the ALTA AVALANCHE STUDIES

M. M. ATWATER, SNOW RANGER AT ALTA, UTAH.
F. C. KOZIOL, SUPERVISOR, WASATCH NATIONAL FOREST - INTERMOUNTAIN REGION.

THE ALTA SNOW STUDIES

Table of Contents

		Page
I.	Introduction	1
II.	The Avalanche Hazard	3
III.	Avalanche Characteristics	17
IV.	Avalanche Hazard Forecasting	32
V.	Avalanche Protective Measures	44
VI.	Conclusions	49
VII.	Annex	
	A. Alta Avalanche Hazard Guide	50
	B. Avalanche Rescue Operations	52
	C. Alta Standard Snow Terminology	56
	D. Alta Snow Study Records and Charts	62
	E. Alta Explosives Operations	69
	F. Safety Organization	79
	G. Desirable Snow Research Projects	84
	H. Avalanche Accidents	84
	I. Climax Avalanches	89

Safety regulations are ineffective without cooperation and understanding by the public.

THE ALTA AVALANCHE STUDIES

by

M. M. Atwater, Snow Ranger at Alta, Utah

and

F. C. Koziol, Supervisor, Wasatch National Forest

I. INTRODUCTION

The following digest and analysis of the Alta snow studies is designed particularly for the instruction of Forest Service personnel who have duties in alpine ski areas. It is also offered for the information of snow observers, skiers, and interested persons generally. The study is based on 10 years continuous observation of avalanche phenomena at Alta, Utah, interpreted in the light of personal experience and snow data from foreign sources.

While this survey derives from and applies particularly to Alta, the methods of avalanche study and hazard forecasting and the safety procedures developed have general application. With modification, they can be employed in any area and will serve as a take-off point for further investigation of a complex, fascinating, and important subject.

There is no suggestion that the final chapter on snow research is included. With decades of much more intensive effort and study behind them, the Swiss are first to admit that the time when man can predict exactly the hour, location, and violence of an avalanche has not yet arrived. James Laughlin, noted American ski mountaineer, reported from Switzerland during the 1948 Winter Olympics that Swiss ski areas were closed for as many as 10 days at a time on account of avalanche hazard.

With widespread and increasing interest in the development of alpine ski areas it is essential that the snow information we have be assembled in brief and logical form. The material presented here is original, not a rehash of previous studies or a review of textbook theory. Field observations at Alta are the source, confirmed whenever possible by other authorities. They are believed to be the only comprehensive body of avalanche research material in this country.

Avalanche research in the United States has taken a course of its own. The emphasis is on practical observation and experience rather than technical or laboratory analysis. There is no parallel in this country for the Swiss Avalanche Institute. In Switzerland, avalanches have been and are a major social and economic problem. The Swiss people have lived and worked for centuries with the hazard at their elbows. The revenue from visitors to their developed ski areas is an important part of the national income. It is only natural, therefore, that the Swiss should have devoted more energy, time, and money to snow research.

Study of the available Swiss literature on avalanches and reports from our own skiers who attended the 1948 Winter Olympics point to one important conclusion. The avalanche is one of the most powerful and complex forces in nature and has not yet yielded all its secrets to man. In Switzerland as well as in this country, the emphasis is turning from abstract research and passive methods of protection to the active and practical approach.

Specifically this means first, stabilization of slopes by skiing whenever that can be done safely and second, control of the avalanche hazard through the use of explosive or avalanche barriers.

Alpine Ski Area Administration

Avalanche hazard, certain to exist in some degree, is the most serious problem of administration in any true alpine ski area. It could be solved very simply and directly on Forest Service land by barring such areas to the public. This is not a satisfactory solution. Interest in winter sports in this country is great. It is increasing rapidly enough to produce an irresistible demand for the development of our finest ski terrain, the alpine zone, characterized by long winters, dry snow, and steep, open slopes.

Another extreme answer to the avalanche problem would be to ignore it, trusting to luck and the fact that the chances of a skier and a snowslide arriving on the same spot at the same time are, mathematically speaking, remote. This approach to the problem would be absurd except that it has actually and seriously been offered.

The Forest Service is vitally concerned with a practical method of gaining maximum public use of alpine ski areas with adequate safety. Practically all the true alpine terrain already developed, under investigation, or still waiting for discovery, lies within the borders of the National Forests. Involuntarily the Forest Service finds itself with a task of supervision, administration, and research which must be undertaken. Otherwise development of one of the finest participant sports will inevitably be marred by disasters for which the Forest Service would justly or unjustly take the blame.

History of Alta Avalanche Studies

For nearly 10 years the Forest Service has been carrying out such a program of snow study at Alta, Utah, in the Wasatch National Forest. Alta, in earlier days one of the most famous silver mining camps of the West, is the first true alpine ski area to be developed in the United States. The first full-time snow observer, Ranger C. D. Wadsworth, was stationed there by the Forest Service in the winter of 1937-38 when construction of the chair lift began. A modern highway and a large public shelter were also under construction.

F. C. Koziol, now Supervisor of the Wasatch National Forest, then attached to the Region 4 division of Lands and Recreation, and Alf Engen originally recommended the development of Alta. The area presented an unusual combination of favorable factors: ideal skiing terrain and climate plus the essential addition of a large city within easy driving distance to assure it of financial support.

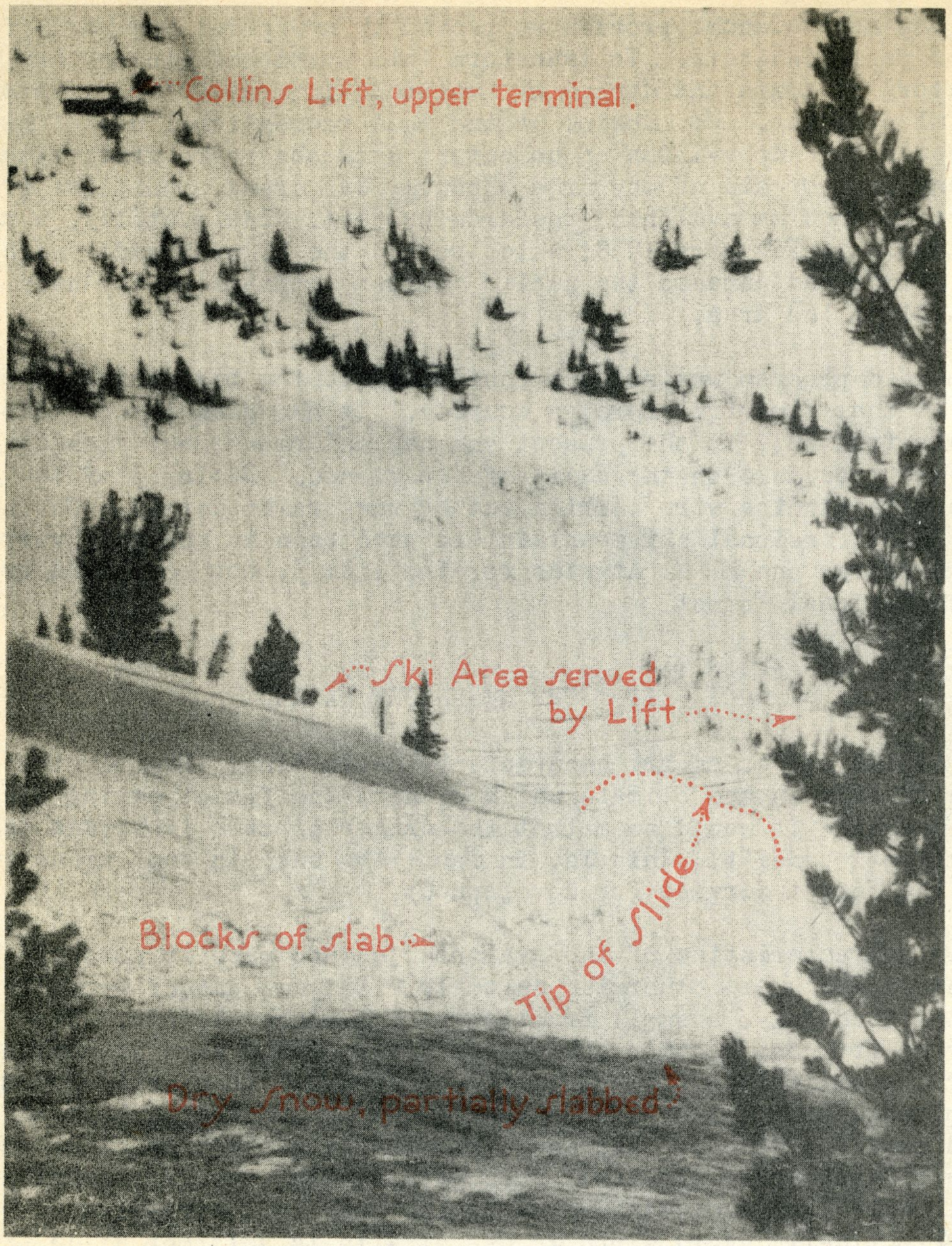
Alta also had an avalanche problem as proved by newspaper and word-of-mouth accounts of past disasters. To transform this abandoned mining camp with a grisly history of death and damage by avalanche into a winter playground took careful planning. Mr. Koziol stated that recreational use of Alta was feasible under the supervision of competent snow observers armed with power to close any part or all of the area whenever dangerous conditions prevailed. He also recommended an avalanche research project. Incidentally, a major avalanche cycle in February 1938, which buried the highway under eighteen different slides and damaged the public shelter, emphasized the need for close control of the area.

The recommended program was set up, conforming to the best information available at that time from foreign sources. It has been in operation continuously from 1937 to the present and has undergone many changes in technique and procedure on the basis of experience. During 3 of the 10 years, the Alta studies were carried out by rangers on detail. During the other 7, professional ski mountaineers have been in charge; Sverre Engen for 4 years, and M. M. Atwater for the last 3, both employed by the Wasatch National Forest.

II. THE AVALANCHE HAZARD

Desirable alpine ski areas are hazardous by definition. Exactly the same conditions of terrain and climate which produce the finest skiing also favor avalanches. It would seem that the danger is more important than the recreational benefit. This is, in fact, the case in some areas suggested to the Forest Service for development.

But certain characteristics of the avalanche hazard make it possible to use most areas which are otherwise suitable. Extreme danger prevails for short periods only, a small fraction of the winter season. The danger varies from one section and one exposure of the area to another, ranging from practical absence of hazard on upward. In a well-chosen, properly planned area the avalanche hazard can be controlled by both active and passive methods. The most important passive protective method is closure of dangerous locations, some permanently, most for short periods only. Skiers themselves have an active part in controlling avalanches. Practically every slope in use at Alta is a former slide path stabilized most of the time now by constant skiing. Carried one step further, this principle becomes useful to the experienced snow ranger when skiing doubtful slopes ahead of the public and releasing minor areas of unstable snow. The final stage of active protection is the use of explosives on larger and more dangerous slopes to release major type avalanches at times chosen by man instead of the gods of the mountain.



Slab and dry snow avalanche released by explosives and in motion on West Rustler. The tip of the slide is entering the lift-served ski area.

Alta Avalanche Accident Record

The best proof that alpine terrain can safely be developed for public recreation is to compare the avalanche accident record of Alta as a mining camp and as a ski area. The mining era lasted less than 10 years during which the camp had a peak population of about 5,000, followed by a longer period of reduced operations. Verifiable records of avalanche accidents in the vicinity of Alta go back only as far as 1875. During the next 35 years there were 67 recorded avalanche fatalities in Little Cottonwood Canyon. Three slides in 3 different years "gobbled up" over 10 persons apiece.

Yet this period was after the heyday of the mining camp, which extended from 1868 to 1873. Persons are still living who escaped the slide of 1874 which destroyed the town of Alta and took some 60 lives. Other eyewitnesses tell of the annual trek of undertakers to Little Cottonwood Canyon when melting snows revealed the victims of the preceding winter.

In contrast to this gruesome record, Alta's decade as a recreational area has seen exactly two avalanche accidents involving persons. In one case the victim was killed, in the other he was rescued. In both cases, the accidents happened in areas which had been closed by the Alta "snow ranger." Closure signs and personal warnings had been disregarded.

The difference between these records is too great for coincidence, especially since the winter recreational use has always exceeded the mining population. It was 10,000 in 1938 and has risen to 100,000 in 1948.

Since the complaint is often made that this record was achieved by a policy of super-cautiousness, with highways and ski slopes closed a good proportion of the time, a few statistics are relevant.

TWO YEAR SAMPLE ALTA HIGHWAY & SKI AREA RESTRICTIONS

(Percentages are in terms of total length of Skiing Season.)

	Days Highway Closed		Days Ski Area Restricted	Days Entire Area Closed	Days Highway Restricted		Hrs. Highway Closed During Lift Operating Period
	Impassable (1)	Hazardous	(2)		Snow Removal (3)	Hazardous	
1946-47	6 3.3%	5 2.7%	25 13%	3 (1)1.6%	8 4.4%	8 4.4%	87 7.3%
1947-48	4 2.2%	6 3.3%	21 11%	2.5 1.3%	16 8.8%	4 2.2%	87.5 7.4%

Skiing season: 180 days.

Total lift operating hours during season:
90 days @ 6 hrs. — 540
90 days @ 7 hrs. — 630
1170

The percentages are not to be added since restrictions on highway travel nearly always coincide with restrictions in the ski area.

(1) Due to avalanches in place across the highway.

(2) This column includes days when restrictions were of a very minor nature.

(3) Generally including less than 2 hours of lift operation time.

These figures show that in general restrictions other than permanent closed areas are in force only 15 percent of the time including restrictions of a very minor nature. The number of skiing hours lost in the course of a 6-months' season due to protective measures is too small to be worth discussion.

Since our knowledge of the mechanics of avalanches is incomplete, a degree of hazard cannot be eliminated. Avalanches occur which do not conform to any pattern of conditions or factors yet discovered. But this element of danger is small. Knowing that it exists, the snow ranger can keep it small. In most cases explosives offer a definite solution to the riddle.

Traffic area at Alta. Shows parking space, highway approach and two lodges adjacent.

Terrain Analysis

In order to get a complete picture, the avalanche hazard in any area must be viewed from both the administrative and the technical angles. The administrative standpoint reveals it as divided into three sections. At Alta these divisions are quite distinct and probably would be so anywhere. The traffic area—highway and parking—is one. The lift-served ski area is a second. By "lift-served" is meant those slopes which the skiers can reach from the lift without climbing on foot. Where touring slopes overhang heavily used runs they are supervised as part of the lift-served area. The touring area adjoins the lift-served. Improvements such as lifts, lodges, and shelters tie in with the divisions they adjoin, lodges generally with the traffic area, lifts with the ski area.

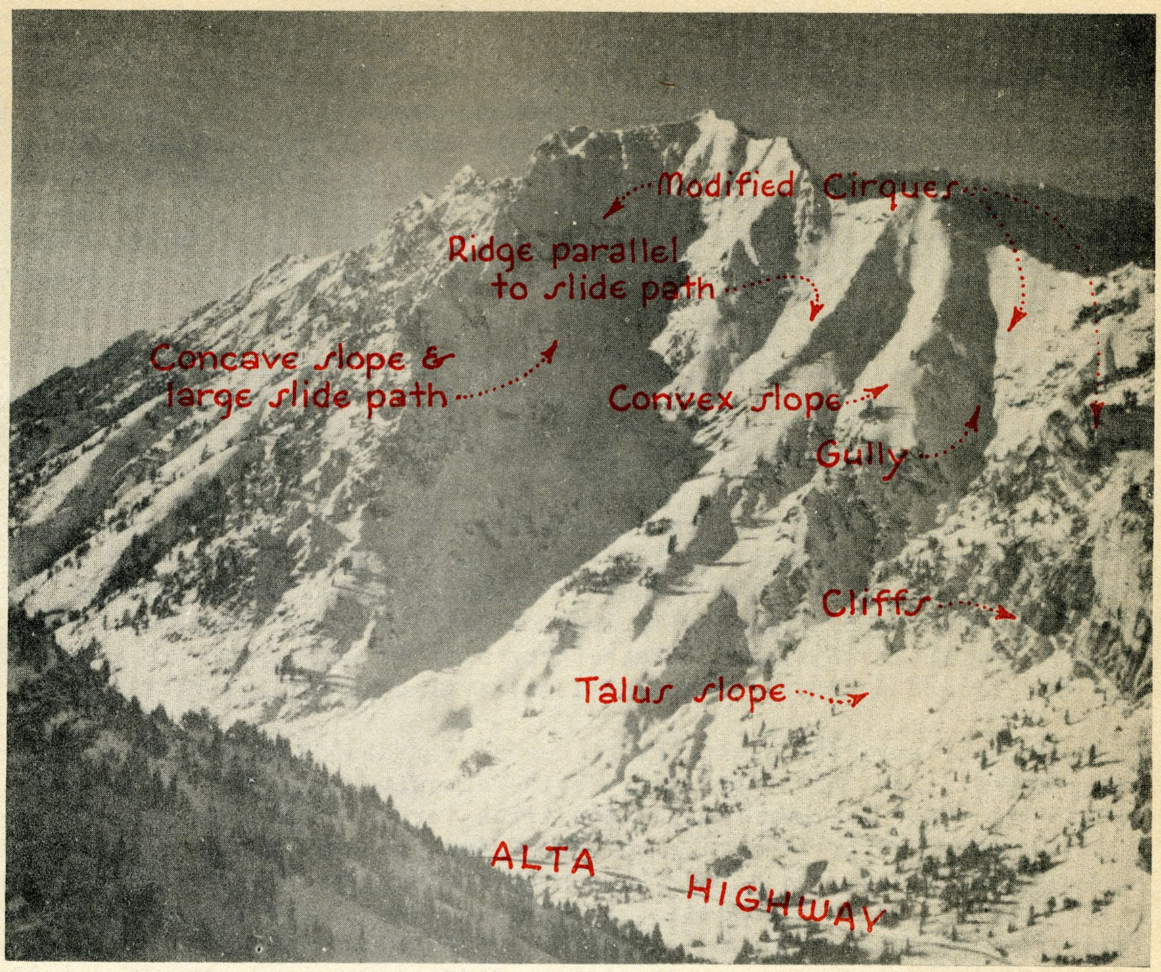
Each division has its own special problems. Use of the area, both numbers and distribution, is an important factor. Alta, for example, is a heavily used area compact in form. The close control necessary in the lift-served division is much easier than it would be if the terrain favored wide distribution of the skiers. The avalanche hazard is concentrated, too. This probably had much to do with causing the high loss of life during mining days when there was no attempt at supervision. With a safety organization functioning, it is actually an advantage. For if the hazard is more severe it is also easier to keep under control.

From the technical standpoint, avalanche hazard falls into two divisions: terrain and climate. Without suitable conditions of grade, shape, and surface of the land, there are no avalanches. The most important of these factors is grade. Authorities agree that slope angles of 25° or more are avalanche favorable. Experience at Alta indicates that in this area at least, the critical grade is somewhat sharper; from 30° on up, with the easier slopes becoming involved only when disturbed by snow moving down from higher and steeper locations.

The size of an avalanche slope has an obvious part to play, increasing the possible weight and violence of a slide in proportion to its dimensions. However, a slide of great width descending a short slope will have less momentum than a narrower one on a very long slope. This is in accordance with the formula so many automobile drivers forget until too late: Energy equals $\frac{1}{2}$ mass x velocity^2, $E = \frac{1}{2}MV^2$.

It is axiomatic that convex slopes are more dangerous than concave because snow settling on a surface that bulges is under a stretching tension. The avalanche habit of fracturing at the exact point where the curve of a convex slope is sharpest has often been noted. At Alta it is our experience that shape, convex or concave, is a minor detail compared to angle and size. For the ski mountaineer, the shape of a slope may indicate the probable fracture point of an avalanche and so assist him in selecting his route. The snow ranger is more concerned with when and how big than exactly where.

All the infinitely varied features of a mountainous terrain are important in the analysis of avalanche hazard. Cliffs are too steep to accumulate snow themselves. However, if water veins exist they are apt to release



Multiple avalanche slopes -- Mt. Superior's impressive slide paths overlook the Alta highway.

falls of rock and ice which will start avalanches on the slopes below. And if snowfields lie above, the descent over a cliff will naturally give a slide a maximum boost in velocity.

Cirques are ideal accumulation zones for wind-driven snow. If their exposure is favorable they are natural reflectors where sun action will be far above general temperatures thus leading to the release of sun slides. Gullies collect and channelize snow descending from above. By increasing the friction, they retard a slide. But if the slide is big and fast enough to overcome this effect, it will issue from the gully with explosive force. Every competent ski mountaineer knows that a gully is the poorest possible place to travel. Ridges lying parallel to the slide path, on the other hand, are relatively secure and generally offer much better traveling conditions.

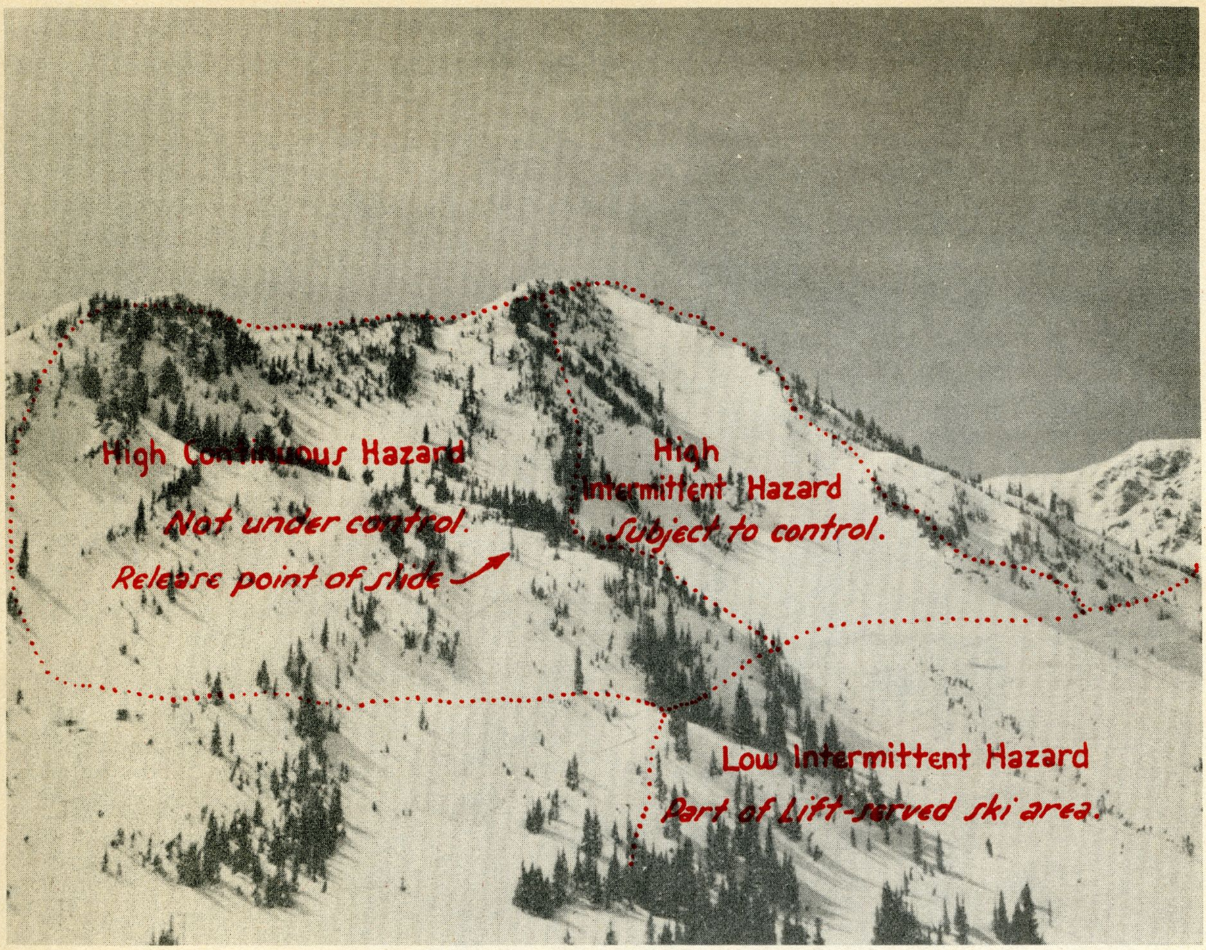
Terraces, talus slopes, and basins, because of their easier grade are effective avalanche barriers. They give the moving snow room to spread out and lose its momentum. But as the winter progresses snowfall, wind action, and successive slides gradually obliterate them.

Ground surface conditions have considerable effect beyond the snow in contact. A broken serrated terrain, boulder-strewn and brushy, will provide a good anchorage for the snowpack as a whole. Slides breaking off at ground level are unlikely. The description is typical of Alta where ground level slides seldom occur. Smooth, even slopes, grass-covered or of bare earth and rock, favor the violent and destructive ground level avalanche typical of the Alps.

