Clays and Clay Minerals, Vol. 30, No. 5, 391–393, 1982.

NOTES

ANAUXITE VIEWED BY SCANNING ELECTRON MICROSCOPY

Key Words—Anauxite, Energy dispersive X-ray analysis, Kaolinite, Morphology, Scanning electron microscopy, Silica.

The clay that has been called anauxite, and grouped with the kaolin minerals, is characterized by a higher ratio of silica to alumina than is expressed in the formula of kaolinite (elemental ratio, Al:Si as 1:1). Dittler and Hibsch (1923) assigned to anauxite an Al:Si ratio of 6:10, or 1:1.6667, whereas Allen (1928) and Ross and Foshag (1928) found chemical analyses that suggested a ratio close to 2:3 or 1:1.5. The Si in excess of that in the kaolinite portion of anauxitic materials has been variously interpreted as being located within the crystals, as double layers of silica on or between kaolinite layers, and as impregnations of colloidal, presumably noncrystalline, silica. Bailey (1980) succinctly described the status of anauxite as a mineral species: "The species anauxite, originally believed to have a higher ratio of SiO_2:Al_2O_3 than kaolinite, has been discredited and shown to be a mixture of kaolinite and amorphous silica."

The purpose of this note is to show scanning electron micrographs of two anauxitic materials and the distribution of various Al:Si ratios with individual specimens. The results graphically support Bailey's appraisal and the interpretation of the origin of anauxite by Allen *et al.* (1969).

MATERIALS AND OBSERVATIONS

Pearly anauxite clay in altered basalt from Bilin, Czechoslovakia, was kindly supplied by Prof. Jiri Konta, Prague. T. F. Bates and V. T. Allen furnished anauxitic clay from the Ione Formation, California.

The typical morphology of the Bilin material is shown in Figure 1 at relatively low magnification. In comparison to most kaolinite, the "anauxite crystals" from Bilin and Ione are large, coarse, compact stacks of plates, commonly vermicular, that break with well-defined fracture surfaces. Furthermore, the individual platy crystals generally are not expanded as much as the accordion-like stacks of crystals in kaolinite that, of course, does not contain excess silica.

A clue to the host of free silica in anauxitic materials is seen in the micro-globular material in the left side of Figure 1 and magnified in Figure 2. Energy dispersive X-ray analysis (EDX) using a KEVEX apparatus was used to determine Al and Si energy "counts." From these data Al:Si ratios using both spot and area modes of scanning were recorded. Spot 1, counting for 100 seconds, yielded 2.2612×10^4 counts for Si and 0 counts for Al. Area 2 showed 2.9024×10^4 counts for Si and 0 counts for Al. Spots 3 and 4 registered Al:Si ratios of 1:42.51 and 1:45.36, respectively. These micro-spherulitic crusts clearly are silica lepispheres, which typically consist of opal-CT when they occur in precursor deposits of cherts. At spot 5 the recorded Al:Si ratio was 1.00:1.954; at spot 6, 1.00:2.167; at spot 7, 1.00:1.950; and at spot 8, 1.00:2.419.

Duplicate runs on the same spot or area usually yielded results within 0.02 ratio units of each other. The Al content may have been slightly underestimated because of partial absorption of Al counts by the Be window of the detector (personal communication from Robert Irwin, KEVEX corporation). If so, the Al:Si ratio should be increased by probably 5% to 10% of its stated value. However, pending more accurate calibration, the unmodified instrumental data are presented because they give undistorted comparisons between the specimens analyzed.

The area above the letter "A" in Figure 1 is a fracture surface and is enlarged in Figure 3. The corrugated pattern on the edges of the clay probably represents silica-rich extensions of

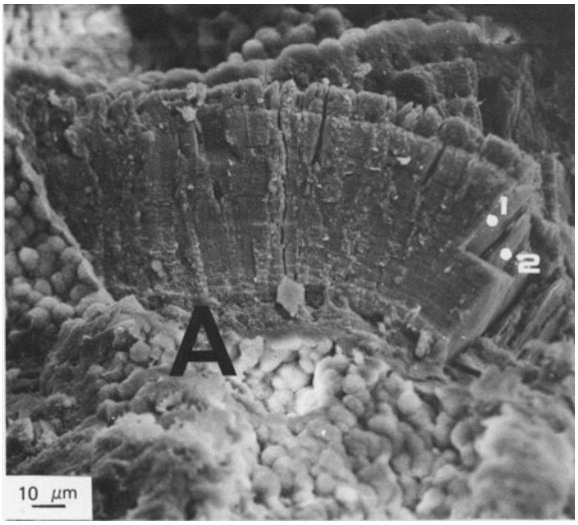

Figure 1. Scanning electron micrograph of anauxitic clay from Bilin, Czechoslovakia. "Anauxite" crystals are coarse, compact (cemented?), and break along fracture or other divisional openings.

