. 21).

The test field has no fence. It is reported that people sometimes walk or ski across it: this would introduce further unnecessary errors into profile tests.

3. Berthoud Pass, Colorado.

Here the conditions are as undefined as at Stevens Pass. The test field (Fig. 23) is located in a small clearing in the timber south of the pass. The snow conditions are certainly inhomogeneous: the trees are so close together that their spheres of influence (on distribution of the snow, temperatures, radiation) overlap probably several times. Moreover the trench where the last profile tests were made was still open. Thus the snow in the vicinity of this trench is uncontrollably affected and every succeeding profile shows these changes as well as the local inhomogenities.

The station is located on the pass. The instrument-shelter and the place where snow temperatures are measured are there also (Fig. 24). Both places are too close to the station and under the influence of the house. The resistance thermometers are located in a snow hump between shelter and house, where there are also horizontal temperature gradients.

The precipitation is measured in the Q 12 park on the north side of the pass. The ram profiles are taken there too.

Wind velocity and direction is measured on the top of Russel Mountain near the terminal of the chairlift, and recorded at the station.

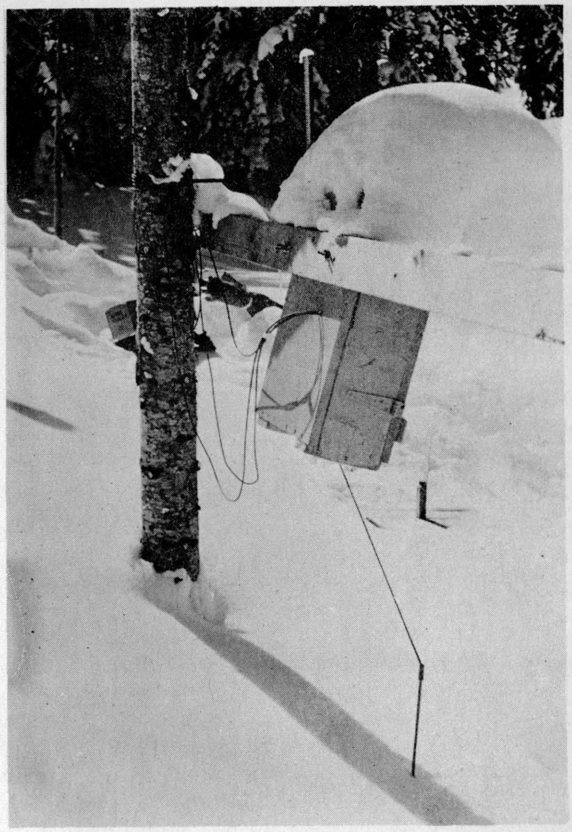

Figure 21. Settlement gage, Test field, Stevens Pass. The transmitter case is inclined for some reason and the rod, which is connected to the transmitter by a cord, is moved to the right by the creep of the snow cover. (Photograph by A. Fuchs.)

4. Loveland Pass ski area.

This station on the east side of the pass is run by the Colorado State Highway Department. Observations on the snow cover and measurements of precipitation are made in a small clearing in the timber north of the maintenance garage (Fig. 25). Here also the snow cover is very inhomogeneous. The two precipitation gages for instance are just in the lee of trees. Different values would be obtained a yard away. The anemometer and wind vane are located on the slope of the Seven Sisters avalanches close to and above a stand of timber: The wind from westerly directions blows through the angle between the slope and trees as through a channel and northerly winds are mostly broken by the timber. (Such winds are not infrequent, as the 1953/1954 records from the pass show.) The velocity is influenced by the objects in the vicinity, which break the wind to different degrees depending upon the direction.

5. Arapaho Basin.

The site of the observations is on the fringe of a forest near the mid-stations of the chairlifts. The precipitation gage is mounted— a little inclined— on the top of the steel structure of the lift, the snow depth gage on the contrary is in the lee of the timber. The wind is measured near the ridge at the terminal station of the lift. Here also the observations are being made under undesirable conditions.

Figure 22. Test field, Stevens Pass Station. View toward NNW. (Photograph by A. Fuchs.)
The snow cover is extremely inhomogeneous-depth variations of about 1 m. (1) Precipitation gage. (2) Instrument shelter placed upon the platform. Door faces west. (3) Trees with snow on the windward side of the trunk indicate windy area. (4) Trees without snow on the trunk and with a bowl in the snow cover to the right indicate sheltered areas.

