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The altitudinal distribution of glaciers on volcanic cones in the Cascade Range, North America America

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Abstract

For an inquiry into the characteristics of the altitudinal distribution of alpine glaciers, the ratio of glacierized area to inter-contour area (**GAR**) was derived using topographic maps of volcanic cones in the Cascade Range, North America. The relationship between the **GAR** and altitude indicated was approximated by a cumulative curve of normal distribution except on the higher part of the volcanic cone, and the author suggests that the altitude of 50 percent **GAR** and the negative (downward) standard deviation on the regression curve might be applicable to specify the characteristics of the altitudinal distribution on an individual mountain or massif.

1. Introduction

Many discussions on the altitudinal distributions both of present and past (especially, late Pleistocene) alpine glaciers have been done by on various alpine regions throughout the world. In these discussions, the altitude of "snowline", "glaciation limit", or "glaciation threshold" have often run into problems (e.g. Andrews and MIller, 1972 ; Kobayashi and Hoshiai, 1955 ; Østrem, 1966 ; Porter, 1977). However, it seems that little basic knowledge has been compiled concerning how the altitudinal distribution of glaciers is related to the "snowline", "glaciation limit" etc. The author designed a project to determin the characteristics of the altitudinal distribution of glaciers in a relatively small area such as an individual mountain or a massif or a small river basin.

The distribution of glaciers in any specified alpine region is so complicated that "the actual snowline" (Nogami, 1970) appears uneven and rugged. This is caused by local variation of snowfall and its ablation due to topographic influence within the alpine zone. Therfore, it is thought that the above mentioned research of small-sized areas would be meaningful to discuss what manner the "snowline" is related with the altitudinal distribution of alpine glaciers.

From this point of view, the present paper aims, as a preliminary research project, at showing the characteristics of altitudinal distribution of glaciers on some large strato-volcanic cones with simple topographic features.

2. Data sources and methods

Nine glacierized strato-volcanic cones of the Cascade Range, North America, were chosen for the research (Fig. 1). They rise singularly above the surrounding mountains and the distribution of glaciers are little influenced by complicated topographies. Topographic maps by U.S. Geological Survey on the scale of 1 to 24,000 or 1 to 62,500 were used to obtain data on altitudinal distribution of glaciers on these volcanic cones ; the area of glaciers (including perennial snow patches) shown on the map (or maps) was mesured using an inter-contour area of 200 feet (on a 1 : 24,000 map), 400 feet or 500 feet (on a 1 : 62,500 map) for every volcanic cone. For Mt. St. Helens, the 1 : 62,500 map compiled before the eruption in 1980 was used. Fig. 2 shows the distribution of glaciers on Mt. St. Helens for every 400 feet of contour. Through the measurement of these areas the relationship between glacierized area and altitude, and further, general tendencies of altitudinal distribution of alpine glaciers were studied.

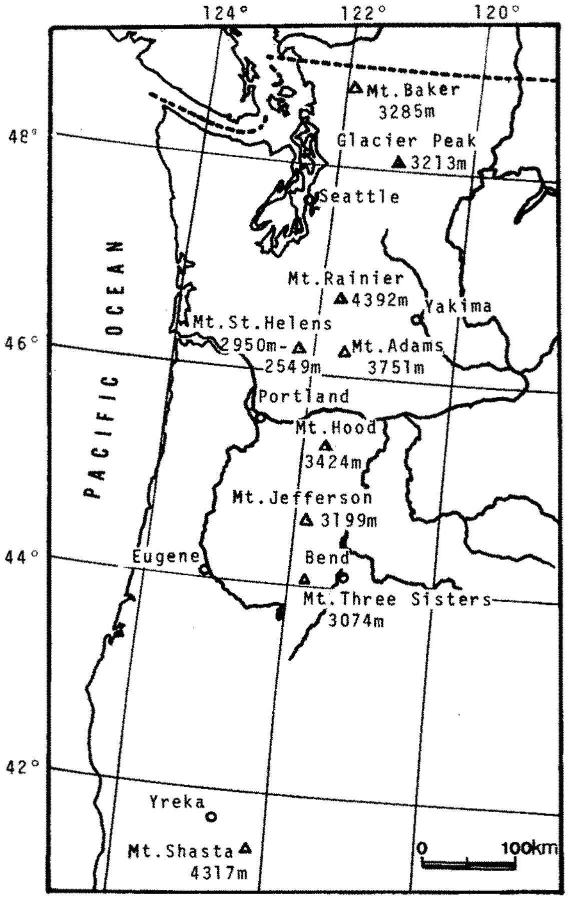

Fig. 1. Location map of investigated volcanic cones.

