Deformation of Trees on Mt. Fuji

Shuichi OKA

INTRODUCTION

Climatological phenomena of diverse scales necessarily require different approaches of study. Despite their importance, those of smaller scales are difficult to clarify, because they are usually so small in areal extent that an ordinary network of meteorological stations cannot detect them in detail. New techniques must be devised. A direct method is to set up a special network of observation with an appropriate density for the phenomenon studied. Indirect methods may also serve the purpose. Yazawa (1952) demonstrated the usefulness of what he called "climatic landscapes". Validity of the climatic landscapes as an indicator of climate still remains a problem.

A author paid special attention to the so-called "wind-shaped" trees. It seems that not all of them can be labeled as "wind-shaped", because wind is not the only cause in the deformation of trees. It is true, as reported by many authors, that most of the deformed trees are seemingly in agreement with the charactor of winds at near-by meteorological stations. But which wind is the most effective; prevailing wind, infrequent but voilent wind or other ? In which is the process of deformation the most eminent ? Deformed trees vary in shape and in degree of deformation. What accounts for the differences ?

Once the causal relationships between the deformed trees and the deforming agents are clearly understood, then the trees may provide information of air currents as accurate as, and in more detail than meteorological instruments do.

The purpose of this paper is to determine what actually is the causative factor of deformation of trees. For this purpose, the author conducted a field survey on Mt. Fuji. The mountain was selected because of its simplicity in shape as well as in the formation of forests. Meteorological data are available at only a limited number of locations. But the conical shape was condusive in supplementing the lack of meteorological data by experimental and a theoretical approaches.

The author's efforts have been directed toward quantification and objectivity of the method.

The author arranged a part of his graduation theses (1968, 1971), composed this paper.

PREVIOUS STUDIES ON DEFORMATION OF TREES

The causes of deformation of trees have been discussed in many ecological studies, which recognize wind action to be of prime importance, both mechanically and plant-physiologically. Climatological approaches have been made to clarify the character of winds in relatively small areas by using the deformed shapes of trees as an indicator.

This has generally been done by comparing physiognomical features of deformed trees and their distribution with meteorological data. Troll (1955) accounted for the different types and directions of deformed trees (Douglas fir) in the Columbia Valley in North America by different actions of winds. Barsch (1963) and Yoshino (1964) described in detail the distribution of winds in the Rhône Valley by classifying the shapes of deformed trees into several types, which are in turn correlated with the near-by meteorological observations.

What actually is indicated by deformed trees has been discussed from diverse standpoints. But it is difficult and highly subjective to classify and to grade the shapes of trees. Therefore, the causative problem of what causes different types of deformation still remains. There is also a gap in the interpretation of the deformed trees when a correlation with meteorological data found at a single location is to be extended to apply for a wilder area. The author and his collaborator observed that the deformation of trees can be made in totally opposite directions in a small area.

Another interesting and important line of study on this problem has been presented by Furukoshi (1957), who tried to explain the causes of deformed trees by using photographic analysis.

AIR CURRENTS AROUND MT. FUJI

Mt. Fuji is Japan's highest conical volcano. It has undoubtedly various effects on air movement. But the effects of such a lofty mountain as Mt. Fuji have not been clearly understood. Air currents over the mountain is merely a guesswork from scrupulous observations of clouds and wind tunnel tests. The result is that there occurs separation on the leeside with increasing wind speed, but that the bifurcation vanishes at an excessive speed. In addition to the turbulence on the leeside, air currents going around the mountain has been understood to some extent.

On the other hand, ground level air flow is practically unknown. It is utterly difficult to draw conclusions from limited number of data at a few meteorological stations. Based on meteorological observations and experiences when climbing Mt. Fuji, Yamamoto (1968) tried to make a flow chart of wind directions. Yoshimura (1971) conducted a survey of deformed trees on Mt. Fuji simultaneously, but quite independently from the author's survey, and deduced the prevailing winds both in summer and winter. His result do not contradict those of the author's.

Thorough knowledge of the system of air flow near the ground would greatly contribute to the study of the motion of the free atmosphere.

DEFORMED TREES ON MT. FUJI

The author made investigations on the slopes and foot of Mt. Fuji during 1967 – 1971. Isolated and simple in shape as it is, extremely diverse climatic conditions are observed on this mountain. Timber line lies at the height of about 1300 – 2800 meters. Local differences in height of the tree line seems great, but this is accounted for mainly by differences in the lava ejection period. Mt. Fuji is a favorable field for the study of deformed trees, since the forests are simple in composition with larch as a single dominant species, and little is needed to take into consideration the effect on different species.

