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VOLCANIC NECKS OF THE MOUNT TAYLOR REGION, NEW MEXICO*

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INTRODUCTION

Several years ago, while studying the geology of the Albuquerque quadrangle, New Mexico, I had a distant view of that geological wonderland made classic by Major Dutton in his report on the Mount Taylor region. Since that time I have been anxious to visit the district, more especially to get a closer view of the remarkable volcanic buttes in the valley of the Rio Puerco, which Major Dutton interpreted as remnants of necks formerly connecting with overlying volcanoes which have long since been worn away.

The buttes are most abundant in an open valley excavated by the Puerco river through the eastern part of the great lava sheets surrounding the Mount Taylor volcanic mass, the valley being open to the north and south, inclosed on the west by the ragged escarpment of the larger Mount Taylor mesa and on the east by the smaller Prieta mesa. The mesa surface is from one to two thousand feet above the valley floor; the valley is from 8 to 12 miles wide east and west, and the area studied is about 18 miles north and south.

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The desire to visit the district was strengthened by the tendency on the part of some observers to regard vertical columnar structure and undisturbed, surrounding sediments as features not to be expected in volcanic necks, but rather as indicative of some other origin for buttes which exhibit such features. Thus the Devils tower, in Wyoming, has been referred by Professor T. A. Jaggar, Junior, to a laccolithic origin partly because it rises above undisturbed sediments, and its beautiful columnar structure is more or less nearly vertical. In a recent textbook, "Elements of Geology," by Professor W. H. Norton, it is implied (page 276) that vertical columns would not be found in a volcanic neck. Dutton states that vertical columns are found in many of the Mount Taylor buttes, and rather implies that they are surrounded by undisturbed sediments. It was believed that a careful study of the buttes in the Rio Puerco valley, with possible alternative interpretations in mind, might serve to determine which features are characteristic of volcanic necks, which of remnants of laccoliths or columnar sheets of lava, and which are common to both topographic forms.

An opportunity to visit the region was offered in the spring of 1906, during a geological excursion through parts of New Mexico, Arizona, and Utah. The excursion, which included a wagon trip of over 1,500 miles during a vacation of four months, was made possible by appropriations from Harvard University and the Massachusetts Institute of Technology and private gifts from Mr George G. Crocker, Senior, and other friends of the Institute. Ten days were spent in a trip to the Mount Taylor region, where the principal buttes between Cabezon and a point a few miles north of Juan Tafoya were studied and the data presented below were collected. The district included between these two Mexican villages was selected because it contains, according to Dutton, the largest and best preserved buttes in the Mount Taylor region.

I was accompanied in the field by Dr H. W. Shimer, of the Massachusetts Institute of Technology, who made a study of the stratigraphy of the Puerco valley, the results of which will soon be published. The photographs reproduced on plates 27 and 29 were taken by Doctor Shimer. I am indebted to Professors W. M. Davis, J. B. Woodworth, and T. A. Jaggar, Junior, for reading the manuscript of this paper and offering criticisms and suggestions.

Purpose of the Investigation

Briefly stated, the objects of the trip were as follows:

(1) To ascertain further details regarding the structure of the supposed necks and their relation to the surrounding sediments.

(2) To see if it were possible to harmonize the facts observed in the field with some other theory of origin than that elaborated by Dutton.

(3) To determine as far as possible what features may be used as critical evidence in discriminating between volcanic necks and remnants of eroded laccoliths or columnar sheets of lava.

The Conclusions reached

The studies led to several conclusions which are stated more fully in subsequent pages, but which may here be summarized as follows:

(1) Those buttes of the Mount Taylor region observed by us are undoubted volcanic necks, as determined by Dutton, and do not admit of any other interpretation.

(2) Vertical columnar structure is apt to characterize the upper portions of volcanic necks, as should be expected from theoretical considerations and as is fully exemplified in many of the Mount Taylor necks. Such structure, therefore, can not be used as evidence in discriminating between necks, and remnants of laccoliths or columnar lava sheets.

(3) Frequent sections about many of the necks show them to be surrounded by horizontal sediments which have not been disturbed by the intrusion of the necks. Disturbed sediments, therefore, are not a necessary accompaniment of volcanic necks, and the absence of such disturbance can not be urged as an evidence of some other origin for any butte whose nature is in doubt.

(4) Vertical columns which curve outward at the base, as in the Devils tower and in some of the Mount Taylor necks, are more apt to occur in volcanic necks than in remnants of laccoliths or columnar sheets of lava.

(5) In general, it appears that the selection of any specific structural feature as a guide to the critical distinction between volcanic necks and remnants of laccoliths or columnar sheets of lava is unsafe. There are few, if any, features which might not occur, to some extent at least, in buttes having different origins. The concordant testimony of a variety of evidence from a large number of different buttes, however, can hardly leave any doubt as to their origin, especially when the general geological history of the region is taken into account.

Literature

The only detailed account of the buttes of the Mount Taylor region is that by Dutton in his paper, "Mount Taylor and the Zuñi plateau." The paper discusses several problems of wide scope, the volcanic buttes being but one of the interesting features considered. The fifteen pages devoted to the lava-capped mesas and the buttes, however, give a good idea of the essential features with which we are concerned, and offer the best explanation yet available as to the manner in which the great cylindrical masses of lava came up through the surrounding sediments. A dozen illustrations show the typical appearance of the buttes.

As seen in the field, the nature of the buttes is so evident that no one who has seen them would doubt the manner of their origin. It is therefore not surprising that Dutton regards them as true volcanic necks and does not discuss alternative theories or interpretations. We read on page 167 that "the experienced geologist who has traveled much in these regions will recognize their significance at a glance," and on page 168, that "the interpretation here given is such as would be accepted at once by any geologist, but the general reader might like some further proof of it. He can have an abundance." Then follows a detailed description of many of the buttes, which will be referred to again in subsequent pages.

Dutton was unable to visit the two finest buttes in the region, Cabezon and Great neck, but saw them from a distance. My own observations included these two and a number of intervening ones; so that the data collected were not repetitions of those presented by Major Dutton, but rather supplementary to them.

Professor Newberry, in his report on the geology of the exploring expedition from Santa Fé to the junction of the Grand and Green rivers, figures the great Cabezon peak on plate XI of the report, but does not discuss its origin, except to say that it has a general resemblance to the Needles of the San Juan valley (page 117). Concerning the Needles he writes (page 107):

> "This is a mass of erupted rock, rising with perpendicular sides from the middle of the valley. . . . Its altitude is about 1,700 feet above its base; above the river, 2,262 feet. It is everywhere surrounded by stratified rocks, and its isolated position and peculiar form render its origin a matter of some little doubt. My conviction, however, is very decided that its remarkable relief is due to the washing away of the sediments which once surrounded it, and which formed the mold in which it was cast. In no other way can I imagine its vertical faces of 1,000 feet to have been formed."

The figure of Cabezon, while not very accurate, shows the vertical columnar structure, and the figure of the Needles (plate X) indicates that the same structure is found in that apparent neck.

Reference has been made to the Devils tower, or Mato Tepee, of Wyoming, and its interpretation as a remnant of a laccolith. Professor Jaggar, in his paper, "Laccoliths of the Black Hills," mentions the occurrence of a somewhat annular type of drainage about the tower, the presence of agglomerate exposed at one place near its base, the compact character of the rock composing the tower, and its association with undoubted laccoliths in the same general region as some of the evidences in favor of a laccolithic origin for the tower, but says (page 266):

"The most conclusive evidences against a subjacent conduit to the Mato Tepee mass are the presence of black shale in the agglomerate, the undisturbed horizontal beds which the tower rests upon, and the vertical columns."

