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TERTIARY IGNEOUS ROCKS OF THE NAVAJO COUNTRY, ARIZONA, NEW MEXICO AND UTAH

by

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GENERAL SETTING

The Colorado Plateau, the major physiographic province of which the Navajo country is a part, includes some impressive manifestations of intrusive and volcanic activity: the Mount Taylor field at the southeastern corner; the Datil section along the southern margin; the San Francisco field south of the Grand Canyon; the extensive flows and related rocks on the northwest corner in the high plateaus of Utah; the stock-laccolithic intrusions of the Henry Mountains and similar mountains in the Canyonlands and adjacent sections, and the Navajo-Hopi volcanic field.

CHARACTER OF THE NAVAJO-HOPI FIELD

Outside the Navajo-Hopi field the petrography and mode of occurrence of igneous accumulations on the Colorado Plateau are interesting but hardly remarkable. The very extensive flows are chiefly basaltic. Intermediate and silicic rocks are found in Mount Taylor, the San Francisco Peaks, the Marysvale region of Utah, and in tremendous accumulations just outside the boundaries of the plateau, particularly in the San Juan Mountains and the Mogollon-Gila country. Within this circle of more or less normal volcanic rocks occurs the Navajo-Hopi petrographic province, characterized by distinctive petrographic types and structural forms. The rocks are generally alkalic and basic; not alkalic to the extent of containing large quantities of feldspathoids or sodic pyroxenes or amphiboles, but to the extent of containing abundant biotite and alkalic feldspar, chiefly sanidine. Feldspathoids and sodic pyroxenes are present in some rocks, but generally in only accessory amounts. Iron-magnesium minerals, chiefly diopside, biotite, olivine and magnetite, usually make up 60 percent or more of the rocks. Except in the Carrizo Mountain intrusive mass, which is not part of the Navajo-Hopi petrographic province but is a geographic overlap, hornblende is almost entirely lacking.

Volcanic forms include flows, dikes, and, most distinctive of the area, diatremes; volcanic pipes that consist mainly of breccia, formed in great part by gaseous explosion. That the diatremes and, in part, the dikes are but remnants of a once more extensive volcanic terrain is clear, but erosion has removed the surface accumulations for the most part. In much of the area only the conduits remain, and the surface on which flows or pyroclastic ejecta may have accumulated and the surface of the volcanic rocks themselves can only be conjectured.

SUBDIVISIONS OF THE NAVAJO-HOPI FIELD

The volcanic rocks of the Navajo-Hopi field may be considered under various groupings, depending on the purpose of the discussion. For the purpose of this paper, the broad subdivision into three groups suggested by Appledorn and Wright (1957) appears satisfactory: the Hopi Buttes field, an area of approximately 1500 square miles west of the field conference area, including many necks and diatremes with related flows; the Monument Valley field, embracing about a score of dikes and diatremes; and the Chuska field, the least defined of the three, including necks, plugs and flows of both the Chuska Mountains and Chuska Valley and other occurrences along the New Mexico-Arizona line.

The field conference area lies chiefly in the second of these, the Monument Valley field, but extends through (on the third-day segment) the southernmost tip of the Chuska field. In addition, it is within view of Carrizo Mountain, a mountain mass a few miles west of Shiprock, the southern representative of the laccolith-stock mountains of the group that includes the Henry Mountains, La Sal Mountains, Abajo Mountains and Ute Mountain, as well as the La Plata and San Miguel mountains at the juncture between the Colorado Plateau and the southern Rocky Mountains. (The intrusive mass of Carrizo Mountain, exposed over an area of about 120 square miles, is chiefly porphyritic hornblende diorite.)

