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A PARAGENETIC CLASSIFICATION OF THE MAGNET COVE MINERALS

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INTRODUCTION

Specimens of lodestone, aegirite, eudyalite and other minerals from Magnet Cove, Arkansas, have found their way into collections all over the world. Yet there have been no general mineralogical papers written on this area since the classical report by J. F. Williams.[1] Williams' petrographic, mineralogic, and crystallographic descriptions, coupled with the work of others which he incorporates in his report, leaves little to be added in those fields. However, the problems of petrogenesis and mineral genesis were covered with far less detail. Contributions to the petrogenesis of the Magnet Cove area were made by H. S. Washington in the first years of the present century.[2] The present paper will make a few comments on the character of the intrusion and on the origin of the minerals.

Magnet Cove lies in southwest central Arkansas in the Ouachita Mountains physiographic province near its southeastern border where the strongly folded Paleozoic sediments disappear beneath the Cenozoic sediments of the Gulf Coastal Plain (Fig. 1). A good highway connects the area with the city of Hot Springs, which lies about 12 miles to the west. The writer visited the area in the summer of 1929, accompanied by Prof. G. L. Knight. Mr. J. W. Kimzey of Magnet was of great assistance through his kindness in directing us to the localities where the best collecting could be found. The writer is very grateful to George C. Branner, State Geologist of Arkansas, for helpful suggestions during the preparation of the manuscript.

[1] *Ark. Geol. Survey, Ann. Rept.*, **1890,** Vol. 2, pp. 163–343.

[2] Igneous complex of Magnet Cove, Arkansas: *Bulletin Geol. Soc. Am.*, Vol. **11,** pp. 389–416, 1900. The Foyaite-Ijolite series of Magnet Cove; A chemical study in differentiation: *Jour. Geol.*, Vol. **9**, pp. 607–622; 645–670, 1901.

The Magnet Cove intrusive complex is elliptical in plan with a maximum diameter of about 15,000 feet. The more resistant peripheral intrusives form a rim which surrounds the cove or basin. The rim is broken through only at the northern and southwestern portions where the narrow valley of Cove Creek crosses the complex. The floor toward the center of the cove is relatively flat except for a 50-foot hill of calcareous and siliceous tufa in the west central portion. Another tufa mass lies to the west across Cove Creek. The hills composing the rim of the cove are densely wooded while the

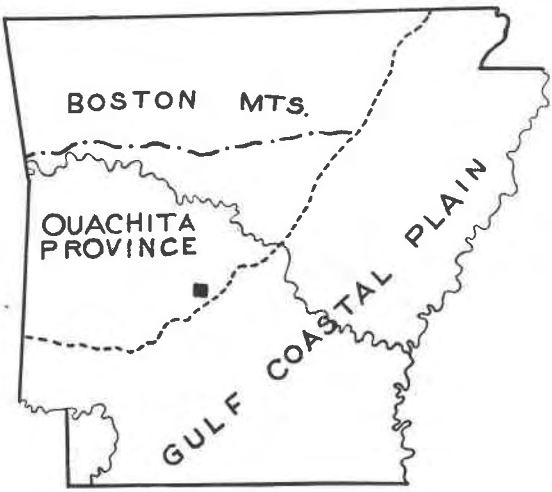

FIG. 1. Index map of Arkansas showing location of Magnet Cove.

cove floor is cultivated, so bed rock exposures are extremely discontinuous. This renders difficult any attempt to study the structural relationships of the igneous and sedimentary rocks.

The sedimentary rocks in the Magnet Cove area are Upper Devonian and Lower Mississippian in age. The oldest rocks belong to the Arkansas novaculite formation and consist of novaculite and interbedded shale. The novaculite beds are resistant to erosion and form ridges which are very prominent north and east of the cove. Overlying the novaculite formation are the Hot Springs sandstone and Stanley formations of Lower Mississippian age. The Stanley formation is largely shale, but with some sandstone. The igneous rocks are definitely intruded into the sedimentary series, and consequently are younger in age. The alkalic intrusions found here and elsewhere in Arkansas have been referred to the mid-Cretaceous,[3] but from the local evidence one can only say that the Magnet Cove complex is post-Stanley.

