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Positive and Negative Striations in Pyrite

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Abstract

Most pyrite crystals exhibit striations parallel to [001] on their {210} faces (positive striations), but a small percentage of them show striations perpendicular to this direction (negative striations). To clarify the genetic difference between the two types of striations, the surface microtopography of {210} and {100} faces as well as internal heterogeneity were studied on crystals with negative striations collected from four localities in Japan. It is concluded that positive striations are associated with the pile up of edges of growth layers on the {100} faces, whereas negative striations relate to the growth layers freely developed on the {210} faces, and also that there is a clear discontinuity between the stages of the formation of positive and negative striations. It is conjectured that the conditions for the formation of negative striations are rather specific, and that the transformation of the {210} faces from *S*-face to *F*-face may be due to impurity adsorption.

Introduction

Most pyrite crystals exhibit striations parallel to [001] on their {100} and {210} faces. It is also known that a small percentage of pyrite crystals show striations perpendicular to [001], *i.e.*, parallel to [$\bar{1}$20], on their pentagonal faces. The former striations may be called "positive," and the latter "negative." Crystals showing positive striations and those with negative striations are shown schematically in Figure 1.

Previous work by one of the authors (I.S.) has established that when crystals with negative striations occur, such crystals predominate, and are rarely seen where most pyrite crystals show positive striations. Interestingly, if pyrite crystals occur in an ore body as pentagonal forms with negative striations, the crystals occurring in associated bed rock always show the same external forms. In contrast, in the case of crystals with positive striations, pyrite crystals in the bed rock are always cubic, irrespective of the crystal habits of pyrite in the ore body (Sunagawa, 1957). It is therefore conjectured that crystals with negative striations must have been formed under a specific growth condition.

It has been widely believed that the striations on the {100} and {210} faces are composed of an oscillatory combination of cubic and pentagonal faces. However, this is not the case. Sunagawa and Endo (1968) showed with surface microtopographic studies of pyrite that the striations on the {100} faces were truly steps of growth layers developing on the {100} faces, whereas those on the {210} faces were formed by the pile up of edges of growth layers spreading from the {100} faces. Sunagawa (1957) observed that many pentagonal faces on pyrite crystals belong not only to the {210} form but to several other {*hk*0} forms, whose indices vary from crystal to crystal.

For crystals with positive striations, growth layers seemed to develop on {100} but not on {210} faces. Consequently, we believe that the growth of pyrite crystals takes place on the {100} faces by two-dimensional layer spreading and stacking, with the {210} faces formed initially by the pile up of edges of growth layers on the {100} faces (Sunagawa, 1957; Sunagawa and Endo, 1968). This growth mechanism, however, does not adequately explain the formation of negative striations on the {210} faces, though it satisfactorily accounts for the positive striations. Therefore, to determine the origin of negative striations, we studied the mode of occurrence of pyrite crystals with negative striations, the surface microtopographies of their {100} and {210} faces, and their internal heterogeneity. The specimens mainly used in the present study are those obtained at the Shakanai mine, Akita Prefecture. Crystals with negative striations from a few other localities in Japan were also studied for reference.

Observations

Crystals with Negative Striations from the Shakanai Mine

Shakanai mine, Akita Prefecture, is one of the famous Kuroko-type deposits in Japan, bearing black ores (galena-sphalerite-barite with small amount of chalcopyrite, pyrite), yellow ores (pyrite-chalcopyrite), siliceous ore (quartz-pyrite-chalcopyrite), and gypsum ores.

Pyrite crystals in these ores exhibit a wide variety of crystal habits, from cubic to pentagonal and octahedral, but all {*hk*0} faces show positive striations. However, pyrite crystals impregnated in a pumice tuff with brecciated ferruginous chert overlying the black ore body at the No. 1 deposit, show negative striations on {210} faces. Pyrite crystals with negative striations are found only in this pumice tuff, and never in any type of ore body or in the surrounding bed rock.

Pyrite crystals within a single hand specimen of pumice tuff vary widely in grain size, from less than 100μ to over 15 mm in diameter. They exhibit nearly perfect holohedral, pentagonal dodecahedrons with negative striations.

