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GEOLOGY OF SIERRA TINAJA PINTA AND CORNUDAS STATION AREAS, NORTHERN HUDSPETH COUNTY, TEXAS

by

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THESIS

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PREFACE

My first acquaintance with the geography and geology of northern Trans-Pecos Texas was as a field assistant to Dr. Don E. Owen, then a geologist with The University of Texas Bureau of Economic Geology. Although we did not examine the area of this study, nor was the area chosen until some two years later, the background I received from Dr. Owen in the regional stratigraphy of the Permian and Cretaceous rocks, in the petrology of the igneous rocks of the Cornudas and Dog Mountains, and in the broad structural outlines of the northern Trans-Pecos region proved to be an invaluable foundation from which to launch this investigation.

Dr. S. E. Clabaugh, who supervised this thesis, is particularly familiar with the problems involved, as he did his M.A. thesis in the Cornudas Mountains which lie only a few miles to the north. Dr. D. S. Barker was especially helpful with the petrologic problems and made x-ray studies of certain minerals. Treatment of the Cretaceous rocks follows suggestions by Dr. Keith Young. Paul Clifford, a graduate student at The University of Texas, did the initial editing of this thesis.

Lotto Turner, Jerry Stevens, C. R. Bramblett, Robert Jones, and Lester Doughtery were most generous to permit

unlimited access to their ranches. Messrs. Turner and Doughtery were particularly helpful in giving advice on road conditions and in assisting me when I had difficulty in getting about. Special thanks are due Mr. and Mrs. L. R. Tinnin and Mr. and Mrs. Eugene Tonn who made my stay at Cornudas Station most enjoyable.

A fellowship from the Standard Oil Company of Texas provided money for thin sections and aerial photographs, and permitted me to spend a great deal more time writing this thesis than would have otherwise been possible.

Robert O. Gross
May 1965

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A B S T R A C T

Igneous rocks in the Sierra Tinaja Pinta and Cornudas Station areas are part of a group of intrusions of Tertiary age that outline the northeastern margin of the Diablo Plateau; they are part of the larger alkalic petrographic province of Trans-Pecos Texas. Laccoliths, dikes, sills and a cone sheet were intruded into the Hueco and Victorio Peak Limestones of Permian age and into sandstone and limestone of Cretaceous age, which are paleontologically correlative with the Fredricksburg and Washita Groups of central Texas.

The igneous rocks are of four types: (1) porphyritic analcime syenite and associated dike and contact rocks, (2) pyroxene trachyte, (3) porphyritic analcime-nepheline syenite, and (4) olivine-analcime trachyte. When magma reached crustal levels presently exposed in the Sierra Tinaja Pinta-Cornudas Station vicinity, it was in an advanced stage of differentiation and crystallization. Hypersolvus feldspar, augite, and a minor amount of olivine and nepheline in a liquid were

intruded near the base of the Hueco Limestone, and formed the Mayfield Valley intrusion. Filter pressing resulted in squeezing a liquid that contained a few microphenocrysts of hypersolvus feldspar and nepheline into fractures overlying the Mayfield Valley intrusion. This liquid consolidated to form the porphyritic analcime-nepheline syenite of the Miller Mountain, Cerro Diablo and East Mountain intrusions.

Experimental evidence suggests that nepheline syenites can be formed by two mechanisms: (1) differentiation from a magma of different composition, or (2) partial melting of pre-existing rocks to produce magma of nepheline syenite composition. The second mechanism is questionable because partial melting of most sedimentary rocks would produce granite rather than nepheline syenite; the hypothesis of partial melting of subsilicic igneous rocks to explain the origin of nepheline syenites merely postpones the problem of origin of subsilic rocks.

Fractional crystallization in the alkali olivine basalt series can produce phonolites. This mechanism is favored as the origin of feldspathoidal igneous rocks that lie along the northeastern margin of the Diablo Plateau. Block faulting in the northern Trans-Pecos is thought to be related to the initiation of melting at depth.

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I N T R O D U C T I O N

LOCATION AND ACCESS

The Sierra Tinaja Pinta and Cornudas Station areas are on the northeastern margin of the Diablo Plateau, in Hudspeth County, Texas. Both are included on the U. S. Geological Survey Cerro Diablo quadrangle (15-minute series). El Paso is 65 miles to the west; 25 miles to the east is Salt Flat, and Dell City lies 12 miles due east, although by paved road it is 28 miles from Cornudas Station. Geologic mapping was done in two areas, one north of U. S. Highway 62-180, the other south of this highway directly across from Cornudas Station. Figure 1 shows the areas and their geographic relation to other igneous intrusions on the margin of the plateau.

Access to the western and northern portions of the Sierra Tinaja Pinta area is by an improved gravel road, which connects the Mayfield Ranch headquarters with the highway, and by several unimproved dirt roads that reach the mountains from the gravel road. A second improved road, located at the east end of the area, provides an entrance to the East Mountain-Cerro Diablo vicinity. The south sides of Miller and East Mountains are accessible by means of unimproved roads which cross the Brammer Ranch. All these roads are accessible by two-wheel-drive vehicles if one uses some care

LIST OF INTRUSIONS

1 Alamo Mountain
2 Flat Top Mountain
3 Little Wind Mountain or Deer Mountain
4 Wind Mountain
5 Cornudas Mountain
6 Black Mountain
7 San Antonio Mountain
8 Washburn Mountain
9 Chatfield Mountain
10 Dog Mountain
11 Miller Mountain
12 East Mountain
13 Cerro Diablo
14 Mayfield Valley
15 Cornudas Station
16 Antelope Hill
17 Sierra Prieta
18 Cave Peak
19 Marble Canyon
20 Dell City

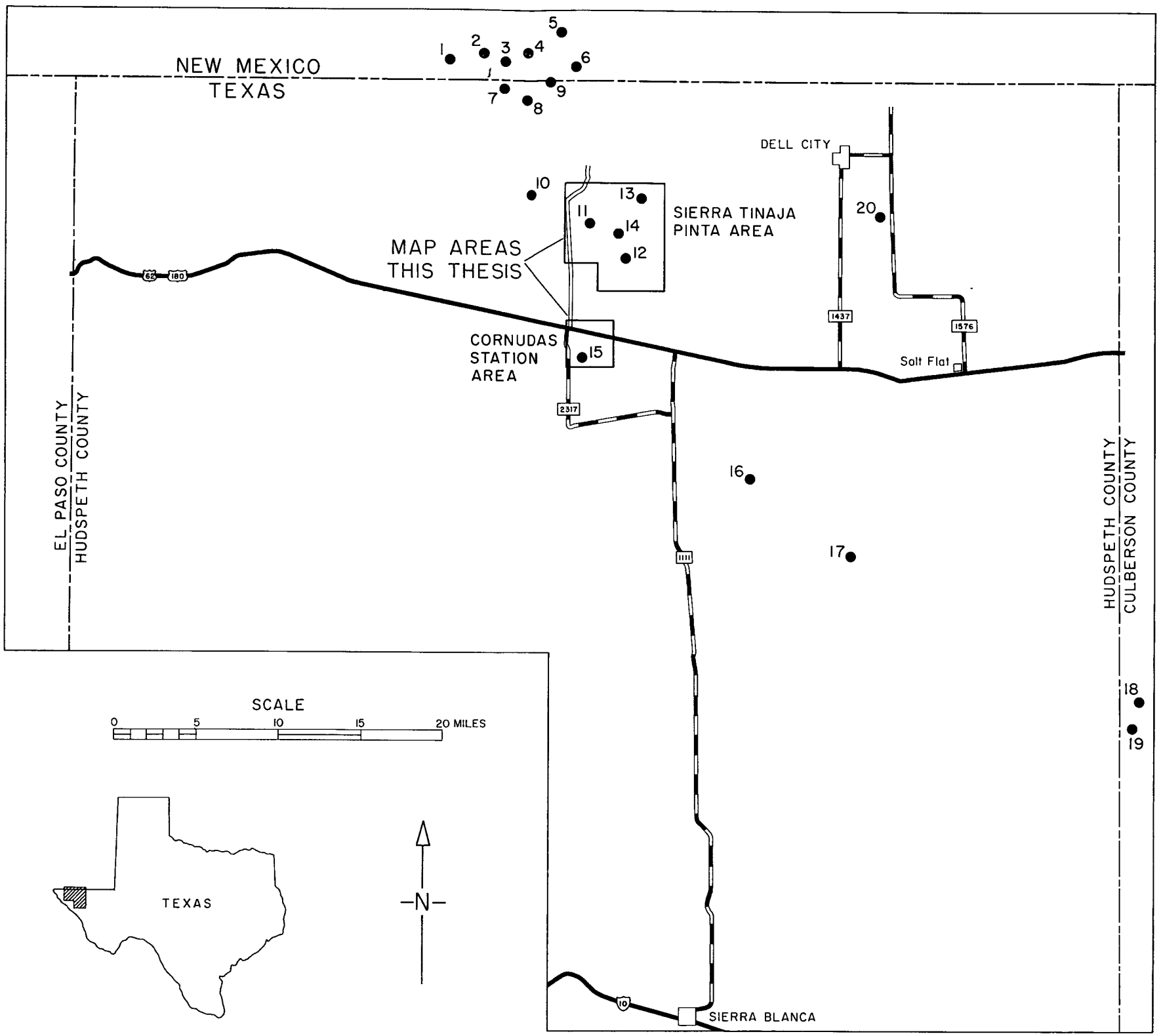


Figure 1. Intrusive igneous rocks of northeastern Diablo Plateau, Texas and New Mexico.

in traversing them. The Cornudas Station area is readily accessible by an unimproved road that leads south from the highway at Cornudas Station.

GEOGRAPHY

Topography, vegetation, and drainage.--A rough mountainous topography, with elevations ranging from 4,240 to 5,722 feet, rises above the general level of the Diablo Plateau to form the Sierra Tinaja Pinta area. The name Sierra Tinaja Pinta includes Miller and East Mountains only; the designation Sierra Tinaja Pinta area includes Cerro Diablo, in addition to Miller and East Mountains. The igneous rocks have proven to be very resistant to erosion and are responsible for preserving this as a local mountainous area. Desert scrub, in which the most characteristic plant is creosotebush (Larrea divaricata), dominates all the lower flatter parts of the area. Yuccas and a few species of cacti, principally of the genus Opuntia, comprise the remainder of this plant community. The lower slopes of the mountains are covered with ocotillo (Fouquieria splendens), centuryplant (Agave scabra), and numerous cacti, including the genera Opuntia, Echinocereus, Echinocactus, Escobaria, and Coryplantha. Desert grassland vegetation occupies the upper part of the mountains; chinograss (Bouteloua breviseta), and sotol

(Dasylirion leiophyllum) are the characteristic members. Isolated junipers grow in the draws on the west slope of Miller Mountain.

Local drainage is radial from the mountain group, but regional drainage is into Salt Basin which is approximately 12 miles to the east. All streams are intermittent, carrying water only after brief, but sometimes torrential rains. A small basin atop East Mountain catches a portion of the scant rainfall and supplies a spring in the draw at the southern base of the mountain. This is the only natural surface water available for some miles about the mountains. It is from this spring and from the petroglyphs upon the surrounding mountains that the area receives its name, Sierra Tinaja Pinta, which may be translated as "mountains of the painted water hole."

The Cornudas Station area consists of a circular group of low, rounded, grass-covered hills that rise only about 150 feet above the surrounding plateau. Drainage is centripetal with an outlet through the southernmost hills.

Two geographic names appear on the geologic map (Plate 6) that are not shown on U. S. Geological Survey topographic maps of the Sierra Tinaja Pinta area. The name "East Mountain" is that used by local ranchers for the mountain so designated on the geologic map. "Mayfield Valley" is the

name here assigned to the large valley north of East Mountain; Mayfield is the name of the owner of the ranch on which the north end of the valley lies. Use of these names will simplify subsequent discussion.

Climate.--Daily weather records, taken at Cornudas Station since 1956, were made available by the Climatologist of the U. S. Weather Bureau in Austin. Mean annual rainfall for the years 1956 through 1963 is 7.93 inches; seasonal variation is marked, with May through September being the period of greatest precipitation. Average annual snowfall is 4.9 inches. Temperature data have been recorded at this station only since August 1, 1962. Data for 1963 indicate that the mean maximum temperature was 79.0°F, the mean minimum was 43.6°F, and the mean annual temperature was 61.3°F.

METHOD AND PURPOSE OF STUDY

Field work upon which this report is based was done from September to November 1964. Geologic mapping, done on aerial photographs at a scale of 1:70,000, was transferred to a photo mosaic at a scale of 1:12,000 from which Plates 6 and 7 were prepared. The attitude of bedding was determined with a Brunton pocket transit, and the section was measured with a 5-foot staff and Brunton. Petrographic examinations were made with a binocular Leitz research model microscope.

I first conceived this study when I was employed by The University of Texas Bureau of Economic Geology in connection with its Texas Geologic Atlas project. Mapping the 15-minute San Antonio Mountain quadrangle, which adjoins the Cerro Diablo quadrangle, pointed out two investigations that would contribute to understanding the geology of the northeastern part of the Diablo Plateau. It was desirable to obtain additional information about the Cretaceous strata and to have a more complete knowledge of the petrology of the intrusive rocks in this district. Such problems were first considered in detail by graduate students (Clabaugh, 1941; Timm, 1941; Zapp, 1941) from The University of Texas working in the Cornudas Mountains, whose main interest was the petrology of the igneous rocks. This report serves both as an extension of their work and as an attempt to supply information desired during work on the Geologic Atlas Project. The primary interest in this study is the petrology of the igneous rocks of the Sierra Tinaja Pinta and Cornudas Station areas, but the stratigraphy of the Permian and Cretaceous rocks is considered in some detail also. The structure of both areas is somewhat unusual, so a relatively long discussion is included to cover this aspect of the geology.

S E D I M E N T A R Y R O C K S

PERMIAN SYSTEM

General Statement

Stratigraphy of the Permian rocks of Trans-Pecos Texas has been in a state of flux since B. F. Shumard (1858, p. 290-297; p. 387-403) first reported Permian fossils collected in the Guadalupe Mountains by G. G. Shumard. Further changes are expected in the forthcoming paper on the geology of the Sierra Diablo by P. B. King. Complexity in the rocks, and hence in their stratigraphy, results from: (1) interaction between tectonic features which divided the area into provinces of similar stratigraphy and structure, and (2) differing conditions of sedimentation which produced extensive areas of limestone on shelves, black shale and limestone in open basins, and evaporites in closed areas (King, 1942, p. 543-544).

History of the stratigraphic names applied to the rocks that crop out in the mapped areas is reviewed in some detail to make the names used more meaningful; anticipated changes are incorporated so that this report will remain current as long as possible. Future changes in nomenclature are to be expected.

Hueco Limestone

Definition and regional stratigraphy.--The Hueco Limestone was named by G. B. Richardson (1904, p. 32-38) from outcrops in the Hueco Mountains, El Paso County, Texas. The formation was then believed to be Pennsylvanian (Richardson, 1904, p. 32), but is now known to have included beds of Mississippian, Pennsylvanian and Permian age (King, 1942, p. 556). Richardson (1914) later applied this name in the Sierra Diablo to beds which King (1942, p. 556) considers to be Wolfcampian and Leonardian.

Beede (1920, p. 7) abandoned the name Hueco and used a three-part division as follows: Helms Group (Mississippian), Magdalena Group (Pennsylvanian), and Manzano Group (Permian) that consisted of the Abo, Yeso, and San Andreas Formations (1920, p. 30-31). King and King (1929, p. 921-922) used a number of names as subdivisions of the Hueco Limestone of Richardson, and also abandoned the name Hueco (King and King, 1929, p. 919). King (1934, p. 741) revived the name Hueco, and used it for beds that contain the Hueco fauna of Girty (Richardson, 1904, p. 33-34), thus making the Hueco identical with Beede's (1920, p. 30) Manzano Group. In his 1934 paper King included rocks in the Bone Spring Limestone that he later (1942, p. 560) placed in the Hueco

Limestone.

The currently accepted usage of the Hueco Limestone is that supplied by King (1942, p. 561) when he defined it as follows:

> As now defined, the Hueco Limestone includes all the beds from the prominent unconformity at the base, up through the highest occurrence of Pseudoschwagerina and associated fusilinids, to the beds next beneath the lowest occurrence of Leonard fossils.

Thus the top of the Hueco Limestone is defined paleontologically--a practice which does not facilitate mapping in the Sierra Tinaja Pinta and Cornudas Station areas. Tables 1 and 2 summarize terminology used by various writers.

The Hueco Limestone belongs to the Wolfcamp Series, a division of the Permian proposed by Adams and others (1939, p. 1674), which King (1942, p. 549) classed as Permian (?) rather than as Permian. King has subdivided the Hueco Limestone differently in the Hueco Mountains than in the Sierra Diablo. These names developed over a period of years, but are summarized in King's 1942 paper (p. 557-558). In the Sierra Diablo two members, the "basal clastic member" and the "limestone member" comprise the Hueco Limestone; in the Hueco Mountains a tripartite system including "lower," "middle," and "upper divisions" is used. The name Powwow was proposed (King and King, 1929, p. 911) for limestone

Table 1. Terminology used by several authors for Hueco Limestone as originally used in Hueco Mountains (after King, 1942, p. 557).

<table>
<tr><th>Richardson, 1909</th><th>Beede, 1920</th><th colspan="2">King & King, 1929</th><th>King, 1934</th><th>King, 1942</th></tr>
<tr><td rowspan="4">Hueco Limestone</td><td rowspan="2">Manzano Group</td><td colspan="2" rowspan="2">Gym Formation</td><td rowspan="2">Hueco Limestone</td><td>Rocks of Leonard age ?
——— ? ———
Hueco Limestone</td></tr>
<tr><td rowspan="3">Magdalena Group</td><td colspan="2">Cisco-Canyon</td><td rowspan="3">Magdalena Limestone</td><td rowspan="3">Magdalena Limestone</td></tr>
<tr><td colspan="2">Strawn</td></tr>
<tr><td colspan="2">Bend</td></tr>
<tr><td></td><td rowspan="3">Helms Group</td><td>Chester</td><td rowspan="3">(Not discussed)</td><td rowspan="3">(Not discussed)</td></tr>
<tr><td>Lake Valley ?</td></tr>
<tr><td>Percha?</td></tr>
</table>

Table 2. Terminology used by several authors for beds originally classed as Hueco Limestone in Sierra Diablo (after King, 1942, p. 557).