ASPECTS OF THE FIELD CONFERENCE AREA

If one's natural impression of a volcanic neck is that it consists of massive rock, frozen in place from a thick "goo" of lava that welled up the throat of an erupting volcano and, when the push from below ceased, gradually congealed, he will need to modify his view after he has scrambled up the face of Shiprock or of any of the necks in Monument Valley. These peaks do not consist of massive rock, despite one's feeling that they must because of their apparent resistance to erosion. Differential erosion signifies merely that more susceptible material erodes away more readily than other material. To some extent the volcanic features of the field conference area are prominent not because they are extremely resistant to erosion but because the shales into which they were injected have been so much more submissive to erosive processes. These pinnacles and crags consist in great part of breccia and tuff-breccia. Williams (1936) estimated that Agathla in Monument Valley is at least nine-tenths breccia. Irregular dike-like stringers through the mass and other impregnations of lava through broken fragments form the rest. Of the fragments, Williams (1936) further estimated that perhaps two-thirds are derived from the magmatic source giving rise to the neck, the remainder being country rock. These xenolithic fragments are

Radiating dikes characterize the prominent landmark of Shiprock. Carrizo Mountains on the skyline (D. L. Baars, Red Rock Country)

mostly sandstone and shale, but include metamorphic and plutonic rocks from the basement. Analysis indicates that the size, number and angularity of the inclusions generally diminish in proportion to the depth of origin. In this respect, and in lack of tilting of the country rock adjacent to the necks, the diatremes of the Monument Valley and surrounding region greatly resemble diatremes of Swabia. A characteristic feature is a crude inward-dipping bedding of the infilled breccia in the upper parts of these necks, particularly Shiprock and Agathla.

For the most part, the Tertiary igneous rocks of Monument Valley and the Chuska field are biotite-rich rocks. In this respect they differ from rocks of the Hopi Buttes field, which are relatively or wholly biotite-free. By Williams (1936) and those following him, the intrusive varieties of these rocks have been called minette, the extrusive varieties, which are chemically and mineralogically identical, and are megascopically indistinguishable, trachybasalt. They have a generally basaltic appearance, except for the common shiny faces of mica flakes, and, of course, they must be labeled something, but it would seem that a trachybasalt ought to be a basalt, displaying some modifying characteristic of trachyte, such as the presence of alkalic feldspar. Most definitions of trachybasalt (and certainly of basalt) state that calcic plagioclase is an essential constituent. The rocks of the field conference area are generally devoid of plagioclase, however, or they contain it in such minute quantities as to be practically free of it. Perhaps some name such as melatrachyte, emphasizing the character of the sole feldspar and also the melanocratic character of the rocks, would be more appropriate. The use of minette for the intru sive varieties more closely approaches accepted usage, though true minettes, without use of a modifying term, are generally considered to be dike rocks in which the chief iron-magnesium mineral is biotite and in which the feldspar is principally potassic. Biotite is abundant in the igneous rocks of the field conference area, but it is generally subordinate to pyroxene, which is mostly diopside, or diopsidic augite. In some rocks the amount of biotite is comparatively low, and the rocks approach vogesite, but these are rare. In few rocks does biotite exceed pyroxene in content, and in none, so far as is known, is the iron-magnesium mineral exclusively, or even almost exclusively, biotite.

It should be pointed out that the lack of plagioclase is not a result of low calcium but rather of low aluminum. Without sufficient aluminum, the calcium, unable to make feldspar, goes into pyroxene. For this reason the pyroxene is strongly diopsidic. An appreciable percentage of the calcium that appears in chemical analysis, however, is bound in calcite.

Composition of the igneous rocks of the Monument Valley and Chuska fields varies, but on the average it may be represented by diopside and alkalic feldspar (commonly sanidine, less commonly orthoclase) in about equal proportions, and biotite in amounts approximately half that of either of the above two constituents. Accessories are olivine, magnetite and other opaques, apatite and calcite. The color of the rocks is light gray in rocks rich in feldspar, through brownish and greenish varieties to rocks, low in feldspar, that are almost black. Diopside and biotite phenocrysts are moderately to well formed and are mostly less than 1 mm in greatest dimension

though they may be larger in places. These minerals also occur in small crystals in the groundmass, along with the accessory minerals. Sanidine occurs in very minute subhedral crystals, but it may occur, in some intrusive varieties and most extrusive varieties, in large amorphous grains, forming the groundmass for all the other rock constituents (that is, showing a pronounced poikilitic structure).