PETROGENESIS

The general distribution of the igneous, sedimentary and metamorphic rocks of Magnet Cove is shown on the accompanying map (Fig. 2). The distribution of the various types of igneous rocks may be seen on the original map by Williams or on a corrected map published by Washington.[4] A large part of the floor of the cove is covered by alluvium and the two tufa hills already described. Igneous rocks crop out at a number of places, especially in the southern part of the basin. The rim of the cove is composed of sedimentary rock, in a large part metamorphosed, and an outermost broad circular band of igneous rocks. Beyond occur the normal sedimentary rocks of the area (shales, sandstones, and novaculites) with a few small dikes. Williams[5] refers to the nephelite-syenite of the basin as the "cove" type, whereas the nephelite-syenite outcropping around the periphery of the complex is called the "ridge" type. Of utmost interest is the occurrence of scattered bodies of metamorphosed calcite inside the cove. The presence within the peripheral intrusives of exposures of metamorphic rock elongated parallel to the edge of the complex should also be noted.

The igneous rocks are alkaline and include such species as ijolite, shonkinite, foyaite, monchiquite, and tinguaite. According to Washington the rocks become decreasingly basic between the center and the periphery of the complex.[6]

THEORY OF WILLIAMS. Williams states that the igneous rocks may be divided into three genetically distinct groups:[7] (1) The oldest intrusives, which are basic, nephelitic, abyssal rocks. They are holocrystalline and around the edges are porphyritic. Their outcrop is confined to the interior of the cove, except for dike offshoots. (2) Monchiquitic rocks which were injected into contraction cracks in the abyssal rocks. (3) The nephelitic and leucitic rocks of the cove

[3] Croneis, Carey, and Billings, Marland, New areas of alkaline igneous rocks in central Arkansas: *Jour. of Geology*, Vol. **37**, No. 6, pp. 542–561, 1929. Miser, H. D., New areas of diamond-bearing peridotite in Arkansas: *U. S. Geol. Survey*, Bull. **540**, pp. 534–546, 1912.

[4] *Bull. Geol. Soc. Amer.*, Vol. **11**, p. 389, 1900.

[5] *Op. cit.*

[6] *Op. cit.*, p. 403.

[7] *Op. cit.*, pp. 342–343.

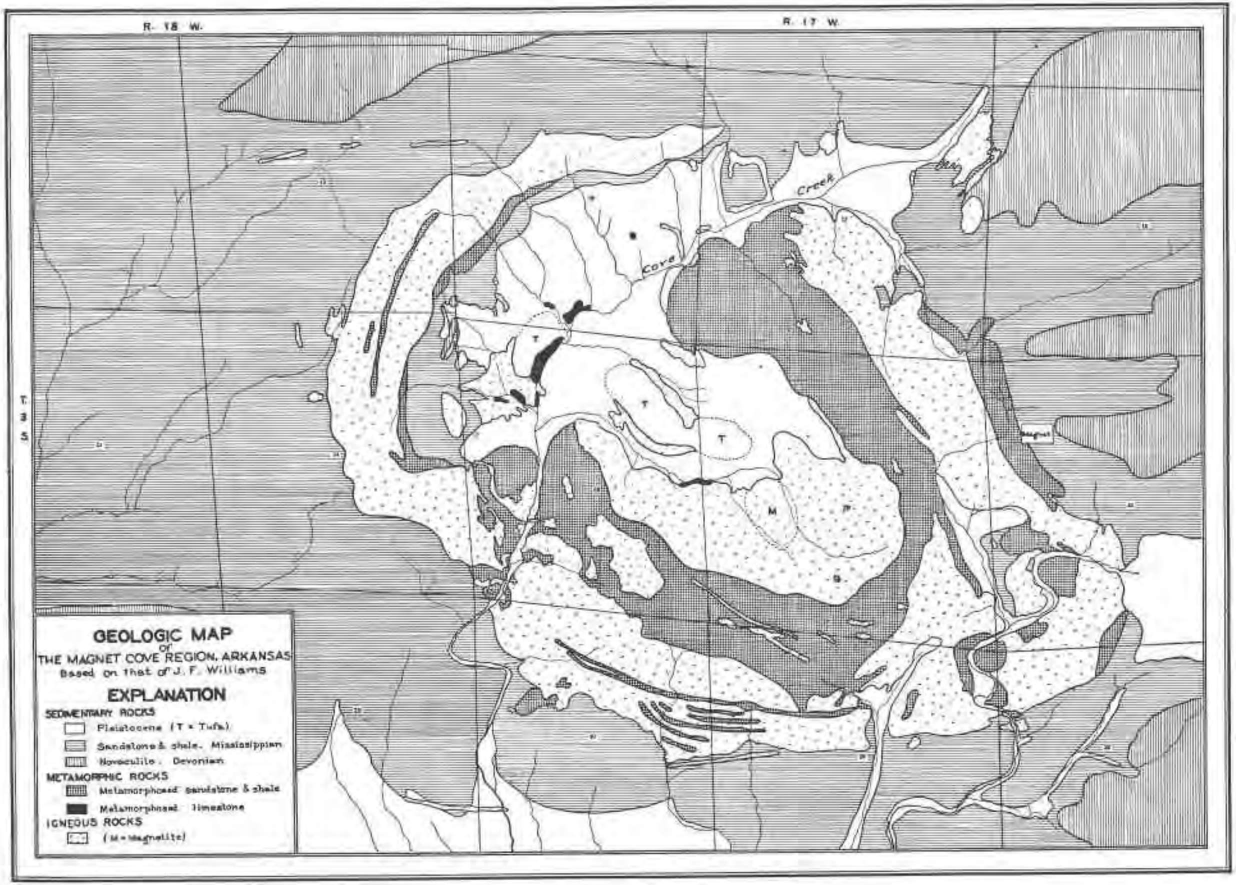
R. 18 W.
R. 17 W.
T. 3 S.
Cove
Creek
T
T
T
M
P
Magnet
GEOLOGIC MAP
of
THE MAGNET COVE REGION, ARKANSAS
Based on that of J. F. Williams
EXPLANATION
SEDIMENTARY ROCKS
Pleistocene (T = Tufa)
Sandstone & shale. Mississippian
Novaculite. Devonian
METAMORPHIC ROCKS
Metamorphosed sandstone & shale
Metamorphosed limestone
IGNEOUS ROCKS
(M = Magnetite)

