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ANAUXITE AND KAOLINITE STRUCTURES IDENTICAL

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Abstract—Single crystal X-ray diffraction patterns reveal that the structure of selected anauxite crystals is the same as the structure of macroscopic kaolinite crystals. Anauxite and kaolinite crystals are intergrowths on a domain scale of units in pseudotwin orientations. Individual domains in anauxite have the triclinic geometry of kaolinite, and give X-ray reflections that compare closely in intensity with those calculated from the atomic parameters of kaolinite. Large crushed crystals of anauxite give powder patterns identical with that of kaolinite. Because it has been shown recently that the chemical composition of anauxite is also identical with that of kaolinite, it is recommended that the term "anauxite" no longer be used.

INTRODUCTION

LANGSTON and Pask (1968) show that anauxite specimens contain a crystalline material with the chemical composition of kaolinite ($2SiO_2 \cdot Al_2O_3 \cdot 2H_2O$) as well as amorphous silica. Their work accounts for the variable amounts of "excess silica" (above that found in kaolinite) that has been reported for anauxite specimens by Allen (1928), Ross and Foshag (1928), and other workers. It is no longer necessary to postulate a kaolinite–anauxite isomorphous series (Ross and Kerr, 1930) or a structural interlayering of double silica sheets with kaolinite type layers (Hendricks, 1942) to account for the variation in silica content that is found in different anauxite specimens.

Hendricks (1929, 1936), Ross and Kerr (1930), Gruner (1932), Brindley (1961), and others indicate the X-ray diffraction powder patterns of anauxite and kaolinite are identical. The existence of a separate card (2–0204) for anauxite in the Powder Diffraction File, however, implies that this identity is not universally accepted. The work of Langston and Pask (1968) confirms that the anauxite structure is similar to that of kaolinite, but their work was not of sufficient precision to eliminate the possibility that there might be slight structural differences that would not show up in the powder patterns.

MATERIALS

Anauxite crystals from four of the anauxite rock specimens studied by Langston and Pask (1968) were used in this investigation. The identification numbers used in this work correspond to their numbers. A more complete description of the materials can be found in their paper.

Anauxite-2*a* and anauxite-2*c* were collected at a recent road cut in the southern portion of the Ione Formation. Anauxite-3 and anauxite-4 are considered to be type materials that were used in some of the early anauxite evaluations. Anauxite-3 from the Ione Formation was received from C. S. Ross of the U.S. Geological Survey and is a portion of the material collected and described by Allen (1928). Anauxite-4, from near Bilin, Czechoslovakia, is described in Ross and Foshag (1928). This portion of their sample was received from the Smithsonian Institution.

Six macroscopic "anauxite" crystals, about 0·2–0·4 mm in diameter, were selected from each of the four "anauxite" rocks. Single crystal X-ray patterns (Laue, oscillation, precession, and Weissenberg) were taken of all of the 24 crystals. The above flakes were selected as their basal surfaces were reasonably flat, rather than curled or crinkled. For this reason, the flakes examined tend to be the best ones. Some optical and X-ray diffraction studies were also made on flakes as large as $2{\cdot}0 \times 1{\cdot}5 \times 0{\cdot}5$ mm that were taken from the anauxite-2*a* specimen.

RESULTS AND DISCUSSION

All of the single crystal X-ray diffraction patterns taken were remarkably similar to one

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another, despite some differences in morphology, color, and luster of the crystals. In turn, these photographs were practically identical with similar photographs from over 100 macroscopic crystals of sedimentary kaolinites taken in a study by Mansfield and Bailey (in preparation).

The distinctive feature about these crystals is that they are intergrowths on a domain scale of pseudotwin and twin units, which show up on the films as superimposed diffraction patterns. Because of this superimposition, it is possible to reconstruct the geometric relationships of the domains despite the mosaic spread of the reflections. All 24 of the anauxite crystals as well as most of the sedimentary kaolinites show two types of intergrowths. First, there is rotation of $\pm 120°$ about the cleavage normal Z^* to create three individual orientations of the lattice. The geometric orientations produced must be described as pseudotwin intergrowths because the "twin" axis Z^* does not coincide exactly with any row line of the direct lattice. Z^* deviates from the direct row line [103] by 2° 03′ because of the triclinic geometry of kaolinite. Second, a twinning operation that has not yet been defined precisely creates six lattice orientations from the original three. The geometric relations involved are to be described in more detail by Mansfield and Bailey.

The individual domains in anauxite were shown to be true kaolinite by several lines of evidence.

(a) The pseudotwin intergrowths are identical with those observed for macroscopic crystals of known kaolinite.

(b) Kaolinite X-ray powder patterns were obtained by crushing large crystals of anauxite.

