ON THE MORPHOLOGY AND SIZE OF SNOW CRYSTALS[1]

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An objective description of snow microstructure requires time-consuming preparation and analysis of *slices*, *sections* and *serials* of intact specimens. Presently, only a handful of snow researchers work with those techniques. For practical reasons most of us will go no further than to cut a sample of snow from a pitwall, disaggregate the sample, spread the particles on a grid, and observe the particles at magnifications up to about 20×. Then, using the *international snow classification*[4] (ISC), we will note the shape of the disaggregated particles. The ISC symbolizes *grain shape* with these mnemonics:

[1] + ⋏ • □ ∧ ○

The ISC gives an additional set of mnemonics for surface materials, but we will not discuss that set in the present paper. Here are our brief definitions of the symbols [1], with more details to follow later in the paper

- \+ New snow crystals
- ⋏ Initially metamorphosed crystals
- • Rounded crystals without melting
- □ Faceted crystals
- ∧ Depth hoar
- ○ Rounded crystals with melting/refreezing.

Note that we use the term *crystal* and not *grain* since the latter has several meanings. Often, "grain" is another way of saying "disaggregated particle." In that sense, a grain may consist of more than one crystal, depending on the thoroughness of disaggregation. To avoid ambiguity, it is preferable to observe crystals and their boundaries, as revealed by transmitted polarized light (innovative field tools are needed!).

Symbol combinations are recommended by the ISC, and are probably used by most ISSW participants. For example, •□ could be used to indicate an equal mixture of rounded and faceted shapes, while •□□ could indicate a predominance of facets. It is also possible to note morphological changes observed over time, writing for example • ⟶ □ .

Morphology and processes are intimately related. For example, in the presence of a weak temperature-gradient, and at temperatures near $0\,°C$, the morphology could evolve as

[2] + ⟶ ⋏ ⟶ •

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[4]*The international classification for snow*, Technical Memo. No.31, National Research Council, Ottawa, 1954. See also *Seasonal snow cover*, Unesco, Paris, 1970.

and in the presence of a strong temperature-gradient as

[3] + ⟶ ⋏ ⟶ □ ⟶ ∧

The simplicity and conciseness of the ISC notation is appealing. However, the symbol set [1] can be extended to cover more possibilities, and with little increase in complexity.

Before discussing the extensions it is necessary to define an *index of crystal area.* Our index is the projected area of a crystal on the grid. Given a typical specimen consisting of about 100 crystals, it is impractical (without automatic digitizing and computer assistance) to visually scan the sample in order to estimate the mean of the projected areas. It is possible, however, to quickly approximate the projected area A_{max} of the largest crystal on the grid. Typically, A_{max} will range from approximately $1/4\ mm^2$ to approximately $16\ mm^2$. Our method is to select A_{max} in mm^2 from the geometric progression $\ldots 1/4,\ 1/2,\ 1,\ 2,\ 4,\ 8,\ 16 \ldots$. We do not attempt to estimate A_{max} for + and ⋏.

Introducing three new symbols (∩ △ ⊕), here is our extension to [1]

[4] + ⋏ ∩ • □ △ ∧ ○ ⊕

Our definitions of [4] follow closely and in most cases paraphrase the ISC definitions of *grain shape*:

+ **New snow crystals**. Unchanged new snow crystals or slightly transformed crystals. For over 50% of crystals, original cloud shapes are recognized from the set of 7 categories of new snow (F1-F7), graupel (F8), pellets (F9), and hail (F0). Modifying features are *broken crystals (p), rime-coated (r), clusters (f) and wet (w).*

⋏ **Initially metamorphosed crystals**. Processes such as rounding, faceting, melting and bonding have progressed. Original new snow shapes are still recognized, but for less than 50% of sample crystals.

∩ **Cylindrical crystals**. Rounding and bonding, but not melting, have produced elongated, cylindrical shapes. A_{max} is usually less than $1/2\,mm^2$.