General Geology

The sedimentary rocks of the region consist of yellow and gray Cretaceous sandstones and shales, generally with a gentle dip to the northward in the Puerco Valley district. After the tilting of these beds the

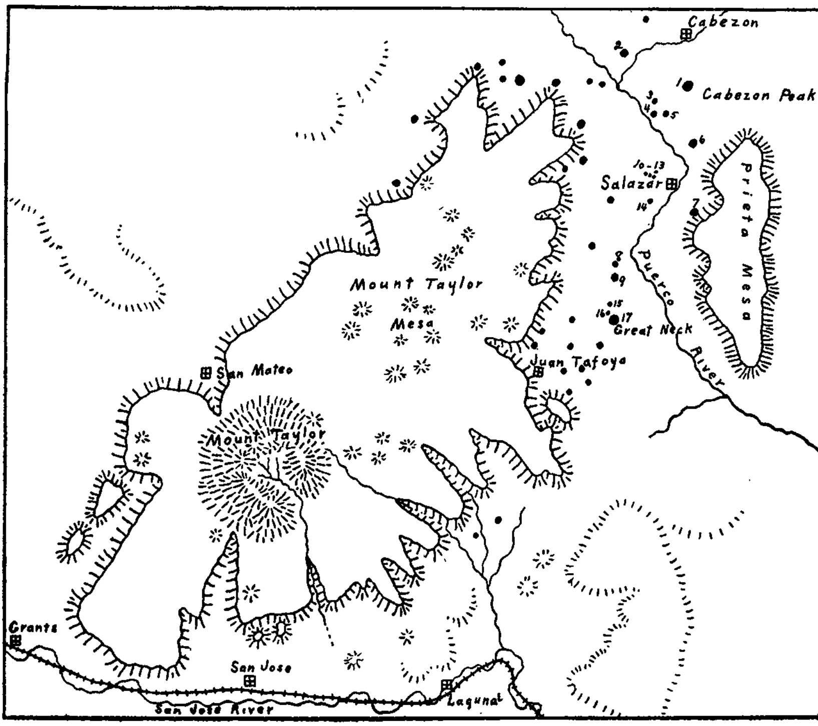

FIGURE 1.—*Sketch Map of the Mount Taylor Region.*
Black dots show location of some of the necks.

region was reduced by erosion to a surface of rather faint relief. This peneplain neatly bevels across the inclined layers, as can be distinctly seen in the walls of both the Mount Taylor and the Prieta mesas. The amount of dip is generally so small, however, that in a limited exposure the beds appear horizontal. In speaking of the exposures about the volcanic buttes, the imperceptible northward dip will be ignored and the beds regarded as horizontal, except in those cases where local tilting is evident.

On this surface of faint relief was built the massive cone of the Mount Taylor volcano and the surrounding lava flows. For detailed descriptions of the main volcano, the lava flows, and the minor cones rising above the flows, the reader is referred to Dutton's essay. According to Dutton, the lava flows are not derived from the main volcano, but from numerous vents scattered over the tableland. Repeated outflows from these vents interlaced to build up a lava cap several hundred feet in thickness and some hundreds of square miles in area. Cinder cones were built on the lava cap in places, indicating occasional explosive phases at some of the vents.

Thus closed the period of vulcanism, and there followed a long era of quiet, during which we have no evidence of any recurrence of lava outbreaks. With the exception of recent basalt fields farther south and west, wholly distinct from and not to be confused with the lavas of the Mount Taylor and Prieta mesas, there is no trace whatever, so far as the region has been studied, of any recurrence of volcanic activity since the period of eruption which formed the great lava cap of the region. Concerning the age of the flows which make up this cap, Major Dutton writes (page 177):

"They were Tertiary; probably Middle Tertiary. . . . None of them can be regarded as recent in any sense whatever. Nowhere on the surface of Mount Taylor or of its surrounding lava sheet has any fresh-looking rock been found. The traces of time are visible everywhere."

Since the close of the volcanic period, the history of the region has been one of erosion. The country of low relief and the lava cap which overspread part of it were subjected to renewed dissection. Deep valleys were cut through the lava cap into the underlying softer rock, and extensive sapping of these softer beds all around the edge of the lava cap caused continual decrease in the size of the mesa. The deepening and broadening of the Puerco valley has isolated the eastern end of the mesa forming the smaller remnant called Prieta mesa. Today we find that the lava cap and over 1,000 feet of the underlying sediments have been removed over extensive areas, so that we recognize in Mount Taylor mesa and its isolated remnants a tableland of sandstone capped by lava, which represents only a portion of its former greater extent. The buttes occur in the eroded area.

The numerous vents from which the lava spread out to form the great surface cap must have connected with some kind of conduits extending downward through the sandstone to the depths from which the lava rose. As soon as the resistant cap was removed, the underlying sandstones would be quickly worn away; but here and there ought to be left standing some masses of resistant igneous rock representing the lava which hardened in the conduits. A view across the Puerco valley reveals many shafts or cylindrical masses of lava rising as buttes well above the valley lowland, produced by erosion of the softer beds. The conclusion is most natural that the buttes represent "necks" of lava which hardened in tube-like conduits leading from unknown depths up to vents on the former surface, the surface, together with the cones and flows which were built upon it, having been removed hereabout by erosion. Such a conclusion is strengthened if, like Dutton, one sees sections of such shafts of lava in the side of the mesa connecting above with cones and lava flows not yet wholly destroyed. He does not doubt that under the portion of the lava cap which still remains are many other such "necks" leading up to the cinder cones and other vents still seen on the surface of the cap, which will some day be revealed by the removal of the cap and the enclosing sediments.

It is essential to the better appreciation of what is to follow that the three main points in the history of the Mount Taylor region, as noted above, be kept in mind. These are, briefly, (1) the reduction of the region to a peneplain; (2) the occurrence of a period of volcanic activity during which the peneplain was covered with a lava cap derived from numerous vents; (3) the extensive erosion of the region, including the removal of the lava cap and underlying sediments from large areas, and the exposure of the shafts of lava which hardened in the conduits.

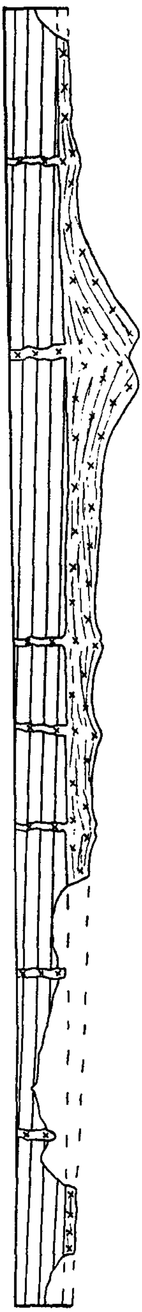

FIGURE 2.—*Ideal Cross-section, northeast-southwest, through Mount Taylor, Mount Taylor Mesa, Puerco Valley, and Prieta Mesa.*

Structural Details

We may now consider the structural details of some of the Mount Taylor buttes, after which it will be in order to examine critically the several theories which might be advanced in explanation of their origin. Doubtless most of the buttes have names by which they are known to the Mexicans, but as I was not able to learn these names in all cases, I designated the buttes by numbers in my notebook and will so refer to them now, adding the correct name when possible.

Number 1, Cabezon peak. This is probably the finest butte in the Mount Taylor region, although Great neck, described on a later page, is a close second. As stated in Major Dutton's report, the topographers who ascended Cabezon found its altitude to be 2,160 feet above the valley bottom. Its diameter is given as about 1,400 feet. A famous landmark

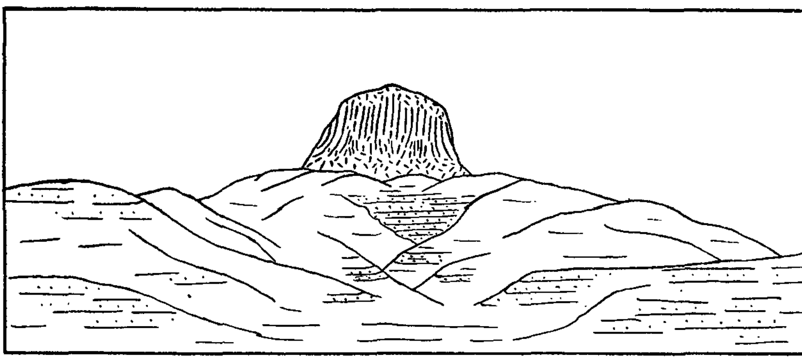

Figure 3.—*Cabezon, showing Exposure of surrounding horizontal Sediments.*

for many years, it has been figured in several of the early exploration reports. It is indeed a most striking feature in the landscape, with its dark shaft outlined against the sky or against the yellow sandstones of the surrounding country.

We approached Cabezon from the east, our first good view of the peak being that reproduced in plate 25, figure 1. From a point a few miles nearer we could see that the butte possessed fine vertical columnar structure, and that down toward its base the columns in places curved outward toward the periphery. The main tower rises above a circular terrace of Cretaceous sandstones which appear to be horizontal, but which are not well exposed on the east. The immediate base of the tower is more or less obscured by a talus of broken columns.

