ANAUXITE FROM THE IONE FORMATION OF CALIFORNIA

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ABSTRACT

A mineral having the composition of 5 $H_2O \cdot 2\ Al_2O_3 \cdot 6\ SiO_2$ and for which the name ionite was proposed,[1] forms an important part of the Ione formation of California. Recent work shows that it is probably identical with anauxite from Bilin. Evidence is given which indicates that it is formed from biotite or chlorite by loss of magnesium, calcium, iron, and alkalies and with corresponding increase in water. Chemical analyses and optical data are given. An explanation of the occurrence of rutile in clays is offered.

While mapping the Jackson Quadrangle, H. W. Turner observed a micaceous mineral with pearly luster in the Ione formation. In his paper[2] on the Rocks of the Sierra Nevada he published the following statement regarding it.

> "Very characteristic of the sandstone of the Ione formation are pearly scales of a foliated mineral allied to kaolin. In some cases these scales are colored red by hematite, as in the red sandstone at the quarry southeast of Ione. The mineral under the microscope shows very low polarization colors and seems to extinguish parallel to the basal cleavage lines. Dr. W. F. Hillebrand separated some of this micaceous mineral by means of a heavy solution and made the analysis quoted (No. 1 in Table). A microscopic examination of the material analyzed showed only a few particles of quartz in the field of view. The foliated mineral comprised all the remainder of the material. Perhaps one or two percent might be deducted for the silica of these quartz grains.
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> "This mineral appears to resemble rectorite[3] in composition but does not show any strong double refraction.
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> "Professor S. L. Penfield has kindly examined this silicate of aluminum and writes that as it "is not clear and transparent, it is impossible to be sure that it does not contain microscopic quartz or chalcedony silica deposited on it," and is inclined to consider the mineral an impure kaolinite, notwithstanding the high percentage of silica."

The writer's attention was called to this mineral on account of its widespread and uniform occurrence in the Ione clays and sands, which are being used in the manufacture of brick and pottery. It occurs as small books or aggregates with perfect basal cleavage which are usually oriented with the cleavage parallel to the bedding

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[1] *The American Mineralogist*, Vol. **12**, p. 78, March, 1927.

[2] H. W. Turner. Rocks of the Sierra Nevada. *14th Annual Rept., U. S. G. S* pt. II, **1892**, p. 464.

[3] *Am. J. Sc.*, 3rd Series, Vol. **XLII**, p. 11, 1891.

of the rock. The edges of most flakes are irregular, but a few were found which show hexagonal outline and the angle between the faces is approximately 60° and 120°, so that the forms closely resemble those of the micas and certain chlorites. This similarity suggests that the Ione clay mineral also belongs to the monoclinic system. It is biaxial with $2V$ variable, equal to 18° in some grains and 32° as a maximum in others. It is optically negative, X is the acute bisectrix, which is very nearly normal to the (001) cleavage. Some crystals are elongated parallel to (010), the plane of symmetry, and the axial plane is parallel to that direction. The dispersion is slight, $\rho > v$. The indices of refraction were determined by the immersion method with the following results, which are the average of several determinations:

$\alpha = 1.559$, $\beta = 1.564$, $\gamma = 1.564$; $\gamma - \alpha = .005$. The value for the birefringence was checked by using a Berek compensator on thin sections cut normal to the cleavage. The extinction on most of the unbent flakes is parallel, but a few show inclined extinction with a maximum value of 4° with the cleavage. In thin section, this clay mineral is usually colorless. However, some lamellae are faintly colored brown and are slightly pleochroic. The pleochroism shows best in sections normal to (001) and the mineral appears very pale brown when the cleavage is parallel to the vibration direction of the lower nicol, and colorless when at right angles to it. The above listed optical properties are not those of kaolinite as determined by Dick[4] or Larsen,[5] nor do they agree with those of rectorite.[6]

Two samples of this pearly mineral were carefully prepared by the writer from the coarse Ione sandstone forming the banks of the Mokelumne River, one mile west of Lancha Plana, Amador County, California. Microscopic examination showed them to be remarkably pure. Dr. Clarence S. Ross of the U. S. Geological Survey has kindly separated material from the same locality, and through his courtesty the analysis of it by Mr. Fairchild is listed in the accompanying table which records the four independent analyses now available.