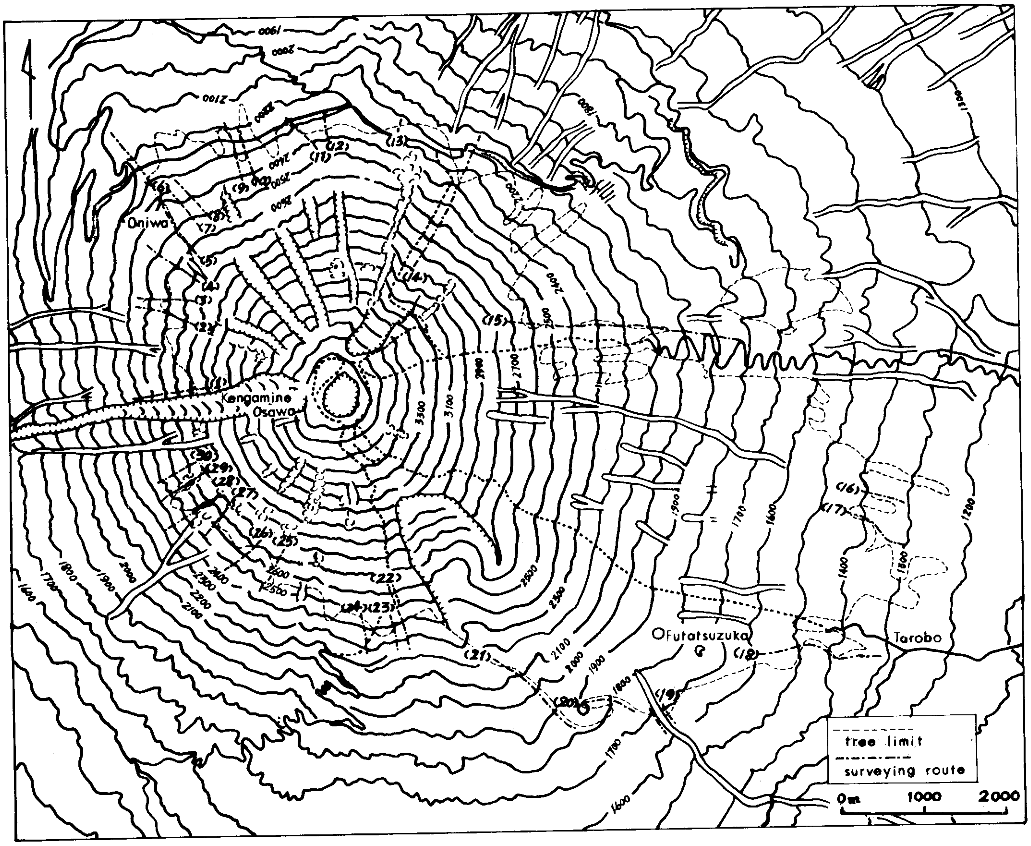


Fig. 1 Index map.

The types and the directions of deformation of larch were surveyed along some 30 routes on the mountain (Fig. 1). When the tip of the crowns of trees are inclined toward the north, or when the longest boughs are directed toward the north, the direction of deformation is decidedly to the north. A tentative survey for quantification was also made, the result of which will be published elsewhere. In addition, the author selected at random several trees near the tree line as samples of closer investigation.

Distribution of Deformed Trees

A larch (*Larix leptolepis*) is a deciduous coniferous tree with a narrow conical crown, a straight trunk and boughs which are level or slighly bent upward. The author recognized the following types of deformation of the larch (Fig. 2).

1) Cushion type (C type) This is generally low in stature and trunks seems to creep on the ground. The upper part of the crown is flat as if it were pruned. This type is found above 2000 meters.

2) Flag type (F type) This is a type of deformation which has its crown on one side only. Boughs are almost entirely lacking on the other side of the trunk.