Figure 23. Test field, Berthoud Pass. Located in a small clearing near cosmic ray station. (Photograph by A. Fuchs.)

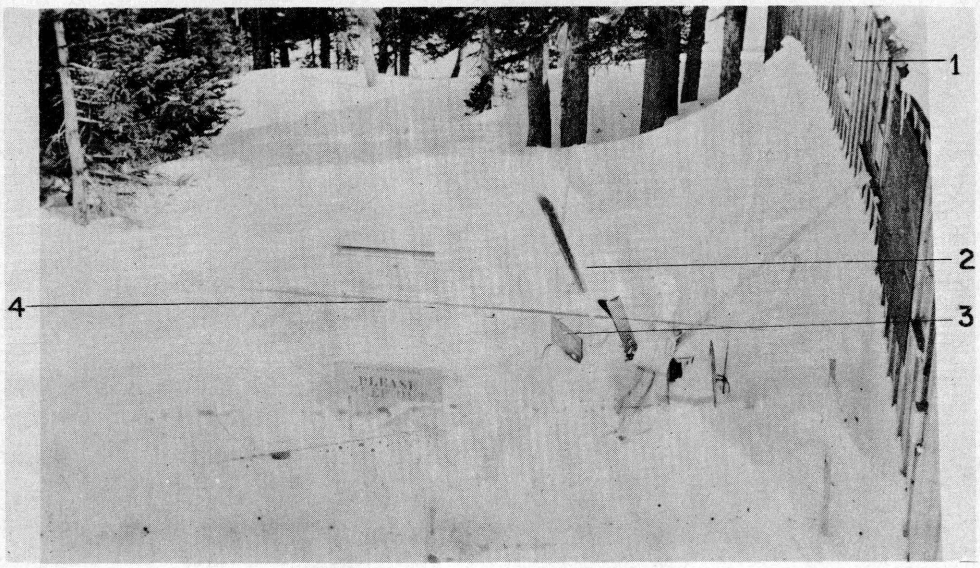

Figure 24. Berthoud Pass Station. Instrument shelter and snow temperature measurement device. (Photograph by A. Fuchs.)

1) North wall of the station.
2) The resistance thermometers are placed in the snow wall here, quite near the ski.
3) Case containing the connections for the thermometers.
4) Instrument shelter. The door faces west.

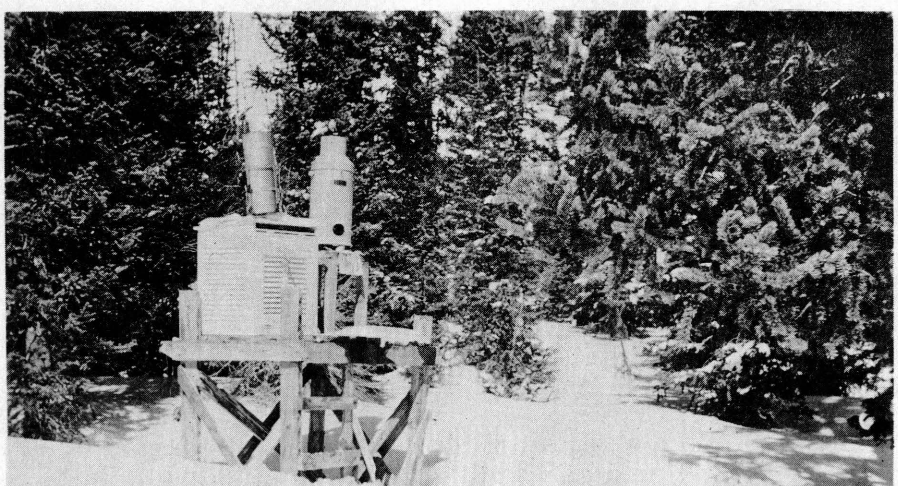

Figure 25. Test field, Loveland Pass ski area station. (Photograph by A. Fuchs.) This is a clearing north of the highway maintenance garage. Instrument shelter and precipitation gages are shown. The snow cover is wavy because of inhomogeneous sedimentation.

CHAPTER III

RECOMMENDATIONS FOR FUTURE AVALANCHE RESEARCH IN THE UNITED STATES

A. General Recommendations

As we have seen in Chapter I, some practical problems are already partially understood and are being studied. In this chapter, I shall discuss the program I would recommend for future work.

