# REVIEW OF TECHNIQUES FOR SELECTION OF SNOW COURSE SITES IN WESTERN STATES 1/

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Abstract--Guidelines are developed for snow course site locations and snow course network planning. Physical conditions as well as the ultimate use of the snow course data are considered in developing these criteria.

## Introduction

Snow surveys have been conducted in western states for the past fifty years as the foundation for seasonal streamflow forecasts. Economic needs for the data and its interpretation are well known. (1) This basic use had always guided snow course or network development. The same principle was true in the East where snow courses were first established in the Androscoggin Valley. (2) This basis still remains the fundamental principle guiding establishment of snow courses today.

## Definition of Snow Course and Snow Course Network

Early development of snow surveying concentrated more on equipment to measure the snow than with selection of snow course sites. The first snow courses in the East "were not definitely located, that is, the same locality was visited each time but the place where readings were taken might have been a few hundred yards apart in two different trips to the locality." (2) In the West, however, the first snow courses were marked and samples were taken within three to four feet of the same point on the course each time a survey was made. (3) Many of the early western snow courses had 40 or more sample points in span of half a mile. (4) The first snow courses were established for basic use in seasonal runoff forecasting. This is summed up in the definition of a snow course given by Clyde and Houston. (4) "The course method snow surveying is not an attempt to determine quantitatively the actual amount of snow stored on any watershed, rather it is to establish a relation between snow cover at designated locations and subsequent stream runoff from the watershed." This continues to be the accepted concept of snow courses in the West.

For larger watersheds which cannot be represented by a single snow course for an index, a group of snow courses or a network are established. Procedure for a network is generally the same as for a single snow course in that attempt is made to sample all dissimilar water-producing areas of the watershed.

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Problems and Solution in Snow Course Site Locations

Physical conditions have a large influence on selection of the snow course site. One of the immediate problems is accessibility. Since snow courses are in the areas covered by snow this rules out customary modes of travel by auto except along mountain passes. A snow course to be useful must be in such a location that it can always be measured. Clyde (3) remarked "Reasonable accessibility of snow course is the best guarantee of continuous records and low cost surveys."

Over-snow machines and aircraft have made many areas accessible to snow surveyors. However, these too have their limitations. Travel by over-snow machines, for the most part, is restricted to forest roads or secondary mountain roads. A few machines can travel forest trails and cross country without regard to roads, but these cases are definitely in the minority. Thus, selection of snow course sites, with over-snow machine operation in mind, should be based on the use of existing forest roads.

Use of aircraft or helicopter in making snow surveys may solve some travel problems. However, the limitation of these machines must be recognized. Mountain flying even in the best of circumstances has considerable hazard connected with it. Both helicopter and conventional aircraft require about the same weather minimums in order to operate in mountain areas. Landing fields or cleared areas for helicopter landings are required as well as unobstructed approaches for entry in and out of these fields or areas. Considerable economic justification is necessary in order to provide these facilities in the mountains.

Foot travel will undoubtedly remain an important mode of travel to snow courses for a long time. Thus physical limitations of individual snow surveysors using snowshoes or skis must be taken into account. Travel by skis over terrain as shown in Figure I (F-286-8) demands large amount of physical endurance. Proper shelter must be provided where more than one day's trip is necessary. Foot travel routes must be chosen so as to minimize avalanche hazard.

A second item to consider in snow course site selection is the security of the site after it has been chosen. Nothing is more frustrating to a technician than termination of useful data. In the West where national forests embrace a large part of the snow accumulating watersheds, special permits and arrangements can be made to insure the security of a snow course. Similar arrangements can usually be made on private lands. Land use may change over a period of years which can destroy the snow course site for use as such. Road widening has been responsible for the destruction of a good many snow courses. Logging, bettle-kill and forest fires are other influences which materially alter the usefulness of established snow courses. These are a few items which should be kept in mind when considering the future security of a snow course.

Snow courses should always be located in an area that will be free of ponding or surface water collecting beneath the snowpack resulting from poor drainage. This can usually be determined during field inspection from the physical characteristics of the area, although intrusions of beaver cannot always be foreseen.

The final physical properties of snow course site selection to be considered after accessibility, security, and drainage criteria are satisfied is canopy cover. Several items must be considered under canopy cover. These are discussed here by the authors only at random since in each individual area only some of these items may be a problem or there might be no alternate course of action to solve them.