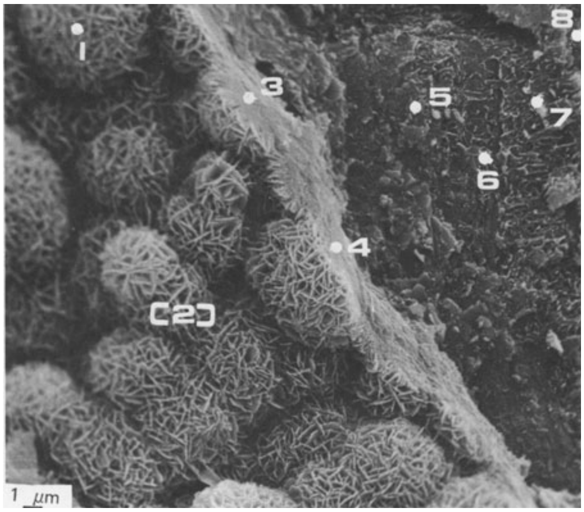

Figure 2. Enlarged part of left edge of Figure 1. Note close association of silica lepispheres with the platy material.

Figure 3. Magnified view of the central "A" portion of Figure 1 along a fracture surface which probably served as an avenue for impregnation by silica-bearing solutions.

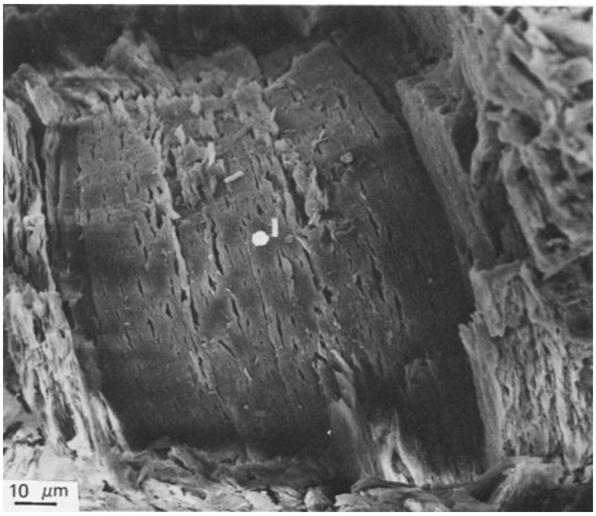

Figure 5. Scanning electron micrograph of an anauxitic stack of plates from the Ione sample showing tight compaction, but replete with tiny lenticular solution (?) vugs. Fracture is apparently along a divisional opening.

the clay flakes. Spots 1, 2, and 3 gave Al:Si ratios of 1.00:2.242, 1:2.175, and 1:2.062, respectively. Nonuniformity in composition (i.e., excess silica), which characterizes anauxitic materials, is contraindicative of the uniformity in composition which is an attribute of a monomineralic material.

The Ione clay shown in Figures 4 and 5 occurs in crystals and stacks that are relatively large, a property that also characterizes the Bilin material. The Ione stacks, or portions of them, are commonly bent and/or twisted. Such deformation is interpreted as resulting from secondary packing of the clay around sand grains, a sedimentary process that was not a part of the hydrothermal origin of the Bilin anauxite. An EDX scan of the entire area of Figure 4 yielded an Al:Si ratio of 1.00:1.349.

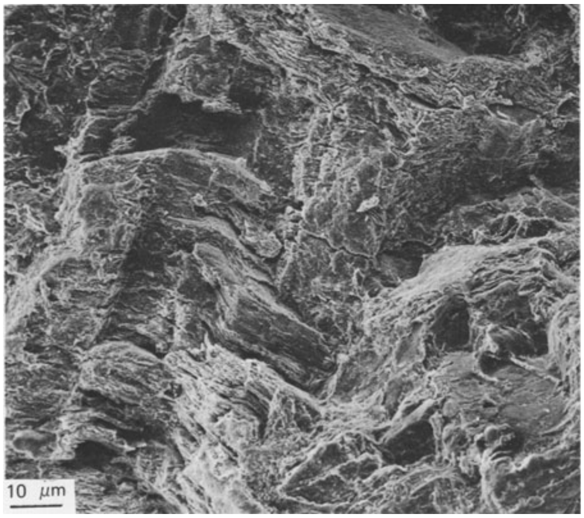

Figure 4. Scanning electron micrograph of anauxitic clay from the Ione Formation, California. Crystal stacks are slightly twisted.