The ideal — and in my opinion the shortest way to a really good result — would be to accommodate the means to the problems. Both basic and practical avalanche research should be done, and new instruments should be constructed. But such a program would make great demands on personnel, stations, and equipment and would cost a lot of money.

We have to take into account the means available at the present time, but we should not lose sight of the ideal. We must try to make the best use of these means.

1. Test fields and techniques for making profile surveys.

The conditions for the deposition and metamorphism of the snow cover should be as clear as possible. The field should be even and horizontal and the material of the ground uniform. In the test area the snow cover should be as homogeneous as possible in its layers; the objects which catch the wind (trees, huts, structures for instruments) should not be in a position to cause inhomogeneous deposition of the snow. The radiation must be distributed uniformly.

During a winter, 15 to 16 profile studies should be made. If there are 3 rows of pits, the test area of the field must have a minimum size of 40 x 50 ft, in deeper snow layers about 40 x 60 ft. A fence is necessary to protect the field against trespassers.

Information concerning the technique of making profile studies can be obtained from SIPRE Translation 14 (Bader et al, Snow and its Metamorphism, p. 21). The following can be added:

The colored threads must be laid after the profile surveys. The material should be wool, as hairy as possible and with low tensile strength. Then, if one thread is hit unintentionally by the shovel during digging, it is cut without far-reaching displacement of the horizon. Thin, smooth threads with high tensile strengh are not good; it is too easy to displace or pull out a long section.

The wall of the pit where the measurements are made should face north and be perpendicular to the threads: therefore the threads should lie approximately north-south.

The following technique of profile digging has proved to be good. The pit is dug to the ground. During this work, some of the threads will be cut by the shovel, since their exact location is not known in advance, and some threads lying in a soft layer will be displaced. When all the threads are exposed, the wall of the pit is cut back about 10 in. During this work, one must be careful to leave the threads in their horizons. Each thread is cut by scissors as soon as it is well exposed, leaving only 1 in. of thread projecting out of the wall.

Usually the ram profiles are made first. The rammsonde should be left in the snow cover and the wall of the pit cut just north of it. This gives a height gage for all the other measurements.

The survey of the temperature profiles can be begun during the digging. The thermometers should be pushed into the snow in increments (about 1 in. each minute) or should be shifted in the same horizon two or three times by pulling the thermometer partially out and pushing it in at different angles.

The excavated material must be shoveled back into the pit after the profile survey is completed. A new thread is laid and the place where the new thread crosses the wall of the old pit is marked with a rod. The distance from this rod to the wall of the

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next pit must be at least 1.5 times the snow depth.

2. Measurement and recording of snow and weather data.

In order to obtain a satisfactory time profile, all the data must be measured on the test field, or in its vicinity. For practical problems, some measurements have to be made in addition to the standard observations (for instance wind velocity on the test field and on a slope with defense constructions). The instruments must be arranged in such a manner that they do not effect the deposition of the snow cover and its metamorphism.

a. Instrument shelter: I would propose that the support for the shelter have removable sections so that the instruments can be kept at a roughly constant distance of 4 ft from the snow surface. The bottom plates of the shelter should never be permitted to touch the snow surface or the platform. The door of the shelter should face north in order to protect the instruments from the sun when the door is open.

b. Anemometer and wind vane: These two instruments can best be mounted on a cross arm on the top of a pole which is approximately 5 m higher than the maximum snow depth at that place. The crossarm should be approximately 1.5 m long and perpendicular to the prevailing winds.

It seems to me that the anemometers now in use should be altered, if possible, to make contact after each quarter of a mile of wind movement rather than after each mile. Thus the record would show the variation of the wind movement in more detail.

c. Settlement: If the settlement is measured by sliding contacts on a vertical wire (SIPRE Tr. 14, p. 21-22), the holder of the sliding contacts has to be as light as possible and must not absorb radiant energy. I think a very light plexiglass frame would be the best. No thermocurrent must be produced at the sliding contacts and soldered joints.

The same frames might be used as holders for thermocouples or resistance thermometers; thus the depth of the temperature measuring points will always be known.