Forest cover has a profound influence on the amount of snow that may be measured beneath it. Extremes in the West range from the very dense conifers of the Pacific Northwest to barren or sage-covered areas typical of the high plateau intermountain areas of Oregon, Utah and Nevada. Examples of these conditions are shown in Figure II (Ore-40141) and Figure III (Nev-674). Experience has shown that snow courses located in protected mountain meadows have a minimum of drifting and for the most part show an increase in snowfall of 15 pecent or so over those in dense forests. (5) In the Rocky Mountain areas, as shown in Figure IV, aspen groves often provide ideal locations for snow courses since they do not pose an interception problem but do provide protection from wind action. A dense forest area should be avoided if possible due also to the large wells surrounding each tree which gives a very unrepresentative measure of snow depth and water equivalent. Thus, small protected meadows provide the best location as to forest cover.

Wind action is an important physical element that must be considered. In forests (areas as mentioned above) some protection can usually be found in the open areas. A particularly difficult area is the high plains in Montana, Wyoming, North and South Dakota. The Missouri River Division of the U. S. Corps of Engineers describes the problem and makes these recommendations for locating snow courses in the plains. (6) "Inasmuch as moderate to high winds and resultant severe snow drifting characteristically accompany snow storms in the plains area, the land use at a prospective snow course location should be a definite factor to consider in the selection of the snow course. Preliminary studies of plains snow data collected to date indicate the tendency for snow to be blown from barren areas to collect in sheltered locations such as coulees, depressions, etc., or in fields containing some vegetative cover such as corn fields, tall grass meadows, etc. If possible, each snow course location should be representative of the predominant land use in its vicinity." Field inspection during period of snow cover is usually very fruitful in appraising wind drifting.

Orientation or aspect is another item that should be considered when selecting a snow course site. A very flat or shallow slope may be subject to ponding, while an extremely steep slope can be subject to snow slides or creep. A slight slope to insure drainage is best. A north facing slope will provide the maximum accumulation of snow due of course to minimum of winter melt. Southern or western slopes therefore should be avoided, if possible. Care must be taken to avoid areas which may trap large amounts of snow due to drifting from wind often located on the lee side of a hill.

If necessary to use such an orientation some forest cover should be found to provide limited protection, as shown in Figure V. Care must be exercised in using forest cover as mentioned above for if a dense cover were found compounding effects might develop on southern orientation due to interception plus winter melt. Shadow effect from massive mountains cannot always be avoided, nor should it be, but the effect must be recognized. This is the final item under exposure to be described. The authors are fully cognizant that there are a great many more. There may be many items that could pose problems in individual cases, but in the main it is felt that the majority of these are perhaps special cases of these general items developed here.

As presented in the introduction, ultimate use of a snow course has a marked influence on site selection. Snow course data is primarily used as an index for streamflow forecasting. In this capacity it measures the residue of water content remaining after the winter accumulation of snow. Thus, it should be above the winter melt line. (3) In order for the snow course to be a good index it must also be located in the water producing areas of the watershed. This may be reflected in the elevation of the snow course. A. R. Codd and R. A. Work described this problem as follows: (7) "Probably the most important factor in the location of the snow course is the elevation zone within the basin where the snow course is to be placed. As elevation must be selected where a minimum of pre-season melting occurs. In most portions of the West, the elevation is selected where snow will remain past April first, and a good portion be left by May first. However, south of 37 or 38 degrees latitude, February or March readings may be most advantageous. At the same time, the course should not be so high that the area sampled is too small to be representative of a major water-producing elevation zone. An area-elevation curve of the basin aids materially in preliminary studies. Snow survey courses must be established at different elevations on a given watershed to define the rate of change in snow cover with elevation. This rate of change varies from year to year. Water supply forecasts based solely on high snow courses may prove in error due to excess or deficiency of low snow cover. In some stream basins, such as those of the Malheur and Owyhee rivers of southeastern Oregon, low elevation (4 to 5 thousand feet) snow courses are essential to best forecasts even should such courses be bare of snow by April first in as many as 8 or 9 years out of 10."

The success of snow surveys in providing data for the most accurate method of streamflow forecasting (8) is largely determined by the above principles of location within the water-producing areas.