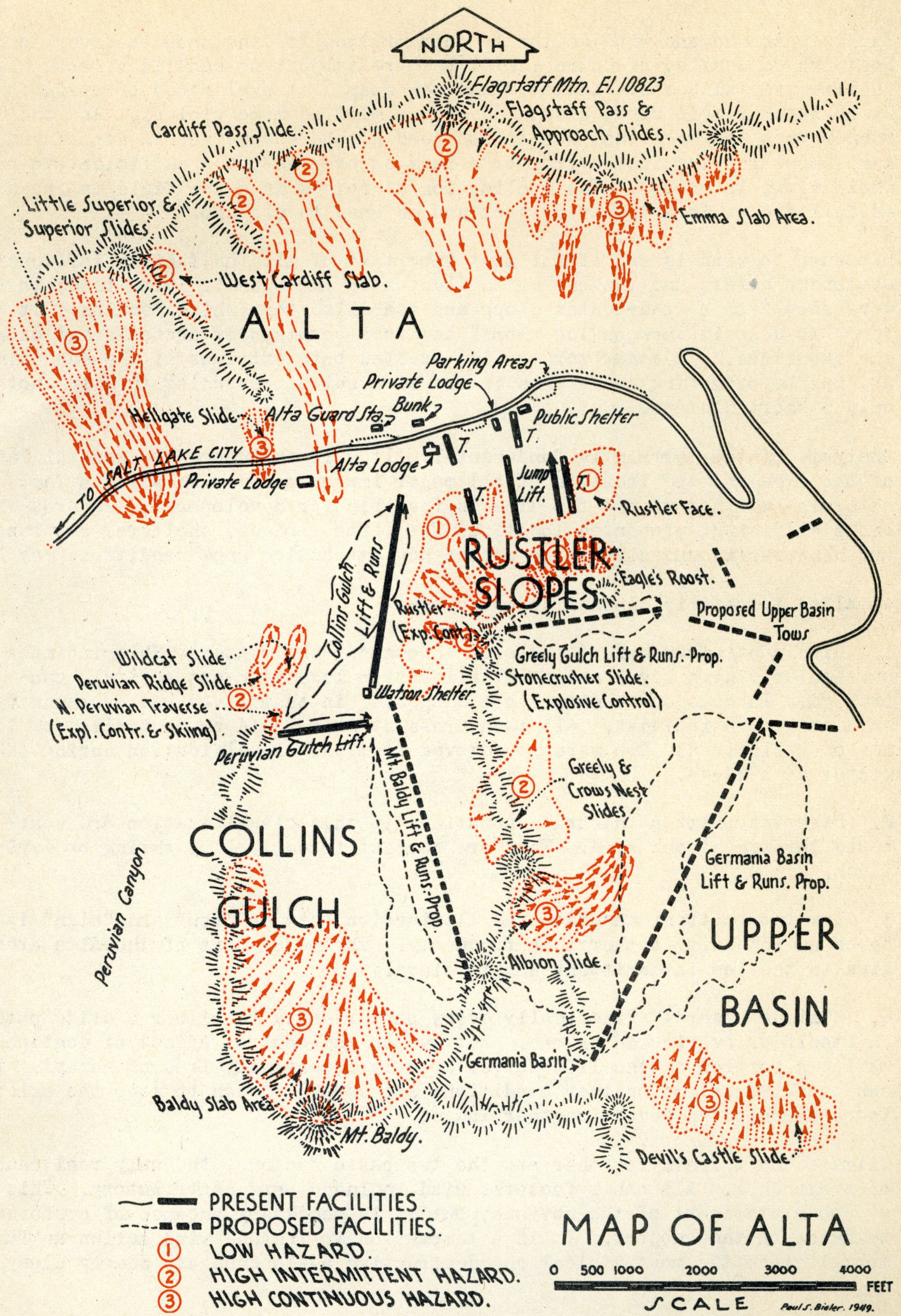
Vegetation of any kind except grass has a restraining effect on avalanches. Tree cover is the most important. Alta was quite heavily forested when the miners arrived. As they removed the trees for fuel and mine timbers, avalanches became proportionately worse. Under national forest administration natural reforestation has made good progress with noticeable effect on the slide hazard. It is interesting to note that the Swiss avalanche researchers consider reforestation to be one of the most important parts of the avalanche hazard control program. Recent studies carried out in Switzerland indicate that trees or any rounded obstruction are a more effective avalanche barrier than a solid wall.

It is a mistake, however, to regard a forested area as safe. Two of the major slides of the winter of 1947-48, Coal Pit and Argenta, originated in locations with fairly good timber cover. The wild snow powder flowed down among the trees like sand or water without damage to them or noticeable hindrance to the avalanches in their initial stages. Nevertheless, forest cover is highly beneficial. It cannot prevent avalanches under extreme conditions, but it is an effective barrier. It helps indirectly to lower avalanche hazard by promoting the growth of other vegetation, by breaking up the even flow of wind and thus the formation of snowslab, and by providing relatively safe routes for ski travel.

Argenta avalanche detail. Accumulation zone and release point. A timbered area on a lee slope may be a deterrent but not an absolute avalanche preventative. (This is close up detail of photo on page 93 .)



Terrain analysis. Rustler Mountain.
Slide in high continuous hazard area was man-caused -- note tracks. He got off with minor injuries.


NORTH
Flagstaff Mtn. El. 10823
Flagstaff Pass & Approach Slides.
Cardiff Pass Slide.
Emma Slab Area.
Little Superior & Superior Slides
West Cardiff Slab.
ALTA
Parking Areas
Private Lodge
Bunk
Public Shelter
Hellgate Slide
Alta Guard Sta.
T.
TO SALT LAKE CITY
Alta Lodge
Private Lodge
Jump Lift.
Rustler Face.
RUSTLER SLOPES
Eagle's Roost.
Collins Gulch Lift & Runs
Rustler (Exp. Cont.)
Proposed Upper Basin Tows
Greely Gulch Lift & Runs.-Prop.
Stonecrusher Slide. (Explosive Control)
Wildcat Slide
Peruvian Ridge Slide
W. Peruvian Traverse (Expl. Contr. & Skiing).
Watson Shelter
Peruvian Gulch Lift.
Mt. Baldy Lift & Runs.-Prop.
Greely & Crows Nest Slides
COLLINS GULCH
Peruvian Canyon
Germania Basin Lift & Runs. Prop.
UPPER BASIN
Albion Slide.
Germania Basin
Baldy Slab Area
Mt. Baldy.
Devil's Castle Slide
PRESENT FACILITIES.
PROPOSED FACILITIES.
1 LOW HAZARD.
2 HIGH INTERMITTENT HAZARD.
3 HIGH CONTINUOUS HAZARD.
MAP OF ALTA
0 500 1000 2000 3000 4000 FEET
SCALE
Paul S. Bieler. 1949.

Exposure to sun and wind action is another item for the snow observer to note. Southern exposures, of course, will be more subject to sunslides, both the shallow damp slides of midwinter and the deep, wet avalanches of spring. Where natural reflectors exist the effect will be more violent. And the snow ranger must remember that sun action need not be extensive. A single wad of damp snow dropping from a tree or a rock outcrop is often sufficient to put a whole slope in motion. The combination of forces in a snowfield is frequently as delicate as in a balancing rock and as easy to disturb.

Exposure to wind is one of the most important of all the factors influencing avalanche hazard and the one which fluctuates the widest. Wind tends to remove snow from a wind-beaten slope and stabilize that which remains. It tends to deposit snow on lee slopes and form cornices or unstable and dangerous snowslabs. In other words, wind creates both extremes at the same time and may be promoting avalanches in one area while preventing them in another only a short distance away.

Analysis of the terrain is fundamental. It will influence the general layout of the area and the location of all major improvements. It will in fact determine whether or not the area is feasible for development. An area which lacks sufficient protected locations for lifts, lodges, shelters, ski runs and highways is undesirable no matter how attractive snow conditions may be.

At Alta, terrain is classified as follows:

1. High continuous hazard: closed throughout the winter. This includes particularly high level and critically steep locations not actively controlled. In some cases slopes not dangerous in themselves but overhung by such areas are included. All such areas at Alta could be controlled by the use of explosives. Two were so removed from the classification during the winter of 1947-48.

2. High intermittent hazard: Locations in this classification are scattered throughout the area. They are subject to control by skiing or explosives.

3. Low intermittent hazard: The distinction between "low" and "high" is based on intensity rather than frequency. The major part of the Alta area lies in the low intermittent hazard class.

4. Minimum hazard: Practically every part of Alta is either a slide path in itself or overlooked by one. But due to the control effect of continuous skiing a portion of the lift-served area is essentially free of hazard. It can be skied unless weather conditions are severe enough to keep the skiers indoors—which is severe weather indeed.

Climate and terrain together are the two basic factors, the only real cause of avalanches. All other factors, wind included, are contributory. This may be a statement of the obvious, but it is necessary because of confused thinking on the subject. It is a temptation to include wind action as fundamental since the most violent and destructive avalanches are nearly always

ALTA SNOW DATA

	1944-45						1945-46						1946-47						1947-48					
	Snow Fall (1)	Water Ratio (3)	Cumulative Snow Depth	Settlement o/o	Major Storms (4)	Large Ava. Occurrence (2)	Snow Fall	Water Ratio	Cumulative Snow Depth	Settlement o/o	Major Storms	Large Ava. Occurrence (2)	Snow Fall	Water Ratio	Cumulative Snow Depth	Settlement o/o	Major Storms	Large Ava. Occurrence (2)	Snow Fall	Water Ratio	Cumulative Snow Depth	Settlement o/o	Major Storms	Large Ava. Occurrence (2)
Nov.	-	-	30		U	0	109	.08	38		U	0	69	.09	46		2	0	118	.07	44		1	0
Dec.	57	.12	45	73	U	3	83	.11	72	59	1	2	63	.07	58	80	2	0	80	.06	53	88	2	1
Jan.	18	.18	56	38	U	0	85	.09	101	65	2	3	61	.08	83	59	3	3	46	.09	66	71	1	1
Feb.	67	.10	94	43	U	2	49	.07	94	114	1	0	53	.07	95	77	2	1	66	.07	79	80	3	1
Mar.	76	.10	122	63	U	2	65	.10	111	73	4	0	68	.08	86	113	4	5	165	.08	127	70	5	7
Apr.	57	.09	132	84	U	1	55	.11	113	96	1	3	60	.08	94	86	2	2	74	.12	112	120	1	4
Totals	275	Av. .118	Max 132	Av. 60%		8	446	.093	Max 129	Av 67%	9	8	374	Av. .078	Max. 109	69%	15	11	549	Av. .081	Max. 134	Av. 71%	13	14
47 & Av.	411	.092	126	69%	10	10.2																		

(1) New snow depths not taken on separate 24-hour stake.

(2) Days.

(3) Inches of water per inch of snow.

(4) U - unknown.

its aftermath. But it would be incorrect. The fact remains that sufficient snowfall in favorable terrain is all that is necessary to produce an avalanche and that in the absence of either one, no avalanche can take place.

Climate Analysis

Like terrain, climate to the snow observer is a combination of a number of factors: snowfall type and quantity, wind force and direction, temperature, humidity, barometric pressure, storm characteristics. Their roles in the rise and fall of avalanche hazard are analyzed in the next section. The discussion here is limited to the general character of an alpine winter climate, specifically, Alta's. It is not the same as that of any other alpine area, even in the vicinity, and is described merely as a sample of what the snow observer needs to know.

The Wasatch Mountains are a steep and high range rising abruptly at the edge of a semi-desert. The altitude of the canyon floor at Alta is 8500 feet and the surrounding peaks reach or exceed 11,000 feet. When the westerly, moisture-bearing winds strike these mountains, the result is impressive. Snowfall at the rate of an inch an hour is not uncommon. Storms which deposit 3 feet or even more of new snow in one continuous downpour are not unusual. Alta's desirability as a ski area and the character of its avalanche hazard depend on the individual traits of these storms.

Alta's typical snowfall is dry; that is, there is not enough free moisture in the snow crystals so that they will adhere when squeezed in the glove. It is varied in type: flake, granular and pellet in all sizes and combinations. Its weight averages .092 of an inch of water per inch of snow, which is heavy for a "dry" type of snow. These characteristics promote rapid settling and cohesion, those qualities of flotation without stiffness, and packing without becoming icy, which delight the heart of the skier.

Alta's winds, generally westerly, are highly erratic in direction and force in contract to the Alps, where wind direction is practically a constant. For an elevation of 8,000 to 10,000 feet, Alta's temperature is comparatively mild. Three or four days only of below zero weather during the season are normal. Daytime maximums are apt to be above freezing. The bulk of the temperature curve lies between 12° and 32° Fahrenheit. This is in marked contrast to temperatures in the alpine regions of Colorado where the average and the extremes are considerably lower. Corrected barometric pressure and relative humidity records for Alta are not available. Both fluctuate rapidly and widely.

The following table gives cumulative snow data for the past 4 years. It yields interesting sidelights on the variability of some of the major factors with which the snow ranger must deal. For example, there are the monthly snowfall extremes of 18 inches in January 1945 and 165 inches in March 1948; or the water content extremes of .18 of an inch of water per inch of snow, January 1945 against .06 of an inch, December 1947.

The tabulation also shows the futility of any attempt to analyze an area's avalanche hazard on the basis of gross statistics. A few of the more obvious contradictions are as follows:

1. There were the same number of large avalanche cycles in 1944-45 as 1945-46. But the former had 61 percent less snowfall. However, that snow was markedly heavier and the cumulative snow depth was actually greater.

2. 1946-47 had 78 percent of the large avalanche occurrence of 1947-48 with only 68 percent of the snowfall. In this case that snow was less in weight and cumulative depth.

3. To narrow the field of view a little, March 1947 had 71 percent of the avalanche occurrence of March 1948 with only 41 percent of the snowfall.

4. An apparent trend in favor of avalanches in March and proportionate to the weight of snow and number of major storms reverses itself in March 1946.

To sum up, avalance occurrence does not consistently follow the season, the total snowfall, the monthly snowfall, the water content or even the major storms. It is plain that the problem of avalanche forecasting is not going to yield to the adding machine unassisted.

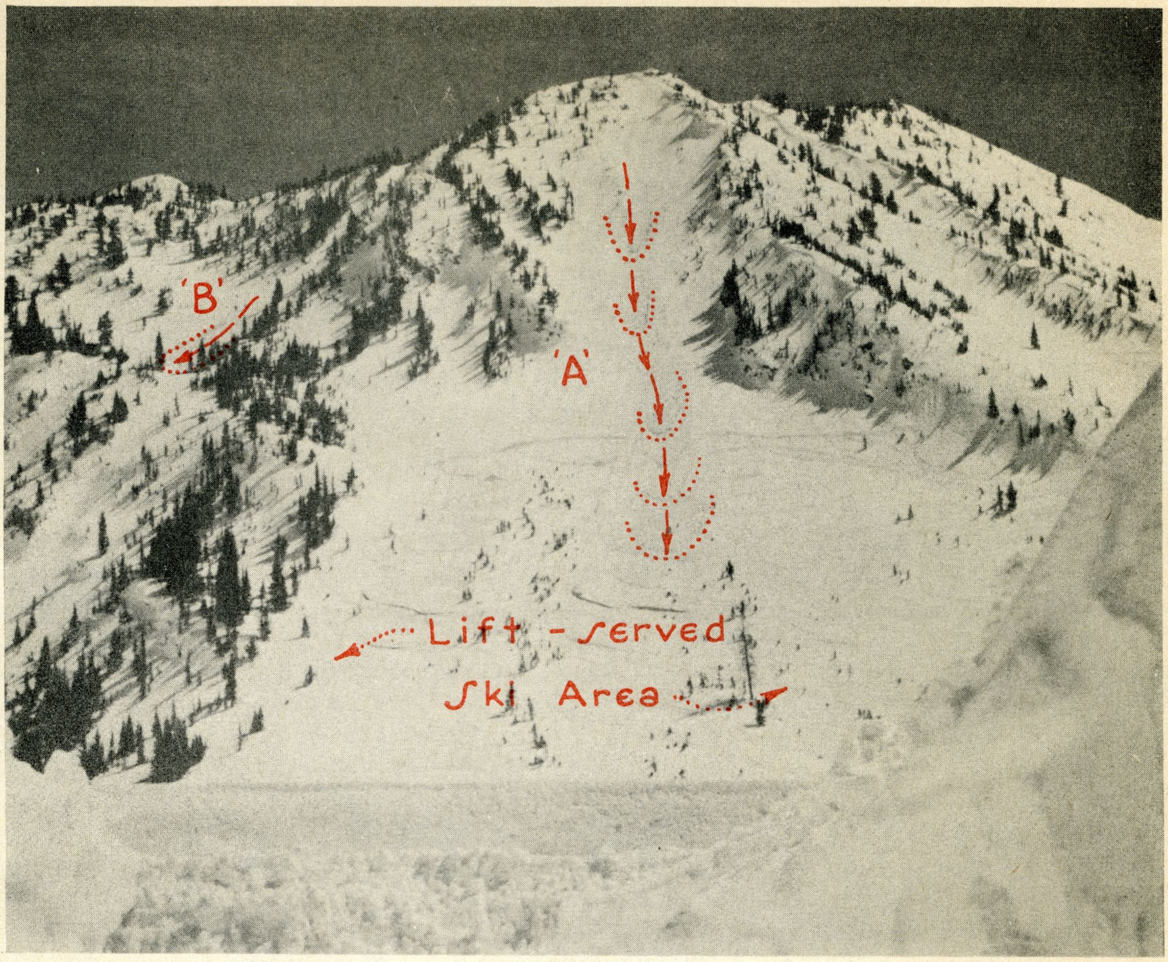
III. AVALANCHE CHARACTERISTICS

To the victim of its power, it makes little difference what kind of an avalanche buried him. But for purposes of analysis and study, classification is necessary. The latest Swiss practice is to recognize only two types, packed snow and loose snow. This method has the advantage of simplicity but it leaves many of the possibilities uncovered. At Alta, four types are recognized: dry snow, damp and wet snow, slab, and combinations. They are further classified as to size in terms of danger to life and property: 1. Sloughs or small. 2. Medium. 3. Large or major.

Dry snow avalanches are composed of loose, new fallen snow possibly drifted but not materially altered otherwise. They start at a narrow point, travel rapidly on an elongated gradually widening path, increasing in size as they descend. If of major proportions they are sometimes accompanied by destructive air blast. Being so light, the slide travels in the air as well as on the ground. Danger to the skier is as much from suffocation in this cloud of snow dust as from physical violence.

At Alta dry snow avalanches are not a great problem. Snow of this type is so unstable that it begins to slide before any great depth can build up. Thus, to become large size a dry avalanche must have a very large slide path. Only a few such paths exist at Alta. These are well known and closed early when dry snowslide conditions develop. The contract is Switzerland where these slides may fall thousands of vertical feet over cliffs. Some areas in this country can probably match that situation.

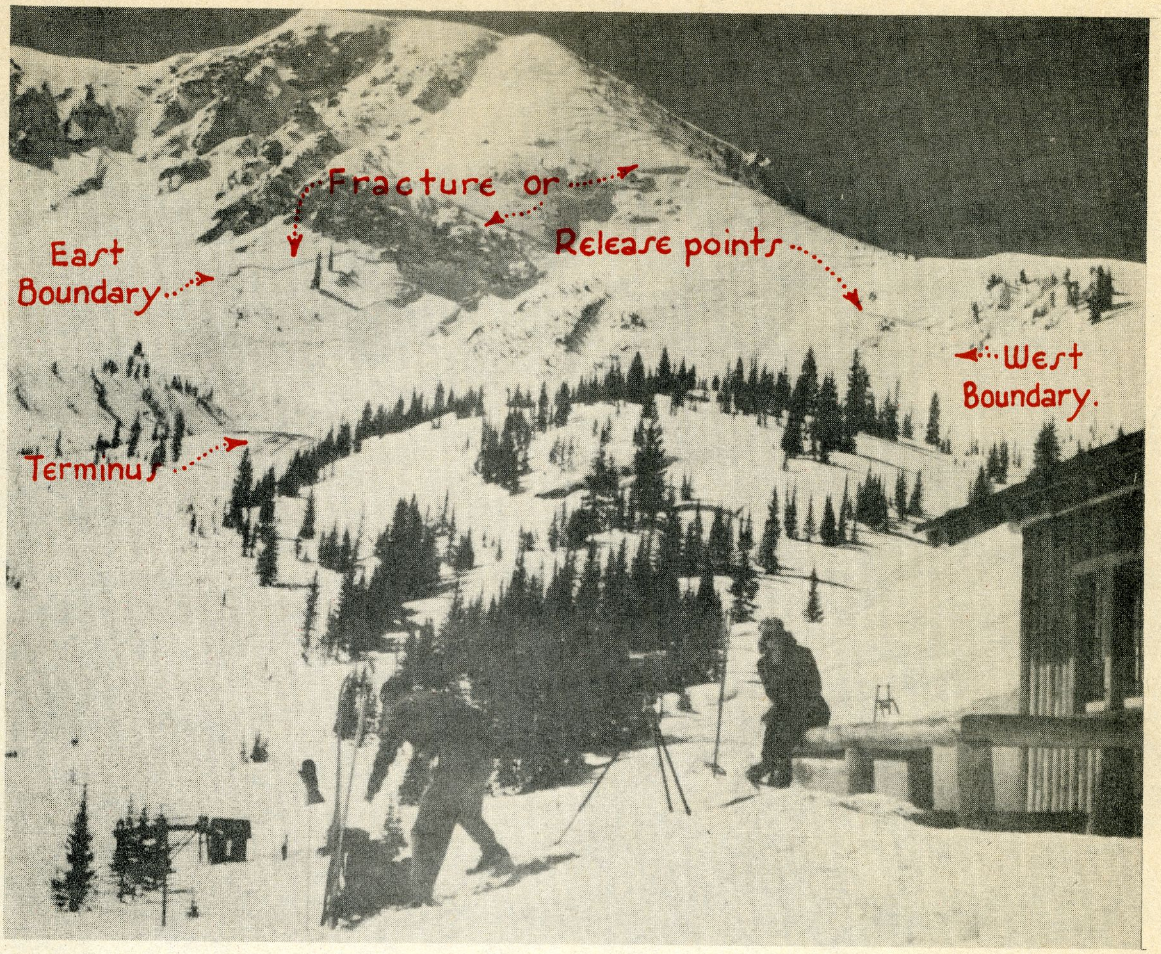
Small dry snow avalanches or sloughs on Cardiff. These are a sign of stabilization.



A - Large dry snow avalanche from Rustler Face, explosives release. Note wave-like appearance of slide path and penetration of the lift-served ski area.

B - Secondary avalanche, slab type, caused by explosion . Rustler Face.

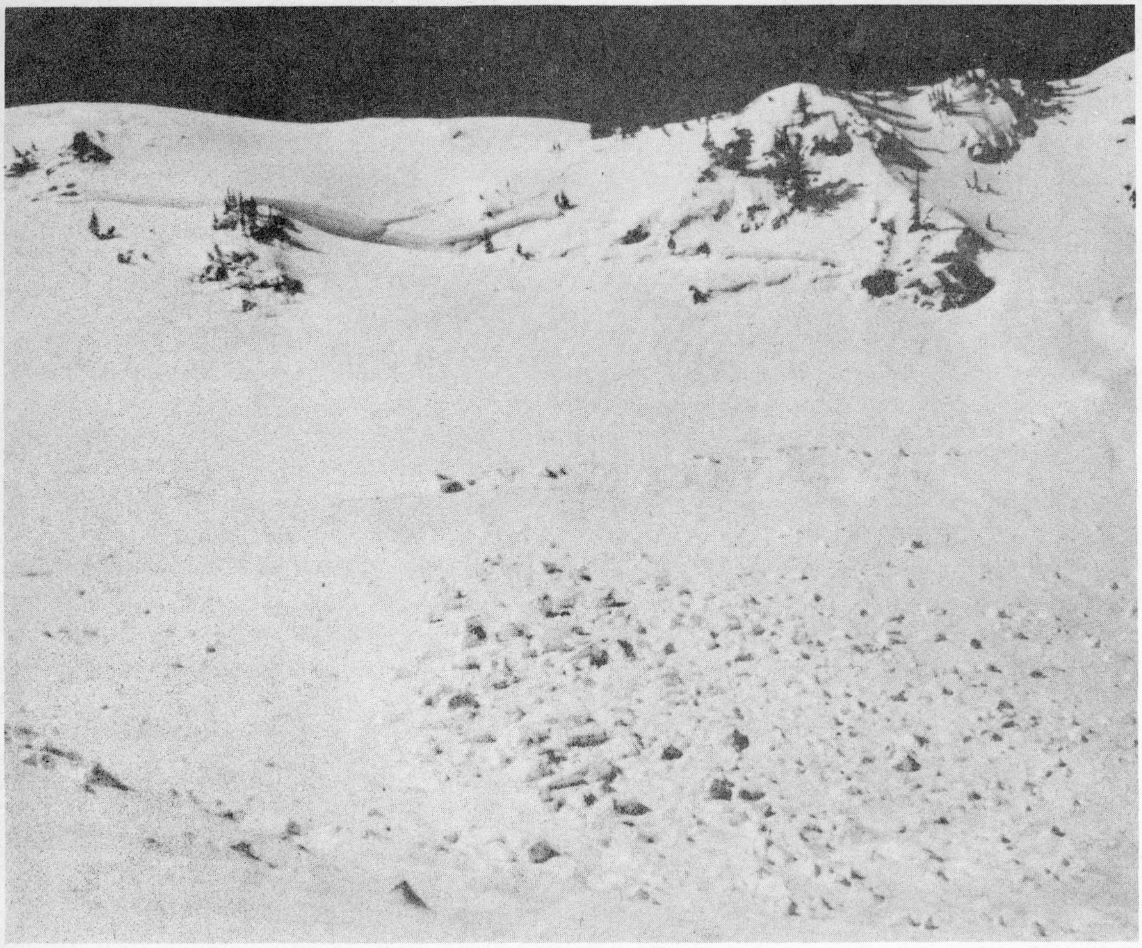
Damp sunslide. Note the distinct fracture line. Sunballs rolling down on either side first indicated that sun action was strong on this slope.



Major slab avalanche from Mt. Baldy, 1000 yards wide, fracture plane, 6 feet deep. Terminus can be seen on mound directly up from Peruvian lift terminal.

Baldy avalanche detail, east end. A delayed action, slab type slide released by new snowfall. This is a high continuous hazard area, permanently closed. Not under explosives control.

Baldy avalanche detail, center. The half-moon contour in the middle foreground is a knoll some 30 feet higher than surrounding terrain. It was overwhelmed by the slide.



Baldy avalanche detail, west end, showing depth of fracture and slab strata. Note "stopwall" running across the center of the slope. At this point, due to easier grade, the slab remained in place. The large, square edged blocks in the slide paths are typical of slab fracture.

Baldy avalanche detail terminus, looking downhill toward Peruvian lift. Note the large slab blocks still intact after traveling half a mile, though corners are rounded off.

Controlled avalanche on Rustler Face. Type: slab and dry snow. Note the blocks of slab.

A damp or wet snow avalanche may also start at a narrow point if release is caused by some disturbance such as a wad of snow or falling rock. However, it almost immediately spreads to its full width and is much more likely to start in that manner. Slides of this type being heavier, develop more friction and travel more slowly. In fact the typical wet spring avalanche is slow enough so that any reasonably alert person can get out of the way. Their principal threat is to stationary objects like buildings or parked cars.

In the case of damp slides, the word "slow" is a comparative term. While they may not travel at the explosive speed of a dry avalanche, any skier had better have a long start and a good wax job before trying to outrun one of them. They are second on the danger list at Alta. Because damp snow has considerable inherent stability it will cling to a steep slope until dangerous amounts build up. Since slides of this type develop maximum volume at or soon after the start, they do not need a long run. Experience has taught us at Alta that during a damp snow storm, especially if wind action is strong, the avalanche hazard rises much more rapidly, and the cycle is apt to be much more violent than with any other type of snow except slab. The most dangerous damp slides are those where release is due to simple accumulation of weight during a storm. Damp sunslides are more likely to slough off a few inches at a time.

Slab avalanches at Alta as in any other area where they take place, are the most dangerous of all. This is the only kind of avalanche which can fairly be called vindictive. Unlike other forms of unstable snow, it does not resolve the problem quickly by sliding or settling. It retains its instability for any length of time.

If found on the surface, snowslab or windslab has a characteristic dull, chalky, nonreflecting appearance, but it is generally disguised under layers of later fallen snow which may themselves be perfectly stable. Release of a slab avalanche is sudden, violent, and extensive. Motion pictures of explosive-released slabs in 1948 show practically the entire slope in motion at once.

A skier caught in a slab avalanche has practically no chance to do anything for himself. He is instantly knocked off his feet, pounded by the grinding, rough-edged blocks, and carried down at greater speed than he could attain in a straight schuss. The outcome for him is purely a matter of luck, generally bad.