Richardson, 1914	Beede, 1920	King & King, 1929			King, 1934		King, 1942		King, 1962
Hueco Limestone	Word (part)	Delaware Mt. Fm. (part)			Delaware Mt. Fm. (part)		Bone Spring Limestone	Cutoff shaly mem.	Cutoff Shale
	Leonard	Leonard Fm.	Victorio Peak mem.		Bone Spring Limestone	Victorio Peak massive mem.		Victorio Peak gray mem.	Victorio Peak Limestone
			Bone Canyon mem.					Black lime-stone	Bone Spring Limestone
	Manzano	Hess Fm.		Gym Formation			Hueco Limestone	Lime-stone	No change from King, 1942
		Upper Wolfcamp Fm.			"Basal beds"			Basal clastic mem.	

conglomerates and red shales that occur locally in the Hueco Mountains at the base of the Hueco Limestone, and was later (King, 1934, p. 743) designated the "Powwow conglomerate member of the Hueco Limestone." King and Flawn (1953, p. 98) used the name Powwow member to replace the term "basal clastic member" previously used in the Sierra Diablo.

The name Deer Mountain red beds, taken from the mountain of that name southeast of Cerro Alto, and not from the Deer Mountain of the Cornudas group (King, 1934, p. 743) was first used in 1929 by King and King (p. 925) for beds of red shale some 1,100 feet above the base of the Hueco in the Hueco Mountains area. This was later changed to Deer Mountain red shale member (King, 1934, p. 743) and placed in the "upper division" of the Hueco. In 1942 King (p. 558) referred to it as Deer Mountain red beds member and tentatively placed it at the top of the Hueco. This may be the "Unit 2" of Clabaugh (1941, p. 10), Timm (1941, p. 15) and Zapp (1941, p. 18) in the Cornudas Mountains, although it is also possible that Unit 2 belongs to the Chupadera Formation (King and King, 1929, p. 923).

The Hueco Limestone, like the younger Permian rocks, is marked by many lithologic and faunal facies. From the southern and southwestern Sierra Diablo region to the Hueco and Franklin Mountains, it is a thin to thick-bedded, gray,

calcitic limestone, with a well-defined, but restricted, invertebrate fauna, deposited in an extensive shelf sea (King, 1962, p. 44). A second facies, present in the central and northern Sierra Diablo, consists of thin-bedded dolomitic limestone, containing principally fusilinids, which was deposited along the margin of the Delaware basin. In the northeastern Sierra Diablo is a marl and thin to thick-bedded limestone facies which contains a much more varied invertebrate assemblage than further southwest (King, 1948, p. 13).

Local features.--A maximum thickness of about 400 feet of Hueco Limestone is exposed in the Sierra Tinaja Pinta and Cornudas Station areas, where it has been uplifted to the present erosional level by igneous intrusions. Here the Hueco is a black limestone occurring in beds several feet thick separated by shale partings, and it contains the gastropod Omphalotrochus and echinoid plates and spines, probably of the genus Echinocrinus (King, 1942, p. 556). In lower parts of the section black chert nodules are abundant, and the rock emits a strong hydrocarbon odor when struck with a hammer. In the upper part the chert is absent, and the color is somewhat lighter.

The contact of the Hueco with the overlying Victorio Peak Limestone is gradational, and it is essentially a color change from the black limestone of the Hueco to the light to

dark gray dolomitic limestone of the Victorio Peak. This color change was picked as the formational boundary because it is readily mappable, it outlines the structure well, and it corresponds rather well with the contact as mapped by King (1949). The contact may not coincide with the boundary between the Wolfcamp and Leonard Series, but coincidence is not required for the purpose of mapping. The contact between the Hueco and Victorio Peak Limestones is unconformable in many parts of the Sierra Diablo; the beds above and below are parallel at most places, but the unconformity is angular at other localities (King, 1942, p. 561-562). I have found no evidence for an unconformity in the Sierra Tinaja Pinta-Cornudas Station vicinity; the apparent conformity has been noted in the Cornudas Mountains by Clabaugh (1941, p. 10). King (1962, p. 42) later pointed out that the unconformity prominently exposed in the Sierra Diablo becomes an obscure hiatus on the platform.

Two problems arise in mapping the color change described above. Where intrusions have bleached the black Hueco Limestone to a chalky gray, the distinction breaks down. In such areas the Hueco-Victorio Peak contact appears as a dashed line on the geologic map (Plate 6); it has been located by extending (with the aid of aerial photographs) the contact from areas where the color difference is

unaffected by igneous rocks.

In the vicinity of Cerro Diablo this color change is not nearly so distinct as in the remainder of the mapped area. The darkest chert-bearing limestones crop out only against the intrusion; truly light colored rocks occur only at some distance from the intrusion, and a sequence of dark gray beds intervenes. In this area the contact was picked at the base of a thin layer of yellow and light gray shale above which light gray dolomitic limestones and a few light colored shale beds occur. King (1949) picked the contact slightly higher in the section, but he may have used paleontologic data not available to the writer.

Victorio Peak Limestone

Definition and regional stratigraphy.--The beds referred to here as Victorio Peak Limestone, a term only recently elevated to formational rank (King, 1962, p. 45), have been known by a number of names since they were included in the Hueco Limestone of Richardson (1904, p. 34-35). The history of the term Hueco has been outlined in the preceding section and is not repeated here. Tables 1 and 2 summarize this subject. The rocks in question are part of the Leonard of Beede (1920, p. 33) and of the Leonard Formation of King and King (1929, p. 922). The name Victorio Peak, taken from

the mountain by that name in the northern Sierra Diablo, was proposed in the 1929 paper of King and King (p. 922) as a member of the Leonard Formation. The term Victorio Peak massive member was used by King in 1934 (p. 753), but as part of the Bone Spring Limestone, a term originated by Blanchard and Davis (1929, p. 962), who spelled it Bone Springs. In 1942 King (p. 568-770) divided the Bone Spring Limestone into three members, a lower "black limestone," a middle "Victorio Peak gray member," and an upper "Cutoff shale member." The Sierra Tinaja Pinta and Cornudas Station areas are included on King's 1949 map; he uses the name Bone Spring Limestone for the strata in question. However, this usage has been changed by King's most recent writing (1962, p. 45) in which he restricts the name Bone Spring to its typical black limestone facies, and uses the names Victorio Peak Limestone and Cutoff Shale as "formations of the Leonard Series, partly or wholly equivalent to the Bone Spring Limestone." On the basis of (1) King's (1942, p. 571) description of the Victorio Peak gray member in Apache Canyon as fairly thin bedded, dolomitic limestone, (2) his statement that such limestones of Victorio Peak age (p. 571) lie directly and probably unconformably on the Hueco Limestone at Sierra Tinaja Pinta, as they do in Apache Canyon, and (3) in accordance with the latest statement concerning the rank of the name Victorio Peak,

I am calling the beds Victorio Peak Limestone. I anticipate that in King's forthcoming publication on the Sierra Diablo region, this use of Victorio Peak Limestone will be retained. I have not observed the Cutoff Shale in either of the areas mapped for this thesis. The Cutoff Shale is not a widespread unit; it represents a black shale and limestone facies spreading from the Delaware basin onto the shelf area (Stehli, 1954, p. 275).

Intertonguing between the black Bone Spring Limestone and the light gray Victorio Peak Limestone is evident in the Sierra Diablo, demonstrating the Victorio Peak to be the lateral equivalent, in the platform and shelf areas, of the upper part of the black limestone of the Delaware basin (King, 1962, p. 43). In the platform areas the Victorio Peak is 1,000 to 1,500 feet thick and is a thin-bedded, dolomitic limestone with interbedded layers of white porcelaneous dolomite and few fossils; nearer the basin it is calcitic, light-gray, thickly bedded, and contains large productids, spiriferoids and sponges (King, 1962, p. 44).

Local features.--The Victorio Peak Limestone, approximately 1,300 feet thick in the Sierra Tinaja Pinta and Cornudas Station areas, is, in general, a light-gray dolomitic limestone forming beds about 3 feet thick. Weathered surfaces are paler than fresh surfaces. The formation

contains a few thin beds of yellow and light gray shale, rare lenses, up to 1 1/2 feet thick, of very fine grained light brown sandstone, and thin beds of very fine grained dolomite. On the extreme northeastern edge of the Sierra Tinaja Pinta area it contains an interval of yellow shale about 50 feet thick. Fossils are generally absent, although a few bellerophontid gastropods occur in beds cropping out at the north end of Miller Mountain. A small amount of chert occurs as nodules at two horizons--one a short distance above the base of the formation, a second and more prominent one just below the Cretaceous sandstone at the west base of Cerro Diablo. The Victorio Peak is slightly more porous than the Hueco.

The contact with the overlying Unit 1 of the Cretaceous is unconformable; the beds above and below are so nearly parallel that no discordance can be observed in the local area. The light colored limestone below and the sandstone above constitute a striking boundary.

CRETACEOUS SYSTEM

General Statement

G. B. Richardson (1904, p. 50) noted the presence of Washita strata at Sierra Tinaja Pinta, although he failed to show them on the geologic map accompanying his publication,

and he measured a section of Washita beds in the Cornudas peaks area. Only one brief note (Holster, 1959, p. 132-133) of the Cretaceous rocks at Sierra Tinaja Pinta occurs in geological literature since that time, although the Cretaceous sections in the Cornudas Mountains and at Black Mountain (Sierra Prieta) have received some attention. The best available geologic map of the Sierra Tinaja Pinta area (King, 1949) does not show the Cretaceous rocks.

Beede (1920, p. 26) mentions Comanchean rocks at Black Mountain and in the Cornudas Mountains, and Baker (1921, p. 18) states that Washita beds rest directly on the Permian in the Cornudas Mountains, but no detailed correlation or subdivision of either section was attempted until 1933 (Adkins, p. 354-355). In a "general section at Cornudas Mountains" measured by M. B. Arick, Adkins (1933, p. 354) states that the lower three feet of conglomerate, twenty-five feet of sandstone, and seven feet of shale are Duck Creek equivalents (?), and that the overlying twenty feet of nodular limestone is a Denton and Fort Worth equivalent. The total section is somewhat thicker than the fifty-five feet measured by Arick and reported by Adkins (1933, p. 354). Students from The University of Texas, working in the Cornudas Mountains, neither mapped subdivisions of the Cretaceous rocks, nor measured a section, but did collect fossils

which confirmed the equivalence of the strata to the Georgetown Formation of central Texas (Clabaugh, 1941, p. 18).

In a measured section entitled "section at northwest corner of Black Mountain (Sierra Prieta)" measured by Beede and Adkins in 1921, Adkins (1933, p. 354) made the following correlations:

Weno equivalent(?).	
Denton equivalent(?).	about 40 feet
Fort Worth.	about 30 feet
Duck Creek.	total 44.6 feet
Fredricksburg (Kiamichi and ? Cox).	total about 189.5 feet

This statement follows:

> The Finlay limestone wedges out northwards between Sierra Blanca and Cox Mountain, leaving the overlying Kiamichi and the underlying Cox in contact at Cox Mountain and at Sierra Prieta. . . . Obviously, north of the last appearance of the Finlay (=Edwards-Comanche Peak-Goodland), the entire Cretaceous below the Duck Creek is in the marginal facies.

These relationships are presented (Adkins, 1933, p. 292) in a "profile from Cornudas Mountains (Texas - N. M.) to Conchos Valley south of Indian Hot Springs" part of which is reproduced here as Figure 2. This cross section and the measured sections indicate that the Cretaceous beds at Sierra Tinaja Pinta are most like those at Sierra Prieta. My Unit 1

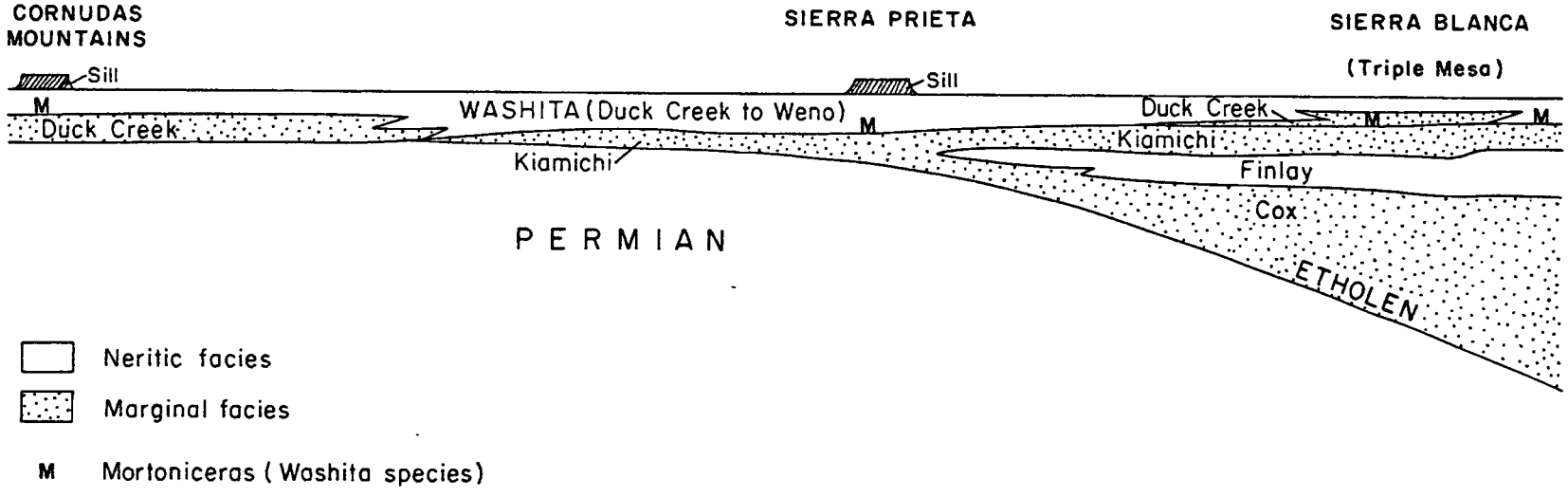


Figure 2. Profile from Cornudas Mountains (Texas-New Mexico) to Sierra Blanca. After Adkins (1933, p. 292).

corresponds to the 189.5 feet of strata called Fredricksburg (Kiamichi and ? Cox) by Adkins, and my Unit 2 includes the 114.5 feet of strata called Duck Creek, Fort Worth, Denton equivalent (?) and Weno equivalent (?).

The Cretaceous strata in the Sierra Tinaja Pinta area are poorly exposed, and owe their preservation to protection afforded by overlying igneous rocks. Talus from the intrusions covers most of their outcrop, so that the Cretaceous section is clearly exposed only in the ravines which dissect the steep eastern face of Miller Mountain and the western face of Cerro Diablo. The units have been mapped as a continuous band, as this results in a more readily comprehensible map pattern, but this was accomplished by extrapolating between outcrops. The first order division of the sequence is into two parts--a lower sandstone interval, called Unit 1, and an overlying limestone interval, called Unit 2; it is these lithologic units that were mapped in the field without regard to their fossil content. Further subdivision is undoubtedly possible, but for the purpose of this study is impractical. A measured section of the Cretaceous beds appears in the Appendix.

Unit 1

Unit 1, of which 269 feet were measured on the west

side of Cerro Diablo, is a thin to thick-bedded, light brown, fossiliferous, conglomeratic sandstone. At some localities, as on the southwest side of East Mountain, cross-bedded sandstone occurs in the lower part, but none is present where the section was measured. Fossils are, in general, scarce in Unit 1; 6 inch-thick beds of sandy limestone occurring in the upper 75 feet are most fossiliferous. I collected the following fossils which were identified by Keith Young:

Lima sp.

Texigryphea washitaensis (Hill)

coral

gastropods

Cerithium sp.

According to Young (oral communication, 1965), these and fossils in overlying beds indicate that Unit 1 is paleontologically correlative with part of the Fredricksburg Group of central Texas.

Unit 2

Unit 2, of which 114 feet were measured at Cerro Diablo, is a fossiliferous, nodular limestone which is sandy at the base and shaly in the upper part. I collected the following fossils which were identified by Young:

Tylostoma sp.

Alipes sp.

Cinulia sp.

Ctenostreon texanus (Roemer)

Mortoniceras sp.

Holectypus sp.

Enallaster longisulcus (Adkins and Winton)

Pholadomya sp.

Texigryphea washitaensis (Hill)

Cardium cf. subcongestum Böse

Neithea sp.

Holectypus charltoni Cragin

Holectypus sp.

Nerinea sp.

coral

Tylostoma sp.

Neithea georgetownensis (Kniker)

Neithea subalpina (Böse)

Alectryonia quadriplicata (Shumard)

Lima wacoensis Roemer

Lima sp.

Enallaster sp.

Haplostiche texana (Conrad)

Mortoniceras shumardi (Marcou).

According to Young (oral communication, 1965), Unit 2 is

paleontologically correlative with parts of both the Fredricksburg and Washita Groups of central Texas. Specifically, the upper part of Unit 2 is a Weno-Pawpaw equivalent (Young, oral communication, 1965).

Correlation of Cretaceous Rocks

The terms Unit 1 and Unit 2 are used for the mapped units because a regional stratigraphic study, which is beyond the scope of this thesis, would be required for any assurance that formational names were used properly. Isolated outcrops of Cretaceous rocks in different facies north of Sierra Blanca (see Figure 2) make correlation difficult. The discussion here is based on the regional stratigraphic concepts of Adkins as illustrated in his cross section of the area north of Sierra Blanca (1933, p. 292), and on the formational names as proposed and used by graduate students at The University of Texas who have worked in the Sierra Blanca area and southward.

The same statement made by Adkins (1933, p. 354) about the sandstone interval at Sierra Prieta may be applied to Unit 1 (the sandstone) at Sierra Tinaja Pinta, i.e.:

> The Finlay limestone wedges out northwards between Sierra Blanca and Cox Mountain, leaving the overlying Kiamichi and the underlying Cox in contact. . . .

Later workers have avoided using the name "Kiamichi" in Trans-Pecos Texas, and have used various temporary field names instead. Wade (1954, p. 54) and Brunson (1954, p. 48), who set up the type sections of the Cox Sandstone and Finlay Limestone, used the designations "K32 formation" and "K33 sandstone" for beds of Kiamichi and Duck Creek age which had previously been included in the "Kiamichi Formation." Atwill (1960, p. 66-67) also rejected the use of the name "Kiamichi" in Trans-Pecos Texas, and discussed the need for naming another formation which is "considered to be faunally and sequentially correlative with part of the Kiamichi-Duck Creek interval of north-central Texas." He considered three possible names for this formation: (1) "Flat Mesa Formation," taken from the topographic feature of that name northwest of Sierra Blanca, (2) Benevides Formation, proposed by Amsbury (1958) for outcrops in the Pinto Canyon area, and (3) "Lujan Formation," used by Nicols (1958, p. 26-28) in the Sierra de los Fresnos, Chihuahua, Mexico. The only one of these three names that has been formally proposed is Benevides. Eventually the terms "Flat Mesa" and "Lujan" may have formal status, but, as yet, they are only temporary field names. In the Pinto Canyon area the Benevides Formation is a 125-foot thick section of dark gray shale overlain by a yellow-brown skeletal calcarenite (Amsbury, 1958).