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[4] Allan B. Dick. Supplementary Notes on Kaolinite, *Mineralog. Mag.*, **XV**, p. 124, 1908.

[5] Larsen, E. S. *Bulletin, U. S. G. S.* **679**, p. 249, 1926.

[6] Larsen, E. S. and Wherry, E. T. Leverrierite from Colorado. *Journal Wash. Acad. Science*, Vol. **7**, p. 215, 1917.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
SiO_2	55.88	54.7	55.0	52.46	55.13	41.02	42.10
Al_2O_3	30.24	31.2	31.1	32.20	31.14	17.99	19.45
Fe_2O_3	0.42	1.2	1.4	1.69		10.50	8.20
FeO	0.16						
MgO			0.41			20.04	17.35
CaO	tr	tr	0.01	0.30			
Na_2O	0.34	x	x	0.25		tr	tr
K_2O	0.42	x	x	0.31		9.35	8.14
H_2O-	0.63	1.8	12.13	13.48	13.73	1.71	5.83
H_2O+	11.72	11.0					
TiO_2	0.50			0.55			
	100.31	99.9	100.05	101.24	100.00	100.61	101.07

x not determined.

1. Ione "anauxite." W. F. Hillebrand analyst. *14th Ann. Rept. U. S. G. S.*, pt. II, **1892**, p. 464.
2. Ione "anauxite." Mokelumne River. F. A. Moss, analyst.
3. Ione "anauxite." Mokelumne River. Prof. W. S. Morley, analyst.
4. Ione "anauxite." Mokelumne River. Mr. Fairchild, analyst.
5. Calculated composition to agree with formula $5\ H_2O \cdot 2\ Al_2O_3 \cdot 6\ SiO_2$.
6. Fresh biotite. A. Johnstone. *Quart. Jour. Geol. Society*, Vol. **45**, p. 368, 1889.
7. Biotite of composition No. 6, subjected to CO_2 water for one year. A. Johnstone.

These analyses do not differ greatly, and the SiO_2 and Al_2O_3 percentages are very close to that calculated for the formula $5\ H_2O \cdot 2Al_2O_3 \cdot 6\ SiO_2$. Water content is lower, but it is probable the iron, magnesia and alkalies occupy space not yet replaced by hydrogen.

In a preliminary paper read before the Mineralogical Society of America, the name ionite[7] was proposed for this mineral. During

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[7] Abstract. *The American Mineralogist*, Vol. **12**, p. 78, March, 1927. The designation of a hydrocarbon as ionite by Purnell in 1878 was unknown to the writer when this proposal was made.

the discussion of the paper, Dr. A. F. Rogers suggested that the properties of this hydrous silicate of aluminum were similar to those of beidellite or possibly anauxite. Beidellite is easily eliminated for it differs chemically, possesses slightly lower indices of refraction[8] and greater birefringence. X-ray patterns made on powdered crystal flakes from the Ione formation were compared with those of beidellite from the type locality and are decidedly different. The published data[9] on anauxite do not show very close agreement with the properties of the mineral in the Ione.

Messrs. Clarence S. Ross and William F. Foshag have recently investigated the anauxite from Bilin and were able to furnish material for comparison, and to contribute valuable information concerning it. The optical properties, redetermined by Ross[10] and Foshag are as follows:

Monoclinic six-sided or irregular plates with perfect basal cleavage; extinction parallel to cleavage;

$$\alpha=1.559,\ \beta=1.564\ \gamma=1.565;\ \gamma-\alpha=.006;$$
$$2V=0^\circ-42^\circ;\quad \text{negative;}\quad \text{dispersion } \rho>\nu$$

Dr. Foshag's analyses of the anauxite from Bilin indicate an alumina-silica ratio of 1:3, rather than the formula $3\ Al_2O_3\cdot 10\ SiO_2\cdot 8\ H_2O$ as previously given. The optical properties and chemical composition of anauxite as determined by them agree very satisfactorily with those of the mineral in the Ione, and show that the two are probably identical. Dr. P. F. Kerr[11] has compared the X-ray pattern of the Ione mineral with that of anauxite from Bilin, and is of the same opinion.

