Classification of Snow Avalanches

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Abstract

A classification of snow avalanches based on the mechanism of the avalanche was proposed. The underlying intent of this classification was to set forth a simple and easy to understand practical classification for amateurs as well as specialists. Classical Japanese names were used as denomination of the avalanche which suggest some characteristics of the individual avalanches.

I. Introduction

The classification of avalanches has long been a subject of active discussion. However, no satisfactory conclusion has been obtained as yet. Here, the author proposes a classification of snow avalanches based on the mechanism of the avalanche, with the following ideas incorporated:

i) The classification should be simple so that it can be used by amateurs and specialists alike.
ii) The denomination of the avalanche should suggest some real image of the individual avalanches including at least a part of the mechanism of its occurrence.

From this point of view, a classification of snow avalanches was proposed by use of classical Japanese names which suggest some characteristics of the individual avalanches.

II. Basis of Classification of the Avalanches

The historical classifications of avalanches were based on the following ideas or combination thereof. While each of these proposals insisted upon their own merits, no satisfactory conclusions were reached which could applied universally.

Here, the author has attempted a brief review of the basic ideas of such historical classifications:

1) *The property of the snow deposit* (*dry or wet, new or old, soft or hard, fine powder or coarse granular, etc.*)

It is impossible to observe the properties of the snow cover at the time of avalanche release. And the composition of snow layers in the deposit is generally very complicated. Hence this cannot be a practical basis for the classification of the avalanche.

2) *Level of slide plane in the snow deposit* (*superficial or the whole layer*)

This is a fairly practical basis, but it is much too simple to classify all avalanches only by the level of the slide plane. And it is necessary to combine some other appropriate parameters with this for practical usage.

3) *Season* (*late autumn, early or mid winter, early, mid or late spring*)

The locality and elevation also have similar climatic effects on the snow cover as well as the season. And it is not practical to select the season as the basis for classification of the avalanche.

4) *The shape of the starting crack of the avalanche and the type of avalanche motion*

It seems to be rather reasonable to use this as a basis of classification of avalanches. The crack lines of a material by fracture appear normal or at an angle of about 45° to the directions of the principal stresses. The former appears when the material is broken by tearing, and the latter by shearing, as shown in Fig. 1. Therefore, the starting crack of the avalanche can give the mechanical property of the snow cover. The starting crack of an avalanche, normal to the steepest line of the slope shows a brittle fracture of the snow cover, and that of 45° a shear fracture. Such aspects make it possible to classify the avalanche into two types "line avalanche" and "point avalanche".

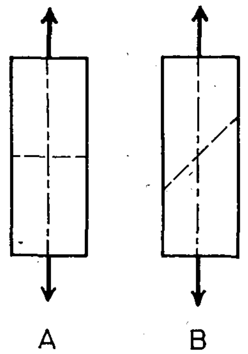


Fig. 1. Fracture line of snow,
A: *Brittle fracture by tearing,*
B: Shear fracture

The first crack of the line avalanche, runs transversally which shows the line avalanche results from a brittle fracture of the snow cover by tearing. The point avalanche can be identified by the first crack which originates at point source and runs along in a direction of about 45° to the stress. It shows the maximum shear fracture of the snow cover.

For practical purposes, however, it is difficult to observe the starting point and to distinguish a point avalanche from a line one due to the following reasons. (1) If two point avalanches were released simultaneously from some neighbouring point sources, A and B of Fig. 2, it would be rather difficult to identify them if they were two point avalanches released from the points A and B or a single line avalanche from the crack line ACB. (2) It is extremely difficult to observe the actual running of the first crack of an avalanche which is generally unforeseen in its timing and location. (3) Many avalanches are released during snow storms and bad weather which of course would prevent the observation. (4) The starting point is frequently in accessible owing to steepness of slope or danger of another avalanche.

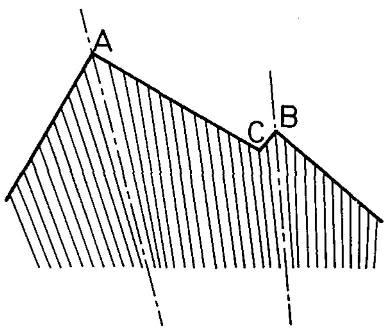


Fig. 2. Crack line of some avalanche

For these reasons, the shape of a starting crack cannot be a practical basis for the classification of avalanches.