Because the pumice tuff containing pyrite crystals is soft enough to crush in one's hands, crystals can be easily separated from the mother rock, and concentrated by water decantation. Crystals were sieved into the 5, 10, 20, 40, 80, 150, and 200 mesh size-fractions respectively, and the frequency of occurrence of different types of habit was counted under the binocular microscope. Identification of different habits was made semiquantitatively. The result (Fig. 2) clearly shows that frequency of occurrence of different habits collected in a small hand size specimen changes gradually with crystal size. Among smaller crystals the cubic habit predominates, whereas almost all of the larger crystals show pentagonal habit. This change of crystal habit with grain size substantiates results obtained previously by Sunagawa (1957) on a great number of pyrite crystals from other Japanese localities. The results suggest that the pyrite crystals assumed the cubic habit at the earliest

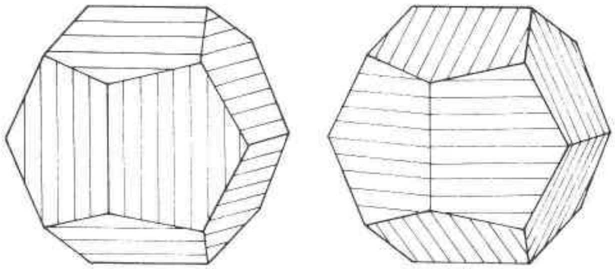


FIG. 1. Positive (left) and negative (right) striations.

stage of growth. Thereafter {210} faces started to develop gradually, and finally a pentagonal habit appeared. In other words, pyrite crystals changed from cubic to pentagonal habit as they grew larger.

Surface microtopographies of both {100} and {210} faces were observed on crystals for each grain size category using the phase contrast microscope. The {100} faces, which appear only on smaller crystals, exhibit rectangular growth layers (Fig. 3) elongated parallel to [001]. This results in the appearance of striations on the {100} faces and confirms the observations reported previously by Sunagawa and Endo (1968). Surface micrographs of the smaller {210} faces that appear on small- to medium-size cubes (up to 40 mesh) exhibit positive striations only. They are essentially similar to those of ordinary {210} faces with positive striations reported previously. These striations can be associated with the edges of growth layers on the {100} faces. No free development of growth layers is noticed on these {210} faces. This definitely shows that at least up to this stage, the {210} faces are formed by the

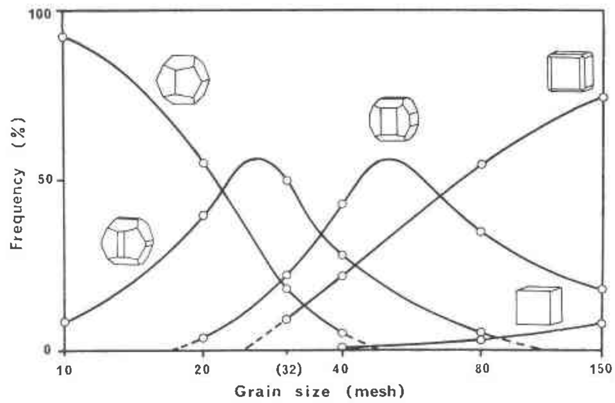


FIG. 2. Frequencies of appearance of different habits of pyrite *vs* their grain sizes as obtained in a small hand-size specimen.

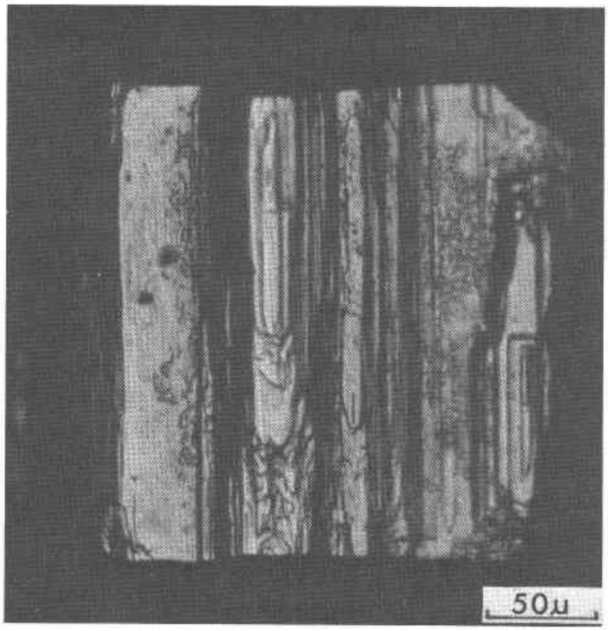


FIG. 3. Interference contrast photomicrograph of (100) face of a smaller crystal from the Shakanai mine, showing elongated rectangular growth layers. All photographs of crystals showing striations in this article have been reproduced in equivalent positioning, *i.e.*, with the vertical edges being parallel to [001].