The field occurrence presented the first suggestion of the origin of the Ione anauxite. In tracing the Ione sandstone eastward towards Valley Springs, a weathered green mineral of a chloritic nature was found to have locally the same mode of occurrence as the anauxite to the west. Its cleavage flakes lie parallel to the bedding, and the space between the sand grains is packed with the

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[8] E. S. Larsen and E. T. Wherry. *Jour. Wash. Acad. Science*, Vol. **7**, pp. 207–17, 1917; and Vol. **15**, p. 465, 1925.

C. S. Ross and E. V. Shannon. *Jour. Wash. Acad. Science*, Vol. **15**, p. 467, 1925.

[9] E. Dittler und J. E. Hibsch. Über Anauxit und Cimolit von Bilin. Tschermak's Mineralogische und Petrographische Mitteilungen. Bd. **36**, p. 85 (1923).

[10] See following article in this Journal.

[11] Personal communication.

foliated green mineral. The field relations and a study of the heavy separates show that this bed is a part of the same formation, being deposited during the progressive overlap of the Ione Formation to the east. Thin sections of the sandstone containing chlorite show several grains of feldspar sufficiently fresh to show the twinning lamellae. Feldspar is absent from the sections containing anauxite, which seems to indicate that anauxite develops under conditions that remove the feldspar. The chlorite itself is cut by innumerable small veinlets of anauxite (Fig. 1) which stand out prominently under high magnification, due to a lack of color and to a lower index of refraction, and under crossed nicols show lower birefringence. The chloritic mineral is thus replaced by parallelly oriented anauxite, and grains are present which consist mostly of chlorite with little anauxite, while others are nearly all anauxite with only traces of the original chlorite. The similarity of crystal form and optical orientation suggests that anauxite inherits these from chlorite, and the change in chemical composition causes a loss of color, lower refringence and birefringence and in most cases an increase in the size of the optic angle. Zschimmer[12] in his work on the bleaching of biotite found that as the specific gravity decreased, due mainly to a loss of iron, calcium and potash and corresponding increase in water,

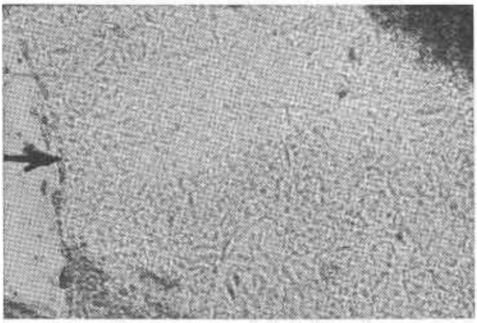

Figure 1

Chlorite, (dark), being replaced by veins of anauxite (white). Ordinary light. X230.

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[12] Eberhard Zschimmer. Die Verwitterungsprodukte des Magnesiaglimmers und der Zusammenhang zwischen chemischer Zusammensetzung und optischem Achsenwinkel der Glimmer. Inaugural Dissertation, Jena, 1898.

the pleochroism disappeared, the index of refraction decreased and the optic axial angle increased. This alteration is not wholly comparable to the development of anauxite, as it takes place under conditions which produce a golden colored mica that is a stable product for those conditions. But, the results are valuable because they show that a considerable change in composition can take place along these lines and the mineral retain its orientation, while certain optical properties vary with the composition. The analyses of the Ione anauxite show only small residual amounts of iron, magnesium, calcium and alkalies and its optical properties are in accordance with what one would expect by analogy with the above.

In preparing samples of the Tertiary stream gravels of the Sierra Nevada for microscopic study by boiling in HCl, the writer found that the chlorite changes to a pearly white mineral, the refractive indices of which are much lower than those of the chlorite before treatment. The chemical composition of this pearly substance was not determined, but it has the characteristic surface appearance of the Ione anauxite and it retains the needles of rutile which occur in the chlorite. Very small needles of rutile can be observed under high magnification in anauxite from the Ione. Some of these are twinned and the occurrence of ring-like forms composed of six individuals in contact at angles of 65° or 54° makes it clear that the inclusions are rutile. This is further substantiated by the analyses of Hillebrand and Fairchild, which show 0.5 and 0.55% TiO_2, respectively. In the other analyses TiO_2 was not determined, and it is included in the Al_2O_3. Teall[13] and others have observed needles of rutile as fine as .001 mm. in clays. This is easily explained if anauxite is a common mineral in clays. The large surface area of its cleavage flakes and its low specific gravity would allow it to act as a raft, floating the inclusions along with the fine sediments to be deposited with them.