The ultimate use may also determine the number of samples taken on a snow course. The index method of streamflow forecasting merely uses the mean of the snow course samples. Connaughton (9) analyzed snow course data in Colorado and applied statistical procedures using the mean and its variation to determine number of samples necessary for ten percent plus or minus error about the "true mean." Pearson (10) later developed and applied the same statistical criteria to Utah data to determine the number of samples necessary to obtain a stable mean. Using the criteria of a maximum error of 5 percent of the "true" snow course average and using the standard error to set the limits on the actual amount of variation. Pearson found nine samples sufficient to accurately determine the snow course average. Court (11) approached this problem from another direction in dealing with number of samples on a snow course. Court correlated individual samples to runoff and found that for his data five points was sufficient for an index. He also used the median instead of the mean in relation to runoff and stated "The present study indicates that a water equivalent figure sufficiently accurate for the practical use to be made of it can be obtained from the median of only five snow course points (sample)". In summing up the efforts of Pearson and Court on sample size of snow courses, it appears that well located snow courses require samples only in the order of 5 to 9. Actual ground conditions discussed earlier will of course be the controls on actual number of samples required. It must be borne in mind that only a few courses have been studied in these instances and that present procedure of establishing snow courses with sample size of 12 to 15 should be continued until a record is obtained which will permit the analyses suggested by both Court and Pearson.

One other method of forecasting known as the water balance (12) or Quantitative Method may have an indirect influence on snow course site locations mainly because more snow courses will be required in order to appraise water equivalents in different areas of the watershed. In locating a new network on a watershed in which forecasts are to be made, a good procedure is to install ample snow courses at the outset thus making possible the use of the water balance method forecast at an earlier date than if only a minimum number were established in order to use the index procedure.

There are, in addition to streamflow forecasting, other uses for the survey data. Snow survey data are used in the determination of building design in mountain areas, and in evaluating design problems of bridges and pipelines, and highway clearance plans.

These many other uses that snow survey data have are usually fulfilled with a simple mean of snow depth and water equivalent. These will be satisfied by the same principles that provide a good index for streamflow forecasting.

## Guidelines for Snow Course Site Selection

Physical guidelines may be summarized as follows:

1. Reasonable accessibility to insure measurement each year.
2. Security should be assured in order to perpetuate the usefulness of the records.

3. Well drained area on a slight slope.
4. Exposure should be in a protected mountain meadow, free from wind action--a north facing slope in preference to southern or western.
5. Elevation of key courses should be great enough to reduce winter melt and be in the water-producing areas of the watershed, but low level courses also are needed.
6. There should be at least 9 to 15 samples to insure a fairly stable mean. Sample size can be reduced or increased after a record has been obtained.

