ble to the study of other sluggish phase transformations when it is important to know the true equilibrium crystal structure for a given temperature. The principal limitation is availability of solvents which do not contaminate the crystallizing phase under study.

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A DISTINCTION BETWEEN NATURAL AND SYNTHETIC EMERALDS

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Introduction

When crystals are grown under different physico-chemical conditions, their crystal faces exhibit different growth patterns. Growth patterns on crystal faces vary so sensitively according to the differences in growth conditions that one can easily notice the difference in localities if he observes surface structures of crystal faces under a reflection microscope. The writer previously reported in this journal that hematite crystals from different localities exhibit different characteristics of surface structures, from which he deduced the differences in supersaturation conditions of hematite formation between each locality (Sunagawa, 1962). Tolansky and Sunagawa (1959, p. 60) also observed distinct differences of surface structures of crystal faces between natural and synthetic diamonds and discussed the differences of mechanism and conditions of crystal growth between the two diamonds.

A result of comparative studies on the surface structures of crystal faces of natural and synthetic emeralds will be reported in this paper. The present observations using a reflection and phase contrast microscope have shown that a clear distinction can be made between natural and synthetic emeralds. These observations have also given information concerning the differences in conditions of crystal growth between the two emeralds, which will also be discussed in this paper.

A hexagonal prismatic crystal of Chatham's synthetic emerald was kindly offered by Dr. Ruth Weiner of the Johns Hopkins University. A hexagonal prismatic natural emerald crystal of gem quality embedded in biotite schist from the Urals, another prismatic crystal of poor gem quality from South Carolina as well as several beryl crystals from Japanese localities were investigated for comparison.

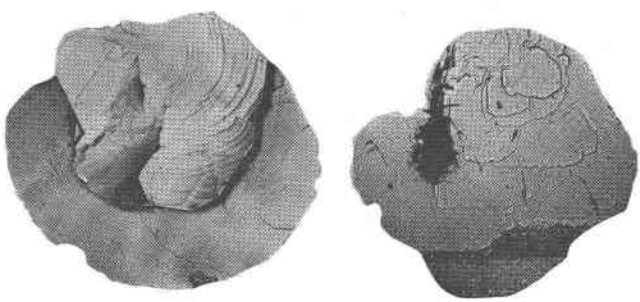
Although most of the natural crystals examined, except the one from the Urals, are not of gem quality but near ordinary beryl in their color, it is considered that there is value in comparing those with synthetic emerald for the following reasons:

1. Emerald is after all a mere variety of beryl which contains some Cr_2O_3; 2. Although most gem-quality emeralds occur in schistose rocks, some occur in pegmatites or veins in limestones; 3. Synthetic emeralds are said to be grown by means of hydrothermal processes that resemble somewhat growth conditions of pegmatitic beryl.

The main comparison has been made between Chatham's synthetic crystal and a natural one from South Carolina; natural crystals from the other localities have been used for reference.

Observations

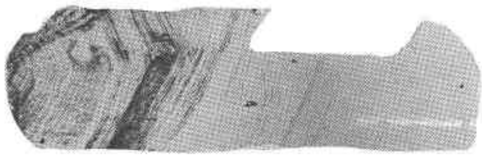
Figures 1a and b are low-magnification reflection photomicrographs of the $\{0001\}$ faces of Chatham's emerald and of natural emerald from South Carolina, respectively. Distinct differences can be seen on these photomicrographs; that is, the surface of the synthetic crystal exhibits strong distortion and twist, and growth layers originate from the ends of twist boundaries, whereas that of the natural crystal is flat, and twist of the surface is not observed. The growth layers on the former take on circular form, whereas those on the latter assume a slightly deformed hexagonal form. Figures 2a and b are similar photomicrographs of $\{10\bar{1}0\}$ faces of the synthetic and natural emeralds, respectively. It can be observed that the synthetic crystal shows rectangular growth layers



(a) (b)

FIG. 1. Photomicrographs of $\{0001\}$ faces of synthetic (a) left and natural (b) right emerald crystals. ×5.