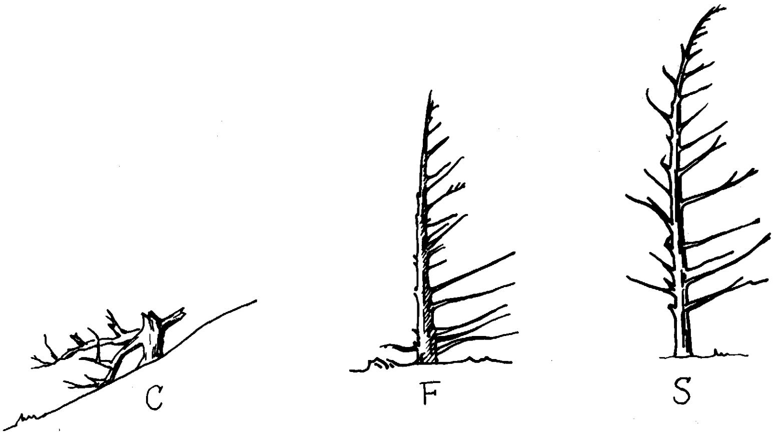


Fig. 2 Types of deformation of larches.
C-, F- and S-type

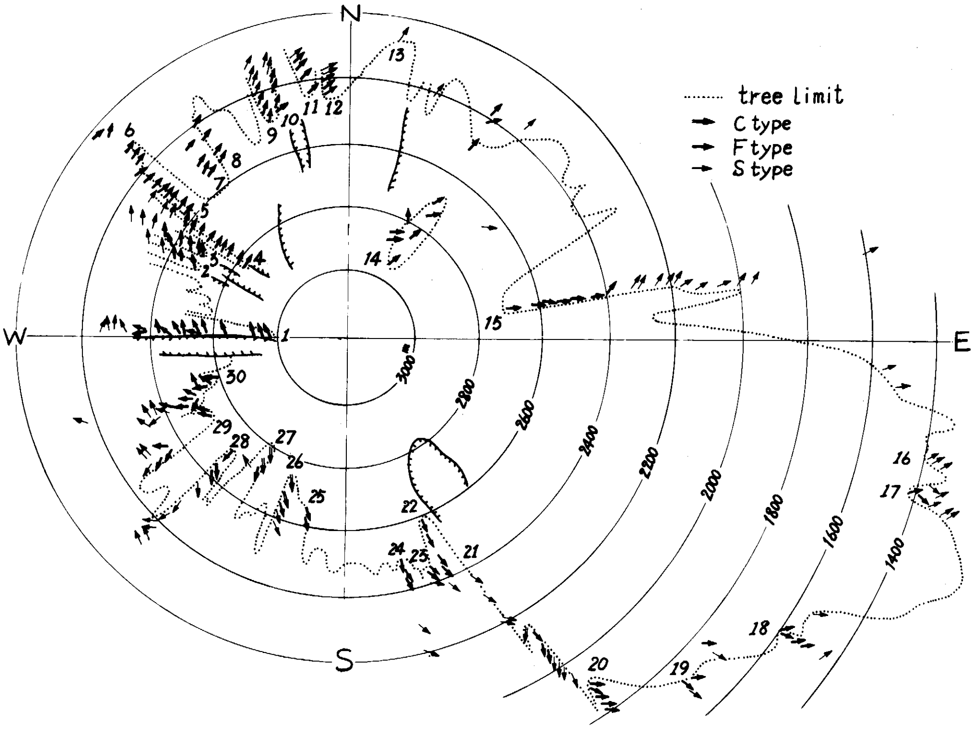


Fig. 3 Distribution of deformed larches.

3) S type This type shows only a slight degree of deformation. Asymmetry of the crown is observed. The upper part of the trunk is conspicuously deformed. This type appears in valleys and amidst dense forests.

4) N type Deformation is scarcely noticeable for this type. These trees are found in the inner part of a community and at low altitudes.

If these various types indicate different causes, as was stated by Troll (1955), they are suitable for analyzing the significance of deformed trees more concretely. The distribution of the deformed trees is shown in Fig. 3, which is presented on a circular graph as a model of Mt. Fuji. Along each route chosen for the survey, the C, F, S and N types are generally observed in this order from higher to lower altitudes. The C type appears only near the tree limit above 2000 meters, but is lacking on the eastern slope where the tree limit descends to 1400 meters. The F type appears peculiarly around the tree limit. The S type seems to be confined to dense communities. Therefore, the C and F types can be treated equally.

It is interesting to note that there is a great discrepancy in directions indicated by different types of deformation. This is especially true of the difference between the C and F types and the S type. For example, on the 15th route (Subashiri), the F type is directed toward N80°–90°E at the level of 2400–2700 meters, but below this level, the S type is directed toward N40°–60°E. On the 23rd and 24th routes (Fujinomiya), the direction shown by the C and F types at a height between the tree line and 2450 meters is about S40°E, but the S type at lower altitudes changes to S80°E–N70°E. The 25th–30th routes on the southwestern slope also indicate the same trend. These facts would suggest that different types of deformation may have been caused by different agents.

Another discrepancy of deformation is observed in valleys and at lower altitudes. This is illustrated in Fig. 4. In the Gotemba area, trees may be categorized into two types, namely the S type in the upper part of the crown and the F type in the lower part. The directions of the upper and lower parts of a tree differ by 40°–50° at a maximum. This also suggests that different agents are affecting the trees. In Fig. 3, the directions of the F type of the lower part of trees are separately shown.

On a ridge or in a col, however, this unconformity of the direction is scarcely seen. This is distinct on the 6th route (Oniwa), where both the C, F and S types show a uniform

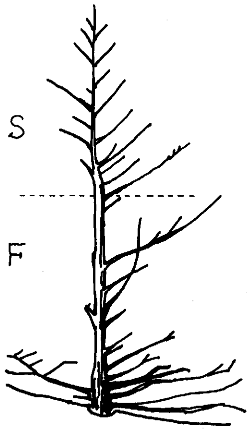


Fig. 4 A tree can be categorized into two types.

direction of deformation of N20°–30°E.

It is noted in Fig. 3 that arrows indicating the directions of deformation show a certain pattern surrounding the mountain. But the problem is whether or not this implies the same, homogeneous agent, such as a synoptic wind field, which is different only in strength.

CLIMATOLOGICAL SIGNIFICANCE OF THE DEFORMATION OF TREES

Since wind actions are considered as an important factor in producing deformed trees, the author attempted to analyze the character of winds around Mt. Fuji by conducting experiments and observations at Oniwa and Tarobo on the slopes in order to clarify the factor of deformation.

Wind

A meteorological station on the top of Mt. Fuji, provides valuable information regarding the meteorological conditions of the mountain. But in the region under study, only two records of temporarily conducted meteorological observations are available. One is the result of a special observation on the hillside during 1948–52 conducted by the Meteorological Agency, and the other from 1968 is at Kengamine-Osawa, half way up on the western side of the mountain conducted by the Ministry of Construction. On the top of the mountain, strong Westerlies and Northwesterlies prevail in winter, but winds are variable and weaker in summer (Fig. 5). The effect of the mountain on air streams at a constant wind direction on the top is shown in Fig. 6. Days with consecutively observed Northwesterly and Southwesterly winds at the top of Mt. Fuji whose velocity exceeds 5 m/s(15 m/s in winter)