5) *Boundary conditions*

This is the basis of the classification of the snow avalanche the author proposes.

A snow cover loses its balance of the required sustenance on a slope and an avalanche can be released when:

i) The depth of newly deposited snow exceeds a critical depth.
ii) An external force is applied to a new snow deposit on a crusted surface of an old snow deposit.
iii) A crusted snow layer loses its mechanical sustenance at its bottom by the underlaying snow deposit.
iv) The superficial layer of the snow deposit thaws and loosens.
v) The whole layer loses its mechanical sustenance at the bottom layer due to growth of depth hoar at the bottom.
vi) The whole layer loses its mechanical sustenance at the bottom due to weakening or thawing of the bottom layer by ground heat.

The above mentioned boundary conditions seem to cover all of the mechanisms of the avalanche release, and the particular mechanism of individual avalanche can easily be identified through the property of the remaining snow cover shortly after the avalanche release and a record of the weather condition.

Hence, a classification of the snow avalanche based on the boundary condition at the time of occurrence, *i.e.* the mechanism of the avalanche release, was proposed as shown in Chapter IV.

III. Balance of Snow Deposit on a Slope

1) *Theoretical treatment*

The snow layer may be treated as a kind of soil layer, although its characteristics are quite different in many respects from those of the soil. Hence, we may treat the balance of snow deposit by means of the "earth pressure theory".

The Coulomb's characteristic equation shows,

$$\tau = c + p \tan B \,, \tag{1}$$

where τ is shear strength of the snow layer under pressure p,
c cohesive force of the snow,
B angle of internal friction of the snow.

Both the constants, c and B, vary in very wide range for snow, according to the snow property.

$$c = \text{several } 10\,\text{kg/m}^2 \sim \text{several t/m}^2 \,,$$
$$B = 20^\circ \sim 50^\circ \,, \quad \tan B = 0.36 \sim 1.2 \,.$$

A snow deposit is an agglomerate of snow particles, crystals of ice, and shows a similar structure to soil, *i.e.* "flocculent", "honey-combed" and "single grained". But one of the most important characteristics of the snow deposit which differs from the soil is the metamorphism. The metamorphosis of snow proceeds actively near the freezing point and slowly at low temperatures. The structure of snow deposit is altered by the metamorphosis from new snow to compact snow, and finaly to granular snow.

Now we shall disscuss the balance of snow deposit on a uniform slope with an inclination A, (see Fig. 3). Consider a vertical snow column with a unit horizontal cross sectional area and mean density d in the snow deposit. The pressure p_v exerted by this snow column on a horizontal surface at a vertical depth Z_v from the surface is,

$$p_v = d \cdot Z_v . \tag{2}$$

The snow density d varies in a range of 100~300 kg/m^3 for powder snow. And this pressure p_v produces a shear force f_z parallel to the slope at depth Z_v in the snow deposit,

$$f_z = d \cdot Z_v \sin A \cos A . \tag{3}$$

As far as the shear strength t of the snow deposit is larger than, or at least equal to, the shear force f_z, the snow deposit is sustained on the slope. Namely, the condition for sustenance of the snow deposit on the slope is,

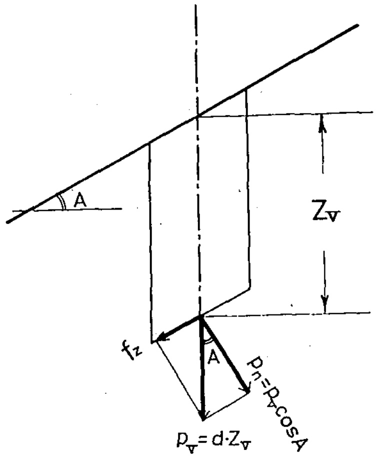


Fig. 3. Balance of snow deposit on a uniform slope

$$t \geqslant f_z ,$$
$$c + p_n \tan B \geqslant d \cdot Z_v \sin A \cos A , \tag{4}$$

where p_n is the pressure normal to the slope,

$$p_n = d \cdot Z_v \cos^2 A . \tag{5}$$

Then,

$$c/d \geqslant Z_v \cos^2 A (\tan A - \tan B) , \tag{6}$$

or

$$Z_v \leqslant \frac{c}{d \cdot \cos^2 A (\tan A - \tan B)} . \tag{7}$$

This equation gives the depth of a snow cover which can be sustained on a uniform slope with an inclination A for given snow properties of c, d and B.