Continuing to the town of Cabezon, we obtained a fine view of the

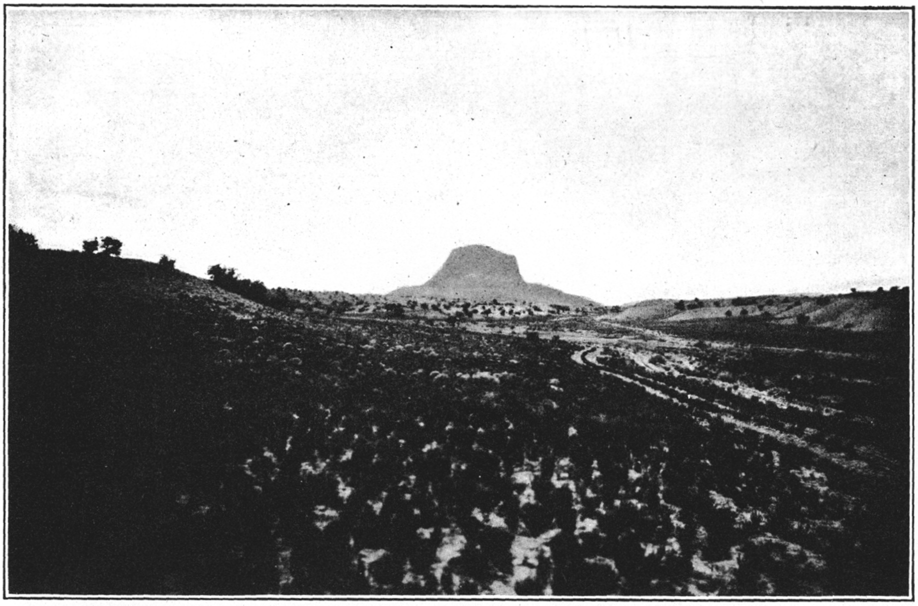

FIGURE 1.—CABEZON PEAK FROM THE EAST
Showing relation of neck to surrounding country

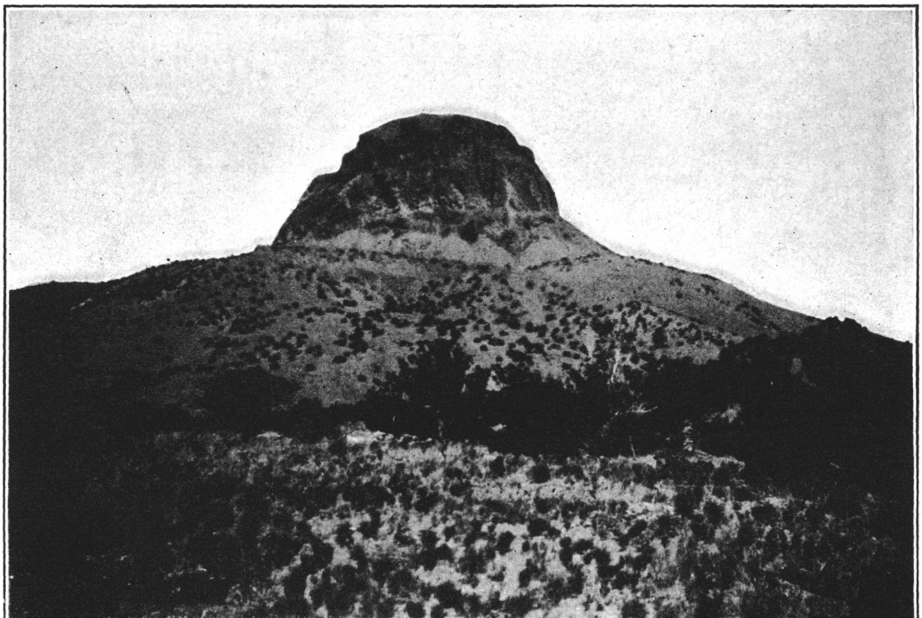

FIGURE 2.—NEAR VIEW OF CABEZON PEAK FROM THE SOUTHWEST
Showing vertical columnar structure

CABEZON PEAK

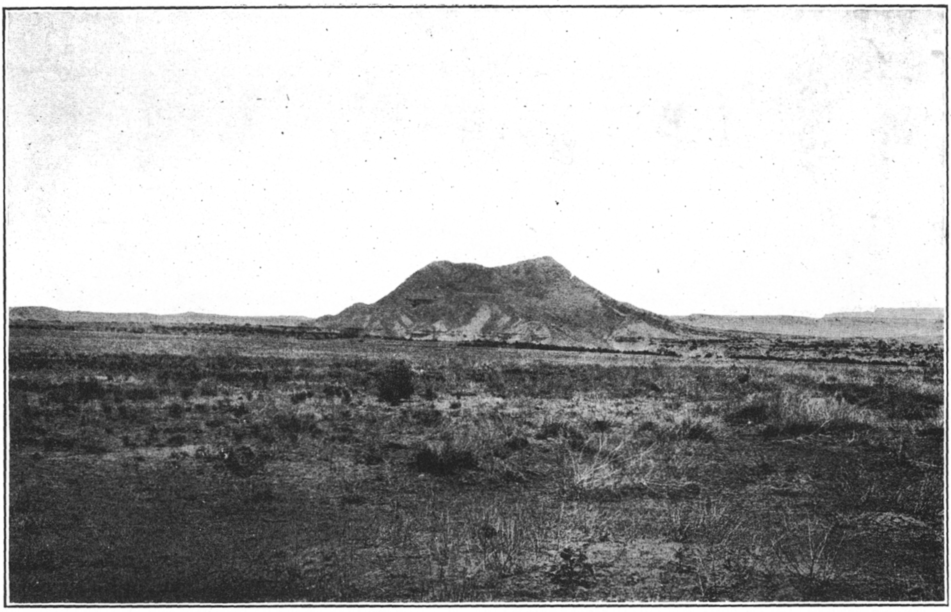

FIGURE 1.—TWIN PEAK (BUTTE NUMBER 12) FROM THE EAST

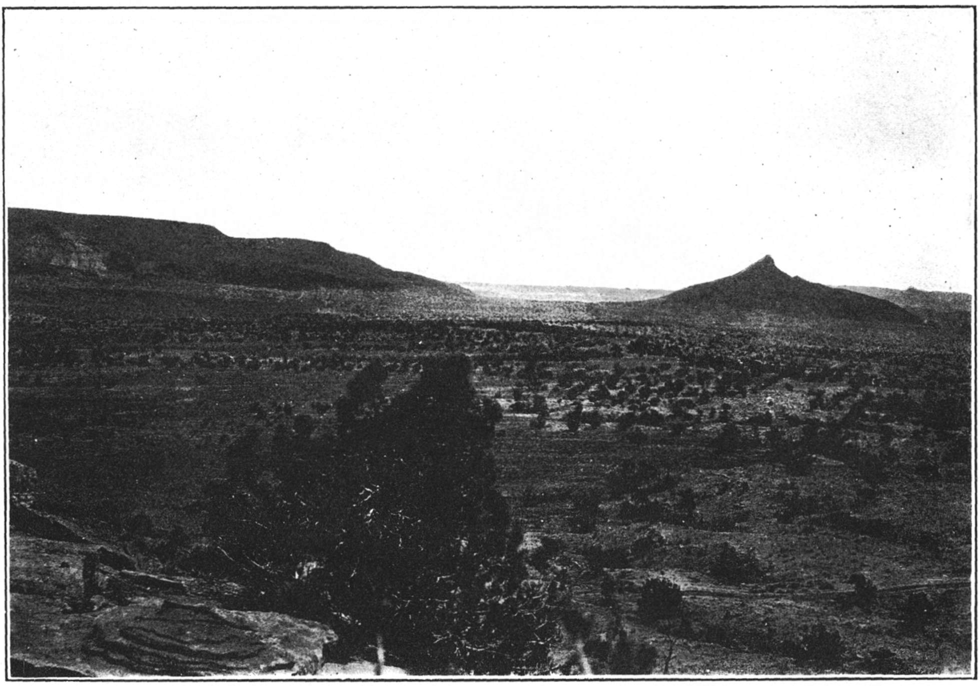

FIGURE 2.—CERRO COCHINO (BUTTE NUMBER 6) AND PRIETA MESA FROM THE NORTH

TWIN PEAK, CERRO COCHINO AND PRIETA MESA butte, and observed that the horizontal Cretaceous beds which form the terrace or encircling platform continue close up to the tower without any signs of disturbance. From the northwest and west vertical columns curving outward toward the base are seen, as well as some places which suggest a cross-section view of more or less radially disposed columns. White and yellow sandstone, apparently not greatly affected by heat and quite horizontal, were found near the top of the terrace, within less than a hundred yards of the base of the tower.

We examined Cabezon around more than three-quarters of its circumference (see plate 25 and figure 3), finding it very symmetrical, cylindrical in shape, with a number of exposures of the horizontal beds about its base and abundant evidence of vertical columnar structure, although the columns are nowhere so perfectly developed as in the Devils tower. We observed no direct contact between the igneous rock and the sediments as we did in other cases, and found the base of the tower and the surrounding sediments more obscured by talus and vegetation than was usually true.