FIG. 2.

rim and the tinguaitic dikes. These rocks cut the rocks formed in the two earlier periods of intrusion.

Williams gives no views in regard to the structure of the complex other than to say that all of the igneous rocks are intrusive in form. In regard to the metamorphosed calcite he states that the coarse crystals were formed either by contact action of igneous rock on common limestone, or, since limestone is not found in the local column, through contact with local hot spring deposits.[8]

THEORY OF WASHINGTON.[9] Washington doubts Williams' thesis of three distinct groups of rocks and three distinct periods of intrusion. He believes that the igneous complex was formed through ". . . a single intrusion of magma, which differentiation had split up into two main groups of central, basic, ijolitic rocks and peripheral, less basic syenites, the monchiquitic and tinguaitic dikes being both contemporaneous and subsequent injections of these differentiates into the cracked cover and cooled igneous mass and surrounding rock." It is suggested that the igneous body is a laccolith with the shape of a thick disk. Evidence given by Washington supporting the laccolithic theory follows.[10]

1. The broadly elliptical shape of the area, surrounded by shales and sandstones.
2. The quaquaversal upturning and the metamorphism of the contiguous shales at many places along the border.
3. The existence of a zone of what is apparently highly metamorphosed shale along the highest parts of the ridge and elsewhere on the outer slope, representing the remains of the original cover.
4. A platy parting approximately parallel to the walls, which has been developed in place in the foyaite.
5. The serial arrangement of the various igneous rocks from the center outward and concentric with the general border of the igneous area.
6. The, on the whole, regular change in structure and size of grain from the center to the periphery.

The outcrops of metamorphosed calcite are omitted from Washington's map and no discussion is given in either of his papers as to the origin of this material.

THE WRITER'S VIEWS. It is the writer's opinion that the metamorphosed calcite deserves more attention than has been paid it by previous investigators. It is important for the following reasons: 1. Contained within it is an important group of contact meta-

[8] *Op. cit.*, p. 181.

[9] Washington, H. S., Igneous complex of Magnet Cove, Arkansas: *Bull. Geol. Soc. America*, Vol. **11**, pp. 389–416, 1900. The foyaite-ijolite series of Magnet Cove; a chemical study in differentiation: *Jour. Geol.*, Vol. **9**, pp. 607–622; 645–670, 1901.

[10] *Bull. Geol. Soc. Amer.*, Vol **11**, p. 396, 1900.

morphic minerals. 2. It may have had an effect upon the chemical composition of the magma, as suggested by Shand: "Both nephelite and leucite are or were developed in these rocks which show an increasing proportion of magnesia and lime toward the center of the area, where several masses of contact altered limestone have been found."[11] 3. The origin of this limestone may throw some light on the mechanics of the intrusion.

