THE CLASSIFICATION OF GLACIERS

Holding the view that recent glacier research had shown complexities and diversities in glacier structure not covered by the Lagally-Ahlmann classification, Dr. Arnold Court of the California Forest and Range Experiment Station, Berkeley, circulated a letter to a score of glaciologists putting forward his proposals for a new classification based on the thermal properties of glaciers.

Dr. Court sent a copy of the letter to this Journal in the hope that it would lead to a symposium of opinions out of which would emerge an agreed new classification.

Dr. Court's letter is printed below and is followed by extracts from a number of letters written in reply to it.

Glacier Thermal Classification

Glaciers have been described by a "geophysical classification", which properly applies to the summer time vertical temperature distribution in a single column, rather than to an entire glacier. This classification has found increasing usage since its proposal by Lagally in 1932 [1] and independently by Ahlmann in 1933 [2]. However, no general agreement has been reached on which set of terms should be used, nor on their exact definitions.

Belated acceptance seems desirable of Ahlmann's invitation, made in 1935, that "The suitability of terms . . . can be decided by international discussion" [3]. Initiation of such discussion is the purpose of this note. It arose from an attempt to define for a meteorological glossary the terms of the "geophysical classification".

The Lagally-Ahlmann classification applies only to the main portion of a glacier, below the layer of seasonal temperature change. The thickness of this layer varies with latitude, altitude, aspect and other factors, but is at most 15 m. or 50 ft. Consequently, the classification is not applicable to ice masses of less than this thickness. Such thin masses should not be called glaciers. Perhaps *glacieret*, a term which is used occasionally without specific definition, should be reserved for ice masses thin enough to have seasonal temperature changes (of at least 0·1° C.) at all depths.

Basically, the Lagally-Ahlmann classification distinguishes whether the body of a glacier is at the pressure-melting point throughout, only in its upper portion, or not at all. The terms proposed by Lagally in 1932, by Ahlmann in 1933 and 1935, and the alternatives suggested here, are:

	Lagally	*Ahlmann* 1933	*Ahlmann* 1935	*Proposed*
Pressure-melt throughout	warm	temperate	temperate	permelting
Pressure-melt upper part	transitional	sub-arctic	sub-polar	refreezing
Pressure-melt nowhere	cold	high-arctic	high-polar	nonmelting

While Lagally proposed three separate types, Ahlmann formally offered only two, temperate and arctic or polar. He subdivided the second according to whether any surface melting occurs, rather than on whether only part of the glacier body was colder than the pressure-melting point. In recognizing Lagally's one-year priority, Ahlmann declared in 1935, "The principles of Lagally's classification fully agree with mine" [3]. In 1948 he reiterated that Lagally's "three glacier types: the cold, the warm, and the transitional . . . completely agree with my high-polar, temperate, and sub-polar types" [4].

Logically, any classification should be based on a single attribute, if possible. Lagally's straightforward three-fold division on the basis of temperature alone is preferable, in this respect, to Ahlmann's use of two criteria, temperature profile and surface melting.

Neither Lagally's nor Ahlmann's terms seem suitable for glacier description. "Warm" is hardly applicable to any glacier, even at the pressure-melting point, and "Übergangstyp" (transition type) is not sufficiently descriptive to be used alone. On the other hand, a glacier in the Himalayas, Alps, or Andes can have a "high-polar" portion, although Ahlmann indicated that all Alpine glaciers are "temperate". A classification of thermal structure should describe that structure, rather than refer to latitude or other extraneous factors.

The terms suggested in the last column of the table above are intended to imply thermal characteristics; perhaps better terms will result from general discussion. The *permelting* portion of a glacier is permeated by melt water throughout its thickness, at least in summer. The *refreezing* portion has

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a layer in which there is refreezing of melt water which, by inference, permeates some upper layer. The *nonmelting* portion has no surface melting and hence no percolating melt water; it must therefore be colder than the pressure-melting point at all depths below the surface layer.

These terms need not apply to an entire glacier but, as indicated, to portions. Some glaciers, of course, may be entirely permelting, others may be nonmelting from accumulation area to terminus.

A three-fold classification, with terms such as those proposed here, can be subdivided further quite readily. The "Baffin type" glaciers, firnless yet well below freezing for the most part, studied by Baird[5], and also found in Argentina, as noted by Heinsheimer[6], are *firnless nonmelting*.