pile up of the edges of growth layers spreading on the {100} faces. Goniometric measurements of the {210} faces revealed that these faces actually consisted of not only {210} but also narrow strips of {310}, {520}, {830}, *etc.*

In contrast, the {210} faces which are dominant on the medium-to-larger (40 to 20 mesh) crystals exhibit quite different surface characteristics. On the {210} faces of medium size crystals, areas showing positive striations coexist with areas having fairly flat surfaces. On the flat areas, thin growth layers develop freely; they are elongated in the direction of negative striation [$\bar{1}$20]. In the areas of positive striations, small patches of flat areas containing short negative striations occur (Fig. 4). These areas of negative striations become wider as crystals become larger and, on crystals larger than 20 mesh, entirely cover the {210} faces (Fig. 5). This indicates clearly that the origin of the negative striations differs from that of the positive striations, and that they have been formed by the steps of growth layers freely developed on the {210} faces. The difference between positive and negative striations can be seen more clearly in Figures 6a and 6b, phase contrast photomicrographs of much higher magnification.

The above observations suggest at least two distinct stages in the formation of {210} faces. In the earlier stage the {210} faces are formed by the pile up of the edges of growth layers spreading on the {100} faces, and are characterized by the development of positive striations. In this stage, growth layers cannot develop freely on the {210} faces. The {210} faces are considered to have been formed by the attachment of chains; thus the faces have the characteristics of Hartman's (1963) *S*-faces. In the later stage, growth layers develop freely on the {210} faces to form negative striations. In this stage, therefore, the {210} faces are formed by the attachment of slices, *i.e.*, through a layer-by-layer process; thus they are *F*-faces. In other words, the {210} faces change character from *S*-face to *F*-face, from earlier to later stages. We thus conjecture that a somewhat abrupt change of conditions occurred during the growth of these crystals. This is supported by studies

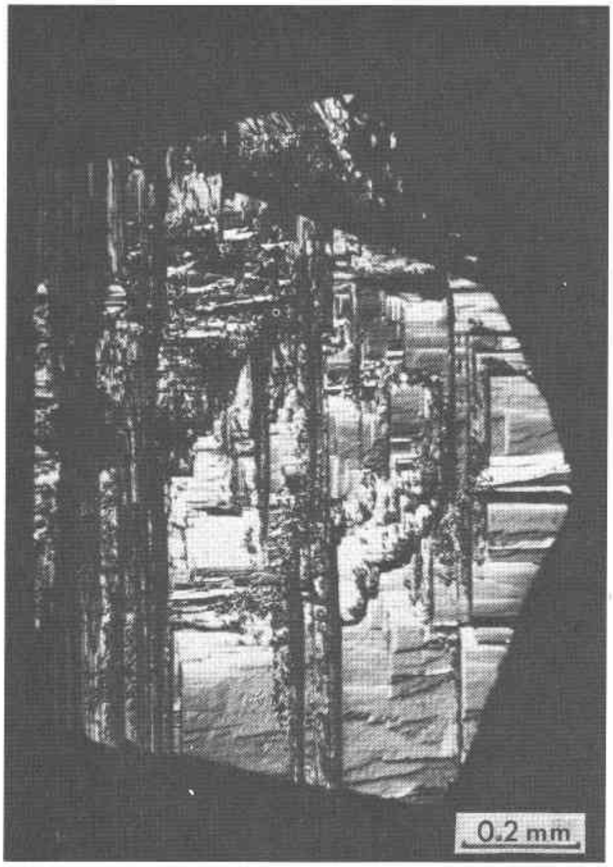


FIG. 4. Interference contrast photomicrograph of (210) face of a medium size crystal from the Shakanai mine, showing the coexistence of both positive and negative striations.