In general the buttes of the Mount Taylor region do not rise above the former level of the lava cap, as indicated by the adjacent remnants of the lava-capped mesas. Cabezon is one of the two exceptions which we noted. It is evident that both Cabezon and Great neck rise above the level of Prieta mesa, although Cabezon is little, if any, higher than the top of Mount Taylor mesa to the west, while Great neck does not reach that level. Both buttes show features which are of special interest in connection with the unusual heights to which they attain. Thus, while the main portion of Cabezon is made up of dark, compact basalt, the talus slopes show much vesicular basalt, black, gray, and red in color, weathered down from the summit. The surface of the lava cap on Prieta mesa slopes upward toward the north, as if rising toward a large cone which formerly existed above the Cabezon butte, but which has been destroyed by erosion. Both buttes are of unusually large diameter, thus having a better chance for the preservation of their upward continuations in overlying lava flow or cones. The slopes at the base of Cabezon are strewn with fragments of a peculiar agglomerate, to be described in connection with butte number 3.

Number 2, Twin Peak (plate 26, and figure 4). As seen from a distance, this butte appears to be somewhat elongated in a north and south direction. It is surrounded by Cretaceous sands and shales, which were easily distinguished and which were apparently quite horizontal. Erosion has left the northern and southern ends of the butte somewhat higher than the middle portion; hence the name, "Twin Peak." This butte was not seen at close range, but the sediments appear to continue well up toward the top of the neck at the northern end, indicating a more or less nearly vertical contact.

Number 3 (plate 27). This butte is rudely cylindrical in cross-section, is fairly flat-topped, of smaller diameter than Cabezon, and does not form so prominent a landmark as many of the others. A complete circuit of this butte was made for the purpose of examining it carefully on all sides.

On the eastern side the yellow and brown Cretaceous shales and sandstones are well exposed, and are seen to be quite horizontal and little affected by heat. They may be traced to within less than fifty feet of the butte at this point, but the precise contact is obscured. All sediments have been stripped away from this side of the butte down to the level of a hard sandstone layer, and this layer and its underlying beds

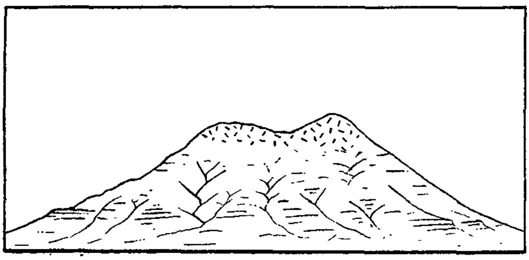

FIGURE 4.—*Twin Peak, showing horizontal Sediments well up Sides of Butte.*

are seen to be horizontal so close to the butte which rises above them that the appearance from a distance suggests a horizontal contact between igneous rock resting directly upon the sediments. A closer examination shows that in no exposure does the igneous rock rest upon the sediments; but large remnants of the sediments found well up toward the summit of this butte on other sides proves that the contact is essentially vertical.

The internal structure of the butte is fairly typical of the greater number of those examined. It is found to be composed of a peculiar agglomerate consisting of angular or somewhat rounded fragments of vesicular, generally reddish lava, loosely held together, often containing fragments of sandstone and shale, and shot through in all directions by great tongues or stringers of more massive columnar lava. The columns in this butte are often finely developed at right angles to the contact with the agglomerate, showing that the liquid lava was the last to be intruded. Doubtless in many cases there have been several alternations of the two types of activity. The agglomerate suggests a more or less explosive

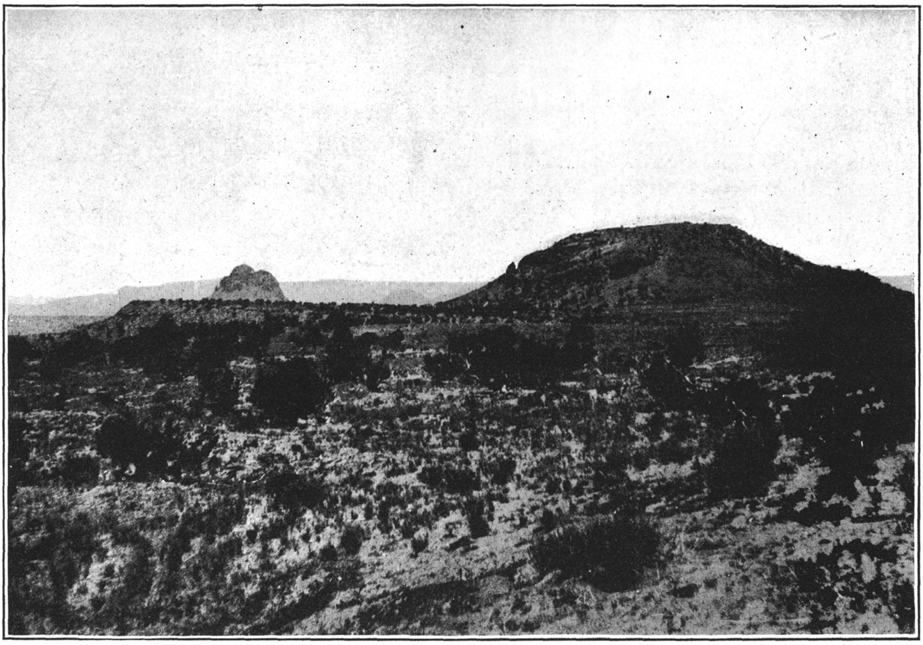

FIGURE 1.—BUTTE NUMBER 3 FROM THE NORTHEAST

Top of number 5 in the distance, Mount Taylor mesa forming skyline beyond

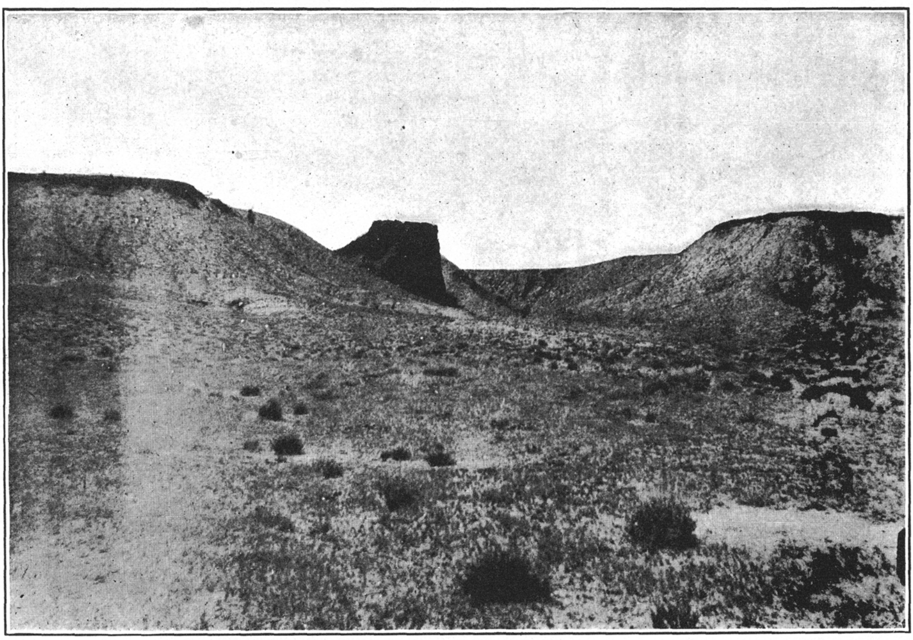

FIGURE 2.—BUTTE NUMBER 14, SOUTHWEST OF SALAZAR

Showing undisturbed surrounding shales capped by sandstone

BUTTES NUMBERS 3 AND 14

phase of volcanic activity. Both sedimentary and igneous fragments are often rounded and appear to have been churned up together. Distinctly bomb-like masses of lava are often seen. The sedimentary fragments vary in size up to three feet in diameter, and are frequently much baked on their outer surfaces. As a rule, no evidence of stratification is visible in the agglomerate, but occasionally distinct traces of rude bedding are made out near the side of the butte, as if during a somewhat quieter phase of the eruption an old conduit were filled up with the fragmental material which was not carried clear away from the exit.

Up through the great mass of agglomerate came the basaltic lava, apparently rising higher than the agglomerate in places and flowing over it. How much higher the lava reached is problematical. On the south-eastern side is seen a splendid contact between the agglomerate and the lava, the line of contact running up the face of the butte to near the top,

FIGURE 5.—*Butte number 4, showing horizontal Sediments surrounding igneous Core, with vertical Contact exposed on south Side.*

and then becoming horizontal where the lava flowed out over the agglomerate, while the columns, being at right angles to the contact, are horizontal so long as the contact is vertical, but change to vertical where the contact is horizontal. In other places the columns are less regular.

At various points around this butte the sandstone was found in place well up the sides of the neck, while in the ravine the igneous rock could be followed down to much lower levels, leaving no doubt in the mind of the observer that the contact was essentially vertical, and that the sediments must formerly have enclosed the rudely cylindrical butte on all sides, having since been partly removed by erosion.