In order to refine the automatic recording of the settlement of the snow cover, the case holding the electrical transmitter and its supporting construction should be as close as possible.

d. Temperature: The holder of the thermocouples or resistance thermometers has to be as light as possible and must not absorb radiant energy (see section c above). It is important to have no heat flow from or to the measuring point through the wires. Therefore two or three loops should be coiled around the thermocouple or resistance thermometer and these loops should lie in the same layer as the measuring point.

The measuring points and the wires should absorb as little radiant energy as possible.

The snow area around the measuring points must be completely undisturbed. Therefore the holders have to be placed onto the snow surface from a distance by a long rod. The length of the wires within the snow cover should be at least 5 m.

3. Instrument hut on the test field.

For some measurements, a tight small hut placed on the edge of the test field will be necessary. Junction boxes for electrical instruments must be protected from snow and moisture.

The disturbing influence of the hut on the deposition of the snow cover should not be far-reaching because some measurements have to be made in its vicinity. If possible the hut should be placed in the ground up to half or two thirds of its height so that it will be covered by snow at the beginning of the winter.

4. Recording and analysis of data.

All the snow and weather data must be evaluated and plotted daily or at short time intervals. This will make the work more interesting for the observer and less work will accumulate by the end of the winter. Some questions in connection with snow cover and avalanche occurrencecan be solved only in this manner.

B. Duties of the Observation Stations

1. Alta (Utah).

Doubtless Alta will continue to be the center of avalanche research in the U. S. There new methods have been and will be developed and some new problems can be explored. The climate of Alta seems to be the most favorable. At Stevens Pass (coastal zone) there is heavy snow cover, high temperature, and low wind action. At Berthoud Pass (high alpine zone) on the contrary there are very strong winds and very low temperatures with little snow. The climate of Alta has an intermediate position between the two extremes. The other stations could undertake some studies according to their climate. For instance, wind action could be studied at Berthoud Pass, and observations on creeping of the snow cover could be made at Stevens Pass, where it is extreme.

If Alta is to do more intensive research work, two men are needed to do this work exclusively.

a. Changes in the test field: The field now in use must be made even and horizontal. A construction (perhaps a dam or a trench and dam) has to be made on the side next to the mountain in order to protect the horizontal field against the creeping movement of the snow cover on the slope. Its shape must be planned in summer. During the leveling, a hut could be sunk into the ground in the southern edge of the field with an entry from the downgrade side of the slope. Some of the trees may have to be removed to obtain clearer conditions for the sedimentation of the snow. When the method of blind firing during storms is developed, the avalanche coming down between the station and the test field can be controlled permanently in order to have a safe approach at any time.

b. Changes in instruments: The instrument shelter should be removed from the sphere of influence of the station. It seems to me that it should be near the test field. If the precipitation intensity gage is used in its present form, a new mount should be made, allowing free and undisturbed access to the prevailing winds. The anemometer and weather vane should be placed on a pole near the test field. (Concerning changes in the settlement gage, see section A, 2c.)

c. Snow cover and avalanche prediction: Work on the relations between development of the snow cover and avalanches has begun promisingly and should be extended. I am sure that much clearer relations will be obtained after better test conditions are adopted.

I would like to outline the program I consider best, regardless of the means now in use or available. The development of the snow cover should be observed on sloping fields as well as on the horizontal field (for instance, fields with exposures towards several directions but with the same angle of slope on a dome - or cone - shaped hill) and should be compared with the natural occurrence of avalanches. The instruments should be developed so that measurements of the pertinent data of the snow cover can be made repeatedly at the same places without destroying the snow area or influencing its metamorphism. On the sloping fields, the same observations should be made as on the horizontal field, and the creeping of the snow cover should be measured continually in all the layers.

The present location of the Alta station is not suitable for this task. No suitable sloping test fields can be found in the vicinity, the snow and wind conditions are influenced by the narrow valley, and the avalanches are controlled by explosives.

It is possible at Alta to (1) improve the methods used on the test field and (2) expand observations on avalanches in adjacent areas where no avalanche control is necessary. After storms, a plane could fly over Alta and the adjacent valleys to the north, east, and south several times. In this manner all the avalanches could be photographed or plotted upon a map or aerial photos. As these observations progress, some representative avalanche slopes will be noted. In the vicinity of these avalanche areas, staff gages readable from a distance can be mounted and pole-like baffles can be placed so that lee marks in the snow surface will give the prevailing wind direction at the end of the storm. Later perhaps, instruments can be developed to report by wireless some weather and snow data and the occurrence of the avalanche.