(a)

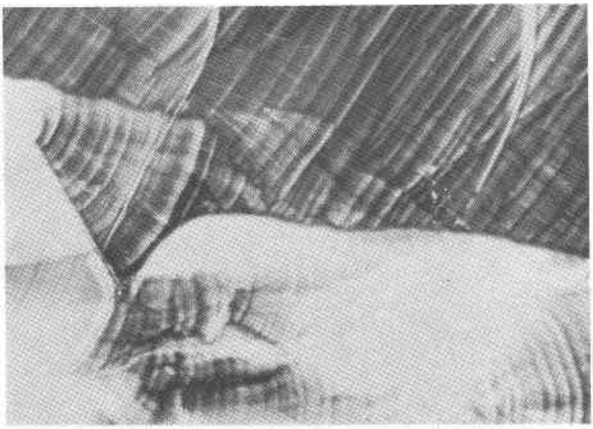


(b)

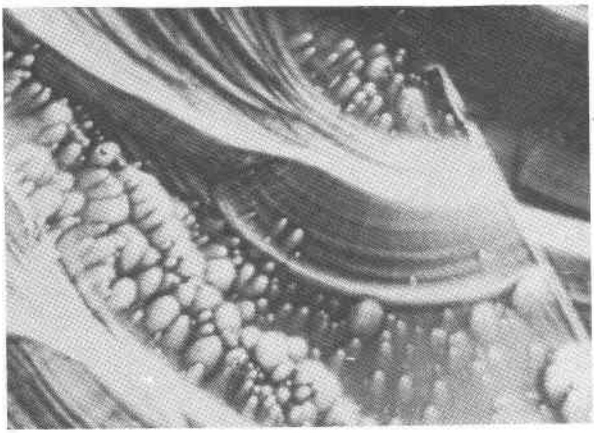
FIG. 2. Photomicrographs of $\{10\bar{1}0\}$ faces of synthetic (a) (upper) and natural (b) (lower) emerald crystals. $\times 5$.

having longer sides parallel to the edges between the prism faces, whereas the natural one shows rhombic growth layers that have their longer diagonals normal to the edges. The main growth centers are situated at the center of the face in the former case, whereas they occur near the bottom of the crystal in the latter case.

Figures 3a and b are phase contrast photomicrographs of a part of the (0001) face of the synthetic emerald. Three characteristic features are noticeable on these photomicrographs: one is that growth layers are so closely spaced that edges of individual growth layers cannot be resolved, which results in a profile of curved steps instead of an ordinary step-wise profile; the second is that growth layers have spiral characters starting from the ends of twist boundaries; and the last is that there are many tiny conical hills in addition to the main growth layers. These conical growth hills are concentrated in several small areas on the surface and are found to be spirals, which were revealed under higher magnification. In contrast with these features, the (0001) face of the natural emerald from South Carolina exhibits quite different growth features, which can be seen on the phase contrast photomicrograph shown in Fig. 4. On this surface are many growth spirals, most of which are composite spirals. The spiral growth layers originate either from clusters of screw dislocations or aligned screw dislocations. The spacings between successive spiral layers are much wider than those observed on the synthetic crystal, and hence the profile is step-wise, not of curved steps as in the case of the synthetic crystal. No tiny conical growth hills similar to those observed on the synthetic crystal have been observed on this surface. Two-



(a)



(b)

Fig. 3 a, (upper) b (lower). Phase contrast photomicrographs of (0001) face of synthetic emerald. ×150.

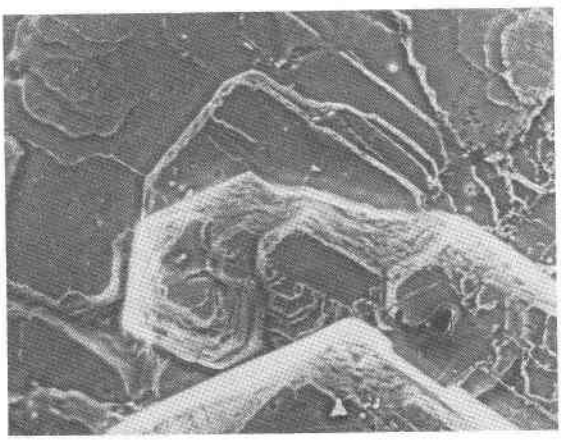
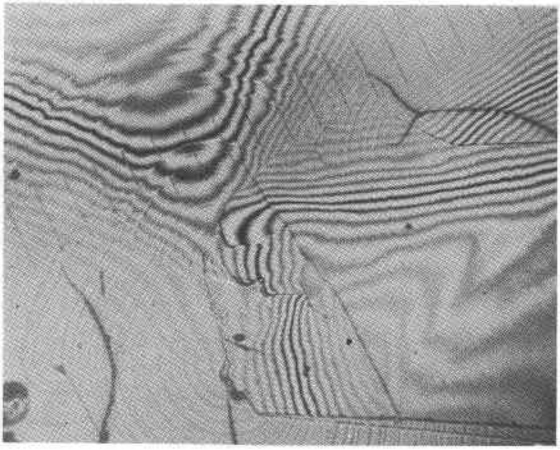
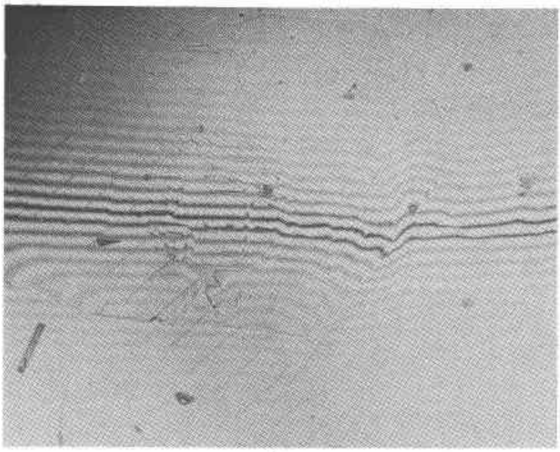