Twiss (1959, p. 31) used the name in the Van Horn Mountains for a section of dark gray limy shale and sandstone. He justified using the name on the similarity of lithology, thickness, and fauna to the Benevides of Pinto Canyon (Twiss, 1959, p. 36). For these same reasons, Underwood (1960, p. 133) extended the name Benevides to the Eagle Mountains vicinity. Underwood (1960, p. 138-139) wrote as follows:

> Northward thinning of the Benevides is represented by the 56 feet of sandstone and interbedded limestone, in part fossiliferous, which crops out on Cox Mountain and is correlative with the Benevides (Brunson, 1954, p. 95-97). Still further thinning of the Benevides is reflected at Sierra Prieta, about 30 miles northeast of Sierra Blanca, by the 26 feet of thin bedded and cross-bedded sandstone that underlies beds correlative with the Duck Creek Formation of north central Texas (Adkins, 1933, p. 354). In the Cornudas Mountains, about 45 miles north of Sierra Blanca, no rocks correlative with the Benevides have been reported; the oldest Cretaceous rocks are paleontologically correlative with the Washita Group of central Texas and rest on rocks of Permian age (Adkins, 1933, p. 354-355; Clabaugh, 1941, p. 8).

He continues (p. 139-140):

> Between Triple Hill and Flat Mesa, about 5 miles north-northwest of Sierra Blanca, the Benevides stratigraphic interval consists of 108 feet of cross-bedded sandstone with lenses of sandy limestone (Brunson, 1954, p. 83-85). These exposures are the same as those cited as Kiamichi by Adkins (1933, p. 352-353).
>
> The Benevides is paleontologically correlative with the Kiamichi of north central Texas and possibly with the lower part of the Duck Creek Formation as well.

Thus, my Unit 1, based on (1) its similarity to the sandstone

section at Sierra Prieta, (2) Adkins' statement that the sandstone interval at Sierra Prieta is correlative with the Kiamichi and Cox, and (3) Underwood's correlation of the Benevides Formation with part of the Sierra Blanca section (1960, p. 139), is faunally and sequentially correlative with parts of both the Cox Sandstone and the Benevides Formation.

Figure 2 shows that my Unit 2 belongs, in part, to what Adkins designates as "Washita (Duck Creek to Weno)." Unit 2 is paleontologically correlative with both the Fredricksburg and Washita Groups of central Texas (Young, oral communication, 1965). Ctenostreon texanus (Roemer), which occurs in the lower 15 feet of Unit 2, is a typical Fredricksburg form and is the basis for correlation of part of Unit 2 with the Fredricksburg. Mortoniceras sp. and fossils occurring above it demonstrate correlation with the Washita Group. The Fredricksburg-Washita Group boundary lies within a lithologic unit--further proof of the validity of the suggestion that these two groups should not be used in Trans-Pecos Texas (Wade, 1954, p. 68-69).

Underwood (1960, p. 155) has hinted that the beds identified at Sierra Prieta by Adkins (1933, p. 354) as "Duck Creek," "Fort Worth," "Denton," and "Weno?," and the beds identified by Adkins (1933, p. 354-355) in the Cornudas

Mountains as "Denton and Fort Worth equivalents" belong to the Espy Limestone, although he did not make such a statement directly. The name Espy Formation was proposed by Huffington (1943, p. 1005) for "the Washita beds mapped by Smith (1940, Pl. 1) east of Love Hogback and the southeastern part of Devil Ridge." Underwood (1960, p. 144) used the term Espy Limestone and restricted it to "that body of rock between the Benevides Formation and the Eagle Mountains Sandstone." Correlative beds crop out in places northwest of Sierra Blanca (Underwood, 1960, p. 155). He also stated (p. 157):

> The age of the Espy is late Albian to early Cenomanian; it is paleontologically correlative with the Georgetown Limestone of central Texas and is approximately paleontologically correlative with part of the Duck Creek, as well as the Fort Worth, Denton, Weno, Pawpaw, and Main Street formations of northeast Texas.

Unit 2 is tentatively correlated, on the basis of similar lithology, stratigraphic position, and fossil content, with part of the Espy Limestone as restricted by Underwood.

QUATERNARY SYSTEM

Quaternary deposits have been mapped as two types: talus and alluvium. The talus, which mantles slopes about the bases of intrusions, consists principally of fragments of igneous rock, although a minor amount of limestone blocks

is also present. These deposits have been examined for outcrops of the bedrock which underlie them, and, where possible, the bedrock has been mapped. Talus is mapped only where the underlying rock is completely obscured.

The alluvium consists of thin gravel deposits surrounding bedrock outcrops, and valley fill of gravel, sand and flour-fine dust. Older alluvial deposits, which are only a few tens of feet thick, are now being dissected by intermittent streams that lace valley floors.

I G N E O U S R O C K S

GENERAL STATEMENT

The presence of igneous rocks at Sierra Tinaja Pinta was recorded as early as 1904 (Richardson, p. 50), but no detailed petrologic study of them has been made. Clabaugh (1941, p. 22) suggested the alkalic composition of the intrusives at Sierra Tinaja Pinta; King (1949), on a large-scale map, showed their outcrop accurately. Holster (1959, p. 132-133) applied the names syenite prophyry and analcite porphyry to rocks in the Sierra Tinaja Pinta area and the name phonolite to the Cornudas Station intrusion. Huang (1959, p. 399) reported the mineral eucolite from Miller Mountain, which he recognized as a laccolith of nepheline syenite porphyry, and pointed out that this was the only known occurrence of the mineral in Texas.

These rocks, part of the alkalic petrographic province of western Trans-Pecos Texas (Eardley, 1960, p. 19), form a portion of a highly alkalic sub-province of the front ranges of the Rocky Mountains. Undersaturated feldspathoidal rocks are most abundant, although there is a minor amount of trachyte, saturated with silica.

Many specific rock names (such as pulaskite, laurdalite, etc.) are available for rocks of this type, but these

Table 3. Terminology used for igneous rocks described in this report.

<table>
<tr><td rowspan="2">TEXTURE[1]</td><td colspan="4">ALKALI FELDSPAR GREATER THAN 60 PERCENT OF TOTAL FELDSPAR</td></tr>
<tr><td colspan="2">(Analcime + Nepheline <10%)</td><td colspan="2">(Analcime + Nepheline ≥10%)</td></tr>
<tr><td rowspan="3">Phaneritic</td><td colspan="2" rowspan="3">Syenite</td><td>Analcime>Nepheline</td><td colspan="2">Nepheline>Analcime</td></tr>
<tr><td rowspan="2">Analcime Syenite*</td><td>Anal <5%</td><td>Anal >5%</td></tr>
<tr><td>Analcitic Nepheline Syenite*</td><td>Analcime-Nepheline Syenite*</td></tr>
<tr><td rowspan="2">Aphanitic</td><td>Analcime <5%</td><td>Analcime 5-10%</td><td rowspan="2">Analcime Phonolite</td><td colspan="2" rowspan="2">Nepheline Phonolite</td></tr>
<tr><td>Analcitic Trachyte* If <1% = Trachyte</td><td>Analcime Trachyte*</td></tr>
</table>

1. Pegmatitic and aplitic types are absent.

* Types present in the area of this report.

Porphyritic: phenocrysts >5%. Mineral modifiers precede each rock name.

terms have been avoided in favor of common names such as syenite, phonolite and trachyte used with appropriate mineral and textural modifiers. Table 3 indicates the terminology used in naming the igneous rocks described in this report. The rocks are grouped into four major types: (1) porphyritic analcime syenite and associated dike and contact rocks; (2) pyroxene trachyte; (3) porphyritic analcime-nepheline syenite; (4) olivine-analcime trachyte. Analcime syenite and analcime-nepheline syenite are volumetrically far more important than the pyroxene trachyte and olivine-analcime trachyte. The locations from which samples were collected are shown on the geologic maps (Plates 6 and 7); a modal analysis of each sample of igneous rock appears in the Appendix.

PETROGRAPHY

Porphyritic Analcime Syenite and Associated Dike and Contact Rocks

Occurrence.--Porphyritic analcime syenite (Samples 25I, 27I, and 31I) forms the major portion of the Mayfield Valley laccolith; the aphanitic margins of this intrusion (Samples 22I and 24I) are porphyritic analcitic pyroxene trachyte; dikes extending into the country rock are altered porphyritic trachyte (Samples 23I and 26I). One sample (9I) from the Cornudas Station intrusion resembles the porphyritic

analcime syenite in the Mayfield Valley intrusion.

Macroscopic characteristics.--Fresh surfaces of the analcime syenite are light gray; weathering produces spheroidal boulders and gruss of light to dark brown color. This is the only intrusion that weathers to yield a topographically low area; its relatively coarse grain size and massive structure probably account for this susceptibility to weathering. The texture is holocrystalline, porphyritic and phaneritic; feldspar phenocrysts are up to 6 mm in length, but most are of medium size; the groundmass is fine to medium grained. One sample, 25I, is equigranular and of medium grain size.

Microscopic characteristics.--The principal constituent is an alkali feldspar which occurs as subhedral prismatic crystals in both the groundmass (0.9 mm average size) and as phenocrysts (3 to 6 mm in length). Sericitization is rather extensive and has developed only in this intrusion, probably because of a sufficiently high water pressure resulting from the greater depth of intrusion.

The alkali feldspar, under crossed nicols, shows Carlsbad and faint, very fine albite twinning; portions of a few phenocrysts also exhibit both albite and faint pericline twinning. A mottled or spotted appearance is a striking feature of the feldspar; distinct perthitic texture is

not well developed. Staining of potassium feldspar with sodium cobaltinitrite shows that the mottling results from incomplete exsolution of the potassic and sodic fractions, which are present in approximately equal amounts. The alkali feldspar is, thus, a mesoperthite. The centers of phenocrysts are unaffected by staining; although untwinned, these cores may be a slightly calcic plagioclase or perhaps anorthoclase. The margins of these crystals are rich in potassium feldspar. Outside these margins clear thin rims of albite occur on practically every grain.

Analcime, which commonly constitutes 12 percent of the rock, occurs (1) as wedge-shaped grains of medium size interstitial to the feldspar groundmass, (2) lining cavities in which calcite forms the center, and (3) as replacement of feldspar. Lonsdale (1940, p. 1598) has interpreted analcime of the first type as having formed during the late magmatic stage of consolidation.

The most abundant mafic mineral is pale green augite ($2V=60$ to $70°$, $c\wedge z=45°$) which occurs principally as subhedral to anhedral prismatic phenocrysts up to 2 mm in length, but smaller crystals are also present. The pale green color and relatively low extinction angle suggest that the augite is slightly aegiritic.

Biotite, in grains of medium size, occurs in no other

rock type in the Sierra Tinaja Pinta area, but some fine-grained biotite is present in the Cornudas Station intrusion. The larger grain size of the biotite in the Mayfield Valley intrusion is also attributed to the greater depth of intrusion and subsequently higher water pressure in this intrusion. One subhedral prismatic crystal of eudialyte, about 0.3 mm in length, was found in Sample 25I. Sample 9I differs from the analcime syenite of the Mayfield Valley intrusion only in that the biotite in 9I is a dark green pleochroic variety rather than the red-brown type of other samples.

Two varieties of apatite, one a very fine-grained acicular variety, the other a fine to medium-grained variety that contains abundant inclusions, are present in Sample 9I. This second type is characteristic of all the rocks of the Cornudas Station intrusion, but is present in only one sample (22I) from the Sierra Tinaja Pinta area.

The aphanitic margins of the Mayfield Valley intrusion (Samples 22I and 24I) differ slightly in mineralogy and considerably in texture from the main body of the intrusion. Sample 24I occurs between the country rock and material like that in 22I. Both rocks are porphyritic, but the difference in size between phenocrysts and groundmass is much greater in 22I (phenocrysts average 5 mm, groundmass 0.7 mm) than in 24I (phenocrysts 2 to 4 mm, groundmass 0.8 mm). Trachytic

texture is well developed in 22I, but is absent in 24I.

Mineralogically, 24I is much like the porphyritic analcime syenite of the main mass of the intrusion, but 22I differs considerably from both. The main differences between 24I and the main body of the Mayfield Valley intrusion are that analcime is slightly less abundant in 24I, and that the augite has been altered about its margins to aegirine; acicular aegirine also occurs in the groundmass and constitutes approximately 10 percent of the rock.

Sample 22I contains only about 2 percent analcime; the most significant mineralogical difference is that it contains about 2 percent of nepheline, which occurs as subhedral to euhedral equant grains averaging 0.5 mm in size. Aegirine constitutes about 7 percent of the rock. Minor biotite, apatite and magnetite are also present. The apatite, which occurs as euhedral to subhedral, prismatic grains averaging 0.28 mm in length, is of an unusual type in that it has a very cloudy appearance due to abundant inclusions of a dark colored, euhedral, prismatic mineral. Identical apatite occurs in the Cornudas Station intrusion, but none is present in the other intrusions.

Samples 23I and 26I are porphyritic augite trachytes that occur as dikes, 5 to 7 feet in width, that extend from the Mayfield Valley intrusion into the marble zone at its

north end. Both rocks are highly altered; feldspar phenocrysts are completely altered to sericite and a zeolite(?) in 26I. Phenocrysts of pale green augite, like that in the main body of the intrusion, exhibit rims of aegirine; fine-grained euhedral prismatic aegirine also occur in the groundmass.

Olivine, in anhedral, equant grains ranging from 1.5 to 0.3 mm in diameter, constitutes about 1 percent of the rock; small grains are completely altered to an aggregate of sodic pyroxene surrounding a core of iddingsite, but the centers of larger grains are unaltered. Optical data (optic sign +, 2V=60°, high birefringence) indicate that this is an iron-rich variety. Alteration about the margins is strong: an aggregate of very fine-grained sodic pyroxene comprises the outermost rim; iddingsite and magnetite lie inside this; magnetite and hematite fill fractures in the freshest center part.

Minor apatite is the only other constituent of the rock itself, but "veinlets" of prehnite and a minor amount of calcite cut the rock. Sample 23I differs from Sample 26I only in that the feldspar is fresher in 23I, and marble in intimate contact with 23I contains grossularite as well as prehnite and calcite. A small amount of quartz occurs in one of the prehnite veins and probably formed during

Table 4. Modal analyses of samples of analcime syenite. Percentages are based on counting 1,000 points.

MINERAL	1	2
Mesoperthite	77.1	77.0
Analcime	12.0	13.1
Augite	4.2	0.8
Biotite	2.1	2.0
Magnetite + Hematite	4.6	7.1
Apatite	tr	tr
Eudialyte	tr	-

tr indicates mineral is present but was not encountered in point count. Spacing of points = 2/3 mm.

1. Sample 25I, analcime syenite, Mayfield Valley intrusion.

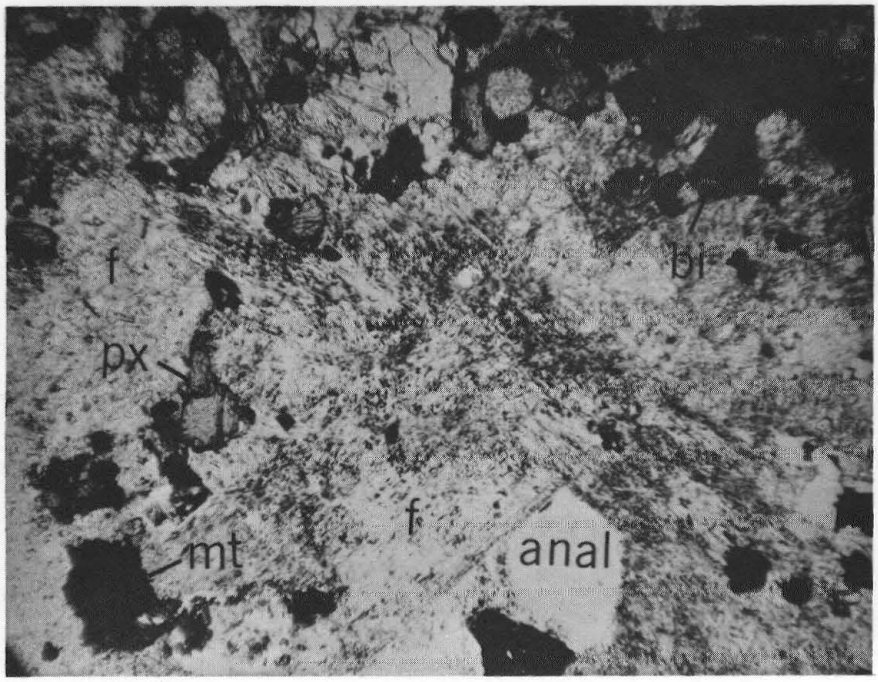
2. Sample 31I, porphyritic analcime syenite, Mayfield Valley intrusion.

EXPLANATION OF PLATE 1

A. Photomicrograph of analcime syenite. Sample 25I; f - mesoperthite, anal - analcime, px - augite, bi - biotite, mt - magnetite.

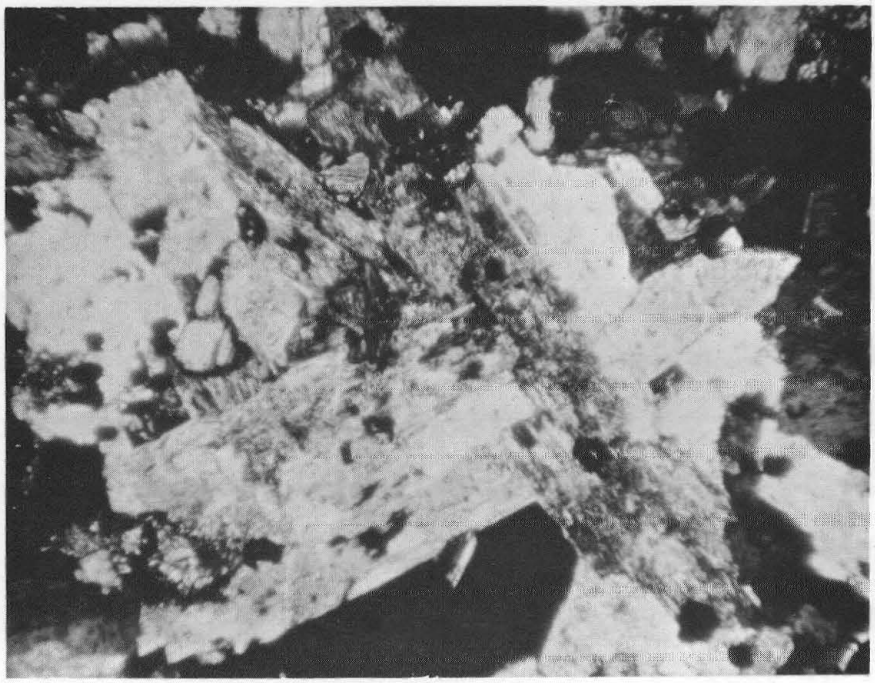
B. Photomicrograph of analcime syenite. Same as above with nicols crossed. Note mottled appearance of feldspar.