The suggestion of Williams that the limestone may be a local tufa deposit is untenable, because tufa deposits are superficial whereas the grain of the metamorphosing igneous rocks is evidence of intrusion at some depth. Perhaps Williams meant a tufa deposit interbedded with the Mississippian sediments, but that would be a very remarkable coincidence for no such deposits have been reported occurring elsewhere in the vicinity. According to the stratigraphic column given below limestones are absent from the formations outcropping in the Magnet Cove area. The nearest limestone lies at a stratigraphic depth of 3,500 to 4,000 feet in the Womble formation (Devonian) while more limestones appear in the still older rocks.

Calcite dikes, associated with intrusions of granite and nephelite syenite, have been reported by various writers, most recently by Osborne.[12] But the purity of the Magnet Cove calcite in respect to other possible igneous minerals argues strongly against a magmatic origin for this material.

The best suggestion that the writer can make in regard to the origin of the metamorphosed calcite is that it was originally part of a limestone bed and has been carried up by the magma a distance of several thousand feet. Powers records among other instances one in which inclusions in stock-like masses in the Crazy Mountains had been apparently carried up a stratigraphic distance of four miles.[13] A stock of nepheline rocks in Sekukuniland, Transvaal, a little over six square miles in area encloses a block of limestone nearly half a mile square. A similar condition exists in the Fen District, Norway, except that the stock is smaller and the enclosed limestone block is relatively much larger.[14]

[11] Shand, F. J., *Eruptive Rocks*, p. 232.

[12] Osborne, F. F., The nepheline-gneiss complex in Dungannon Township, Ontario, Canada: *Am. Jour. Science* (5), Vol. **20,** pp. 33–60, 1930.

[13] Powers, Sidney, The origin of inclusions in dikes: *Jour. of Geol.*, Vol. **23,** p. 179, 1915.

[14] Shand, F. J., *Op. cit.*, p. 231.

SURFACE AND SUBSURFACE STRATIGRAPHY AT MAGNET COVE, ARK.

Data from Croneis, *Ark. Geol. Survey Bull.* 3

Period	Formation	Thickness	Character
Mississippian	Stanley formation	6000+ ft.	Shale and sandstone. Novaculite conglomerate near base.
	Hot Springs sandstone	200+	Quartzitic sandstone.
Devonian	Arkansas novaculite	950±	Novaculite and shale.
Silurian	Missouri Mt. "slate"	300	Shale and slate.
	Blaylock sandstone	1500	Compact sandstone and shale.
Ordovician	Polk Creek shale	200	Black graphitic shale.
	Bigfork chert	700	Chert and shale.
	Womble formation	1000±	Clay shales and limestone.
	Blakely sandstone	550±	Sandstone and shale.
	Mazarn formation	1000±	Clay shale, sandstone, and limestone.
	Crystal Mt. sandstone	850±	Sandstone.
Cambrian ?	Collier shale	300±	Clay shale and chert. Limestone near top.

The writer believes that evidence is more favorable to the intrusive body being a stock than a laccolith for the following reasons:

1. In the usual concept of a laccolith the neck is constricted, which would impede the upward movement of large inclusions.
2. According to the laccolith hypothesis the structure in the vicinity of the igneous mass should be anticlinal. Instead the region is one of close folds (Fig. 3), and apparently "the adjacent sedimentary rocks have not been greatly disturbed by the intrusion."[15]
3. With one exception the points enumerated by Washington in favor of laccolithic shape and differentiation *in situ* could apply equally well to a stock. In fact, Washington states: "The question whether the mass is a true laccolith, as it seems to be, or a stock or other form of intrusive mass is, after all, of secondary importance.[16] The point which would not apply equally well to a stock is the

[15] Branner, George C., Informal communication.
[16] *Op. cit.*, p. 398.

third one, namely the presence of highly metamorphosed shale ("hornstone") along the highest parts of the ridge which is supposed to represent remains of the original cover. But these hornstone outcrops are elongated and are arranged in a parallel manner to each other and to the periphery of the complex. It is inconceivable to the writer that the forces of erosion could so act upon a laccolithic cover as to leave remnants of this elongated shape and parallel orientation. It is much more probable that the hornstone outcrops are truncated edges of steeply-dipping strata into which the