It should be noted that this butte and its enclosing sediments are found several hundred feet lower, both as to actual present elevation and as to stratigraphic position, than the Cabezon and Twin Peak buttes. There is seen to be no relation between the buttes, so far as absolute or relative elevations are concerned. Their heights and the part of the sedimentary series still found about them depend on the amount of destruction accomplished by erosion at each particular point.

Number 4 (figure 5). This butte resembles number 3 in being composed of both agglomerate and columnar basalt. A detailed description of the structural features of the different buttes would in most cases be essentially a repetition of that given above for number 3. Accordingly only critically important points will be specifically mentioned in the remaining descriptions.

The horizontal Cretaceous beds are well exposed about the base of number 4, and in some places well up the sides. This is especially true on the south side, where horizontal sediments are seen well up toward the summit, making a vertical contact with the igneous core of the butte.

Number 5 (plate 30, and figures 6 and 7). This butte is of special interest because of the unusually good exposures it affords. On the north-

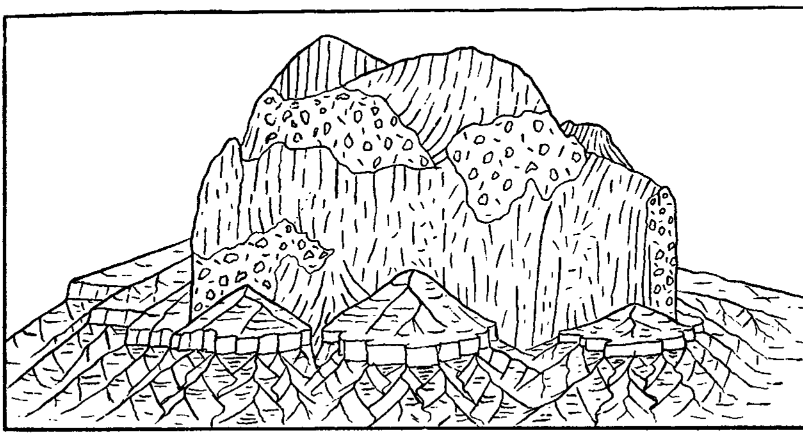

FIGURE 6.—*Diagrammatic Sketch to show Relation of surrounding horizontal Sediments to igneous Core of Butte number 5 and the complex Structure of the Core.*

ern and western sides the yellow sandstones and shales are beautifully exposed and show practically no disturbing effect of the intrusion. Gullies have cut back through the sediments to the butte, ending abruptly against the more or less vertical wall of igneous rock. These give peculiar niches or alleyways, flanked on either side by steep walls of horizontal sediments, with a back wall of igneous rock formed by the side of the butte. The precise contacts are sometimes well shown, and are seen to be essentially vertical. The sediments are usually cut off square, without any evidence of disturbance whatever, but occasionally they show a slight dip away from the contact. In one place a distinct stringer or dike is seen running from the butte out into the sediments.

The upper part of the butte shows fair vertical columnar structure in places, and vertical columns are found well down the butte on one side at least. Elsewhere the columns are curved and rather irregularly developed. Radially disposed columns appear to be shown in cross-section. On one side of the butte rudely bedded agglomerate is found, with vertical columns close by. In places the agglomerate is shot through in every direction with columnar and more massive lava, producing as complicated

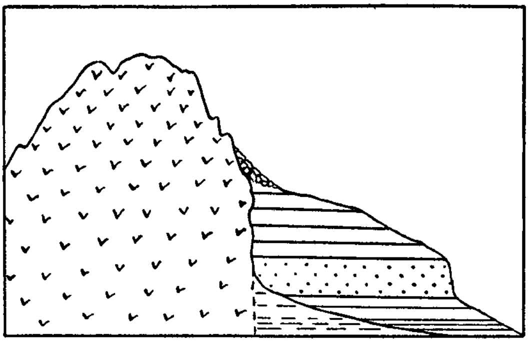

FIGURE 7.—*Cross-section showing Relation of horizontal Sediments to igneous Core of Butte number 5, western Side.*

a mixture of the two as one could well imagine. The lava is in part very vesicular, in part more dense. The accompanying text figure 6 is generalized from field sketches and photographs, and, while showing the general relations fairly well, indicates a much less complicated structure for the igneous core than actually exists. The sandstones near the contact with the butte appear somewhat more yellow than those farther

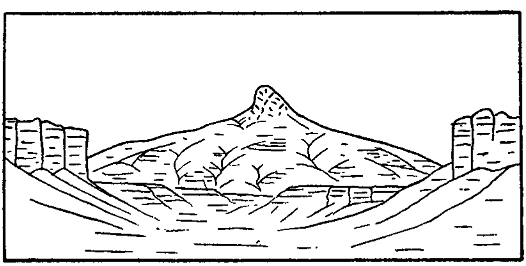

FIGURE 8.—*Cerro Cochino, showing igneous Core rising above surrounding horizontal Sediments.*

away, and are possibly a little firmer, suggesting some metamorphic influence of the butte. It might be that this induration has made the beds more resistant to erosion, in part accounting for the small zone of sediments often left about the necks; but the results of baking may not be so pronounced. In most cases it is hard to detect any metamorphism whatever. The circular benches of sediments are more likely due to the protective action afforded by the central cores of igneous rock rising well above them and the accumulated talus of large lava fragments which are sometimes found about the bases of the towers.

Number 6, Cerro Cochino (plates 26 and 28, and figure 8). This butte is composed of a very large bench or terrace of the horizontal Cretaceous sediments, from the top of which rises a shaft of igneous rock. The right-hand butte shown in figure 21 of Dutton's report is evidently Cerro Cochino. We made no detailed examination.

Number 7 (plate 28). Southeast of the Mexican village of Salazar is a large butte surrounded by horizontal sandstones and shales. The butte appears to be elongated in a north and south direction, although we did not make a close examination. Just north of it, in the side of

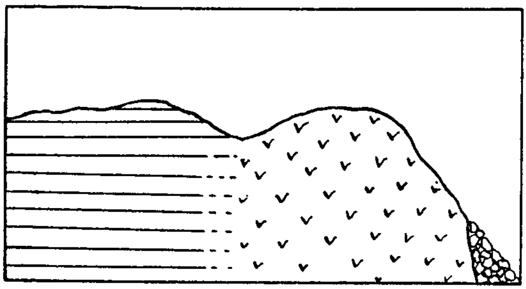

FIGURE 9.—*Cross-section showing Contact of horizontal Sediments with igneous Core of Butte number 8.*

Precise contact covered with wash.

Prieta mesa, there is evidence of a fault, the displacement being 75 feet or more, as nearly as we could estimate.

Number 8 (figure 9). This is a medium-sized butte showing fine columnar structure, the columns pointing in almost every direction, except that no good vertical ones were seen. The sediments have been stripped away from every side but the southeast, where they are seen making a vertical contact with the igneous rock of the butte almost to its summit. The beds remain horizontal. A small dike, a few feet in width, can be traced from the butte a short distance northward.

Number 9. This butte contains a large proportion of agglomerate, and as seen from a distance appears to be somewhat elongated in a north-south direction. Small hummocks are seen at intervals southward toward Great neck; these hummocks may be minor buttes similar to the larger ones, or remnants of a dike; it was not possible for us to visit them.

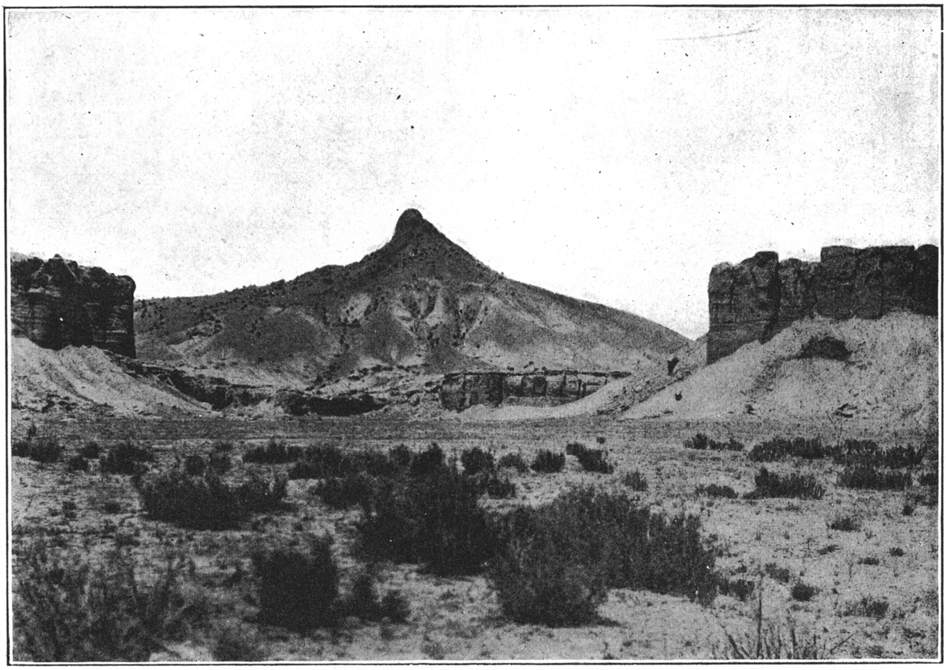

FIGURE 1.—CERRO COCHINO (BUTTE NUMBER 6) FROM THE WEST
Showing undisturbed sediments well up toward top of butte