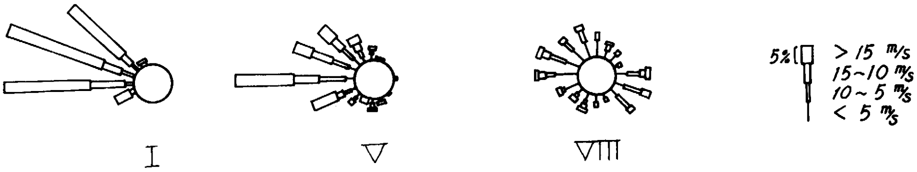


Fig. 5 Wind-roses at the top of Mt. Fuji (1937 - 1941).
January, May and August

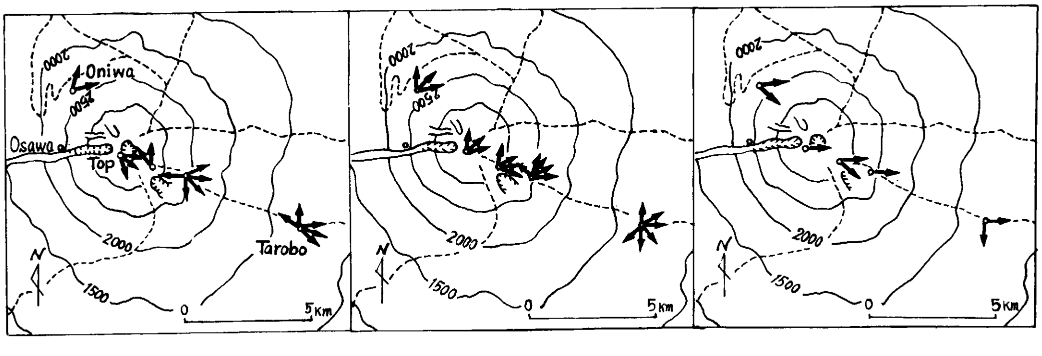


Fig. 6 Effect of the mountain on air stream at a constant wind direction at the summit.

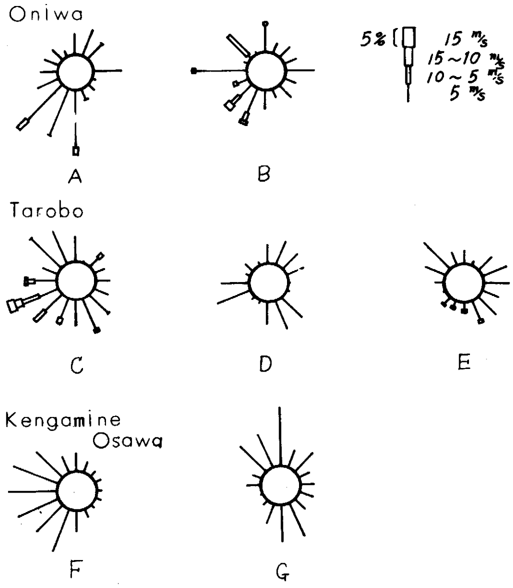


Fig. 7 Wind-roses for stations on the slopes of Mt. Fuji. Only frequency at Kengamine Osawa.
A) 17–25, July, 1951 B) 10–19, August, 1952
C) 16–31, January, 1951 D) 8–17, May, 1948
E) 10–19, August, 1952 F) 1–24, January, 1970
G) 1–31, August, 1969

were selected for each season, and the deflection of winds on the slopes was studied. The map illustrates that winds go round the slopes of the mountain except for the leeside, where an upcurrent is noted. A windrose for each station was constructed (Fig. 7), and the types of weather charts associated with strong winds were checked. The results were as follows. When Southwesterlies were dominant at each station, an eastward moving depression was present over the archipelago of Japan. On the other hand, when prevailing winds were Southwesterlies or Northwesterlies at Tarobo and Westerlies at Oniwa, weather charts depicted a typical winter pattern, with an anticyclone over the continent and a well developed cyclone over the Aleutian area. In case of a typical summer weather situation, the diurnal variation of the wind direction is conspicuous. The presence of winds flowing around the mountain has been confirmed by a wind tunnel test by Abe (1932). He pointed out that separated flow becomes conspicuous on the leeward side above a certain level of wind speed. Soma (1969) made it clear that separation vanishes at an excessive wind speed. These results are in good agreement with the observed fact that at Tarobo on the leeside the surface wind direction in winter becomes Northwest when the Northwest winter monsoon is comparatively weak, or it is very strong, but Southwesterly winds predominate when the monsoon is moderately strong.

The distribution of directions of deformed trees shown in Fig. 3 would then be related with the Southwesterly wind system, e.g. a trough or a depression crossing Japan. This is further supported by the fact that this pattern of atmospheric pressure field occurs quite frequently during the sensitive growing period except in midsummer. This dose not, however, exclude the processes affecting the shape of trees during the winter, which will be discussed in the following section.

Reddening and Polishing of Trunks

The author observed at Tarobo on March 7 and at Oniwa on May 9, 1970 that barks on one side of trunks had been polished into a fresh, reddish surface (Photo. 1). The polishing was not noticed in the warm season except on exception which will be dealt with later. At Tarobo, the reddening was characteristically observable between 1 and 2 meters above the snow surface. Here and elsewhere the polished side of a trunk corresponds almost exactly to the side on which branches and boughs are lacking. On March 7, the Northwesterly monsoon set in with renewed intensity and the snow surface was seen to have been incessantly blown off. The polished side is also coincident with the surface wind direction during the monsoon period, that is implied by the newly formed "ripple" pattern on the snow surface (Photo. 2). Therefore, it must be concluded that at least some of the deformation of trees are caused by wind action during snow covered periods.