INDIVIDUAL SITES

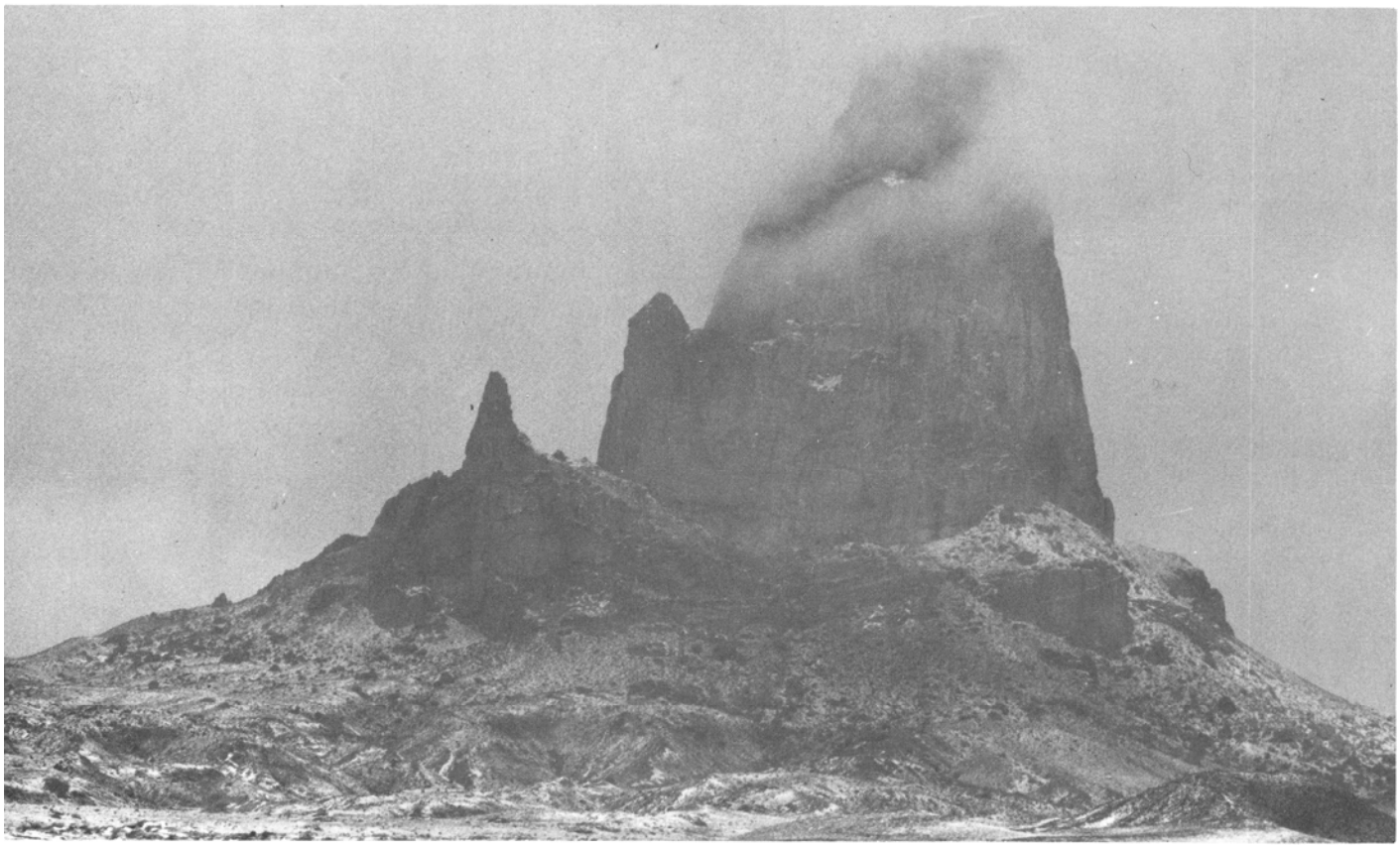
Apart from features that may be seen along approaches to the area, the volcanic features that will be most readily seen by participants on the field conference will be Church Rock, a few miles east of Kayenta, Black Rock neck (Tyende dikes), just northeast of Kayenta, Chaistla and Agathla, a few miles along U.S. Highway 163 north of Kayenta, and, north of Monument Pass in Utah, Alhambra Rock. At least 15 other necks and dikes are to be found in the Monument Valley region, some visible in the distance from the highway, others requiring more effort to see, and still more to reach.