If the vertical snow depth Z_v exceeds this limit Z_0, *i.e.* "critical depth",

$$Z_v > Z_0 = \frac{c}{d \cdot \cos^2 A (\tan A - \tan B)} , \tag{8}$$

the snow cover cannot be sustained on the slope any more. When the depth Z_v of the snow deposit exceeds the critical depth Z_0, and the snow deposit slides down the slope. This is the fundamental condition of occurrence of a powder snow avalanche. The critical depth Z_0 of a snow deposit varies with the time lapse according to the change of snow structure caused by metamorphism.

In the next section, we shall evaluate the stability of a snow cover on a slope.

2) *Numerical calculation*

To estimate the critical condition of stability of a snow cover on a slope under various situations, the following values were given to the individual parameters;

Inclination of the slope $A=15°, 20°, 30°, 45°, 60°, 75°, 80°$,
Angle of internal friction of the snow deposit $B=15°, 30°$,
Cohesive force of the snow deposit $c=100\sim3\,000\ kg/m^2$,
Density of the snow deposit $d=100\sim300\ kg/m^3$.

Through a simple combination of c and d, c/d covers a very wide range, $1/3\sim30$ m. Thus 1/3, 1 and 2 m were taken as the practical values of c/d.

Table 1. Normal critical deph Z_{0n} of snow deposit on a slope

Angle of internal friction, tan B		tan 15°=0.268					tan 30°=0.577			
Angle of the slope, A		15	30	45	60	75	30	45	60	75
Coefficient of the vertical critical depth Z_0 $\frac{1}{\cos^2 A(\tan A-\tan B)}$		∞	3.7	2.7	2.8	4.2	∞	4.8	3.3	4.8
Coefficient of the normal critical depth Z_{0n} $\frac{1}{\cos A(\tan A-\tan B)}$		∞	3.2	1.9	1.4	1.1	∞	3.4	1.7	1.2
Normal critical depth, Z_{0n}	for $c/d=1/3$ m	∞	1.1	0.6	0.5	0.4	∞	1.1	0.6	0.4
	$c/d=1$ m	∞	3.2	1.9	1.4	1.1	∞	3.4	1.7	1.2
	$c/d=2$ m	∞	6.4	3.8	2.8	2.2	∞	6.8	3.4	2.4

Taking Z_n as the normal depth of the snow cover to the slope, *i.e.* thickness of the snow cover, the normal critical depth Z_{0n} of the snow cover to the slope can be calculated as follows (see Table 1 and Fig. 4).

Although this result was obtained by a simplified model, it shows the general tendency of the critical depth Z_{0n} with regard to the angle of the slope.

3) *Boundary conditions*

Calculation of stability of snow cover on a slope in the previous section was based on two assumptions.

i) The snow deposit was assumed to be a homogeneous material whose behavior can be expressed by the Coulomb's equation and which can be strengthened mechanically by applied hydrostatic pressure.

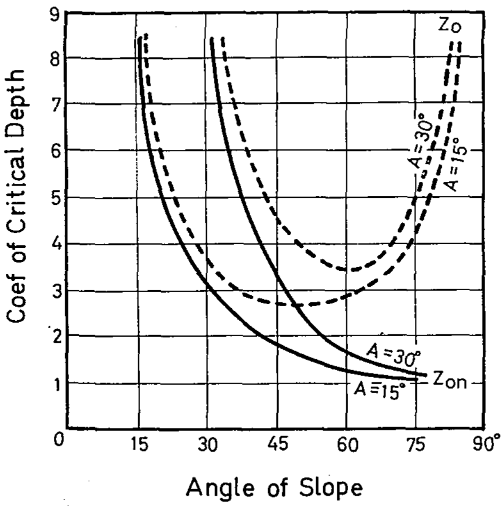


Fig. 4. Coefficient of critical depth
For vertical depth, Z_0: $1/(\tan A-\tan B)\cos^2 A$,
For normal thickness, Z_{0n}: $1/(\tan A-\tan B)\cos A$

When a snow fall makes a new deposit exceeding 1 m in one night, it seems to satisfy this assumption. Actually, we have many avalanche releases under such conditions.