Profile surveys of the fracture areas of typical avalanches should be made whenever possible.

d. Investigations on the effect of explosives: This work should clarify the optimal conditions for avalanche control by explosives. The kind of explosive (detonation velocity), the quantity, the position of the explosive in the snow cover, and the direction of the explosive action should be studied in relation to the effect on the snow cover. The changes in the snow cover (dimensions of the crater, distribution of the snow thrown out, changes in the structure in relation to distance of the point of the burst, changes in strength as a function of place and time) and the propagation of the pressure wave through the air and the ground are essentially the objects of these investigations.

For the time being the following procedure could be used. The snow cover of the flat or slightly inclined test fields should be as homogeneous as possible. The effect of the explosives can be characterized by strength tests (a sufficient number of ram profiles). Also, if thin vertical columns of fine-grained pigment insoluble in water are injected into the snow cover and excavated after the explosion, they will show deformations of the snow cover and intense movements of air. If the snow cover contains depth hoar or other easily disturbed layers, transmitters of slight movement can be inserted into the snow to indicate the collapse of these layers (by oscillograph). The propagation of the pressure wave through the air and the ground can be determined by the devices used in seismic investigations of ground (geophones, microphones, oscillographs). The blasting should be filmed. All these investigations should be carried out in snow covers with different stratifications (for instance a heavy wind slab at the top or a deep soft new snow). In order to obtain good results many tests have to be made within a short time; good instruments and a well trained crew are needed.

I believe that some good test fields could be found in the Albion basin.

e. Firing tests: The goal of these tests is to find a device which meets the following demands: accuracy of fire, effective explosion, mobility on snow-covered roads and by chair lifts, possibility of blind firing during storms and at night, a minimum of duds.

In my opinion one of the following should be chosen: 1. the 75-mm recoilless gun of the US Army; 2. a mortar; 3. the rockets used for avalanche control by the Austria avalanche service.

It would also be desirable to have a very light launcher and very light ammunition (shells, rockets, rifle grenades) with a range up to 200 m, which can be carried in rucksacks. Such equipment would be helpful to troops moving in avalanche areas: one or two shots from a safe place onto the slope which must be crossed would check the avalanche hazard.

2. Stevens Pass (Washington).

a. Changes on the test field: The test field should be moved. From what I could see of the vicinity in winter, the place near the beginner's rope tows seems to me the most suitable. A fence with conspicuous signs is needed to protect the field against skiers. Instrument-shelter, precipitation gage, anemometer, and vane should be located near the field. A hut on the edge of the field will be necessary also. A second measuring point for the wind conditions on an exposed place is recommended.

Concerning changes in instruments see sections A2 and B1. In this region very heavy storms and a deep snow cover are usual, causing extreme values of settlement. Therefore, I would recommend installing an automatic settlement gage for the new snow too and also a gage to measure the thicknesses of the snow layers (by sliding contacts).

b. Snow observations and avalanche prediction: The most important duty of the station is the prediction of the avalanche hazard to the traffic on the road and the skiers on the slopes. The relation between the development of the snow cover and avalanche occurrence must be worked out under much better defined conditions than hitherto. During this work it will probably be necessary to obtain some data on the snow cover of different slopes (for instance by staff gages readable from a distance, by signs showing roughly the creep of the snow cover, and by a remote signaling plant for some avalanches (see Alta)). All the observed avalanches in the vicinity of the road, whether practically important or not, should be drawn on a map with the time of their occurrence.

c. Observations on important avalanches: Some preparatory work will be necessary in order to develop defense measures. Photos should be taken of the entire slidepaths in order to record the fracture lines, the slidepath, and the distribution of the deposited snow.

3. Rocky Mountain area west of Denver.

The four observation stations located pretty close together — Berthoud Pass, Loveland Pass, Arapaho basin, and Climax — are apparently in the same, in some measure homogeneous, climatic region. Thus these stations might collaborate on a signal communication service for snow and avalanches and on some research work.

a. Signal communication service for snow and avalanches: For estimating the avalanche hazard it is very valuable to have snow and weather data from several places. Then the observer can survey a more extended area and can make his decisions with greater confidence than if he knew only the snow conditions at his own station. Also, the observer at one station can collect and represent graphically all the data from the contributing stations, leaving them more time for other work. Therefore I recommend this collaboration and would like to sketch this organization as follows:

One of the stations — I think Berthoud Pass would be the most suitable — becomes the center. This station receives snow and weather data from the other observation stations at certain intervals (during critical situations several times daily). Of course the central station makes its own observations too. All these data are analysed and graphically represented to give the observer a permanent synopsis of weather and snow cover data, to guide his control measures.