Slab is a type of windpacked snow. The manner of its formation is not thoroughly understood. Most authorities agree that it develops on lee slopes from wind action on falling snow, rarely from snow already fallen and picked up by the wind. Contour of the surface is a necessary condition so that just the right degree of turbulence is created in the windborne mixture of air and snow. On one slope at Alta where the wind customarily blows parallel to the contour we find wind crust and other stable forms of snow interspersed with patches of slab on the lee edge of several minor depressions of gullies. A deeper gully with the same exposure but protected by scattered trees is not slabbed by wind from this quarter.

Evidence from some observers that slab always forms under conditions of low temperature and high relative humidity has not thus far been confirmed by experience at Alta.

The behaviour of windslab is better understood than the manner in which it forms. It is a brittle, unstable structure. Typically it is very hard, but it may be soft, an intermediate stage of development perhaps, and still retain its brittle quality. It has a very poor bond to the undersurface. Under an old slab there is generally an air gap since the slab cannot settle at the same rate as the general snow mass. If there is an air gap under the windslab, it is unquestionably in a condition of stress. Under the skis it has a hollow, drumlike sound. On gentle slopes it will fracture with long cracks running outward, and settle with a dull thud. On steep slopes it seems almost to explode, as if it were under tension.

Our motion picture sequences of slab avalanches do not, however, confirm this explosive effect. They show the entire shield breaking loose at once and then fracturing instantly into blocks.

Because of the erratic wind conditions at Alta, slabs do not form consistently on any particular slope or exposure. Neither are they so likely to be extensive or to be piled one on top of the other. Two of the permanent closed areas at Alta are favored slab locations. One, which overhangs the lift-served area, is now under control by explosives and has been removed from the danger list.

Any one of the three types of avalanche already described can and frequently does occur in combination with either one or both of the others. The typical natural release slab avalanche, for example, is nearly always the result of new snow falling on a slab already in place. Although a great weight of snow may be involved, the false stability of slab may keep it in position indefinitely, one slab piling on another until finally a very minor increase in snow depth or any other disturbance sets off its chain reaction. In one case at Alta, two inches of new snow started a slab avalanche cycle.

A slide may change from one type to another during its descent. The Argenta avalanche of March 1948, began as a slab-plus-dry snow combination. It traveled a mile and a half, picking up heavier snow on the way and developing much internal friction and weight as it squeezed itself through a series of gullies. When it finally came to rest on the canyon floor it was damp.

Contributory Avalanche Factors

Major storms are the principal direct cause of avalanches at Alta. This is just another way of stating the basic formula: Sufficient snow in a favorable location. A storm is divided for analysis into a number of factors of varying effect and importance. Of these natural factors, ten have been identified and evaluated to the point where they can be used as a basis for the study of snow behaviour and the forecasting of avalanche hazard at Alta. They are: 1. Old snow depth. 2. Old snow surface. 3. New snow depth. 4. New snow type. 5. New snow weight. 6. Rate of accumulation. 7. Wind force. 8. Wind direction. 9. Temperature developments. 10. Snow settlement.

It can be argued that the terrain is also a variable and should be included in this list. If avalanche study had reached the point where forecasters could attempt to classify the hazard for each particular slope in the area, this would be true. Such classifications could probably be made on the basis of present knowledge, but gathering the necessary data is a task beyond our resources. The terrain is therefore treated as a constant favorable to avalanches and is not included in calculations of the hazard.

1. The function of the old snow depth is to provide a smooth, even slide path. It begins by covering up minor obstructions such as rocks and low-growing brush. As it deepens it reduces the effect and even eliminates entirely the effect of larger barriers like terraces, gullies, and basins. Frequently the old snow becomes involved to some extent and adds volume to the slide. Beyond the point where it covers minor ground obstructions, the old snow depth is always a factor favorable to avalanches. At Alta that point appears to be a 24 to 36 inch depth. The dividing line would undoubtedly be different in other areas.

2. The old snow surface is a good example of the Dr. Jekyll-Mr. Hyde character which avalanche factors assume, and another reason why it is impossible to lay down arbitrary rules or formulae of forecasting. Fundamentally the problem is simple. A crusted surface makes a poor bond with later fallen snow and provides an excellent slide path. A loose snow surface offers a good bond and a high friction slide path. Unfortunately we can't stop there. A crusted surface protects the underlying snow from getting involved in a slide. It also promotes an early start of the avalanche cycle so that the unstable snow will come out piecemeal instead of all at once.

It should be stated early that these avalanche factors play a dual role most of the time, that they cannot be considered singly on a basis of addition and subtraction, and that we do not have enough data to evaluate them exactly either singly or in combination. On the other hand we do have enough data to distinguish between dangerous situations and those which are merely unstable. No snow ranger can afford to shut the area down just because a little snow is moving; there is snow in motion on about half the days of a winter season at Alta. Neither can the snow ranger afford to take long chances with public safety. Unable to draw a hairline distinction among the overlapping, dual-performing factors which result in avalanches, he must act when the indicators are markedly favorable. He must also act in time for protective measures to do some good, a matter, experience has taught us, of at least 2 hours at Alta. Since a major avalanche hazard can disappear in five minutes, strictly accurate predictions are impossible. It frequently happens that a storm of dangerous proportions will unexpectedly end within the 2-hour limit.

3. The new snow depth illustrates another and different type of fluctuation. Strictly speaking, any amount of new snow at all is a factor favorable to avalanches. But the snow observer finds that there is an amount beyond which danger becomes acute, other factors being favorable. At Alta, this amount of dry snow is about 12 inches. It is one of the best guide posts the snow ranger has. When the 1-foot mark on his snow stake disappears he can start mulling over the other factors in earnest. Remembering his 2-hour factor he has probably been uneasy for some time anyway.

4. A standard snow terminology has been constructed for Alta to aid in study and record keeping. Every snow observer must either adopt a terminology or construct one of his own. Records are worthless unless they are definite and consistent. The Alta snow terminology is included in the Annex.

The type of snow is classified according to form—crystalline (powdery), granular, pellet; size—fine, medium, coarse; and weight—dry, damp or wet. No type of new snow can properly be called stable. For the observer it is a question of marked departure one way or the other from its average ability to stay in place. On this basis both granular snow and pellet snow of average water content are unstable and favorable to avalanches. All types of dry crystalline snow and mixtures of one or more types are normal and negative in their effect.

5. The influence of water content brings us to snow weight, a factor closely allied to type. For analysis of its effect on avalanches, it is again a question of departure from normal. Average snow weights at Alta range between .07 and .09 of an inch of water per inch of snow. The familiar dual-role performance comes in. Damp snow is sticky and its type is therefore unfavorable to avalanches. Damp snow is also abnormally heavy and therefore its weight is a favorable factor.

6. Rate of accumulation of new snow is chiefly important in combination with other factors, principally wind action. Like the depth of new snow it is always favorable to slides in some degree. But from the standpoint of slides of dangerous proportions, it often has a negative or even unfavorable value. At Alta snowfall rates above .6 of an inch per hour are in the danger zone.

7. Wind action, force-plus-direction, is undoubtedly the most important variable in the list of contributory avalanche factors. If the snow observer is careful to remember that in action wind force and wind direction are inseparable, they can be analyzed one at a time. Force is a modifying and direction a selective factor. Acting favorably they are present in an overwhelming majority of dangerous avalanche cycles resulting from major storms.

Snow falling in quiet air is distributed evenly over the surface of the area. Wind modifies this process in two ways. First it removes snow from parts of the area and dumps it in others. This uneven distribution increases by geometric rather than arithmetic progression as the wind velocity goes up. Second, it alters the form of the snow, grinding large particles into smaller ones, possibly changing them from crystalline to granular in the process and thus subjecting the snow to violent fluctuations in temperature and humidity. In the act of depositing it on the surface, wind leaves the snow crusted or packed, slabbed or drifted, altered in size, shape, weight and depth. Instead of a blanket of even depth and texture we have a chaotic mixture.

To the forecaster, wind force can never be a factor unfavorable to avalanches. Even though building a safe wind crust in one location it is busily constructing a dangerous slab in another. If below critical levels, its value is zero. At Alta, the critical level is in the neighborhood of 10 miles per hour.

8. Wind direction is the selector which distributes the effects of wind force throughout the area. It is responsible for the wide variation in the hazard, which may be critical on one set of exposures and moderate or non-existent on others. At Alta, for example, NW storms can endanger the highway when the major portion of the ski area is unaffected. SW storms find "Closed to Skiing" signs up on many runs while highway traffic is undisturbed.

Force is obviously the dominant member of this team. As the comparative analysis in the next section shows, critical wind velocity acting on enough snow can produce a general avalanche cycle regardless of wind direction.

9. Temperature changes before, during, and after a storm, play a rather subtle part in the development of avalanche cycles. Our data at Alta are neither extensive nor accurate enough to be of more than general value. The typical Alta storm begins at temperatures in the neighborhood of 32°. The temperatures fall gradually during the storm and rise gradually afterward. This is the forecaster's "normal" indicated by observations to be favorable to snow stabilization. Temperatures which fluctuate rapidly up or down, especially the former, appear to favor unstable snow conditions. Storm temperatures which produce damp snow have demonstrated their bias in favor of large avalanche cycles and the same is true for markedly low temperatures.

Prolonged cold after a storm, unusual at Alta, retards settlement and preserves any instabilities which may exist. Rapidly rising temperatures promote damp slides and a quick end to the avalanche cycle whatever its intensity.

10. Settlement is a stabilizing factor. It goes on continuously, fair weather or foul, and thus acts to keep the snow in place. Storm settlement rates fluctuate widely and their effect needs further study.

To summarize, major storms are the principal direct source of dangerous avalanches at Alta. New snow depth, rate of accumulation and wind action are dominant and can produce large avalanche cycles regardless of the other factors. It is in borderline situations that the minor factors become important and cause the trained snow observer to apply restrictions which appear unnecessary to the layman. The reverse is also true, that a skillful administrator can keep the area open when rule of thumb indications would encourage closure.

There are several other avalanche factors worthy of mention but they cannot be analyzed without more study. Few storms are continuous. Observations indicate, as they logically should, that these breaks in the course of a storm are beneficial, even if quite short. Settlement takes place, minor avalanche cycles run their course and relieve the tensions in the snow pack. Not least in importance, the snow ranger catches a glimpse of his test areas. Whether or not they have sloughed out will influence all his decisions during the next onset of the storm. But on the basis of the data available it is not possible to assign any consistent value to this factor.

Barometric pressure probably has some direct effect on snow conditions but we have not been able to identify it. Relative humidity undoubtedly plays a continuous part in snow development from the time it is formed until it becomes water again. However, accurate and consistent relative humidity readings are very difficult to obtain in cold weather. Our records, although complete for a period of years, are not believed accurate enough for research purposes.

In addition to the natural factors just discussed, there are a number of artificial or accidental elements which may intervene with results difficult to predict. Falls of rock or ice and fractured cornices may start a local avalanche cycle either premature or of more violence than from natural release. Terrain analysis is the snow ranger's only guide in this matter.

Either through ignorance or carelessness, skiers occasionally blunder onto unstable slopes and become the direct cause of their own injury. At the other extreme is the professional snow observer operating possibly on the same slopes, but according to plan and for the definite purpose of causing slough cycles.

During the course of a winter, Alta can expect one or two snowstorms accompanied by thunder and lightning. In one recorded case, a thunderclap released a large avalanche hours ahead of the general cycle. Sound is another item for the snow ranger to tack up on his mental bulletin board.

When snow conditions are unstable, secondary avalanches are always a possibility. Either from ground or air vibrations, or by undercutting the slope, one avalanche may release another. Secondary avalanches during control work with explosives are an example of the same effect and snow rangers must be alert to them. At Alta slides of this type have occurred up to a quarter of a mile from the blasting point. See photograph page 17.

IV. AVALANCHE HAZARD FORECASTING

For reasons which should be fairly obvious by now, avalanche hazard forecasting is not an exact science either in time or location. Within limits, the hazard from slope to slope and exposure to exposure can be sub-classified. The limits are imposed less by the natural avalanche factors involved than by the protective measures available to the snow ranger. Slopes controlled by explosives or stabilized by skiing are safe long after the general danger level is extreme.

But the snow observer's chief aim is to distinguish between the three stages of general avalanche hazard: Insignificant, requiring no action on his part; moderate, requiring restrictions in high hazard areas only; and major, requiring maximum protective measures.

Basis of Avalanche Hazard Forecasting

The principal basis of avalanche hazard forecasting is the observer's snow experience in general and his familiarity with the area in particular. Because of the variables involved, many of them pulling in different directions at the same time, nothing could be more misleading than arbitrary standards or formulae of avalanche hazard. Insignificant and major hazard conditions are not difficult to recognize. It is on the borderline between moderate and critical danger that the snow observer can demonstrate his skill. The ability usually called intuition is nothing of the sort. It is good training in snow craft plus personal acquaintance with the individual character of the slopes.

The most dangerous slide path is not always the most impressive to look at. Terrain analysis would not, for example, reveal that the part of Peruvian Ridge at Alta lying close to the lift is safe 95 percent of the winter, while another part, almost exactly the same in grade, contour, and exposure, is dangerous 95 percent. Only familiarity can convince the snow ranger that the Hellgate slides are more spectacular than dangerous while a very modest appearing abutment half way down Flagstaff Mountain is a slab avalanche breeder of the worst kind.

Detailed and systematic records of past avalanche performance are a type of area familiarity which can be passed on from one administrator to another. They give the observer, new or old, a coherent, annually increasing body of information and reference material. Under comparative analysis, these records reveal definite standards of maximum and minimum hazard. They are the basis of avalanche hazard forecasting and safety procedure at Alta.

Not all avalanches are the direct outcome of storms, but the majority at Alta are. Delayed action avalanches are discussed separately. On the following charts, over 40 major Alta storms are reduced to their common denominators. Wherever possible, the avalanche factors are expressed as ratios suitable for direct comparison. The information is highly concentrated. Comments and explanatory notes follow but the serious student of snow behaviour will find opportunity for his own analyses. Some of the obvious comparisons are indicated.

Fact or values favorable, unfavorable, and negative to avalanches are assigned according to the following table. The dividing lines are arbitrary from necessity. They represent the observer's best judgment on the basis of experience and information to date. See Page 34.

A V A L A N C H E   F A C T O R   V A L U E S

	Old Depth 1	Surface 2	New Depth 3	Type 4	Wt. 5	Rate of Fall 6	Wind Force 7	Wind Dir. 8	Temp. 9	Settlement 10
Favorable to Avalanche +	24" or above	Cr	14" dry 7" damp	Gran. or Pellet	.11 or above .06 or below	.60 or above	.60 or above	Any when 7 is +	Near 32° and rising	.30 or below
Unfavorable to Avalanche -	Less than 24"	Old pwd. or damp surface	10" dry 6" damp or less	Dry/Damp or Damp		.50 or below			Any fall-ing	.50 or above
Negative 0		New pwd. or mixed Cr & Old	14-10" dry 7-6" damp	Mix-tures	.10 to .07	.59 to .51	.59 or below	W Vari-able or any when 7 is 0	Steady except as above	.49 to .31

NOTES

1. #4 - Dry/Damp means dry snow over damp snow.

2. #5 - A ratio. The figure indicates inches of water per inch of snow.

3. #6 - A ratio. The figure indicates inches of snowfall per hour.

4. #7 - A ratio. The figure is the result of dividing the storm duration in hours into the number of hours wind force was at critical levels.

5. #10 - A ratio. The figure indicates inches of settlement per inch of snowfall.

M A J O R   S T O R M   C O M P A R I S O N

D A N G E R O U S   A V A L A N C H E   C Y C L E S

D A M P   S T O R M S

	1	2	3	4	5	6	7	8	9	10	RECAP			DURATION		AV. CYCLE		
No.	Old Depth	Surface	New Depth	Type	Wt.	Rate of Fall	Wind Force	Wind Dir.	Temp.	Settlement	+	-	0	Cont. Snow	Gross	Hrs.	Snow	Remarks
1D	38	Cr	26	Damp Gran & Flake	.14	.52	.73	W	+	.50	6 1,2,3 5,7,9	2 4,10	2 6,8	50	65	1st 25 2nd 45	12" 23"	Large general cycle. Holm boy buried near Flagstaff mine.
2D	59	Cr & Old Pwd.	7	Damp Gran	.19	.58	1.00	W NW	+	.71	6 1,4,5 6,7,9	2 3,10	2 2,8	12	12	6	6"	Large cycle on minor amt snow. Note type & wt. of 3S.
3D	56	Cr	15	Damp	.14	U	+	W	+	U	5 1,2,3 5,7	2 4,9 (6,10	1 8 U)	U	U			Major av. from Superior.
4D	100	Cr	19	Damp	.13	U	+	U	+	U	6 1,2,3 5,7,9	1 4	0 (68,10 U)	U	U			Large general cycle.
5D	43	Old Pwd.	17	Damp	.12	+	+	NW	+	U	7 1,3,5,6 7,8,9	1 4	1 2 (10 U)	U	U			Major av. from West Rustler.
6D	25	Old Pwd.	9	Damp	.13	+	U	NW	+	U	5 1,3,5 6,8,9	1 1,4	1 2 (7,10U)	U	U			Large av. from Rustler Face.

D R Y   S T O R M S

	1	2	3	4	5	6	7	8	9	10	RECAP			DURATION		AV. CYCLE		
No.	Old Depth	Surface	New Depth	Type	Wt.	Rate of Fall	Wind Force	Wind Dir.	Temp.	Settlement	+	-	0	Cont. Snow	Gross	Hrs.	Snow	Remarks
1L	84	Cr	26	Fine Pwd.	.08	.48	1.00	W NW	↓	.34	5 1,2,3 7,8	2 6,9	3 4,5,10	54	54	42	17"	Large general cycle 7 slides across highway.
2L	64	Pel Wnd Cr	37	Pwd.	.07	.54	.57	NW W	↓	.43	6 1,2,3 6,7,8	2 9	2 4,10	68	93	45 51	24"A 28"A	Small followed by large cycle.
3L	77	Cr	42	Pwd.	.08	.60	1.00	W NW	→	.40	5 1,2,3, 7,8	1 9	4 4,5,6 10	69	94	44A 57	26"A 34"	Small followed by large cycle thunder release from L. Superior.
4L	98	Old P Cr	28	Pwd.	.09	.46	.66	NW	↑	.60	6 1,2,3 7,8,9	2 6,10	2 4,5	60	103	50A	26"A	Major cycle N side generally followed by large sunslide cycle.
5L	91	Damp Cr	30	P.G.P Damp	.07	.60	.72	N NW	↓	.68	5 1,3,6 7,8	4 2,4,9 10	1 5	50	58	30	18"	Large slab avs from Baldy and N. Peruvian on different days of 3B.
6L	49	Old Pwd.	36	Pwd.	.06	.81	.68	W SW	↓	.47	5 1,3,6 7,8	1 9	4 2,4,5 10	44	76	22 34	18" 27"	Med. dry cycle followed by large slab cycle.
7L	105	Old Pwd.	32	P. G.P	.07	1.23	.81	SW	↓	.50	6 1,3,4 6,7,8	2 9,10	2 2,5	26	26	13	16"	Major cycle. Coal pit & S side generally.
8L	103	Cr Damp Old P	20	P.G.P	.09	1.33	1.00	SW	↓	.55	7 1,2,3,4 6,7,8	2 9,10	1 5	15	15	14	18"	Major cycle. Argenta. Major slab from Baldy.
9L	105	New P Cr	33	Pwd.	.09	1.10	.90	W	↓	.42	5 1,2,3 6,7	1 9	4 4,5,8 10	30	30	19	20"	Large general cycle. Slab + and dry.
10L	116	Cr	23	P.P.G	.08	.74	.74	SW	→	.22	7 1,2,3,6 7,8,10	0	3 4,5,9	31	31	16	12"	Large general cycle. Slab + dry.

S P E C I A L   S T O R M S

	1	2	3	4	5	6	7	8	9	10	RECAP			DURATION		AV. CYCLE		
No.	Old Depth	Surface	New Depth	Type	Wt.	Rate of Fall	Wind Force	Wind Dir.	Temp.	Settlement	+	-	0	Cont. Snow	Gross	Hrs.	Snow	Remarks
1S	98	Cr & Old P	11	Coarse Pwd.	.05	.46	-	N	+	.45	3 1,5,9	2 4,6	5 2,3,7 8,10	24	24			Notably unstable snow Med. general cycle. Note Wt.
2S	53	Cr	7	P&P	.05	1.00	+	W SW	-	.28	6 1,2,5 6,7,10	2 3,9	2 4,8	7	7			Notably unstable snow. Small cycle of 1S
3S	120	Cr	12	P.G.P Damp	.20	.75	+	NW to SW	-	.50	5 1,2,5 6,7	4 4,8,9 10	1 3	16	20			Major slab Peruvian Gulch with much old snow. CF 2D type & wind dir. Only case of wind force T & wind dir.
4S	117	Cr	25	P&P Damp	.11	.30	0	SW to NW	+	.58	5 1,2,3 5,9	3 4,6,10	2 7,8	U	82			Large sunslide cycle following med. direct cycle.
5S	78	Cr & Old P	29	Pwd.	.06	.79	+	W SW	-	.31	5 1,3,6 7,9	0	5 2,4,5 8,10	40	40			Large sunslide cycle after storm.
6S	72	Old Pwd.	18	Pwd.	.05	.94	.77	W SW NE	-	.61	6 1,3,6 7,8,10	2 2,9	2 4,5	19	53			Small dry cycle followed by large slab cycle released by 2" add. snow.
7S	72	Old Pwd.	17	Pwd.	.07	.70	.75	W to E	-	.23	6 1,3,6 7,8,10	1 9	3 2,4,5	24	34			Small dry cycle followed by major slab (stone crusher) explosive release. Note wind dir.

Notes on Major Storm Comparison Chart

1. #1 - Measured in inches.

2. #2 - P or Pwd. means powder snow. Cr means crust.

3. #3 - Measured in inches on a 24-hour basis.

4. #4 - Damp/Pwd. means damp snow over powder snow and so on. P alone or Pwd means powder snow. P & P means powder and pellet snow. G means granular snow.

5. #5 - A ratio. The figure indicates inches of water per inch of snow.

6. #6 - A ratio. The figure indicates inches of snowfall per hour.

7. #7 - A ratio. The figure is the result of dividing the storm duration in hours into the number of hours wind force was at critical levels.

8. #8 - Detailed information on wind direction in terms of hours is not available.

9. #9 - Where used, the arrow indicates the direction of temperature development.

10. #10 - A ratio. The figure indicates inches of settlement per inch of snowfall on a 24-hour basis.

11. Recap. The upper figure in each box is the total number of avalanche factors operating. The lower figures refer to the individual avalanche factors. Plus means favorable to avalanches. Minus means unfavorable to avalanches. 0 means negative effect.

12. Duration - measured in hours.

13. Avalanche cycle. The first column indicates storm duration in hours when avalanche cycle began. The second column indicates inches of snowfall when avalanche cycle began.

14. Special storms. The storms in this group do not fit into any regular pattern. They are included to remind the observer that analysis of recognized avalanche factors offers him a logical background for his reasoning, not a yardstick he can apply with blind faith and mechanical precision.

Many of the facts revealed by the preceding charts are not exactly news to the experienced snow observer, but it has not previously been possible to demonstrate them in a logical manner. This method of analyzing snow behaviour is practical rather than technical, based on experience rather than experiment. It has its limitations, like any other method. The principal one is lack of sufficient data. This is a matter both of volume and of detail. A hundred storms compared would yield much more accurate information than forty and will

A V A L A N C H E   F A C T O R   F R E Q U E N C Y   T A B L E

		Old Depth 1	Sur-face 2	New Depth 3	Type 4	Wt. 5	Rate of Fall 6	Wind Force 7	Wind Dir. 8	Temp. 9	Settle-ment 10	Depth + Wind 3-7	Rate + Wind 6-7	Depth + Rate 3-6-7	Remarks
16	+	16	10	15	3	6	10	15	11	6	2	14	9	8	#6 Unknown in 2 cases, #7 in 1, #8 in 1.
Large Cycles	-	0	1	1	6	0	2	0	0	9	6	0	0	0	#10 in 4.
	0	0	5	0	7	10	2	0	4	1	4	0	0	0	Freq. of 90% or above: #1,3,7,3-7 Freq. of 70% or above: #1,3,6,7,8,3-7
%	+	100	63	93	17	38	71	100	73	37	17	93	64	62	Freq. of 60% or above: #1,2,3,6,7,8,3-7,6-7,3-6-7
%	-	0	6	7	33	0	14	0	0	56	50	0	0	0	Freq. of 60% or above: None
%	0	0	31	0	50	62	15	0	27	6	33	0	0	0	Freq. of 60% or above: #5
5	+	5	2	5	1	2	4	2	4	2	2	2	1	1	
Border-	-	0	2	0	0	0	1	0	0	3	2	0	0	0	
line Cycles	0	0	1	0	4	3	0	3	1	0	1	0	0	0	
%	+	100	40	100	20	40	80	40	80	40	40	40	20	20	Freq. of 60% or above: #1, 3,6,8
	-	0	40	0	0	0	20	0	0	60	40				Freq. of 60% or above: #9
	0	0	20	0	80	60	0	60	20	0	20				Freq. of 60% or above: #4, 5,7
16	+	14	9	11	0	2	7	4	1	1	9	1	3	1	
Minor	-	2	4	3	9	0	3	0	0	13	1	0	0	0	
Cycles	0	0	3	2	7	14	6	12	15	2	6	0	4	0	
%	+	87	56	68	0	13	43	25	6	6	56	6	19	6	Freq. of 60% or above: #1, 3
	-	13	25	19	56	0	25	0	0	81	6				Freq. of 60% or above: #9
	0	0	19	13	44	87	32	75	94	13	38		25		Freq. of 60% or above: #5,7,8

when they have blown themselves out over Alta and other alpine ski areas yet unnamed. Our observations on several of the avalanche factors are not accurate enough. To mention a few, there are snow settlement rates, wind direction, the amounts of snow transported by wind at different levels and different rates of snowfall, snow weights, the effect of humidity.

Of the facts revealed, four are outstanding:

1. The almost infinite variety of conditions which can produce avalanche conditions.

2. The strong preponderance of favorable factors necessary to produce dangerous avalanche conditions.

3. The importance of combinations of avalanche factors.

4. The dominance of wind force as a contributory factor.

Process of Avalanche Hazard Forecasting

Obviously, the process of avalanche hazard forecasting is not simple and a different matter from recording avalanche data after the crisis is over. The hazard fluctuates from hour to hour and from one part of the area to another. Forecasting is a continuous process. During a storm, the snow ranger must keep a sort of mental box score of the avalanche factors. Fortunately for him, the hazard does not become critical all of a sudden. There are exceptions, but ordinarily an observer who knows his business is not taken by surprise. He is continually comparing his mental picture of the avalanche situation with conditions as he actually finds them in his test plots. Field testing is an essential part of the process of forecasting.

Long range weather prospects influence his decisions. The time of day must also be considered. A storm beginning in the afternoon will probably not become dangerous soon enough to affect the skiers. A stormy morning, with the Weather Bureau predicting no improvement, is an obvious hint to "batten down the hatches." Always he must keep several jumps ahead of the avalanche hazard. He can never forget that 2-hour time margin necessary for clearing the area.