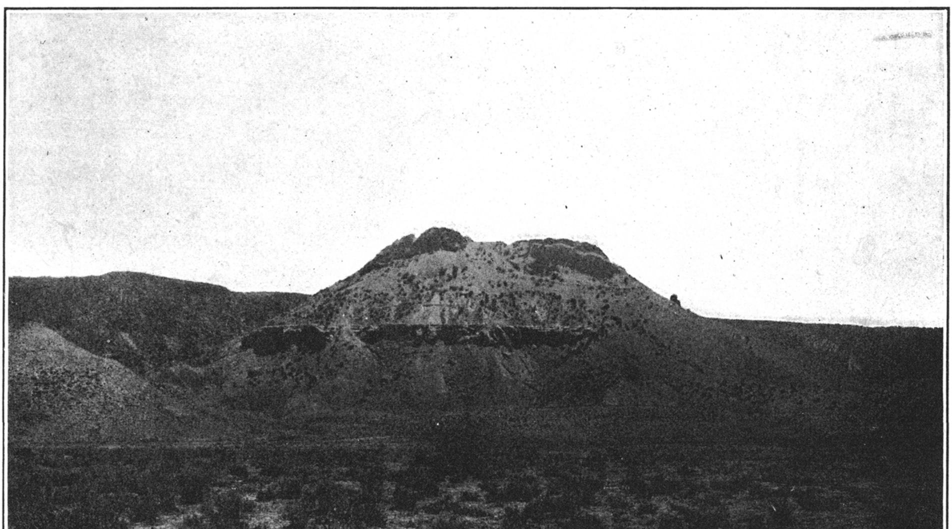

FIGURE 2.—BUTTE NUMBER 7, IN THE SIDE OF PRIETA MESA
Showing undisturbed enclosing sediments

BUTTES NUMBERS 6 AND 7

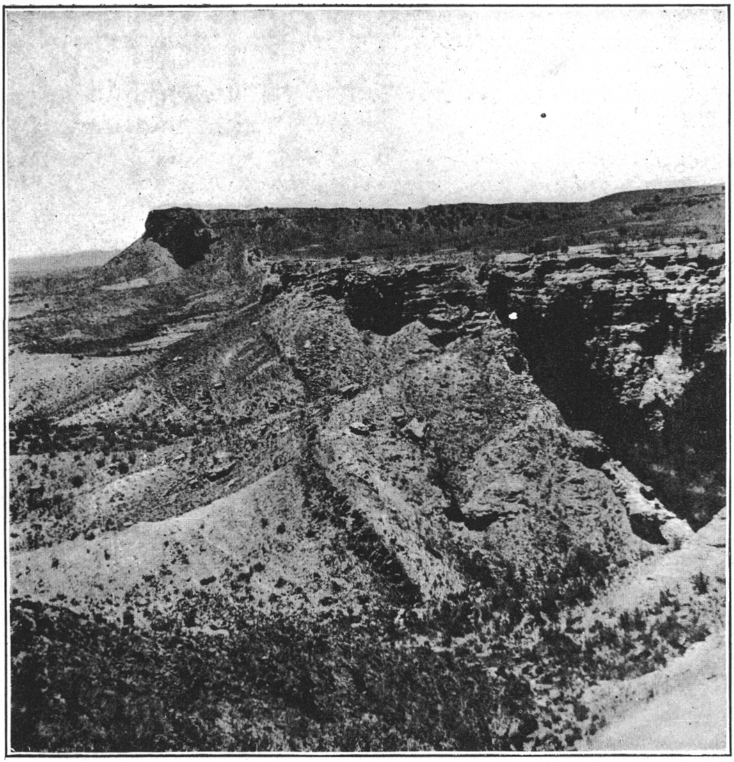

FIGURE 1.—DIKE OCCUPYING FAULT FISSURE WEST OF SALAZAR

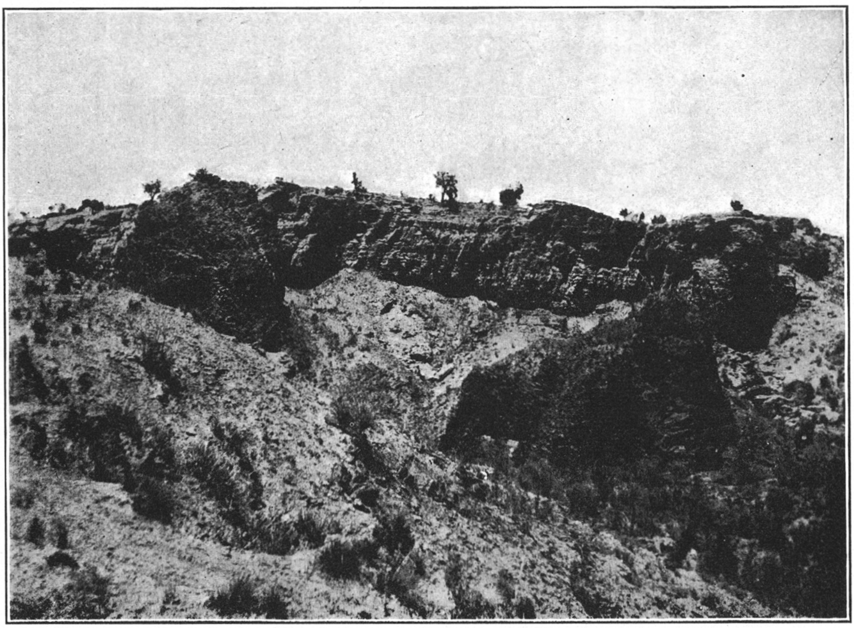

FIGURE 2.—BUTTE NUMBER 11 AND 12, ASSOCIATED WITH ABOVE DIKE

DIKE OCCUPYING FAULT FISSURE, AND BUTTES 11 AND 12

Numbers 10, 11, 12, 13. The relations of four small buttes west of Salazar are of special interest. A north-and-south dike (plate 29), from 2 to 4 feet in width, occupies a fault fissure, the evidence of faulting appearing where a somewhat massive sandstone meets softer sands and shales at the fissures. At one point the dike suddenly expands into a butte some 20 feet in width by 35 in length, composed of the peculiar agglomerate so often found in the large buttes, and of columnar basalt, the columns being irregularly curved. A short distance south is a much larger butte, also an expanded portion of the dike, showing beautifully curved basaltic columns more or less radially disposed (plate 29). From this point a branch dike seems to run off to the west, expanding into small buttes at two points. The first of these two buttes is composed in part of the agglomerate containing sandstone fragments, while basaltic columns are approximately horizontal on either side, showing a form

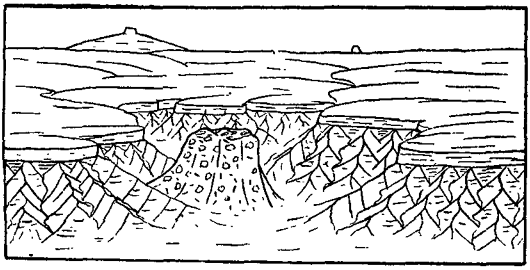

FIGURE 10.—*Diagram showing Relation of Butte number 14 to surrounding Sediments (Shales capped by Sandstone) and to other Buttes in the Region.*

transitional between dike and butte. It is clear that the buttes represent igneous rock which filled tubular conduits leading up through the sediments, just as the associated dike represents igneous rock which filled a fissure in the sediments.

Number 14 (plate 27, and figure 10). Southwest of Salazar is a butte, 75 or 100 feet in diameter, composed almost entirely of agglomerate which included large fragments of sandstone and shale. This butte is surrounded by horizontal gray shales capped by yellow sandstone. On three sides these beds rise practically to the present summit of the butte, erosion having etched out a semicircular depression about the immediate contact, leaving the butte somewhat isolated from the enclosing sediments. That the contacts about this rudely cylindrical butte must have been vertical is quite evident. The direct contact is occasionally still visible, the beds being bent upward in some places near the butte, but remaining horizontal elsewhere. Sedimentary rocks, well exposed, were traced all around the butte without discovering any indication of a dike.

Numbers 15 and 16. About a mile north of Great neck is a small butte which appears to be composed wholly of agglomerate, although its western side was not seen. One-third of a mile northwest of Great neck is another small butte composed of both agglomerate and beautifully columnar basalt, the columns being irregularly disposed.

