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## GEOLOGY AND MINERAL DEPOSITS OF PRE-CAMBRIAN ROCKS OF THE VAN HORN AREA, TEXAS

By  
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and  
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Bureau of Economic Geology  
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Prepared in co-operation with the United States  
Geological Survey



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*The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.*

*Sam Houston*

*Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.*

*Mirabeau B. Lamar*

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# GEOLOGY AND MINERAL DEPOSITS OF PRE-CAMBRIAN ROCKS OF THE VAN HORN AREA, TEXAS

Philip B. King<sup>1</sup> and Peter T. Flawn<sup>2</sup>

## ABSTRACT

*Introduction.*—This publication describes the geology of pre-Cambrian rocks exposed in the vicinity of Van Horn—their principal area of outcrop in Trans-Pecos Texas. The pre-Cambrian rocks of the area had previously been studied in reconnaissance by Von Streeruwitz for the Dumble Survey (1890–1893), by Richardson for the U. S. Geological Survey (1904, 1914), and by Baker for the Texas Bureau of Economic Geology (1927). The present report is a joint undertaking of the U. S. Geological Survey and Bureau of Economic Geology. Following a summary of the geomorphology and pre-Cambrian geology of the area, the stratigraphic and petrographic nomenclature used in the report is set forth.

*Northwest and northeast Van Horn Mountains, Wylie Mountains, Eagle Mountains, Carrizo Mountains, and Sierra Diablo foothills.*—The geology of the pre-Cambrian rocks in their several areas of occurrence is described in six chapters, five by Flawn on the smaller southern areas and one by King on the large northern area. These are summarized together under the present heading.

Pre-Cambrian rocks are exposed in many places within a 20-mile radius of the town of Van Horn, in an area that has sometimes been called the “Van Horn dome.” Actually, the structure is not domical in the usual sense, but rather, the pre-Cambrian rocks come to the surface in a number of separate but adjacent mountain uplifts. The largest area is in the eastern and southern foothills of the Sierra Diablo. Near the line of the Texas and Pacific Railroad this is separated by a graben of younger rocks from another area in the Carrizo Mountains to the south. Farther south, pre-Cambrian rocks emerge again in smaller areas on the northeast side of the Eagle Mountains, on the west side of

the Wylie Mountains, and in two areas in the Van Horn Mountains, one of which is known locally as the Mica Mine area.

The most highly metamorphosed and perhaps the oldest pre-Cambrian rocks lie to the south, in the Carrizo, Eagle, Wylie, and Van Horn Mountains, and constitute the Carrizo Mountain group. This is a body of altered sedimentary rocks, including meta-arkose, metaquartzite, schist, phyllite, and limestone, which has been intruded by large volumes of igneous rocks, originally rhyolite and diorite, now altered to metarhyolite and amphibolite. Extensive exposures of the group in the Carrizo Mountains show a sequence of sedimentary rocks as much as 19,000 feet thick, which does not appear to have been repeated by folding or faulting.

The group shows much homogeneity in original character from place to place, suggesting that it is a single sedimentary series rather than several, but it shows considerable variation in degree of metamorphism. Rocks farthest south, in the Van Horn Mountains, are the most metamorphosed (medium metamorphic grade, or amphibolite facies), retain few of their original sedimentary structures, and are extensively veined by pegmatite. Rocks farther north, in the Carrizo and Eagle Mountains, are less metamorphosed (low metamorphic grade, or greenschist facies), and preserve many of their original sedimentary structures. Their metamorphic history is complex, however, as a retrogressive and cataclastic metamorphism is superimposed on an earlier progressive regional metamorphism. The associated intrusive metarhyolites are also cataclastically altered and in part mylonitized. The cataclastic metamorphism was perhaps produced by dislocative movements that were associated with the Streeruwitz overthrust, immediately beyond.

The Streeruwitz overthrust, whose trace lies in the Sierra Diablo foothills a little north of the Texas and Pacific Railroad, is

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a line of major discontinuity in the pre-Cambrian rocks. Along it, the dominantly metamorphic and igneous rocks of the Carrizo Mountain group have been thrust northward over the dominantly sedimentary Allamoore and Hazel formations. The original stratigraphic relations of the rocks on the two sides of the overthrust are unknown, but presumably those on the north are younger, and they may be much younger.

The Allamoore formation, the oldest unit north of the overthrust, consists of interbedded cherty limestones, phyllites, and volcanic rocks, the latter including pyroclastics, flows, and perhaps shallow intrusives. Some of the limestones contain structures that may be of algal origin. Because of the complex structure, the thickness of the Allamoore cannot be determined, but it is certainly thousands of feet thick.

The Allamoore is succeeded by a very different, but comparably thick, deposit, the Hazel formation, whose basal part is a thick coarse conglomerate, made up almost wholly of angular rock fragments derived from the Allamoore formation. The two formations are obviously unconformable, and were probably separated by a time of orogeny which may still have been in progress when the earlier Hazel deposits were being laid down. The conglomerates are interbedded with, and are succeeded by, a thick, uniform mass of fine-grained, silty red sandstone which constitutes the upper part of the Hazel formation.

After deposition of the Hazel formation, both it and the Allamoore were deformed together during a time of orogeny that was probably related to movements on the Streeruwitz overthrust. For some miles north of the trace of the overthrust both formations are thrown into recumbent folds and thrust sheets that were driven northward. Deformation dies out away from the overthrust, and in the northernmost exposures the rocks are little disturbed.

The deeply eroded edges of the deformed and partly metamorphosed Hazel and Allamoore formations and the Carrizo Mountain group are overlain unconformably by another and coarser red clastic deposit, the Van Horn sandstone, whose maximum thickness is about 800 feet. The Van Horn

contains numerous rounded cobbles and boulders, made up not only of rocks from formations immediately beneath, but also of red granite and rhyolite porphyry probably derived from the north, and of meta-rhyolite derived from the Carrizo Mountain group to the south. The Van Horn is a continental, post-orogenic deposit, which is tilted and locally faulted, but is not folded, thrust, or metamorphosed like the rocks beneath. Its age is uncertain; it is unlike any Cambrian deposits in the region and may have been laid down before the Cambrian, in late pre-Cambrian time.

On Beach Mountain, a part of the Sierra Diablo foothills, the Van Horn and older formations are overlain unconformably by a remnant of Ordovician rocks whose lowest unit, the Bliss (?) sandstone, was the first fossiliferous marine Paleozoic deposit laid down in the region. The Ordovician and other older Paleozoic systems have been extensively eroded from the pre-Cambrian area as a result of deformation in late Pennsylvanian time, so that in most places the next formation above the pre-Cambrian is the Hueco limestone, of early Permian (Wolfcamp) age. In part of the Sierra Diablo foothills even this was removed by erosion, so that Cretaceous rocks lie directly on the pre-Cambrian. Aside from unconsolidated bolson deposits of late Tertiary and Quaternary age, the only other rocks associated with the pre-Cambrian are lavas and small intrusives, probably of early Tertiary age.