Although it makes no difference to an avalanche whether there is anyone in the area or not, it does make an important difference to the snow ranger. The number of skiers on the slopes, the amount of traffic on the highway, the availability of shelter for everyone in case the road becomes impassable, whether or not he has communication with the highway foreman, the highway patrolman and other authorized officials who share his responsibility for public safety all influence the margin of safety which the snow ranger must allow.

Whether a dangerous avalanche cycle does or does not occur is of secondary importance to the administrator of an alpine ski area. His concern is to gauge the hazard in time to do something about it. For this reason if no other, no snow observer can ever hope to make a perfect score. He cannot guarantee an avalanche every time he closes a slope or a general cycle every time he closes the area. In two hours the picture can change entirely. And even a superficial glance at the charts will convince anyone that the dividing line between avalanche conditions of moderate or high intensity is often too shadowy to distinguish until after the show is over.

Delayed Action and Fair Weather Avalanches

Delayed action and fair weather avalanches are not frequent at Alta. The case can very well be different in other areas with other climatic conditions. But whatever their number, they are a continual source of worry for the administrator.

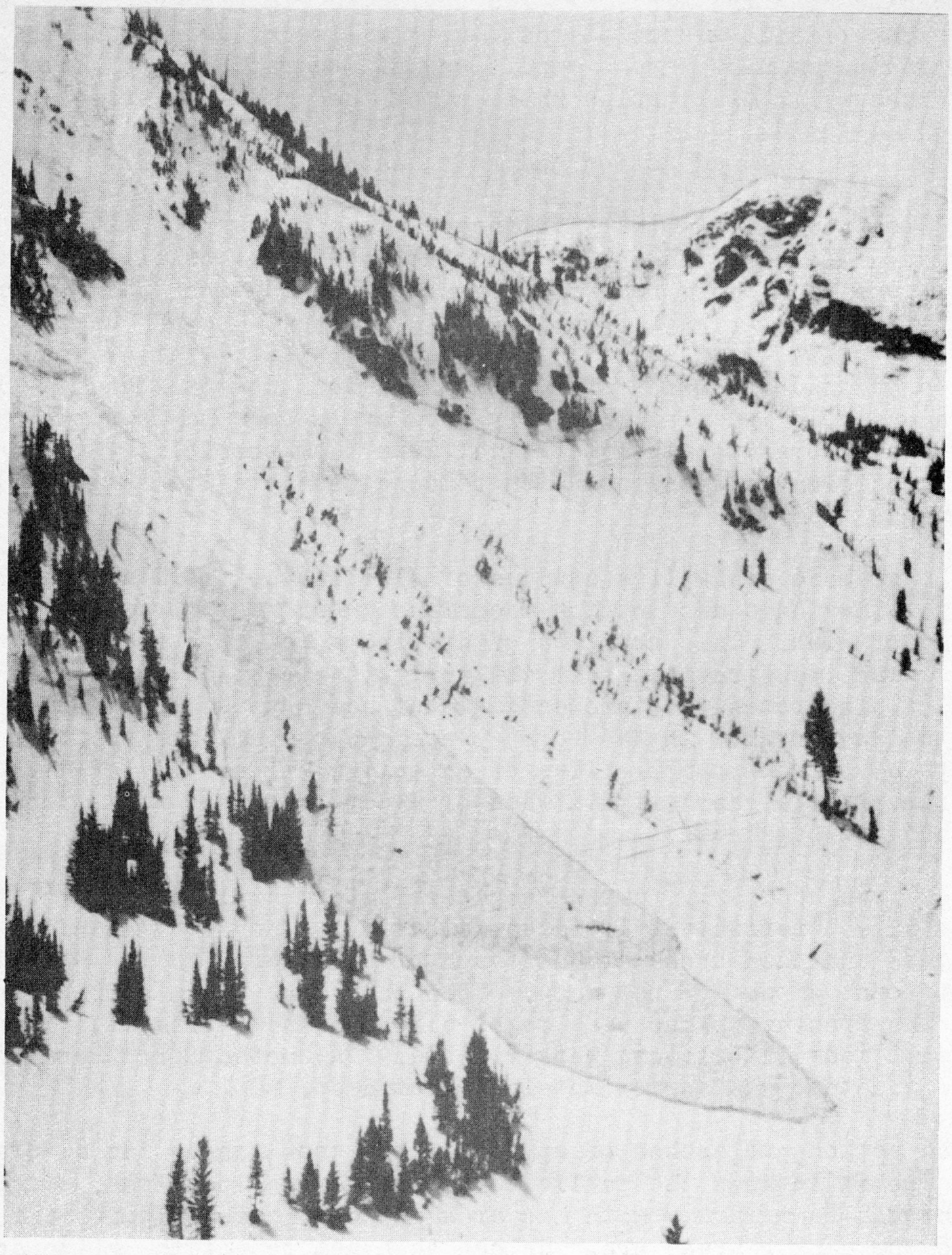
When prolonged cold follows a storm, the snow does not pack and settle and may remain unstable indefinitely. Dry snow avalanches may occur long after the skiers have forgotten the storm that made them possible. A much more dangerous condition is windslab which remains unstable even after all other slopes have settled.

The Swiss have made exhaustive studies of slab in the field and in the laboratory. They have developed a technique known as the ram profile of testing for slab. This consists of driving a rod into the snowpack and determining its structure from the variable amount of resistance encountered. This process is interesting, but has obvious limitations for the practical observer. In the first place, he has neither the time nor the facilities to make ram profiles of an entire ski area. In the second place no ram profile can tell him when or under just what conditions a slab is going to break off.

Unless they fracture early, during a general storm avalanche cycle, slabs are apt to show a persistent if false stability. They stay in place under great weights and then break at the touch of a ski or with the addition of an insignificant amount of new snow. (See the major storm comparison chart, #68.) In the fracture plane of a major slab avalanche from Mt. Baldy at Alta at least four slab layers were visible. In another from Peruvian Gulch, the fracture was approximately 8 feet deep.

For delayed action avalanches of any type, the snow ranger has several answers. One is to keep the public out of dangerous locations. It is his job through familiarity with his area and constant field testing to know where the danger areas are. He can then act to get the slide down and out of the way as soon as feasible. The only good avalanche is one that has happened. On most slopes the experienced observer, knowing the release points, can ski them down with reasonable safety. On the big slide paths he must use explosives.

Overhanging cornices are a delayed action hazard similar to slab.



Ground level avalanche, result of deep thawing.

Wet spring avalanche on Superior. Medium size.

Digging for car buried by wet spring avalanche. Car was parked in recognized slide path.

Damage to car by wet spring avalanche of moderate size.

Fair weather avalanches are not too difficult a problem. If a major storm is followed by clear skies and rapidly rising temperatures, a damp sunslide cycle is certain to develop. Its intensity will be governed by the amount of new snow and the temperature itself. Ordinarily, these cycles are only moderately dangerous. The hazard follows a circular path around the area according to the position of the sun with only a limited number of slopes in motion at a time. Here the snow ranger should remember two points. Natural reflectors can produce sunslide temperatures although the thermometer may be below freezing. Skiers on a sunbeaten slope may release a damp slide prematurely, after the normal cycle has passed, or in greater volume than from natural release.

The big wet avalanches of spring are a similar problem. At Alta, spring avalanche cycles of dangerous intensity do not start unless temperatures have been above freezing for at least 36 hours. For a large wet avalanche, thawing and resulting water seepage penetrate so that the snow breaks out in depth.

Wet avalanches, though enormously powerful, are comparatively slow moving. Their principal threat is to buildings or other fixed objects. Unless caught in one that he started himself, the skier can ordinarily avoid them. Since wet avalanches habitually follow the same track year after year, permanent improvements can be located accordingly. As in the case of damp sunslides, the spring avalanche hazard circles the area with the sun. When shadows point at a slope like warning fingers, it is time for the skier to be elsewhere.

V. AVALANCHE PROTECTIVE MEASURES

Protection from avalanches begins with the planning of an alpine ski area. The location of permanent improvements must be secure, the principal ski slopes must be safe naturally or adaptable to avalanche control.

Once an area has been developed, safety becomes a day to day task for the administrator. He discovers it falling into the same general divisions as the hazard, the traffic area, the lift-served ski area, and the touring area. In each of them he uses both active and passive safety procedures.

Passive Protection:

Passive avalanche protection is based entirely on restrictions. The highway is closed entirely, closed for a few hours, or open for travel under convoy only. In and near the lift-served area there are slopes closed to skiing, most of them temporarily during periods of high hazard, a few, throughout the winter.

Many skiers object strenuously to the idea of a permanently closed slope. They reason that no slope is dangerous all the time and that with modern methods of control, any slope can be made safe most of the time. Up to a point, this reasoning is sound. But there are two excellent justifications for closing a known slide path permanently. One is inability to apply control measures, either skiing or explosives. The other is lack of information about snow conditions on that slope. The area may be perfectly safe and it may be harboring a slab. The snow ranger has no right to open it to the public unless he knows.

Both of these reasons boil down to time and distance. If the safety organization is large and competent enough to cover the entire area there will be no slopes closed permanently.

The touring area is rather a knotty problem. Close supervision beyond the limits of the developed ski area is impossible even in Switzerland where safety organizations are much larger than in this country.

The situation is probably as difficult at Alta as it would be anywhere with its high proportion of day visitors and the magnificent slopes on every hand which invite the skier to leave the beaten path. Unfortunately, for both the snow ranger and the ski mountaineer, many of these slopes overlook the heavily used runs, the parking area, and the highway.

The touring policy in force at Alta is not offered as a completely satisfactory answer to the problem of what to do about the skier's characteristic ambition to go a little higher and steeper than anyone else. But it is workable and becomes more effective as American skiers become better educated to alpine snow conditions. The policy has five cardinal principles:

1. Any touring slope from which a man-caused avalanche would endanger the area in use by the general public is in the zone of close supervision. At Alta the snow ranger has ample powers to enforce closures on these slopes.

2. Beyond the territory where the ski mountaineer can, either directly or by example, endanger the general public, he is on his own.

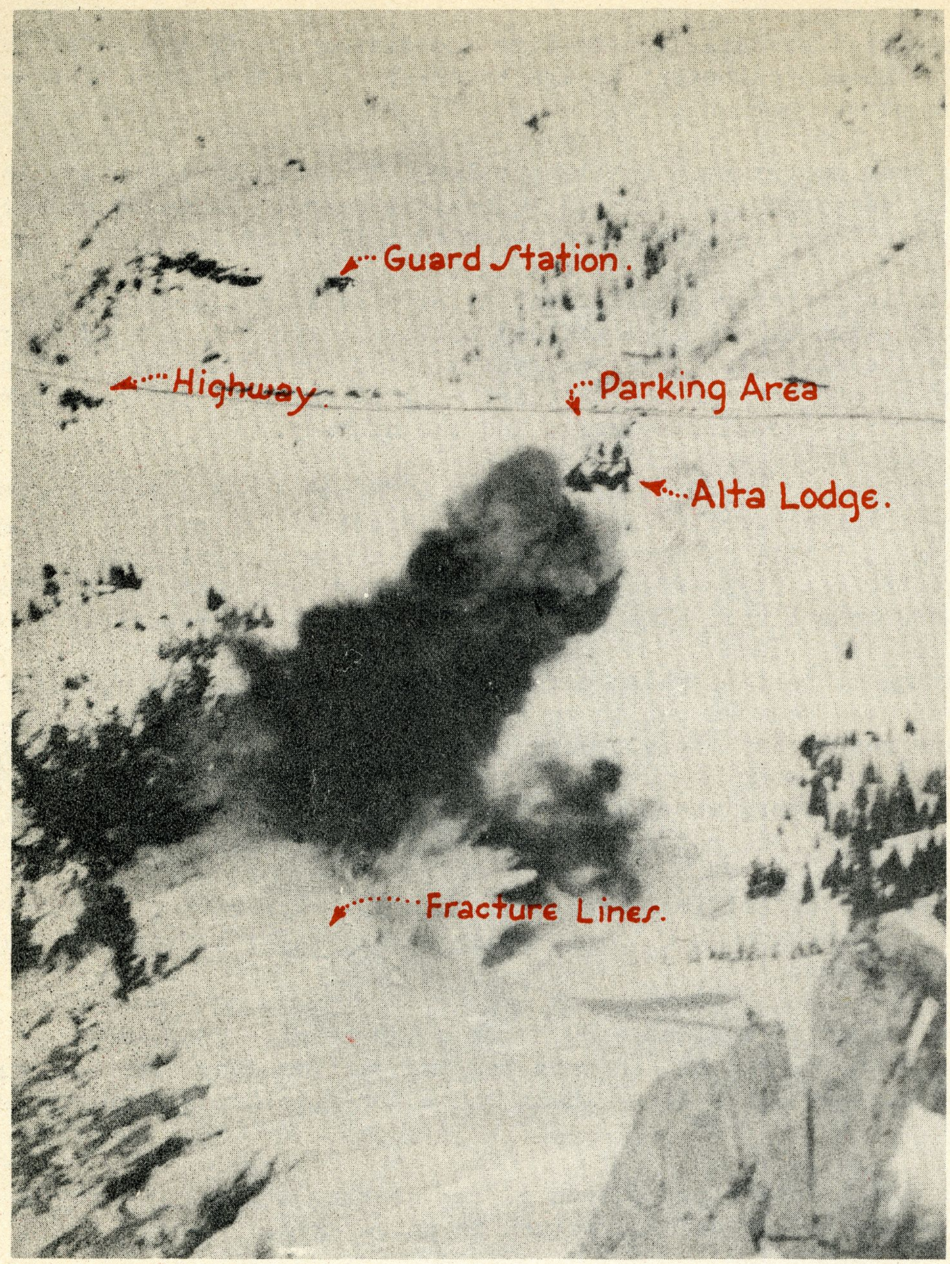
3. During periods of critical avalanche hazard, touring is prohibited or restricted. In practice this is generally during major storms when no one wants to tour anyway.

4. The snow ranger is available 24 hours a day to give snow, weather, and trail information. Often he can warn touring parties away from certain exposures or certain areas along their route, or give advance notice of an incoming storm.

5. The standard mountain precaution of registering a touring party's departure, route, objective, and return is encouraged.

Active Protection:

Active methods of avalanche protection have already been mentioned. It has been amply proved at Alta and elsewhere that no slope constantly skied from the top will avalanche in depth or develop dangerous hidden instabilities. If this were not true, the development of alpine ski areas would be extremely difficult. Practically every slope in general use at Alta is a former slide path stabilized by skiing.



Controlled avalanche blast on Rustler Face. Note the cracks already appearing in the slabbed surface.

Even a moderate amount of use has this effect. It is not necessary for the slope to be packed; thoroughly cut up is enough. For this reason Alta snow rangers encourage the lifts to operate and the skiers to ski in the worst weather either can stand.

On most slopes the experienced snow ranger can release any unstable snow by skiing the release points. This is standard practice at Alta and in several newly developed areas in Colorado. For the major slide paths, explosives are the only answer. A detailed account of the use of explosives at Alta is in the Annex.

Cornices have already been mentioned as a phase of the delayed action avalanche problem. Smaller ones can be broken off with skis or shovels. Larger cornices which threaten the ski area should be blown off.

There is one other direct method of avalanche protection which should be described briefly. Avalanche barriers are extensively used in Switzerland and are fairly effective. Two avalanche barriers have been constructed at Alta. One, a masonry wall, has been of no apparent benefit. The other is a series of posts laced together with cable protecting the upper terminal of one of the lifts. Its value is questionable.

The objection to artificial avalanche barriers is their cost in proportion to the good they do. It seems likely that more can be accomplished at less expense with explosives. At Alta the only barrier under consideration at all is a snowshed for a portion of the highway.

Educational Program:

All the methods of protection, active and passive, which the snow ranger can employ are worthless without the cooperation of the skiers. No safety organization is or can be large enough to keep track of each individual who visits the area. Yet each individual, through carelessness or ignorance, is a potential cause of disaster to himself and to others.

Cooperation is not gained by putting out a set of regulations, standing "Closed Area" signs in the snow, and expecting people to believe a certain slope is dangerous just because someone wearing a badge says so. Skiers are no more observant and even less receptive to regimentation than the rest of the American public. They don't read the bulletin boards and they won't obey the signs unless they have been let in on the reasons.

Few skiers have any real appreciation of the destructive force of an avalanche because they have never seen one in action. Naturally, if the safety organization is functioning as it should, they aren't around when the big avalanches come down. Skiers who have been coming to Alta for years had never seen anything but good avalanches—which are not always impressive—until the explosives control program of 1947-48. During that winter, hundreds of skiers got their first good look at a big avalanche in motion. The improvement in observance of safety regulations was marked.

Unless skiers understand why, they are reluctant to heed signs.

Every alpine ski area should be the origin of an educational program. Through motion pictures, photographs, lectures, and personal contact, the skiers should be taken behind the scenes and shown what a complex, difficult and often dangerous job it is to keep an alpine area open for their pleasure. It is a dramatic subject.

VI. CONCLUSIONS

1. Public use on a large scale of alpine winter sports areas is feasible. The 10-year record of Alta where every administrative problem exists in aggravated form, is proof.

2. Avalanche hazard is the most important of these problems. It is certain to exist to some degree in every true alpine ski area.

3. Critical avalanche hazard is not continuous in time or location. Sufficient knowledge of snow behaviour is now available so that trained observers can foresee the approach of dangerous general avalanche conditions. To some extent, localized avalanche hazard can be predicted.

4. The basic causes of avalanches are terrain and climate. Ten contributory factors have been identified and are employed at Alta as the basis of avalanche hazard forecasting. Further research is required to improve and correct our understanding of these factors and to evaluate others known to exist.

5. Avalanche safety at Alta depends upon certain active and passive protective measures, tried and found satisfactory in most cases. Passive methods are based on restrictions. Active methods include stabilization of slopes through use, protective skiing by trained observers, and explosive release of major type avalanches.

6. Avalanche hazard forecasting is a flexible, continuous process. Formulas, valuable as a guide, are misleading if used arbitrarily.

7. Administration of an alpine ski area requires specially trained and qualified personnel. Familiarity with the area is as important to the administrator as general snow experience.

8. The Alta Snow Studies provide basic information from which safety plans for other alpine areas can be derived.

9. An educational program to familiarize skiers with avalanche safety problems is essential.

10. The Forest Service is vitally concerned in snow research due to the demand for the development of western alpine ski areas, most of which are within national forests.

A L T A   A V A L A N C H E   H A Z A R D   G U I D E

1 Condi-tion	2 Rate of Fall	3 Type	4 Wt.	5 Wind Force	6 Wind Dir.	7 Temp.	8 Weather Present	9 Weather Forecast	10 Visi-bility	11 Field Test	12 New Snow	13 Action
1	.80+	Any	Any	100%	Any	Any	Storm	ctd Storm	100 yd or less	Stable or Unsta.	12"+	Blizzard condition, highway closed & area clear of day visitors. Skiing restricted to min. hazard area.
											18"-24"	Entire area closed until storm breaks. Protective skiing in minimum & low int. hazard & explosives control in high int. hazard areas necessary before reopening.
2	.60-.80	Any	Any	60%+	Any	Any	Storm	Severe Storm Condition Any	Any	Any	12"	Prepare to close highway & clear area of day visitors. Close high int. hazard areas to skiing.
											14"	Highway closed except convoys during breaks. Protective skiing necessary.
											16"+	Highway closed & skiing restricted to minimum hazard area unless slough cycle takes place. Protective skiing. Explosive control in high int. hazard areas.
3	.40-	Any	Any	40%	Any	Below	Breaks in Storm	Moderate Storm Condition Any	Any	Any	14"+	High int. hazard areas closed. Field testing & observation important.
4	.60+	Dry	.07 to .09	50 to 60%	NW & N	Below 32°	Storm	ctd Storm	Poor	Unsta.	12"	High hazard to traffic area. Prepare to close.
	"	"	"	"	SW & S	"	"	"	"		12"	High hazard to ski area. Close high int. hazard slopes. Protective skiing. Explosives control.
	"	"	"	"	NE & E	"	"	"	"		10"	High hazard on Rustler Face, Stonecrusher & W. Rustler.
	"	"	"	"	W	"	"	"	Fair to Poor		14"	Borderline conditions. Field testing & observation important.
5	.50+	Damp Gran orPel	.11+	50%+	Any	Near 32° steady or rising	"	"	Any	Unsta.	6"	Close highway & high int. hazard areas. Protective skiing in all other areas.
4a	Any	Dry	.05-	Any	Any	Below 20°	"	Any	Any	Unsta.	10"+	Highly unstable snow condition. Unless sloughing is continuous, use max. protective measures after 12".
6	.40-	Damp or dry Damp	Any	40%-	Any	Near 32° Falling	Breaks in Storm	Any	Any	Any	14"	Same as Condition 3.
7	Any	Any	Any	Any	Any	Any	Thnd. & Lghtn.	Any	Any	Any	10"	Close highway & high int. hazard areas until thunderstorm has passed. If nearby close lifts.
8	.60+	Damp flake or Mixed	.11+	50%+	See Cond. 4	Near 32° Steady	Storm	ctd Storm	Any	Unsta.	14"	Same as Condition 4.
9	Any	Any	Any	Any	W & variable	Rising Slowly	Storm Ending	Fair	Fair to Good	Becoming Stable	Any	Depending on what closures in effect reopen low int. hazard area after protective skiing. Reopen high int. hazard areas after explosives control. Reopen hwy. when avalanche cycle has taken place or field testing shows stable.
	"	"	"	"	NW N	"	"	"	"	Evidence of Slab	"	Warn touring parties of slab danger on northerly exposures.
	"	"	"	"	SW S	"	"	"	"	"	"	Warn touring parties of slab danger on northerly exposures.
	"	"	"	"	E NE	"	"	"	"	"	"	Explosives control before reopening any slope on or overlooked by Rustler.
10	"	"	"	50%-	Any	"	Cloudy	Cloudy	"	Becom. Stable	"	Little danger of fair weather slides.
	"	"	"	"	"	Rising Rapidly	Clear	Clear	Good	Unst. on sunbeaten Slopes	12"-	Small sunslides.
	"	"	"	"	"	"	"	"	"	"	12-16"	Medium sunslides.
	"	"	"	"	"	"	"	"	"	"	16"+	Large sunslides. Close hwy. during danger period on Superior. Close high int. hazard slopes when sunbeaten.
11	.60+ dur. storm	"	"	60%+	Any NW & NE espec.	Any	Any	Any	Any	Wind hacked	10"+	Slab conditions likely on lee slopes. Protective skiing & explosives.
12	Any	Dry	Average	60%+	Any	Below 10°	Clear	Clear & Cold	Good	Unsta.	12"+	Delayed action slab or slab & dry avalanches likely. Warn touring parties protective skiing & explo.
	"	"	"	40%-	"	"	"	"	"	"	16"+	Delayed action dry avalanches likely. See Condition 12.
13		Old settled	Any			Above 32° 2 nts. in succes.	"	Clear & Warm	"	Deep Thaw		Spring avalanche condition. See Condition 10

NOTES

Column 1. An old snow depth of 24" or more is assumed.

Column 2. Measured in inches per hour.

Column 4. Inches of water per inch of snow.

Column 5. Per cent of time wind is at or above 10 mph.

Column 9. Weather forecast by Weather Bureau and observer's instruments. Salt Lake forecasts are not too accurate for Alta.

Column 10. Visibility is extremely important for observer making on the spot decisions. Every break in the storm should be utilized to see what has taken place in hazard areas too distant for direct inspection.

Column 11. Indications of unstable snow: Snow ring or ski penetrate deeply and easily; snow sifts into the track behind skis; slides easy to start in test plots; new snow is brittle and cracks extensively when run over by skis on either hard or soft surface. Snow is tacky, balls up under skis and breaks away easily from undersurface; snow is slushy and rotten and skis occasionally break through.

ANNEX A. ALTA AVALANCHE HAZARD GUIDE

The following instructions are intended particularly for the guidance of administrators new to the area. They may also serve as a suggested model for setting up similar instructions in any alpine ski area.

The table of avalanche conditions is based on the Major Storm Comparison Chart with the addition of the factors of visibility and field testing. These two factors must confirm the estimates an observer makes on current hazard conditions.

General Instructions

1. The following table of avalanche hazard conditions and protective action is not a complete set of rules telling you what to do under any and all circumstances. You are expected to use your judgment, which will improve with practice and familiarity.

2. The table sets up a series of representative conditions definitely favorable or definitely unfavorable to avalanches of dangerous size. Conditions in the field will seldom fit the pattern exactly. The most important items to keep track of are (1) the new depth, (2) rate of fall, and (3) wind force and direction combination.

3. The most difficult hazard to forecast is the prolonged storm with many fluctuations in violence. Field testing and observation will be your most important guides in borderline cases. When in doubt, play it safe until you find out.

4. Remember the 2-hour allowance for making safety measures effective. The critical snow depths in Column 12 of the table are averages, not exact dividing lines. Unless otherwise indicated in Column 13, they are the points beyond which trouble may be expected at any time unless conditions improve.

5. Read the explanatory notes before attempting to use the guide.

6. Remember that you are forecasting hazard, not avalanches themselves. If conditions are dangerous, it makes no difference whether slides actually occur or not. To say that there was no hazard because no dangerous avalanche occurred is like saying there was no hazard in driving around a curve on the wrong side of the road because you didn't meet anybody. The standards of avalanche hazard set up in the guide are based on fact, not opinion. The Major Storm Comparison Chart is your reference.

7. When apparent unsafe conditions have developed during an overnight storm or are developing as a result of a fresh daytime storm, public safety demands that preventive action be taken to protect life and property.

Protective action will take the form of one or more of the following, either simultaneously or in progressive steps. (1) Close highway to traffic and snow removal by agreement with Road Foreman and Highway Patrolman if the latter is available. (2) Close highway to public travel but agree on partial snow removal. (3) Place highway traffic on limited basis under convoy only, if proper traffic officers are available. (4) Close certain intermittently hazardous slopes and runs. (5) Close all skiing and shut down lifts. (6) Restrict touring to safe trails. (7) Touring completely closed. (8) Warn touring parties as to most likely danger areas to avoid.

THE ALTA SNOW STUDIES

ANNEX B. AVALANCHE RESCUE OPERATIONS

If a skier is buried in an avalanche, prompt and organized rescue operations are the only hope of getting the victim out alive. There are records of persons who lived as long as 72 hours while buried. Ordinarily, they are either killed instantly or die within a short period from exposure, shock and suffocation.

In the 1946 avalanche accident at Alta, the victim was dug out within an hour and a half. Observation on the ground indicates that he would have been dead in a few more minutes. In the 1948 Colorado avalanche accidents investigators indicated that at least two of the three victims died of suffocation and exposure.

Avalanche rescue operations are divided into two phases: Immediate action and follow up.