The central station has to keep records on avalanche data. After an avalanche period all the avalanches should be typified and drawn on a map, not only the avalanches which menace the highways but also any other avalanches observed in the vicinity. In this manner, the observer will learn more and more about the relation of avalanches to development of snow cover on slopes with different exposure. These observations should be completed by photographs and observations from a plane, which should include the adjacent valleys also. Snow profile surveys should be made in typical fracture areas whenever possible.

The equipment and duties of the different stations are as follows:

Berthoud Pass. The test field should be installed in the Q12-park on the north side of the pass. The present field near the cosmic ray station is bad. Q12-park should be leveled and an instrument hut built in a suitable place on the edge of the field. The instrument shelter, anemometer, weather vane, and temperature measuring device should be on the field.

The wind measuring device on Russell Mountain (near the terminal of the lift) should stay there. At this place the wind conditions in the undisturbed atmosphere can be observed very well.

Probably it will be necessary to install other test fields besides the Q12-park, which is relatively calm — for instance in a place where the wind is usually eroding the snow and in another place where drift snow is deposited (see also section b below).

The following data should be observed: temperature (thermogram, maximum, minimum), wind velocity and direction (automatically recorded), snow depth, new snow (depth and density), temperatures of the snow cover, snow surface features and hardness, beginning and end of snowfall and of snow-drifting periods, avalanche occurrence. The precipitation intensity and the settlement should be measured too (as at Alta). The semimonthly field surveys should include ram—density—stratigraphic—temperature profiles.

Loveland Pass ski area and Arapaho basin. These stations on both sides of the Loveland Pass should provide a good insight into snow condition in relation to exposure. Both stations have approximately the same elevation, are only 3.5 mi apart, and their exposure is quite symmetrical: The valley of the North Fork (Arapaho basin) is open toward WSW, the valley of the upper Clear Creek toward ENE. The end of the North Fork valley faces the prevailing winds, the end of the Clear Creek valley away from the wind. Comparison of the snow and wind conditions on the analogous slopes in both areas would be very instructive. I recommend that staff gages readable from a distance, and if possible anemometers, be erected on representative opposite slopes (for instance, on the south slope of Mt. Release and the north slope in the Seven Sisters area; the south slope in the vicinity of the Little Professor Slide and the north slope in the vicinity of the Pallavicini slide).

In both areas horizontal test fields should be constructed. The best position can be chosen and some details settled only when the area is without snow.

I recommend the following measurements and observations: temperature (maximum and minimum), snow depth, new snow (depth and density), temperature of the snow cover 10 cm below the surface, features and hardness of the snow surface, beginning and end of storms and snow-drifting periods, avalanche occurrence. Complete profile surveys should be made twice a month.

Climax: The high-altitude research station at Climax operates during the whole year and some observations on snow and weather are already being made. Therefore extension of the observations and reports would not take much more time. The same daily and semi-monthly observations should be made as at Loveland.

I think that the prediction of avalanche hazard would be facilitated by observation at a place north of Berthoud Pass, in order to have a survey of the snow conditions farther north. At this station just the snow depth and new snow depth should be observed twice a day and reported weekly (on critical days, twice daily by phone).

It would be desirable to have a second station with the same function between Loveland and Climax in order to close the gap between the two stations.

After studying the snow surveys of the Loveland, Arrow, and Frisco stations, I think that the best places for the proposed stations would be Fraser and Dillon. Both locations have open terrain towards NW and SW at approximately the same altitude (8,570 and about 9.000 ft.).

b. Study of the wind effect on sedimentation, resedimentation and metamorphism of the snow cover: The vicinity of Berthoud Pass seems to be suitable for tests to show how the snow is deposited, then removed and redeposited by strong winds during the winter. I would recommend as a first step that two rows of staff gages be erected across the ridge between Frazer River and Vasquez Creek. The northern row should be laid in the line of the First Creek over the ridge into the slope of the valley of Vasquez Creek as far down as the gages can be read from the ridge with binoculars. The southern row should lie in the same direction in the line of Current Creek and should go over the headwall and the plateau into the west slope. The two rows should be surveyed in order to draw exact profiles. The gages must be readable by binoculars with an accuracy of 1 in.