On a slope beneath a cornice, a deep snow deposit with a low density and low cohesive strength is easily produced by snow drift. And avalanche occurs frequently on such a slope.

ii) The slope was assumed to be uniform and infinitely wide.

Under this assumption, we may consider that a snow cover on a slope is sustained only by the shear strength of the snow deposit across the plane, parallel to the slope.

Many of the avalanche sites have a sufficiently wide extension, as compared to the thickness of the snow deposit there. This fact may enable us to treat the actual avalanche slope as having an infinite extension. However, in the field a number of avalanches occur in gullies and narrow valleyes. In such cases, this assumption cannot be valid any more, and we must consider the statical balance of the snow deposit on the slope not only by the sustenance at its bottom, but also by sustenance at its sides, at the upper, lower and lateral levels.

Let us consider the statical balance of a snow block, length l, width b and with normal thickness Z in a snow cover on a slope. The snow block is sustained on the slope by:

a. Shear force τ across the bottom plane of the block.
b. Shear force τ' across the lateral side plane.
c. Tensile force S'_t at the upper end of the snow block.
d. Compressive force S'_c at the lower end of the snow block.

Hence, the total sustaining force F of the snow block on the slope is given as,

$$F=(bS'_t+2l\tau'+bS'_c)\,Z_0+bl\tau\,. \tag{9}$$

Neglecting the difference of the strength of the snow for tensile, compressive and shear force, and assuming the strength to be a half of the shearing strength τ_0 at the level of $\frac{1}{2}Z_0$ in the snow deposit, *i.e.*,

$$S'_t=S'_c=\tau'=\frac{1}{2}\tau_0 \text{ and } \tau=\tau_0\,,$$

then,

$$F=[(b+l)\,Z_0+bl]\,\tau_0\,. \tag{10}$$

The balancing condition of the snow block on the slope is,

$$[(b+l)\,Z_0+bl]\,\tau_0 \geqslant Z_0\cdot d\sin A\cos A\,, \tag{11}$$

or

$$bl\left(\frac{Z_0}{l}+\frac{Z_0}{b}+1\right)\tau_0 \geqslant Z_0\cdot d\sin A\cos A\,. \tag{12}$$

Actually, a narrow and short slope is safer from avalanche hazard than wider slope, as the equation shows.

However, when the snow deposit has a very weak or no mechanical sustenance at its bottom, *e.g.*, in the case of slab avalanches and whole layer avalanches, a correction factor for the equation is necessary, as will be shown later.

4) *Metamorphosis of snow deposit*

The snow crystal deposited on the ground changes its form from the original angular shape to roundish grains by sublimatic evaporation and condensation, or by thawing and refreezing, with the lapse of time. This change of individual snow grains is reflected on the structure of snow deposit as a whole; from new snow to compact snow and finally to granular snow. Such changes of snow grain shape or snow deposit structure is called metamorphosis of snow.

Metamorphosis of snow is generated by migration of water molecules through sintering, sublimatic evaporation and condensation, or melting and refreezing. The vapour pressure around a pointed corner is greater than that on a flat surface. Such a vapour field generates migration of water molecules from the pointed corner to the flat surface through sublimation. Migration of water molecules by melting has the same tendency with that by sublimation and changes the grain shape to a roundish, but more rapidly.

As a result, the sharp corner and the small grains disappear, feeding the roundish surface and the large grains as the metamorphosis proceeds. Concurrently, the point of touch of neighbouring grains grows into large ice bonds. In a glacier, especially in temperate glacier, the grains grow very large through recrystallization during long lapse of time. The mechanism of grain growth may be explained by the strain theory of metallography. But it is unnecessary here for classification of avalanches.

If the snow deposit is exposed to warm air or intensive solar radiation in the daytime, the mechanical strength of the snow deposit is lowered almost linearly in accordance with the rising of the snow temperature. A sufficient amount of heat absorption, generates thawing in the snow deposit. Under such conditions, snow grains and ice bonds are thinned and covered with a water film, and the mechanical strength of the snow deposit is weakened furthermore.