Immediate action

1. The area administrator takes charge of rescue operations, sounds general warning, does not hesitate to requisition any needed equipment or call for volunteers. All ski patrolmen and experienced skiers are ordered to report to a central location.

2. Question the informant or eyewitness to get the exact location of the accident. Even if in poor physical condition, any eyewitnesses should return to the accident location with the first party to point out where the victim was last seen. This is extremely important.

3. Dispatch the first party. The administrator does not necessarily lead this party but it must be in command of a qualified ski mountaineer and first aid man. It consists of not less than three persons. Ten is a desirable number, large enough to do the necessary work and small enough to travel fast.

4. The first party goes lightly equipped with whatever can be picked up at once. Speed is the first consideration.

5. Upon reaching the location of the accident, the leader of the first party posts an avalanche guard as protection from new slides unless he decides that this is not necessary.

6. Seek by any means to find the spot where victim was last observed on the surface. From this point downhill, members of the first party make a rapid search of the slide surface for the victim or any part of his equipment.

7. If any indication of the victim is found, begin to probe in the vicinity. If no indication is found, begin to probe in likely locations. These are obstructions in the slide path such as trees, boulders, or flat spots, also the tip and edges of the slide. A human body is bulky and all other things being equal, is likely to be thrown toward the surface or the sides.

8. If the victim is found, send a messenger to the follow-up party, and commence first aid. Unless danger of further avalanches is acute, the first party should not attempt to move the victim. More important is to treat for shock and suffocation.

Note: If no eyewitness of the accident is available, omit first half Step 6. The first party must work at maximum speed.

Follow-up

1. In a well-organized area, the follow-up party can start in half an hour. It must start in an hour. It goes completely equipped for extended rescue operations with everything except food. It may be dispatched in groups. The priority of equipment is: probes, shovels, miscellaneous equipment such as toboggans and flashlights.

2. The area administrator will lead this party after notifying County Sheriff. It includes every able-bodied person available within the time limit. People not physically qualified for the exhausting work of rescue should not be taken. They can play their part by preparing and transporting supplies.

3. In the 30-60 minutes at his disposal, the area administrator organizes and equips the follow-up party, notifies authorities outside the area of the accident and possible need for further help, obtains if possible correct name or names of the victims, and appoints a leader to take charge of any further reinforcements and equipment.

4. If the first party has been unsuccessful, the follow-up party begins systematic probing of the slide, beginning at the tip and working up. Probers are spaced about 4 feet apart and probe every 4 feet. If a last location for the victim is known, a special group probes any sections of the strip from this point downhill left by the first party.

5. The first party is relieved and sent out of the area. Exhausted rescuers will become casualties themselves if allowed to hang around.

6. With the first party the administrator can send a message giving an estimate of what further equipment and assistance he is likely to need.

7. Shovel crews accompany the probers, relieving them at intervals and digging in any likely spots. They should be prevented from haphazard digging and waste of energy.

8. Systematic probing of any ordinary slide should not take over 3 or 4 hours. If this is unsuccessful, the slide must be trenched. This work should more properly be under supervision of County Sheriff or his deputies.

9. Trenches are dug parallel to the contour down to ground level or undisturbed snow at interavls of 6 feet. If sectional probes are available the interval can be increased to 10 feet. Digging begins at the tip of the slide and proceeds uphill. It is best to space the shovel crews along one trench with frequent reliefs. In this way snow from one trench can be thrown into the one just completed.

10. If trenching is necessary, the operation ceases to be of an emergency type. A constant system of relief crews must be organized.

General Instructions

1. Regardless of his physical injuries, the victim must be treated first for suffocation and shock. Get the snow out of nose and mouth. Apply artificial respiration if breathing has stopped. Get the victim warm, with body heat if nothing else.

2. Leaders are responsible for the safety of their parties. Avalanche guards must be kept on duty if there is the slightest danger of another slide in the same vicinity. Rescuers must know where to go in case of an alarm. If the danger becomes critical, leaders must not hesitate to call off operations.

3. The administrator must be prepared to make a detailed accident report. These reports are essential for improving safety regulations in all areas.

Avalanche Accident Report

1. Date, time and location of accident.

2. Names of victim, other members of party with any information on mountain experience.

3. Summary of events leading up to accident: departure point, route and objective of party.

4. Eyewitness account of accident, if available. Otherwise, observer's deductions based on tracks and any other evidence. Important points: Location of skier in relation to release point of slide; how was slide released.

5. Summary of rescue operations. Times and names are important.

Time of accident.
Time report of accident received and from whom.
Time first party dispatched. Leader. Number in party.
Time first party arrived at scene of accident.
Time follow-up party dispatched. Leader. Number in party.
Time follow-up party arrived at scene of accident.
Procedure at slide.
Time and location of victim when found, injuries sustained.
Cause of death or outcome otherwise.
Time operation was concluded.

6. Weather and avalanche hazard background: wind, temperature and snow data; restrictions in force, if any; type of slide and extent.

7. Terrain data, including maps and diagrams.

8. Recommendations and conclusions.

Avalanche Rescue Equipment

The following is minimum equipment which should be available at all times in a central location:

25 probes; sectional preferred. Otherwise wooden rods or metal rods, ½" diameter, minimum 10' long.

25 snow shovels.

12 electric headlamps. Carton of spare batteries.

2 gasoline lanterns.

First aid kit: standard ski patrolman's kit satisfactory.

Toboggan with blankets. Collapsible toboggan preferred, light enough to be backpacked.

The following is recommended equipment:

12 emergency rations
4 chemical hot pads for toboggan
2 gasoline stoves and 2 1-gal. gas cans
Camp cook kit
1 mountain tent
100 ft. of climbing rope
12 prs. climbers

In recent years, the Swiss have developed the use of trained dogs to locate people buried in avalanches. The method is highly successful leading, according to reports, to 75 percent survival. The dogs are able to find victims buried as deep as 12 feet and in a fraction of the time required by probing.

Avalanche dogs are strongly recommended for alpine ski areas. The Swiss use principally German shepherd dogs and training is reported to be very simple. After being encouraged to find a skier buried in snow for the purpose, the dog quickly gets the idea.

Any hardy, powerful and intelligent dog should be satisfactory.

THE ALTA SNOW STUDIES

ANNEX C. STANDARD SNOW TERMINOLOGY

To anyone concerned with snow area supervision, the need for a uniform method of describing snow conditions is obvious. Whatever the viewpoint, recreational, practical, research, the observer finds in use a great many descriptive terms whose meanings overlap or vary from one locality to another. The result is confusion, misinformation to the public, and stalemate for the analyst.

The purpose of this study is to construct a standard terminology, simplified yet inclusive, so that reports of snow conditions will mean the same thing whatever their purpose and wherever they originate.

It is possible to classify and subclassify snow condition in endless detail. For all practical purposes, however, it may be described in quite simple terms. The character of snow depends on three principal factors: 1. The form and size of the snow particles; 2. Moisture content; 3. Age.

Although in this study snow crusts are treated as a separate major classification, it is purely for convenience and clarity. Actually their character depends upon the same three factors, but principally upon age, a term which includes all the modifying factors which influence snow after it has fallen.

<u>Snow</u>

A. New: Snow falling or freshly fallen.

   I. Dry: Fell at temperatures 5 degrees or more below freezing. If squeezed in the hand it either refuses to pack or disintegrates readily. Little resistance to penetration by ski or snow ring of ski pole.

      a. Powder: Crystalline and flaky.

1. Fine: similar to whole wheat flour.
2. Medium: similar to bran.
3. Coarse: similar to corn flakes.
4. Flake: similar to goose down.

b. Granular: Irregular, non-crystalline, sandy.

1. Fine: similar to fine sand
2. Medium: similar to corn meal
3. Coarse: similar to coarse ground coffee.

c. Pellet: Round but irregular and rough-finished.

1. Fine: similar to birdshot
2. Medium: similar to BB shot
3. Coarse: similar to tapioca

II. Damp: Fell at temperatures close to freezing-thawing. Sticks to skis in wads. Packs readily in the hand but will shatter.

a. Flake: Very sticky.
b. Granular: Packs very firmly.
c. Hail: Frozen, slick-surfaced, globular.

III. Wet: Fell at temperatures above freezing. Snowball packs firmly and becomes wet and slippery on the surface. Water can be squeezed out with added pressure. Forms suction on a moving ski.

a. Flake: Coarse and soggy.
b. Granular or sleet: Melts on contact except with other snow.
c. Hail: Coarse and soggy.
d. Slush: Extreme form of wet snow, melts on contact.

B. Old: Snow which has settled or which has been packed.

I. Old powder: Includes all types of dry snow. Ski or snow ring makes shallow penetration. Will not form snowball.

II. Windpack: Snow made firm by wind action but not crusted or slabbed. Stiff, brittle, unresilient.

a. Dry
b. Damp
c. Wet

III. Skipack: Snow which has been skied down. May be hard or soft but is smooth and resilient.

a. Dry: Always remains soft.

b. Damp: Becomes concrete hard.
c. Wet: Becomes icy or slushy depending on temperature conditions.

IV. Corn: Damp or wet. A coarse textured snow similar to rock salt, the product of repeated thawing and refreezing.

V. Slush: Drips water when held in hand.

<u>Snow Crusts</u>

A. Form

I. Breakable: Will not support weight of skier making slow turn.

II. Unbreakable: Supports the weight of skier making slow turn.

III. Variable: Breakable and unbreakable crusts interspersed.

B. Types:

I. Wind crust: Forms by wind blowing across or against a slope. Rippled, non-reflecting surface. Strong bond to undersurface.

II. Windslab: (or snow-slab) Formed by wind action on lee slopes. Snow is under tension, has poor bond to undersurface. Fractures readily and extensively. May be soft or hard. Smooth chalky surface.

III. Suncrust: Light, thin, polished. Formed by strong sun action for a short period followed by freezing.

IV. Rain crust: (or glaze) Formed by rain falling and freezing as it falls. Very hard.

V. Common crust: Rough, granular surface. Formed by freezing and thawing. Becomes corn snow eventually. Slush forms under high temperatures or heavy skiing.

VI. Icy crust: A slushy surface frozen.

<u>Ground Movements of Snow</u>

A. Sloughs: Dry, damp and wet.
Minor snow movements, more of a settling process downhill than true snowslides. Generally take place during or soon after a storm. Are not dangerous in themselves; are beneficial in that they relieve tensions and weight. However, they indicate unstable conditions which may lead to slides on slopes which have not sloughed.

B. Sunballs: Balls of wet or damp surface snow which run down a slope when sun action is effective, increasing in size as they descend. Their activity is an accurate measure of sun action; usually start under a cliff or trees or wherever a natural reflector exists; are not in themselves a sign of snow instability but indicate possibility of sun slides.

C. Snowslides and Avalanches:

I. Types.

a. Wild snow; chaotic, formless snow movements occasionally reaching large proportions; take place as result of abnormal quantity of new, very dry snow, laid down at low temperatures.

b. Dry: Composed of any or all forms of dry snow; has distinct pattern, generally starting at a point or narrow break-off, becoming wider and deeper in descent, moves rapidly and when of major proportions can develop destructive air blast; comes down during or shortly after a major storm but cycle may be prolonged by cold weather which retards normal settling.

c. Slab: Composed of windpacked slabs and may be soft or hard; especially prevalent on lee slopes. Unstable condition may persist for long periods; generally breaks off on a wide front with angular lines of fracture; descends with great power and speed. Typically, the entire slopes moves at once; most dangerous type to skiers.

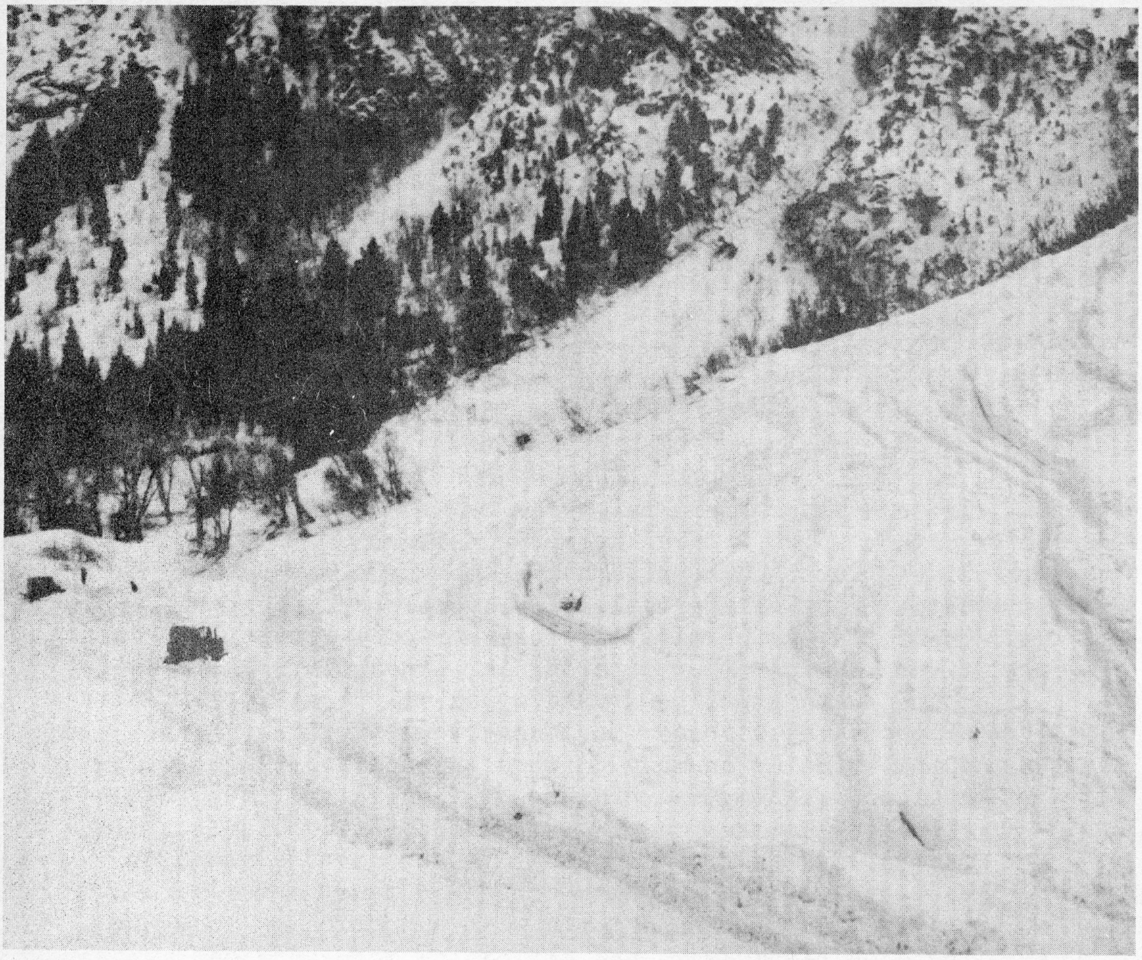
d. Damp: Similar in many outward characteristics to slab avalanches; composed of snow at temperatures hovering close to thawing-freezing; breaks off like slab but almost always under a cliff, at the crest of a slope or where there is a definite convex contour; moves more slowly than slab and starts with a portion of snow moving down blanketwise and dislodging more snow on the way, rather than whole slope moving at once.

e. Wet: Caused by rain, sun action, prolonged thawing conditions; moves comparatively slowly but can attain great size and power; produces snow boulders and has tendency to run in same path yearly and become channelized. Sun slides are those directly attributable to sun action generally in connection with a reflector. The largest wet avalanches are produced by rain and general thawing conditions which penetrate to greater depth than sun action.

II. Size:

a. Small: Distinguished from sloughs by being definite movements with form and pattern; may run considerable distances but are shallow, lack momentum and are not dangerous.

b. Medium: Attain fair size and momentum but not enough to overcome obstacles; stop as soon as they reach an easier grade or other obstruction; may be extensive but are shallow; mildly dangerous to life and property.



Terminus of the Coal Pit slide showing the characteristic channeling of a wet avalanche. Highway buried 23 feet deep is being uncovered by tractor.

c. Large: Involve snow in depth as well as width; build up sufficient momentum to overcome obstacles and reach or approach the bottom of the slope; are dangerous to life and property.

d. Major: Climatic snow movements whatever the type; extensive in all dimensions; develop sufficient momentum to overcome all obstacles and reach or travel beyond the bottom of the slope; are highly dangerous to life and property.

D. Classification of Avalanche Hazards.

1. 0 or None: Absence of hazard to highway or ski areas in general use by the public.

2. 1 or Low: Low degree of hazard; generally appears at beginning of a storm before hazard has had time to develop or after one when conditions are nearly stable again.

3. 2 or Moderate: Intermediate state of avalanche hazard; critical areas would be closed to skiing until slopes had been tested; highway travel possibly restricted; direction of hazard is important.

4. 3 or High: General avalanche conditions; skiing closely restricted or prohibited; highway closed or open only for short periods.

5. Addition of plus or minus to any of the above classifications indicates the direction of hazard, increasing for plus, decreasing for minus.

<u>Snow Condition Reports</u>

Where reports of snow conditions are made to the public, particularly for winter recreational purposes, only major classifications would be used.

The following items are of interest to the general public:

1. Total depth of snow.
2. Depth of snow fallen in previous 24 hours.
3. Type of new snow; dry, damp, or wet.
4. Condition of the surface; new snow, old snow skipacked, crusted, etc.
5. Condition of the undersurface as it affects skiing conditions.
6. Weather conditions and forecast.
7. Avalanche hazards (if any). Closures.
8. Condition of highways.
9. Classification of skiing conditions, which may vary on different parts of the area.

Skiing conditions are classified as follows:

- I. Excellent
  1. New powder
  2. Old powder
  3. Skipack dry or damp
  4. Corn snow
  5. Common crust unbreakable
- II. Good
  1. Damp new snow
  2. Damp old snow
  3. Skipack wet
  4. Unbreakable crusts
  5. Windpack dry or damp
- III. Fair
  1. Variable crusts
  2. Icy crusts unbreakable
  3. Windpack wet
  4. Wet new snow
  5. Wet old snow
- IV. Poor
  1. Breakable crusts
  2. Slush
  3. Dust surface on spring snow

THE ALTA SNOW STUDIES

ANNEX D. ALTA RECORDS AND CHARTS.

The following charts and records are in current use at Alta.

1. Alta Snow Studies Chart
2. Major Storm Comparison Chart
3. Composite Weather Graph
4. Weather Bureau Co-operative Observers' Meteorological Record (not illustrated)
5. Anemometer Record Sheet
6. Recording Barograph Sheet
7. Hygro-Thermograph Sheet
8. Comparative Avalanche Data graph (covering the past four seasons)
9. Monthly Summary (based on Alta Snow Studies Chart)
10. Periodic Reports (covering any unusual occurrence) Not illustrated.
11. Annual Report (not illustrated).

ALTA SNOW STUDIES

MONTH OF December 1947 — OBSERVER Atwater

DAY	1 TEMP MAX	MIN	2 WIND 24 HR TOTAL & AVER.	VELOCITY 6 HR. AV. 0600 1200 1800 2400	PREVAIL. DIR.	SNOW MOVEMENT VALLEY	CORNICE	3 PRECIPITATION NEW 6 PM TO 6 PM 24 HR. FALL	WATER CONTENT	FORM	OLD TOTAL DEPTH	SETTLEMENT	4 STATE OF WEATHER BAROMETER 0800 1200 1800	DAY CONDITIONS FORECAST 0800 BY W.B.	ACTUAL	NIGHT ESTIMATE	5 SNOW SURFACE CONDITIONS SKI SLOPES	NORTH EXP.	SOUTH EXP.	6 AVALANCHE CONDITIONS HAZARD 0800 EST.	1700 ACT.	OCCURRENCE TIME	LOCATION	TYPE	DETAILS	REF TO SUP	7 CLOSURES PRINCIPAL SKI SLOPES LOCATION	OPEN	CLOSED	HIGHWAY OPEN	CLOSED	8 ADMIN TOURING	DAILY USE	MISC.
1	35	27	86 3.6	[illegible]	[illegible]	0	0	6	0.67	Damp Med.	48	2		Cloudy Snow	Cloudy, foggy Inter. Lt. Snow	Lt. Snow	Damp New Ski Pack	Damp Sun	New Cr.	0	0	-	-	-	—							Open	35	
2	35	26	134 5.5	[illegible]	[illegible]	0	0	5	0.40	Med. & F.Damp	50	3		Cloudy Int. Snow	Same	Clear	"	"	"	0	0	DN	W. Rust. Stone-crusher	Dry	Small, stopped middle of slope. " " " "							"	35	Col. [illegible]
3	35	15	100 4.1	[illegible]	[illegible]	0	0	-	-	-	49	1		Pt. Cloudy	Clear Cloudy evening	Lt. Snow	New Powder Damp Ski Pack	Damp		0	0	1330	Peruvian	Dry	Art. small in test Peruvian plot.							"	185	
4	29	21	131 5.4	[illegible]	[illegible]	Lt.	Lt.	2	T	M&C Pwd.	49	2		Pt. Cloudy Int. Snow	Cloudy - Lt. Med. Snowfall	Cloudy Int. Snow	New Powder			0	0	-	-	-	—							"	150	
5	31	21	123 5.1	[illegible]	[illegible]	0	0	1	T	M&C Pwd.	49	1		Pt. Cloudy Int. Snow	Cloudy morning Int. Snow Clearing Aft.	Cloudy Int. Snow	New Powder Ski-Pack	Old Powder		0	0	-	-	-	—							"	115	
6	27	16	188 7.8	[illegible]	[illegible]	Lt.	Med.	7	0.55	M&C Pwd.	53	3		Inc. Cloudy Snow	Snow began 1300	Cont. Hvy-Med. Snowfall.	New Powder			0	1/	[illegible]	[illegible]	[illegible]	Small (all before storm of 1300) [illegible]	[illegible]	Balance of Area #1 Rust	1400				"	280	
7	19	12	162 6.7	[illegible]	[illegible]	0	Lt-0	6	0.31	M&C Pwd.	54	5		Pt. Cloudy Int. Snow	Snow ended 0700 Cloudy, Int. Snow. Cont. Snow 1900	Cont. Snowfall	New Powder Drifted			2	2-	0925 [illegible]	[illegible]	[illegible]	[illegible]		Nina-Wildcat Bal. of area	1000 1300	1000	0945	0600	Closed	525	Snow Removal
8	15	9	143 6.0	[illegible]	[illegible]	Lt.	Med.	13	0.95	M&F Pwd.	63	4		Pt. Cloudy Int. Snow	Cont. Snow to 1600 Int. after	Cont. Snow from 2100	New Powder			1/	2-	1115 [illegible]	[illegible]	[illegible]	[illegible]		[illegible]						40	
9	11	6	168 7.0	[illegible]	[illegible]	Lt. to 0	Lt. to 0	10	0.51	M. Pwd. Pellets	68	5		Int. Snow Cont. by Night	Int. Snow 0800-1000 Cont. 1000-1700	Clearing	New Powder Drifted			3 Hvy. 2 Ski	1 1	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			1215	0700	"	60	Snow Removal
10	[illegible]	0	73 3.0	[illegible]	[illegible]	0	0	T	$	C. Pwd.	65	3		Pt. Cloudy Int. Snow	Clear Snow after 1600 Int.	Clear	Ski Pack soft	New Powder		0	0	—	-	-	—		[illegible]					Rest	85	
11	16	0	136 5.6	[illegible]	[illegible]	0 to Lt.	0 to Med.	6	0.16	C. Pwd. M. Pel.	66	5		Pt. Cloudy Int. Snow	Snow 0700 Int. to 1400 ... Cont. from ...500.	Snow ended 2030 Clearing	"	Old Powder		0	0	-	-	-	—							"	150	
12	[illegible]	4	66	[illegible]	[illegible]	[illegible]	0	3	T	[illegible]	63	6		Pt. Cloudy	Cl[illegible]	Clear			"	0	[illegible]	[illegible]	N. S. Exp.	[illegible]	Rustler & Sloughs							Open	175	

1947-1948

MAJOR STORM COMPARISON CHART

Settlement Ratio: S / Total Fall — Snow to Water Ratio: In Water / In Snow

Wind Ratio: Hrs. above 8 mph. / Total Hrs. — Rate of Fall: In Snow / Hrs.

Av. Factors		TIME Begin	End	Duration	Interval	SNOW Surf. Cond.	Depth New	Rate of Fall In per hr.	Water Content	In water per In snow	Depth old	Net Gain	Settlement & Ratio	Form of new snow	TEMPERATURE Before	During High	Low	After	WIND Dir.	Av. Force	Hrs. abv 8 & ratio	Action on Snow	Barometer	Humidity	COMPARISON Favorable to Avalanches	Unfavorable to Avalanches	SNOW MOVEMENTS Date	Time	Location	Type	Size	
Old Depth Old Surface New Depth New Wt. New Type Rate of Fall Wind Force Wind Dir. Temp. Settlement	Storm #1	1700 2 Nov	1800 11 Nov	Cont. Snow 119 hrs	24 hrs	Damp	71"	0.67	5.22	.07	9"	39	32 .45	Flake Damp Pwd.	Above 32°	46 28 30 28 15 22 31 28 18 22	22 14 12 13 6 11 20 16 10 14	Below 32°	W	Below Critical Level			No data	No data	New Depth Rt. of fall	Old Depth Surface Wind Force Temp. Settlement Wt. Wind Dir. Type						1/
	Storm #2	1300 6 Dec	1700 9 Dec	Cont. Snow 44 hrs	0	Pwd	36"	0.81	2.32	.06	49"	19"	17 .47	C.MF. Pwd. M Pel 9 Dec	Below 32°	27 19 15 11	16 12 9 6	Below 32°	W & SW	7.0	30 .68	Variable	No data	No data	Old Depth New Depth Rate of fall Wind Fce. Wt.	Temp. Settlement Wind Dir. Surface Type	6 Dec 7 Dec 8 Dec 9 Dec	Early A.M. Early A.M. 0925 1115 DN	Rstlr Flgstf Peruv Sup Flgstf Rstlr F. W Rstlr Stone-crshr. W Rstlr Rstlr F. Flgstf Bowl Flgstf Baldy Flgstf	Dry " " Slab " " " Slab & Dry " " " " " "	Small Med. Small Med. Med. Med. Med. Med. Med. Med. Med. Large Med. Large Med.	2/
	Storm #3	0500 22 Dec	1200 22 Dec	7 hrs	4 days	Wind Cr.& Wind Pack	7"	1.00	0.41	.05	53"	5"	2" .28	Pwd. & Pel	Above 32°	25	14	Below 32°	W & SW	5.9	6 .85	Hvy.	Mid range	No data	Old Depth Old Surf. Wt. Rt of fall Wind Fce. Settlement	New Depth Temp. Type Wind Dir.	22 Dec	All day	Area Test Plots	Soft Slab	Small	3/
	Storm #4	0500 23 Jan 0900 25 Jan	1700 24 Jan 1500 25 Jan	Cont. Snow 36 6 42 hrs	3 days	Wind Cr.& Wind Pack	19"	0.45	First Phase 1.36 2nd & 3rd Phase 0.99	.20 (7") .07 (12")	59"	14"	5" .26	Damp Gran 1st Phase N & F Pel 2nd Phase N & F Pwd. 3rd Phase	Near 32°	27 26 18	22 17 6	Below 32°	W & NW NE	9.7	42 1.00	Hvy.	Mid range & low	High	Old Depth Old Surf. New Wt. New Type Wind Fce.	New Depth Rt. of Fall Temp. Dev. Wind Dir. Settlement	23 Jan " " " 24 Jan " 25 Jan 26 & 27 Jan " 26 Jan	1100 DMP " 1100 DN 1130 DN 1575	N Rstlr Sup. Baldy Station Rezall W Rstlr Flgstf Var'ites Areas Rstlr Face	Slab " " " Slab " " Dry Slab	Small Large " " Small Small Med. Small (Art) Small & Med. Large (Art exp)	4/
	Storm #5	1600 2 Feb 2300 2 Feb	2100 2 Feb 0900 3 Feb	5 10 15	7 days	Wind Cr. Wind Pack	10"	0.66	0.72	.07	66"	8"	2" .20	C.M&F Powder	Below 32°	29 22	20 9	Below 32°	W	11.5	15 1.00	Hvy.	Low		Old Depth Old Surf. Wind Fce. Settlement	New Depth Wet Wt. New Type Rt. of Fall Wind Dir. Temp. Dev.	3 Feb 4 Feb 4 Feb	A.M. Early 1500 1500	Area Rstlr Face Stone Crshr	Dry Dry Dry	Sloughs Large art. exp. Small art. exp.	5/

1/ A prolonged storm depositing great quantities of snow. Unfavorable factors prevailed.