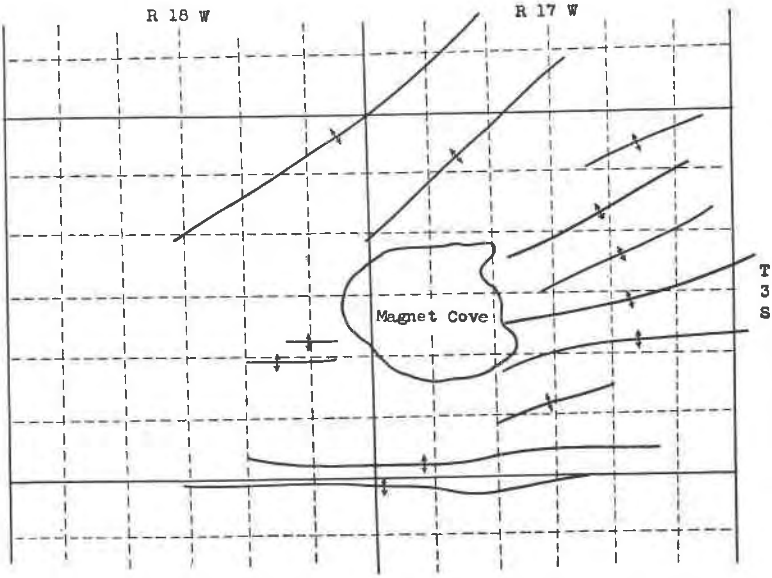

FIG. 3. Map of anticlines in Magnet Cove area. Map furnished by George C. Branner. Data from L. S. Griswold's report on the novaculties of Arkansas (*Ark. Geol. Survey*, vol. **3**, 1890).

peripheral intrusives were injected in a roughly conformable manner. Williams noted a sill intruded between layers of sandstone[17] and the tendency of the dikes to parallel the strike of the sedimentary rocks.[18]

The writer suggests the following sequence of events in the Magnet Cove area:

1. Close folding of the Paleozoic sediments.

[17] *Op. cit.*, p. 177.
[18] *Op. cit.*, p. 198.

2. The intrusion of a mass of alkaline magma containing inclusions of limestone obtained from deeper sediments.

3. Differentiation of this magma, producing the various types of igneous rock occurring in the cove interior. Assimilation of limestone may have played a part in this process as suggested by Shand.

4. Intrusion of the peripheral igneous mass which probably was an acidic differentiate of the magma filling the main stock. The shape of the igneous body was strongly influenced by the structure of the sedimentary rocks.

5. Differentiation of the peripheral intrusive mass.

6. Differential erosion, producing a topographic basin, and hot spring deposition on the floor of the cove.

The smaller dikes were intruded into the already crystallized igneous rocks and into the country rock at various periods during the differentiation and solidification of the magma. In places the magma dragged up the strata producing local dips away from the complex.

Minerals

The chemical character of the magmas has been fully described by Washington.[19] The igneous rocks contain no quartz, but do contain abundant potash feldspar and nephelite, showing that the original magma was relatively low in silica and high in alkalies. The only occurrence of free silica is near Magnet where contact metamorphism has caused the formation of quartz crystals in country rock sandstone. But it is probable that the silica in this case was dissolved in part at least from the sandstone and then reprecipitated by the magmatic waters. The most unusual feature at Magnet Cove is the high titanium content of the rocks. This element is an essential constituent of astrophyllite, ilmenite, schorlomite, titanite, dysanalyte, brookite, and rutile. Some of these minerals are found as primary constituents of the igneous rocks while others are contact metamorphic products. Evidently both the original magma and the escaping solutions were unusually rich in titanium.

About 42 distinct mineral species have been reported from Magnet Cove. These may be classified into the following groups: igneous, contact metamorphic, and secondary. Further division is possible within each group.

Igneous Minerals. These are divided into three subgroups depending upon the type of containing rock.

[19] *Op. cit.*

(a) Cove intrusives. These rocks consist of ijolite and biotite-ijolite (Washington's classification). Specimens of *magnetite* derived from an underlying magnetite-rich bed rock may be found in great abundance loose in the soil in the central part of the cove. They are invariably coated with limonite. About one per cent possess polarity. The presence of lodestone gave the locality its name and the magnetite bodies of this vicinity have a decided effect on the magnetic needle, which may explain why the section lines are so irregular. Kimzey has noted that the magnetite in the igneous rock immediately beneath the soil does not possess polarity.[20]

Beautiful specimens of a coarse nephelite schorlomite syenite are obtainable near the center of the cove south of an old church building. This rock is dominantly *nephelite* in oily salmon colored masses and *schorlomite*[21] in large and irregular shiny black anhedrons. A third important constituent is *biotite* occurring in scattered books.