Examples of the current lack of uniformity of usage of the "geophysical classification" can be found in any issue of the *Journal of Glaciology*. Fisher discussed "a truly cold Arctic-type glacier"[7] which later[8] he called merely "cold" in contrast to "temperate", thus mixing Lagally's terms with Ahlmann's. Haefeli and Brentani studied "a cold ice cap"[9], while Röthlisberger referred to "polar ice caps"[10].

Ahlmann considered the depth of winter freezing in a "temperate" (or *permelting*) glacier as "not more than a couple of metres"[2,4]. Butkovich discussed "a temperate glacier (*i.e.* the temperature of the ice at a depth of more than approximately 40 ft. is always the melting point at the corresponding pressure)"[11].

To eliminate these contradictions, international discussion and eventual adoption of suitable definitions and terms are desirable. The terms suggested here may be undesirable to others. To Professor John Leighly of the University of California, the mixing of Latin prefixes and English participles is grating. Whatever terms are adopted, agreement upon them and their definitions will promote international research and understanding of the thermal characteristics of glaciers.

REFERENCES

1. Lagally, M. Zur Thermodynamik der Gletscher. *Zeitschrift für Gletscherkunde*, Bd. 20, 1932, p. 199–214.
2. Ahlmann, H. W:son. Scientific results of the Swedish-Norwegian Arctic Expedition in the summer of 1931, Part VIII. *Geografiska Annaler*, Årg. 15, 1933, p. 161–216, 261–95 (esp. p. 213 ff.).
3. —— Contribution to the physics of glaciers. *Geographical Journal*, Vol. 86, No. 2, 1935, p. 97–113.
4. —— *Glaciological research on the North Atlantic coasts*. London, Royal Geographical Society, 1948. (R. G. S. Research Series, No. 1.)
5. Baird, P. D. Method of nourishment of the Barnes Ice Cap. *Journal of Glaciology*, Vol. 2, No. 11, 1952, p. 2–9.
6. Heinsheimer, George J. Glaciers of the Baffin type. *Journal of Glaciology*, Vol. 2, No. 15, 1954, p. 368. [Letter.]
7. Fisher, Joel E. The cold ice tunnel on the Silbersattel, Monte Rosa. *Journal of Glaciology*, Vol. 2, No. 13, 1953, p. 195–96.
8. —— Internal temperatures of a cold glacier and conclusions therefrom. *Journal of Glaciology*, Vol. 2, No. 18, 1955, p. 583–91.
9. Haefeli, R., *and* Brentani, F. Observations in a cold ice cap. *Journal of Glaciology*, Vol. 2, No. 18, 1955, p. 571–80.
10. Röthlisberger, H. Studies in glacier physics on the Penny Ice Cap, Baffin Island, 1953. Part III: Seismic sounding. *Journal of Glaciology*, Vol. 2, No. 18, 1955, p. 539–52.
11. Butkovich, T. R. Density of single crystals of ice from a temperate glacier. *Journal of Glaciology*, Vol. 2, No. 18, 1955, p. 553–59.

Dr. Valter Schytt (Stockholm) writes:

Terminology is always a difficult problem, and in my opinion, you need weighty reasons for changing terms that have been used for many years. . . . It seems to me that Ahlmann's classification of 1935 has been adopted by most glaciologists, and Dr. Court's objection to Ahlmann's use of two criteria, temperature profile and surface melting, does not seem very serious. . . .

It is, however, the terms that should be discussed, and not so much the actual words used in the definitions. They can easily be changed if necessary—as long as the definition *means* the same.

Ahlmann's terms are related to the general climate of the glacier's environment and to the geographical distribution of the different types of glaciers. There is a good, though not complete, reciprocal accordance between polar glaciers and polar regions and temperate glaciers and temperate regions.

When dealing with the exceptions, *e.g.* glaciers at high elevations in non-polar regions, the word "type" can often be added—"a glacier in the Himalayas can have a portion of high-polar type". Just as a geomorphologist can describe a coast as being of the Atlantic type, irrespective of its geographical situation.

But there are other occasions when Ahlmann's classification is not ideal. My ice temperature measurements close to the edge of the Greenland inland ice near Thule showed that, in the ablation

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area, 1 mile from the edge and 570 m. above sea level, the temperature increased from −13° C. at 8 m. depth (22 August) to 0° C. as close to the surface as could be measured—still we had appreciable melting. At the next station (7 miles from the margin and about 800 m. above sea level) we found that the melt water had heated the firn to the melting point all the way down to our deepest thermometer at 9·5 m. At the third station (Mile 20, 850 m.) the isothermal layer was 5 m. deep. . . .