Photo. 1 Reddened barks on one side of trunks. (May 2, 1970 at Oniwa)

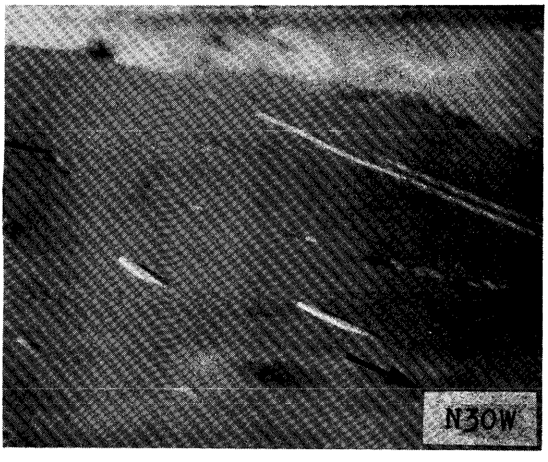


Photo. 2 A "ripple" pattern on snow surface. The pattern shows N30°W - S30°E direction. (March 7, 1970 at Tarobo)

"Paint on a Plate" Test

For the purpose of determining wind action, the author prepared some steel plates which were carefully painted with a uniform thickness with the expectation that the paint on these plates would be readily weathered after some period of exposure to wind and rain.

These plates were placed on deformed trees at the 2 meter level in the vicinity of Oniwa and Tarobo. At Oniwa, the plain plates were set so that they faced the direction of the expected deforming agents (Photo. 3). After an exposure between November 30, 1968 to July 6, 1969, about 50 per cent of the film of the paint was peeled off (Photo. 4).

This was further examined quantitatively by the following method. A one millimeter mesh was made on the exposed painted plate by scribing with a sharp-edged knife. An adhesive cellophane tape was plastered on it, and it was stripped off violently. The number of the meshes in which the paint was peeled off was counted. The result showed the same tendency as the above mentioned observations.

At Tarobo, the painted plates were rolled around trunks at the 2 meter level for the period between November 9, 1969–July 21, 1970. Here too, the greatest degree to which the paint was eroded correspondes to the direction of deformation (Photo. 5).

These results give important information about the causes of deformation of trees. Namely, it is by the wind action with snow flakes that both the film of paint and the larch are most effectively damaged on the same side.

Photo. 3 Painted plates at Oniwa.
(July 6, 1969 at Oniwa)

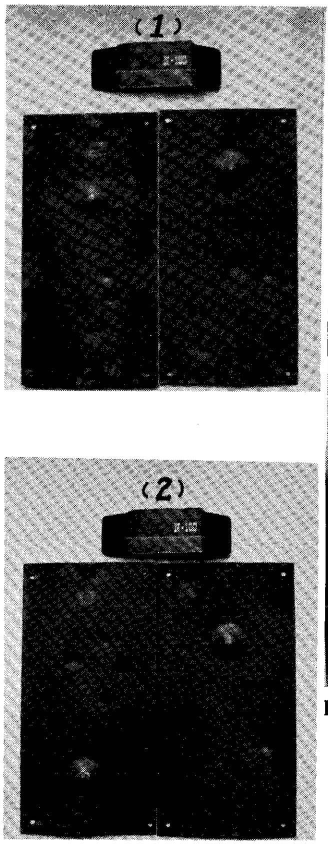


Photo. 4 Comparison of plates
after an exposure.
(1) left: S30°W right: N60°W
(2) left: S60°E right: N30°E

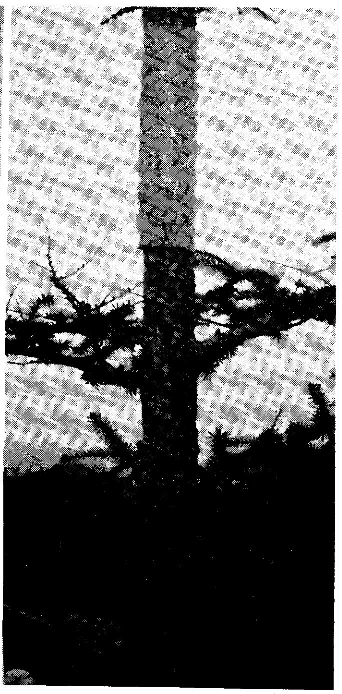


Photo. 5 A painted tin plate rolled
around a trunk at Tarobo.
(July 21, 1970 at Tarobo)

Snow

Snow seems to play an important roll in producing deformed trees.

Measuring temperature and wind velocity at the time when ground snow drift set in, Oura (1968) reported that at Asahikawa, Hokkaido, the critical values were −7°C and 3 m/sec respectively. Greater wind velocities seemed to be required at higher temperatures.

As for snow on Mt. Fuji, Ota (1940) described that snow did not increase in depth during the period December–March, but that the onset of the Northwesterly winter monsoon gave rise to a remarkable abrasion of even crusted snow surface.

According to these results, it can be stated that comparatively weak Northwesterlies at Tarobo in January would sufficient to cause deformation of trees. On the other hand, the length of the snow covered period is also a cause of deformation.

Sekiya (1958) noticed a marked contrast in the snow covered period between the higher and the lower slopes of Mt. Fuji. The discontinuity is at about the 2200–2600 meter level. In fact, the snow cover lasts for some 250 days at 3000 meters, but it dose not exceed 100 days at 1500 meters. This difference would do some harm to normal growth of larch, and result in some type of deformation.

Local Discrepancies in the Directions of Deformation

As stated previously, a conspicuous difference in the direction of deformation of trees among different types was noted. This is particularly worth nothing in the valleys at higher altitudes, such as at Namesawa (Loc. 2 and 3) and Onagashi (Loc. 9 and 10), and in parts of lower altitudes.