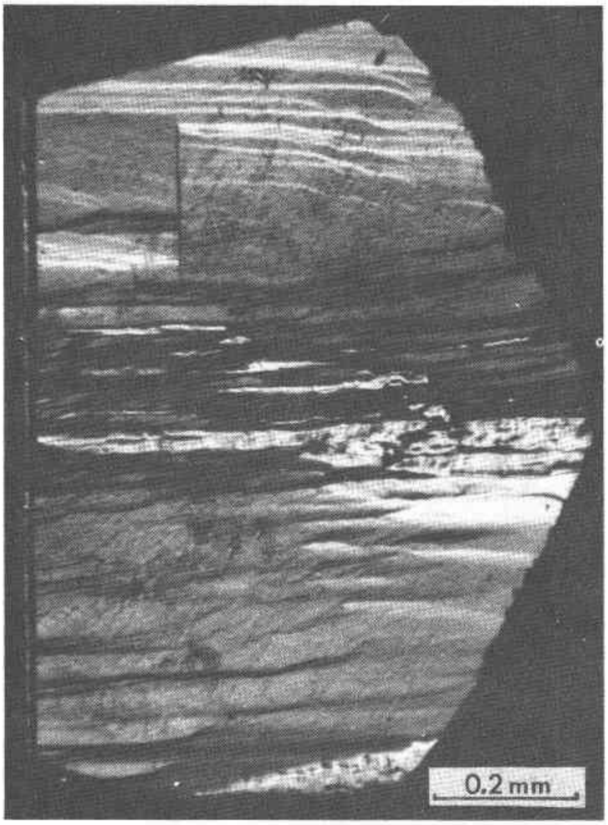


FIG. 5. Interference contrast photomicrograph of (210) face of a larger size crystal from the Shakanai mine, showing growth layers elongated parallel to the negative striations.

of the internal heterogeneity of these crystals, as described below.

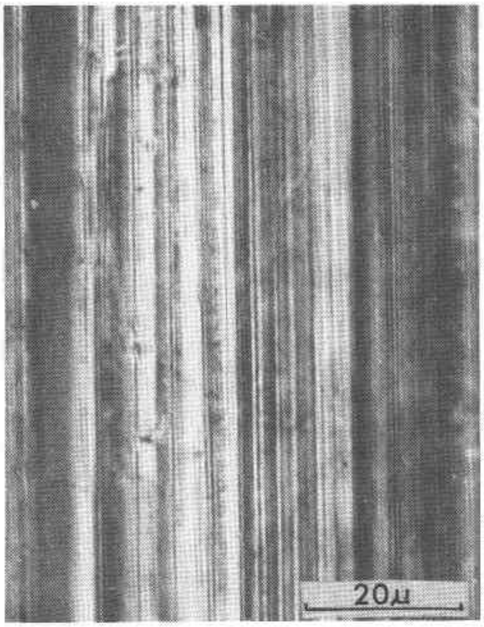
Pyrite crystals of each grain size were sectioned and polished, then etched in concentrated HNO_3 for about 30 seconds at room temperature. After the treatment, any internal heterogeneity became visible under the ordinary reflection microscope.

Crystals smaller than 80 mesh exhibit more or less uniform internal structures, except for the occurrence of a number of small inclusions (Fig. 7a). In contrast, crystals larger than 40 mesh show internal heterogeneity consisting of a polygonal core and a surrounding mantle, the core having been more heavily attacked by the etchant than the mantle. In general, the core occupies the larger volume and shows either pentagonal or cubo-pentagonal forms. The mantle enveloping the polygonal core is generally thin and uniform in thickness and sometimes displays thin zonal bands after electric etching.

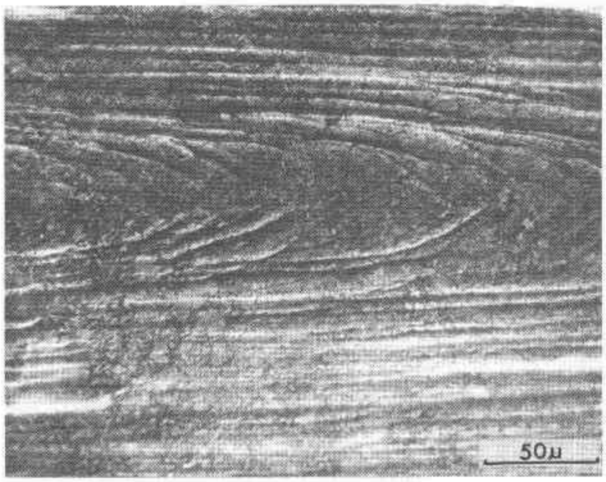
This internal heterogeneity clearly discloses an abrupt discontinuity in growth process between core and mantle. The fact that the mantle appears only among larger crystals corresponds well to the fact that negative striations appear only on larger crystals.