Fig. 4. Phase contrast photomicrograph of (0001) face of natural emerald from South Carolina. ×150.



(a)

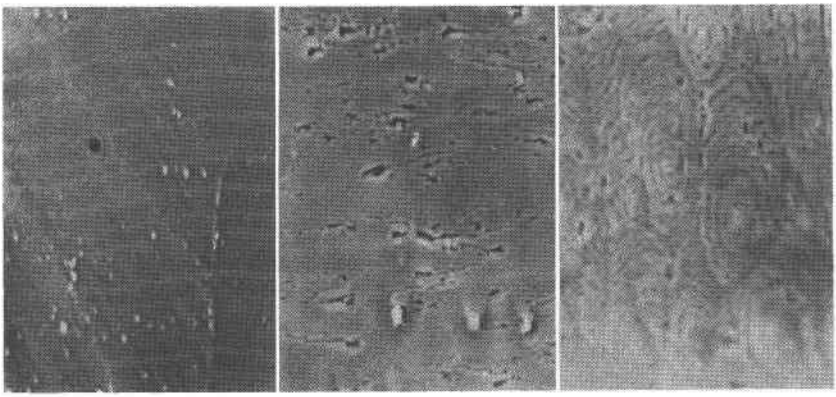


(b)

FIG. 5. Two-beam interferograms of (0001) faces of synthetic (a) (upper) and natural (b) (lower) emeralds. ×45.

beam interferograms (Figs. 5a and b) clearly show the differences in step heights of growth layers, the profile of spirals, and the flatness of the surfaces between the two emeralds.

Figures 6a, b and c are phase contrast photomicrographs of $\{10\bar{1}0\}$ faces of the synthetic emerald. Figure 6a, which is taken under lower magnification, shows two features: 1) white, nearly parallel, curved lines that look like edges of growth layers and 2) many small dots scattered over the surface. A high magnification photomicrograph (Fig. 6b) discloses that between the successive white parallel lines are many faint lines nearly parallel to the former. This shows that the former lines are edges of bunched growth layers and the latter faint lines are those of individual growth layers. In other words, the prism face consists of very closely spaced growth layers which originate from screw dislocations situated at the center of the face. The low visibility of the latter lines under a phase contrast microscope shows that the heights of individual growth layers are very small. A still higher magnification photomicro-



(a) (b) (c)

FIG. 6. Phase contrast photomicrographs of $(10\bar{1}0)$ face of synthetic emerald. a—×105, b—×420, c—×1050.

graph (Fig. 6c) demonstrates that the scattered dots actually consist of individual oval-shaped spirals. Some parts of faint growth layers described above are certainly derived from these spirals.

Phase contrast microscopic observations of the $\{10\bar{1}0\}$ faces of natural emerald from South Carolina have shown that the surface consists of growth layers originating from one or several screw dislocation points, usually situated near the bottom of the crystal. The spirals have rhombic form (Fig. 7). The spacings between successive layers are much wider than in the case of synthetic emerald. At some places growth layers bunch together, forming thicker layers. No small conical hills like those observed on the synthetic crystal have been noted on this crystal.

