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PLANAR AND LAYERED STRUCTURES IN GLACIAL ICE

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ABSTRACT. In metamorphic rocks a sharp distinction between planar structures (e g. in schists) and layered structures (e.g. in banded gneisses) is generally made. This same distinction has not been maintained in descriptions of analogous structures in glacial ice. At least part of the problem lies with the use of the term *foliation*, which, unfortunately, has been applied to both types of structures. On historical and etymological grounds, as well as on the basis of widespread acceptance by petrologists and structural geologists, it is argued that foliation should apply to planar structures in both rocks and glacial ice.

RÉSUMÉ. *Structures planes et rubannées de la glace de glacier.* Parmi les roches métamorphiques, on fait en général une nette distinction entre les structures planes (schiste) et les structures rubannées (gneiss rubanné). Cette même distinction n'a pas été maintenue dans la description de structures analogues de la glace de glacier. Finalement, le problème est lié à l'usage du terme de foliation qui, malheureusement, a été appliqué aux deux types de structures. Historiquement et étymologiquement, aussi se basant sur la large acceptation des pétrologues et des géologues des structures, l'argumentation de l'auteur porte à utiliser le terme foliation seulement aux structures planes à la fois des roches et de la glace de glacier.

ZUSAMMENFASSUNG. *Planare und Schicht-Strukturen in Gletschereis.* Bei metamorphem Gestein wird gewöhnlich scharf zwischen planaren Strukturen (z.B. in Schiefern) und Schichtstrukturen (z.B. in Bänder-Gneisen) unterschieden. Diese Unterscheidung wurde bei der Beschreibung entsprechender Strukturen in Gletschereis nicht beibehalten. Teilweise liegt der Grund dafür im Gebrauch des Ausdruckes *Foliation*, der leider für beide Strukturtypen benutzt wurde. Aus historischen und etymologischen Gründen, aber auch auf der Basis einer weitverbreiteten Übereinkunft von Petrographen und Strukturgeologen wird gefordert, dass der Ausdruck *Foliation* sich nur auf planare Strukturen in Gestein und Gletschereis beziehen soll.

INTRODUCTION

In geology a sharp distinction is generally made between planar and layered structures in metamorphic rocks. The reason is that although their origin may be related, the processes of formation of the two are different. For example, the first might be due to shear, the second to differential migration of certain components in directions normal to the plane of shear. These same distinctions have not been maintained in descriptions of analogous features in glacial ice and as a result statements are often open to misinterpretation and misunderstanding. One finds such recent statements as:

> "Much of the recrystallized surface ice . . . shows a pronounced *layered* structure. . . . The name foliation is appropriate for this structure . . ., and . . . the term will be restricted to a compact secondary *planar* feature caused by flow." (italics added) (Meier, 1960, p. 52)
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> "Glacier ice commonly shows a regular planar structure, usually consisting of alternate layers of relatively clear and bubbly ice. . . . Although the word 'banding' is also frequently used for this planar structure in ice, '*foliation*' gives the true implication of the three-dimensional structure that actually exists." (original italics) (Rigsby, 1960, p. 590)

The confusion introduced here is between the planar and layered structures, and it is clear that at least part of the problem lies with the meaning of the term *foliation*, a term which unfortunately has had a long and diverse usage. A brief historical review may help clarify the situation.

HISTORY OF THE TERM

Use of foliation for the property of some crystalline materials to be composed of thin leaf-like layers or laminae goes back at least to 1650 (see Oxford English Dictionary). It was similarly applied to the splitting of minerals into layers, a property now called mineral cleavage (Werner, 1805, 1962).

That the term in this same sense was applied to analogous structures in rocks seems understandable. The first use in English geological literature I have been able to find is in reference to roofing slate (MacCulloch, 1811, p. 18), and the connotation suggests that the term was in general usage at the time. At least by the end of the next decade it had been extended to coarser-grained rocks. Scrope (1825, p. 223), with reference to an earlier French paper by Von Humboldt, relates the development of the planar structure to an increasing tendency of mica grains to assume parallel orientation, and by this process granites may pass into gneisses, or *foliated granites*.