Negatively Striated Crystals from Other Localities

Pyrite crystals from Ani mine, Akita Prefecture, epithermal chalcopyrite-pyrite-chlorite vein deposits,

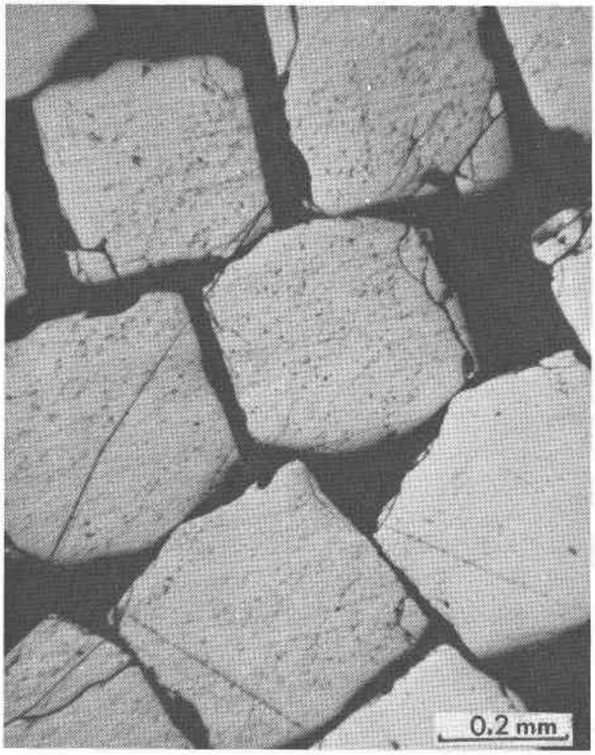


(a)

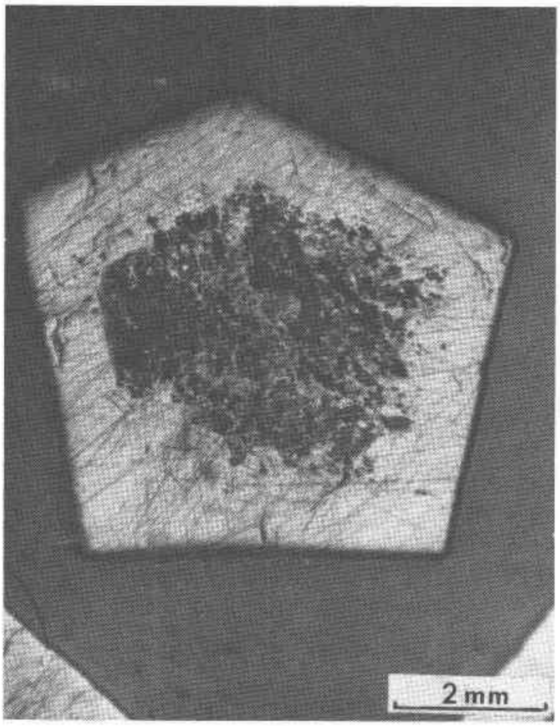


(b)

FIG. 6. Higher magnification phase contrast photomicrograph of positive striations (a) and negative striations (b) observed on crystals from the Shakanai mine.

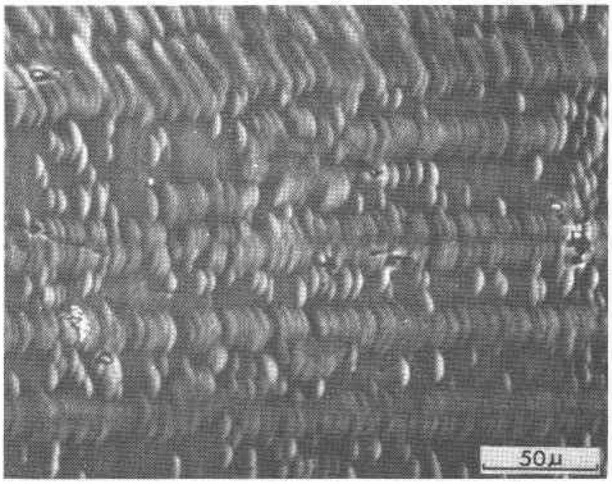


(a)

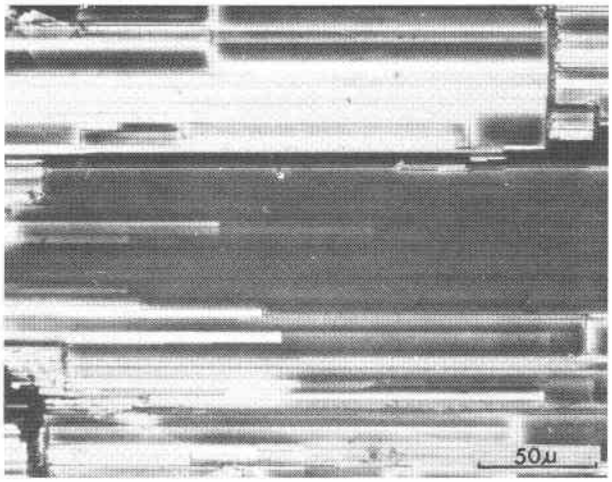


(b)

FIG. 7. Internal heterogeneity of smaller crystals (a) and larger crystals (b) from the Shakanai mine. Note the difference between the two.