The pre-Cambrian and associated rocks are broken in all exposures by normal faults of late Tertiary or later age. In the southern areas of outcrop these are of unsystematic trend, but in the Sierra Diablo foothills most of them trend west-northwest, as do the principal joints of the same area. A considerable body of evidence suggests that the west-northwest faults and joints of the Sierra Diablo foothills originated early in geologic time, perhaps as transcurrent faults during the closing stages of the post-Hazel, pre-Van Horn orogeny, and have undergone successive dislocations during later periods. In one area in the Sierra Diablo foothills the west-northwest structures are crossed by the Hazel fracture zone, a set of en echelon, mineralized fractures of nearly

east-west trend, whose age relation to the other structures is uncertain.

*Pump Station Hills.*—A brief description is included of an outlying area of pre-Cambrian rocks, near Hueco Pump Station in the center of the Diablo Plateau, 55 miles northwest of Van Horn. Here, rhyolites project in low hills and are apparently overlain unconformably by Permian and Cretaceous rocks, although exposures are too poor to establish the relations conclusively.

*General problems of pre-Cambrian rocks.*

—The pre-Cambrian rocks exposed in the Van Horn area are a fragment of the fundamental architecture elsewhere mostly concealed from view, on which the more familiar geologic formations of the southwestern United States were laid. The rocks and structures of the pre-Cambrian of the Van Horn area have many of the characters of a mobile border of a cratonic area, or stable region, but the outlines of the stable region and the mobile belt which bordered it cannot be determined at this time and must await further research.

The pre-Cambrian rocks of the area have been subjected to several periods of metamorphism, with later metamorphic minerals and structures superimposed on the earlier. The rocks of the Carrizo Mountain group have been altered by progressive regional metamorphism which increases southward from low to medium grade. In the northern exposures, however, the rocks were later subjected to retrogressive metamorphism, perhaps related to development of the Streeruwitz overthrust. Intrusion of igneous rocks, now metarhyolite and amphibolite, took place immediately before and during the time of retrogressive metamorphism. Foliation resulting from the regional metamorphism is generally parallel to the original stratification of the rocks. In some of the rocks to the north this foliation is deformed by later, or  $S_3$ , metamorphic structures, which are probably about contemporaneous with the retrogressive metamorphism. Also contemporaneous was a cataclastic alteration of the metarhyolite intrusives, which produced pronounced foliation and lineation, the latter parallel to the  $a$  fabric axis, or direction of transport. Alteration of the Allamoore and Hazel formations appears

to have been a simple progressive metamorphism during a single cycle, apparently contemporaneous with the deformation of the rocks. It dies out northward and the rocks to the north are not altered.

Metamorphic rocks of medium rank, or amphibolite facies, are best developed in the Mica Mine area, where several varieties of equilibrium assemblages are present, which may be grouped mineralogically into a quartzite-muscovite schist sequence and a biotite schist-amphibolite sequence.

Several varieties of amphibolites are present in the Carrizo Mountain group. Those to the northwest are altered from original sill-like dioritic intrusives, but those to the southeast are of more obscure origin and may either have originated from igneous rocks or have been altered from impure carbonate sediments.

*Economic geology.*—The most important mineral resource of the pre-Cambrian rocks of the Van Horn area is its copper and silver deposits, which occur as veins containing metallic sulfide minerals. These have been prospected at many places and have been worked at seven mines, of which the most prolific is the Hazel, which has been worked intermittently since the 1880's. Total production of the district is difficult to ascertain, because of imperfection of earlier records, but it may have produced approximately 130,000 tons of ore, containing 2,600,000 pounds of copper and 4,000,000 ounces of silver. Ores of the district are of relatively low grade, mostly containing  $2\frac{1}{2}$  to 3 percent of copper, but rich pockets have been found.

Ores of the district occur in four principal associations: (1) The Hazel type of deposit, in vertical mineralized fractures such as the Hazel fracture zone, in red sandstones of the Hazel formation. (2) The Blackshaft type of deposit, in a steeply to gently dipping thin bed of crushed and sheared Allamoore formation enclosed in the Hazel formation. (3) Small, poorly productive veins in the Allamoore formation and Carrizo Mountain group. (4) A single deposit (at the Dallas prospect) on a fault of post-Van Horn and pre-Bliss (?) age. Fractures containing the mineral deposits are of diverse ages and origins, but mineralization itself is probably of Tertiary age.

Estimate of reserves of the district is difficult to make as the deposits are so erratic that they cannot be predicted or projected for any distance. One estimate provides 2,100 tons of indicated ore and 18,500 tons of inferred ore, with an average grade of  $2\frac{1}{2}$  percent copper. Various areas deserve further prospecting, especially near such proved deposits as the Hazel and Blackshaft mines. Wider ranging exploration of all the fractures of Hazel type might also be desirable, because of the possibility that they may contain deposits at workable depths which do not reach the surface.

Rocks of the Carrizo Mountain group in the Mica Mine area south of Van Horn contain 80 bodies of mica- and feldspar-bearing pegmatite more than a foot in diameter. Attempts have been made to pro-

duce various grades of mica from the deposits, but they are not now being worked. The deposits probably have no future as a source of mica as a primary product, although it could be produced as a by-product in the mining of feldspar, which has greater possibilities.

Crushed stone from metarhyolite of the Carrizo Mountain group has been produced since 1926 from one quarry and crushing plant and is used as ballast on the line of the Texas and Pacific Railroad. Minor deposits of nitrate and turquoise occur in the pre-Cambrian rocks but are not now being worked and have no possibilities for commercial development. One carload of talc has been produced from a new prospect northwest of Eagle Flat and is being tested to determine its commercial possibilities.

## INTRODUCTION

Philip B. King and Peter T. Flawn

### GEOLOGIC SETTING

This publication describes the geology of pre-Cambrian rocks in their area of largest exposure in Trans-Pecos Texas, that in the vicinity of the town of Van Horn (fig. 1). This district has sometimes been referred to as the "Van Horn dome," but it is domical only in the sense that it has tended to be positive through much of geologic time since the pre-Cambrian. Here, Paleozoic and younger deposits either were laid down on the pre-Cambrian to less thickness than in surrounding areas, or if laid down, were partly or wholly eroded

before the next body of sediments was deposited over them. Actually, pre-Cambrian rocks exposed within a 20-mile radius of Van Horn come to the surface in a number of adjacent but disconnected mountain uplifts—the Sierra Diablo, and the Carrizo, Wylie, Eagle, and Van Horn Mountains.