In such cases Ahlmann's classification falls short, and I did not try to coin any new terms but used descriptive words. Actually Ahlmann's sub-polar glacier is characterized not only by the upper snow and firn layer (in the firn area) being at melting point, but also by a negative ice temperature in its ablation area. This is provided the glacier's altitudinal extension is not too great.

The terms proposed by Court can be used in the accumulation area, but hardly in the ablation area of a "cold" glacier. To say that a thin isothermal (0°) layer must exist just at the surface because of the radiation from sun and sky, would be a purely academic statement. The refreezing on the ice surface inside Thule was very intensive, but only at night or in the shadow or with low air temperatures. Normally no observable refreezing took place, and no melt water could permeate an upper layer.

Both terms, Court's "refreezing" and Ahlmann's "sub-polar", could, however, be used where they are *defined* as referring to glaciers with a "refreezing" or "sub-polar" accumulation area and a "cold" ablation area.

Another disadvantage of Court's terms seems to be that "non-melting" is a little too rigorous. There is of course a gradual transition between a sub-polar and a high-polar glacier. To me a high-polar glacier should have *no* or *very little* melting. I would not call a glacier sub-polar just because I can find one or a few thin ice layers in my snow pits.

Court has chosen the "Baffin type" glacier as an example and has called it *firnless non-melting*. But surely there is melting, or there would be no superimposed ice at the surface.

I agree that terms should be as descriptive as possible. "Refreezing" is descriptive—but it describes something that takes place on every melting glacier, at least some time during the year.

. . . Finally, research work in glaciology is carried out in many countries to-day, and there are many glaciologists who do not use the English language in their daily work, whether it be research or lecturing.

. . . If new terms are to be coined, attempts should be made to select words which can be easily transcribed or perhaps translated by scientists abroad. . . .

To sum up. I welcome this discussion, and I think the time has perhaps come to revise the geophysical classification of glaciers, or rather to initiate this discussion, but to let any definite decision wait until after the end of the International Geophysical Year, by which time much additional information will have been obtained.

Since Ahlmann's terminology has become so widely used, I think it would be a great advantage if his terms could survive the revision and form a basis to an improved one, if such can be designed.

If a new set of terms be adopted, glaciologists in several countries should be asked whether or not the new words can be easily assimilated into their respective languages. Latin words are often suitable, but preferably those which mean something to the normal glaciologist. . . .

Dr. J. W. Glen (Clare College, Cambridge) writes:

. . . Dr. Court suggests the term "refreezing" for a glacier in which, below the layer of seasonal temperature change, melt water permeates through some upper layer only and then refreezes. I do not see how such a state of affairs could persist from year to year, though it might occur at a time of rising summer temperatures in a region with cold glaciers.

No source of cold is available to freeze the melt water—in fact, the heat of the earth and the heat generated during glacier flow both serve to make the bottom of the glacier a source of heat. Lagally's transitional type of glacier had a cold *top* layer and a *bottom* layer at the pressure melting point, heated by the sources mentioned above. For such a glacier "refreezing" does not seem an appropriate term—"melting" might seem better! However, "transitional" seems still better as a general term and is established by use. Lagally's transitional type *is therefore not the same as Ahlmann's sub-polar type*, which refers to a cold glacier but with appreciable melting within the layer of seasonal temperature change. . . .

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Dr. H. W. AHLMANN (Stockholm) has communicated a reply to the effect that he supports Dr. Schytt's ideas. After discussion between them it was felt very strongly by both Dr. Ahlmann and Dr. Schytt that any final settlement of a new classification should wait until the end of the Geophysical Year.

Professor G. MANLEY (London) writes strongly to support Dr. Schytt's plea for easily translatable terms.

Professor R. FINSTERWALDER (Munich) writes that Dr. Court's classification is grounded on sound scientific principles and for that reason merits full discussion.

Dr. F. LOEWE (Melbourne) writes that there are two main types of glacier, those with temperatures below freezing point below the level of marked seasonal variation, and those at the freezing point. Each has two sub-types, those in which the main conditions prevail throughout the year in the surface layer also, and those in which it does not; possibly a third sub-type, where the main property is present in the middle part, but absent at both top and bottom, may occur, thus:

Main type	*Cold*	*Melting*
Sub-type	(a) permacold	permamelting
	(b) winter-cold	summer-melting
	(c) centre-cold	centre-melting

While putting forward this scheme Dr. Loewe adds that he is not sure that a change is really necessary at this stage.