A few years later Sedgwick and Murchison (1829, p. 138) described a "finely foliated red sand-

stone", apparently in reference to "hard, thin-bedded, red, micaceous sandstone". While the descriptive sense is the same, this application to sedimentary rocks was apparently short-lived. One can guess that the demonstration of the secondary nature of slaty cleavage, as distinct from bedding, may have been the reason.

Sedgwick (1835), in a remarkably perceptive discussion, noted that in a "nearly homogeneous mass, easily separable into thin laminae . . ., the cleavage of each part may be carried on indefinitely, or at least so far as the operation is not interrupted by mere mechanical difficulty . . ." and that this is due to a parallelism of mineral flakes throughout the whole mass. His observation applied not only to slates but also to highly crystalline schists. "*Foliated*" he said, "expresses very well the peculiar structure of a mica schist . . .".

Foliation was used in this planar sense by Clough, in descriptions of metamorphic rocks in the famous north-west Scottish Highlands memoir (Peach and others, 1907, p. 207), and by Greenly (1919, p. 201) for the slates of Anglesey. It continues to be used by a large number of workers (Knopf and Ingerson, 1938, p. 7; Turner, 1948, p. 275; Ramberg, 1952, p. 127; Turner and Weiss, 1963, p. 97; and many others). Both Knopf (1941, p. 353) and Fairbairn (1949, p. 5) support this usage on etymological grounds.

The evolution of foliation in this sense involves a logical sequence from the cleavage of minerals, to the cleavage of slates, to the planar structures of schists and gneisses, and finally its generalized application to all planar structures of metamorphic origin.

However, at a fairly early date, a second meaning of foliation developed. Darwin (1846, p. 141) clearly distinguished it from cleavage, the purely planar structure. Sharpe, (1852, p. 445), claiming to follow Darwin, used foliation to describe "divisions of rocks . . . into layers of differential mineral substances", but added that these layers "may be of any thickness, from a line up to one or two feet . . . ." By including *lines* he actually departed from Darwin's previous clear distinction, and in effect made note of the other, more general usage.

More recently, however, Harker (1932, p. 204) closely following Darwin, but wrongly attributing to him the origin of the term, continued and strengthened the layered sense of the term:

> "Foliation consists in a more or less pronounced aggregation of particular constituent minerals of a metamorphic rock into lenticles or streaks or inconstant bands, often rich in some one mineral and contrasting with contiguous lenticles or streaks rich in other minerals."

Following Harker, a number of British writers continue to use this definition of foliation (e.g. Wilson, 1961, p. 458).

Still another usage is worth noting. Bailey (1938, p. 8) justifies the phrase linear foliation; after all pine needles are leaves. This is now universally termed simply *lineation.*

Foliation was apparently first applied to ice by Chamberlin and Salisbury (1909, p. 247) to describe stratiform structures found in the deeper portions of a glacier, and to distinguish them from sedimentary stratification. However, in their discussion of metamorphic rocks (p. 446), the term schist is referred to as "a common term for a foliated crystalline rock". At least in part they used foliated and schistose interchangeably to describe the same feature, and thus failed to distinguish clearly between layered and planar elements.

Conclusion

I make no claim to having made a complete review of *foliation.* However, from the brief history presented, several points seem clear. The term has been applied longest and most consistently in the planar sense, and it is in this sense that it finds widest acceptance by geologists today. On the other hand, foliation in the layered sense has a long history of ambiguity. Further, present day acceptance by some geologists of foliation-as-layers goes back to Harker's clear definition, but this in turn is based on an historical error.

Foliation in this well established planar sense is also consistent with the etymology of the term. To put the argument simply, a metamorphic rock may be made up of thin "leaves". These leaves may be of the same composition or they may be different. If they are different (i.e. arranged in contrasting layers) this is an additional feature to be described.

I therefore conclude that *foliation* is best applied to planar structures in metamorphic rocks (including glacial ice), and I propose to use it in this sense.

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