To the citizen, the pre-Cambrian rocks of the Van Horn area are of more than ordinary interest, as they contain a variety of useful mineral deposits. Their copper- and silver-bearing veins have yielded the largest amounts of copper produced in the

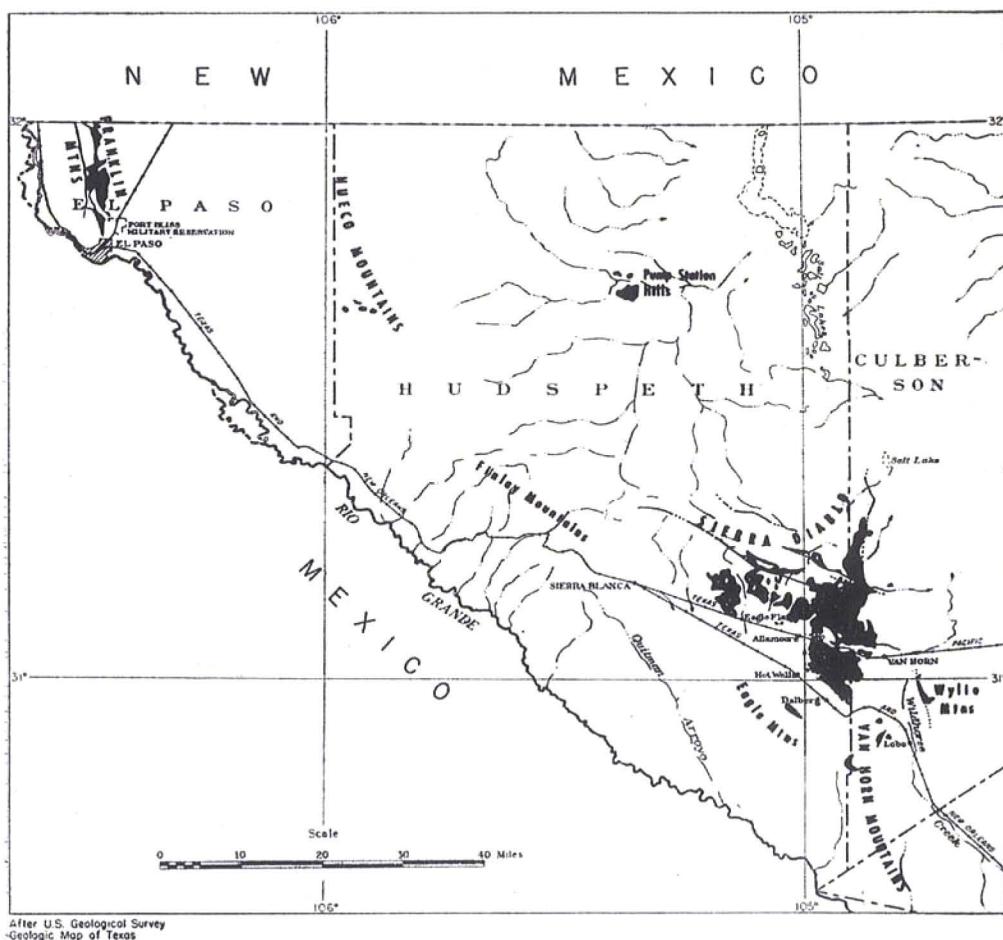


FIG. 1. Index map of part of Trans-Pecos Texas, showing outcrops of pre-Cambrian rocks.

State, and their mica- and feldspar-bearing pegmatites have long been famous. To the geologist, the pre-Cambrian rocks of the Van Horn area are also of interest in affording a glimpse of the fundamental architecture on which the more familiar geologic formations of Texas were laid, and in providing a fragment of those chapters of geologic history before Cambrian time that are otherwise lost to view. The pre-Cambrian rocks of the Van Horn area, unlike those of many areas, are not a monotonous expanse of metamorphic and plutonic rocks but include considerable bodies of partly altered sedimentary rocks whose depositional record, unconformities, and structural features can be worked out by familiar geologic methods.

Elsewhere in Trans-Pecos Texas, outcrops of pre-Cambrian rocks are smaller and more widely scattered (fig. 1). Northwest of Van Horn they emerge in a small area at Hueco Pump Station near the center of the Diablo Plateau (pp. 123-124) and in another area in the foothills at the south end of the Hueco Mountains; farther west they are boldly exposed on the east face of the Franklin Mountains north of El Paso. East and southeast of Van Horn, pre-Cambrian rocks do not come to the surface but are deeply buried beneath great piles of younger rocks. In the west Texas Permian basin and Marathon geosyncline they are covered by Paleozoic sediments, in the Big Bend country and elsewhere by Cretaceous sediments, and in the Davis Mountains by Tertiary volcanics.

#### PREVIOUS WORK

Pre-Cambrian rocks of the Van Horn area were first studied by Von Streeruwitz during the course of his work in Trans-Pecos Texas for the Dumble Survey, and preliminary results were described in various annual reports of that Survey (1890, 1891, 1892, 1893). Rocks collected by Von Streeruwitz and his associates were described by Osann (1893), and further notes on the geology of the pre-Cambrian area were contributed by Dumble (1902) after the termination of the Survey.

Pre-Cambrian rocks of the northern part of the Van Horn area were observed by Richardson during his reconnaissance of Trans-Pecos north of the Texas and Pacific

Railroad (1904), and were subsequently mapped by him in greater detail for the Van Horn folio (1914). Reconnaissance mapping of the southern and remaining part of the Van Horn area was completed by Baker (1927) in the course of his survey of southwestern Trans-Pecos Texas.

Besides the general accounts of pre-Cambrian rocks of the area, brief reports have appeared on their mineral deposits. Pegmatites of the Van Horn Mountains were described by Sterrett (1923, pp. 303-307), Redfield (1946, pp. 29-30), and Flawn (1951b); copper and silver deposits of the Allamoore-Van Horn district were described by Evans (1943) and Sample and Gould (1945); nitrate deposits near Van Horn were described by Mansfield and Boardman (1932, pp. 66-68).

#### PRESENT WORK

This report is a product of the U. S. Geological Survey, represented by Philip B. King, and of the Bureau of Economic Geology, represented by Peter T. Flawn. In 1949, Flawn was directed by Dr. John T. Lonsdale, State Geologist, to undertake a study of pre-Cambrian rocks of western Texas. Mapping was begun in the southern part of the Van Horn pre-Cambrian area, and plans were made not only to complete the mapping of the Van Horn area but also to study outlying exposures of pre-Cambrian rocks such as those in the Franklin Mountains and to investigate pre-Cambrian rocks encountered in wells drilled in western Texas. Work on the Van Horn area has now been completed, and work on pre-Cambrian rocks encountered in wells is in progress, but study of the Franklin Mountains has been postponed on account of extensive military activity in that area.

Previously, between 1931 and 1939, King had completed mapping of the northern part of the Van Horn pre-Cambrian area as part of a study of the Sierra Diablo region for the U. S. Geological Survey. Preliminary results of this work have been published (King, 1940; King and Knight, 1944), but preparation of a final report was delayed as a result of diversion to other work during World War II. Such a report would, however, have lacked decision on a number of questions of geologic

interpretation because detailed petrographic work had not been done. Such petrographic work was carried out during Flawn's investigation.

As the two investigations are mutually supplementary parts of a whole record of the pre-Cambrian geology of the Van Horn area, it is desirable to present them in a single publication. The present publication has therefore been prepared jointly by the two authors, responsibility for the different parts being indicated in the section headings. The two authors have collaborated on the introduction and on the section on economic geology, and each author has contributed other sections on areas with which he is most familiar. Even in those sections for which a single author is responsible, he has greatly benefited from exchange of ideas with the other author, in field conferences, in critical reviews of each other's writings, and in correspondence.

Part of the information contributed to this publication by Flawn is taken from a dissertation submitted to Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Part of this dissertation has been published elsewhere (Flawn, 1950, 1951b).