Other primary minerals found in the Cove series follow:

melanite	diopside
apatite	orthoclase
brookite	titanite
pyrite	ilmenite

(b) Ridge intrusives (foyaite, shonkinite, leucite-porphyry). A new road cut along the state highway between Hot Springs and Magnet offers fresh exposures of the peripheral intrusives on the west side of the cove. The syenite exposed here is both fine and coarse grained. Specimens of the coarse syenite contained gray prismatic *orthoclase* crystals up to two inches in length and subordinate smoky colored *nephelite*, small scattered crystals of *pyrite*, and *fluorite* in minute purple colored grains. The rock is gray in color due to the dominance of orthoclase. Other minerals in the ridge intrusives are:

diopside	titanite
magnetite	rutile
apatite	aegirite
ilmenite	

(c) Dike rocks (including pegmatite, tinguaite, monchiquite, and fine-grained prophyries). Alkaline pegmatite in contact with coarse calcite is well exposed in fragments of rock blasted out of the high-

[20] Informal communication.

[21] Koenig, G. A., Schorlomite, a variety of melanite: *Proc. Phil. Acad. Nat. Sci.*, **1886,** p. 355.

way immediately west of Cove Creek bridge. The rock is a very coarse aggregate of black prismatic *aegirite*[22] crystals, white *microcline* euhedrons, and irregular masses of greenish *nephelite*. The crystals average between one and two inches in maximum dimension. In partially weathered specimens of this rock decomposition of nephelite has released terminated microcline crystals. The microcline did not exhibit the usual twinning. Determination was made by means of the extinction angle on basal sections. Bright pink and glassy grains of *eudialyte* occur with the aegirite; most often the two minerals are actually touching. *Astrophyllite* in brownish yellow plates completes the list of important pegmatite minerals.

Williams describes leucitic dike rocks in which "pseudoleucite" is a most important constituent.[23] *Pseudoleucite* is a pseudomorph after leucite and is composed of radiating orthoclase crystals mixed with nephelite and in some instances aegirite. Williams considers that leucite began to form and that a change in conditions caused a recrystallization and separation into nephelite and orthoclase. Bowen[24] states that pseudoleucite is formed through reaction between leucite crystals and surrounding liquid. Other minerals reported from the dike rocks follow:

melanite	biotite
wollastonite	augite
titanite	olivine
magnetite	amphibole
ilmenite	plagioclase

CONTACT METAMORPHIC MINERALS. Mineralizing solutions given off by the intruding magma metamorphosed both the shale and sandstone country rock and the limestone xenoliths.

(a) Contact metamorphic minerals in shale. Most of the shale inside the periphery of the complex has been metamorphosed to "hornstone." According to Williams this alteration was accompanied by the formation of *feldspar*, *pyrite*, *magnetite*, and *biotite* in the country rock.[25]

(b) Contact metamorphic minerals in sandstone. At the town of Magnet alkaline syenite is intruded in a beautiful white sandstone. Solutions expelled by the magma caused the formation of large

[22] Washington, H. S., and Merwin, H. E., The acmitic pyroxenes: *Am. Mineral.*, **12**, 1927, p. 243.

[23] *Op. cit.*, pp. 268–274.

[24] Bowen, N. L., *Evolution of Igneous Rocks*, p. 245, 1928.

[25] *Op. cit.*, pp. 296–300.

crystals of smoky, milky, and colorless *quartz* in aureoles in the sandstone. The crystals are in some instances arranged in parallel aggregates. Subsequent to the period of quartz formation the solutions given off by the intruding magma deposited *brookite* in relatively small crystals perched upon the faces of the quartz crystals. *Rutile* and *hematite* accompany the brookite, but in much lesser abundance.