(c) Triclinic cell dimensions and cell angles obtained from the single crystal photographs are identical to those obtained for kaolinite by Newnham (in Brindley and Nakahira, 1958).

(d) The intensities of about 80 single crystal reflections that are not overlapped by pseudotwin reflections compare closely with those calculated from the atomic parameters of kaolinite listed by Drits and Kashaev (1960).

The anauxite crystals are just as well crystallized as authigenic sedimentary kaolinites. Aside from appreciable mosaic spread found in all anauxite and kaolinite specimens, the $k \neq 3n$ reflections of anauxite are discrete and do not have any interconnecting streaks due to stacking disorder. Weissenberg photographs are necessary to resolve these reflections, however, because of the near overlap by reflections from the pseudotwin intergrowths. Precession photographs do not resolve these reflections sufficiently, and this probably accounts for the statement by Allen *et al.* (1969) that Ione Formation anauxite is partially disordered kaolinite.

The above results, obtained on 0·2–0·4 mm crystals, were not changed when larger crystals ($2{\cdot}0 \times 1{\cdot}5 \times 0{\cdot}5$ mm) were studied, although the X-ray spots were larger and the resolution was not as good. Petrographic examination of semi-globular masses, up to 2 mm in size, revealed that the smaller single crystals can occur in closely-intergrown aggregates, and that these may be cemented to one another within the aggregates by amorphous silica. The 0·1–1·0 mm crystals in such an aggregate do not have any close orientation relationship to one another and cannot be considered single crystals.

CONCLUSIONS

1. "Anauxite" crystals are not unique. Use of the term "anauxite" should be discontinued. The chemical composition and the crystal structure of the large crystals found in "anauxite" rock specimens are similar in all respects to the composition and structure of authigenic kaolinite examples.

2. The perfection of crystallinity in these large crystals is also as good as in the kaolinite examples. No diffuse scattering between $k \neq 3n$ reflections was observed that would indicate any appreciable disorder of stacking. Amorphous silica may be cementing individual crystals together into aggregates, but the observed perfection of layer stacking precludes interruption of the periodicity by amorphous silica or by double silica sheets within individual crystals.

3. Card No. 2-0204 for Bilin anauxite should be deleted from the Powder Diffraction File.

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Résumé – Des modèles de diffraction de rayons X par des cristaux simples révèlent que la structure des cristaux d'anauxite choisis est la même que celle des cristaux macroscopiques de kaolinite. Les cristaux d'anauxite et de kaolinite sont des enchevêtrements, à l'échelle d'une région, d'éléments présentant des orientations pseudojumelées.

Des régions entières d'anauxite ont la géométrie triclinique du kaolinite et les réflexions de rayons X sont, en intensité, très proches de celles calculées à partir des paramètres atomiques du kaolin. De gros cristaux d'anauxite écrasés donnent des poudres identiques à celles du kaolinite. La composition chimique de l'anauxite, comme on l'a récemment montré, étant également identique à celle du kaolinite il est conseillé de ne plus employer désormais le terme "anauxite".

Kurzreferat – Aus den Röntgenbeugungsbildern von Einzelkristallen ergibt sich, dass das Gefüge ausgewählter Anauxitkristalle dem Gefüge von makroskopischen Kaolinitkristallen gleich ist. Anauxit und Kaolinit Kristalle zeigen Pseudozwillingsverwachsungen. Einzelbereiche im Anauxit weisen die trikline Geometrie von Kaolonit auf und geben Röntgenbeugungen, die in ihrer Intensität eng mit den aus den atomaren Parametern des Kaolinits berechneten übereinstimmen. Grosse, zermahlene Anauxitkristalle geben Pulverbilder, die mit denen des Kaolinit identisch sind. Da kürzlich auch dargelegt wurde, dass die chemische Zusammensetzung des Anauxits identisch mit der des Kaolinits ist, wird empfohlen den Namen "Anauxit" in Zukunft nicht mehr zu gebrauchen.

Резюме—Картины монокристальной рентгеновской съемки показывают, что кристаллы аноксита, выделенные из его агрегатов, имеют ту же структуру, что и макроскопические кристаллы каолинита. Кристаллы аноксита и каолинита представляют сростки в доменной области, индивиды которых находятся в псевдодвойниковой ориентировке. Отдельные домены в аноксите имеют триклинную геометрию каолинита и дают рефлексы на рентгенограммах, которые по интенсивности сравнимы с вычисленными по атомным параметрам каолинита. Крупные дробленные кристаллы аноксита дают порошкограммы, аналогичные порошкограммам каолинита. Так как недавно было доказано, что аноксит и по химическому составу аналогичен каолиниту, то рекомендуется название "аноксит" впредь не употреблять.

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