The pre-Cambrian rocks of the southern part of the Van Horn area were mapped by Flawn on a scale of 1,000 feet to the inch, using for field sheets enlargements of the U. S. Geological Survey's air photographs of the region. The pegmatite-bearing pre-Cambrian rocks in the northwest Van Horn Mountains were mapped in further detail on a scale of 200 feet to the inch by means of plane table and telescopic alidade. A suite of 200 thin sections of the metamorphic and igneous rocks was studied under the microscope.

Field methods employed by King in mapping the northern part of the Van Horn area are described in the chapter on the Sierra Diablo foothills.

#### ACKNOWLEDGMENTS

During the survey of the northern part of the Van Horn area, King was ably assisted by Mr. J. Brookes Knight, who in 1931, 1936, and 1938 made detailed studies of the stratigraphy and paleontology of the Ordovician, Permian, and Cretaceous

rocks. Although these studies do not relate directly to the subject of the present report, part of them are summarized briefly herein. In 1938, King accompanied Mr. S. J. Lasky of the Minerals Branch of the U. S. Geological Survey on an inspection of the mines and prospects of the district, and received valuable suggestions and judgments on both mineral deposits and adjacent rock formations. In the same year King also reviewed the rocks of the Carrizo Mountain group in the Sierra Diablo foothills in company with Mr. Earl Ingerson, at that time with the Carnegie Geophysical Laboratory, and was aided by him in their structural interpretation. Thin sections of some of the rocks collected in the area have been studied by Mr. C. S. Ross, and other determinations have been made by Messrs. K. J. Murata and Charles Milton, all of the Geochemistry and Petrology Branch of the U. S. Geological Survey.

During the survey of the southern part of the Van Horn area, between 1949 and 1951, Flawn was assisted in the field by Messrs. W. E. Tipton, M. E. Dehlinger, D. L. Taylor, T. M. Anderson, and S. M. Awalt. Preparation of his report has been greatly aided by criticism and advice by Dr. John T. Lonsdale and Dr. V. E. Barnes of the Bureau of Economic Geology and Professor Adolph Knopf of Yale University.

Two independent investigations of the mineral deposits of the area have been made, one by Glen L. Evans for the Bureau of Economic Geology in 1943, and the other by R. D. Sample and E. E. Gould for the U. S. Geological Survey in 1944. Partial results of the first have been published in a brief report (Evans, 1943), and the results of the second have been released as an open-file report (Sample and Gould, 1945). Mr. Evans has kindly contributed a considerable body of unpublished information resulting from his investigation for use in the present report, and the U. S. Geological Survey has permitted maps and other data contained in the open-file report to be copied in this one.

Much information concerning the mineral deposits has been obtained by King and Flawn from local residents engaged in prospecting and mining, including Messrs. A. P. Williams, Brent Melton, and Tom

Suttlemeier. Both authors also wish to acknowledge the hospitality of numerous landowners in the area, who were unfailingly courteous in permitting surveys to be made of their properties.

Geologic drafting of the maps, diagrams, and figures accompanying this publication was competently executed by Mr. James W. Macon and Mrs. Ann Connor of the cartographic staff of the Bureau of Economic Geology and Mr. Robert L. Traver of the Office of Geologic Cartography, U. S. Geological Survey.

### GEOMORPHOLOGY

The Van Horn area is part of the southwestern arid region, with scanty rainfall, short mild winters, and relatively high temperatures during most of the year. Meteorological data are available for Van Horn since 1939, and the total annual precipitation during the succeeding ten-year period is as follows:<sup>3</sup>

1939	12.48
1940	5.83
1941	27.27
1942	8.85
1943	8.67
1944	11.40
1945	9.10
1946	10.35
1947	7.09
1948	4.98

Yearly rainfall during the period has thus varied from less than 5 inches to more than 27 inches, which is probably typical of much of the lower country in the vicinity. Somewhat greater precipitation in the higher Sierra Diablo and Eagle Mountains to the northwest and southwest is attested by greater density of plant cover in those areas.

As elsewhere in the arid region, continuous sod cover is lacking in the Van Horn area, and soils are thin, poor, and calcareous (Carter and others, 1928, pp. 7-11, 25-48). Limestones project in bold outcrops, non-calcareous rocks weather largely by granular disintegration, and there are wide areas of interior drainage. Mountains and ridges project with harsh outlines, resistant rocks are carved into mesas and mural escarpments where flat-lying and

into jagged hogbacks where tilted. Streams, although intermittent, have scored the mountains with steep-walled canyons and have built alluvial fans along the mountain bases. Much of the runoff from sudden rains is unchanneled and spreads as broad sheetfloods on the plains.

Drainage of the area of pre-Cambrian rocks near Van Horn is dominated by the Salt Basin, a long intermontane depression without outlet to the sea, whose lowest part is north of Van Horn (fig. 2; King, 1948a, Pl. 23). Drainage on the east faces of the Sierra Diablo, Carrizo, and Van Horn Mountains, and the west face of the Wylie Mountains, leads directly into the basin. Drainage of parts of the Sierra Diablo, Carrizo, Van Horn, and Eagle Mountains farther west gathers into Eagle Flat, another intermontane depression, the eastern part of which slopes into the Salt Basin through a gap which is followed by the line of the Southern Pacific Railroad. The western part of Eagle Flat is an independent drainage basin whose lowest part is at Grayton Lake, 25 miles west of Van Horn.

Salt Basin and Eagle Flat are of tectonic origin. They are down-faulted segments of the crust that have been deeply filled by Tertiary and Quaternary unconsolidated deposits, washed in from the adjacent mountains. In the Salt Basin, the municipal and Texas and Pacific Railroad water wells at Van Horn have been sunk 600 feet in these deposits, and the Southern Pacific Railroad well at Lobo farther south has been carried to 1,300 feet. In Eagle Flat, the Southern Pacific Railroad well at Hot Wells is more than 1,000 feet deep and obtains from the unconsolidated deposits water which has a temperature of 90° to 100° Fahrenheit.

As the Salt Basin is an area of interior drainage, streams which drain into it are adjusted to a slowly rising base level, and along the edges of the mountains they have built up broad bajada surfaces which slope gently away from the mountains. Erosional forces seem to have been refreshed from time to time by renewed down-faulting of the central and deeper part of the basin. On the east face of the Sierra Diablo 15 to 30 miles north of Van Horn, opposite this deeper part, steep allu-

<sup>3</sup> U. S. Weather Bureau, Climatological data, Texas section: vols. 44-53, 1939-1948.

vial fans are being built into the Salt Basin along the bases of fresh fault scarps. On the northeast foot of the Eagle Mountains, similar fans have been built into Eagle Flat, apparently over earlier bajada surfaces, and may mark a similar tectonic renewal of that area. In general, however, erosional and depositional processes are less active in Eagle Flat than in the Salt Basin, partly perhaps because of greater tectonic stability in the recent past, and partly because of the circuitous drainage

connection between this area and the main basin.

The relatively stable interior drainage system of Salt Basin and Eagle Flat is being vigorously attacked by drainage leading into the lower-lying exterior drainage system of the Rio Grande. Glenn Creek (also called Green Creek), which drains south to the Rio Grande between the Van Horn and Eagle Mountains (fig. 2) has intricately dissected the earlier basin fill into myriad spurs and intervening valleys.