PLATE 1



A.

0.5mm



B.

0.5mm

weathering.

Pyroxene Trachyte

Occurrence.--Pyroxene trachyte occurs as the marginal material adjacent to contacts of Miller Mountain, Cerro Diablo and East Mountain intrusions, and includes Samples 1I, 15I, 17I, and 20I. This rock type does not appear on the map as a separate unit because such a small amount is present.

Macroscopic characteristics.--Fresh surfaces of specimens are dark greenish-gray and weathered surfaces are dark brown due to weathering of the pyroxene. Most samples are very fresh because the aphanitic texture resists penetration by ground water. The texture is holocrystalline, equigranular, aphanitic and trachytic; average grain size is 0.25 mm. Most outcrops show prominent jointing.

Microscopic characteristics.--The major constituent is an alkali feldspar which comprises over 60 percent of all specimens. A few microphenocrysts, about 1 mm in length, are present, but 95 percent of the feldspar occurs as subhedral prismatic grains averaging 0.3 mm in length. Neither vacuolization nor sericitization has affected the feldspar.

Under crossed nicols the feldspar shows Carlsbad twinning and some very faint albite twinning; larger grains show the mottled appearance typical of feldspar in the

Table 5. Modal analyses of samples of the pyroxene trachyte group. Percentages are based on counting 1,000 points.

MINERAL	1	2	3
Mesoperthite	63.6	67.0	59.8
Pyroxene	36.4	24.9	39.2
Analcime	-	5.7	0.8
Nepheline	-	2.0	-
Magnetite + Hematite	-	0.4	0.2

Spacing of points = 2/3 mm.

1. Sample 15I, pyroxene trachyte, Miller Mountain intrusion.

2. Sample 17I, pyroxene analcime trachyte, Miller Mountain intrusion.

3. Sample 20I, pyroxene trachyte, Miller Mountain intrusion.

EXPLANATION OF PLATE 2

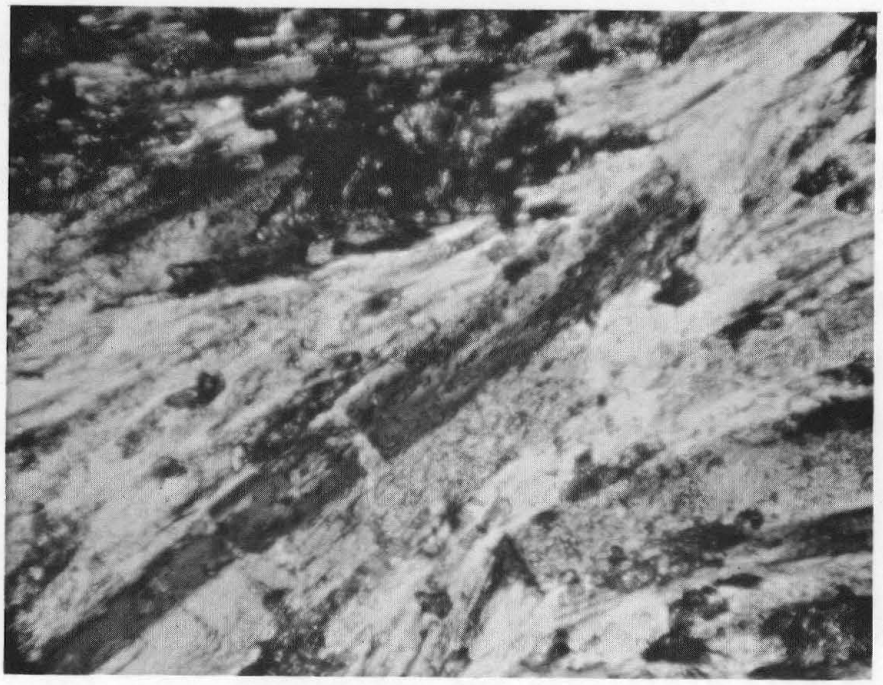
A. Photomicrograph of pyroxene trachyte. Sample 15I; dark mineral is pyroxene; light mineral is mesoperthite.

B. Photomicrograph of pyroxene trachyte. Same with nicols crossed. Note trachytic texture.

PLATE 2

A.

0.5mm



B.

0.5mm

nepheline syenite and analcime syenite. Staining of potassium feldspar with sodium cobaltinitrite shows that smaller feldspar grains are entirely potassium feldspar, except for thin rims of albite, but that the central part of larger crystals consist of untwinned plagioclase, probably albite or a slightly more calcic plagioclase. In many such crystals the distribution of the potassic and sodic portions is irregular, as is suggested by the mottled appearance, but the margins are invariably richer in potassium feldspar. Definite perthitic texture is not present. Clear thin albite rims appear on some grains. The feldspar is called mesoperthite as staining shows that the sodic and potassic fractions are present in approximately equal amounts.

The pyroxene is fine-grained, subhedral, prismatic crystals averaging 0.15 mm in length. Optical data are difficult to obtain because of the small grain size, but the small extinction angle ($c \wedge z < 5°$), and the pleochroism from yellow-green to dark green suggest that it is aegirine.

Analcime, a minor constituent in amounts less than 1 percent in most samples, occurs as wedge-shaped grains between feldspar laths, and in small cavities associated with zeolites and calcite. Hematite, which results from weathering of the pyroxene, is the only other constituent in Samples 1I, 15I, and 20I. Nepheline, now completely altered to an

aggregate of very fine-grained plates of a low-birefringent mineral (probably kaolinite), constitutes about 2 percent of one sample, 17I.

Porphyritic Analcime-Nepheline Syenite

Occurrence.--Porphyritic analcime-nepheline syenite constitutes the major portion of the Miller Mountain, Cerro Diablo, and East Mountain intrusions. The only other rock in these bodies is an aphanitic rock, pyroxene trachyte, occurring at contacts with sedimentary rocks. Samples 2I, 3I, 4I, 5I, 10I, 11I, 12I, 13I, 14I, 16I, 19I, 28I, 30I, 32I, and 33I are of the porphyritic analcime nepheline syenite type, although some (4I and 14I) contain less than 5 percent analcime and are, therefore, called porphyritic analcitic nepheline syenite. Both texture and composition are remarkably uniform.

Macroscopic characteristics.--Handspecimens of this rock are light gray on fresh surfaces, and, due to weathering of mafic minerals, are dark brown on weathered surfaces. Trachytic texture is pronounced and it produces a preferred fracture direction. The platy parting produces flat boulders and sheets rather than spheroidal boulders that commonly develop during weathering of massive igneous rocks. Dark layers of pyroxene and sodic amphibole are conspicuous in

outcrops.

Microscopic characteristics.--Mesoperthite, which occurs as subhedral prismatic grains, is the major constituent in all specimens. This feldspar occurs both as the groundmass, which has an average grain size of 0.5 mm, and as phenocrysts which range from 2 to 4 mm in length. Vacuolization has affected the feldspar, but no sericitization has occurred, probably because water pressure was too low in this relatively shallow intrusion and cooling was too rapid.

Under crossed nicols the feldspar has a mottled appearance; staining of potassium feldspar with sodium cobaltinitrite shows that the mottling results from incomplete exsolution of the potassic and sodic portions, a phenomenon explained by rapid cooling of the relatively small intrusions. Some crystals, however, show a more complete separation which results in a definite perthitic texture. Most grains exhibit Carlsbad twinning; albite twinning characterizes unstained areas, although some such areas show no twinning. Phenocrysts consist of unstained centers, probably of a slightly calcic plagioclase, and are richer in potassium feldspar toward their margins. Clear albite rims most grains, particularly where the mesoperthite is in contact with interstitial analcime.

Nepheline, all of which occurs as phenocrysts ranging

from 2 to 4 mm in size, is euhedral to subhedral and equant to slightly prismatic; some grains show a hexagonal outline. Occurrence of nepheline in such short square prisms suggests that the composition is slightly more silica-rich than Na Al Si O_4 (Saha, 1961, p. 863). These phenocrysts acted as centers for late-stage reaction phenomena in which sodium and water-rich fluids reacted with the nepheline which was then replaced by analcime. Aegirine and a sodic amphibole are abundant about the margins of altered nepheline phenocrysts and probably developed during analcitization of the nepheline. Alteration of nepheline to zeolites, of both massive and fibrous varieties, has also occurred.

The occurrence of analcime as wedge-shaped grains interstitial to the feldspar groundmass, as a replacement of nepheline and mesoperthite, and in veins and cavities which obliterate the igneous texture, demonstrates that it crystallized throughout a range of consolidation of the magma. Interstitial wedge-shaped grains suggest that analcime crystallized, in part, during the magmatic stage (Lonsdale, 1940, p. 1598).

Pyroxene is of two types, aegirine-augite and aegirine, which together comprise a significant percentage of the rock. About crystal margins aegirine-augite is altered to dark green aegirine and a sodic amphibole. Aegirine (strongly pleochroic,

Table 6. Modal analyses of samples of porphyritic analcime-nepheline syenite. Percentages are based on counting 1,000 points.

MINERAL	1	2	3	4
Mesoperthite	77.6	65.1	72.4	65.2
Nepheline	6.4	15.9	6.2	10.7
Analcime	5.3	7.1	5.7	6.2
Aegirine	6.6	10.4	12.4	14.0
Sodic amphibole	-	tr	-	3.1
Magnetite + Hematite	4.1	1.5	3.3	0.8
Zeolite	-	tr	-	tr

tr indicates mineral is present but was not encountered in point count. Spacing of points = 2/3 mm.

1. Sample 5I, porphyritic analcime-nepheline syenite, Cerro Diablo intrusion.

2. Sample 10I, porphyritic analcime-nepheline syenite, East Mountain intrusion.

3. Sample 13I, porphyritic analcime-nepheline syenite, East Mountain intrusion.

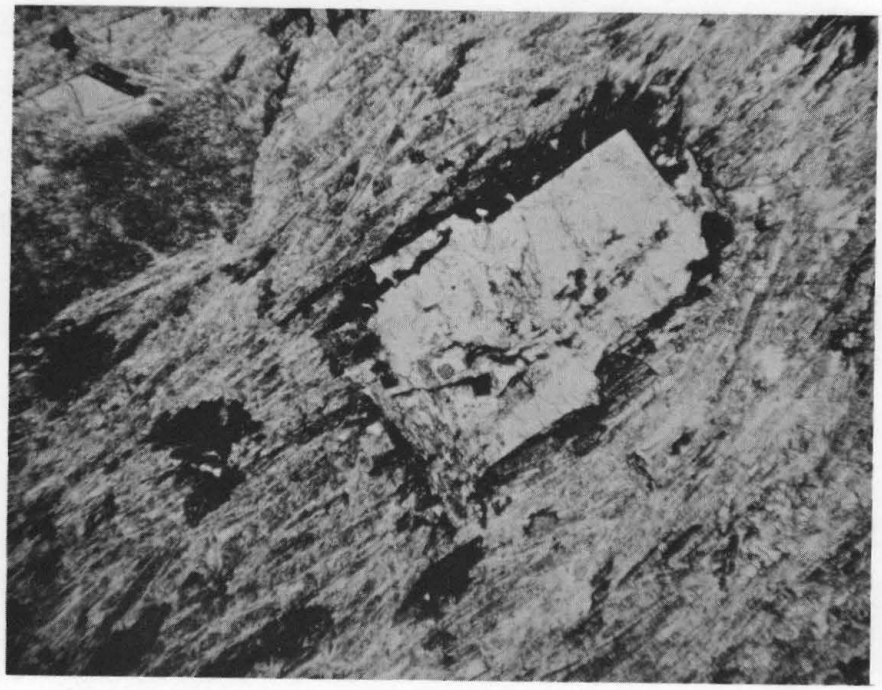
4. Sample 33I, porphyritic analcime-nepheline syenite, Miller Mountain intrusion.

EXPLANATION OF PLATE 3

A. Photomicrograph of porphyritic analcime-nepheline syenite. Sample 101; nepheline phenocryst surrounded by aegirine and sodic amphibole. Groundmass is mesoperthite with interstitial analcime. Note trachytic texture.

B. Photomicrograph of porphyritic analcime-nepheline syenite. Same with nicols crossed. Note alteration of nepheline phenocryst to isotropic analcime.

PLATE 3



A.

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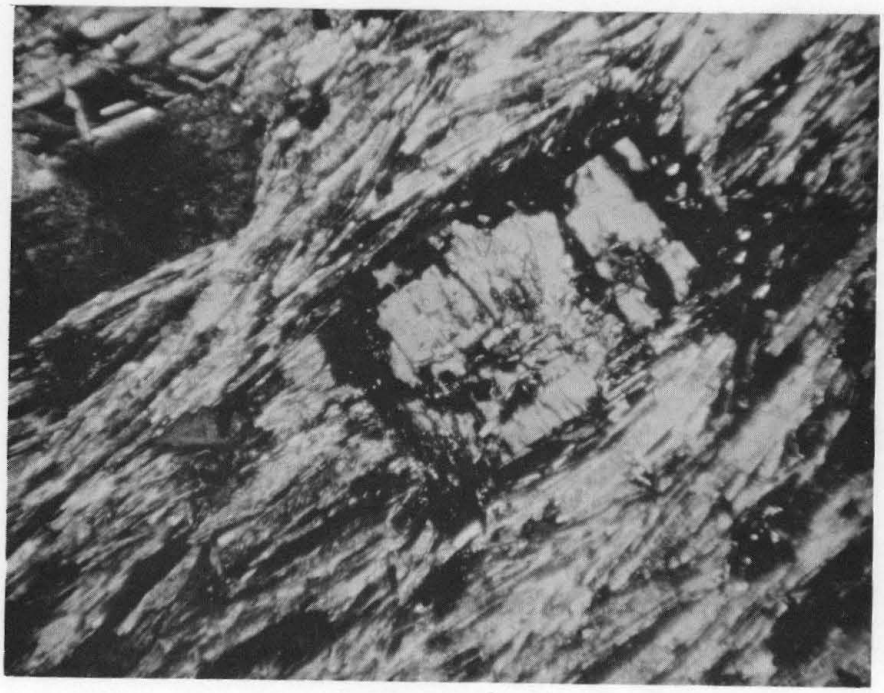

B.

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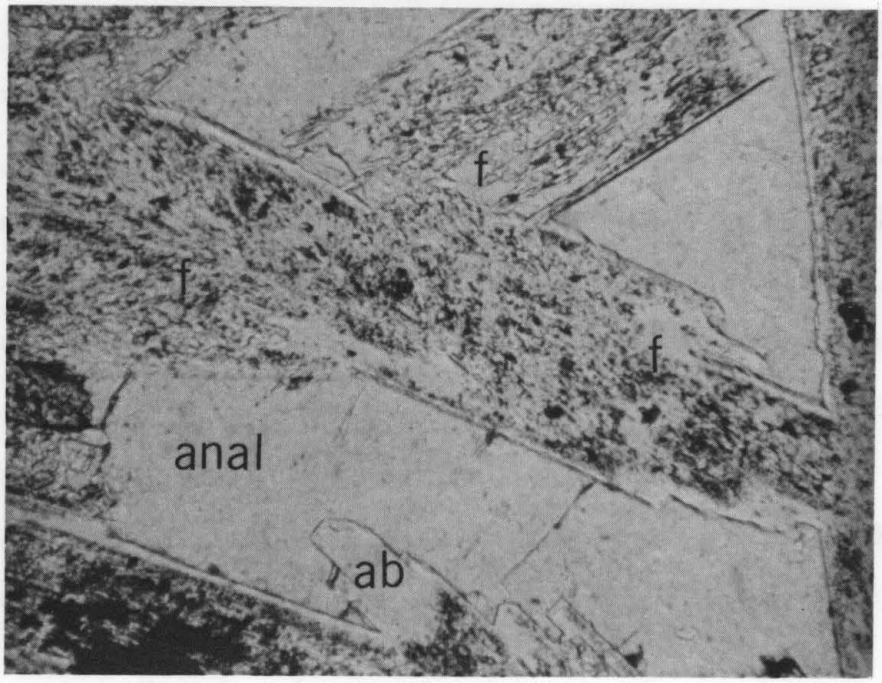
EXPLANATION OF PLATE 4

A. Photomicrograph of porphyritic analcime-nepheline syenite. Sample 5I; f - mesoperthite, ab - albite, anal - analcime; "Magmatic" analcime interstitial to feldspar. Note clear albite rims on mesoperthite.

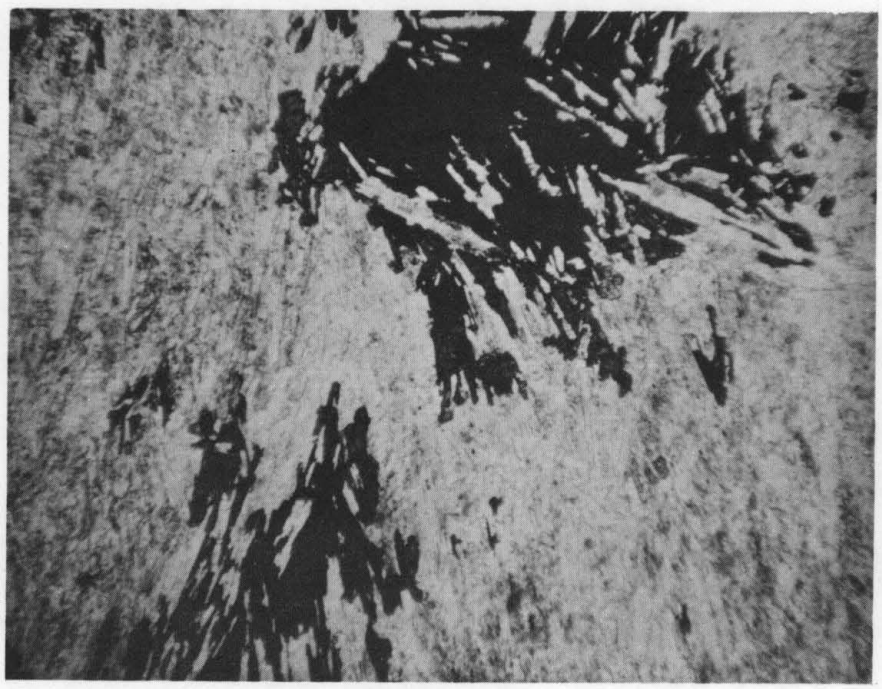
B. Photomicrograph of porphyritic analcime-nepheline syenite. Sample 33I; dark mineral is aegirine and sodic amphibole; light mineral is mesoperthite with some interstitial analcime. Note subophitic-like arrangement between mafic minerals and feldspar.