As the water film fills up the minute gaps of the structure of snow deposit by the surface tension, the snow deposit weekens very much, but it aquires a stronger structure with thicker ice bonds than the original when it is refrozen by the descent of snow temperature in the evening. This refrozen snow layer is called crusted snow.

If the crusted snow is exposed to intensive solar radiation or warm air thawing takes place in it, and the crusted snow structure is decomposed into elemental snow grains by melting of the ice bonds. This results in lowering the cohesive force of the grains in the snow cover, but the apparent density of the snow cover, on the other hand, is scarcely changed. Hence, the balance factor c/d of the snow cover is lowered as thawing proceeds. The thawed layer increases in its thickness through repeated thawing and refreezing.

Depth hoar grows in a snow deposit under some particular conditions. Water molecules migrate from a lower colder level to a higher warmer level in the snow deposit through sublimatic evaporation and condensation and produce depth hoar crystals just like the formation of the frost columns or the leaf snow. These are not interconnected by ice bonds, and the depth hoar layer is extremely weak.

Metamorphism of the snow deposit changes its mechanical strength c and B, and density d. These factors have important effects on the balance of a snow deposit on a slope, thus have a further bearing on the occurrence of avalanches. In other words, metamorphism can be one of the important mechanisms for the avalanche occurrence.

We shall consider the various mechanisms of avalanche occurrence and classify avalanches from this standpoint, in the next chapter.

Table 2. Classification of the snow avalanches (The terms in capital letters are the Japanese names of the avalanche)

General group	Sub-group	
Primary avalanche	AWA (New snow avalanche)	
Secondary avalanche	NADE (Superficial avalanche)	UWA-NADE (Mechanical avalanche)
		ITA-NADE (Slab avalanche)
		NETU-NADE (Solar radiation avalanche)
	ZIKOSURI (Whole layer avalanche)	Hoar-ZIKOSURI (caused by depth hoar)
		ZIKOSURI

IV. Classification of Snow Avalanches

Snow avalanches are classified here into two general groups, the primary avalanche "AWA" and the secondary avalanches "NADE" and "ZIKOSURI", by the mechanism of its occurrence. The secondary avalanches were divided further into 5 sub-groups, as shown in Table 2.

When the depth Z_v of a snow cover on a slope exceeds the critical depth Z_0 for the snow deposit and the slope, as described before, namely,

$$Z_v > Z_0 = \frac{c}{d \cdot \cos^2 A(\tan A - \tan B)},$$

the overlying snow layer can be avalanched by losing the balance sustaining it on the slope.

This type of avalanche is called AWA, primary avalanche or new snow avalanche. AWA means "foam" in Japanese, and it is so called because of its avalanching style.

AWA is released especially during or right after a heavy snow fall, because the critical condition $Z_v \geqslant Z_0$ may frequently be satisfied by a heavy snow fall. A steeper inclination of a slope gives a thinner critical depth Z_0 of the snow cover, as shown in Fig. 4. This type of avalanche can be released even on a fairly gentle slope by a heavy snow fall. Once the author chanced to observe the start of an AWA. This happened early in the morning of December 30, 1930, right after a heavy snow fall which started on the previous day. Two cracks suddenly appeared across the uniform slope starting from one point and they ran in directions of about 45° to the steepest line of the slope, as the maximum shear theory shows. Generally AWA grows to a large scale avalanche with enormous energy, very high speed and a long run, and gives terrific damage to its surroundings. Numerous examples of damage by AWA, are available in which the avalanche crushed houses and destroyed villages and forests which had been standing for several hundred years. These facts prove that no large scale avalanche had occured over a very long time there, possibly because of the insufficient snow accumulation for the gentle slope which has the critical depth thicker than the steep slope. When an accidental extraordinary heavy snow fall and deep accumulation occured, an avalanche was released as a result, with an enormous mass of snow, *i.e.* energy.

2) *NADE and ZIKOSURI, secondary avalanche*

Avalanches may be released even when $Z_v<Z_0$ by other mechanisms. These are the secondary avalanches, and are classified into two general groups, NADE (superficial avalanche) and ZIKOSURI (whole layer avalanche). NADE comes from NADARE (avalanche) and also is a local name for a whole layer avalanche. In this classification NADE is used for the superficial avalanche and ZIKOSURI for the whole layer avalanche. ZI means the ground and KOSURI means scrubbing in Japanese. The secondary avalanches, NADE and ZIKOSURI, can be divided into several sub-groups respectively, as shown in Table 2.