Mr. P. D. BAIRD (Aberdeen) writes:

I do not see the need for a three-fold classification and believe Ahlmann's original two-fold to be best. I prefer the terms "temperate" and "cold" for the cases of glaciers whose temperatures below the annual temperature fluctuation level are all at pressure-melting point and below this.

The third category where surface melting occurs seems a separate function. Can one think of a single continuous ice body where surface melting does not occur *somewhere* on it? Even the Antarctic cap has melting in places.

Finally I deprecate the introduction of complex terms, whether pure Latin or bastard Latin-English.

Cold and temperate are readily translatable into all scientific languages.

Professor R. P. SHARP (Berkeley, Cal.) writes:

. . . I have no particular objection to calling glaciers warm and cold or even thawed and frozen. In fact I prefer simple terms of this type to the philologically correct terms suggested in Dr. Court's letter. I heartily agree that a classification on the basis of temperature alone is far superior to a classification involving also the nature and thickness of the firn mantle. It should therefore be pointed out that the classification applies to a particular spot on a glacier and not to the whole glacier. It seems that we might get out of this dilemma by defining the spot or area on a glacier which we would be willing to accept as representative of the whole. It is conceivable that any one glacier of any extent might be polar in the upper reaches of its accumulation area and temperate at the snout. However, if we agreed that a midpoint in the accumulation area would serve as being representative of the whole glacier, a determination at that point would then permit a classification of the glacier. I don't particularly advocate this and am quite willing to talk about areas of glaciers which may be either polar or temperate, depending upon what part of the glacier they represent.

Dr. G. de Q. Robin (Birmingham) writes:

. . . My views are very similar to those expressed by Schytt. Our detailed knowledge of the temperature distribution in glaciers is not yet sufficient to warrant a new classification at present. Until our knowledge is much more detailed I believe Ahlmann's classification is sufficiently well-known and satisfactory to be used as the standard.

Professor A. Bauer (Strasbourg) while agreeing that not all the existing terms are well chosen, is in favour of a clearer terminology but believes that Lagally's classification is the best. He stresses the importance of any terminology for international use being capable of translation into other languages. Professor Bauer also refers to a discussion germane to this subject in P. A. Shumskiy's "Ice Geography", Part 3 of Osnovy strukturnogo ledovedeniya, *Akademia Nauk SSSR*, 1955.

Dr. R. C. Hubley (Washington, D.C.) writes:

. . . Dr. Court's definitions of *permelting*, *refreezing*, and *nonmelting* portions of glaciers are not very clear, and certainly less concise than thermal classification definitions given by Lagally and Ahlmann.

I would not say that Ahlmann's terms used in his classification are ideal, but at the same time, I do not see that they are so objectionable. The terms "Polar, sub-Polar, and Temperate", when used in the thermal classification refer not to the geographical location of the glacier being classified, but to the type-area for that particular thermal regimen. Thus, for example, it might be said that some glaciers in equatorial mountains are thermally sub-polar or polar in their upper parts, and temperate in their terminal regions.

I do believe there is considerable need for reviewing the whole problem of glacier classifications —not only thermal classifications, but genetic, morphological, dynamic, and general climatic classifications. These perhaps need to be considered all together, but preparation of completely suitable classifications will be a difficult task, and will require more careful, extensive thought and labor than has been previously given to the subject. . . .

Dr. M. M. Miller (Cambridge) writes:

. . . I find it difficult to apply Dr. Court's terms to individual glaciers. Thus I believe it is more acceptable to maintain Dr. Ahlmann's terms, with perhaps the refinement I have suggested in the note accompanying this letter. . . .

Note:

Both Ahlmann and Lagally have recognized a subordinate category in their classifications. Ahlmann refers to this as a *Sub-Polar* type, in which the penetration of seasonal warmth is restricted to a relatively thin layer but is greater than in Polar glaciers. Lagally calls this intermediate type "Transitional" and defines it as characterized by a relatively *thick* annual melt zone.

These differing definitions have created some confusion. Actually, both terms are useful: the Sub-Polar classification to refer only to glaciers which are dominantly Polar but still have certain temperate characteristics and the "Transitional" for glaciers which are dominantly temperate but with a tendency towards Polar characteristics. For this latter category, which includes most of the high elevation glaciers in temperate latitudes, the writer suggests that the substitution of the term *Sub-Temperate* may be more appropriate, since it is etymologically consistent with the Ahlmann terminology, now in most common use in glaciological literature. Thus there would be the following glacier types: *Polar* and *Sub-Polar*; *Temperate* and *Sub-Temperate*.