Number 17, Great neck (plate 30). With the exception of Cabezon, this is the finest butte in the region. According to Dutton's report, it rises 1,800 or 1,900 feet above the valley and has a diameter of about 1,300 feet. Although that writer was unable to visit it, he reproduces a picture of it in his report.

On examination we found the greater part of this butte to consist of columnar basalt. As seen from the northwest, the columns in the main portion of the butte are vertical. Farther around to the west side the columns are vertical above, but curve outward toward the horizontal below. In other places the columns are more irregular. On the north side of the butte agglomerate and irregular basaltic columns are seen.

The summit of the butte presents features of some interest. There appear to be two horizontal layers of igneous rock lying on the columnar portion of the butte and forming a sort of double cap for it. Ascending the west side as far as the contact between the columns and the bottom of the lower layer, I was able to see that the latter consisted of a more or less decomposed, structureless sheet of lava, while above it came a thick layer of agglomerate full of good volcanic bombs and exceedingly vesicular lava. These features suggest that the upper part of this great butte represents its upward continuation, possibly into an overlying volcanic crater where successive layers of material spread out in the bowl of the crater, to be subsequently preserved in part, because of their position immediately above the resistant mass of the butte itself. In this connection it is noted that Great neck rises distinctly above the general level of Prieta mesa just east, although it is lower than Mount Taylor mesa to the west.

Other buttes. From near the summit of the west side of Great neck, one can count from 30 to 35 volcanic buttes, exclusive of the very small ones of those already mentioned. Dutton estimates that in the Mount Taylor region there are probably several hundred of these buttes exposed. Some of these he reports as being exposed in the sides of the great lava-capped mesa which formerly covered the Puerco Valley region, a complete section of a butte connecting with overlying cone and lava flow sometimes being secured. Several of the buttes which we saw from a distance appeared to be but partly exhumed by erosion along the side of the mesa, but we were unable to visit them to determine their exact rela-

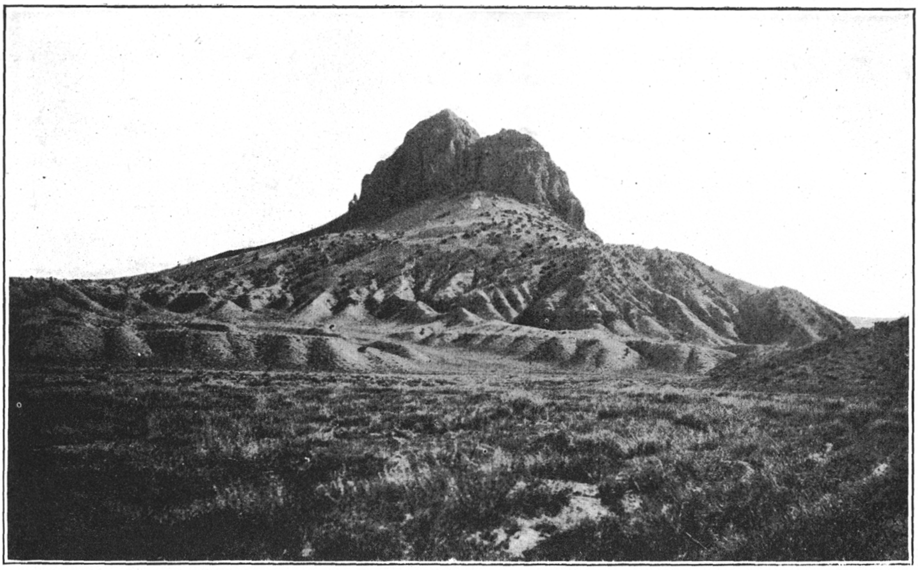

FIGURE 1.—BUTTE NUMBER 5 FROM THE NORTH
Showing undisturbed surrounding sediments

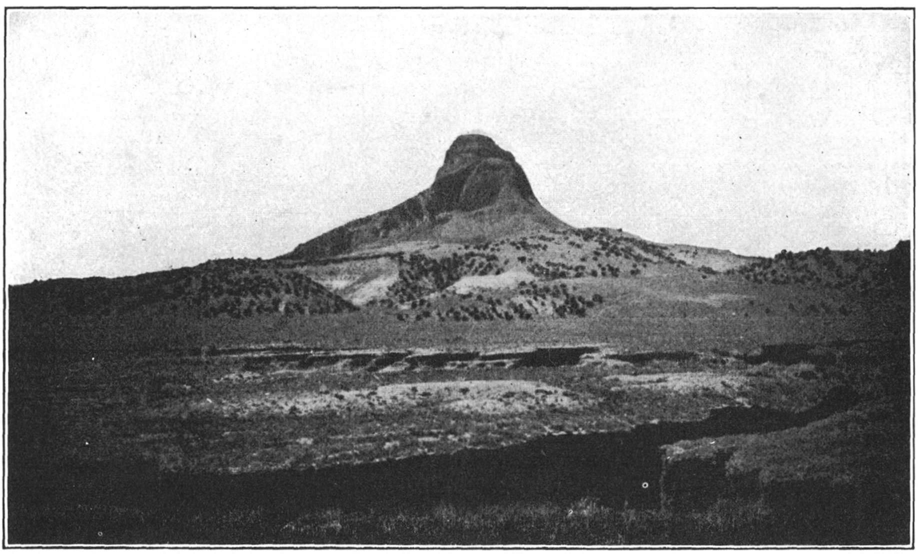

FIGURE 2.—GREAT NECK, FROM THE NORTHWEST

BUTTE NUMBER 5, AND GREAT NECK

tions. At the northern end of Mount Taylor mesa the lava seems to show distinct bedding with a slight dip to the south, while just north is one of the buttes. The features strongly suggest a neck which was a conduit to a volcano, and the lava flows sloping away from that volcano, the cone itself having been removed by erosion.

Dutton has described in some detail a number of the buttes in other parts of the region. According to his descriptions, vertical columnar structure is not uncommon; evidence of repeated eruptions from the same vent is abundant; the buttes are often elongated rather than cylindrical, and the long axis may be prolonged in both directions by dikes. No evidence of recent flows is found in connection with the buttes. It appears, therefore, that there is a general uniformity of essential features in the buttes of different parts of the region. In minor details there is variety, some buttes being large, others small, with every gradation in size between the two extremes. Some are composed almost wholly of agglomerate, some almost entirely of basaltic lava, while others are intermediate in composition; some of the buttes appear nearly circular, others are more elongated, usually in a north-south direction; dikes are visible connecting two or more of the buttes, or extending a shorter distance north and south of a single butte, or appear to be wholly absent. But, as regards those features critically important in the present discussion, the relations are uniform and simple. The buttes are located in the lowlands produced by erosion, are not associated with lavas more recent than the main great lava cap which formerly extended out over them, have evidently served as vents for repeated eruptions, and show every gradation from buttes well stripped of enclosing sediments, through those showing more or less of the sediments making vertical contacts with the igneous rock, to examples just beginning to be exhumed from the walls of the mesa and which still connect with overlying cones and lava flows.

Possible Interpretations

A. As Remnants of Laccoliths or Sills

Can the buttes of the Mount Taylor region be interpreted as remnants of laccoliths or sills, all the overlying beds having been removed by erosion, as well as all the intrusive mass except a small more or less cylindrical shaft? Such an origin has been announced for the Devils tower, in Wyoming, partly because of its vertical columnar structure and undisturbed associated sediments. We have seen that many of the Mount Taylor buttes show vertical columnar structure, though never so perfect as that in the Devils tower, while practically all of them are associated with undisturbed sediments. There is also noted a tendency for the columns to turn outward toward the base in the case of the Mount Taylor examples, another feature which allies them to the Devils tower. Agglomerate is abundant in the Mount Taylor examples, and is found in the lower part of the Devils tower. There are certainly features of strong resemblance between the buttes in the two places. In pointing out this resemblance, I accept Professor Jaggar's photographic and written descriptions of the Wyoming example, as I have not seen the tower.

To such an interpretation for the Mount Taylor buttes there appear to be serious objections. First, we should have to imagine hundreds of laccoliths or sills developing at all possible horizons in a series of sandstones and shales, either near the surface, which was at the same time covered with a flow of the same lava, or else in depth with long subsequent erosion and finally a surface flow similar to the material previously intruded.

We should have to grant, further, that erosion at various levels and at numerous places happened to be so nicely adjusted in every case that the overlying arched beds were invariably completely removed, leaving only the horizontal beds beneath, and that in some remarkable manner erosion always removed just enough of the intrusive mass itself to leave a rudely cylindrical tower, oval or circular in cross-section, resembling a volcanic neck. If the buttes are remnants of either laccoliths or sills, surely in all the examples studied there should be at least one which would show some trace of overlying sediments; one in some other stage of erosion than the penultimate; one which in some way bore distinct resemblance to a laccolith or sill.

