

GLAUCONITIC MICA IN THE MORRISON FORMATION IN COLORADO¹

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ABSTRACT

Glauconitic mica occurs as interstitial clay in a bed of fine-grained sandstone, 15 feet thick, in the upper part of the Brushy Basin shale member of the Morrison formation of Late Jurassic age on Blue and Lone Tree Mesas near Uravan, Montrose County, Colorado. This glauconitic mica, similar to other material ordinarily called glauconite, is interesting because the Morrison formation is generally regarded as nonmarine in origin, whereas glauconite commonly forms in a marine environment.

The identifying properties of the glauconitic mica are: strong 001 *d* spacing, 9.97Å; very weak 002, 5.01Å; strong 003, 3.34Å; 060, 1.51Å; green color, pleochroic; *X* and *Z* indices, approximately 1.578 and 1.600; SiO₂ 49 percent, Al₂O₃ 18 percent, Fe₂O₃ 13 percent, FeO 1.3 percent, MgO 2.8 percent, K₂O 7.8 percent, TiO₂ 1.1 percent, ignition loss 6 percent, others approximately 1 percent.

The glauconitic sandstone is underlain by variegated mudstones about 480 feet thick, which contain montmorillonite (with very sparse relicts of shards), illite, quartz, and also, in several layers, scanty analcime. The Burro Canyon formation of Early Cretaceous age overlies the glauconitic sandstone.

This paper discusses alternative origins of the glauconitic mica possible within the framework of an appropriate chemical environment other than, and apart from, one typically marine.

INTRODUCTION

Glauconitic mica, similar in general appearance to glauconite, but intermediate in mineralogic properties between muscovite and glauconite (Foster, 1956), occurs in a layer of fine-grained sandstone in the upper part of the Brushy Basin shale member of the Morrison formation of Late Jurassic age on Blue and Lone Tree Mesas about 11 miles northwest of Uravan, Montrose County, Colorado. This glauconitic mica is of interest for three reasons. It is intermediate in composition between muscovite and glauconite (glauconite-celadonite) which may be regarded as selected end-member types of dioctahedral potassium micas; it seems to represent an intermediate mineral stage in the alteration of montmorillonite to glauconite; and it occurs in the Morrison formation, which is considered essentially without dispute to be nonmarine in origin (Craig and others, 1955), whereas glauconite has generally been described as being formed in a marine environment (Cloud, 1955; Hendricks and Ross, 1941).

The geologic occurrence, chemical composition, and certain mineralogic

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properties of the glauconitic mica will be described, and an origin for it will be considered.

OCCURRENCE OF THE GLAUCONITIC MICA

The sample of glauconitic mica, which is to be described in some detail, was collected in August 1955, at the head of a steep, dry valley located in the NE $\frac{1}{4}$ NE $\frac{1}{4}$ sec. 2, T. 48 N., R. 18 W., New Mexico principal meridian. The locality is a part of the area mapped geologically by McKay (1955) on the Red Canyon quadrangle (Colorado) map, GQ 58. In this area, the Morrison formation of Late Jurassic age consists of a lower member, the Salt Wash, and an upper member, the Brushy Basin. The Morrison is overlain by the Burro Canyon formation of Early Cretaceous age.

The glauconitic mica, which has the usual glauconite-green color, occurs interstitially in a fine-grained clayey sandstone layer, or lens, about 15 feet thick, which is within 15 feet of the top of the Brushy Basin member of the Morrison formation. The Burro Canyon formation overlies the Brushy Basin at this locality and the lower beds of the Burro Canyon form a nearly vertical cliff of tan sandstone. The clayey sandstone above the zone of glauconitic mica contains less green clay than that from which the glauconitic mica sample was collected.

Almost the entire stratigraphic section of the Brushy Basin member is anomalous in color on Blue Mesa. The Brushy Basin shale member typically is gray, tan, very rarely greenish, and commonly some shade of red along many miles of outcrop in all directions from Blue Mesa. On Blue Mesa however, it ranges in color from light gray through various shades of blue and blue green to pale blue green (5 BG 7/2)¹, and light blue (5 BG 7/6), from which the name of the mesa is taken.