It is observed on the $\{10\bar{1}0\}$ faces of the other natural emerald and beryl crystals that growth layers are thin, widely spaced and originate from clusters of screw dislocations, and that spirals are usually elongated parallel to the *c* axis and have hexagonal form, which resembles more closely the rhombic spirals observed on the crystal from South Carolina than the rectangular spirals on the synthetic crystal. It can also be noticed that many impurity crystals occur on the surfaces of both basal and prism faces of all natural crystals examined, but not on the synthetic emerald.

Summary and Discussion

From the above observations, it can be said with certainty that both synthetic and natural emeralds have been grown by spiral growth mechanism. It is also conjectured that the main growth takes place on the basal plane at the early stage of growth in both natural and synthetic emeralds, and after a certain volume of a crystal is formed, growth takes

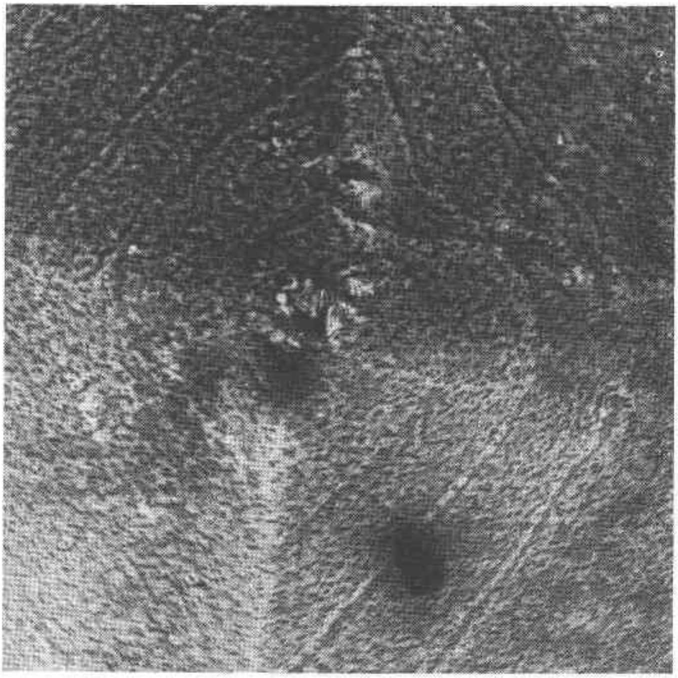


Fig. 7. An example of growth spirals observed on $(10\bar{1}0)$ faces of natural emerald. Phase contrast. ×210

place also on the prism faces, since there are many main growth centers on the basal plane, whereas only a few centers of main growth (not local growth centers) are found on the prism faces in both cases. In this respect, that is, so far as growth mechanism is concerned, no fundamental difference is noticed between natural and synthetic emeralds. However, there are distinct differences in the growth features which is the reflection of growth conditions between the two emeralds as summarized below.

1. Growth layers of synthetic emerald are very closely spaced, whereas those of the natural one are widely spaced.
2. Considerable distortion and twist of the surface are observed on the synthetic one, but not on the natural one.
3. Growth spirals of synthetic emerald originate both from the ends of twist bound-

aries (main growth layers) and many individual screw dislocations which are widely distributed (local growth layers), whereas those of natural emeralds originate from either clusters of screw dislocations (basal faces) or a few single screw dislocation points (prism faces).

4. Growth spirals of the two show different morphologies.
5. Many impurity crystals are observed on the surfaces of natural crystals, but not on the synthetic crystal.

From these observations the differences in growth conditions between the two emeralds can be conjectured as follows:

1. Since spiral growth layers will have closer spacings when spirals are formed under higher supersaturation and *vice versa*, it is concluded that synthetic emerald has grown under much higher supersaturation conditions than natural emeralds.
2. Closer spacings of growth layers also suggest that synthetic emerald has grown more rapidly than natural emerald.
3. Synthetic emerald has grown from purer solutions than has the natural species.
4. Synthetic emerald has undergone stronger stresses than natural ones during growth.

In conclusion, synthetic emerald can be easily distinguished from natural crystal under the reflection or phase contrast microscope, so far as they show growth crystal faces. Such differences in surface structures of crystal faces are derived from the differences in growth conditions between the two emeralds.

Acknowledgment

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RE-EXAMINATION OF "STRUVERITE"—A FURTHER NOTE

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In a paper on "struverite" from Malaya published in *The American Mineralogist* (Flinter, 1959) I found (p. 622–3) that although the original assay by Crook and Johnstone showed the mineral to be Ta-rich, my material was Nb-rich. From this I concluded that either my material was not representative of the original sample or that the original analysis was in-