(c) Contact metamorphic minerals in calcite. The metamorphosed calcite is very coarsely crystalline and is cut by fine-grained dikes and pegmatite. It is beautifully exposed by a recently excavated road cut immediately west of the Cove Creek bridge and the collecting possibilities at the time of the writer's visit could not be excelled.[26] All of the calcite observed contained contact metamorphic minerals. It is a thesis of this paper that there were two periods of metamorphism of the calcite. The first took place while the limestone xenoliths were being carried up by the magma to their present position. This mineralization was similar to that at Vesuvius, where limestone bombs were metamorphosed while they were passing up through the conduit of the volcano. At Magnet Cove the calcium carbonate recrystallized and the blocks were penetrated by solutions from the surrounding magma which caused the formation of contact metamorphic minerals. The second mineralization occurred when the frozen-in calcite bodies were cut by later dikes, especially by the alkaline pegmatite. The intrusion of this latter body caused metamorphism immediately adjacent to the contact, but not for any distance into the limestone. A reaction zone occurs between the two which consists of an outer yellow band and an inner white band. The yellow band ranges from one-half to one inch in thickness while the white band ranges from one-fourth to one-half inch.

The xenolithic rock which has not been metamorphosed by later dikes consists of coarsely crystalline gray *calcite* with isolated patches and veins of fine granular *monticellite*. The monticellite is yellowish brown and glassy when fresh, but in weathered specimens it is brown and earthy. *Magnetite* is disseminated through the calcite in grains up to one-half inch in diameter. Many of these have a spheroidal shape. *Dysanalyte* (or *perovskite*) may also be present in glossy black crystals which are a combination of the forms (100) and (111). *Wollastonite* occurs both in patches of radiating yellow-

[26] Other localities are mentioned by Haltom, Wm. L. Magnet Cove, Arkansas, and vicinity: *Am. Mineral.*, **12**, 484–487, 1929.

ish white needles and in irregular veins, which also contain small striated *pyrite* cubes. *Vesuvianite* was observed in aggregates of yellow green crystals, some nearly an inch across. Eightlings of *rutile* occur in soil derived from the weathering of a metamorphosed calcite mass.

The contact metamorphic minerals formed by the intrusion of the alkaline pegmatite dike into the coarse calcite are confined to the narrow reaction zone along the contact. The outer band (yellow) is a mixture of calcite and minute yellow scales of *mica* (probably phlogopite). The inner band (white) is composed of acicular *wollastonite.* It lies in direct contact with the chilled zone of the pegmatite dike which contains relatively small crystals and masses of nephelite, aegirite, and eudialyte. Dark greenish- or reddish-brown masses composed of minute fibres of *thomsonite* are likewise found in this zone and are very likely the result of reaction between dike and wall rock, for they do not occur in the coarse pegmatite.

SECONDARY MINERALS. Some of the minerals in this class were formed by supergene alteration of primary minerals, but a number are undoubtedly due to alteration by hydrothermal solutions given off by the crystallizing magmas. The group is divided into:

(a) Minerals formed through the alteration of igneous minerals. *Epidote,* hitherto unreported from Magnet Cove, was observed in a felted mass coating large microcline crystals. The feldspar immediately beneath was epidotized for a short distance, but this replacement did not destroy the cleavage of the spar. *Maganopectolite* occurs in the alkaline pegmatite in glassy masses with rectangular outline surrounded by brown manganese oxide. The pectolite is probably a replacement but the writer found no clue as to the identity of the original mineral. Eudialyte alters to yellow glassy *eucolite* which in turn alters to *catapleiite,* according to Foshag.[27] Other minerals derived from primary igneous minerals are:

protovermiculite	leucoxene
cancrinite	hematite
calcite	natrolite[28]
kaolinite	biotite
limonite	

[27] Foshag, W. F., Catapleiite from Magnet Cove, Ark. *Am. Mineral.*, **8,** 70–72, 1923.

[28] Melville, W. H., Natroline from Magnet Cove, Ark. *U.S.G.S.*, Bull. **90,** p. 38, 1892.

(b) Minerals derived from primary contact metamorphic minerals:

rutile, in paramorphs after brookite[29]
hydrotitanite
limonite
chlorite
calcite

(c) Minerals in the tufa. The tufa is both calcareous and siliceous and was not deposited until erosion had carved out the basin and ridge. It antedates, however, the present position of Cove Creek, as this stream divides two tufa deposits that were probably at one time continuous. The position of the tufa in respect to the limestone is highly suggestive. Hot springs located in the cove leached calcium carbonate from the limestone xenoliths and silica from the other rocks and deposited these compounds upon reaching the surface. The same waters may have dissolved *magnetite* from the lower rocks and redeposited it in the tufa.[30]

[29] Williams, *op. cit.*, p. 320.
[30] Williams, *op. cit.*, p. 335.