PLATE 4



A.

0.3mm



B.

0.5mm

$c \wedge z < 5°$) occurs in small wedge-shaped grains in the feldspar groundmass, in rims around altered nepheline phenocrysts, and encloses mesoperthite in a relationship comparable to the subophitic texture common in gabbroic rocks. A few large subhedral crystals also line, and project into, cavities filled with analcime and zeolites. The aegirine thus is a mineral of late formation, but probably crystallized throughout successive stages of consolidation as did analcime. Grains that consist entirely of sodic amphibole may represent a complete alteration of pyroxene.

Minor zeolites, hematite, and magnetite are accessory minerals.

Olivine-Analcime Trachyte

Occurrence.--Olivine-analcime trachyte (Samples 6I, 7I, 8I) occurs in the Cornudas Station intrusion; the other sample, 9I, from this body is an analcime syenite. Two other olivine-bearing rocks (Samples 23I and 26I) were found, but both olivine and analcime are only minor constituents (less than 1 percent), so they are not included here.

Macroscopic characteristics.--Fresh surfaces of samples are light to dark gray; weathering of mafic minerals produces a dark brown surface. The texture is holocrystalline, equigranular, and aphanitic. Average grain size of

specimens ranges from 0.3 to 0.6 mm. Jointing is prominent in some outcrops of these rocks.

Microscopic characteristics.--Alkali feldspar is the most abundant constituent, forming at least 80 percent of all specimens. Grains are subhedral, prismatic, and range from 0.3 mm to 0.6 mm in length; vacuolization is abundant, but sericitization occurs only in 6I.

Under crossed nicols the feldspar shows Carlsbad and some faint albite twinning in which lamellae are very thin. Mottling, like that exhibited by feldspar laths in the rocks of the Sierra Tinaja Pinta area, is prominent, and results from incomplete exsolution of approximately equal portions of potassic and sodic feldspar. The feldspar is thus mesoperthite. Clear albite rims every grain.

Analcime occurs as equant, wedge-shaped, anhedral grains about 0.5 mm in diameter, interstitial to the feldspar, and as "veinlets" into which euhedral feldspar laths project. Olivine, in anhedral equant grains ranging from 0.3 to 4 mm in diameter, is completely altered to antigorite in smaller grains, but cores of larger grains are fresh. The alteration rim consists of fine-grained strongly pleochroic green to red-brown biotite, magnetite and hematite. Optic data on unaltered cores (optic sign (-), 2V=70-80°, high birefringence) indicate this to be an iron-rich olivine.

Table 7. Modal analyses of samples of olivine-analcime trachyte. Percentages based on counting 1,000 points.

MINERAL	1	2
Mesoperthite	80.6	82.6
Analcime	8.4	6.1
Aegirine	1.3	3.1
Biotite	4.6	1.0
Olivine	2.4	3.1
Magnetite + Hematite	2.6	4.0
Apatite	0.1	0.1
Zeolite	tr	-

tr indicates mineral is present but was not encountered in point count. Spacing of points = 2/3 mm.

1. Sample 6I, olivine-analcime trachyte, Cornudas Station intrusion.

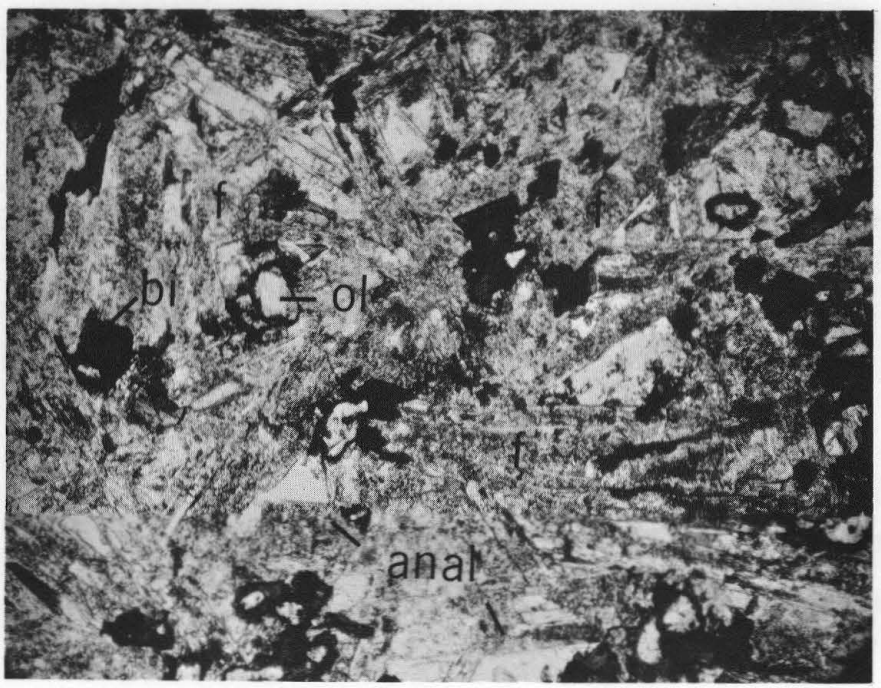
2. Sample 7I, olivine-analcime trachyte, Cornudas Station intrusion.

EXPLANATION OF PLATE 5

A. Photomicrograph of olivine-analcime trachyte. Sample 6I; f - mesoperthite, anal - analcime, ol - olivine, bi - biotite.

B. Photomicrograph of porphyritic augite trachyte. Sample 26I; olivine phenocryst showing reaction rim; ol - olivine, mt - magnetite, px - sodic pyroxene, id - iddingsite.

PLATE 5



A.

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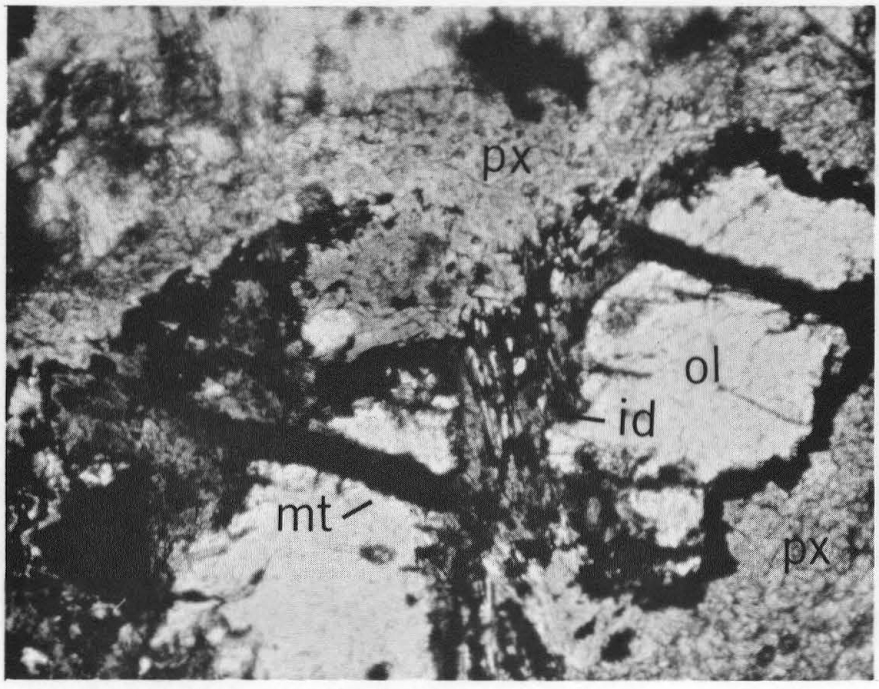

B.

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Minor magnetite, apatite, biotite, zeolites, and aegirine (?) are also present.

Apatite is of two types--minute, water-clear, acicular crystals, and larger crystals (up to 0.3 mm in length) that contain abundant, dark, euhedral, prismatic inclusions oriented parallel to the c axis of the apatite.

AGE

Field relations demonstrate that the intrusions are younger than Cretaceous rocks that are paleontologically correlative with the Washita Group of central Texas. The location of intrusions along the faulted and gently folded margins of the Diablo Plateau suggests that intrusion accompanied or followed development of the faults and folds (Clabaugh, 1941, p. 56). Sellards and Baker (1935, p. 153) stated that the uplift of the Diablo Plateau occurred in late Miocene or early Pliocene time.

Recent work by Wilson and Clabaugh (oral communication, 1965) demonstrates that volcanic rocks in the Davis Mountains volcanic field are late Eocene to earliest Miocene in age. Alkalic rocks, similar to those that occur along the margins of the Diablo Plateau, intrude these volcanic rocks. This indicates that the intrusive alkalic rocks are Miocene or younger.

METAMORPHIC ROCKS

Contact metamorphic effects are, in general, slight, but variation is considerable. Bleaching and recrystallization of the limestone to white marble, and recrystallization of sandstone to metaquartzite are the main changes that have occurred at contacts. Only at the north end of the Mayfield Valley intrusion have new minerals formed.

Miller Mountain and East Mountain intrusions exhibit the weakest contact metamorphism; adjacent to most contacts the limestone shows no alteration at all (Figure 8), but the limestone is converted to marble for a distance of a few feet from the contacts in a few localities. The two small prospect pits, located just north of Miller Mountain (see Plate 6), were dug in outcrops of altered limestone. The limestone is bleached and is covered with dendritic manganese oxide and bands of "limonite." According to L. T. Turner (oral communication, 1964), manager of the Mayfield Ranch, the prospects were located in areas of rather high radioactivity; the concentration of radioactive material was, however, only developed within a few feet of the surface, so the prospects were abandoned. Such areas of bleached limestone, of which there are several, probably are a result of alteration by emanations from the Miller Mountain intrusion; iron,

manganese, and a radioactive element, perhaps thorium, were added. Weathering concentrated these elements to produce the dendritic manganese oxide and the concentric bands of "limonite."

Cerro Diablo intrusion produced only slightly greater contact effects than did the Miller Mountain and East Mountain intrusions; a zone of marble, some 25 feet thick, crops out at the north side of Cerro Diablo. No metamorphic rock was found around the Cornudas Station intrusion.

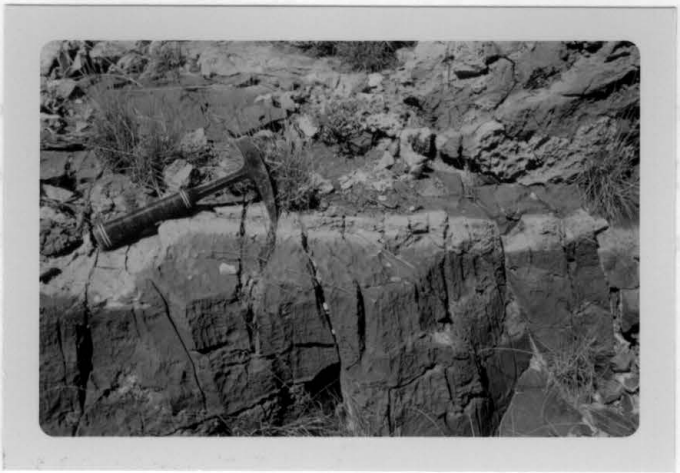
The most extensive contact metamorphism occurred about the Mayfield Valley intrusion. Marble occurs at all the contacts, but the zone attains a thickness greater than 10 feet only at the north end of the intrusion where alteration of the Hueco Limestone is extensive (Figure 3). Occurrence of the marble is of two major types: (1) that in which entire beds of the Hueco are metamorphosed (Figure 3), and (2) that in which marble occurs only along joint surfaces, along bedding planes, and in irregular patches (Figure 4). The limestone has been bleached and recrystallized in the second manner only in places where it was penetrated by hot fluids escaping from the Mayfield Valley intrusion.

Reaction between the intrusive rock and the country rock is apparent only at the north end of Mayfield Valley.

Figure 3. Metamorphosed Hueco Limestone in contact with Mayfield Valley intrusion at north end of Mayfield Valley. In the background is Cerro Diablo intrusion.

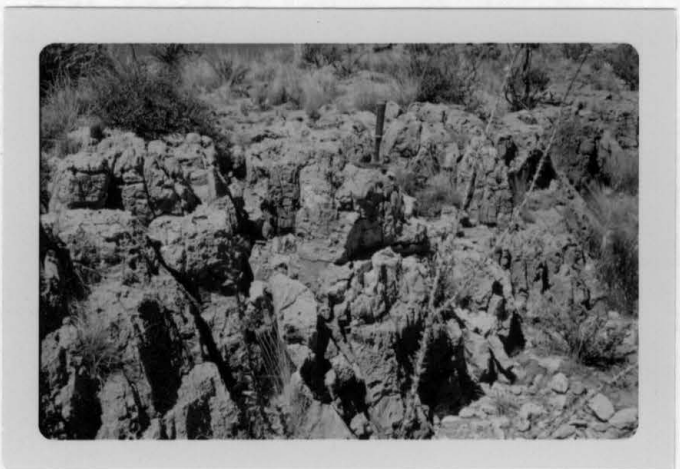
EXPLANATION OF FIGURE 4

Hueco Limestone metamorphosed along: A. joints, B. bedding planes, and C. porous zones. Photographs taken in contact metamorphic zone at north end of Mayfield Valley.



A.

B.



C.

Figure 4

Dikes of porphyritic trachyte extend from the intrusion into the limestone and contain veinlets of prehnite (identified by D. S. Barker by x-ray diffraction) and grossularite.

S T R U C T U R A L G E O L O G Y

REGIONAL SETTING

The Diablo Plateau is a broad, slightly synclinal block bounded by grabens (King, 1935, p. 252); on the east is Salt Basin and on the west is the Hueco Bolson. This northern portion of the Trans-Pecos region is a stable area unaffected by the intense folding and thrusting that occurred to the south and southwest (King, 1935, p. 252). That major alkalic complexes are more often associated with stable regions than with orogenic belts has long been known, but the mechanism of control is in dispute (Bailey, 1964, p. 1103).

Mapping by King (1949) has demonstrated the intimate connection between the igneous intrusions, which form a prominent linear feature along the northeastern margin of the Diablo Plateau, and the Babb Flexure. Figure 1 indicates the positions of the Sierra Tinaja Pinta and Cornudas Station areas in this trend. The monoclinal flexure probably extends further northwestward than indicated by King (Clabaugh, 1941, p. 19-20). A second group of intrusions defines the southwestern boundary of the Diablo Plateau; included are intrusions at Hueco Tanks, Cerro Alto, Granite Mountain, Triple Hill, Sierra Blanca, and Flat Mesa.

Parallelism of structural and intrusive trends suggests a genetic relationship between the two, and it indicates that the igneous rocks are approximately the same age as, or younger than, the folding and faulting that developed the Basin and Range structure in northern Trans-Pecos Texas.

SHAPE OF INTRUSIONS

General Statement

G. K. Gilbert (1877), in his report on the geology of the Henry Mountains, originated the concept of the laccolith, or laccolite as he termed it, and made a significant contribution toward understanding its origin. He illustrated a number of laccoliths which he described as being of idealized type and predicted that many variations of the basic shape would be discovered as other areas were studied. These bodies should also be termed laccoliths he suggested (1877, p. 98).

This prediction was confirmed as geologic surveys completed studies of such areas as the West Elk, San Miguel, La Plata, Carriso, El Late, Abajo and La Sal Mountains (Cross, 1894). The Sierra Tinaja Pinta is another such area of asymmetrical laccoliths that corroborates Gilbert's prediction. Recent studies (Hunt and others, 1953) have

demonstrated minor errors in Gilbert's original work, but the concept of the laccolith remains sound.

The structure of the Sierra Tinaja Pinta area is dominated by a stock, or laccolith, that has domed the strata above an horizon approximately 400 feet below the top of the Hueco Limestone. The Victorio Peak Limestone forms the flanks of the uplift and the Hueco Limestone crops out in the central part. Miller Mountain and Cerro Diablo are asymmetrical laccoliths which lie upon this dome as minor features that have modified its symmetry. East Mountain, a structural feature of the same order as Miller Mountain and Cerro Diablo, is a discordant tabular intrusion. Cropping out around Miller Mountain and Cerro Diablo are non-resistant Cretaceous limestones and sandstones which owe their preservation to the resistant igneous rocks overlying them.

One other major structural feature occurs in the Sierra Tinaja Pinta area; just east of Cerro Diablo, dips reverse direction upon the flank of a dome. The Victorio Peak Limestone constitutes the flanks of the dome, whereas the Hueco Limestone is exposed in the center. It is likely that a laccolith underlies this feature, but erosion has not yet exposed igneous material. This uplift occurred without interference from the larger Sierra Tinaja Pinta uplift; the horizon of intrusion of the underlying igneous body, if one

be present, is probably the same as that of the Mayfield Valley intrusion. Both features probably developed simultaneously.

No direct structural relationship between the Cornudas Station intrusion and the intrusions of the Sierra Tinaja Pinta area is evident, except that both are part of the same regional trend.

Mayfield Valley Intrusion

In the structure section A-A' (Plate 6) the Mayfield Valley intrusion is interpreted to be a laccolith. As only a small part of its upper contact is exposed, it is impossible to demonstrate its shape definitely, but several lines of evidence suggest that it is a laccolith rather than a stock. The upper contact of the intrusion is concordant and lies about 400 feet below the top of the Hueco Limestone. If the Sierra Tinaja Pinta section may be compared with the Sierra Diablo section, in which the Hueco is 500 feet thick (King, 1942, p. 561), the horizon of intrusion of the Mayfield Valley intrusion is about the stratigraphic level of the Powwow conglomerate. This suggests that magma rose through the competent Pennsylvanian limestones and spread laterally at the level of the Powwow conglomerate, sandstone and marl to form a laccolith. The occurrence of laccoliths

Figure 5. Mayfield Valley intrusion viewed from north end of Mayfield Valley. Hueco Limestone is in contact with the intrusion on both sides of the valley. The highest peak in the background is East Mountain.

at the same horizon of intrusion in the Cornudas Mountains (Zapp, 1941, p. 32) suggests an environment in which such intrusive bodies can form. Shaly horizons overlain by competent beds or unconformities followed by competent beds are the most common horizons of intrusion for laccoliths (McCarthy, 1925, p. 8).