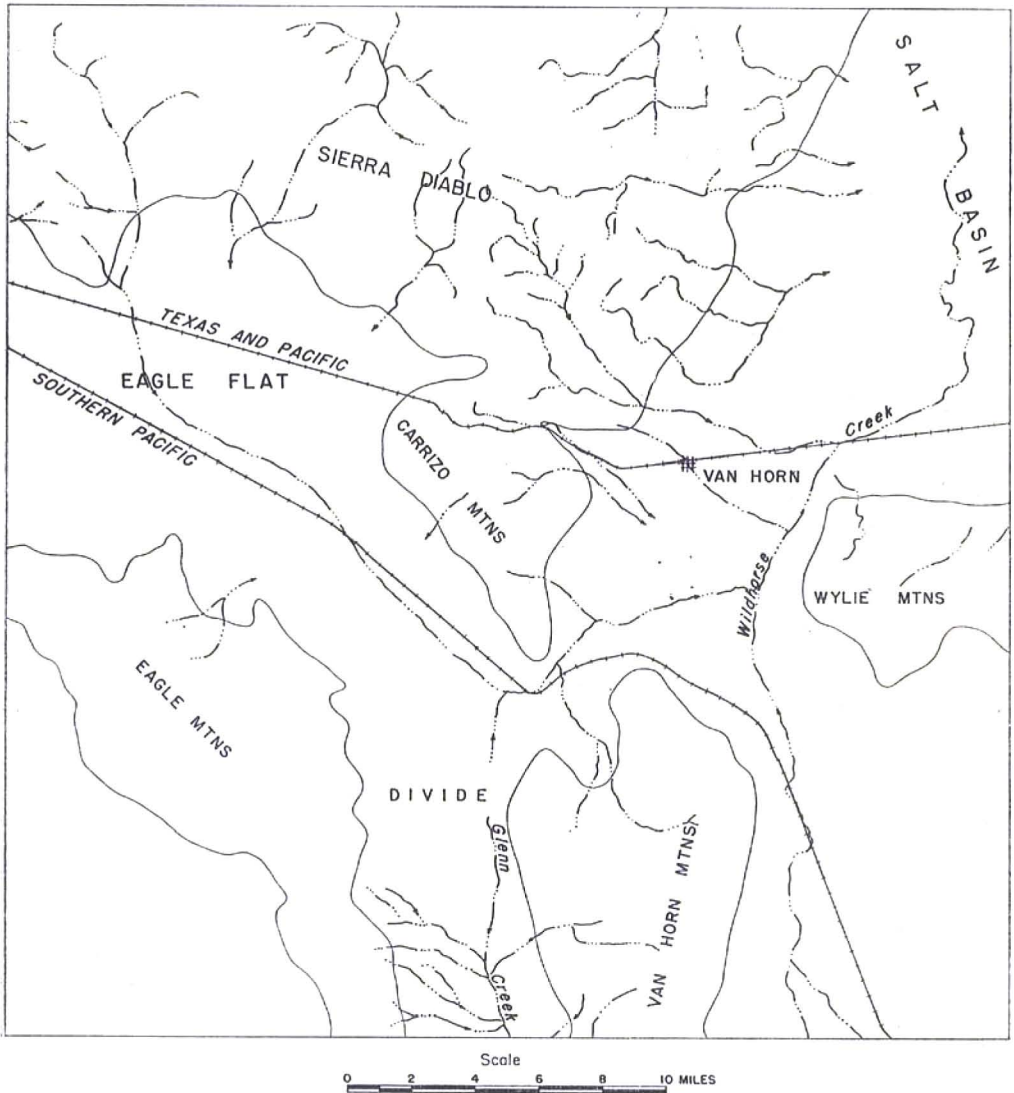


FIG. 2. Map of Van Horn area, showing drainage and outlines of the mountain areas (after U. S. Geological Survey topographic quadrangle maps).



The head of the Glenn Creek drainage is on a low divide between the two ranges about a mile northwest of the Mica Mine pre-Cambrian area of the northwest Van Horn Mountains.

The pre-Cambrian rocks of the Carrizo, Eagle, Wylie, and Van Horn Mountains have been carved into contrasting forms according to their resistance to erosion. Hard rocks, such as quartzite, pegmatite, and rhyolite, project in ridges and hogbacks, and less resistant rocks, such as mica schists, phyllites, and slates, have been worn down to valleys. The topography may, in part at least, be resurrected from that on which the Hueco limestone (Permian) was laid down, because in parts of the Wylie and Van Horn Mountains valleys filled with soft basal Hueco sediments are now being re-excavated. Drainage in the extensive area of pre-Cambrian exposure of the Carrizo Mountains flows between parallel ridges of hard rocks in a trellis pattern. In the smaller exposures of pre-Cambrian rocks elsewhere, much of the drainage probably originated as consequent streams on scarp faces of the mountain blocks and developed by headward extension; part has been superimposed through a former cover of Hueco on to the pre-Cambrian beneath.

The area of pre-Cambrian rocks in the Sierra Diablo foothills is crossed by drainage which leads down from the heights of the Sierra Diablo on the north into Eagle Flat on the south and Salt Basin on the east. Drainage leading into Eagle Flat across the foothills has been maintained under conditions of prolonged still-stand and has carved broad rock-cut plains, or pediments, now for the most part thinly mantled by alluvial deposits. Much of the pediment area is underlain by red sandstones of the Hazel formation, which to the north also form the lower slopes of the Sierra Diablo escarpment, beneath the surmounting cliffs of Hueco limestone. Projecting above the pediment some miles south of the Sierra Diablo escarpment are rocky hills several hundred feet high, the Streeruwitz, Bean, and Millican Hills, that are carved from more resistant conglomerates of the Hazel formation and from limestones and volcanics of the Allamoore formation. In places on the summits of

these hills are traces of accordant levels which may mark earlier pediment surfaces (fig. 6, B).

In the eastern part of the foothill area, Sulphur and Hackberry Creeks, and other streams draining into the Salt Basin, are dissecting the same pediment surface as that on which Eagle Flat drainage is now flowing. Here, red sandstones of the Hazel formation are scored to depths of a hundred feet or more by an intricate network of valleys and ravines. The crests of many of the intervening ridges are capped by gravel deposits (older gravel deposits, Qg, of Pl. 2), which are remnants of a once-continuous, gently sloping, alluvial cover of a pediment that is now nearly destroyed by erosion. Westward, the alluvium of the valley bottoms below rises and merges with the gravel cap above, so that the two sets of deposits cannot be differentiated in the Eagle Flat drainage area. The more vigorous dissection by Salt Basin drainage, as compared with Eagle Flat drainage, may have resulted from renewed downfaulting of the Salt Basin area after the pediments were cut.