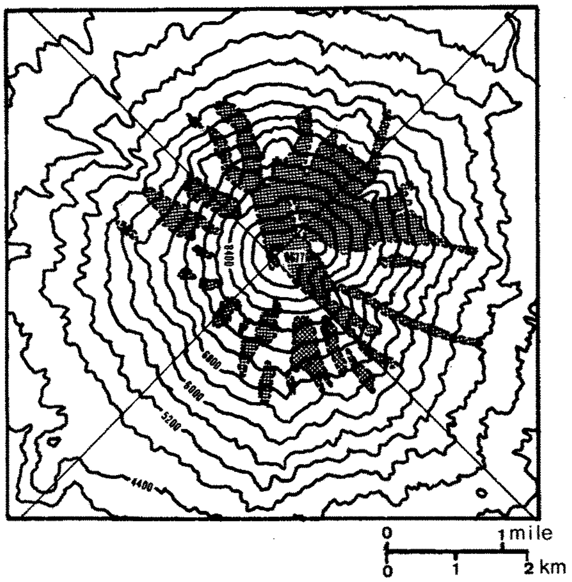

Fig. 2. Distribution of glaciers (inside of bloken line) on Mt. St. Helens before the 1980 eruption (elevation in feet).

3. Results and discussions

As for the relationship between altitude and glacierized area, the higher the former is, the larger the latter is in the lower part of any specific volcano. But, the glacierized area decreases in the higher part of every volcanic cone. Let us refer to Mt. St. Helens, whose map is shown in Fig. 2. The relationship is shown in Fig. 3. The decrease of glacierized area in higher part is easily explained by the decrease of inter-contour area on the volcanic cone. Therefore, inter-contour area controls glacierized area.

In order to eliminate the effect of the inter-contour area, we employ the ratio (expressed as a percentage) of glaciarized area to inter-contour area (referred to hereafter as **GAR**). As shown in Fig. 4, the **GAR** increases with altitude, making a fairly neat rising curve within the lower part of every volcanic cone.

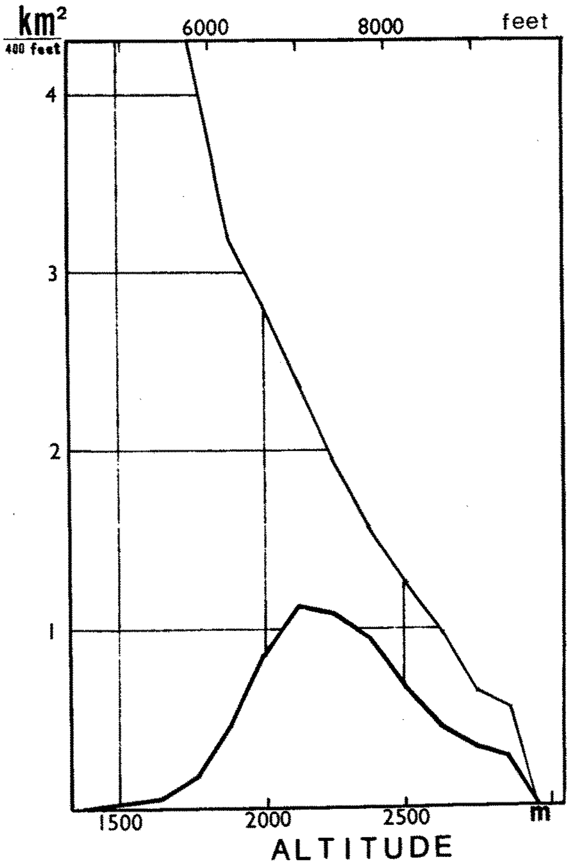

Fig. 3. Altitudinal variations of inter-contour area (thin line) and glacierized area (thick line) on Mt. St. Helens before the 1980 eruption.