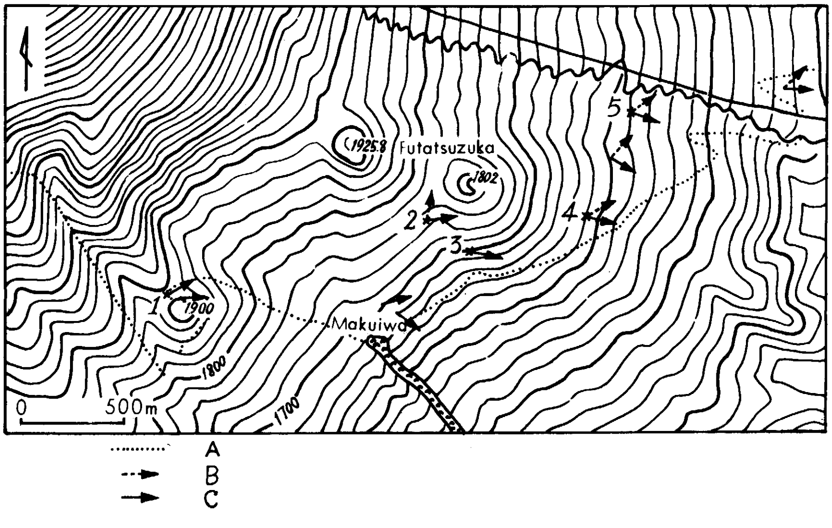


Fig. 8 Local discrepancies in the direction of deformation at Tarobo.

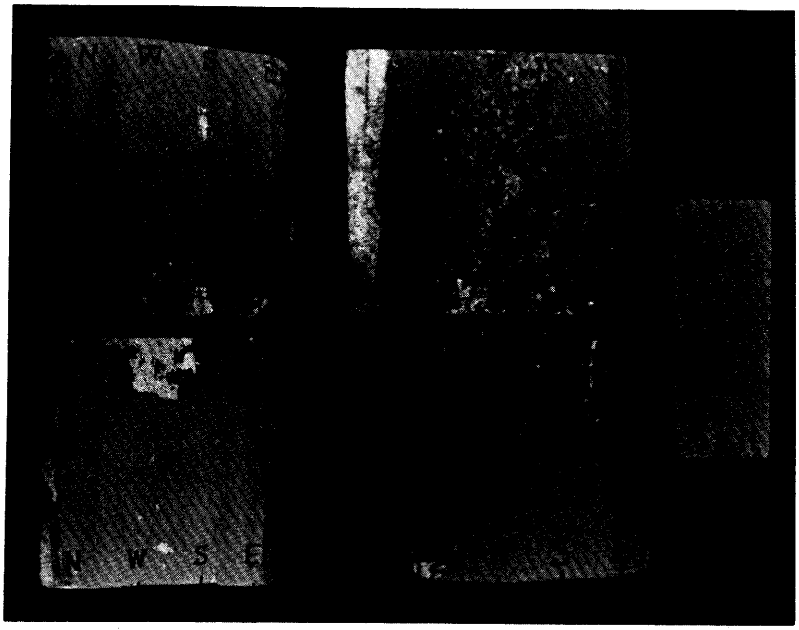
A) Tree limit

B) Direction of deformation of the upper part of the crown.

C) Direction of deformation of the lower part of the crown.

Locations 1 - 5 are the places where painted tin plates were set.

Location 1 Location 2



Location 3 Location 4 Location 5

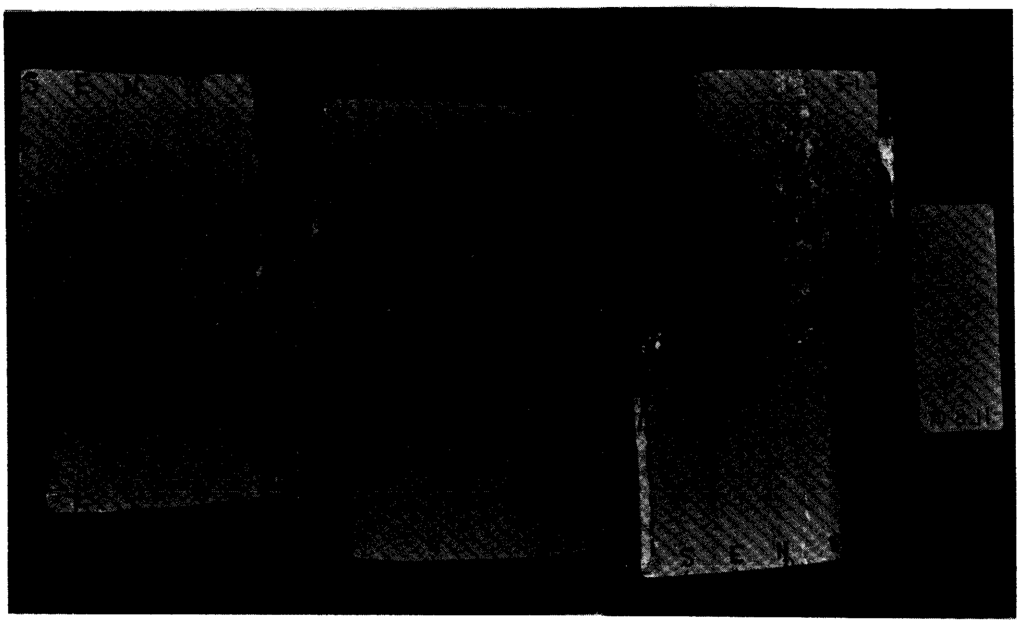


Photo. 6 Painted tin plates after an exposure. The upper ones were exposed in winter, the lower in summer. At locations 1, 2 and 5, the "plucking off" of paint is apparent.