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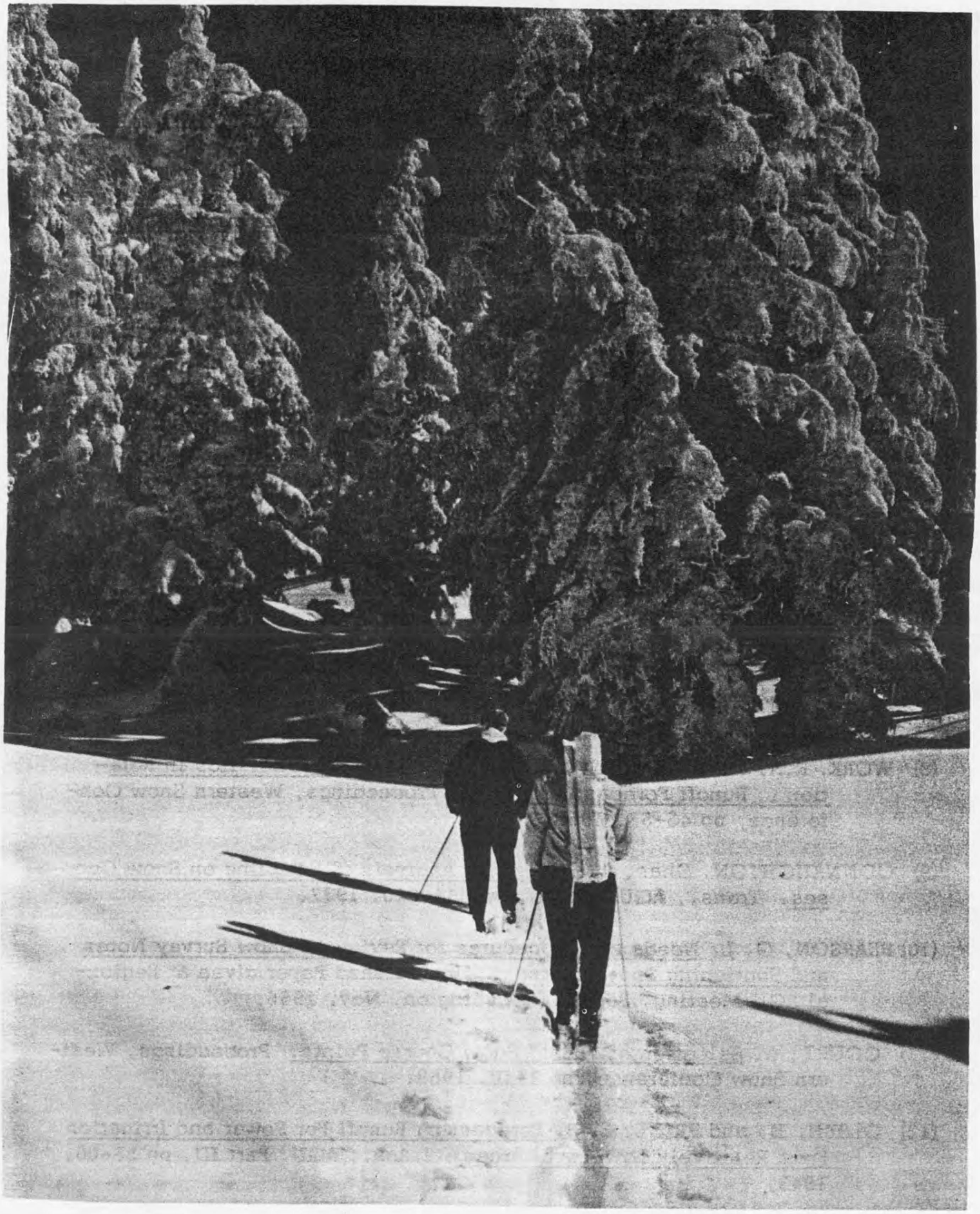