The Brushy Basin member has been called a bentonitic shale but it lacks the fissile character of typical shale throughout much of its thickness; mudstone is probably a better name for the rock. Much of the Brushy Basin section is composed of montmorillonite which originated from the alteration of volcanic debris (Waters and Granger, 1953; Weeks, 1953), but hydrous mica, chalcedonic silica, and analcime (less abundantly) are also present. Shard relicts have been preserved in some of the clays and in replacement by silica and carbonate minerals, attesting to the parent volcanic ash. Alkali feldspar is common in most of the clay, and tiny mica flakes are less abundant. Sandstone lenses, some of them conglomeratic; thin, resistant, silicified sandstone layers, or "ribs"; and silicified, devitrified ash layers occur in varying amounts in the Brushy Basin member. The sandstones are dominantly composed of fine- to medium-grained, subangular to angular quartz and small amounts of alkali feldspar. Chert fragments occur in some of the sandstones and conglomerates. Limestones, here and there fossiliferous with charophytes, constitute a minor

¹ Color descriptions are after Goddard, E. N., and others, 1948 Rock Color Chart, National Research Council.

part of the Brushy Basin member. Other fossils are petrified wood and dinosaur bones.

The Brushy Basin is 500 feet thick in the section that was sampled and is commonly 300 to 375 feet thick in nearby areas. McKay (1955) states that "the Brushy Basin shale member, like the Salt Wash sandstone member, undoubtedly was deposited under fluvial conditions."

CHARACTER OF THE GLAUCONITIC MICA

Near the top of the section on Blue Mesa the bluish and bluish-green rocks of the Brushy Basin member give way to green in the color range: dark yellowish green (10 GY 4/4), dusky green (5 G 3/2), and grayish green (10 G 4/2). This greenish upper zone is observed for a lateral distance of more than a mile along the outcrop in the vicinity of the locality sampled, but its exact and total extent has not been mapped.

The sandstone is friable, fine-grained, and clayey. In thin section it is seen to be composed of angular to subangular quartz grains commonly ranging in size from 0.25 mm to 0.1 mm in cross section (the latter size predominating), and sparse alkali feldspar. The green pleochroic glauconitic mica coats the sand grains, wraps around them, and fills intergranular spaces. Where it is well developed, it covers an estimated 20 percent of the thin section area in the rock. The glauconitic mica shows a microcrystalline, clayey texture similar to that exhibited by montmorillonite and aluminous hydrous mica, which are the typical clay minerals in the sandstones of the Brushy Basin member.

A representative sample of the green sandstone was disaggregated by rolling, but not grinding, with balls in distilled water in a ball mill, and was then fractionated by sedimentation. The clay fraction—particles of minus 2-micron equivalent spherical settling diameter—was separated for further study. Under the microscope the clay fraction of glauconitic mica is pleochroic and green, typical of glauconite. Indices of refraction were measured as 1.578 and 1.600, approximately, for X and Z , respectively. These index values are slightly lower than the indices recorded for most glauconite.

A diffractogram of the glauconitic mica, designated "180," is shown in Figure 1 with the diffractogram of typical glauconite, designated "00," from the Bonnetterre dolomite, Missouri (Hendricks and Ross, 1941). The similarity in patterns is close. In order to increase the registry of the x-ray, the scale factor was reduced by one-half in the range of 2θ above 30° . $\text{CuK}\alpha$ radiation was used on a diffractometer. To obtain the hkl reflections, less fluorescent but weaker Co radiation was used. The oriented clay flakes on a porous tile base show a strong 001 d spacing at 9.97A, a very weak 002 spacing at 5.01A, and a strong 003 spacing at 3.34A. From a specimen of more nearly randomly oriented, pulverized material additional peaks were recorded on a diffractogram at 4.53A, 3.67A, 3.52A, 3.059A, 2.91A, 2.58A (004), 2.409A, 1.665A, and 1.510A (060). The hkl reflections are not strongly developed on the diffractogram, probably indicating incomplete or imperfect crystallization. The glauconitic