2/ This storm had 3 distinct phases. Breaks in snowfall occurred on 7, 8, & 9 of several hours duration. There was little wind 1st phase, critical wind 2nd phase, much wind 3rd phase. The breaks permitted snow adjustments and observation.
1st phase correctly diagnosed as dry slide cycle of moderate intensity.
2nd phase correctly diagnosed as slab slide cycle of moderate intensity.
3rd phase included dry snow plus delayed slab & produced only large slides to occur.

3/ Insufficient snowfall to produce major average cycle. Marked preponderance favorable factors. Storm analyzed because snow was extremely unstable. Skiing in test plots produced slides unusually extensive, though shallow.

4/ This storm notable for fact that 7" damp snow produced large average cycle. Wind force, Snow Wt. & Type were critical favorable factors. Storm paralyzed the area 4 days by knocking out power & telephone. Superficial comparison of average factors does not indicate a critical situation. Shows that forecaster must consider combinations of factors. Note especially snow wt. & type, also wind force. Hazard was correctly diagnosed as moderate though margin was very narrow. Lifts closed and day visitors sent out of area at 1530.

5/ The storm shows an almost equal division of average factors. Should be compared with Storm #4, especially the Wind Force, Snow Type, Snow Wt. combination. Also Storm #3, similar in many ways but with different results.

The Rustler explosive release average took along some slab remaining from #4 but the new snow was wind tough, not slabbed. The Stonecrusher slide was first example of secondary release.

MAJOR STORM COMPARISON

MINOR AVALANCHE CYCLES

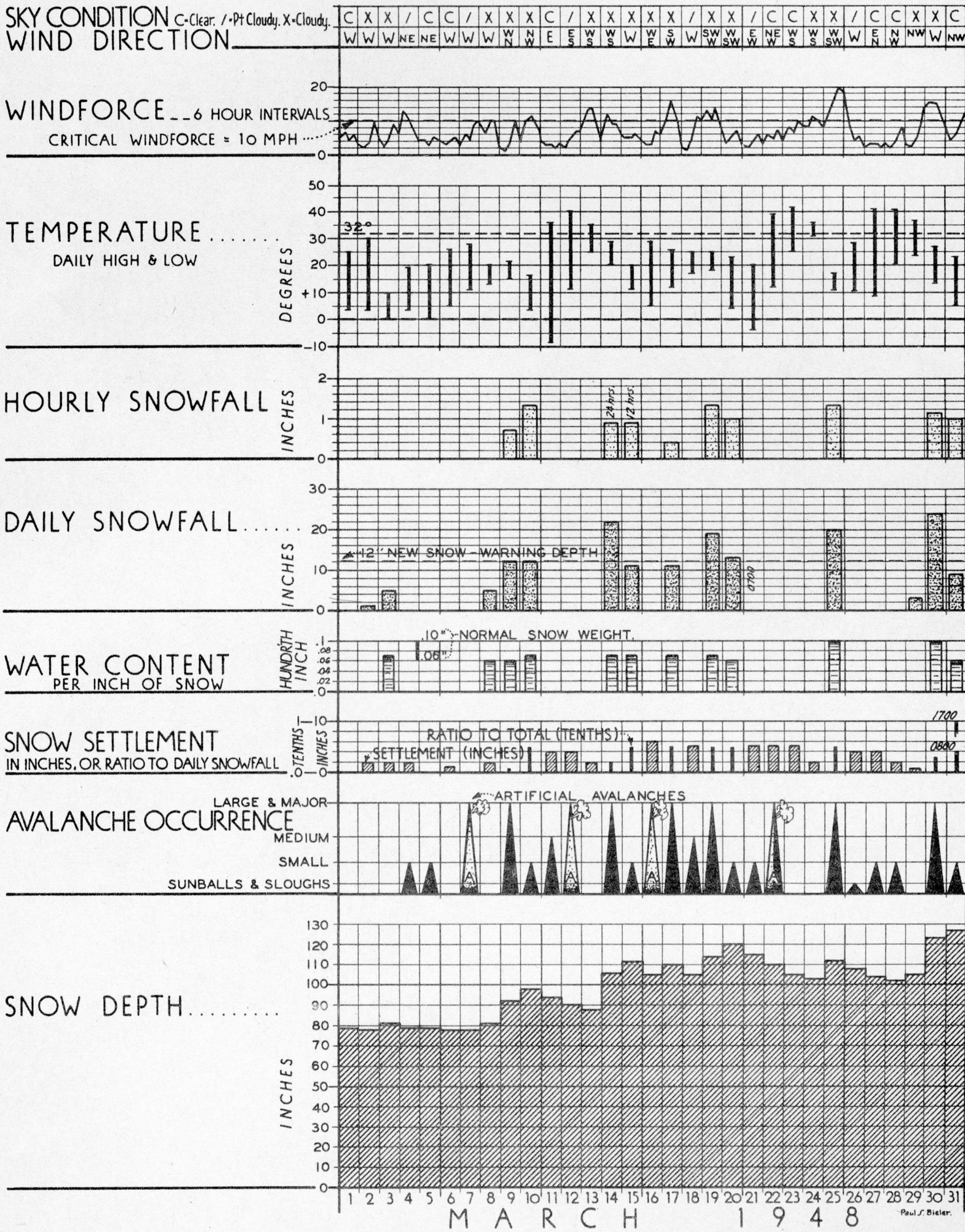
No.	1 Old Depth	2 Sur-face	3 New Depth	4 Type	5 Wt.	6 Rate of Fall	7 Wind Force	8 Wind Dir.	9 Temp.	10 Settle-ment	RECAP +	RECAP -	RECAP 0	DURATION Cont. Snow	DURATION Gross	AV. CYCLE Hrs.	AV. CYCLE Snow	Remarks
1M	60	New P	31	Damp Pwd.	.13	.50	.57	W	-	.62	4 1,3,5,7	4 2,4,9 10	2 6,8	61	73			Small-med. cycle following 10. This is 5B + 16 M, parts of prolonged storm.
2M	103	Cr	18	Pwd. P&P	.07	.66	+	W	-	.50	5 1,2,3, 6,7	2 9,10	3 4,5 8	27	27			Small cycle.
3M	100	Cr	13	P&P Pwd.	.12	.56	0	W NW	-	.23	3 1,2,10	1 3	6 4,5,6 7,8,9	23	23			Medium cycle.
4M	106	Cr	13	G P&P Damp	.12	.28	0	W SW	-	.30	3 1,2,10	4 3,4,6 9	3 5,7, 8	45	45			Small cycle.
5M	113	Cr	17	P&P Pwd.	.07	.73	0	SW	+	.35	4 1,2,3 6	1 9	5 4,5,7 8,10	23	23			Small cycle. Med. sunslides followed.
6M	18	Cr Bare ground	45	Rain Damp Pwd.	.12	.83	0	W NW	-	.37	3 3,5,6	3 1,4,9	4 2,7 8,10	54	54			Small cycle. Oct. storm. note old depth of 13M.
7M	36	Cr	14	Damp	.08	.46	0	NE NW	0	.43	3 1,2,3	2 4,6	5 5,7,8 9,10	30	30			Gen. Med. cycle.
8M	42	Cr	19	P&G Damp	.10	.52	0	N NW	-	.30	4 1,2,3 10	2 4,9	4 5,6 7,8	36	36			Gen. Med. cycle.
9M	43	Damp Cr	24	P&P Damp	.08	.57	0	W	-	.29	3 1,3,10	2 4,9	5 2,5 6,7,8	42	42			Gen. Med. cycle.
10M	52	Cr	34	Pwd. Damp	.08	.51	0	W	-	.32	3 1,2,3	2 4,9	5 5,6,7 8,10	64	67			Gen. Med. cycle.
11M	62	Cr & Old P	12	Pwd.	.07	1.09	+	N NW	-	.13	5 1,6,7 8,10	1 9	4 2,3,4 5	11	11			Gen. Med. cycle.
12M	72	Cr	22	Damp	.08	.52	0	N	+	.27	5 1,2,3 9,10	1 4	4 5,6,7 8	42	42			Small cycle.
13M	9	Damp Old	71	Pwd. Damp	.07	.67	0	W	-	.45	2 3,6	4 1,2,4 9	4 5,7,8 10	U	119			Small cycle Nov. storm, of 6M
14M	64	Damp New	12	Pwd.	.08	.40	+	W	-	.25	3 1,7,10	3 2,6,9	4 3,4,5 8	30	48			Med. slab cycle following large damp cycle of 2D. This is continuation.
15M	66	Cr	10	Pwd.	.07	.66	+	W	-	.20	5 1,2,6 7,10	2 3,9	3 4,5,8	15	15			Small preceding large cycle. of 10. This is beginning.
16M	60	Damp New	16	Pwd.	.10	.55	0	W	-	.25	4 1,3,6 10	2 2,9	4 4,5,7 8	29	36			Small cycle following large of 10.

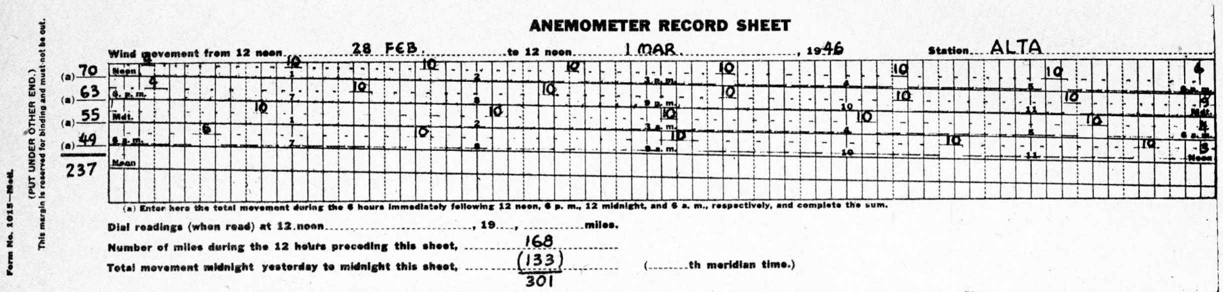
BORDERLINE AVALANCHE CYCLES

No.	1 Old Depth	2 Sur-face	3 New Depth	4 Type	5 Wt.	6 Rate of Fall	7 Wind Force	8 Wind Dir.	9 Temp.	10 Settle-ment	RECAP +	RECAP -	RECAP 0	DURATION Cont. Snow	DURATION Gross	AV. CYCLE Hrs.	AV. CYCLE Snow	Remarks
1B	97	Cr & Old P	16	Gran.	.09	.61	.23	NW	-	.23	5 1,3,4 6,10	1 9	4 2,5,7 8	26	26			Borderline. Large slide from Superior though not into high-way. Note snow type.
2B	67	Cr	31	P&P Pwd.	.10	.59	.32	W	-	.23	5 1,2,3 5,6	1 9	4 4,7,8 10	52	52			Borderline. Med-large cycle. 1 slide across highway in small volume.
3B	111	Cr	31	P&P	.07	.66	.51	SW	-	.11	5 1,2,3 6,9	1 10	4 4.5,7 8	47	51			Borderline. 1 large soft slab from Baldy. Balance of cycle small. of 5L.
4B	88	Damp Old P	33	Pwd.	.07	.91	.30	W SW	-	.53	5 1,3,6 7,10	2 2,9	3 4,5,8	36	36			Borderline. Med-large cycle.
5B	71	New Pwd.	15	Damp & Wet	.16	.47	1.00	W	-	.75	5 1,3,5 7,9	4 2,4,6 10	1 8	32	37			No important avalanche cycle. of 30.

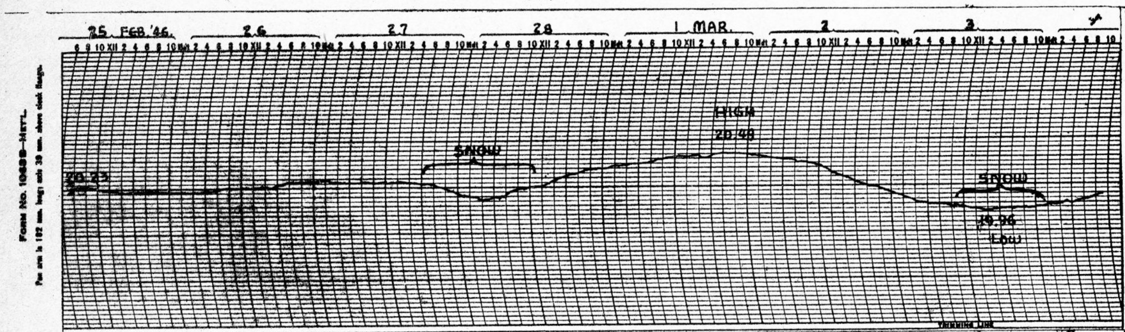
COMPOSITE WEATHER GRAPH ALTA, UTAH.

WASATCH N.F., M. ATWATER., U.S.F.S. OBSERVER

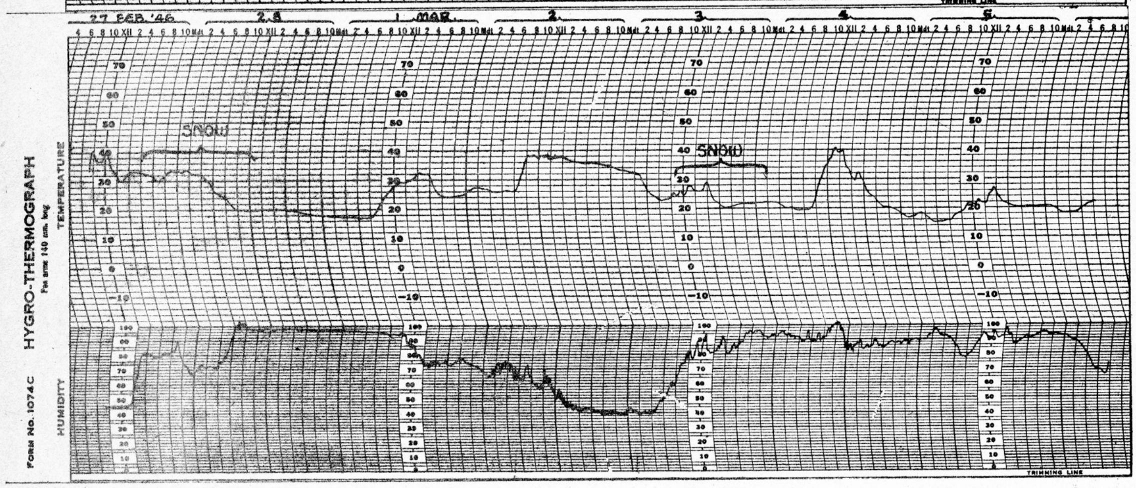




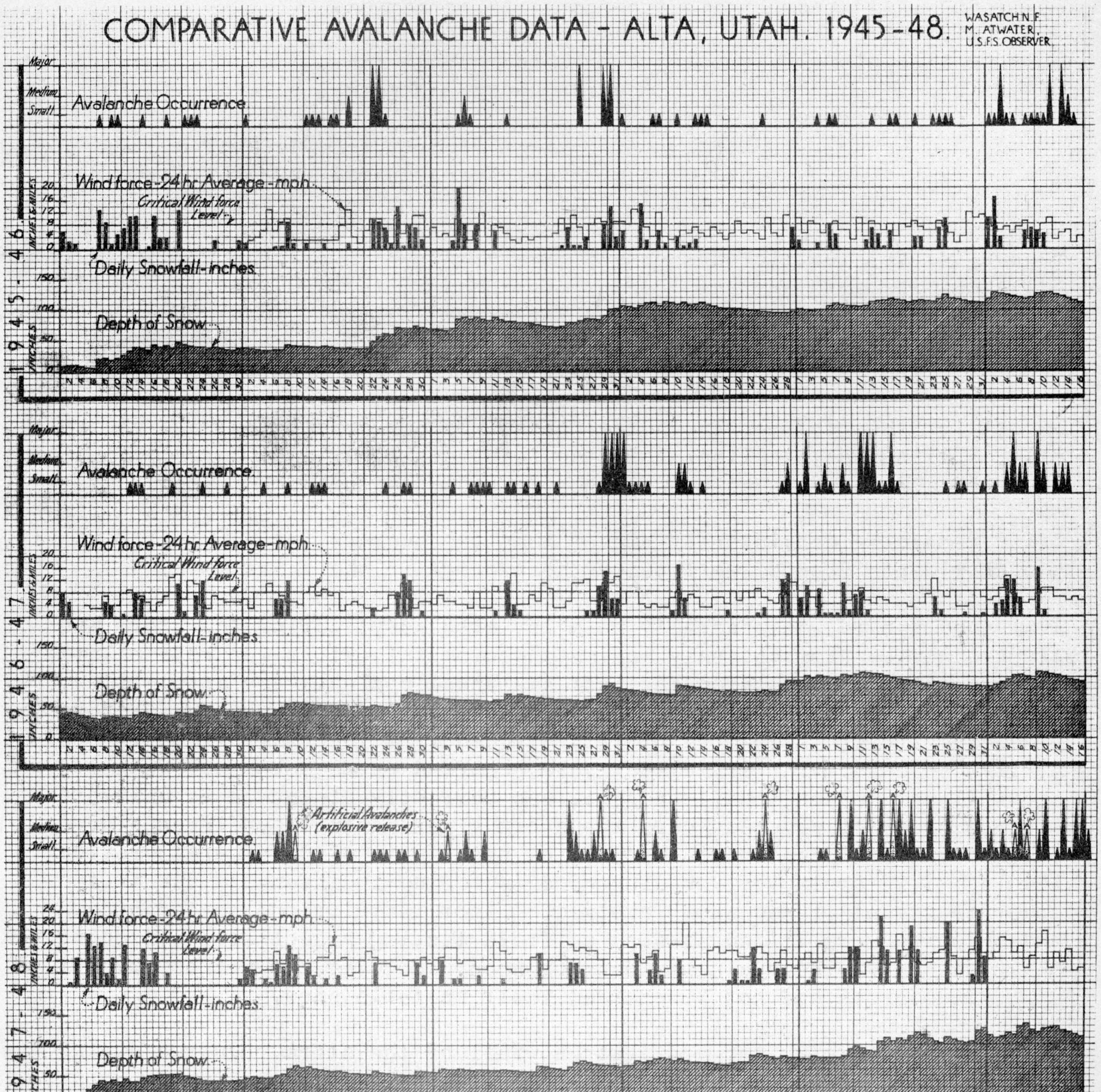
ANEMOMETER RECORD SHEET
Wind movement from 12 noon 28 FEB. to 12 noon 1 MAR. 1946 Station ALTA
(a) 70
(a) 63
(a) 55
(a) 49
237
(a) Enter here the total movement during the 6 hours immediately following 12 noon, 6 p. m., 12 midnight, and 6 a. m., respectively, and complete the sum.
Dial readings (when read) at 12 noon, 19 , miles.
Number of miles during the 12 hours preceding this sheet, 168
Total movement midnight yesterday to midnight this sheet, (133) 301
(th meridian time.)
Form No. 1015—Met'l.
(PUT UNDER OTHER END.)
This margin is reserved for binding and must not be cut.



25 FEB. '46
26
27
28
1 MAR.
2
3
4
SNOW
HIGH
SNOW
29.96
LOW
TRIMMING LINE



27 FEB. '46
28
1 MAR.
2
3
4
5
SNOW
SNOW
HYGRO-THERMOGRAPH
TEMPERATURE
HUMIDITY
Form No. 1074C
TRIMMING LINE



COMPARATIVE AVALANCHE DATA - ALTA, UTAH. 1945-48.
WASATCH N.F.
M. ATWATER,
U.S.F.S. OBSERVER.
1945-46
1946-47
1947-48
Major
Medium
Small
Avalanche Occurrence
Wind force - 24 hr. Average - mph
Critical Wind force Level
Daily Snowfall - inches
Depth of Snow
Artificial Avalanches (explosive release)
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL

Monthly Weather Summary
(Sample - Dec. 1947)

Total snowfall	80"
Water content	4.93"
Snow settlement	67"
Net gain	9" (48" to 57")
Avalanche occurrence:	
Large	December 8
Medium	December 7 and 9
Insignificant	12 days
Highway closed	0
Highway travel restricted	2 (snow removal 1; snow
Ski area closed	0 removal hazard 1.)
Ski area restricted	3 days
Major storms	1 (December 6 - 9)
Use	15,265

Except for the storm early in the month, weather conditions were generally mild. Skiing was excellent throughout the month during a period when many important ski areas have been unable to open due to lack of snow.

After remaining consistently higher than the average for the past 2 years, the snow depth dropped well below the average in the third week.

Avalanche hazard was generally at a low ebb except during the storm mentioned above. From an analytical standpoint this storm was rather interesting. It produced three distinct avalanche cycles: dry snow slides, slab slides, and slab plus dry snow slides. Each cycle and the factors producing it were much more plainly divided from the others than is ordinarily the case. The dry slide cycle occurred on December 6. With moderate snowfall and non-critical winds, it was correctly diagnosed as unimportant. After a break of several hours the storm began again the afternoon of the 6th and snowfall continued through the night with wind force at critical levels. This cycle too was diagnosed as medium in intensity due to the moderate amount of new snow involved. Minor restrictions on the highway and ski area were lifted as soon as field testing and observation confirmed this judgment. The cycle was over by noon. However, it was observed that some slide areas had not discharged their unstable snow.

After another break, the heaviest snowfall of the storm occurred during the night of the 7th and morning of the 8th with only moderate wind.

The danger was recognized that some of the areas which had retained their slab might now avalanche in dangerous volume under the weight of the new snow. Skiing was restricted to the safe area: Nina Curve to Wildcat.

The slab plus dry snow cycle justified these precautions. Rustler Face avalanched into the ski area. Stonecrusher avalanched into Corkscrew. The Stonecrusher slide occurring at 11:15 a.m. was the only one observed in motion due to poor visibility. Slides of all sizes occurred throughout the area, large ones in the Flagstaff Bowl and Baldy cirque.

The storm faded out during the day and recommenced during the night. Some concern was felt for the safety of the highway on the morning of the 9th, Superior being the only critical area which had not thoroughly cleaned itself out. Observation was possible by 11:00 a.m. and a demolition charge exploded near the highway failed to dislodge any slides. The highway was, therefore, opened at noon. Restrictions on the skiing area were precautionary. No important hazard was expected and none developed. The few people in the area had all the skiing they could handle in the safe area.

Rustler Face was blasted on the 10th without releasing any significant quantity of snow.

It is seldom that the avalanche forecaster has such clear-cut situations to deal with. The chart of this storm reveals some interesting details. Why did 7 inches of snow on the 6th produce a dry slide cycle and 10 inches on the 9th produce none? The chart shows that the 7 inches fell with abnormal rapidity and was comparatively heavy. The 10 inches fell at a much slower rate, was lighter, settled more rapidly, and was of a different type.

Wind action has been below average for both November and December. This is indicated principally by the lack of cornice formation. The east shoulder of Baldy is bare. The cornices along the comb of Superior are very small for the time of the year. Wind has also been unusually variable in direction.

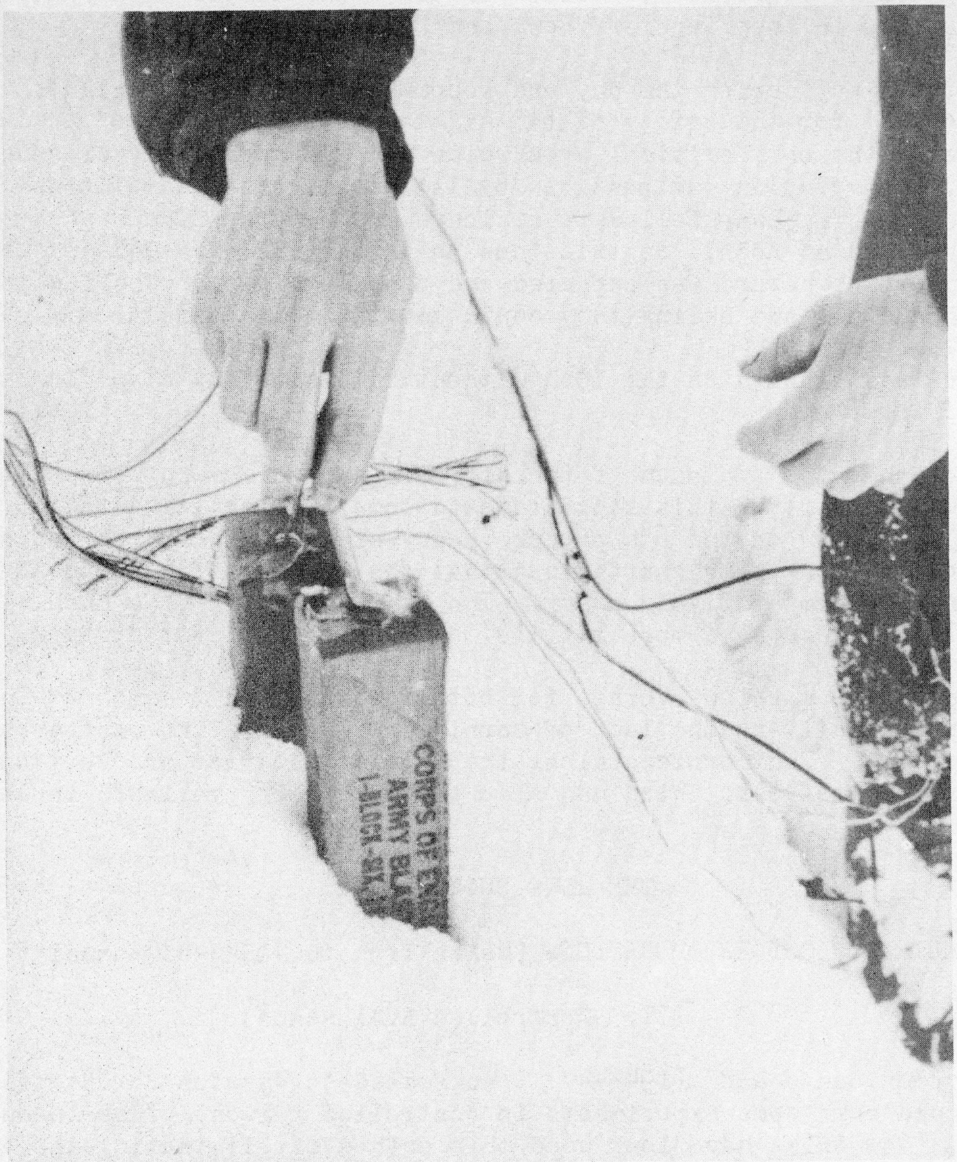
THE ALTA SNOW STUDIES

ANNEX E. ALTA EXPLOSIVES OPERATIONS (Taken from the 1947-48 Annual Report)

III. Controlled Avalanches

During the previous season (1946-47) I suggested to Wasatch Forest officials that we should make some experiments in controlled release of avalanches with explosives. The Swiss have long used this method of eliminating the avalanche hazard in certain critical areas. At Alta the policy of skiing down unstable snow has been in force for some time in locations where this can be done with reasonable safety to the operator. The method is entirely satisfactory but limited in its scope. Through explosives, it appeared likely that we could control or at least mitigate the hazard on larger slopes such as Rustler Face.