• **Rounded equant crystals**. Rounding and bonding, but not melting, have converted ∩ to larger, equant crystals. A_{max} is typically greater than $1/2\,mm^2$.

□ **Faceted solid crystals**. Mostly equant prisms, although needle and plate-like prisms are also observed. They are found at any depth including the surface (surface recrystallization). A_{max} ranges from $1/4\,mm^2$ upwards, but rarely exceeds $4\,mm^2$.

△ **Layered facets**. Larger equant or pyramidal, faceted crystals with obvious layering (striations) and/or steps. This morphology is usually associated with rapid crystal growth in response to positive supersaturations at warmer snow temperatures. A_{max} usually exceeds $1\,mm^2$.

∧ **Skeletal crystals**. Very large crystals formed from joined fins or thin plates, which almost always have obvious striations. Often, the fins join to form hollow pyramids (cup-like crystals). A_{max} may approach $16\,mm^2$ and perhaps higher values.

○ **Rounded crystals due to melting/freezing**. Large, equant, and often spherical crystals that grow in the presence of liquid water. They may form small clusters of a few crystals. A_{max} exceeds $1\,mm^2$.

⊕ **Clusters due to melting/freezing**. Rounded crystals have bonded into large clusters in the presence of liquid water. Over 10 crystals per cluster is common. Bonds are well developed.

Using the extended symbols [4], the weak gradient process [2] extends to

[5] $$+ \longrightarrow \curlywedge \longrightarrow \cap \longrightarrow \bullet$$

and the strong gradient process [3] becomes

[6] $$+ \longrightarrow \curlywedge \longrightarrow \square \longrightarrow \triangle \longrightarrow \wedge$$

Symbol set [4] can be enlarged even further in several ways. For example, the observations of Akitaya[5], Colbeck[6] and Kolomyts[7] reveal a variety of metamorphosed crystals which rival the rich variety of cloud forms (+). However, both [2] and [4] are heavily weighed toward detailed classification of *only* + . One solution is to subclassify *all* types using descriptors analogous to F1-F7. This would be a useful way to classify individual crystals in a specimen, but is probably an unnecessary refinement when dealing with the entire specimen. After all, a storm may deposit a layer which consists exclusively of needles (+ F4), whereas $\square$ (needles) must be a rare observation for an entire specimen of naturally metamorphosed snow. On the other hand, two ISC *modifiers* of new snow carry over to metamorphosed snow as well, namely *wet* which we symbolize as a subscripted W, and *clustering* which we extend to include *bonding*, and symbolize as a subscripted B. As an example, a wet snow process may proceed as

[7] $$+ \longrightarrow \curlywedge_W \longrightarrow \bigcirc \longrightarrow \oplus$$

and a dry snow process as

[8] $$+ \longrightarrow \curlywedge \longrightarrow \cap \longrightarrow \cap_B \longrightarrow \bullet_B \longrightarrow \bullet\square_B$$

where in comparison to [5], process [8] emphasizes the development of strong bonds, which are observed even as facets appear.

In summary, we find that the set of 9 symbols $+ \; \curlywedge \; \cap \; \bullet \; \square \; \triangle \; \wedge \; \bigcirc \; \oplus$ with modifiers B and W can describe most morphological observations, and still retain the mnemonic advantages and simplicity of the ISC system. One can introduce further descriptors where it is necessary to describe individual crystals. It is also necessary to incorporate a description of surface types (e.g.*surface hoar*) and crust morphology.

[5] Akitaya, E. (1974) Studies of depth hoar.*Low Temp. Sci., Ser. A*, 26, 1–67.

[6] Colbeck, S. C. (1986) Classification of seasonal snow crystals. *Water Resources Research*,**22**:9, 59S–70S.

[7] Kolomyts, E. G. (1984) *Kristallo-morphologicheskii atlas cnega*, Gidrometeoizdat, Leningrad.