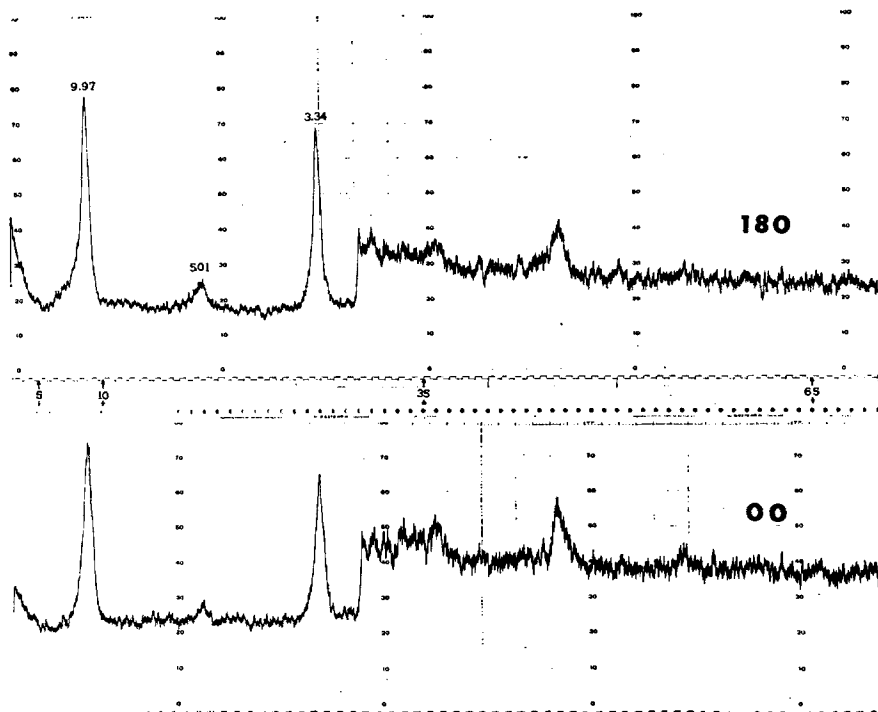


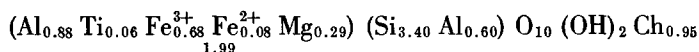
FIGURE 1. — X-ray diffractograms of the glauconitic mica, "180," from Blue Mesa, Montrose County, Colorado, and of typical glauconite, "00," from the Bonnetterre dolomite, Flat River, Missouri. Ni-filtered, Cu $K\alpha$ radiation. The scale factor was reduced one-half at $30^\circ 2\theta$ to increase the registry.

mica is dioctahedral; inconclusively, it is perhaps a 1-M polymorph, but better x-ray data are needed before the type of polymorphism can be characterized definitely.¹

Chemical analyses of the glauconitic mica (55-180), blue mudstone at Blue Mesa (55-177), and common or typical mudstone of the Brushy Basin collected south of Thompson (and Floy), Utah, 60 miles air line northwest of Blue Mesa, are reproduced in Table 1. The formula given in the table for the glauconitic mica was computed by excluding TiO_2 from the clay. TiO_2 is excessively high in the analysis of sample 55-180 for a typically pure clay mineral, and it is thought that much (but an unknown amount) of it is present probably in accessory anatase or other TiO_2 mineral in the clay fraction of the sandstone. If TiO_2 is included in the computation of the formula, it is²:

¹ Since this paper was prepared, x-ray work by Dr. Herbert Glass, Illinois Geological Survey, has shown the structure to be 1-M. Personal communication, Herbert Glass, October, 1956.

² The formula including TiO_2 was computed by M. D. Foster; written communication from C. S. Ross and M. D. Foster, May, 1956, whose comments were most helpful.



The formula of the subject glauconitic mica is intermediate between those of typical glauconite and muscovite. Foster (1956, p. 66) indicates that substitution of Al for Si in typical glauconite is of the order of $(Si_{3.67}Al_{0.33})$, and that substitution in muscovite is in the range $(Si_{2.98} to 3.11 Al_{1.02} to 0.89)$, whereas the tetrahedral substitution of Al for Si in the glauconitic mica of the present writer is intermediate between Foster's values for glauconite and muscovite. The Al and Fe^{3+} in octahedral coordination in muscovite are found by Foster to be of the order of 1.9 and 0.03 in ratio respectively, and in glauconite to be 0.18 and 1.1 to 1.2 in ratio, respectively. In the writer's material, octahedral Al and Fe^{3+} are of the order of 0.9 and 0.7 in ratio, respectively; hence this is intermediate between muscovite and glauconite, for which reason the mineral is called glauconitic mica. Ferriphengite would be more specific (personal communication, M. D. Foster).