#### SUMMARY OF PRE-CAMBRIAN ROCKS

Pre-Cambrian rocks are exposed in six general areas in the vicinity of Van Horn (figs. 1, 3). The largest is in the Sierra Diablo foothills, extending northward along the east side of the Sierra Diablo nearly to Victorio Peak, and westward along the south side beyond Eagle Flat section house (Pls. 2 and 3). Near the line of the Texas and Pacific Railroad this pre-Cambrian area is separated by a graben of Paleozoic and Cretaceous rocks from another in the Carrizo Mountains (Pl. 1). Farther south, pre-Cambrian rocks emerge in smaller areas in other mountain uplifts—on the northeast side of the Eagle Mountains (Pl. 7), on the west side of the Wylie Mountains (Pl. 6), and in two areas in the Van Horn Mountains (Pls. 4, 5).

The most highly metamorphosed and perhaps the oldest pre-Cambrian rocks lie to the south, in the Carrizo, Eagle, Wylie, and Van Horn Mountains, and constitute the Carrizo Mountain group. This is a body of altered sedimentary rocks, including meta-arkose, metaquartzite, schist, phyllite,

slate, and limestone, which has been intruded by large volumes of igneous rocks, now metarhyolite and amphibolite. Extensive exposures of the group in the Carrizo Mountains show a sequence of sedimentary rocks as much as 19,000 feet thick, which does not appear to have been repeated by folding or faulting. The group shows much homogeneity in original character from place to place, suggesting that

it is a single sedimentary series rather than several, but it shows considerable variation in degree of metamorphism. Rocks farthest south, in the Van Horn Mountains, are the most metamorphosed (medium metamorphic grade, or amphibolite facies), retain few of their original sedimentary structures, and are extensively veined by pegmatite. Rocks farther north, in the Carrizo and Eagle Mountains, are less meta-

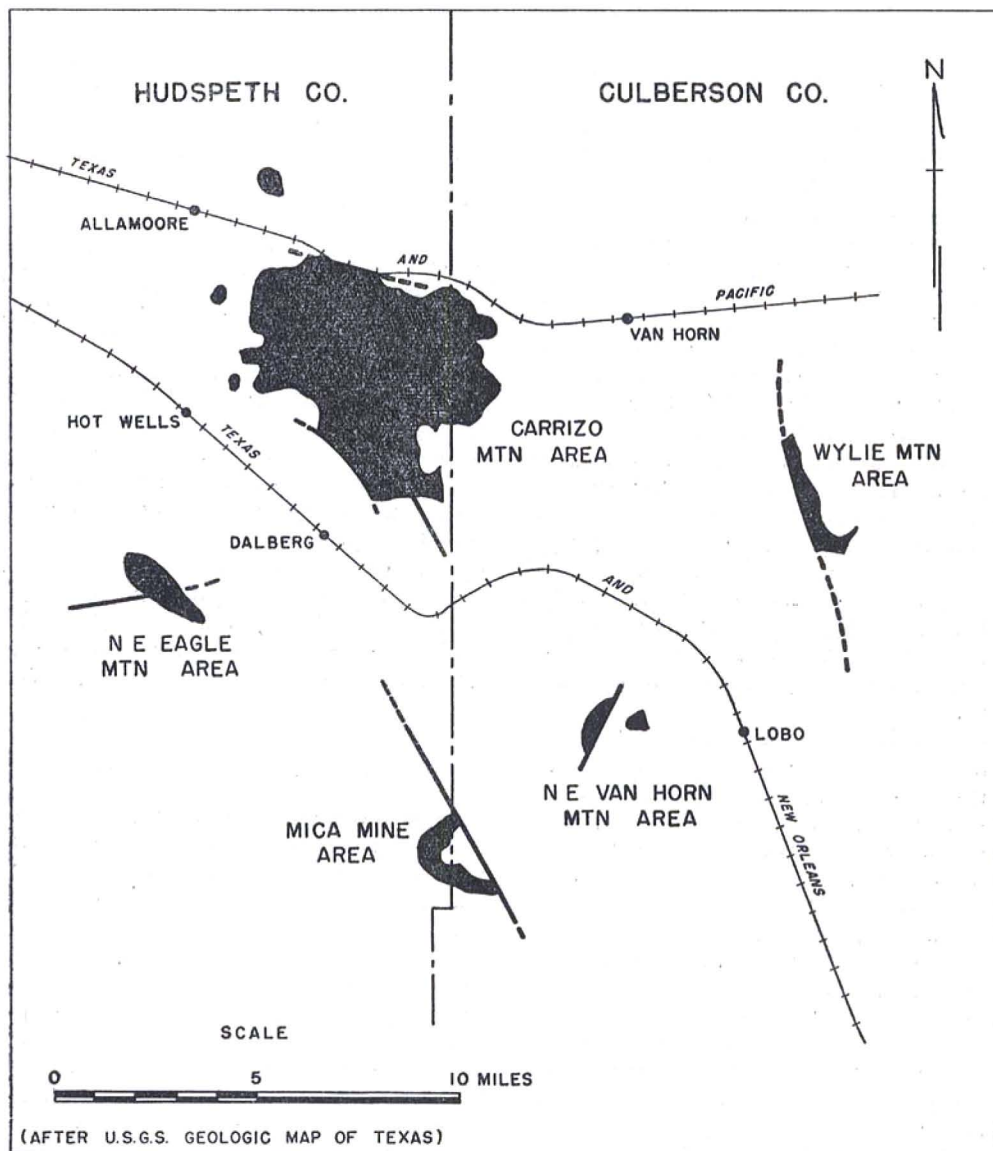


FIG. 3. Map of Van Horn area, showing outcrops of Carrizo Mountain group.

morphosed (low metamorphic grade, or greenschist facies) and preserve many of their original sedimentary structures. Their metamorphic history is complex, however, as a retrogressive cataclastic metamorphism is superimposed on an earlier progressive metamorphism. The associated intrusive metarhyolites are also cataclastically altered and in part mylonitized. The cataclastic metamorphism was perhaps produced by the same forces as brought about the Streeruwitz overthrust, immediately beyond.

The Streeruwitz overthrust, whose trace lies in the Sierra Diablo foothills a little north of the line of the Texas and Pacific Railroad, is a line of major discontinuity in the pre-Cambrian rocks. Along it, the dominantly metamorphic and igneous rocks of the Carrizo Mountain group have been thrust northward over the dominantly sedimentary Allamoore and Hazel formations. The original stratigraphic relations of the rocks of the two sides are unknown, but presumably those on the north are younger, and they might be much younger.

The Allamoore formation, the oldest unit north of the overthrust, consists of interbedded cherty limestones, phyllites, and volcanic rocks, the latter including pyroclastics, flows, and perhaps shallow intrusives. Some of the limestones contain structures that may be of algal origin. Because of the complex structure, the thickness of the Allamoore cannot be determined, but it is certainly thousands of feet thick.

The Allamoore is succeeded by a very different, but comparably thick, deposit, the Hazel formation, whose basal part is a thick, coarse conglomerate, made up almost entirely of angular rock fragments derived from the Allamoore formation. The two formations are obviously unconformable and were probably separated by a time of orogeny which may still have been in progress when the earlier Hazel deposits were being laid down. The conglomerates are interbedded with, and are succeeded by, a thick, uniform mass of fine-grained, silty red sandstone which constitutes the upper part of the Hazel formation.