Maturely eroded laccoliths or sills should show traces of the horizontal contacts between the base of the intrusive mass and the underlying sediments. The contacts seen in the Mount Taylor region were all vertical. It is true that the horizontal contact might be wholly concealed in one or even several remnants of laccoliths or sills, and that vertical contacts might occasionally be seen in such remnants where the intrusive mass cut across the bedding; but it is beyond probability that in so large a number of examples as have been studied in the Mount Taylor region there should be found no trace of horizontal contacts, but many vertical contacts, if the buttes were really remnants of laccoliths or sills.

The structure of the buttes makes the laccolithic or sill hypothesis inadmissible. They are sometimes composed wholly of an agglomerate indicating explosive activity, and at other times have numerous lava tubes running up through the agglomerate, showing repeated uprisings of the lava toward the surface. The agglomerate often contains good volcanic bombs. Dense igneous rock is characteristic of intrusives, but the lava in the Mount Taylor buttes is often vesicular, sometimes extremely so.

Were laccoliths or sills so numerous in the region, we ought to find some of them shown in section in the sides of Mount Taylor mesa; yet nothing of this character has been observed there. On the other hand, good sections of volcanic necks still connecting with overlying cinder cones and lava flows have been described by Dutton, these necks bearing every resemblance to the closely associated but more completely eroded examples farther out from the mesa.

In view of the above facts, it would seem inadmissible to assign a laccolithic or sill origin to the Mount Taylor buttes; hence we must conclude that vertical columnar structure and undisturbed associated sediments are not safe guides in distinguishing between remnants of laccoliths or sills and volcanic necks.

B. AS REMNANTS OF SURFACE FLOWS

Can the Mount Taylor buttes be regarded as remnants of surface flows? This would explain the vertical columnar structure and undisturbed sediments as well as the vesicular character of the lava in places.

Again we meet the serious difficulty of being compelled to postulate an erosion which happened to leave several hundred more or less cylindrical towers of lava, but which failed to leave any larger remnants which could be readily recognized as undoubted flows. The great lava caps of Mount Taylor mesa and its outlying remnants, at a fairly uniform and distinctly higher level, are obviously not to be considered in this connection. The fact that no distinct lava-flow remnant has been observed among the great number of buttes seen in the erosion lowlands of the region is sufficient to negative the hypothesis here considered.

But there are other objections to the hypothesis. The buttes occur at different elevations above the valley floor as well as at different stratigraphic horizons. In order to interpret the buttes as remnants of flows, we must assume numerous flows at different levels, or else a single flow over a very uneven topography. But we have already seen that there is no evidence of any volcanic activity in this part of the district later than that which produced the great lava cap, and that this lava cap spread out over a surface of relatively faint relief.

Remnants of surface flows should show horizontal contacts with the underlying sediments, and only rarely vertical contacts where the lava flowed against some cliff or valley wall; yet no horizontal contacts were seen in connection with the Mount Taylor buttes, although the erosion of ravines is often favorable for the disclosure of such contacts if they existed, while vertical contacts are visible about most of the necks and sometimes almost completely around them.

The structure of the buttes, as already described, indicates their function as conduits leading to some surface higher up, and is quite distinct from the normal structure of flows. The stringers and dikes, which sometimes run from the buttes into the surrounding sediments, are not normal accompaniments of surface flows. Sections of the buttes in the sides of Mount Taylor mesa exclude the flow-remnant hypothesis.

C. AS VOLCANIC NECKS

If the buttes of the Mount Taylor region are to be regarded as true volcanic necks, representing the material which remained in tubes or chimneys connecting with vents at some overlying surface, they ought to show certain critical features.

Being revealed only as a result of the removal of overlying cone and surface flows, volcanic necks ought to be found in the areas subjected to great erosion. They are essentially erosion features. We should expect them to occur in the valley lowlands and not on the adjacent highlands, especially if the highlands represented the former surface and were covered with portions of surface cones and flows not yet destroyed by erosion. Neither should the necks rise above the former level of the lava cap, as indicated by associated mesa remnants, unless, as might occasionally happen, the upper continuation of the neck into the cone were more or less preserved. The buttes of the Mount Taylor region occur only in the valley lowlands produced by erosion since the volcanic period, and seldom rise above the former level of the lava cap as indicated by the elevation of Mount Taylor and Prieta mesas. The exceptions noted have features which indicate that their upper continuation into the overlying cone are to some extent preserved.

Volcanic necks should often show evidence of repeated eruptions, both explosive and quiet. The different tongues or stringers of lava would show irregular columnar structure where various eruptions of different dates were represented; but where a single lava flow welled up to the surface and then solidified, the lava remaining in the conduit might show quite regular columnar structure. That part of the lava cooling deep in the conduit would have the surrounding sedimentary walls as the cooling surface, and the columns would therefore tend to develop a radial arrangement; but that portion of the lava nearer the top of the conduit would find a much more effective cooling surface in the free air above the crater, and the columns developing perpendicular to this cooling surface would be vertical. Passing downward, a point would finally be reached where the cooling effect of the sedimentary wall would exceed the cooling effect of the more distant upper air, resulting in a change from vertical to radial columns. If the lava in the neck was continuous with a lava cone above, both being highly heated and the cone having a crater in it situated above the neck, there would result a vertical columnar structure in the upper part of the neck, the columns gradually curving outward and becoming radial farther down.* The vertical columnar structure would extend much deeper in necks of large diameter than in necks of small diameter. The buttes in the Mount Taylor region conform to these expectations quite closely. Many of them show evidence of repeated eruptions, with irregular columnar structure in the different lava tongues. Some are composed almost wholly of lava, with vertical columnar structure in the upper part, the columns curving outward and becoming radial farther down. The larger necks show the best vertical columns, while the smaller necks quite uniformly show an irregular or more radial arrangement. In many cases, of course, only the deeper portions of the smaller necks are preserved, the higher portions standing the best chance for preservation in the necks of large diameter.

Volcanic necks, continuing indefinitely in depth, should be exposed at any elevation or stratigraphic horizon below the former surface to which erosion happened to reach. The buttes of the Mount Taylor region are found at all levels, from the former upland surface down to the bottom of the present valleys.

The erosion of volcanic necks might occasionally show a limited horizontal contact due to irregularity in the walls of the neck, but most of the contacts exposed by erosion should be more or less vertical. All the contacts observed about the Mount Taylor buttes were essentially vertical.

Regarding the attitude of the sediments enclosing the necks, it would appear that they might reasonably be expected to remain practically undisturbed, if we admit the gradual enlargement of the vents from formerly insignificant apertures, as advocated by Dutton. Our own observations led to the conclusion that there were fissures in the region, many of which could not be detected without more detailed field study than we could make, but a few of which were more noticeable because they were opened and filled with lava, forming dikes which are still preserved, or else associated with differential movements developing faults which are sometimes visible in the mesa walls. Along these fissures were occasional vents, probably of exceedingly small diameter to begin with, where escaping volcanic material found its way to the surface. Con-

* I submitted the problem to Professor Wm. Hallock, of Columbia University, and am indebted to him for information on this point.

tinued explosive ejection through the most favorable of these vents resulted in their enlargement by the continuous detaching of fragment after fragment from the sedimentary walls of the expanding tube or chimney. Such a process would not tend to disturb the attitude of the surrounding sediments. It is true that a mass of lava over a thousand feet in diameter, thrust up bodily through horizontal sediments, could hardly be expected to leave those sediments horizontal. In the gradual enlargement of a vent from a few inches or feet to a thousand feet or more in diameter, by the progressive sapping of the surrounding walls, the sediments would be less apt to suffer disturbance, since fragments from the walls of the conduit would break off more readily than would great masses of sediments be flexed upward by the locally applied force. It is this latter process which appears to have been active in producing the volcanic necks of the Mount Taylor region. The horizontality of the beds associated with the Mount Taylor necks are therefore to be regarded as a normal feature.

Résumé

In conclusion, it appears that the various phenomena associated with the buttes of the Mount Taylor region accord perfectly with that hypothesis which interprets them as true volcanic necks, but do not admit of their interpretation as remnants of flows, sills, or laccoliths. Vertical columnar structure must be regarded as a normal feature in the upper parts of volcanic necks, as must also the lack of disturbance noted in the sediments about such necks. Inasmuch as the most conclusive evidence on which a laccolithic origin was ascribed to the Devils tower of Wyoming consisted of features which are very characteristic of the volcanic necks of the Mount Taylor region, and since the descriptions of the tower mention no features that might not occur in connection with a volcanic neck, the writer feels that the origin of the tower should be regarded as an open question until further field study affords evidence upon which a decisive answer may be based.

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