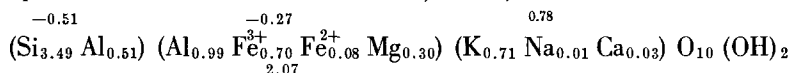
ORIGIN OF THE GLAUCONITIC MICA

The origin of the glauconitic mica in the Blue Mesa locality presents some

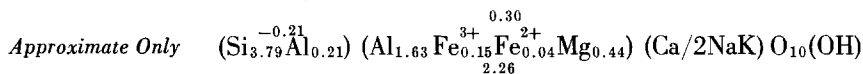
TABLE 1.—ANALYSES OF MUDSTONES FROM THE MORRISON FORMATION

	Sample 55-180	Sample 55-177	Sample 55-223
SiO ₂	49.03	56.64	58.40
Al ₂ O ₃	17.93	20.99	24.16
Fe ₂ O ₃	13.11	3.90	3.07
FeO	1.31	0.66	0.35
MgO	2.79	2.95	4.51
CaO	0.39	0.65	0.69
Na ₂ O	0.10	0.45	0.51
K ₂ O	7.84	7.11	0.39
TiO ₂	1.06	0.61	0.44
P ₂ O ₅	0.37	0.22	0.13
H ₂ O ⁺	6.00	5.77	7.29
Total	99.93	99.95	99.94

Sample 55-180: Glauconitic mica. Blue Mesa, Uruvan, Colorado.



Sample 55-177: Blue mudstone. Hydrous mica, analcime, chlorite (slight). Blue Mesa.
Sample 55-223: Pink bentonite. Montmorillonite with small amount of quartz and hematite. Near Thompson (Floy), Utah.



Excess plus charge due to free SiO₂ and to Fe₂O₃.

Analyses by Bruce Williams Laboratory, Joplin, Missouri. The cost of these was defrayed by Grant No. 541 of the University of Missouri Research Council.

intriguing, and not unequivocally solved, geologic problems. The occurrence of the mica in rocks regarded to be nonmarine in origin, its high content of ferric iron (but not as ferric oxide), its probable derivation from montmorillonite, the geologic time of its formation, its relation to the anomalously blue color of the Brushy Basin, and the geologic conditions and mechanism by which it was formed are open to numerous interpretations. All variants of the problem are not discussed here; geologic facts bearing on its origin follow:

1. The rocks of the Brushy Basin member (indeed all the Morrison formation) are "fluvial and lacustrine" in origin according to McKay (1955), and Craig and others (1955). This conclusion is a result of a comprehensive study of the sedimentary structures and lithofacies of the Morrison, its sedimentary petrography, and its fossil content of algae (charophytes), freshwater mollusks, ostracods, petrified wood, and dinosaur bones.

2. The Brushy Basin is generally bentonitic (rich in the clay mineral montmorillonite) throughout its occurrence in Utah, western Colorado, and New Mexico. Montmorillonite has been identified as the predominant clay mineral in the upper part of the Brushy Basin in seven stratigraphic sections studied in detail by the writer.

3. The color of the Brushy Basin at Blue Mesa below the upper green zone is most intensely blue in the upper part of the section, becoming paler blue toward the base. In much of Utah and Colorado, red iron oxides are abundant in the Brushy Basin, but only a relatively small amount of red mudstone occurs in it at Blue Mesa. The red color here is pale, sparsely and irregularly distributed, and well down in the stratigraphic section.

4. The sandstone in the Burro Canyon formation above the Brushy Basin does not show the blue color or the green of the glauconitic mica displayed in the Brushy Basin.

5. The glauconitic mica in the sandstone in the Brushy Basin at Blue Mesa occupies the same position and relationship in that sandstone as does montmorillonite in the sandstones of the Brushy Basin elsewhere.

6. Typical clay of the Brushy Basin contains less than 1 percent K_2O . The montmorillonite in the Brushy Basin was largely derived from the alteration of volcanic ash; the evidence of this statement is the preservation of recognizable relict shards in some montmorillonitic layers.

7. Typical clay of the Brushy Basin contains less than 5 percent Fe_2O_3 (conventionally reported as iron oxide) of which a significant part may be in iron oxide minerals that color the mudstone red or brown.

8. The glauconitic mica contains more than 13 percent ferric iron, but not as hematite or goethite, the simple iron oxides. Hence, the glauconitic mica must have been formed in an environment that was oxidizing with respect to iron, but the oxidation must not have been a direct result of gaseous oxygen. This is an important point. Too frequently, geologists erroneously ascribe green colors in sedimentary rocks to the effect of reducing conditions when the fact is that the iron is present largely in the higher oxidized ferric state within

a silicate mineral (Keller, 1953), but not as red ferric oxide mineral coating the exterior of other grains. The oxidation potential apparently was high enough during formation of the glauconitic mica to place the iron in the ferric state, i.e., remove electrons, but this process did not involve the combination of oxygen with the iron.