3) *UWA-NADE, superficial mechanical avalanche*

When a new snow fall accumulates on a crusty surface of an old snow deposit, the new deposit can easily be avalanched by some little external force or shock, for example by skiing, even for $Z_v<Z_0$. The critical depth Z_0 of the new snow deposit to be sustained on a crusty surface slope is much less than that of a general case without crusted plane, due to the considerably small friction at the bottom of the new deposit.

This type of avalanche is named UWA-NADE (UWA means superficial). Although UWA-NADE cannot generally be a very large avalanche, human lives have been lost frequently or people have been injured by it.

4) *ITA-NADE, slab avalanche*

When weather conditions of high air temperature and intense solar radiation in the daytime and cold weather in the night time continue, an icy crust is formed over the snow surface. The crust increases its thickness downward from the surface of the snow deposit as long as such weather conditions continue. If the weather condition changes and the crust growth stops, the snow deposit under the crust still retains its original structure. The crusted snow is generally much more rigid than the uncrusted. Due to the difference of the mechanical and structural properties of the crusted snow and the underlying original soft snow, the latter shows more shrinkage in volume than the former in the process of settling by their own weight. As a result, the adhesive force between the crust layer and the underlying original deposit is extremely weakened, sometimes to zero due to an appearance of a cavity between them. Finally a superficial avalanche may be released by the collapsing of the bridged crust layer which lacks in the sustenance at the bottom by the underlying snow deposit. The debris of this avalanche is mainly fragments of snow slab. Therefore, this type of avalanche is called a slab avalanche, ITA-NADE (ITA means slab).

The foreseeing of an occurrence of ITA-NADE by superficial observation is difficult, due to lack of information of snow deposit structure beneath the surface. It may be possible to obtain information on the imminent occurrence of ITA-NADE through pit observations of the snow deposit by some specialists.

5) *NETU-NADE, solar radiation avalanche*

Under warm weather conditions, intense solar radiation, high air temperature, warm rains and warm winds in spring, wet-metamorphosis proceeds into the deep levels of the snow deposit and weaken its mechanical strength, *i.e.* cohesive force c of the snow deposit decreases in eq. (8). When the depth Z_v of the metamorphosed snow layer exceeds its critical depth Z_0 which is smaller than that of the powder snow deposit due to the decrease of c and the increase of d, an avalanche of the metamorphosed layer can be released.

Since such metamorphosis of the snow deposit is activated by thermal action, especially by solar radiation this type of avalanche is named solar radiation avalanche, NETU-NADE (NETU means heat or thermal).

The NETU-NADE is frequently released in spring, especially on steep slopes facing south-east on high mountains. The snow cover accumulated on such a slope, is subjected to active wet-metamorphosis through solar radiation. The snow surface is cooled by radiation from snow to the sky in the evening and night time particularly if the sky is clear, and the surface is refrozen forming a crusty surface. The following day, the snow cover is exposed to intensive solar radiation and warmed again. With the approach of spring, heat absorption of snow exceeds heat loss by radiation from the snow to the sky in the night time, and the wet metamorphosis of snow penetrates into deeper levels of the deposit. When the thickness of the wet-metamorphosed snow reaches the critical depth Z_0, NETU-NADE can be released.

NETU-NADE is generally released 1~2 hours after the sun shine on the slope and is seldom released 1~2 hours after sunset.

Therefore, it is rather easy to foresee the occurrence of NETU-NADE from the observations of the snow surface and weather. It is frequently released in the daytime in spring when the sun shines very brightly.

6) *Hoar-ZIKOSURI, whole layer avalanche caused by depth hoar*

In cold districts, a depth hoar layer grows near the bottom of the snow deposit through active sublimatic evaporation and condensation under a large temperature gradient in the deposit. As the depth hoar is a coarse hoar crystal connected to a basal snow grain with a very thin ice bond, the depth hoar layer is extremely fragile mechanically. When the load of overlaying snow layer exceeds the sustaining strength of the depth hoar layer, the overlaying snow layer begins to slide and collapses into an avalanche. This type of avalanche is named whole layer avalanche caused by depth hoar, Hoar-ZIKOSURI (ZI means ground, and KOSURI scrubbing).