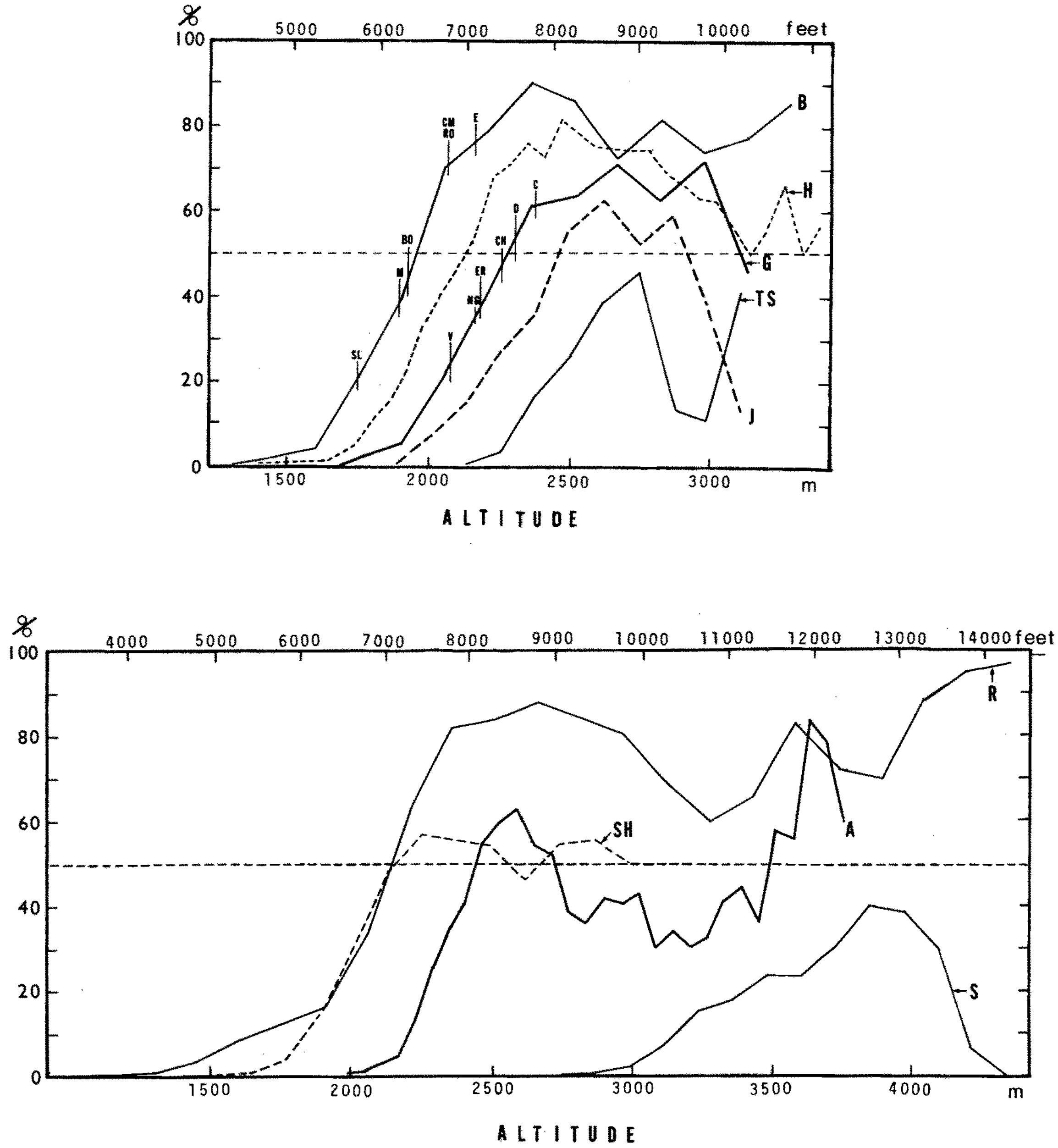

Fig. 4. Altitudinal variations of glacierized/inter-contour area ratio (**GAR**). **A** : Mt. Adams, **B** : Mt. Baker, **G** : Glacier Peak, **H** : Mt. Hood, **J** : Mt. Jefferson, **R** : Mt. Rainier, **S** : Mt. Shasta, **SH** : Mt. St. Helens and **TS** : Mt. Three Sisters. The vertical lines crossing over the curve of Mt. Baker and Glacier Peak represent the firn line altitudes of glaciers on Mt. Baker and Glacier Peak (Post *et al.*, 1971). BO : Boulder Glacier, C : Cool Glacier, CH : Chocolate Glacier, CM : Coleman Glacier, D : Dusty Glacier, E : Easton Glacier, ER : Ermin Glacier, M : Mazama Glacier, NG : North Guardian Glacier, RO : Roosevelt Glacier, SL : "Sholes" Glacier and V : Vista Glacier.