Special attention will be placed in this paper in the case of Tarobo. The discrepancy in the direction such as shown in Fig. 4 illustrates local variation (Fig. 8).

The upper and lower parts of the crown have frequently been deformed to face different directions, the maximum departure being 50 degrees. There are places such as at a col below Hoei, a parasitic crator, where there is no discrepancy at all. The lower part of a crown lying between 1 and 2 meters above ground almost always indicates the same direction as the polishing and reddening of barks.

Therefore, at least this part of the deformation can be attributed to wind action during the period of snow cover. The upper part must, however, be explained in a different way. As mentioned previously, the paint - on - a - plate test gave favorable results in this regard. But, there was an exception to this rule. At Location 1, and nowhere else, the "plucking off" of the paint occured not only in winter but also in summer (Photo. 6).

In order to ascertain this exceptional case, the author conducted meteorological observations on August 3, 4 and 5, 1970. On August 3, when there was a stationary front along the Pacific coast of Honshu, Southwesterly winds with a velocity of about 5 m/sec were observed at Location 1, whereas winds were rather weak elsewhere. This implies that under such a topographical condition as the Hoei Col, winds from a constant direction prevail regardless of season. Generally, however, the deforming agent acting on the upper part of a crown can not have such a destructive force as to cause a stripping - off effect of the film of the paint. Consequently, it is considered that the deformation of the upper part is related to the prevailing southwesterly winds when cyclones pass.

CONCLUSION

The author made every possible effort to determine what actually produces deformation of trees. A conclusion has been reached that the F type of deformation is made by the same cause which brings about the reddening and polishing of trunks, but that the causes of the S type are different from those of the F type. The S type is supposedly formed by winds with snowflakes during the period of snow cover, especially, at the onset of the Northwest monsoon, whereas the F type is related to strong Southwesterly winds which are brought by a passing depression.

Can these explanations obtained from the observations at Oniwa and Tarobo be extended to apply for wider areas? From timber line downward, the C, F and S(or N) types are successively found in this order. The C and F types appear characteristically near the tree line, while the S and N types are dominant in a dense community. It is worth nothing that the directions of deformation also vary in accordance with the change of the types with altitude along the Subashiri, Fujinomiya, and the Southwestern slopes. In addition, larch of the S type are directed northward around Kagosaka Pass and Lake Yamanaka at 1000 meters asl.

Considering the above mentioned points, it can be stated that both the physiognomical features and directions of deformation are unique at the tree line. The explanations for Oniwa and Tarobo can fundamentally be applied for other areas.

The extent to which the deforming effect during the snow covered period is at work is controlled by the height and density of a community, snow depth or the length of the snow covered period. A certain wind speed is required, but wind speed above this critical speed is of no importance. The effect seems to be confined to the lowest layer of at most 2 meters above the snow surface. Thus, the effect is regarded as a phenomenon reflected by small scale land forms.

The C type seems to lie under the snow in winter. Therefore, this type may be an indicator of prevailing winds not in winter but in summer. Onodera (1963) gave a similar suggestion as for creeping pines. The author, however, is of the opinion that snow functions as a "polishing powder", because the top of the crown of this type appears as if it were pruned and polished. The direction of deformation is difficult to determine for this type. In this paper, only those that were clearly determined were investigated for the winter season.

From the above mentioned viewpoint, the author selected as an indicator of winds in winter the polished and reddened barks, which are undoubtedly related to wind driven snow, and the S type, which is in good agreement with the Southwesterlies. The distributions are shown in Fig. 9.

A circuit graph was constructed, assuming a model of Mt. Fuji. Emphasizing the wind-shaped trees only on the ridges, the author drew streamlines along the slopes of Mt. Fuji. The figures clearly show the existance of an up-current in summer and down-current in winter (Fig. 10).

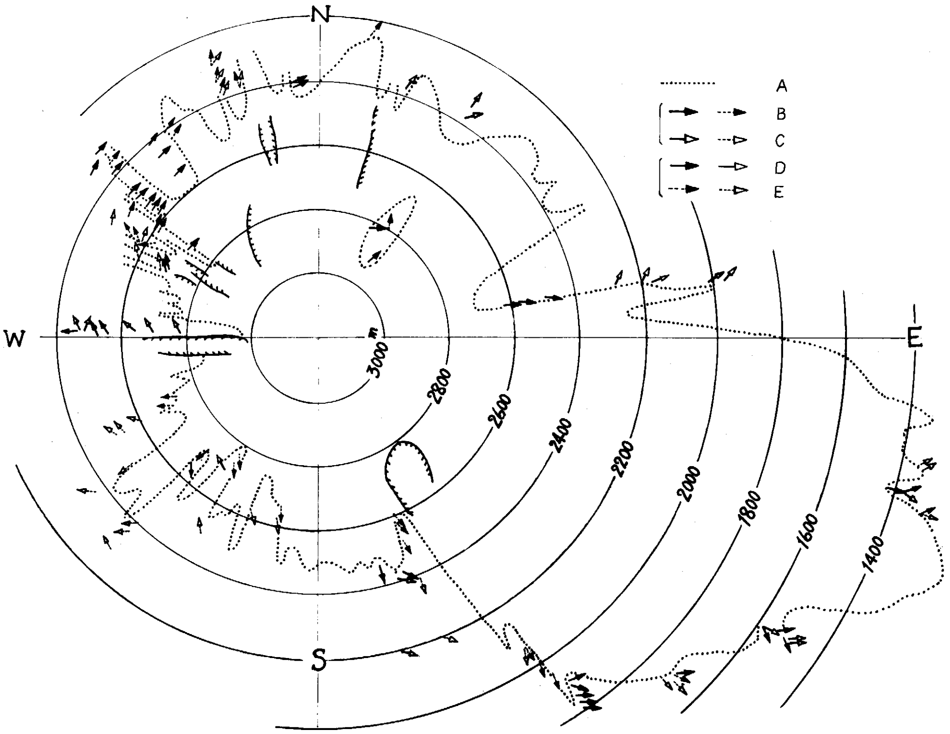


Fig. 9 Distribution of direction of deformation by the agents.