After deposition of the Hazel formation, both it and the Allamoore were deformed

together during a time of orogeny that was probably related to emplacement of the Carrizo Mountain group on the Streeruwitz overthrust. For some miles north of the trace of the overthrust both formations are thrown into recumbent folds and thrust sheets that were driven northward. Deformation dies out in this direction, and in the northernmost exposures the rocks are little disturbed.

The deeply eroded edges of the deformed and partly metamorphosed Hazel and Allamoore formations and Carrizo Mountain group are overlain unconformably by another and coarser red clastic deposit, the Van Horn sandstone, whose maximum thickness is about 800 feet. The Van Horn contains numerous rounded cobbles and boulders, made up not only of rocks from formations immediately beneath but also of red granite and rhyolite porphyry, probably derived from the north, and of meta-rhyolite derived from the Carrizo Mountain group to the south. The Van Horn is a continental, post-orogenic deposit, which is tilted and locally faulted but not folded. thrust, or metamorphosed like the rocks beneath. Its age is uncertain; it is unlike any Cambrian deposits and may have been laid down before the Cambrian, in late pre-Cambrian time.

The tilted and faulted Van Horn is truncated and overlain unconformably by the Bliss (?) sandstone, of early Ordovician age, the first fossiliferous marine Paleozoic deposit laid down in the Van Horn area.

#### STRATIGRAPHIC NOMENCLATURE

The stratigraphic names used for the pre-Cambrian rocks of the Van Horn area have undergone progressive modification from the time of their first study by Von Streeruwitz, as illustrated in Table 1.

The name "Carrizo schist" was first used by Von Streeruwitz (1891) for the metamorphic rocks of the Van Horn area, because of their typical occurrence in the Carrizo Mountains; the same rocks were called the "Carrizo formation" by Richardson (1914). Unfortunately, the name Carrizo has also been used for the well-known Carrizo sand of the Eocene series in the Texas Coastal Plain, and in 1933 Sellards

Table 1. Development of stratigraphic nomenclature of pre-Cambrian rocks of Van Horn area.

Von Streeruwitz, 1891	Dumble, 1902	Richardson, 1914		Sellards, 1933		Geologic map of Texas, 1937		King, 1940		This report, 1952	
Carboniferous	Silurian	El Paso limestone	Ordovician	El Paso limestone	Ordovician	El Paso limestone	Ordovician	El Paso limestone	Ordovician	El Paso limestone	Ordovician
Diablo sandstone (Devonian ?)	Potsdam sandstone (Cambrian)	Van Horn sandstone	Upper Cambrian (?)	Van Horn sandstone	Cambrian	Van Horn sandstone	Cambrian	Bliss sandstone		Bliss (?) sandstone	
	Hazel sandstone							Van Horn sandstone	Cambrian or pre-Cambrian	Van Horn sandstone	pre-Cambrian (?)
(not classified)	Texan marble (placed above Hazel sandstone)	Millican formation	Algonkian	Millican formation	pre-Cambrian	Millican formation	pre-Cambrian	Hazel sandstone		Hazel formation	
								Allamoore limestone	pre-Cambrian	Allamoore formation	pre-Cambrian
Carrizo schist	(not discussed)	Carrizo formation		Carrizo Mountain formation		Carrizo Mountain schist		Carrizo Mountain schist		Carrizo Mountain group	

(1933, p. 38), with the concurrence of the U. S. Geological Survey, changed the name of the unit in the Van Horn area to "Carrizo Mountain formation." On the geologic map of Texas (Darton, Stephenson, and Gardner, 1937) and in subsequent publications (King, 1940; King and Knight, 1944) the unit was termed "Carrizo Mountain schist"—the term schist being applied not in a strict petrographic sense but to denote a body of foliated metamorphic rocks whose subdivisions had not been worked out.

Flawn's detailed work on the Carrizo Mountain demonstrates that it is a body of metamorphic rocks of great thickness, which in individual areas can be subdivided into a considerable variety of rock types, most of which are mappable as separate entities. Many of these entities are well-defined sedimentary units a thousand feet or more in thickness, which would be formations in their own right in a sequence less disturbed and more widely exposed. It seems inadvisable to apply formal stratigraphic names to these subdivisions, because of the paucity of available geographic names, the limited area of exposure, and the impossibility of correlating units in one area of outcrop with those of another. The sedimentary rocks of the Carrizo Mountain in all exposures were originally feldspathic and arkosic sands and interbedded argillaceous sediments. They may, therefore, have been a single sedimentary series. Nevertheless, in view of the disconnected nature of the exposures and the considerable variation in degree of metamorphism from place to place, the possibility has not been eliminated that the unit is heterogeneous and comprises more than one series of rocks.

Flawn's work indicates the inadvisability of continuing further use of either "schist" or "formation" as a designation for the Carrizo Mountain. The term schist, however useful in general reconnaissance mapping, is not applicable to detailed mapping, where many lithologic types of other than true schists must be differentiated. A formation is, of course, merely a unit of mapping (Ashley and others, 1933, pp. 430-431) and as such may include both small and large bodies of rock; in practice, however, it is generally used for relatively small, narrowly defined rock units.

The Carrizo Mountain has more the nature of a "terrane" as this term was used in some geologic reports of half a century ago, but this term has passed out of favor. It also has some of the characters of a "complex," which is a "large mass \* \* \* \* composed of diverse rocks of any class or classes, \* \* \* \* characterized by highly complicated structure" (Ashley and others, 1933, p. 445), but to most geologists the word "complex" connotes a greater degree of metamorphism, plutonism, and indecipherability than possessed by the Carrizo Mountain. If the Carrizo Mountain could be divided into named formations that could be matched from one area of exposure to another, it would correspond to the formal definition of a "group" (Ashley and others, 1933, p. 429). Informally, "the term group may be applied in reconnaissance work, particularly in Alaska, to assemblages of rocks that have some stratigraphic unity but that have not yet been subdivided. It is to be expected that in later work, such groups will be divided into named formations" (Ashley and others, 1933, p. 438). Similar informal use of the term "group" for metamorphic and partly metamorphic units appears in many of the reports of the Canadian Geological Survey. The case of the Carrizo Mountain resembles these in some particulars but differs in that the unit has been mapped in detail and has been subdivided into unnamed and uncorrelated units in local areas of exposure.

The U. S. Geological Survey, through its Committee on Geologic Names, prefers to class the unit as the "Carrizo Mountain formation" for the following reasons:<sup>4</sup>

The code of rules used by the Survey states that a group is composed of two or more formations. This means that each formation of the group has been formally proposed with a statement of the geographic feature from which its name came, a type locality, description of its boundaries, and lithology, and an interpretation of the age and correlation. Descriptions of the Carrizo Mountain indicates that it contains several lithologic units to which no names have been applied. Because it is not intended to formalize these units at this time, it is recommended that the Carrizo Mountain be treated as a formation. In the future, if the units of the Carrizo Mountain are formalized, the Carrizo Mountain can be raised to the rank of a group.

<sup>4</sup> Memorandum from J. B. Reeside, Jr., Chairman, February 18, 1952.