These gages are read at different time intervals, perhaps every 5 days during quiet periods, and daily, if visible, during and after storms and snow drift periods. Semi-monthly profiles surveys should be made at 4-6 places on each row.

After 1-2 years, these observations and those in the Loveland Pass area will begin to yield useful results. Then the program can be expanded (for instance to study the distribution of creeping and the formation of depth hoar on some slopes).

c. Investigation on the effect of fences and wind baffles on the snow cover: In many avalanche areas, objects that catch the wind could probably change the deposition of the snow cover so that either less snow is transported from the windward to the lee side (for instance Stanley Peak, Bethel Mt.), or more snow is deposited in places where it can be supported by trees or barriers (for instance, perhaps in some parts of the Seven Sister slide area), or the formation of cornices is prevented (for instance in the Arapaho basin).

The effect of snow fences in flat country is already pretty well known, and in Europe some experience has been obtained with fences and wind baffles in the mountains. The task of research in this country would be to test the results of these experiences and to make new investigations with controlled conditions in order to learn what kinds of fences and baffles are practical for what climate.

I should like to recommend the following procedure: Choose a uniform slope with most of the snow swept away, which can be inspected from a distance and need not be controlled by explosives (for instance the south slope of Bethel Mountain, Fig. 10). The first winter, three fences of different heights could be erected in the middle of the slope in a row transverse to the prevailing winds. The extension and depth of the snow on both sides of the fences can be studied by reading staff gages from afar. The next winter, arrangements of several fences in series could be tested. The following step would be to study the fence patterns in the area near a ridge which would most effectively prevent transportation of snow onto the leeward side and the formation of a roll or a cornice.

Model tests in a wind tunnel to study the flow pattern would be a great help in this work.

Tests with wind baffles can only be made in wind-exposed defined areas, not in bowls and gullies (Seven Sisters). I am not sure if they can be used in the high alpine zone of the Rocky Mountains.

d. Observations in reforested areas: The goal of each avalanche defense construction should be an effective and permanent protection at the lowest maintenance cost. Timber meets these requirements best. In many places where timber is destroyed by fire or cutting, avalanches began to occur. Therefore, it is obvious to try to re-establish the former state by reforestation.

The timber can have two different functions. It prevents drifting of snow and supports the snow cover.

A great number of the avalanche paths which I have seen in the United States probably could be controlled entirely or partially by timber. But the problem is the same as in the European alpine reforestation area: Is there an inexpensive way to protect the growing timber? Since I have seen trees that are very resistant to avalanches at Alta (Utah) and young needle trees growing in the path of the Alberta slide (Fig. 13), I believe it would be possible to plant these trees on narrow terraces or in shallow holes in order to protect them against the slow sliding of the snow. When they are taller, they will be tough enough to withstand the creeping movement and the avalanches. Therefore, I think it would be worthwhile to plant young trees, control the avalanche by explosives, and see what happens.

If this method proves to be practicable, a number of avalanches which menace highways could be controlled by explosives while a new timber is growing up. As the trees grow, the blasting could be reduced after 20 or 30 years. After that, I think the blasts would produce successively fewer avalanches and more stabilization in place.

I recommend 1) Contact experts on reforestation near the timberline. 2) Choose test slopes and plant different sorts of trees in different ways. 3) Observe the avalanches and the trees (during the winter and when all the snow has disappeared).

C. Installation of New Observation Stations

If an avalanche-control service is installed in SW-Colorado (Wolf Creek Pass and Red Mountain Pass), it will be necessary to install observation stations at Wolf Creek Pass and Silverton also. The following data should be observed: temperature (maximum, minimum), wind velocity and direction (only by a vane), snow depth, new snow depth and density, condition of the snow surface, settlement. Semimonthly complete profile surveys would also be desirable.

At Wolf Creek Pass, the only sites possible at this time are in the vicinity of one of the two maintenance garages. Some observations have already been made at one place, but there the conditions are very poor.

At Silverton there is plenty of room for a test field on the wide flat valley floor. Staff gages and wind signs (see section B, 1c) which can be read from a distance might be very useful in studying the snow cover on some slopes.

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