For two reasons we did not consider using mortars or light artillery, the Swiss practice. In the first place, the weapons were not available. In the second place, there was the possibility of dud projectiles turning up on the highway or in the ski area.



Arming the charge for a controlled avalanche. Inserting the cap into prepared receptacle in military demolition block. (Tetrytol)

With the Supervisor's approval, I carried out the explosive experiment using common 40% dynamite. The area chosen was the annual cornice on the North Peruvian ridge. I successfully removed this cornice twice during the season, with the release of large slides and elimination of hazard to the approaches to a favorite Alta run. I learned also that there would have to be improvements in equipment and technique before the method could be employed extensively. Common dynamite proved to be an unsatisfactory explosive, subject to deterioration from cold or damp, awkward to handle and store, and lacking in shock power. Electrical detonation of the charges was satisfactory but I found that we needed a lighter, more portable type of wire and a smaller blasting machine.

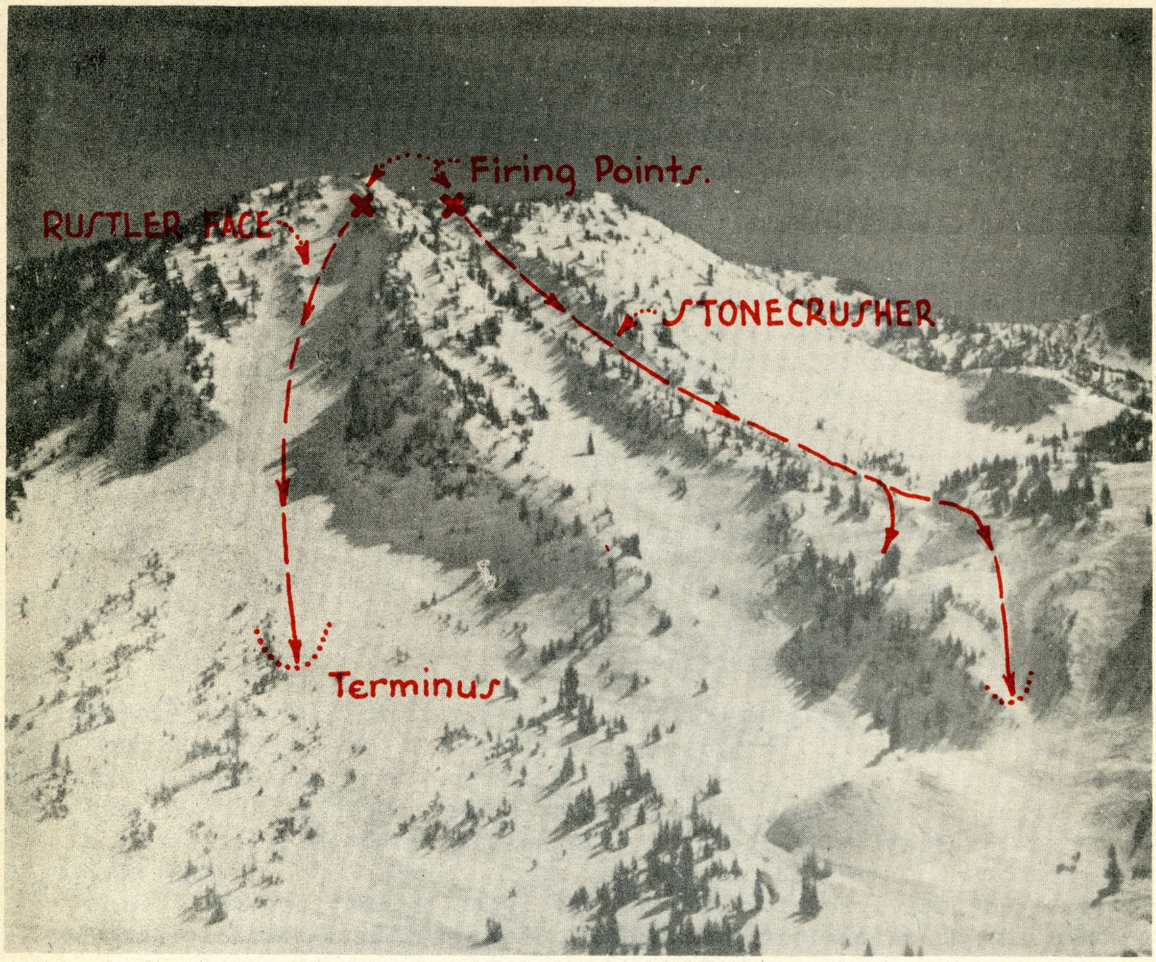
On the basis of this experimental work, it was decided to carry out a larger program during the 1947-48 season. The Salt Lake Winter Sports Association solved one important problem by agreeing to furnish the necessary labor to transport explosives to the firing points. The equipment difficulties were solved with a pocket-sized blasting machine and a light flexible type of wire.

The Wasatch Forest was also successful in obtaining an explosive with desirable characteristics. This was tetrytol, a military demolition. It was supplied in two forms. One was a series of blocks joined by primacord making a chain about ten feet long and weighing twenty pounds. The second was separate half-pound blocks. In both cases, the explosive was dry, insensitive to cold or damp, and stable to handle or store. Its high rate of detonation satisfied the primary requirement of maximum shock power.

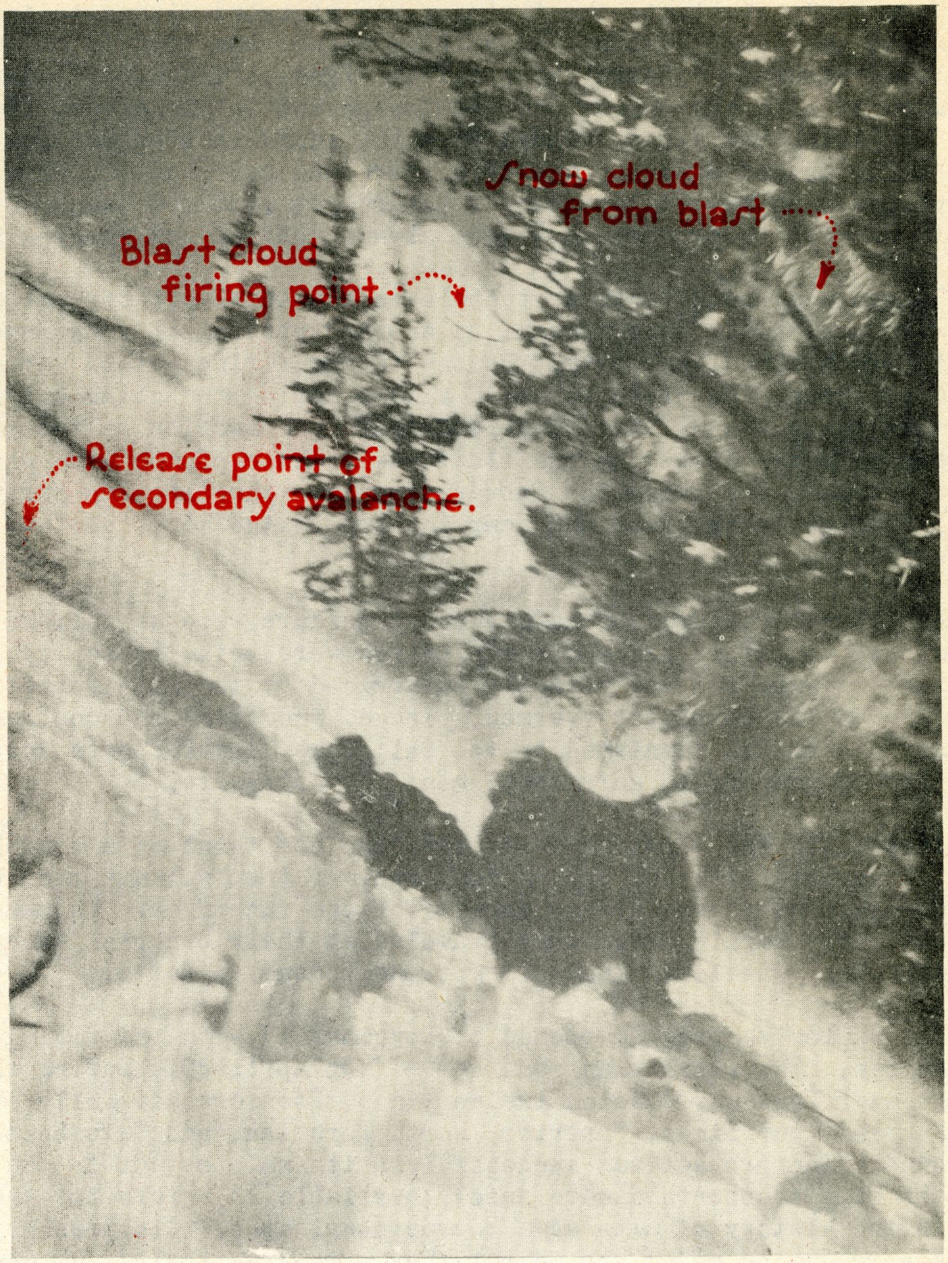
The area chosen for the project was on Rustler Mountain extending from Rustler Face to West Rustler. The principal reason for this selection was that these slopes form one of the most dangerous and annoying avalanche hazards in the ski area. If successful, we could do more good there than in any other comparable location. Secondary reasons were that the lift would be available for transport at least part way to the firing points; the danger area could be adequately controlled for safety to the public; the firing points would be accessible except under conditions of the most extreme danger, and the location was ideally situated for observation and photography of the results.

Our original intention was to plant a series of charges at ground level, high up on Rustler Face, and wire these charges to a remote firing point. However, this plan had to be modified as the equipment was not available until after winter had set in and a heavy snowpack was already in place. Various other problems of technique and procedure had to be worked out and improved as we went along.

One of the most important was a safety plan to guard the public. We adopted the principle from the start that the time to set off our charges was when the snow was unstable, not when conditions were most convenient. This frequently meant operating on days when use of the ski area was heavy. The safety plan set up and which functioned successfully was as follows:



Controlled avalanches on Rustler Face and Stonecrusher. Note how Stonecrusher slide jumped over one gully and came down the next.



Secondary avalanche caused by blast buries snow ranger to waist.

All areas endangered by slides from the blasting area and the approaches thereto were closed, posted, and patrolled during the entire operation. The reason for closure during the time the blasting party was traveling was that we often released slides on the way up to the firing points. When ready to blast, the firing party signaled either to the lift terminal or to the guard station. A warning signal was sounded on the siren followed after an interval by a firing signal. The public address system was used to warn any skiers who had trespassed in the closed area. The reason for giving the firing signal from the guard station was that observation of the danger area was possible there and not possible from the firing points. On several occasions, skiers got into the danger area while operations were in progress but were always spotted and removed in time.

In order to be effective, the blasts had to be set off while snow conditions were unstable. This brought up another problem of some importance, the safety of the blasting party. Routes to the firing points varied according to conditions. We often released slides during the climb but in such a manner that there was no unreasonable danger. Protection of the party from secondary slides released by the blast was a phase of the same problem. Such slides did occur, involving the snow surrounding the blasting party. But we had good anchorage among trees and near the top of the slope so that the danger was not excessive.

Additional features of safety and procedure were as follows: The lift was closed to public use while explosives were being transported. All blasting parties were led and directly supervised by the Alta forest officer, who carried the detonators, armed, placed, and fired the charges. Essential assistance was furnished by the Salt Lake Winter Sports Association in the form of helpers to carry equipment and materials.

Eventually the blasting parties became something of a social function. It is characteristic of skiers that many of them volunteered, or requested permission to come along, merely for the fun of it. In manageable numbers and after warning that they traveled at their own risk these people were welcome. I believe they all got their money's worth.

The explosive program opened on November 13 with the firing of the first charge. The final blast was set off on April 20. During this period Rustler Face was blasted twelve times, Stonecrusher Gully six times, West Rustler four times, Superior, North Peruvian, and Twin Lakes Pass each once. The project was successful in its main object to the extent that the slopes concerned were safely available to skiers for the first time in the history of Alta as a recreational area. Closures were still necessary during major storms but they were drastically cut down in number and time. In addition, much valuable information and experience for future operations were gained.

Probably the most important benefit to the area was the major slab avalanche released in Stonecrusher on February 24. This slide would certainly have come down of its own accord sooner or later and with every likelihood of tragic results. Less spectacular but of scarcely less value was the constant removal of overhanging snow masses from Rustler Face, including two slabs of

Major explosive released slab avalanche in Stonecrusher. The accumulation zone, release point, and slide path. Compare photo with complete slide annex E.

Terminus of the Stonecrusher avalanche lying in Corkscrew, the most heavily used run at Alta.

CONTROLLED AVALANCHES: 1947 - 1948

Date	Location	Charge	Type of Explosion	Snow Surface	Results
13 Nov.	Rustler Face	20 lb. chain	Trench	Dry, settled	Medium, dry, to upper traverse
9 Dec.	Superior	20 lb. chain	Surface	37" new, settled	Local shattering
10 Dec.	Rustler Face	20 lb. chain	Buried	37" new, settled	Crater
18 Dec.	Rustler Face	40 lb. chain	Buried	Dry, settled	Crater, small dry snow av.
18 Dec.	Stonecrusher	2½ lb. blocks	Surface	Dry, settled	Medium dry snow av.
3 Jan.	Rustler Face	20 lb. chain	Surface	8" new	Medium dry snow av. to lower traverse
	Stonecrusher	2½ lb. blocks	Surface	"	Small, dry snow av.
	West Rustler	2½ lb. blocks	Surface	"	None
28 Jan.	Rustler Face	20 lb. chain	Surface	19" new settled	Large slab-plus-dry av. to lower traverse
4 Feb.	Rustler Face	20 lb. chain	Surface	10" new	Large slab-plus-dry av. below upper traverse
24 Feb.	Rustler Face	20 lb. chain	Surface	25" new slabbed	Large dry snow av. some slab to dead tree near bottom
	Stonecrusher	6½ lb. blocks	Surface	"	Major slab avalanche, filled Corkscrew, jumped into Nina Curve, Secondary nearby
7 Mar.	North Peruvian	4½ lb. blocks	Trench	Unstable Cornice	2 large slab-plus-dry snow av. One of these due to fracture of cornice under weight of operator
12 Mar.	Rustler Face	20 lb. chain	Surface	29" new	Large dry-plus-slab, reached dead tree
	Stonecrusher	4½ lb. blocks	Surface	"	Med.-Large dry, reached ski area
	West Rustler	4½ lb. blocks	Surface	"	Large slab-plus-dry into ski area
16 Mar.	Stonecrusher	4½ lb. blocks	Surface	33" new	Small dry snow
	West Rustler	4½ lb. blocks	Surface	"	Large soft slab into ski area
22 Mar.	Rustler Face	20 lb. chain	Surface	30" new	Large dry snow below upper traverse, large secondary slab av. in Eagle's Nest
	Stonecrusher	4½ lb. blocks	Surface	"	Medium dry snow
	West Rustler	4½ lb. blocks	Surface	"	Med.-Large slab-plus-dry into ski area Small secondary nearby
5 Apr.	Rustler Face	20 lb. chain	Surface	19" new	Med.-Large slab-plus-dry to upper traverse
5 Apr.	Rustler Face	20 lb. chain	Surface	"	Large blocks of slab plus some dry, to same point
7 Apr.	Rustler Face	20 lb. chain	Surface	16" new, settled	Medium, dry, did not reach ski area
20 Apr.	Twin Lakes Pass	20 lb. chain	Trench	Unstable Cornice	Cornice removed so telephone line could be repaired
	Twin Lakes Pass	"	"	"	"

noteworthy size. In my opinion, the major natural slide from Rustler Face on March 30 might well have had disastrous results without our explosive program.

A somewhat unforeseen benefit from the operation was its educational value to the public. Hundreds of skiers during the course of the winter saw this work going on, watched the results and received convincing proof of the value of safety regulations in an alpine ski area. The movies and photographs taken throughout the course of the project are available for further public education and study.

A fitting termination to the project was the running of the first Rustler Cup race, a giant slalom set from the top of Rustler Mountain.

The following tabulation summarizes the work done. More detailed information is available in the individual reports filed after each blast operation.

NOTES ON EXPLOSIVES OPERATIONS

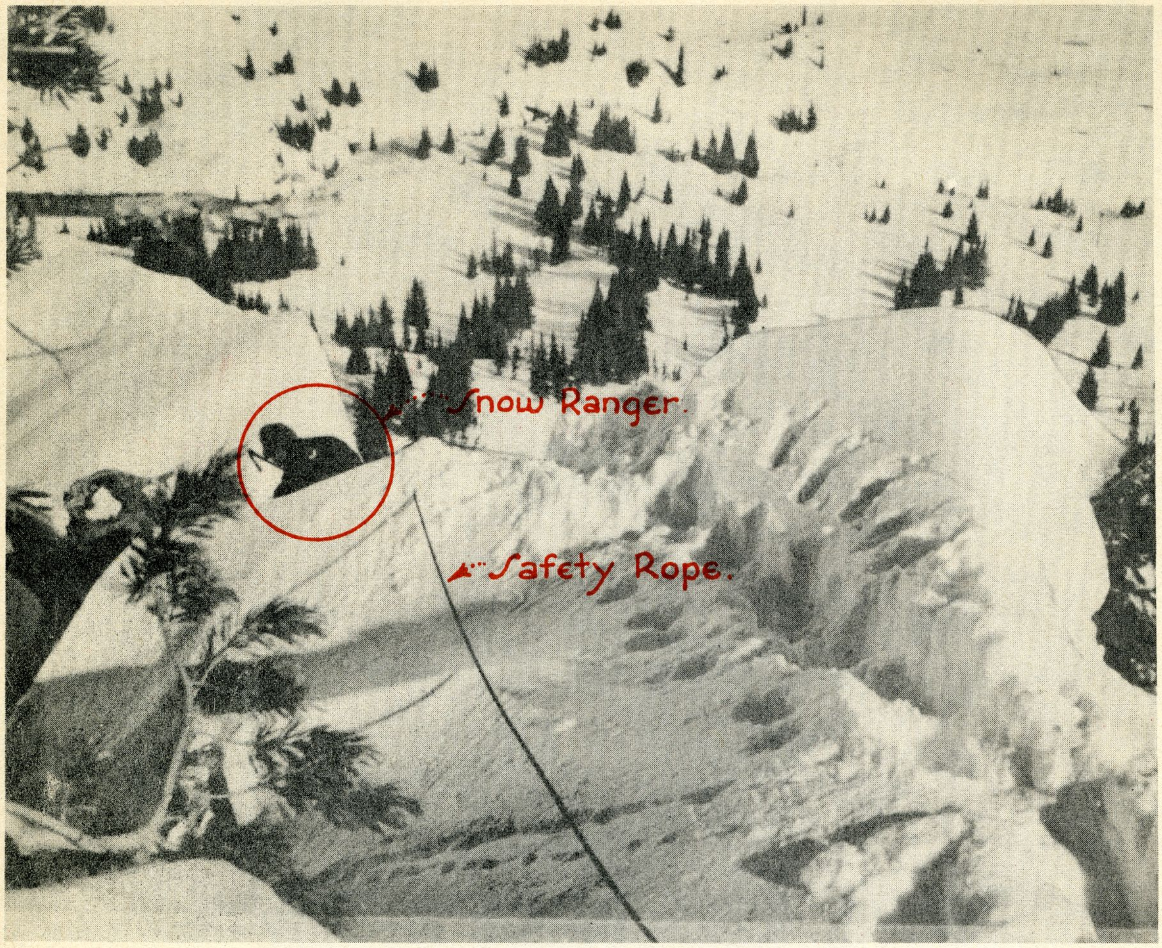
1. The use of explosives is the only positive method of eliminating the hazard of delayed action avalanches. According to eyewitness reports from Alf Engen and James Laughlin during the 1948 Winter Olympics, it is employed as a matter of course on the major Swiss ski areas. Our own operations at Alta prove that the hazard exists, that it is serious, and that explosives can take care of it. Like the Swiss, we did not attempt to make fine distinctions between degrees of hazard. When there was a definite possibility of danger, we blazed away and obtained a definite answer.

2. Hand-placed charges have the advantages mentioned in the report: maximum power and control. They also have serious disadvantages. Operations of this type are time-consuming, laborious, and hazardous to the operators. A number of areas in need of control at Alta are inaccessible. In some instances hand-set charges will always be best; but definitely the next step in the program is to begin the use of projectiles, the Swiss method. The following weapons are recommended: The 81 mm mortar, the 57 mm recoilless cannon and rocket projectors such as the bazooka.

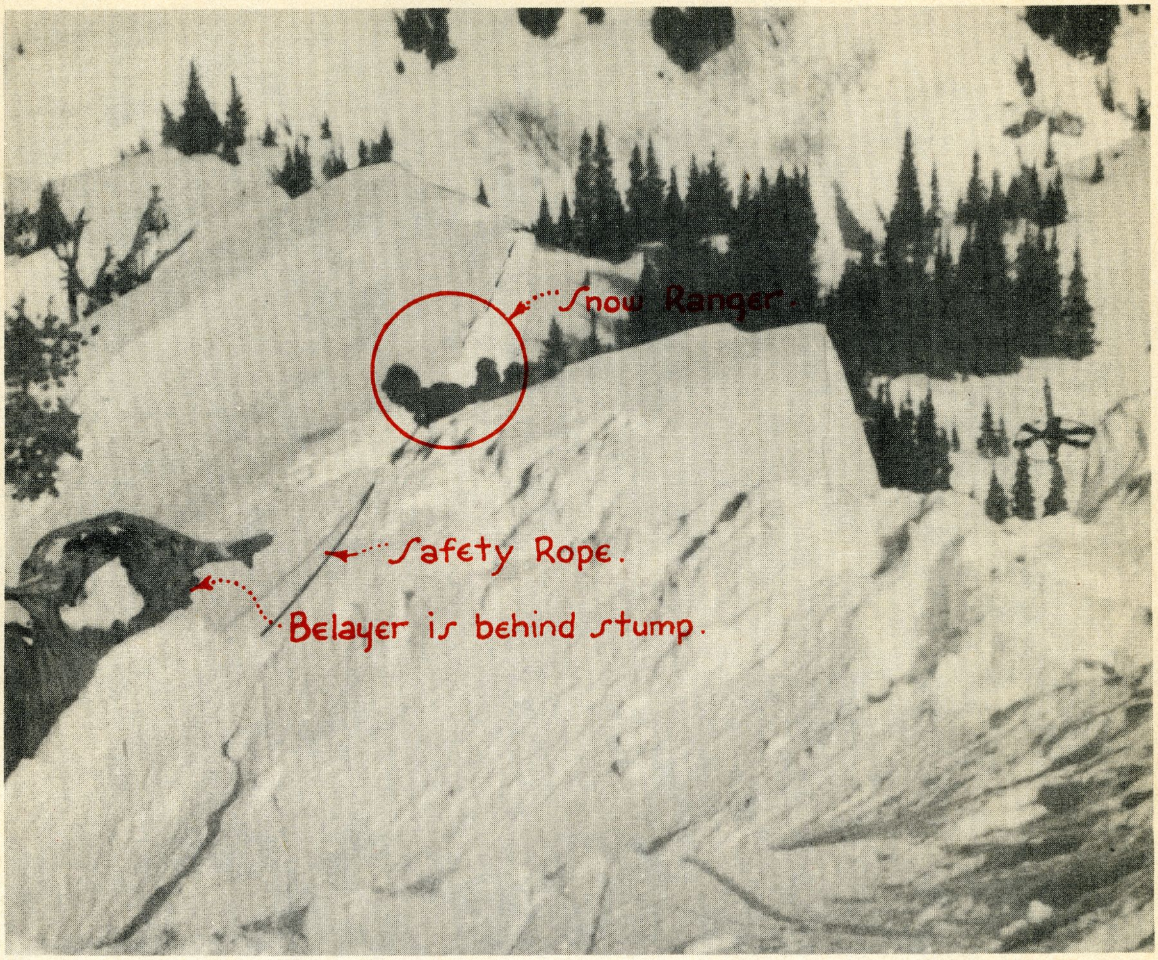
Mortars are the weapon employed by the Swiss but for several reasons, the other two appear more promising. Disadvantages of the 81 mm mortar are: (1) it requires a solid emplacement; (2) it is not readily portable; (3) accurate firing, especially in the mountains, is difficult for anyone but a mortar expert; and (4) the weapon does not have too good a crew safety record. Advantages of recoilless cannon and rocket projectors are: (1) they are readily portable; (2) no elaborate emplacement required; and (3) flat, high speed trajectory improves accuracy.

3. It is not sufficiently emphasized in the report that buried charges were much less effective than explosions on the surface. Snow is an excellent insulator and shock absorber. The two buried charges on Rustler Face produced only craters. With surface explosions we never failed to clean out all loose or unstable snow in the blast area.

Starting out to plant the explosive charge for cornice removal.
Note safety rope.



Halfway out. Approaching the unstable cornice. Safety rope belayed by assistant.



Cornice fractures under snow ranger. Serious accident prevented by safety rope.

Blast removes North Peruvian cornice. Part which fractured prematurely is just right of the explosion.

4. Cornice removal is a special problem. The following recommendation is made on the basis of the results of operations of the past two seasons. To control annual cornices which endanger the area, charges should be installed before the cornices form and wired to safe firing points. Upon removal of a cornice, a new charge can be installed. The charges should be of the chain type and should cover the full extent of the cornice.