If we assume that the climatic conditions for accumulation and ablation of ice and snow is a function of altitude alone, the depth of ice and snow would also be a function of the altitude alone. Consequently, the **GAR** would change from 0% to 100% at a certain altitude on every volcanic cone.

In reality, the lower limit of glaciers are dispersed higher and lower, centering around a certain altitude. The firn line altitudes shown in the figure are dispersed, too. This shows that a local variety of mass budget of ice and snow, depending on local climatic conditions, would result in deviations of the altitudinal distribution of glaciers even on such a simple topography as a volcanic cone.

The altitude of 50% **GAR** is the altitude on which mass budget of ice and snow balances from spacial point view. Under favorable conditions, glaciers may extend below this altitude. The tendency is that the lower the altitude, the less the **GAR**. This is considered to show a prevailing pattern of spacial diffusion or the decrease of probability.

However, the **GAR**-altitude relationship in a higher part is quite defferent from those in mid-level and lower level parts. The cases of Mt. Jefferson and Mt. Shasta show extreme examples. In their highest parts, the area without glaciers surpasses that covered by glaciers. Then, the **GAR**s of Mt. St. Helens, dividing the volcanic cone into 4 parts, eastern, northern, western and southern sectors were measured (see Fig. 2). The result is shown in Fig. 5. Here, the arrangement of the **GAR**-altitude curves are remarkably disturbed especially in higher parts of the western and southern sectors. And, the differences of the **GAR** between northern/eastern sectors and southern/western sectors are great. The difference between the northern sector and the southern sector in lower parts resuls mainly from the difference of ablation, but the disturbed distribution of glaciers in higher parts must be caused by some other factors. We, here, only would like to point out that wind-blown snow around the summit may be its major cause.

Now again, note the rising curve within the lower part of every volcanic cone. The **GAR**-altitude curve seems to amount to the shape of a cumulative curve. So, we fit a cumulative curve of normal distribution with mean μ and standard deviation σ. Fig. 6 shows plots of all the **GAR** data on normal probability graph paper, taking each volcanic cone as a regional unit. This indicates that the **GAR**-altitude relationship can be approximated by a cumulative curve (a line in Fig. 6) of normal distribution except the higher part of a volcanic cone. For Mt. Rainier, however, the plots seems to be divided into two groups as if the plots of the higher parts above 1800m were adjusted to the curve for Mt. St. Helens. It is thought that the influence of the topography aside from the volcanic cone appears because Mt. Rainier is adjacent to non-volcanic mountains in the lower region below about 1700m. The scattering of plots in the higher part is noticeable on every volcanic cone.

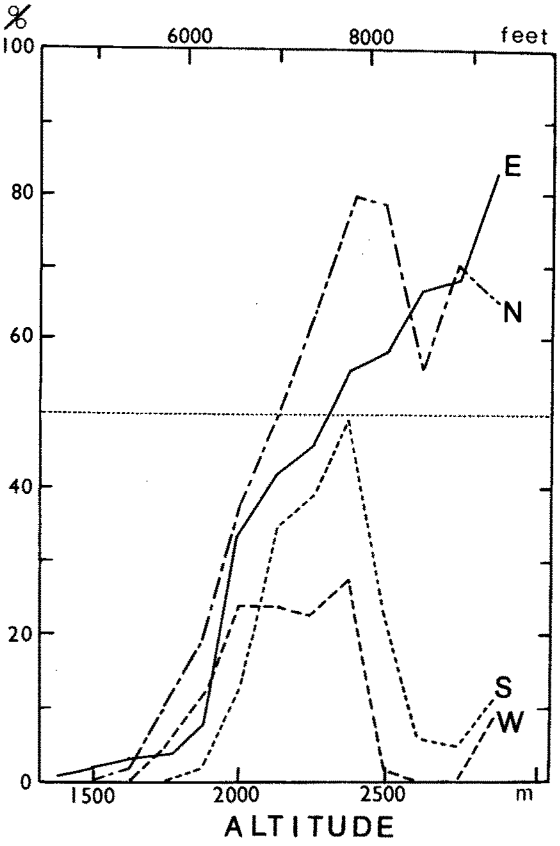

Fig. 5. Altitudinal variations of **GAR**, dividing Mt. St. Helens before the 1980 eruption into 4 direction sectors.