Hoar-ZIKOSURI is frequently released in midwinter, but it is difficult to foresee its occurrence only by surface observation.

7) *ZIKOSURI, whole layer avalanche*

In spring, as the weather becomes warm, the ground heat absorbed by the snow deposit through its bottom can exceed the coldness of the snow penetrating through its surface, and active metamorphosis of snow takes place near the ground and proceeds upward in the snow deposit. Snow grains and ice bonds are gradually melted, coarse grains take the place of the original fine grains, and its mechanical structure is loosened and weakened. Such a change of snow structure proceeds downward from the surface and upward from the bottom of the snow deposit, in spring. As a result, the snow deposit as a whole is sustained on the slope by loosened and weakened snow at its boundary, though some central part of the deposit still retains its original strength.

Sometimes a cavity is formed between the snow bottom and the ground, due to thawing of the snow at the bottom.

The most important sustaining member of a snow deposit on a slope, in general cases, is the bottom layer of the deposit. But in this particular case, the side walls of the snow block take its place, as the bottom sustenance becomes very weak or zero. The snow block is sustained on the slope by tensile force through the upper side, by compressive force through the lower side, and by the shear force through the lateral sides of the snow block; namely, the main sustaining force $bl\tau$ becomes zero and the snow block is sustained only by $(bS_t'+2l\tau'+bS_c)Z$ in eq. (9).

As the whole deposit becomes very weak in sustaining itself on the slope, it shows a remarkable creep. Consequently horizontal cracks appear in the upper side and folded swells are seen in the lower side of the slope. The snow deposit is sustained only by the shear force through the lateral sides, somewhat like a bridge. To discuss the stability of such a type of snow deposit, the earth pressure theory cannot be applied, but the theory of bridge mechanics may be useful. The central part of this snow bridge is thinned by thawing, and finally collapses and releases a whole layer avalanche, ZIKOSURI.

The ZIKOSURI runs down consisting of huge snow blocks, and generates enormous sounds. It scrapes the ground *en route*, and only bare ground, wet mud and rocks remain behind it. No human structures can withstand the huge energy of the ZIKOSURI.

The foreseeing of the occurrence of ZIKOSURI is rather easy, because it is generally released:

i) In spring.
ii) After intensive sunshine, warm rain and wind.
iii) With the appearance of cracks and fold swells on the snow surface, beforehand.

V. Summary

All avalanches were classified into 6 groups by the mechanisms of their occurrence. This classification satisfies the following conditions.

i) The classification system is the simplest and the most convenient for use even by amateurs.
ii) The type of mechanism of the avalanche occurrence can easily be inferred from the surrounding conditions.
iii) Each type of avalanche can easily be distinguished from the others by this classification, through climatic condition and history of the snow deposit.
iv) Weather conditions may suggest the occurrence of the avalanche.

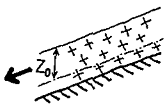
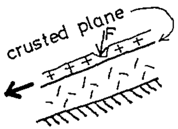
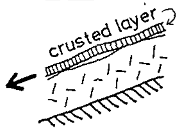
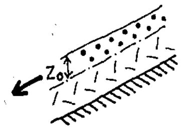
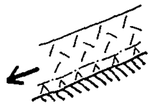
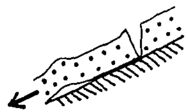
The gists of the system of our classification of avalanches are given in the Table 3.

Mechanisms and foreseeing of occurrence and some general descriptions of avalanches are given. Nomenclature and definition for indivisual avalanches are as follows:

1) *AWA, new snow avalanche*

When the depth Z_v of a new snow deposit exceeds the critical depth Z_0 which is required for stability of asnow cover by the earth pressure theory, AWA is released.