(a)



(b)

FIG. 8. Phase contrast photomicrograph of surface microtopographies of (210) faces of pyrite crystals with negative striations from the Ani mine. (a) first type, (b) second type.

show a simple pentagonal habit. The {210} faces exhibit negative striations, which are quite clear and straighter than those observed on the crystals from the Shakanai mine. It is interesting to note that in the Ani mine, even pyrite crystals in the bedrock matrix exhibit a simple pentagonal habit with negative striations. This is especially noteworthy because, according to previous observations (Sunagawa, 1957), pyrite crystals in bedrock are in most cases simple cubes, irrespective of the habit of pyrite crystals in the ore deposits. Two types of negative striations exist. One is essentially the same as the previous case and consists of a large number of small growth pyramids. The other is characterized by the development of extremely straight parallel lines. In the former case, the growth pyramids are trapezoidal in form and aligned in rows parallel to the negative direction (Fig. 8a). In the latter case, the straight-line striations are inferred to be elongated rectangular growth layers (Fig. 8b). Therefore, in both cases the negative striations are associated with the growth layers freely developed on the {210} faces.

The internal heterogeneity of the crystals from the Ani mine was studied by the same method and under the same conditions as those from the Shakanai mine. In contrast to the Shakanai crystals, all were practically homogeneous from the center to the surface, core and mantle being indistinguishable. This homogeneity suggests that there was no stage of formation of positive striations in the Ani crystals and that they may have grown in pentagonal habit from their very beginning.

Pyrite crystals showing negative striations are also found in vein-type deposits at the Osarizawa mine, Akita Prefecture, and at the Washiaimori mine, Iwate Prefecture. Surface microtopographies of their {210} faces resemble those of the second type observed in the crystals from the Ani mine (Fig. 8b).

Conclusion

Observations of the surface microtopography and of internal heterogeneity of pyrite crystals with negative striations collected from four localities in Japan lead to the following conclusions:

(1) Positive and negative striations have different origins. The positive striations are associated with the pile up of edges of growth layers developed on the {100} faces. No free development of growth layers is noticed on the {210} faces with positive striations, conveying the impression that such {210} faces may be *S*-faces. The negative striations may be closely associated with the free development of growth layers on the {210} faces, suggesting that such {210} faces are *F*-faces.

(2) There is apparently an abrupt change in the growth process between the stages of formation of positive striations and negative striations, respectively. In the case of crystals from the Shakanai mine, positive striations may have possibly been formed at an early stage, whereas negative striations may have been formed only at a later stage. In the case of crystals from the Ani mine, it is considered possible that there was no stage of formation of positive striations.

(3) From the above observations and the fact that crystals with negative striations occur only occasionally and, when they do occur, most pyrite crystals embedded in the neighboring bedrock also show negative striations, it is conjectured that only under certain conditions do growth layers develop freely on the {210} faces, which in turn results in the appearance of negative striations.

The specific conditions required for the formation of negative striations are not yet clear. However, the most reasonable explanation may be impurity adsorption. Although electron probe microanalysis and laser spectroscopic analysis were applied to find the chemical difference between the mantle and core portions of the Shakanai specimens, the results were inconclusive in that no significant differences were detected. Colorimetric analyses were kindly made of Co contents in bulk crystals of different sizes by Professor H. Sakai of Okayama University, as shown in Table 1. A clear decrease in Co contents was noticed as crystals become larger. However, this again does not provide conclusive correlation, except that the mantle portion may contain less Co than the core portion. What impurities one might suspect to be responsible for their genesis, therefore, remains to be solved in future studies.

Table 1. Cobalt content in pyrite from the Shakanai mine

Grain size (mesh)	5	10	20	40	80
Co content (ppm)	1.5	2.5	3.0	4.4	6.4

Acknowledgment

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