The disadvantages of placing charges after the cornice has formed are: hazard to the operator and incomplete removal of the cornice.

THE ALTA SNOW STUDIES

ANNEX F. SAFETY ORGANIZATION

The following outline of the Alta snow safety organization and how it functions is offered as a sample, not necessarily a model. In any alpine ski area the safety organization will be an individual problem.

Safety organization can be of two types. Decision can rest on one man or on a committee. Both types are in use at Alta; both have advantages and disadvantages. The point to be remembered is that decision and responsibility are inseparable. No person not sharing the responsibility can share the power of decision. He can advise but not determine. It is Forest Service policy at Alta that no commercial operator or representative shall have any decisive vote on safety measures.

At Alta safety measures in the lift-served and touring area are decided by the Forest Service administrator. He makes decisions on the basis of personal observation, field testing, and whatever reliable information he can obtain from trustworthy advisors.

The principal advantage of one-man control is speed of action. The disadvantages are the heavy load of responsibility on a single pair of shoulders, and the limitations of time, distance, and communication.

Safety measures in the traffic area at Alta are determined by a committee consisting of the Forest Service administrator, the State highway foreman and the State highway patrolman. The advantages of committee control are, shared responsibility, more information, and better coverage. The principal disadvantage is time loss in assembling the committee. This is cancelled to some extent by the fact that any committee member can take emergency action on his own responsibility.

It is almost too obvious to mention that in any area and with either type of safety organization, success depends upon the experience, good judgment, and familiarity with the area.

ANNEX G. DESIRABLE SNOW RESEARCH PROJECTS

There are a number of snow research problems on which we need more accurate information. It can be obtained without going in for expensive equipment or laboratory techniques. The following subjects all tie in with our present methods of research and are of the practical type. They have not been undertaken due principally to lack of funds and manpower. In some cases the problem is to design or obtain some relatively simple piece of equipment.

1. Snow pressure and leverage. New unconsolidated snow exerts both pressure and leverage. Both forces unquestionably play a part in the release of avalanches. The pressure factor is easily found by reducing the snow to water and calculating the weight in pounds pressure per square feet. Leverage is a function of snow depth and angle of slope on which the snow is lying. Data already on hand suggests that there may be a very close relationship between avalanche release and the combination of these two factors.

The subject is worth investigation.

2. Rates of fall. At the present time rates of fall are calculated on the basis of the amount of new snow accumulating in 24 hours. These rates vary widely during a storm and thus influence the onset of the avalanche cycle. Settlement in the new snow and the old snowpack is an error factor. More accurate data are needed through frequent sampling.

3. Settlement rates. At the present time settlement is measured on the basis of the snowpack as a whole, old and new snow lumped together. They should be separated.

4. Better methods of determining the time of occurrence of slides are needed. Most avalanche cycles take place during a storm and so escape observation. A seismograph might register large slides. Possibly some simple time device could be planted in test plots to record the start of general cycles.

5. Wind transport of snow, the most important research job we could undertake.

6. Educational and training movie.

ANNEX H. AVALANCHE ACCIDENTS

Fairly complete data are available for the three avalanche accidents summarized here. Each one illustrates a typical course of events leading to disaster.

Case 1, 1948

Members of party: A and B, guests at Blank, excellent skiers; enthusiastic but inexperienced ski mountaineers; C and D, ski instructor and ski patrolman respectively, excellent skiers and experienced ski mountaineers.

Events leading up to accident: C and D were going to test the Blank Creek Run, known to be dangerous at that time. A and B went along at their own request.

The accident: C skied onto the slope followed immediately by A and B; slab plus dry snow avalanche fractured while all three were on the slope. C made an experienced ski mountaineer's typical test run of a doubtful slope, a short fast dip in and out of the danger zone. Only the edge of the slide touched him. B and A went farther out onto the slope. B, nearest to the release point, managed to ski out to one side. A attempted to outrun it straight down the gully. He went over a rock ledge, apparently fell, and was picked up there by the slide. B, looking for A, went out onto another avalanche slope and started a second slide which buried the tip of the first one.

Rescue operations: They were prompt, considering the distance from help, and well organized, accident happened at 2:00 p.m.; first party reached the scene at 3:30 p.m.; follow-up party reached the scene at 9:45 p.m., victim was found at 5:00 a.m. the following morning. Elapsed time: 15 hours. Cause of death: suffocation. Immediate action was unsuccessful. Systematic probing was unsuccessful. Body was finally located by trenching.

Weather and hazard data: Successive storms followed by prolonged cold; snow had not settled and was unstable.

Terrain data: See sketch map.

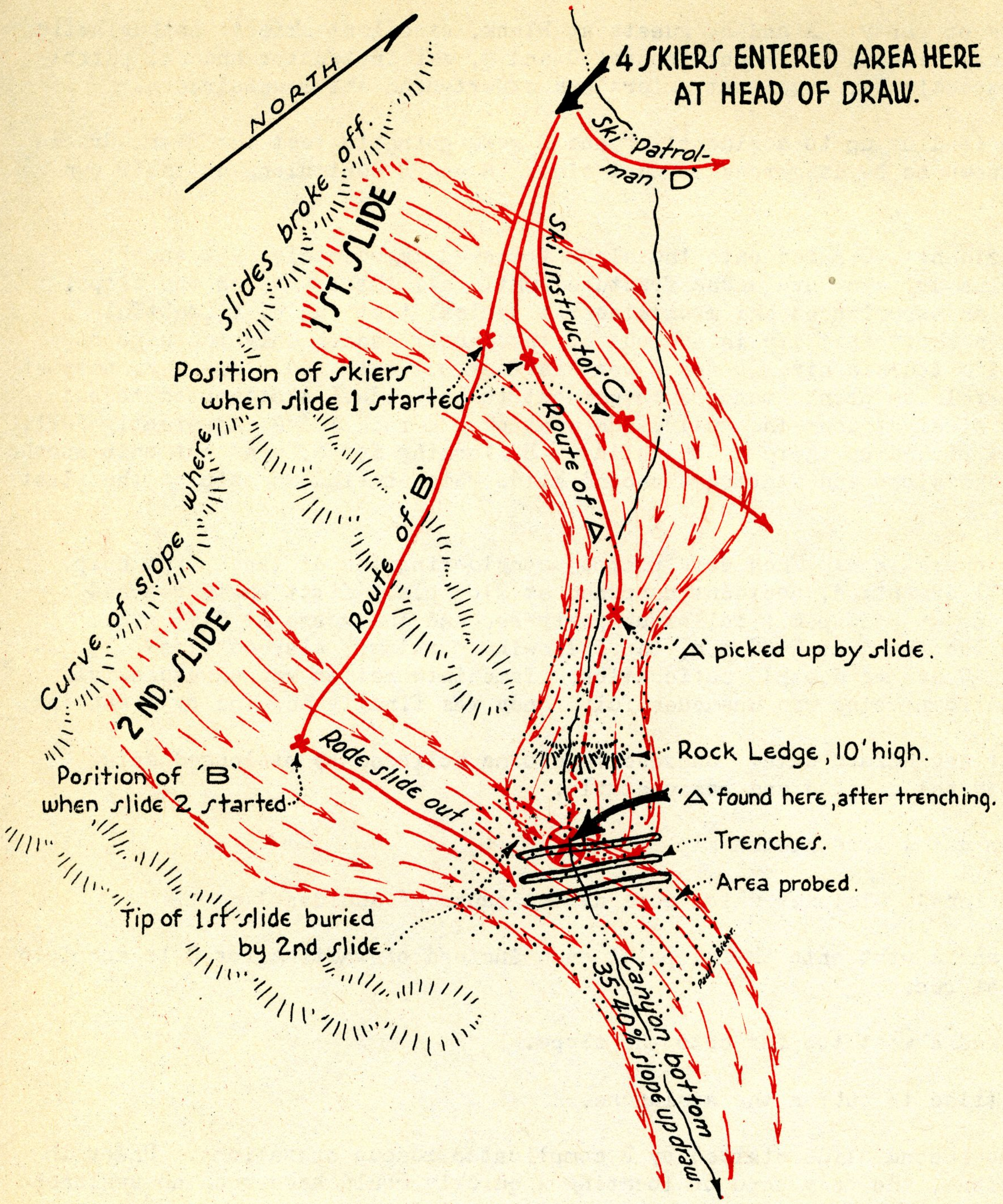
Conclusions: Mistakes which were direct cause of accident:

1. B and A went onto the slope at once instead of waiting for C to complete his test run.

2. B and A went too far onto the slope.

3. A tried to outrun the avalanche.

4. The second slide started by B complicated rescue operations. Under the conditions, the only hope of locating A quickly would have been an avalanche dog.



AVALANCHE ACCIDENT

CASE 1.

Case 2, 1948

Members of party: Three, names not reported, skiing experience unknown.

Events leading up to accident: The three skiers were touring the Blank Trail, a little-used run.

The accident: The three went onto the slope one closely behind the other. A slab plus dry snow avalanche broke off immediately and caught all three. No. 2, protected by trees, was not completely buried. He dug himself out and knew where the No. 3 skier went under; no observation of No. 1.

Rescue operations: No. 2 immediately went for help. The accident occurred at 4:00 p.m. approximately; first party arrived at 5:00 p.m. Directed by eyewitness body of No. 3 was found in 30 minutes or less, one foot under; artificial respiration unsuccessful. Immediate action was unsuccessful in finding No. 1; operations terminated due to darkness and extreme cold; follow-up party arrived 8:00 a.m., following morning; body located by systematic probing at 2:15 p.m. 12 feet under. Elapsed time: 22 hours approximately. Cause of death not reported; No. 3, probably suffocation; No. 1 probably killed by crushing.

Weather and hazard data: Severe storm in progress, with sub-zero temperatures and 20 inches plus of new dry snow.

Terrain data: The accident occurred on a 30-40 degree slope open with scattered trees, overhung by a cornice.

Conclusions: 1. No. 2 skier should have spent a few minutes looking for No. 3 whose position he knew accurately.

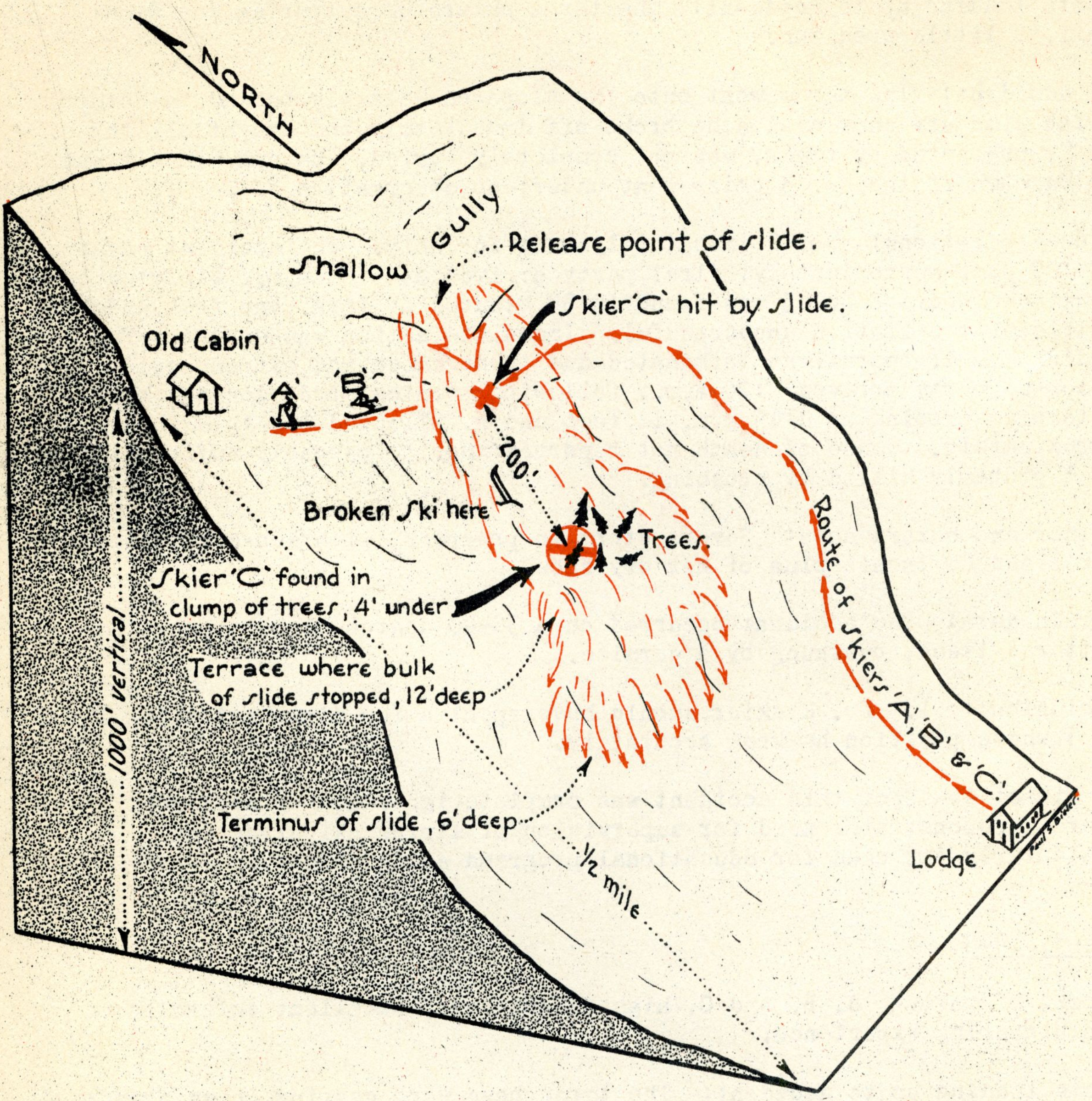
2. Direct cause of this accident was complete ignorance of avalanche hazard. Demonstrates need for supervision of alpine ski areas and particularly the need for educational programs among skiers.

Case 3, 1945

Members of party: A, B, and C, high school boys, excellent skiers, some mountaineering experience.

Events leading up to accident: The three boys were camping in an abandoned mining cabin located in a high continuous hazard area. Their presence there was unknown until they appeared at the lodge at noon to get supplies. They were warned two separate times not to attempt to return. They went anyway.

The accident: The boys climbed to the contour of the cabin. The last traverse to the cabin took them across a wide, shallow gully. A and B got over safely. A damp snow avalanche, starting from above, picked up C.



AVALANCHE ACCIDENT
CASE 3.

Rescue Operations: A stayed at the scene of the accident. B went for help. The accident occurred at 4:00 p.m. approximately; first party arrived at 5:00 p.m. approximately, guided by B. The two boys were able to give valuable information on where C went under. A piece of his equipment was found nearby. His body was located in about 30 minutes entangled in a clump of trees, 4 feet under. He had a broken leg and was suffering from shock, exposure, and suffocation. He began to breathe when snow was cleared from his mouth and nose. The follow-up party arrived 5:30 p.m. in time to complete the evacuation. C survived.

Weather and hazard data: A severe damp snow storm was in progress; highway was closed and skiing restricted to minimum hazard area. A general avalanche cycle was in progress.

Terrain data: The accident took place in a high continuous hazard area permanently closed to skiing. See diagram.

Conclusions: The cause of this accident was failure to obey specific warnings, safety regulations, and elementary ski mountaineering procaution. It demonstrates the necessity for cooperation by skiers and the need for education.

Prompt and effective rescue operations saved the victim's life.

ALTA AVALANCHE AND SNOW STUDY

ANNEX I: CLIMAX AVALANCHES

There is a type of avalanche which poses a special problem for administrators of alpine ski areas. This is the avalanche which runs at long intervals, but with climactic violence.

The annual avalanches like Rustler, Baldy, Superior, Red Pine, and Hellgate at Alta are a routine problem. They are expected and a large amount of data are available for determining the conditions favoring their occurrence. Skiers are aware of the hazard because they see it every year and cooperate with safety regulations.

The opposite is true in the case of the long-term avalanches like Coal Pit, Emma, Gad Valley and Flagstaff at Alta, and Argenta in Big Cottonwood. The annual avalanches are the result of fairly simple storm conditions which will arise in any average winter. But the climax avalanches are the result of very unusual weather combinations which occur ordinarily only once in a decade or even longer.

Data on these avalanches are incomplete and scanty. Since they run at such long intervals, the public and even the administrators forget or do not know that the potentialities exist. In the case of an alpine ski area newly developed or under investigation, the climax avalanches might be an entirely unknown quantity. In 10 or 20 years, vegetation and forest growth hide the scars. They may run in paths not readily identifiable. The Emma slidepath at Alta is well defined and is in fact the scene of annual avalanches of importance. But Coal Pit would scarcely be chosen as a likely place for a climax avalanche to develop among a host of more impressive slopes. Argenta, in Big Cottonwood, is impressive enough, but the trained observer would be likely to cross it off his list because of the natural obstacles.

In any plan for the development or operation of an alpine ski area, the climax avalanches must be considered. But they are certain to take place when the right conditions are present. And they are the most likely to result in major disaster. A short-term investigation of a new area, for instance, might reveal no data whatever. Permanent improvements or main ski runs, seeking to avoid a lesser hazard, might be located in the path of major destruction.

Historical records, no matter how fragmentary, are of value in calculating the climax avalanche hazard. They will at least point out some of the locations. Due to the early day mining activity at Alta records in this area are fairly extensive. They have been of great assistance in planning and operating the area.

During the season of 1947-48, two climax avalanches ran; Coal Pit in Little Cottonwood and Argenta in Big Cottonwood. With modern methods of recording and analyzing data, it is possible to work out rather complete case histories for those two which reflect some light on others where only fragmentary information is available.

Emma Mine

History: As mentioned above, the Emma is an annual slide path. Four climax avalanches have been recorded.

1874. The slide destroyed the mining town of Alta, killing 60 persons. Other fatalities occurred during the fire that ensued. No weather data are given.

March 7, 1884. Twelve persons were killed; 1.71 inches of rain are mentioned.

February 16, 1939. Violent storm in progress.

January 7, 1941. Damaged cars and tows west of Emma; 8 inches damp new snow.

Terrain Data: The Emma slide path lies on the north side of Little Cottonwood Canyon overlooking the upper parking area. Forest and grass cover is deficient due to heavy cutting during early mining days and the hillside has been cut by erosion into many gullies. There is a 1700-foot difference in elevation between the canyon floor and the ridge summit. The upper third of the slide path is above 30 degrees in grade. At its approximate center there is a sort of terrace or definite change in grade of considerable width after which the hillside steepens again but remains below the critical angle. This terrace catches the annual slides. The climax avalanches overshoot it and issue on to the parking area from a large gully.

The exposure favors the formation of slab and cornices from northerly winds. The slide path is approximately ½ mile wide and a mile long.

Weather data: The Emma avalanche has not run during the period for which comprehensive records are available. However, there are some interesting and significant hints. The 1884 slide was touched off by 1.71 inches of rain. A March rainstorm would have the Alta administrator "battening down the hatches" on general principles alone. Abnormal weather in an avalanche area is almost always dangerous. But he would have excellent reasons for his action. In terms of snowfall, that much rain would amount to 15 inches of damp snow containing .12 of an inch of water per inch of snow, or 21 inches of dry snow of .08 of an inch average water content, or 35 inches of light snow with .05 of an inch water content. These are all critical amounts of snow. Wind force and direction would play a less important part in a rain storm, but this would be made up for by the lubricating and loosening effect of water percolating into the snow pack.

The 1939 slide was winter's greeting to the first Alta administrator. Detailed weather data are not available, but Ranger Wadsworth's reports yield some valuable information. It had been a winter of abnormal snowfall with numerous storms from the north and northwest. Such conditions would promote the formation of cornices and slab on the Emma slide path. The avalanche ran during a violent northwest storm. It destroyed some mine buildings which had been undisturbed for 50 years, and sheared off the top of the public ski shelter, then under construction. As a result the plans for the shelter were altered in favor of an avalanche-proof roof at parking area level instead of a third story projecting above the highway.

This is proof positive of the necessity for considering climax avalanches in alpine ski area planning.

Major slides were general along the north side of Little Cottonwood on this occasion. Eighteen different avalanches reached the highway and it was buried for a total of 3,000 yards throughout its 9-mile length. Most of the parking area was also buried.

The 1941 slide was less violent than 1939's. Again the parking area suffered. There was damage to several cars standing in the unprotected portion and to a tow installation. Oddly enough, the Emma slide proper did not run, at least not in major volume. This fact is calculated to keep any snow observer from becoming too "cocksure."

Eight inches of damp new snow are mentioned in the report on this slide, a hazardous situation but not hazardous enough in itself to produce a cycle of such violence. Again appears the background of abnormal snowfall with a concentration of northerly storms. The damp new snow was the detonator, not the main charge.

The existence of general avalanche conditions is proved by the Greeley Hill slide one week earlier. Artificially released by the victim, this slide caused the only avalanche fatality in Alta's reincarnation as a ski area.

It would be interesting to have more data, such as total snow depths, and the storm sequences and characteristics. But even without them a pattern begins to emerge which is confirmed by Coal Pit and Argenta.

Argenta (Big Cottonwood)

History: Prior to 1948, very little information is available. On February 8, 1899, 28 slides reached the bottom of Big Cottonwood canyon. It is logical to assume that Argenta was among them.

After the 1948 slide, a prospector who had lived in the vicinity for many years stated that he had seen Argenta run in even greater volume. However, no dates were given.

Argenta ran on March 25, 1948 at 4:00 p.m. covering the highway 30 feet deep and damming up the stream. A violent storm was in progress. Complete weather data are available for Alta, nearby. A climax avalanche occurred on Mt. Baldy, same exposure as Argenta, on the same date.

Terrain data: The release point and accumulation zone of Argenta lie in a bowl near the top of the range which separates Big Cottonwood and Little Cottonwood. The exposure is north and northeast and the location has good vegetative and forest cover.

The bowl retains annual slides. A climax avalanche overcoming this barrier forces its way down a winding gully and then issues on to a steep brushy slope which overlooks the highway. The slide path is over a mile long with a difference of nearly 2,000 feet in elevation.

Weather data: The following information is taken from the Alta records. The Argenta avalanche took place during a month of excessive snowfall and violent southwest storms. Release came during the fourth major storm of the month. Of these, the last three came on southwesterly winds of critical force. Total snowfall for the month had been 130 inches. Snow depth was 112 inches. Conditions therefore promoted the formation of slabs and cornices on northerly exposures. Normal sloughing and consolidation of the snow pack had not taken place. Coal Pit ran exactly a week earlier. Baldy ran on the same day. It was plainly a case of accumulation of an abnormal amount of snow, its weight eventually fracturing the slabs lying one on top of the other. Photographs of the fracture plane of the Baldy avalanche reveal at least three slab layers.

Argenta was a slab and dry snow avalanche which was predominantly damp by the time it reached the bottom of the canyon. This was the result of its long travel and the friction developed in the gully.

Argenta climax avalanche; shows natural obstacles overcome by this slide.

Following is a tabulation of the March storms:

Date March	Snowfall Inches	Water Content Inches	Wind Force	Wind Direction	Notes
8 - 10	29	1.87	Critical	N & W	
14 - 15	33	2.52	Critical	SW	
19 - 20	30	2.31	Critical	SW	Coal Pit
25	20	1.96	Critical	SW	Argenta

In addition there were minor storms on the 3rd and 17th. During the period 8-25, when this storm sequence took place, there were only 3 days without snowfall.

Coal Pit

History: As in the case of Argenta, Coal Pit is a slide path known from early mining days, but no exact dates of earlier occurrence are available.

The slide ran March 19, 1948 between 4:00 and 4:30 p.m. during a violent storm. It tore out a large pipeline, crossed the bottom of the canyon and went 200 yards up the opposite side. It buried the highway 20 feet deep for a distance of 300 yards. Some of the trees broken off by this slide were 10 inches in diameter, a measure of the force of the avalanche as well as the time lapse since last occurrence.

Terrain data: The accumulation zone and release point of Coal Pit are a complex of steep and narrow gullies overhanging the mouth of Little Cottonwood canyon. The exposure is northwest to northeast. The gullies combine to form a very precipitous chute which issues on to an extensive talus slope. Forest cover is good. The slide path originates on the topmost crags of the canyon and finally funnels into a very narrow chute at the bottom. The difference in elevation is at least 2,000 feet.

Weather data: Same as for Argenta with certain exceptions and modifications. Coal Pit ran one week earlier than Argenta, on the third major storm of March instead of the fourth.

Coal Pit's valley elevation is at least 2,000 feet below that of Argenta. A major factor in the production of this slide is that the March storms were very deep, snowfall being about as heavy in the valley as at Alta. The snow type varied, becoming progressively heavier and damper as the elevation decreased. Dumped into the Coal Pit accumulation zone by strong southwest winds, possibly slabbed into the bargain, the sheer weight of the snow was the deciding factor. Normally this snow would have melted or sloughed out piecemeal but the storm sequence was too rapid for this development to take place.

Coal Pit at the extreme upper elevation probably started as a dry slide but ended as a typical wet avalanche as shown by the characteristic channeling. In a house about 400 yards down the highway from the slide, its sound was

Slide path and terminus of Coal Pit avalanche. This slide climbed three hundred yards up the opposite side of the canyon. Note the characteristic channeling of a wet-damp snow avalanche. See case description for more detail on page 94.

likened to the rumble of heavy trucks or a train. No airblast was noted although there is a difference of opinion on this point. With a faster moving dry snow or slab type avalanche on such a precipitous slope, airblast should be practically a certainty. The slide apparently splashed or bounced when its main front hit the easier grade of the talus slope. This probably accounts for the phenomenon of trees in the slide path sheared off twenty feet above the level of the slide at rest.

Conclusions

1. Due to their destructive power, climax avalanches are a serious problem in alpine ski areas or on approach roads.

2. Since they run infrequently, information may be deficient as to their location and the conditions favorable to their occurrence.

3. Climax avalanche paths are often difficult to recognize. Administrators of alpine ski areas must seek by every means to locate climax avalanche slide paths and to obtain background weather data. Good terrain analysis will recognize likely locations. Historical records however fragmentary are valuable. Observation of the destruction of old slides is important. Aerial photos should be of value in many cases. Consultation with old timers should also be helpful.

4. The plan of any alpine ski area will be influenced by climax avalanche possibilities. Permanent improvements especially must be so located as to have positive protection.

5. Case histories of climax avalanches in the vicinity of Alta where complete weather data is available yield information of general value. Climax avalanche occurrence depends upon special combinations of weather and snow conditions operating over a period of time.

6. Active protection from climax avalanches in areas of particular importance is feasible through the use of explosives. In example, Rustler Face, an annual avalanche path at Alta known also to be a climax avalanche site, was blasted three times during the March 1948 storm sequence. On each occasion a large slide was released. Nevertheless, on March 30, during the final major storm of the month, a natural slide from Rustler Face reached the bottom of the canyon. If the older snow had also been involved, a climax avalanche would probably have occurred.

The End