Of the above, Agathla, sometimes called Capitan, 10 miles north of Kayenta, is the most impressive. It rises well over 1,000 feet above the surrounding plain and rests on a base over half a mile in diameter. It consists, like most of the others, chiefly of breccia, with branching dikes and sheets of the igneous rock. Fragments of shale and sandstone are common, granitic and metamorphic rocks much less common, and limestone rare. The size of the fragments is generally small, from less than an inch to a few feet. Rarely one may find a fragment as much as 20 feet across. Near the top of the neck a crude bedding may be observed in the breccia, dipping inward. This is not observed toward the base.

Chaistla Butte is about 4 miles south of Agathla. In structure and composition it is similar, but it is smaller, being somewhat over 400 feet in height, less than a quarter of a mile through at the base.

Alhambra Rock, about 5 miles southwest of Mexican Hat, Utah, just north of U.S. Highway 163, is a conspicuous landmark in this part of Monument Valley. Unlike most of the other neck-like features discussed, which are generally equant, almost circular in plan, Alhambra Rock is elongated. In the main this is due to the presence of north-trending dikes that widen from a few feet to 100 feet. Where the width is narrow, the dikes form only a low inconspicuous ridge, but at the widest part they form a high abrupt prominence, which may be seen for miles. The dikes narrow down to a foot or less a short distance from the widest part. Two extend southward for perhaps a mile; one, generally no wider than 6 inches, has been traced northward for nearly 10 miles. The thick prominent part of the dike contains numerous inclusions of granite and sandstone and a few of limestone.

About 3 miles east of Kayenta, readily seen from the town, occurs the neck-like feature called Black Rock neck by Williams (1936), the Tyende dikes by Gregory (1917). It is similar to the necks described above. It is a neck formed by two dikes with breccia between. Breccia of sandstone and the minettic rock constitute fully three-quarters of the exposed mass. Biotite is readily observed in hand specimens of the intrusive rock, and occasional grains of olivine may be seen. Abundant diopsidic augite is found in thin section. The peak rises about 300 feet above the surrounding plain.



Winter storm on Agathla. H. L. James

Five miles farther to the east, along U.S. Highway 160, rises Church Rock, consisting of several dikes with cross connections and associated breccia that form tapered columns, suggesting the spires of a church to some observers. The highest tower rises about 300 feet above the base. The matrix rock and the agglomerate are very similar to those described above. A laterally tapering dike, highly agglomeratic, extends eastward from Church Rock for several hundred feet, decreasing in width to 4 or 5 feet at its end.

A dike consisting of sandstone blocks 15 to 20 feet in greatest dimension, boulders of granite and basalt, and smaller fragments of slaty rock and limestone, bound together by intersecting dikes and dikelets of nearly feldspar-free rock (monchiquite), occurs 7 miles northeast of Church Rock. It is about 300 feet long, 50 feet wide.

Still farther to the northeast, along Comb Ridge, may be found a group of necks and dikes known collectively as the Porras Dikes (named for an early Spanish missionary). They consist chiefly of two necks and associated dikes that extend for about a mile along a north-trending line. The necks are at the north end. They rise about 300 feet above the sandstone of the ridge, nearly 700 feet above the valley at the base of the ridge. They consist also of agglomerate or breccia intersected by a network of monchiquitic or minettic dikes and dikelets.