Miller Mountain Intrusion

Miller Mountain is an asymmetrical laccolith with at least two horizons of intrusion (see cross section A-A', Plate 6). The lowest horizon of intrusion, demonstrated by the beds that rest directly upon the intrusion in the valley on the west side of Miller Mountain, is approximately 100 feet below the top of the Hueco Limestone. I interpret the horizon of intrusion, along the eastern side, as being within Cretaceous Unit 1, because the platy parting in the intrusion is concordant with bedding in both Unit 1 and the Victorio Peak Limestone.

Examination of the geologic map (Plate 6), however, shows one area on the east side of Miller Mountain where the parting is nearly vertical. This probably represents the area of supply of the magma. The outcrop of Unit 1 is cut off by this feeder and the horizon of intrusion is lower to the north of this point. Figures 6, 7 and 8 are photographs

Figure 6. East side of Miller Mountain intrusion viewed from East Mountain. Note concordance of the intrusion. Hueco Limestone in foreground. Conical peak at right is San Antonio Mountain of the Cornudas group.

Figure 7. West side of Miller Mountain intrusion. View looking north. The intrusion is concordant with the Hueco Limestone.

Figure 8. Close-up view of the contact between pyroxene trachyte of Miller Mountain intrusion and Hueco Limestone. Note lack of metamorphism of Hueco.

of the Miller Mountain laccolith, showing that the intrusion is concordant. Laccoliths of this same shape are known in the Judith Mountains, Montana (Weed and Pirrson, 1898, p. 555).

Cerro Diablo Intrusion

Cerro Diablo intrusion is a body with the same general shape as Miller Mountain laccolith, although the Cerro Diablo laccolith is larger and thicker. The platy parting in Cerro Diablo laccolith is concordant with the bedding in Cretaceous Unit 2 on the west side, and beds of the Hueco Limestone rest upon the laccolith on its east and north sides. Thus, the horizon of intrusion is within the shale in the upper part of Unit 2 on the west side, and is within the Hueco Limestone on the north and east sides. This horizon in the Hueco is slightly higher than that in which the Mayfield Valley laccolith occurs. Figure 9 is a photograph of the Cerro Diablo intrusion.

East Mountain Intrusion

East Mountain intrusion is a discordant tabular body which lies upon the Hueco Limestone at the north end, on the Victorio Peak Limestone on the west, east and south sides, and upon Cretaceous Unit 1 on the southwest side. Figures 10

Figure 9. West side of Cerro Diablo intrusion. Victorio Peak Limestone and Cretaceous Unit 1 and Unit 2 crop out below the intrusive rock. The base of the intrusion lies about halfway between the valley floor and the top of the peak.

EXPLANATION OF FIGURES 10 AND 11

Figure 10. East Mountain intrusion viewed from top of Miller Mountain. Hueco and Victorio Peak Limestones in center of picture.

Figure 11. East Mountain intrusion (above) and Mayfield Valley intrusion (below). Bedded rock between the intrusions is 400 feet of Hueco Limestone. South end of Mayfield Valley.

Figure 10

Figure 11

and 11 show the relation of the intrusion to surrounding rocks.

Cornudas Station Intrusion

The Cornudas Station intrusion is a cone sheet that lies between a cylindrical block of Hueco Limestone and an enclosing mass of Victorio Peak Limestone (see cross section A-A', Plate 7). Thickness of the dike ranges from 5 to 10 feet. Extrusive rocks may have accumulated above this center, but none crop out in the vicinity now.

CONNECTIONS BETWEEN INTRUSIONS

Feeders connecting the various intrusions were not observed; their location must, therefore, be based on petrologic evidence, and, for the Miller Mountain laccolith, on the orientation of platy parting (see discussion of Miller Mountain intrusion). Cross sections A-A' and B-B' (Plate 6) show the hypothetical feeders. The mineralogical similarity of the Miller Mountain-Cerro Diablo-East Mountain group to the Mayfield Valley intrusion and the structural control by the Mayfield Valley body on the shapes of the overlying group suggest that feeders connect the two levels of intrusion. This problem and the relationship of the Sierra Tinaja Pinta intrusions to the Cornudas Station intrusion are

considered in more detail in the discussion of petrogenesis.

JOINTING

Each of the three intrusions, Miller Mountain, Cerro Diablo and East Mountain, contains at least two sets of joints; one is approximately parallel to the contact; the other is a radial set. Both are interpreted as resulting from contraction of the igneous rock due to cooling. In addition to these two sets, Miller Mountain laccolith has a set, striking N. 50° W., which is unrelated to the shape of the intrusion.

The attitude of jointing in the Permian limestones is difficult to measure because weathering has widened the joints until the dip is modified from its original angle. There is a cracking, in three directions, in the Victorio Peak Limestone which apparently results from weathering rather than from tectonism.

PLATY PARTING

Miller Mountain, Cerro Diablo, and East Mountain intrusions each exhibit prominent platy parting which is particularly well developed near the contacts of the bodies. Weathering accentuates the feature so that flat boulders and sheets are produced rather than the spheroidal boulders into

which massive igneous rocks commonly weather. The planes of parting are parallel to both the contacts of the intrusions and to the mineral orientation. This parting represents either planes of laminar flow in the magma or surfaces developed during cooling and resultant contraction of the magma. Both interpretations explain the parallelism of the parting to the contacts.

FAULTS

Three faults, each directly associated with intrusion of magma, have been mapped in the Sierra Tinaja Pinta area. A fault, with 15 feet of vertical displacement, at the north end of Mayfield Valley laccolith demonstrates that the laccolith broke through, and lifted, its roof. The other faults are actually the two ends of one fracture which developed when Cerro Diablo laccolith lifted its roof.

SEQUENCE OF STRUCTURAL DEVELOPMENT

Sierra Tinaja Pinta Area

The sequence of structural development of the Sierra Tinaja Pinta area is illustrated by Figure 12. Figure 12-A shows the beginning stages of development of the Mayfield Valley laccolith. Magma has risen to a level near the base

EXPLANATION OF FIGURE 12

A. Intrusion of magma near the base of the Hueco Limestone. Fracture pattern above intrusion from Billings (1945, p. 48-49).

B. Spreading of magma up fractures and along bedding planes near the top of the Hueco.

C. Thickening of Miller Mountain and Cerro Diablo laccoliths and lateral spreading of magma in Cretaceous rocks.

D. Erosion to present topography. See cross section A-A', Plate 6.

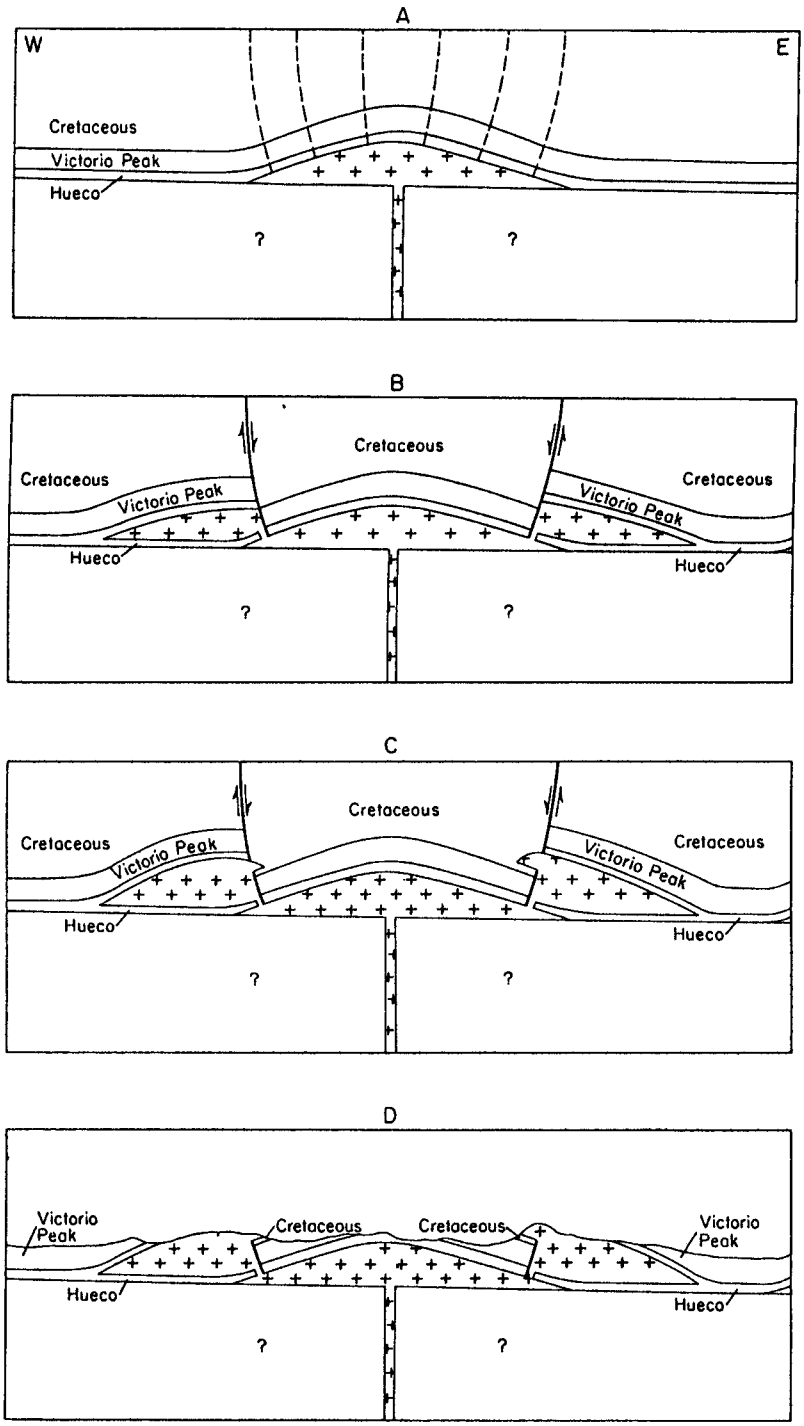


Figure 12. Structural development of Sierra Tinaja Pinta area.

of the Hueco Limestone, possibly at the top of the Powwow conglomerate, where it spread laterally and vertically, establishing the tension fractures as shown (Billings, 1945, p. 48-49).

As the Mayfield Valley laccolith grew in size, magma spread up these fractures to a horizon near the top of the Hueco Limestone where it spread outward and raised its roof (Figure 12-B). The magma continued upward and again spread laterally, this time at two horizons, one in Unit 1 (Miller Mountain laccolith), the other at a shale interval in Unit 2 (Cerro Diablo) to produce Miller Mountain and Cerro Diablo laccoliths (Figure 12-C). Erosion to the present topography produced the outcrops we see today (Figure 12-D).

Cornudas Station Area

Figure 13 illustrates the development of the Cornudas Station structure. A magma reservoir at depth, exerting pressure on its roof, produced tension fractures oriented as shown in Figure 13-A. The magma pushed a cylinder of Permian and Cretaceous rocks upward (Figure 13-B), and occupied the fractures around it. Possibly due to extrusion on the surface, the magma no longer exerted pressure on its roof and the central block subsided into the reservoir; drag produced the inward dips on the block (Figure 13-C).

EXPLANATION OF FIGURE 13

A. Intrusion of magma and development of fracture pattern.

B. Magma raised a cylinder of sedimentary rock and occupied fractures around it.

C. Subsidence of central block producing drag on its margins. Erosion to present level. See cross section A-A', Plate 7.

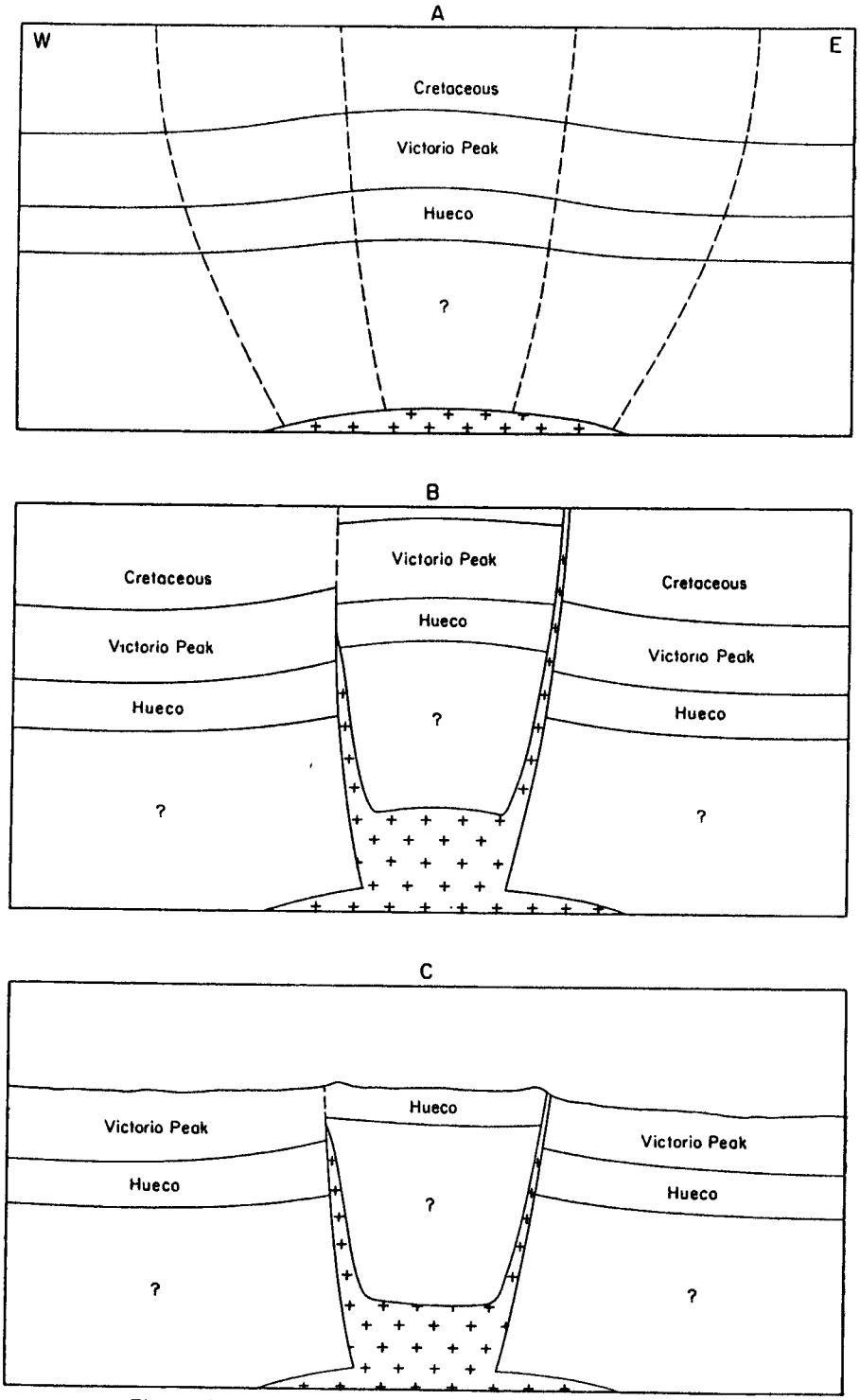


Figure 13. Structural development of Cornudas Station area.

P E T R O G E N E S I S

GENERAL STATEMENT

The origin of alkalic rocks (rocks chemically characterized by high percentages of alkalis relative to silica and alumina) and alkalic magmas is a subject that has received attention greatly in excess of the abundance of the alkalic rocks. Daly (1933, p. 38) has pointed out that the visible quartz-free alkalic rocks of North America have a volume probably less than 0.1 percent of the volume of the known igneous rocks of North America. The problem of the origin of subsilicic magmas and feldspathoidal rocks is, by no means, solved. An excellent review by Tilley (1957) of the pertinent data, collected both in the field and in the laboratory, renders a summary here unnecessary. Recent experimental work relevant to the problem has been conducted chiefly at the Geophysical Laboratory of the Carnegie Institution of Washington; results are available in the annual reports of the Director.

When magma invaded the lowest crustal levels presently exposed in the Sierra Tinaja Pinta-Cornudas Station vicinity, it was in an advanced stage of differentiation and crystallization. I can find no clues to the origin of this already subsilicic alkalic magma in the immediate vicinity,

and the petrology of the entire trend of intrusions is, at present, not well enough known to contribute much information. A small diorite intrusion in the Cornudas Mountains suggests that a more mafic magma was available for differentiation (Timm, 1941, p. 47). Intrusions at the southeastern end of the trend are apparently more varied in composition than those in the northwestern part. The central part of the Cave Peak intrusion consists of granite associated with rhyolite porphyries and breccias; syenogabbro borders the Marble Canyon syenite (Holster, 1959, p. 131-133).

SEQUENCE OF INTRUSION

Structural (see Figure 12) and petrographic evidence suggest the following sequence of intrusion:

1. A mush, consisting of crystals of hypersolvus feldspar, augite and minor olivine, nepheline, apatite and magnetite, suspended in a liquid, was intruded near the base of the Hueco Limestone, and formed the Mayfield Valley intrusion. Sample 22I from the chilled margin indicates that a very small amount of nepheline was present at this stage. Rocks of the Cornudas Station intrusion are of similar composition, but were not necessarily intruded

at the same time.

2. Filter pressing, resulting in squeezing of liquid containing a few small crystals from the Mayfield Valley body, sent a liquid up fractures above the intrusion to form the Miller Mountain, Cerro Diablo and East Mountain intrusions. Chilled margins of these intrusions show that microphenocrysts of feldspar were a minor constituent in the liquid (Sample 1I), that nepheline was present in a very small amount (Sample 17I), and that analcime had not yet begun to crystallize.

3. Consolidation of the magmas produced the hypersolvus porphyritic analcime-nepheline syenite of the Miller Mountain, Cerro Diablo and East Mountain intrusions, the hypersolvus porphyritic analcime syenite of the Mayfield Valley intrusion, and the hypersolvus olivine-analcime trachyte of the Cornudas Station intrusion.

4. Final consolidation phenomena resulted in replacement of nepheline by analcime, crystallization of some aegirine, partial exsolution,

sericitization, and albitization of feldspar, and, finally, development of zeolites and analcime in cavities.

