ON THE SPLITTING OF CRYSTALS

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Specimens and photo: Boris Kantor, if other not mentioned.

The formation of "split crystals" is a wonderful aesthetic action of Nature, which is as yet enigmatic to a great extent. Snow white hemimorphite "fans", cactus-like crystals of quartz and amethyst, zeolite spherocrystals and other split crystals allow no collector to stay indifferent. They are also of strong interest to scientists. However, there is no consistency of terminology as well as exact understanding of the essence of the phenomenon in the publications pertaining to this topic. It sometimes happens that the split crystals are taken for dendrites or varieties of skeletal crystals while spherulites and spherocrystals for radiated aggregates. Even such an authority in the science of crystals as Ichiro Sunagawa (1924–2012) was of the opinion that *"spherulites are formed if geometrical selection takes place on a spherical substrate particle"* (Sunagawa, 2005, p. 153) i.e. he referred spherulites to the category of radiated aggregates.

Taking these discrepancies into account, it is appropriate to recall what the terms *"split crystal"* and *"split growth"* really mean. They were introduced into the Russian literature at the instigation of Dmitry P. Grigoryev, founder of the scientific ontogeny of minerals (Grigoryev, 1965) with some earlier references (Lehmann, 1911; Popoff, 1934; Niggli, 1948). It should be noted that D.P. Grigoryev thought split crystals to be not mineral individuals but mineral aggregates.

So, a *split crystal* is a mineral individual, divided (split), in the process of its growth, into two or more parts geometrically equal or similar, having a common base and deviating from one another at slight angles (*Fig*. 1). These parts are referred to as *subindividuals.* The subindividuals are intimately related to the mother crystal reiterating its elements of morphology and complying with its symmetry. Despite their composite structure, split crystals should be classed as mineral individuals in view of their genetic evidence: all the parts of each of them have a common base and are derived from the same crystal seed, the same growth center.

The growth of a crystal accompanied with its splitting is known as the *split growth*.

Along with the term *"split growth", "mosaic growth"* is also used in the same meaning (Grigoryev and Zhabin, 1975).

The split crystals are notable not only for their evident morphological features but also genetic ones. The split growth is always a definite sequence of events: the crystal structure partition into blocks; segregation of subindividuals and their autonomous development; and the formation of a specific aggregate-like *"intergrowth"* of subindividuals – split crystal.

1. Split crystal of **quartz**.
Mother crystal surrounded by subindividuals.
Height 5.3 cm. Dashkesan, Azerbaijan.

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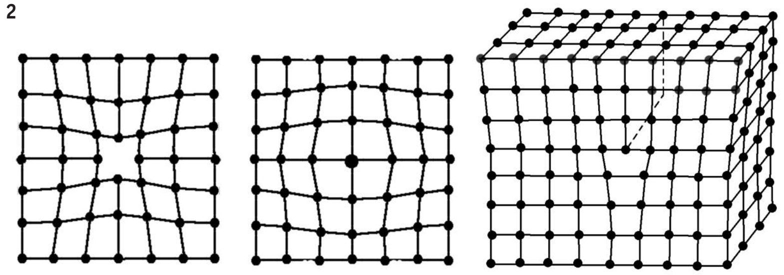

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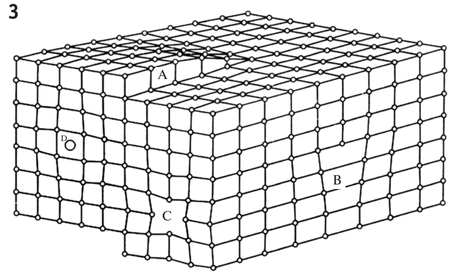


2. Lattice defects: vacancy, interstitial atom, edge dislocation.

3. Screw dislocation.

Various authors identify a variety of natural conditions to be the factors of the split growth:

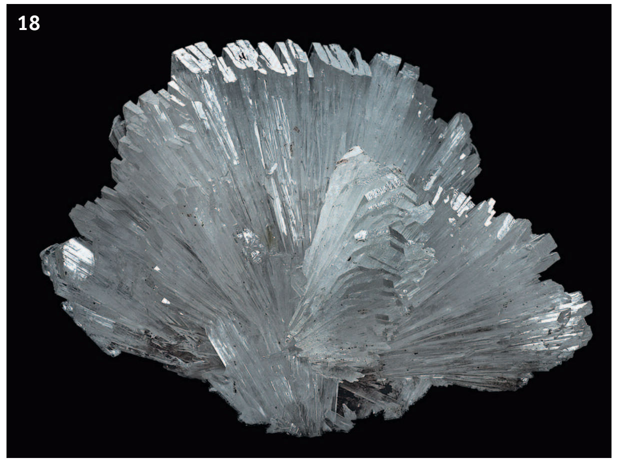
- mechanical deformation, isomorphism phenomena (with some atoms or ions substituted with other ones of essentially different size), rapid cooling or crystallization (Niggli, 1948);
- chemical properties of the environment; a feeding solution high supersaturation; mechanical strains caused by the growing crystal interaction with a hindrance (Godovikov *et al.*, 1989; Krasnova and Petrov, 1997; Godovikov and Stepanov, 2003);
- high growth rate (Godovikov *et al.*, 1989; Sunagawa, 2005);
- Rehbinder effect (interaction with a surfactant layer; Spiridonov, 2019);
- adsorption of micro particles by the growing crystal; scratches; borders of twinning and micro blocks slightly deviated at mechanical strains; heterometry (lattice stress due to compositional heterogeneity), etc.

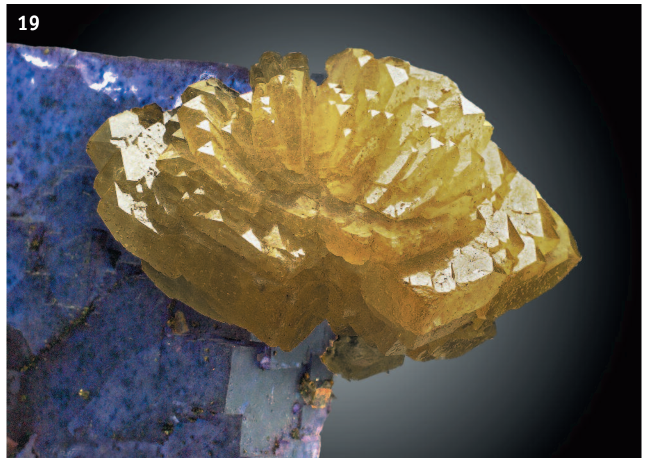
The diversity of splitting factors gave a reason for Dmitry P. Grigoryev to note in 1961: *"As yet, there is no possibility to indicate the cause of this phenomenon precisely and accurately"*.

But the cause of a phenomenon becomes clear as far as the essence of the phenomenon and its mechanism are understood. Then it becomes possible to judge how and why any external factor initiates or enables this mechanism. The mechanism of split growth was understood later when the defects of real crystal structures, the lattice defects, were studied to a sufficient extent. Every natural crystal *"provides"* itself with these lattice defects – vacancies, interstitial atoms, substitution impurity atoms as well as edge and screw dislocations (*Figs*. 2, 3), etc. *"Formation of lattice defects is the crystal's response to the outer implications. To recompense these implications having kept its physical and thermodynamic state, the crystal complicates its structure"* (Egorov-Tismenko, 2005). There are many defects in any real crystal. For example, the dislocations may number from 10 to 10^5 per cm^{-2}.

To our opinion, the crystal splitting is nothing else than a way to minimize the crystal's free energy. The actuating mechanism always consists in getting rid of some part of the lattice defects at the price of the expansion of the crystal surface (Kantor, 2009, 2017_2). It can be shown that such a means is effective enough to provoke split growth. All lattice defects store whatever quantity of potential energy because they involve some changes of interatomic distances and lattice distortions which lead to local elastic deformations and mechanical strains. Therefore, the cause of the splitting phenomenon should be sought in the phenomenon of this energetic trend.

The lattice defects are agile: they are able to wander within the crystal under mechanical or thermal effect. Having reached the crystal surface, the defects annihilate.