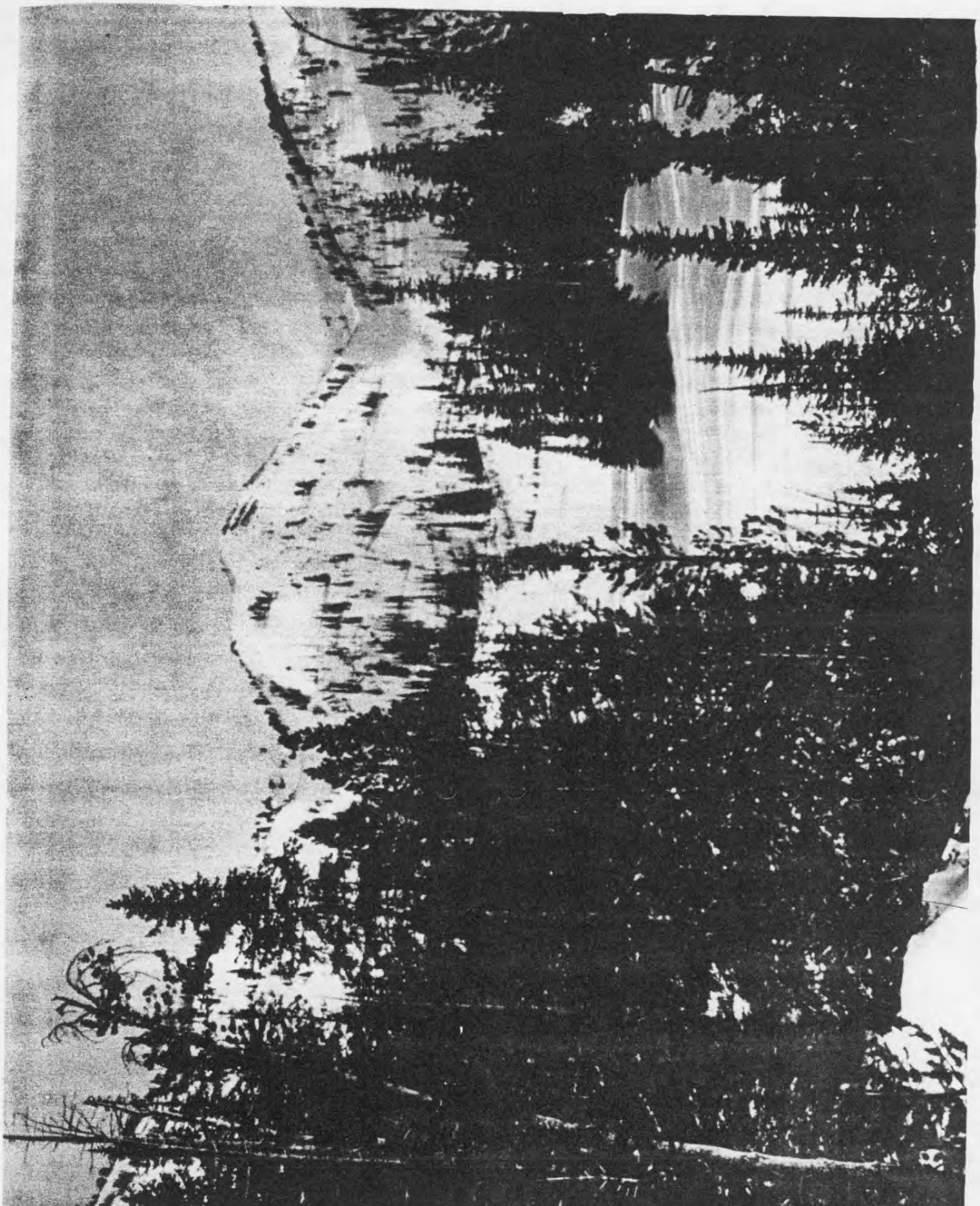
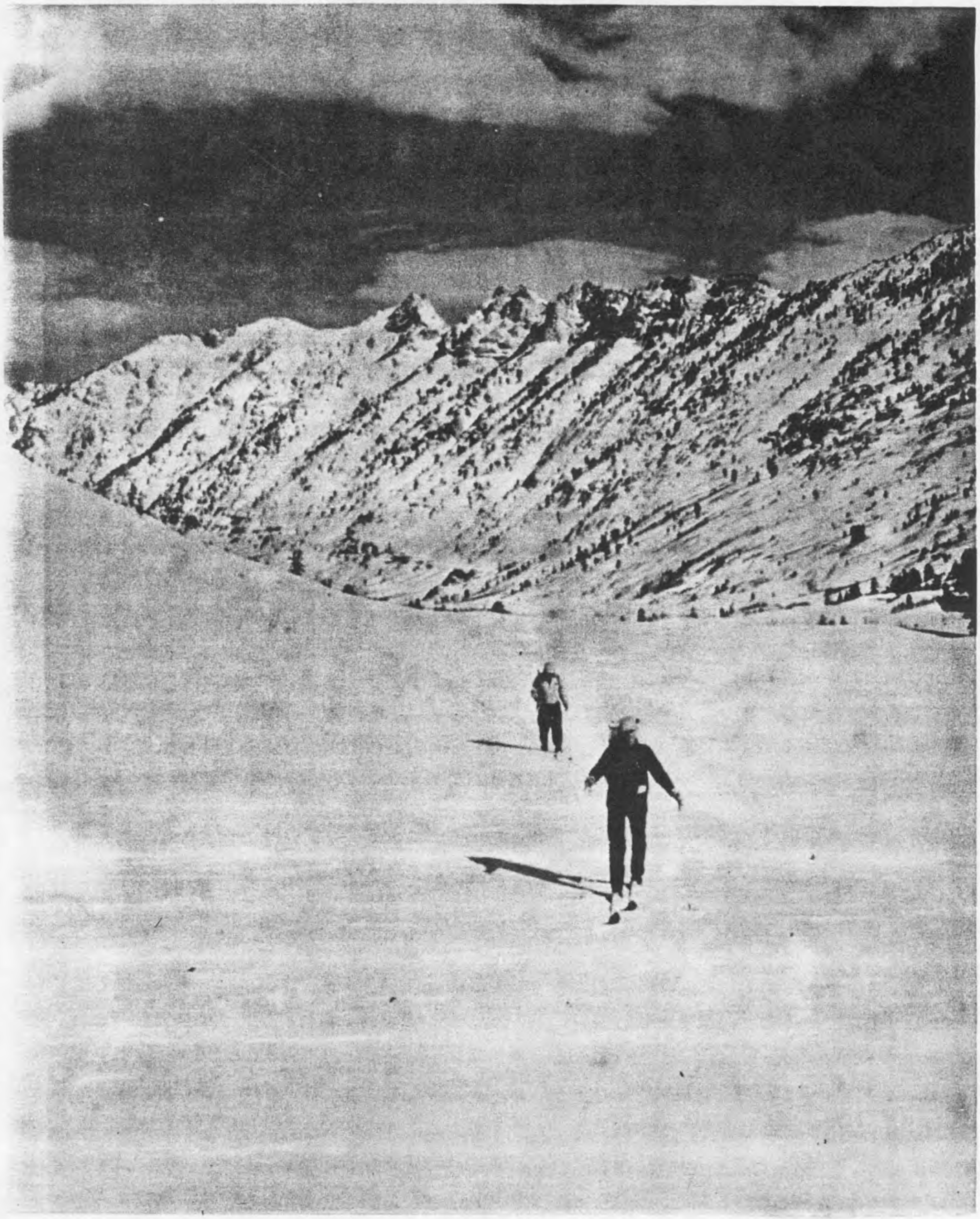