It is probable that much of the chlorite, which forms anauxite, was originally biotite. The alteration of biotite to chlorite, which is often accompanied by the development of rutile is widely recognized, and references to it are made in many of the text books of petrography. Near Nevada City, the bed rock of the Manzanita Hydraulic Mine is granodiorite, of which biotite forms a

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[13] J. J. H. Teall. On the Occurrence of Rutile Needles in Clays. *Mineralog. Mag.*, Vol. 7, p. 201, 1887.

part. In places this is altered to a white compact rock, in which the angular quartz grains occupy the same position as in the fresh rock. White, earthy kaolin probably derived from the feldspars, and plates of anauxite containing rutile inclusions constitute most of the remainder. There is little doubt that the anauxite was derived from the biotite of the granodiorite for its occurrence is identical. The composition of the biotite in the Sierra Nevada granodiorites is known to vary. One of the biotites described[14] contains 36.02% SiO_2 and 18.80% Al_2O_3, and another has 35.75% SiO_2 and 14.70% Al_2O_3. It is conceivable that the original silica-alumina content of the biotite would determine the composition of the anauxite formed from it by removal of the other constituents, provided both silica and alumina remain constant. It might be argued that if such differences existed, these should be shown in the optical properties. With this idea in view, the indices of anauxite from various parts of the Ione were measured. The greatest difference observed in the refractive index of γ was .005 which is too near the limit of accuracy of the immersion method to be certain of the results. The four analyses of anauxite from the Ione show slight disagreement. This might be accounted for by a personal factor. On the other hand, the anauxite in the Ione sands probably was derived from many different biotites and the composition might depend on the original silica-alumina content of the biotites, and the stage to which the replacement had progressed. It is significant that there is less variation in these analyses than in the silica-alumina content of the biotites mentioned.

An experiment by Johnstone[15] shows how certain constituents in biotite may be removed. Biotite (see Analysis No. 6 in Table) was placed in water containing CO_2 for one year, and the effects noted. The smaller particles lost their pleochroism and much of their color. The resulting product (Analysis No. 7) shows decided loss of magnesium, iron, and potassium which have been removed as carbonates or bicarbonates.

The anauxite of Bilin was formed by the action of CO_2[16] in connection with volcanic activity. The iron, magnesium, calcium

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[14] *Amer. Jour. Sci.*, 4th Ser., Vol. **7**, p. 294, 1899.

[15] A. Johnstone. Action of Pure Water and of Water saturated with CO_2 on the minerals of Mica Family. *Quart. Jour. Geol. Soc.*, Vol. **45**, p. 367, 1889.

[16] E. Dittler und J. E. Hibsch, *loc. cit.*

and alkalies in the basalt were taken into solution as carbonates and bicarbonates, leaving hydrous aluminum silicates behind. Pseudomorphs of anauxite after augite were formed by this process.

Among the rocks of Guinea, Lacroix[17] described a series of mica schists which have been deprived of their alkalies. He gives analyses showing that the removal is progressive, increasing towards the surface. This, he considers, is due to the porosity of the soil rendering easy the penetration of surface waters, along with suitable topographic conditions for the retention of abundant moisture at the surface. But, the heavy forest cover which develops under tropical conditions is even more essential and he cites cases where the leaching is limited to the forested area. This seems logical as alkalies, lime, iron and magnesia are some of the elements taken up by plants, and further in this environment abundant CO_2 would be present to aid in their removal as carbonates and bicarbonates.

The writer considers the anauxite of the Ione formation to have formed by surface weathering under tropical or subtropical climate. The calcium, magnesium, iron and alkalies were removed from biotite as bicarbonates and carbonates. Further evidence for this and a more complete description of the occurrence and importance of this mineral in the Ione formation will be given in another paper.

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[17] Lacroix, Les Latérites de la Guinée. *Nouvelles Archives du Muséum d'Histoire Naturelle.* Series 5, No. 5, p. 306, **1913.**