Along Comb Ridge and adjacent to it, at a point 11/2 miles south of the passage of the San Juan River through Comb Ridge (at the Mule Ear) and at an area on Garnet Ridge 5 miles north of Dinnehotso, are found local occurrences of garnets. The garnets occur in a number of igneous and metamorphic rocks that cover the surface irregularly. Their presence is due to the same neck-forming processess discussed above, but the Tertiary minettic igneous material is so minor, the varied inclusions so abundant, and the latter so much more resistant than the former, that the xenoliths give one the impression of erratics discarded by a glacier. The volcanic origin of this phenomenon is now established, but the surface expression of obvious volcanic features is so slight that the conclusion comes only from careful study of the sites. Some early investigators actually called the xenoliths glacial erratics.

One small exposure of hornblende gabbro is found in an inconspicuous cone 4 miles due east of Monument Pass, forming a pimple on the broad surface of the valley east of the pass. This feature, called Tse Ajai, is approximately 200 feet across, is rather low, but may be readily seen from the overview at the east end of the pass.

Other volcanic features in or near the field-conference area include a small dike 2 miles south of Oljeto (near the state line 10 miles west of Monument Pass) and two dikes and an associated neck forming two ridges, each a mile long, at the base of Black Mesa north of Chilchinbito (20 miles south of Kayenta). The breccia-agglomeratic character of these rocks and the type of matrix material are similar to the other dikes and necks described above.

The road through Many Farms, Canyon de Chelly and St. Michaels passes between the Chuska field of volcanic rocks on the east and the Hopi Buttes field on the west, both too far away to be observed. At St. Michaels one is just a few miles south of Black Rock or Black Butte, a mass of minette-vogesite and breccia, not particularly different from the necks in Monument Valley except that the igneous rock is massive in the upper part and is characterized by horizontal columnar joints.

Nearby, to the west, and also to the south, are found dikes and small intrusive masses that have lower biotite contents. The rocks are best called vogesite.

OTHER PARTS OF THE NAVAJO COUNTRY

The volcanic rocks of the Chuska field, which is skirted by the road from Ganado to St. Michaels and thence southward to Lupton, are similar in composition to those of the Monument Valley field, but structural forms are more varied. Flows and lava domes are common and fairly extensive, and massive plugs as well as agglomeratic necks are present.

Shiprock, however, at the northeast corner of this field, is very similar to the necks of Monument Valley. Like them, it consists of minettic agglomerate. It rises over 1,400 feet above the surrounding plain. Three prominent dikes project from it, one to the northeast (the least impressive), one to the west, and one to the south (the longest). The dike on the south forms a ridge that is 300 feet high at the base of the peak and still 100 feet high 31/2 miles away.

An unusual and provocative rock in the Chuska field is kimberlite tuff, found in Buell Park. It consists chiefly of the minerals olivine, enstatite, chrome-diopside and garnet. The olivine is strongly altered to serpentine or to iron-oxide and serpentine. The pyroxenes are also altered, but to a lesser extent. In times past peridots (olivine) and garnets could be collected from ant hills, but the ants have been unable to keep up with the demand. Unfortunately diamonds have never appeared at such sites. Either they do not occur in the rock or the ants are holding them back till the market is better.

The rocks of the Hopi Buttes field also include both necks and flows. The necks are diatremes, containing abundant agglomerate-breccia, but there is more massive igneous rock in them than in most of the Navajo necks and dikes. Flows are rather extensive, and were once much more so. A once broad lava field is now represented by isolated mesas and buttes. The principal rock type differs from the typical rock of Monument Valley and the Chuska field in an almost total absence of biotite and in lower content of feldspar.

SUMMARY AND EVALUATION

The rocks of the Navajo country are alkalic and basic, representing a distinct petrographic province. They have much in common with the alkalic provinces of Montana and Wyoming.

Diatremes, strongly resembling the Swabian diatremes, are a characteristic feature of the region. They offer an exceptional opportunity to study basement and other subsurface rocks.

The ages of the various Tertiary rocks of the Navajo country may differ somewhat, but they are generally considered to fall in the Pliocene.

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