EVIDENCE FROM EXPERIMENTAL PETROLOGY

General Statement

A great deal of experimental work has been done on the alkalic rocks (see Tilley, 1957, for a summary), but application of many of the results to rocks requires chemical analyses, or at least partial chemical analyses, of the rocks or their minerals. Chemical data are not available for rocks of the Sierra Tinaja Pinta-Cornudas Station vicinity, but certain experimental results may be used if reasonable composition are assumed for the minerals, and the bulk chemical compositions of the rocks calculated (see Table 8). Bulk compositions thus obtained can be recalculated in terms of $Na\ Al\ Si\ O_4$, $K\ Al\ Si\ O_4$ and $Si\ O_2$ and plotted in the "residua system." Results of this procedure are illustrated in Figure 14.

Note that all four rocks plot in the minimum temperature trough. Analcime-nepheline syenite plots near the minimum in the silica deficient portion of the anhydrous system; pyroxene trachyte is near the minimum on the Ab - Or join.

Table 8. Mineral compositions assumed for calculating bulk compositions of rocks of the Sierra Tinaja Pinta-Cornudas Station area.

MINERAL	ASSUMED COMPOSITION
Mesoperthite	50% $Na\ Al\ Si_3\ O_8$
	50% $K\ Al\ Si_3\ O_8$
Analcime	$Na\ Al\ Si_2\ O_6 \cdot H_2\ O$
Nepheline	$Na\ Al\ Si\ O_4$
Augite and "Pyroxene"	50% $Ca\ Mg\ Si_2\ O_6$
	50% $Na\ Fe\ Si_2\ O_6$
Aegirine	$Na\ Fe\ Si_2\ O_6$
Olivine	$Fe_2\ Si\ O_4$
Biotite	$K\ Fe_3\ Al\ Si_3\ O_{10}\ (OH)_2$

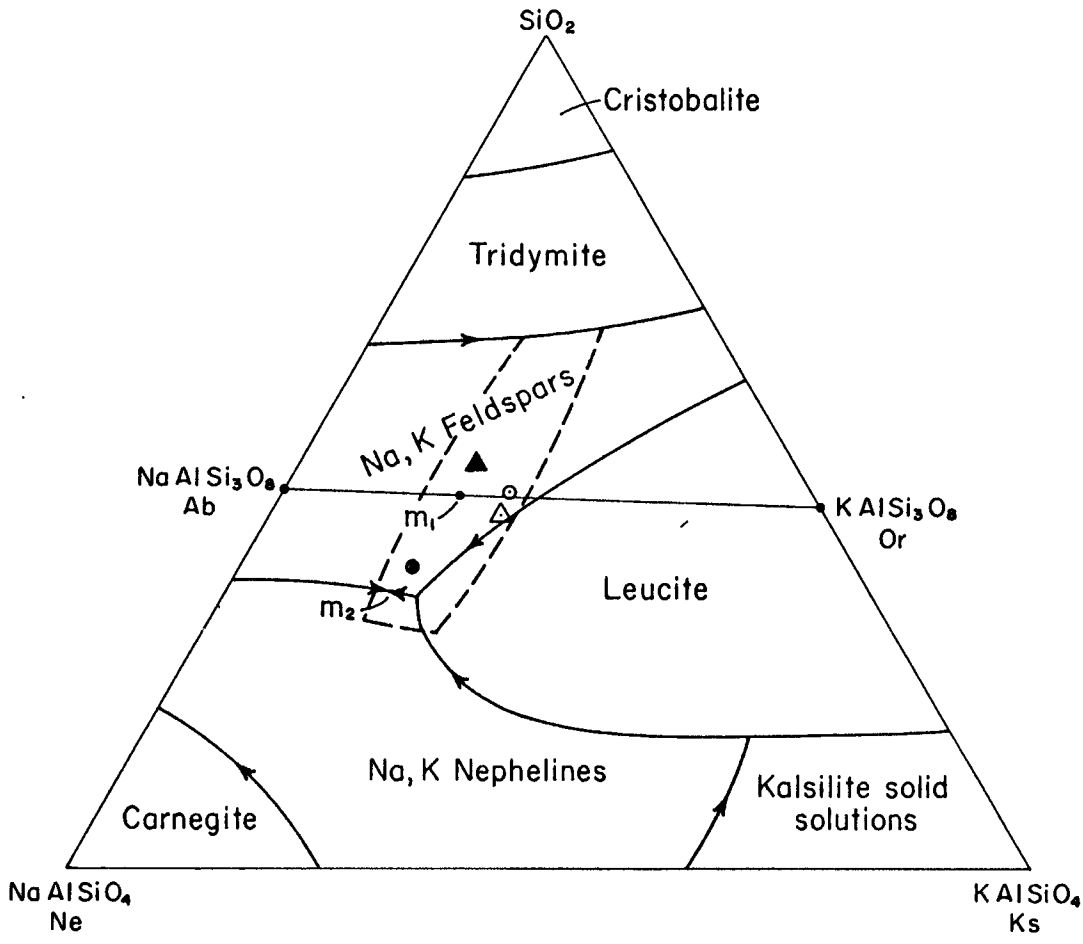


Figure 14. Calculated compositions of some rocks from the Sierra Tinaja Pinta-Cornudas Station area plotted in the system Na Al SiO_4-K Al SiO_4-SiO_2. Anhydrous system at 1 atmosphere. Dashed line shows area of minimum temperatures. After Bowen (1937, p. 12).

Other conclusions drawn from this diagram would be questionable due to uncertainty in the method used to obtain bulk compositions of the rocks.

The Analcime Problem

Many petrologists (including Pirsson, 1896; Gilluly, 1927; Jahns, 1938; Lonsdale, 1940; Turner and Verhoogen, 1960; Wilkinson, 1962) have suggested, on the basis of textural evidence, that analcime is a "primary" mineral formed during late magmatic consolidation. Experimental evidence has now shown that this may be true for some rocks. Yoder (oral communication, 1964) stated that analcime has a stability field in the system $NaAlSiO_4$ - $KAlSiO_4$ - SiO_2 - H_2O at a water pressure of 10 kb. Such a water pressure certainly cannot exist in hypabyssal intrusions, however.

The upper stability curve for analcime, based on the reaction nepheline + albite + water = analcime, has been published by Yoder (1950, p. 323; 1954, p. 121), by Yoder and Fawcett (1963, p. 146), and by Greenwood (1961, p. 3931). Comparison of this curve with the beginning of melting (solidus) of nepheline syenite yields interesting results. Curves showing the beginning of melting of nepheline syenite have been published by Tilley (1957, p. 331), by Yoder and Tilley (1962, p. 463), and by Barker (1965, p. 19). Only the

curve by Barker is based on reliable experimental work; other curves are "constructed" curves based only on limited experimental work.

Figure 15 indicates that analcime is a primary magmatic mineral, in a rock of nepheline syenite composition, at water pressures and temperatures within the cross-hatched area. The point of intersection of the analcime stability curve and the nepheline syenite solidus curve is not known from experimental work, but must be determined by projecting the known portions of the curves. This intersection is in the vicinity of P_{H_2O} = 3.75 kb and T = 625° C. If water pressure may be assumed to be equal to total pressure, and if the mean density of material overlying an intrusion be 2.5, the depth of intrusion corresponding to a water pressure of 3.75 kb is about 16 kilometers, or approximately 10 miles. Field study of the intrusions mapped for this thesis indicates a depth of intrusion corresponding to about 0.5 kb water pressure. According to Figure 15 analcime cannot be a "primary" mineral at such a water pressure; a nepheline syenite crystallizes at about 800° C at this water pressure.

Experimental evidence is thus in conflict with petrographic evidence. This conflict may be resolved by rejecting the conclusion, based on petrographic evidence, that analcime can form as a primary magmatic mineral. A more likely

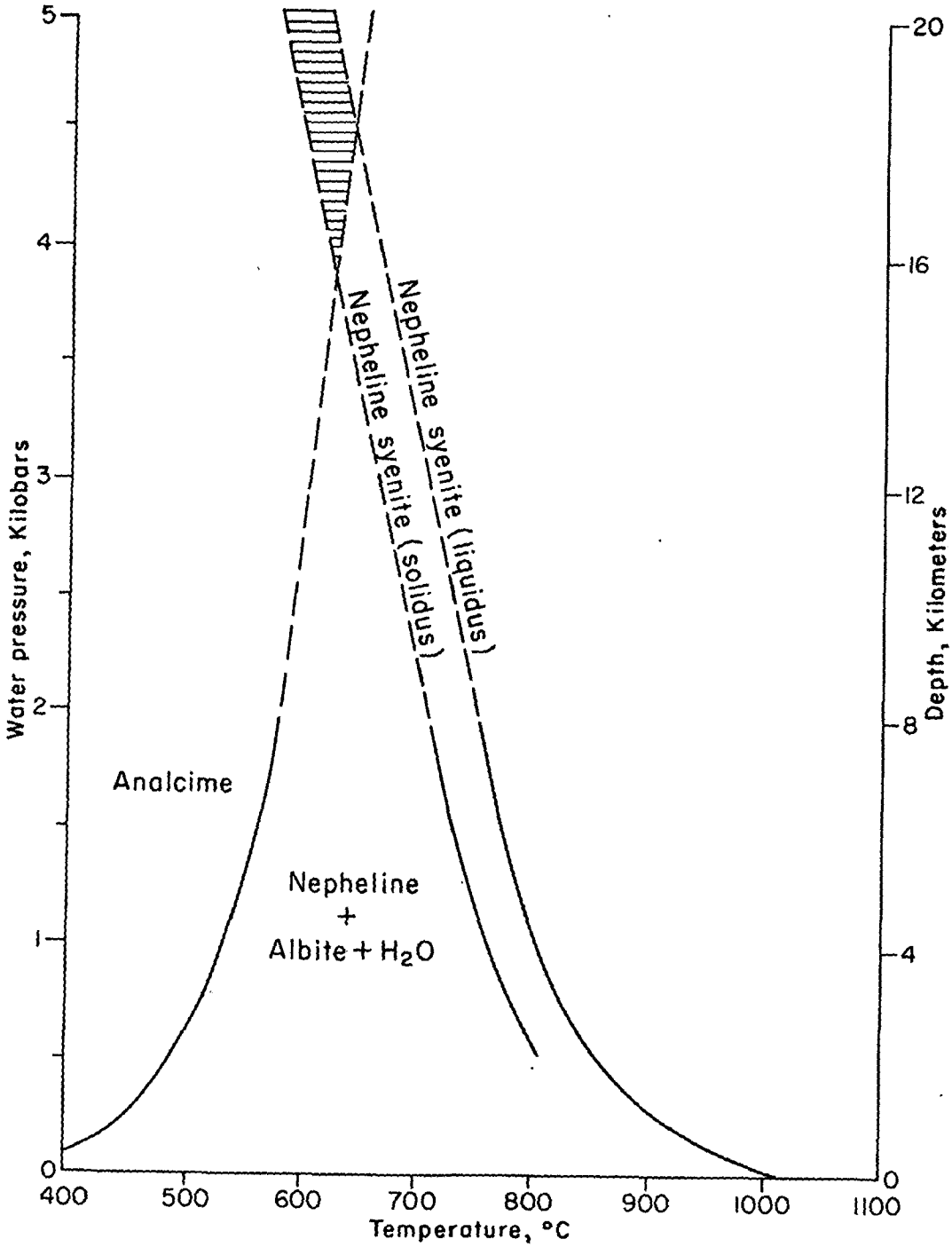


Figure 15. Upper stability curve of pure analcime (Greenwood, 1961, p. 3931) and liquidus and solidus of nepheline syenite (Barker, 1965, p. 19). The cross-hatched area indicates region of magmatic analcime.

possibility is that the position of the analcime stability curve is influenced by factors not considered in the experimental system. Shifting of the nepheline syenite solidus to lower temperature at a particular water pressure is impossible in the system studied, as the minimum melting composition (anhydrous) of nepheline syenite was used for the experimental work. The minimum melting composition in the anhydrous system does not change significantly up to 2 kb water pressure (Barker, 1965, p. 20).

Greenwood (1961) has investigated the system analcime - water - argon to determine if the upper stability of analcime is affected by water pressure less than total pressure due to the presence of another volatile constituent. Results are shown in Figure 16. The analcime stability curve shifts to the left as the partial pressure of water decreases; this complicates, rather than explains, the existence of primary analcime at low water pressures.

Yoder and Fawcett (1963, p. 146-147) suggested that the presence of calcium in analcime may lower the upper stability curve below that of pure analcime, but they did not state whether this lowering is in terms of water pressure or temperature. Data published by Ames and Sand (1958, p. 479) indicate that calcium in analcime shifts the upper stability to lower temperature for a given water pressure relative to

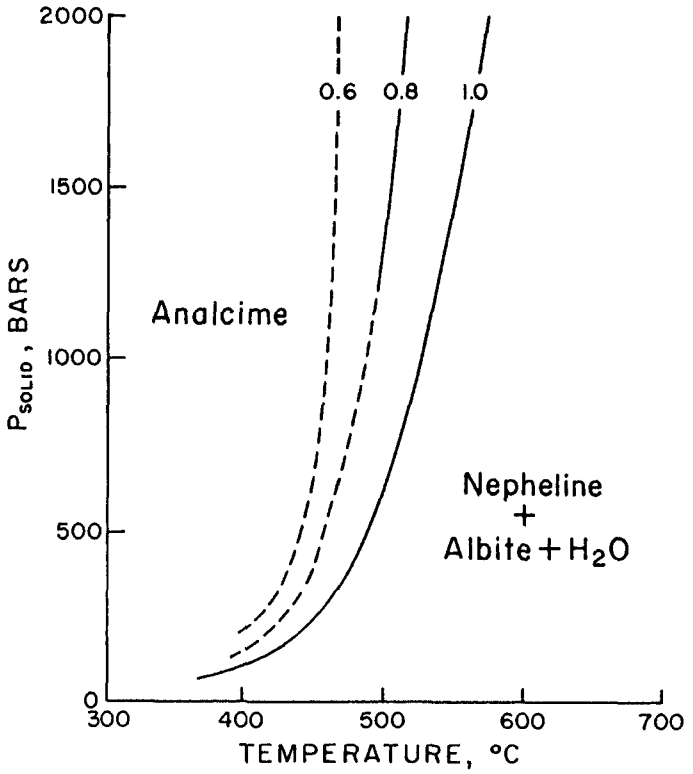


Figure 16. Upper stability of pure analcime in the system analcime-water-argon (from Greenwood, 1961, p. 3942).

pure analcime. Fyfe and others (1958, p. 174) published the upper stability curve of calcic analcime confirming the shift to lower temperature for a particular water pressure. This also makes the problem more extreme.

Probably the most promising suggestion for the explanation of primary analcime at low water pressure is that potassium in analcime shifts the stability curve to higher temperatures for a given water pressure.

If the feldspathoid stable during magmatic consolidation were a potassium-rich type, exchange of alkalis between albite and the potassium-rich feldspathoid at lower temperature and water pressure would produce sodic analcime and potassium feldspar according to the reaction (Barker, oral communication, 1965):

$$K\,Na_3\,Al_4\,Si_8\,O_{24} \cdot 4\,H_2O + Na\,Al\,Si_3\,O_8 =$$

$$4\,Na\,Al\,Si_2\,O_6 \cdot H_2O + K\,Al\,Si_3\,O_8.$$

This enrichment of analcime in sodium is consistent with the fact that chemical analyses of analcime indicate that most has a high soda and low potash content (Wilkinson, 1962, p. 206). That potassic analcime exists is known from experimental work (Fudali, 1963) and from natural occurrences (Larsen and Buie, 1938, p. 838). Experimental study of the upper stability of potassic analcime seems to be in order.

The generalization that analcime is stable at higher water pressure, for any given temperature, rather than the pair albite-nepheline appears valid, however. This has an interesting application to the rocks of the Sierra Tinaja Pinta area where the feldspathoid in the deeper Mayfield Valley intrusion is analcime, but in the shallower Miller Mountain, Cerro Diablo, and East Mountain intrusions nepheline is present. The difference in water pressure at the two levels of intrusion is probably one significant factor. Alteration of nepheline to analcime indicates that analcime became stable as the temperature decreased.

The Origin of Nepheline Syenite

Of wide petrologic application is the system Na Al Si O_4 - K Al Si O_4 - Si O_2, called "petrogeny's residua system" (Schairer and Bowen, 1935; Bowen, 1937; Schairer, 1950; Schairer, 1957). Figure 14 is a simplified illustration of the anhydrous system at atmospheric pressure. Two areas of temperature minima, separated by the alkali feldspar thermal barrier, occur in the system. Compositions of most granites plot within the thermal trough in the Ab - Or - SiO_2 part of the system; compositions of many nepheline syenites plot in the thermal trough in the Ne - Ab - Or - Ks quadrilateral; syenites plot in a position intermediate between these two

thermal troughs near the minimum in the system Ab - Or. Yoder (oral communication, 1964) has pointed out, however, that this is largely coincidental; analyses of rocks should be plotted on this diagram only at the appropriate water pressures. The coincidence of granites and nepheline syenites with thermal minima indicates that these rocks are the final products of magmatic differentiation; conversely, the first liquid to appear, if a rock were heated to the temperature at which it begins to melt, would be either of granite or nepheline syenite composition, depending on the composition of the rock being heated. Thus, two mechanisms for originating nepheline syenites are pointed out: differentiation from a magma of different composition, and partial melting to produce a magma of nepheline syenite composition. The compositions of most sedimentary rocks, however, plot within the Ab - Or - SiO_2 triangle, and, if partially melted, would produce melts of granite composition. Practically the only rocks with compositions in the Ne - Ab - Or - Ks quadrilateral are subsilicic igneous rocks, although a few rare sedimentary rocks qualify (Barker, 1965, p. 26). Barker (1965, p. 25) has recently proposed a mechanism for the origin of a nepheline syenite magma by partial melting of a shale and evaporite sequence; however, the lack of coincidence of feldspathoidal rocks with evaporite sequences seems to limit the

frequency with which such a process occurs. Partial melting of crustal rocks as a mechanism to produce feldspathoidal syenites, therefore, merely postpones the real problem. Derivation of nepheline syenite from granite, produced by partial melting of crustal rocks, is prevented by the alkali feldspar thermal barrier, although there is experimental evidence that granite may be derived from nepheline syenite (Bowen, 1945, p. 88). "Iron albite" ($Na\ Fe^{+3}\ Si_3\ O_8$) may play a significant role in the development of nepheline syenite from quartz syenite, but this has not as yet been demonstrated (Bailey and Schairer, 1964, p. 77). That this barrier may be crossed in nature is also suggested by field evidence (Shand, 1945, p. 505). Origin of feldspathoidal syenites by limestone syntexis lacks demonstrable field evidence (Tilley, 1957, p. 334).