Figure I





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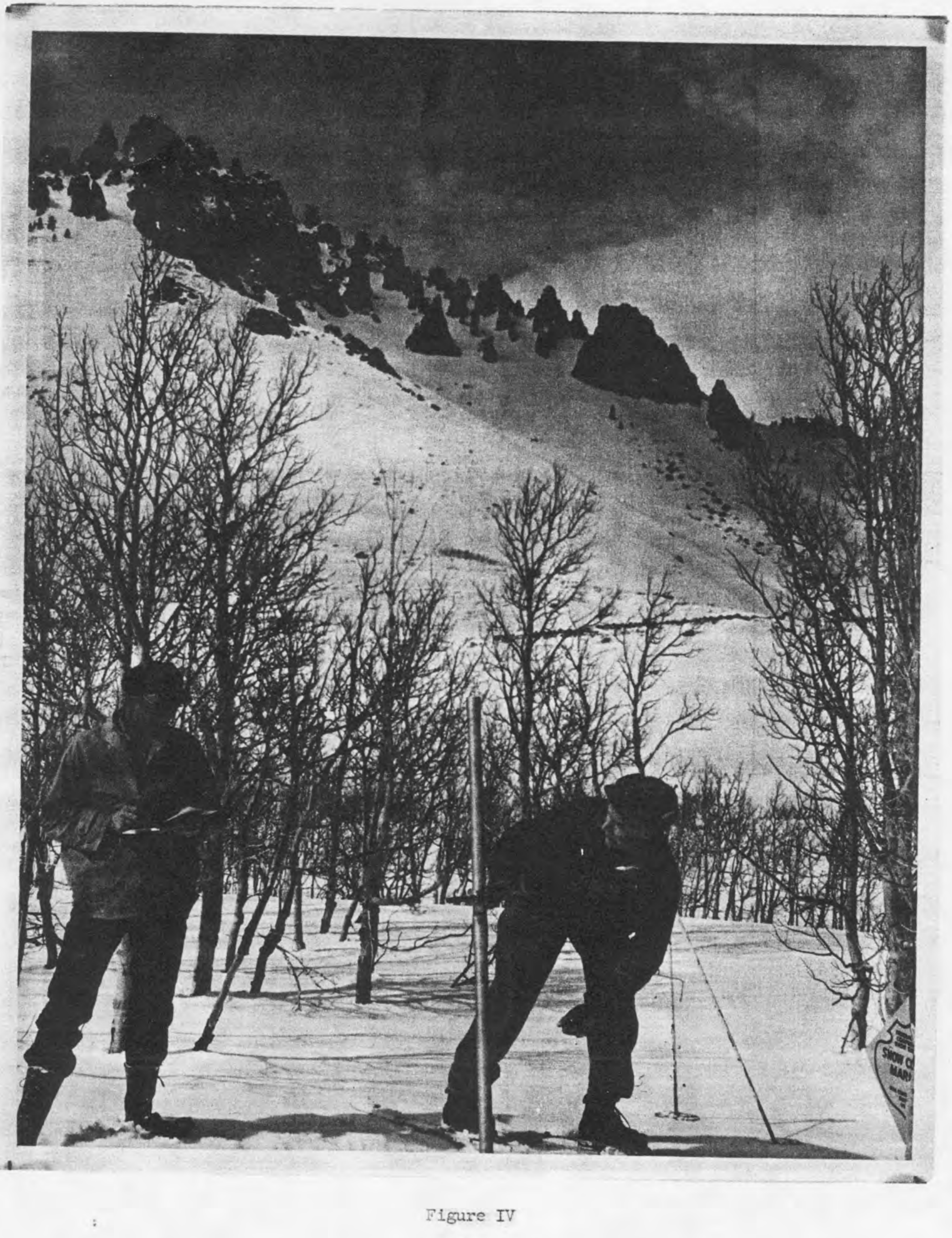