Table 3. The gists of the classification of avalanches

	Primary avalanche	Secondary avalanche				
	AWA (New snow av.)	NADE (Superficial avalanche)			ZIKOSURI (Whole layer avalanche)	
Denomination	AWA (New snow avalanche)	UWA-NADE (Mechanical avalanche)	ITA-NADE (Slab avalanche)	NETU-NADE (Solar radiation avalanche)	Hoar-ZIKOSURI (Whole layer avalanche by depth hoar)	ZIKOSURI (Whole layer avalanche)
Symbol	∴∴∴∴	//// ////	═══════	‖ ‖ ‖ ‖ ‖	//////////	/////////
Avalanche snow	Deep new snow deposit	New snow deposit on a crusted surface	Crusted superficial layer	Superficial layer loosened by solar radiation	Whole layer on a depth-hoar layer	Whole layer with loosened bottom
Main cause and sign for occurrence	Deep new accumulation more than critical depth	External force (*e.g.* by skiing)	Bridging of crusted superficial layer due to shrinkage of underlying deposit	Intense solar radiation, warm wind and rain	Growth of depth hoar layer at a deep level	Warm weather Cracks and folded swells can be seen before the start of ZIKOSURI
Mechanism of occurrence						
Avalanching and debris	Long run with high speed in foam-like style	Crushed snow blocks debris	Debris is comparatively large pieces of snow slab	Not big scale avalanche with slow speed	Large blocks debris	Slow speed avalanche and large blocks debris
Season	Early winter	Middle winter	Late winter	Early spring	Middle winter	Middle spring

Symbol of snow (by International Classification): +++ new snow, ⟋⟍ ⟋⟍ compact snow, • • • (wet) granular snow, ∧∧∧ depth hoar

During or directly after a heavy snow fall, AWA can frequently be released. It has a high speed and an enormous energy, and brings terrific damages along its path. (Nothing remains on the surface behind it.) Although AWA has no particular time to be released in a day, a number of records of AWA in midnight and dawn are found when a heavy snowfall occured.

2) *UWA-NADE, superficial avalanche*

New snow deposit on a crusted surface of old deposit can easily release UWA-NADE by the triggering action of external force or shock, for example by skiing.

When a snowfall makes a new accumulation on a sunny slope after several successive clear days, an occurrence of UWA-NADE may be expected.

3) *ITA-NADE, slab avalanche*

A cavity is sometimes formed between the crusted snow layer and the underlying original soft snow deposit as the metamorphosis of the snow proceeds, due to the difference of mechanical property and the difference in the rate of shrinkage between them. Finally the bridged crusted snow layer collapses due to lack of mechanical support at its bottom and releases an ITA-NADE. The débris shows a slab like form.

It is difficult to foresee the occurrence of ITA-NADE. And a release of this type of avalanche is a rare occurrence in the middle part of Japan.

4) *NETU-NADE, solar radiation avalanche*

When a snow cover is exposed to intensive solar radiation in spring, snow melting takes place at the surface and melt water penetrates into the deposit downward. As a result the mechanical structure of the snow deposit is loosened and weakened, while the snow density is increased, *i.e.* the ratio c/d is considerablly decreased. This makes the critical depth Z_0 of the weakened snow deposit smaller than that of the original snow deposit. And NETU-NADE is released when the depth Z_v of the weakened snow exceeds the new critical depth Z_0. NETU-NADE can be released even on a gentle slope and by a thin snow cover which is insufficient for the occurrence of AWA (new snow avalanche).

Intensive sunshine in spring, especially in high mountains, may cause the release of NETU-NADE on the south-east to south west slopes. Generally it is released from late morning to the afternoon, according to the direction of the slope.

5) *Hoar-ZIKOSURI, whole layer avalanche caused by growth of depth hoar*

When the depth hoar layer grows at the bottom of the snow deposit and the load of the overlying snow layer exceeds the sustaining strength of the depth hoar layer, the whole layer of the snow deposit is avalanched. This is named Hoar-ZIKOSURI.

It is difficult to foresee its occurrence, except by pit observation of the snow deposit from the surface down to the bottom.

6) *ZIKOSURI, whole layer avalanche*

In spring, the heat absorbed by the snow deposit through its surface and bottom can raise the snow temperature to 0°C and begins to thaw the snow structure. According to wet metamorphosis of the snow deposit the structure of the deposit is loosened and weakened. Finally ZIKOSURI is released when the snow depth Z_v exceeds the critical depth Z_0 of metamorphosed snow making avalanche debris of block type.

Indications of the occurrence of ZIKOSURI are:

i) Cracks and folded swells appear on the surface of the snow cover before hand; they are good indications for forcast of ZIKOSURI.

ii) Intense sunshine, warm rain and wind accelerate the occurrence of ZIKOSURI.