Mr. J. E. Fisher (New York) suggests that if a change is really needed attempts should be made to find three suitable adjectives for the three types of glacier which should be completely self-expressive even to the layman; but, "until more is known about glaciers what about withholding any decision for a little while?"

Dr. G. J. Heinsheimer (Argentina) writes:

Lagally's terms are not so bad. Why not correct them slightly? If you would distinguish glaciers at melting-point temperatures, glaciers partly below melting-point temperatures and glaciers through-

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out below melting-point temperatures, everybody would know that melting-point corresponds to several temperatures according to pressure differences.

Editorial Note

As was to be expected this correspondence shows that many different views are held. A point is made, and ought to be strongly emphasized, that the coining of new, and particularly of hybrid Latin-English words, for phenomena which have long been known and named, is to be deprecated. Another point, well made, is that any new words must be capable of being easily translated into other languages. Particular attention should be paid to Dr. Glen's letter. This implies that several writers have misconceived the true meaning of Lagally's "transitional type" of glacier.

Attention is also drawn to the classification of glaciers published by G. A. Avsyuk (Institut Geografii, Moscow) in *Izvestiya Akademii Nauk SSSR. Seriya Geograficheskaya*, 1955, No. 1, p. 14–31, and received from Dr. T. Armstrong (Cambridge) who has supplied the English translation which is printed below.

This *Journal* and the British Glaciological Society will be willing to help in the process of consolidation of ideas but the great difficulty in achieving the general acceptance of a new or revised classification (if found necessary) could perhaps be lessened, now that the problem has been enunciated, by discussions and tentative agreement at different centres in the different countries, rather than by sporadic correspondence. This, at any rate, seems to be the next step, but one not necessarily to be taken immediately.

Avsyuk's Classification of Glaciers by Temperature Regime

He distinguishes five types, each with a characteristic method of ice formation.

(1) *Dry polar type.* Ice formation by recrystallization (*i.e.* no melt water). The whole thickness of the ice is substantially below freezing point, its mean a little below the annual mean air temperature.

(2) *Moist polar type.* Ice formation by recrystallization and infiltration. Temperatures very similar to (1) above, but the air temperature occasionally rises above freezing point, causing temperatures of 0° C. in the ice up to a depth not exceeding 1 cm., and therefore melt water; this does not affect temperature regime of the main mass of ice, however. Mean ice temperature remains lower than annual mean air temperature.

(3) *Cold type.* Ice formation by "cold infiltration". Higher air temperatures cause enough melt water to soak into the firn, but not enough to reach the bottom of the active layer or to start run-off. Mean temperature of ice is higher than annual mean air temperature (though both are of course negative). Three temperature zones: (i) Surface, down to depth reached by melt water. This zone reaches 0° C. in warm period of year. (ii) Central zone, from lowest depth reached by melt water to lower limit of active layer. Temperature always negative. (iii) Bottom zone. Temperature gets lower with depth.

(4) *Marine type.* Ice formation by "warm infiltration". Enough melt water to penetrate whole active layer and raise it to 0° C. Some continues to bottom of glacier, emerging as a melt water stream which is characteristic of this type. Winter temperatures do not penetrate enough to re-freeze whole depth, therefore the bottom layer is always at 0° C. (This is true wherever a marine type of glacier may be situated.) Upper layer has negative temperatures in winter, with the lowest at the surface.

(5) *Continental type.* Ice formed by infiltration and congelation. Enough melt water to penetrate the annual accumulation, and to form streams. Thin firn layer, never greater than one year's accumulation. Below is a dense, non-porous layer. Thus melt water, though plentiful, only brings a shallow surface layer up to 0° C.; air temperature, especially in winter, has a much greater influence. Mean temperature of ice is a bit higher than annual mean air temperature. Three zones: (i) Surface, 5–10 m. thick, is negative in winter and 0° C. in summer. (ii) Central zone, continuing down to lower limit of active layer (15–20 m.) is always negative, temperature decreasing with depth. There is seasonal fluctuation. (iii) Bottom zone, on down to bottom of glacier, has constant negative temperatures.

Avsyuk also has a map showing world distribution of glaciers by these types.

T. E. A.