Figure 5 shows a tightly cemented crystal stack replete with microvugs. Spot 1 on a solid clay portion gave an Al:Si ratio 1.00:1.214, but the entire face of the stack was higher in silica, and yielded an Al:Si ratio of 1.00:1.895, presumably the result of extra silica in the vugs.

DISCUSSION

The Al:Si ratios in anauxite clay from Czechoslovakia and California vary from about 1.00:1.51 to 1.00:2.53. The ratios are lowest on fresh basal cleavage faces and highest on fracture surfaces cutting across the stacks of plates. Because the 1.51 ratio is close to those estimated from bulk chemical analyses made 50 years ago, this value probably represents a "normal" soaking by silica and impregnation between cleavages plates. The higher Si content along planes opened by fracture or dissolution and along crystal boundaries represents further enrichment by silica in micro-vein fillings.

The Bilin clay originated during the hydrothermal alteration of basalt, in which augite and/or biotite were altered to, or replaced by, anauxitic material. Solutions saturated in silica that were present during and possibly after the alteration are likely sources of silica for cement between plates, fracture fillings, and lepispheres.

For the California clay, Allen *et al.* (1969) suggested that "The excess silica may be in the form of amorphous colloidal silica, and may have been deposited irregularly within the kaolinite platelets after their deposition. A possible source of the amorphous silica was the clay-rock which overlies the sandstone of the Ione Formation unconformably and is the lowest member of the rhyolitic series. The alteration of volcanic glass to clay minerals is recognized in other regions as furnishing silica that is deposited lower stratigraphically." The micrographs presented herein thus are in accord with the interpretation of these authors.

The notably compact stacking of the kaolinite plates in these specimens is probably due to the cementing properties of the silica which permeated through the stacks. Less clear, however, is a reason for the rather consistent, very large size of crystal stacks observed in these anauxitic materials. The stacks are larger, on the average, than the stacks generally observed in typical (or normal) kaolinite—why? Equally intriguing is the question, why does not more "anauxite" occur in hydrothermal deposits of kaolin, for example, in Mexico and Japan where excess silica is present in disseminated microscopic crystals, instead of impregnations that characterize "anauxite"?

CONCLUSIONS

Scanning electron microscopy shows that anauxitic clay from Czechoslovakia and California consists of similar stacks of kaolinite flakes that are notably larger and more tightly packed (cemented?) than typical kaolinite. Silica lepispheres are closely associated with the Czechoslovakian material. Elemental Al:Si determined by EDX methods vary widely in these clays. These observations support the interpretation that silica solutions present during and/or after crystallization of the clay impregnated the clay with noncrystalline silica, apparently between cleavage plates and along fractures, solution micro-cavities, and divisional openings. Questions remaining unanswered are why does anauxitic kaolinite occur in relatively large crystals compared to monominerallic kaolinite, and why is it not geologically more abundant, especially in hydrothermal kaolin deposits.

Department of Geology
University of Missouri
Columbia, Missouri 65211

WALTER D. KELLER

REFERENCES

Allen, V. T. (1928) Anauxite from the Ione Formation of California: *Amer. Mineral.* **13,** 145–155.

Allen, V. T., Fahey, J. J., and Ross, M. (1969) Kaolinite and anauxite in the Ione Formation, California: *Amer. Mineral.* **54,** 206–211.

Bailey, S. W. (1980) Structures of layer silicates: in *Crystal Structures of Clay Minerals and Their X-ray Identification,* G. W. Brindley and G. Brown, eds., Mineralogical Society, London, 1–124.

Dittler, E. and Hibsch, J. E. (1923) Über anauxit und cimolit von Bilin: *Tschermaks Mineral. Petrogr. Mitt.* **36,** 85.

Ross, C. S. and Foshag, W. F. (1928) Anauxite, a mineral species, based on material from Bilin, Czechoslovakia: *Amer. Mineral.* **13,** 153–155.

(Received 20 July 1981; accepted 21 December 1981)