Figure IV

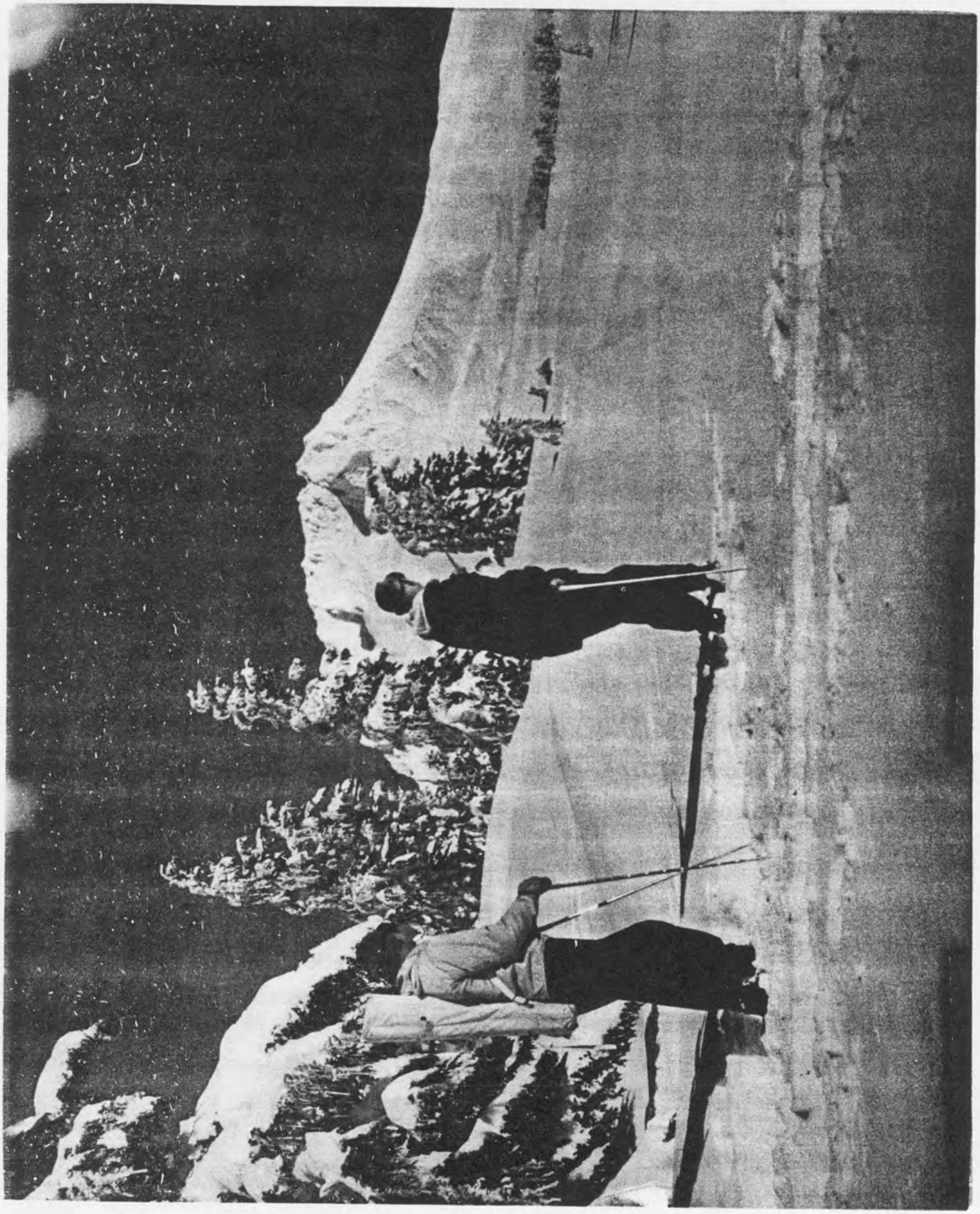

Figure V