A) Tree limit

B) Direction of deformation. Attention is directed to the fresh, reddish surface of trunks.

C) Direction of S type deformation.

D) Direction of deformation in valleys.

E) Direction of deformation on ridges.

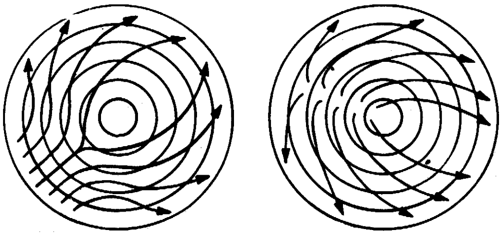


Fig. 10 Assumed air stream around the mountain according to the direction of deformation and the contour lines. (indicated by concentric circles)
left: Southwesterly in summer right: Northwesterly in winter

There still remains some difficult problems. How to distinguish the physiognomical features of deformed trees is one. In this paper, four types are tentatively classified and measurements of the directions of deformation have been conducted. But the classification of types can by no means exclude subjectivity, and each dose by no means correspond to different causes. Errors are inevitable in the measurement of the direction of deformation, but the magnitude of the errors cannot be determined.

An objective and quantitative method of distinguishing the shapes and the direction of deformation must be devised for further studies of deformed trees. For this purpose of generalization, inspection of deformed trees other than larch or of areas other than Mt. Fuji is also necessary. Above all, despite its importance, an observation at the time of snow accumulation and of snow melting has not been done with satisfaction. Factors such as topography, soils etc. must also be evaluated objectively and quantitatively, because the phenomena of different levels or orders are related to these factors as well.

Another complexity of the phenomenon was noted on the windward side of Mt. Fuji, where the directions of deformation show as complex a pattern as on the leeward side. A detailed investigation of winds on this side, and a wind tunnel test would give fruitful answers to this problem.

ACKNOWLEDGEMENT

The author is indebted to Prof. Dr. T. Yazawa, Dr. I. Maejima and Dr. K. Nakamura of the Department of Geography, Tokyo Metropolitan University, for their continuous advice and encouragement. He is also indebted to late Mr. S. Yamamoto of the Kawaguchi-ko Meteorological Station, for the unforgettable discussions. He also wishes to express appreciation to many of his colleagues who helped carry out the field survey under a scorching sun in summer and freezing snowfall in winter.

References Cited

Abe, M., 1936: The Formation of Clouds on Mt. Fuji. *Jour. of the Meteor. Soc. of Japan,* vol. 14, p. 74 - 81. (in Japanese)

Barsch, D., 1963: Wind, Baumform und Landschaft. *Freiburger Geographische Hefte,* Heft. 1, s. 22 - 130.

Furukoshi, T., 1957: On the Lifeform of Larches around the Timber Line of Mt. Fuji. *Collected Lectures of the 67th Meeting of the Japanese Forestry Society,* p. 202 - 206. (in Japanese)

Oka, S., 1968: *Deformation of Larch on Mt. Fuji.* (unpublished) (in Japanese)

1971: *Study on Deformation of Trees as "Kiko Keikan" (Climatic Landscapes).* (unpublished) (in Japanese)

Ota, H., 1940: Accumulated Snow on the Summit of Mt. Fuji. *Collected Papers of Japanese Society of Snow and Ice,* Vol. 1, p. 17 - 20. (in Japanese)

Oura, H., 1968: Study on the Occurrence of Blowing Snow. *Jour. of the Japanese Soc. of Snow and Ice,* vol. 30, no. 6, p. 1 - 7. (in Japanese)

Sekiya, H., 1958: On the Timber Line in Mt. Fuji. *Memoirs of Indust. Meteor.,* vol. 22, no. 1, p. 23 - 29. (in Japanese)

Soma, S., 1969: Functions of Turbulent Separation on the Problem of Topography and Airflow. *Meteor. Inst.* (in Japanese)

Troll, C., 1955: Der Mount Rainier und das Mittere Cascaden Gebirge. *Erdkunde,* Bd. 9, s. 264 - 274.

Yamamoto, S., 1968: Air Stream on the Slopes of Mt. Fuji and Climbing Routes. *Geophysical Notes of the Tokyo District Meteorological Observatory,* no. 1, p. 46. (in Japanese)

Yazawa, T., 1952: *Kiko Keikan* (Climatic Landscapes) (in Japanese)

Yoshimura, M., 1971: Windverbreitung in Gebiet des Mt. Fuji. *Erdkunde,* Bd. 25, s. 195 - 198.

Yoshino, M. M., 1964: Some Local Characteristics of the Winds as Revelaed by Wind-shaped Tree in the Rhône Valley in Switzerland. *Erdkunde,* Bd. 18, s. 28 - 39.