Experimental work at elevated water pressures in the Ab - Or - SiO_2 portion of the system has shown significant changes from the anhydrous system (Bowen and Tuttle, 1950; Tuttle and Bowen, 1952), but the principles outlined above are not altered. Substantial lowering of the liquidus, and reduction of the leucite field in the system Ne - Ks - SiO_2 - H_2O, has been demonstrated (Fudali, 1963, p. 1106), but again no change in the preceding discussion is indicated. At a water pressure of 10 kb, analcime has a field of stability in

the system (Yoder, oral communication, 1964), but no such water pressure can be realized in hypabyssal intrusions.

In light of present experimental evidence, the origin of nepheline syenite by differentiation from a mafic magma such as alkali olivine basalt is more reasonable than derivation by partial melting of crustal rocks. Partial melting as a mechanism to produce a magma of nepheline syenite composition from crustal rocks is not to be rejected, but it lacks experimental evidence at present. Yoder and Tilley (1962) have shown that both alkaline and tholeiitic series could be produced by partial melting of eclogite; which type is produced depends on the garnet-omphacite ratio of the eclogite and on pressure (depth). Alkali basalt magmas are, in general, produced from the same source rock at greater depths than tholeiite magmas.

That a more mafic magma was available for differentiation of the alkalic rocks along the northeastern Diablo Plateau has already been suggested. Eardley (1960, p. 24) envisioned an olivine basalt parent magma for the entire alkalic petrographic province of Trans-Pecos Texas. Once a magma of melilite-nepheline basalt composition is available, the series melilite nephelinite-tephrite-phonolite-alkali rhyolite can be produced by fractional crystallization (Bowen, 1945, p. 86-88). Melting at depth

was probably related to block faulting that developed in the northern Trans-Pecos during late Tertiary time.

A P P E N D I X

VOLUMETRIC MODAL ANALYSES OF IGNEOUS ROCKS

* - indicates 1,000 points counted. Spacing of points = 2/3 mm.

tr - present but not encountered in point count.

Analcime syenite

Modal Percentage	Sample Number			
	25I*	27I	31I*	9I
Mesoperthite	77.1	78	77.0	74
Analcime	12.0	15	13.1	20
Augite	4.2	<1	0.8	-
Biotite	2.1	1	2.0	4
Magnetite + Hematite	4.6	5	7.1	2
Apatite	tr	1	tr	<1
Eudialyte	tr	-	-	-

Dike and contact rocks associated with analcime syenite

Modal Percentage	Sample Number			
	22I	23I	24I	26I
Mesoperthite	83	88	80	85
Analcime	2	-	7	-
Nepheline	2	-	-	-
Augite	2	7	3	12
Biotite	2	<1	-	<1
Aegirine	7	5	10	3
Apatite	<1	<1	<1	<1
Olivine	-	<1	-	<1
Magnetite + Hematite	2	<1	-	<1

Pyroxene trachyte

Modal Percentage	Sample Number			
	1I	15I*	17I*	20I*
Mesoperthite	71	63.6	67.0	59.8
Pyroxene	25	36.4	24.9	39.2
Analcime	3	-	5.7	0.8
Nepheline	-	-	2.0	-
Magnetite + Hematite	1	-	0.4	0.2

Analcime-nepheline syenite

Modal Percentage	Sample Number					
	2I	3I	4I	5I*	10I*	11I
Mesoperthite	78	78	80	77.6	65.1	73
Nepheline	7	10	12	6.4	15.9	12
Analcime	5	7	3	5.3	7.1	5
Aegirine	5	5	5	6.6	10.4	7
Sodic amphibole	2	tr	-	-	tr	3
Magnetite + Hematite	3	<1	<1	4.1	1.5	-
Zeolite	<1	-	-	-	tr	<1

Modal Percentage	Sample Number					
	12I	13I*	14I	16I	19I	28I
Mesoperthite	78	72.4	80		74	77
Nepheline	10	6.2	8		7	10
Analcime	5	5.7	2		5	5
Aegirine	7	12.4	7		7	5
Sodic amphibole	tr	-	3		2	3
Magnetite + Hematite	-	3.3	-		5	<1
Zeolite	-	-	tr		-	-

Analcime-nepheline syenite--continued

Modal Percentage	Sample Number 30I	32I	33I*
Mesoperthite	68	81	65.2
Nepheline	10	7	10.7
Analcime	5	7	6.2
Aegirine	7	5	14.0
Sodic amphibole	-	-	3.1
Magnetite + Hematite	<1	tr	0.8
Zeolite	10	-	tr

Olivine-analcime trachyte

Modal Percentage	Sample Number 6I	7I	8I
Mesoperthite	80.6	82.6	83
Analcime	8.4	6.1	7
Aegirine	1.3	3.1	7
Biotite	4.6	1.0	-
Olivine	2.4	3.1	3
Magnetite + Hematite	2.6	4.0	<1
Apatite	0.1	0.1	<1
Zeolite	tr	-	<1

MEASURED SECTION

Method.--The section was measured with a 5-foot staff and a Brunton pocket transit.

Location.--West side of Cerro Diablo. The exact location is shown on the geologic map of Sierra Tinaja Pinta area.

Stratigraphy.--Entire Cretaceous section. The division is into two parts called Unit 1 and Unit 2. Fossil identifications are by Keith Young.

Bed	Thickness in feet	Feet above base
top of section		
Unit 2		
Cerro Diablo laccolith		
2. Shale, yellow to gray; contains beds of limestone, 1 foot thick, yellow on weathered surface, olive (dark yellow-green) on fresh surface; nodular, fossiliferous; Alectryonia quadriplicata (Shumard), Haplostiche texana (Conrad). .	53	61-114
1. Limestone, medium gray nodular, fossiliferous beds 6" to several feet thick; interbedded with marl and 1 inch thick lenses of dark gray shale; fossils identified in basal 15 feet are: Tylostoma sp., Alipes sp., Cinulia sp., Ctenostreon texanus (Roemer), Enallaster longisulcus (Adkins and Winton), Pholadomya sp., Texigryphea washitaensis		

Bed		Thickness in feet	Feet above base
	(Hill), Cardium cf. subcongestum Böse, Neithea sp.; fossils identified from 15 to 45 feet above base: Holectypus charltoni Cragin, Holectypus sp., Nerinea sp., coral, Tylostoma sp., Texigryphea washitaensis (Hill), Neithea georgetownensis (Kniker), Neithea subalpina (Böse), Alectryonia quadriplicata (Shumard); fossils collected from 45 to 55 feet above base: Texigryphea washitaensis (Hill), Lima wacoensis Roemer, Mortoniceras shumardi (Marcou), Lima sp., Holectypus charltoni Cragin, Enallaster sp., Alectryonia quadriplicata (Shumard).	61	0-61
	Total thickness of Unit 2	114 feet.	
Unit 1			
11.	Sandstone, light gray on fresh surface, light brown on weathered surface, hard, fine grained, siliceous, orthoquartzite, burrowed; contains Texigryphea washitaensis (Hill) and Cerithium sp.	5	264-269
10.	Sandy claystone, light gray, burrowed; interbedded with beds of brown sandstone <1 inch to 1 foot thick, burrowed; includes 6 inch thick beds of abundantly fossiliferous nodular limestone which contains gastropods and pelecypods. .	58	206-264
9.	Sandstone, light gray on fresh surface, light brown on weathered surface, bedding massive and indistinct, medium grained calcareous orthoquartzite; broken pelecypods abundant; Texigryphea washitaensis		

Bed	Thickness in feet	Feet above base
(Hill); contains a few 6 inch beds of sandy limestone, a few chert pebbles, and coral at base. . .	10	196-206
8. Sandstone, light gray on fresh surface, light brown on weathered surface, bedding massive but indistinct; burrowed; medium grained orthoquartzite.	30	166-196
7. Sandstone, light yellow, bedding indistinct, medium grained orthoquartzite	35	131-166
6. Pebbly granule conglomerate, cherty siliceous orthoquartzite, light gray, massive bedding but indistinct; pebbles round, granules and coarse sand subround	57	74-131
5. Sandstone, light gray, hard, fine grained siliceous orthoquartzite; massive beds.	20	54-74
4. Sandstone, red-brown, bedding indistinct, coarse grained, granular cherty hematitic orthoquartzite . . .	5	49-54
3. Sandstone, light brown, indistinctly bedded, friable; fine grained orthoquartzite	37	12-49
2. Sandstone, dark red brown on weathered surface, gray on fresh surface, hard, 2 foot thick beds, laminated, siliceous orthoquartzite.	2	10-12
1. Sandstone, light brown, poorly bedded, very thin beds, fine grained siliceous orthoquartzite; one fossil found - *Lima* sp.	10	0-10

Total thickness of Unit 1 . . . . . 269 feet.

Victorio Peak Limestone

Total thickness of Cretaceous rocks = 383 feet.

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EXPLANATION

QUATERNARY

- Qal — Alluvium
- Qt — Talus

TERTIARY

- Tns — Porphyritic analcime–nepheline syenite
- Tas — Porphyritic analcime syenite

CRETACEOUS

Comanche Series

- Ku_2 — Unit 2
- Ku_1 — Unit 1

UNCONFORMITY

PERMIAN

Leonard Series

- Pvp — Victorio Peak Limestone

Wolfcamp Series

- Ph / Phm — Ph, Hueco Limestone; Phm, metamorphosed Hueco

Geologic contact, dashed where approximately located

U / D — Probable fault (U, upthrown side; D, downthrown side)

10 — Strike and dip of beds

Horizontal beds

30 — Strike and dip of platy parting

80 — Strike and dip of joints

Strike of vertical joints

20 1 — Location of sample

Location of measured section

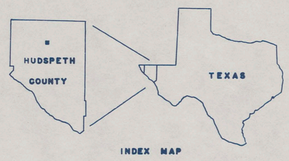
Intermitent stream showing direction of flow

Earthen tank

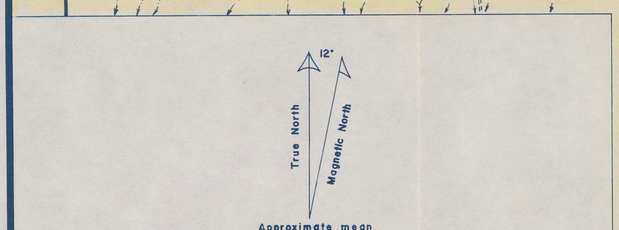
Gravel road

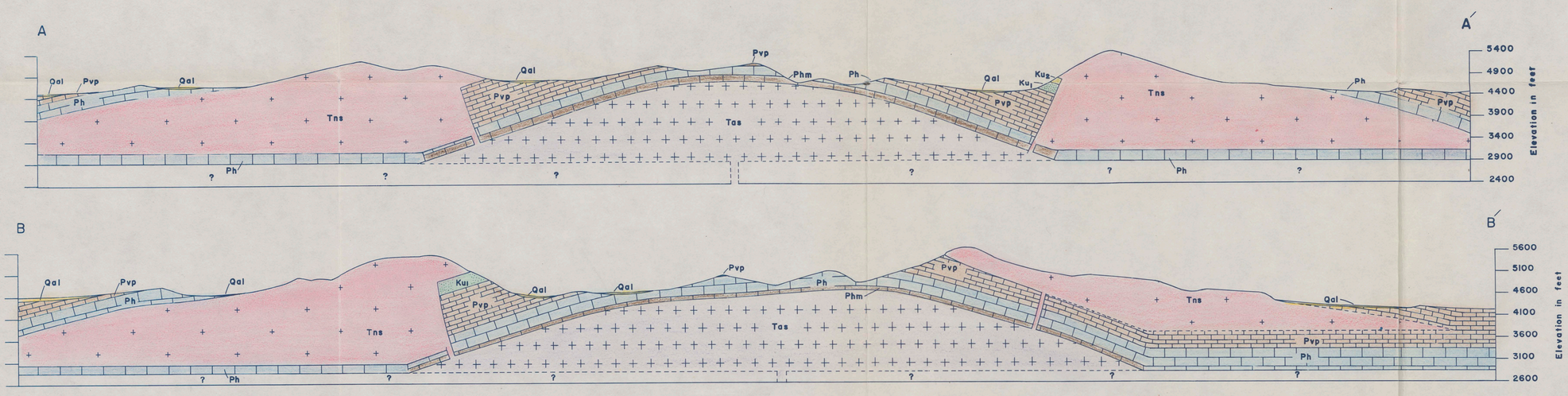
Primitive road

Prospect pit



INDEX MAP



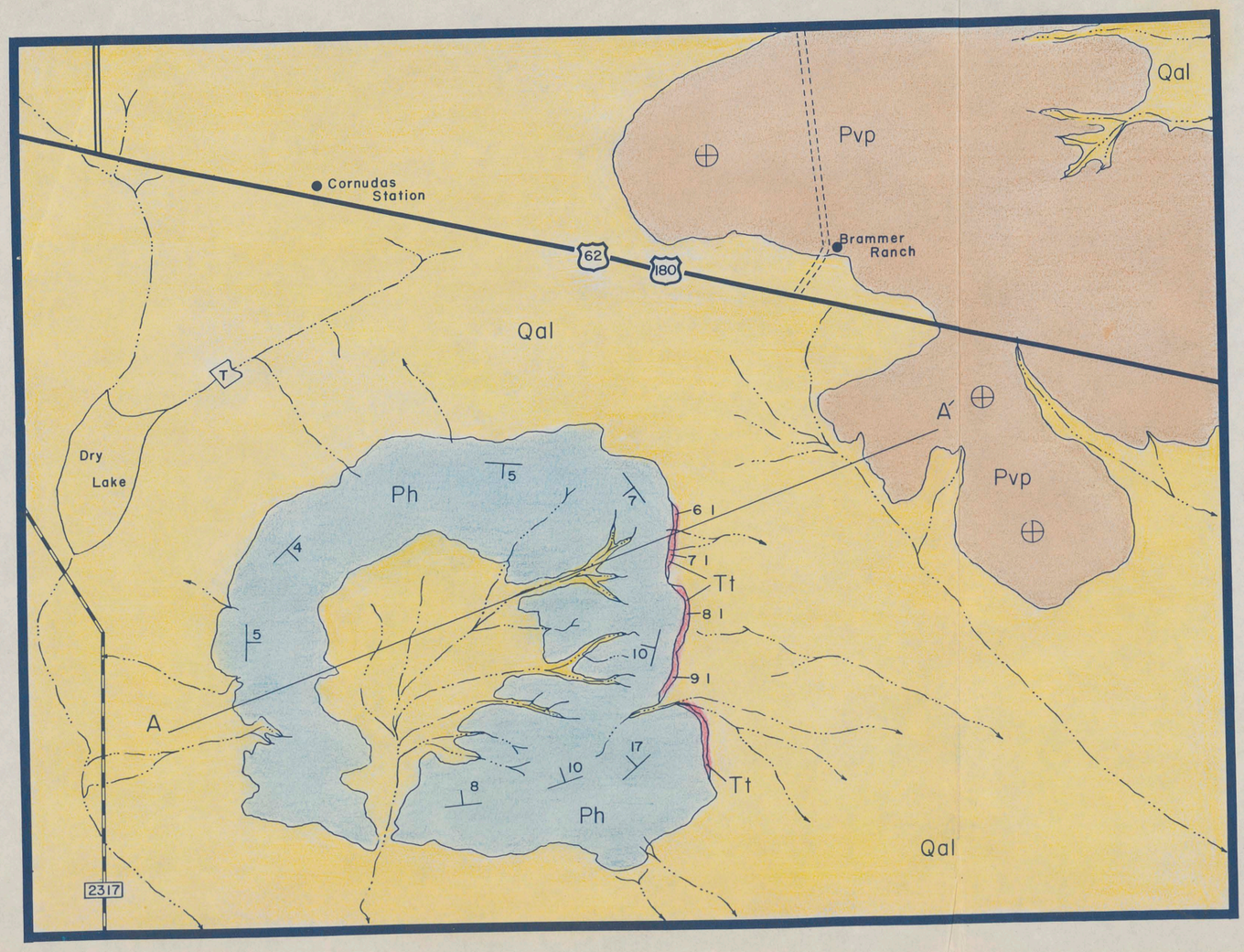


GEOLOGIC MAP AND CROSS SECTIONS, SIERRA TINAJA PINTA AREA, HUDSPETH COUNTY, TEXAS

Robert O. Gross

PLATE 6

May 1965



EXPLANATION

- Qal — Alluvium — QUATERNARY
- Tt — Olivine-analcime trachyte — TERTIARY
- Leonard Series: Pvp — Victorio Peak Limestone — PERMIAN
- Wolfcamp Series: Ph — Hueco Limestone — PERMIAN

Geologic contact

10 — Strike and dip of beds

Horizontal beds

62 — U.S. Highway

2317 — Ranch to market road

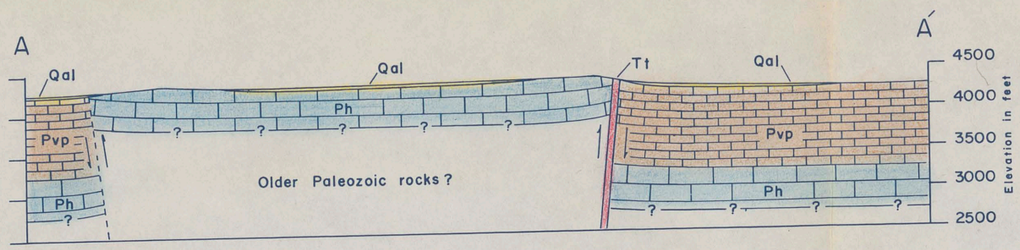
County road

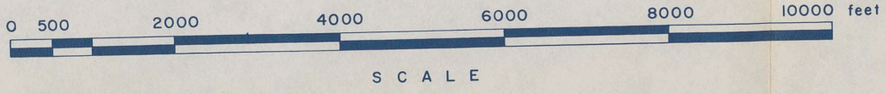
Primitive road

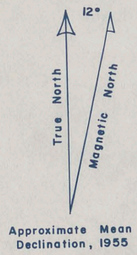
Intermittent stream showing direction of flow

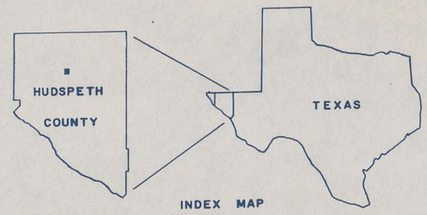
T — Earthen tank

10 I — Location of sample









GEOLOGIC MAP AND CROSS SECTION, CORNUDAS STATION AREA, HUDSPETH COUNTY, TEXAS

Geology by Robert O. Gross

PLATE 7

May 1965