When we fit a cumulative curve of normal distribution to a **GAR**-altitude relationship, the estimated altitude of 50% **GAR** (μ) and negative standard deviation, $-\sigma$, might be applicable to specify the characteristics of the altitudinal distribution of glaciers on a given individual mountain or massif. The former means the mean altitude of lower limits of glaciers and the latter shows a parameter of downward deviations of the distribution of glaciers from the former. These values for each volcanic cone are shown in

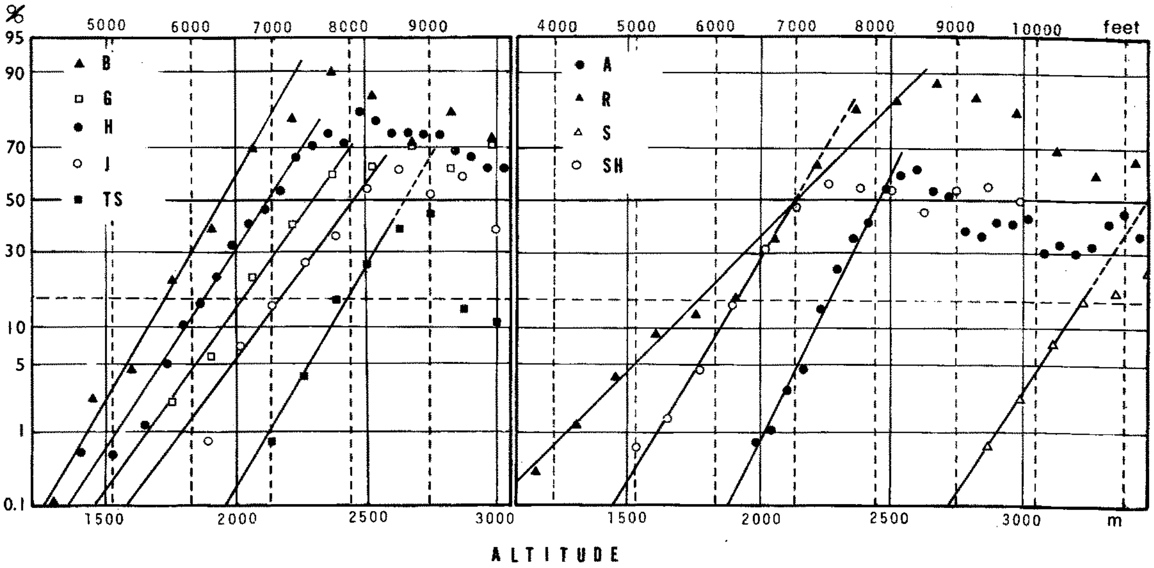

Fig. 6. Plots of **GAR**s and calibration curve for each volcanic cone on normal probability graph paper. **A** : Mt. Adams, **B** : Mt. Baker, **G** : Glacier Peak, **H** : Mt. Hood, **J** : Mt. Jefferson, **R** : Mt. Rainier, **S** : Mt. Shasta, **SH** : Mt. St. Helens and **TS** : Mt. Three Sisters.

Table 1. Let us compare $-\sigma$ for Mt. Rainier with that of Mt. Adams. The absolute value of $-\sigma$ for Mt. Rainier is clearly larger than that for Mt. Adams. This means that the downward dispersion of glaciers on Mt. Rainier is much larger than that on Mt. Adams. In this connection, the vertical distance from the estimated altitude of 50% **GAR** to the lowest limit of glaciers (shown as downward range in Table 1) on Mt. Rainier is much larger than that on Mt. Adams, too. Such differences among mountains are considered to be the result of climatic conditions such as wind and solar radiation, and topographic conditions such as the slope-gradient and degree of roughness. Furthur investigations into this matter are the subject for future studies.

Table 1. Characteristics of the invertigated volcanic cones and altitudinal distribution of glaciers present.

Name of Volcano	Latitude	Altitude of the summit (m)	Distributions of Glaciers			
			Estimated altitude of 50% GAR μ (m)	Altitude of the lowest limt (m)	Downward range (m)	Downward standard deviation $-\sigma$ (m)
Mt. Baker	48°46′N	3285	1940	1340	600	−200
Glacier Peak	48°07′N	3213	2300	1680	620	−270
Mt. Rainier	46°51′N	4392	2140	1020	1120	−370
Mt. St. Helens	46°12′N	2950	2130	1440	690	−230
Mt. Adams	46°12′N	3751	2450	1970	480	−190
Mt. Hood	45°22′N	3424	2120	1340	780	−240
Mt. Jefferson	44°20′N	3199	2450	1870	580	−280
Mt. Three Sisters	44°06′N	3074	2650	2250	400	−220
Mt. Shasta	41°25′N	4317	3480	2780	700	−250

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