16. **Apophyllite** split crystal. 7 cm tall.
Momin Akhada, Rahuri, Maharashtra, India.

17. **Calcite** split crystals. 12.5 cm.
Verkhny mine, Dalnegorsk, Primorye, Russia.

18. **Hemimorphite** crystal, "bunch" splitting.
3.5 cm wide. Ojuela mine, Mapimi, Mexico.

19. **Baryte** bow-tie crystal on fluorite.
5.2 cm. Denton Mine, Illinois, USA.

20. Bow-tie like splitting of **apophyllite** crystal.
Width 4.5 cm. Nashik, Maharashtra, India.

21. **Quartz** bow-tie crystals, up to 12 cm long.
Dashkesan, Azerbaijan.

22. Flat fan-like splitting:
(a) "bunch", (b) "bow-tie".

23. **Quartz** split crystals on **magnetite**, with **epidote** overgrown. 9.5 cm.
Upright crystal *A* is bunch-like split while lying crystals *B* and *C* are bow-tie like. Dashkesan, Azerbaijan.

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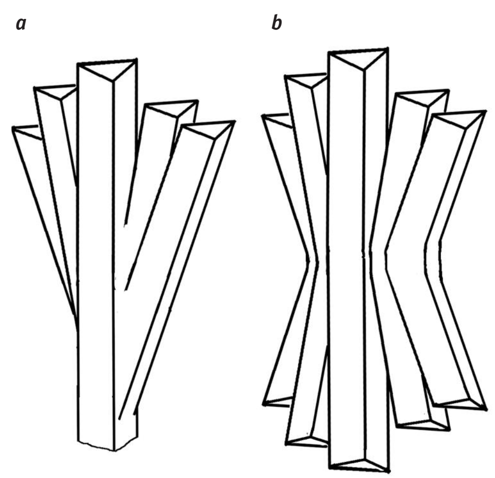

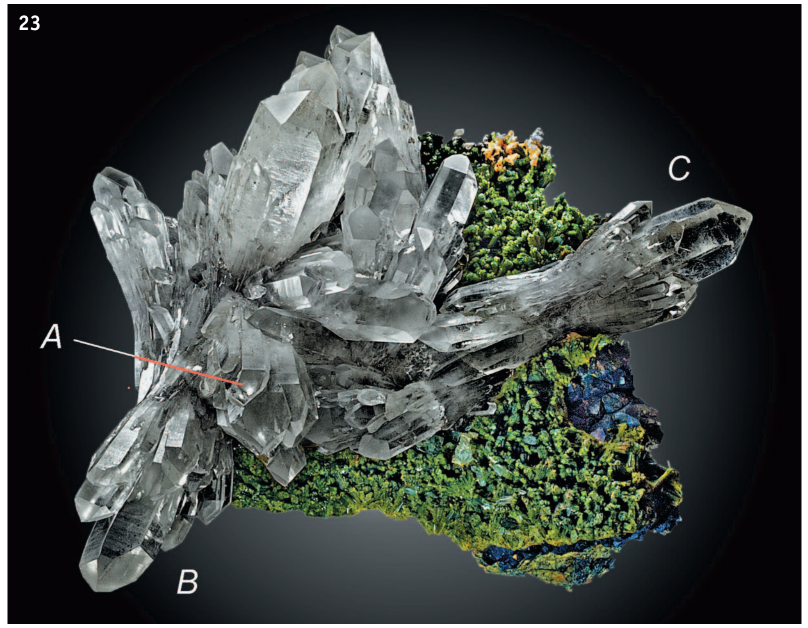

process. At one-act splitting *"fans"* and *"bunches"* (*Figs.* 1, 16, 17, 18), *"bow-ties"* (*Figs.* 19, 20, 21) and *"rosettes"* of subindividuals arise as well as *"roses"* and spherulites. There is no principal difference between bunch- or fan-like and, on the other side, bow-tie types of splitting (*Fig.* 22). *"Bunch"* and *"bow-tie"* crystals may even combine in the same specimen having been developed from neighboring growth centers (*Fig.* 23). Both may be observed with detached or closely