Using the foregoing facts, the following interpretation of the geologic history and origin of the glauconitic mica is offered.

1. Sedimentation during Brushy Basin time resulted in deposition of sedimentary and volcanic detritus 300 feet, or more, thick over wide areas in Utah, Colorado, and adjoining states to give rise to the Brushy Basin member.

2. Devitrification, hydrolysis, and other weathering processes converted in varying degree the volcanic material to montmorillonite and other 2:1-layer clay minerals. It is postulated that alteration of ash to clay had not occurred completely by the close of Brushy Basin sedimentation, and that permeability of ash-containing rocks of the Brushy Basin was still relatively high. Evidence for incomplete alteration of the ash and appreciable permeability includes (1) the preservation of relict shard structures, and (2) the relatively continuous blue color throughout the Brushy Basin at Blue Mesa.

3. Toward the end of Brushy Basin time alteration of the volcanic ash had developed montmorillonite, as described above in paragraph 2, but in the Blue Mesa region specialized conditions prevailed which then began to give rise to the development of blue and green minerals in the mudstone. The color alteration was obviously later than the deposition of Brushy Basin, and older than Burro Canyon sedimentation because sandstone in the Burro Canyon does not show the color effects displayed by the Brushy Basin.

4. The green color at the top of the Brushy Basin, and the fading of the blue color downward, indicate that the most intense part of the chemical and mineral alteration which produced the color and mineral change took place at the top of the Brushy Basin. It is also inferred from the foregoing evidence that the alteration was, therefore, supergene in character, not hypogene.

5. Hence, in time, near the close of Brushy Basin sedimentation but prior to Burro Canyon deposition, and in space, in the Blue Mesa region, it is inferred that downward moving solutions percolated through partly montmorillonized and still permeable ash deposits of the Brushy Basin member, converting the montmorillonite in part to hydrous mica, and at shallower depths and locally, to glauconitic mica. Whether the movement of ground water resulted from a very temporary playa above (no evidence of shore deposits was observed), from a change in groundwater drainage, or as an effect of tectonism, is not known. The exact geologic and topographic expression of the Blue Mesa area during alteration of the montmorillonite to hydrous and glauconitic mica can not be described in detail at this time. We are no more lacking, however, in specific knowledge of this process of alteration than in our ability to describe in detail the groundwater conditions, or conditions of diagenesis, under which large-scale dolomitization, silicification, and oxidation of sediments—changes which are regularly accepted by geologists—take place.

6. During the alteration of the clay minerals, part of the magnesium (see analysis 55-223 in Table 1) was leached from the montmorillonite, and significantly large amounts of potassium were added. L. C. Craig (oral communication, June 1956) has suggested that potassium may have been furnished in abundance by saline brines coming from the salt beds beneath the very large salt anticlines that occur to the southwest. Paradox, Salt, and Sinbad Valleys, which are complexly faulted, salt-cored, anticlinal valleys, occur within 10 miles (or less) of Blue Mesa. Hydrolysis of potassium-containing volcanic ash releases potassium which might combine with the clay.

Ferric iron was added in relatively large amount to montmorillonite when the latter was converted to glauconitic mica. A specific source of the iron is not clearly evident, but removal of a small amount of the red iron oxide from only part of the rocks of the Brushy Basin elsewhere would suffice generously to supply the iron in the glauconitic mica in the Blue Mesa region. Excess gaseous oxygen apparently was not active at the site of glauconitization; but the redox potential was high enough to sustain a ratio of Fe^{3+} to Fe^{2+} approximating 10:1.

Accompanying these chemical changes, the original montmorillonite structure (octahedral substitution and charge deficit) was converted to the mica structure (tetrahedral substitution and charge deficit). The exact chemical energy and process by which this change occurs is not well understood by clay mineralogists.

7. At the beginning of Burro Canyon sedimentation, the specialized geologic conditions at Blue Mesa no longer existed.

The occurrence of the glauconitic mica on Blue Mesa leads to the following opinions by the writer.

Probably much material previously called glauconite is not typically glauconite as now defined by Foster (1956), but is glauconitic mica or some intermediate mineral.

The environment under which glauconitic minerals (mica), and perhaps even normal glauconite, form is not necessarily marine. These minerals form under chemical conditions that should be described in terms of Eh, pH, and concentration (Krumbein and Garrels, 1952) if possible, rather than "marineness," etc.

The origin and geologic significance of glauconitic mica and glauconite are probably diverse and complicated. They merit much more study by geologists.

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