The Texas Bureau of Economic Geology believes, on the other hand, that the case of the Carrizo Mountain is sufficiently ambiguous to warrant special treatment. The unit does not correspond with other "formations" as these are commonly differentiated in Texas, and although it is impracticable to subdivide it into named divisions, it deserves informal designation as a "group" in much the same manner as the metamorphic units in Alaska and Canada. The Carrizo Mountain is therefore treated as the "Carrizo Mountain group" in the present report, although without prejudice as to whatever usage may be adopted in subsequent reports of the U. S. Geological Survey.

The present Allamoore and Hazel formations were studied in reconnaissance only by Von Streeruwitz, and no complete interpretations of them were offered. The limestones of the Allamoore formation were noted in so few places that it was not realized that they constituted a distinct stratigraphic unit; they were thought to represent "Carboniferous" limestone tilted up in zones of unusual disturbance. The red sandstones of the Hazel formation were included in his †Diabolo sandstone<sup>5</sup> (Von Streeruwitz, 1891, pp. 682-683), which he supposed might be of Devonian age, possibly from analogy with the Old Red sandstone of Europe. From descriptions of Von Streeruwitz it is evident, however, that he also included in the †Diabolo the Van Horn sandstone and thick red phases of the Powwow member of the Hueco limestone, so that the name has no value in precise work.

Dumble (1902) subsequently recognized the lithologic, stratigraphic, and structural differences between the red sandstones of the Hazel and Van Horn and applied the name Hazel sandstone to the former. Richardson, in the limited time available for mapping the Van Horn folio, was unable to separate Dumble's Hazel sandstone from the conglomerate, limestone, and other rocks with which it was associated and accordingly grouped all the pre-Cambrian rocks of the Sierra Diablo foothills as the †Millican formation (1914, p. 3).

Subsequently, King (1940, pp. 147-148) demonstrated that the †Millican was divisible into two well-marked stratigraphic units, separated by a major unconformity, and it was recommended that the name †Millican be abandoned as a stratigraphic term.

It could not be restricted to a part of the former unit without greatly changing its original meaning. It could be retained as a group term for the two formations, but the writer believes that this is undesirable, since the sediments in the two formations are so distinct in their nature, and since the unconformity between them indicates that they were formed during unrelated times of deposition.

For the lower of the two units the new name Allamoore limestone was proposed, for the village of Allamoore. "The village itself stands on alluvium, but outcrops of the limestone rise in prominent hills a few miles north." Two spellings of the name were available—"Allamoore" for the post office and "Allamore" for the railroad station; the spelling given to the post office was adopted. While it is true that limestones constitute a prominent part of the Allamoore, nearly half of the unit is made up of volcanic rocks and phyllite, so that in the present report it seems desirable to alter its original title to Allamoore formation.

For the higher of the two subdivisions of the †Millican formation Dumble's term Hazel sandstone was revived. This was originally applied by Dumble only to the red sandstones which are a prominent part of the unit, but these are so indissolubly linked with conglomerate of almost equal volume, that the term was extended to include this also. In the present report it seems desirable to give greater recognition to the large component of conglomerate in the unit, and its designation is accordingly changed to Hazel formation.

The name Van Horn sandstone has not been changed since the term was first proposed by Richardson (1904, p. 23), but its definition and age designation have been emended. It was originally placed with some doubt in the Upper Cambrian, but King (1940, pp. 152-153) subsequently determined that the fossiliferous beds at the top were separated from the main body of the unit by a significant unconformity.

<sup>5</sup> A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey.

The upper fossiliferous beds were correlated with the Bliss sandstone of the Franklin Mountains, but the age of the main body of the formation beneath was left undecided as between Cambrian or pre-Cambrian. In the present report it seems desirable to express the stronger presumption that the unit is of pre-Cambrian age by classing it as "pre-Cambrian (?)". Further discussion of the definition and age of the Van Horn will be found in the section on the Sierra Diablo foothills.

#### PETROGRAPHIC NOMENCLATURE

In describing the metamorphic rocks of the Carrizo Mountain group, Flawn has indicated the approximate mineral composition of the rock in each thin section studied by means of tables of estimated modes. These are basic data for the rock units and are vulnerable only to the extent that variations may exist which are not represented in the specimens collected. If the terminology used herein should be different from that used by the reader, he can make adjustments to his own terminology by referring to the tables.

Although mineral compositions of the metamorphic rocks can be determined with relative ease it is much more difficult to arrive at names to be used for them, as there are considerable divergences between terminology used by different geologists. In order that names used in succeeding pages shall have precise meaning, it is desirable to indicate here the particular usage employed in this publication.

The common rock terms "schist" and "gneiss" have been very loosely applied. In the Van Horn area, the term "schist" has been used to imply merely the foliated and metamorphic nature of the rocks. In other areas, very coarsely layered metamorphic rocks similar to many in the Van Horn area have been called "gneiss" by some geologists (cf. Moneymaker, 1938, pp. 286-289), even though the layers of different mineral composition were obviously original sedimentary beds.

"Schist" and "gneiss" are here interpreted primarily as structural terms for different sorts of foliated metamorphic rocks. The fundamental structure, or foliation, comprises any class of mineral orientation, such as slaty cleavage, schistosity,

or gneissosity, but may be used in context as a synonym of each of them.<sup>6</sup> Schist is here applied to coarsely crystalline, strongly foliated, thinly fissile metamorphic rocks, and gneiss to more massive foliated rocks with augen and/or mineral banding of metamorphic origin. Professor Knopf (personal communication, 1952) has pointed out that in European literature the term schist has been further restricted to rocks with dominant quartz content. It so happens that most schists do contain a large quartz component, but there are rocks in which quartz is lacking that can appropriately be called schists by every other qualification.

The quartzo-feldspathic rocks which form great thicknesses of the Carrizo Mountain group in the Van Horn area cannot well be termed either schists or gneisses. Their foliation reflects parallel orientation of whatever mica is present, but they are massive or slabby rather than schistose, and they lack the augen and metamorphic banding characteristic of gneisses. It is, moreover, obvious that they are altered clastic sedimentary rocks, and recognition of their original nature is desirable. These rocks are therefore termed "meta-arkose" where the feldspar content exceeds 25 percent and "metaquartzite" where quartz is preponderant; intermediate types are termed "feldspathic metaquartzite." This usage follows definitions of unaltered sedimentary rocks recommended by the Committee on Sedimentation (Allen, 1936, p. 44), in which arkose is described as "a sandstone containing 25 or more percent of feldspar, usually derived from the disintegration of acid igneous rocks of granitoid texture." To metamorphosed quartzo-feldspathic rocks such alternative titles as "arkose gneiss" or "granulite" (Harker, 1939, p. 246) might be applied, but these expressions fail to convey either their origin, their composition, or both.

Ideally, the term "meta-arkose" should apply only to those rocks which were

<sup>6</sup> Adolph Knopf, personal communication, 1952. Slightly different usages have been employed by Turner (1948, p. 275) and Harker (1939, p. 203). According to Turner "synonymous use of foliation and schistosity to cover all those megascopically conspicuous parallel fabrics of metamorphic origin which impart a definite fissility to the rocks in which they occur, perhaps accords best with current terminology;" thus apparently not divorcing mineral orientation from fissility. Harker carefully distinguishes between schistosity (fissility or cleavage) and foliation (mineral orientation and segregation).

originally sedimentary arkoses, and whose reaction to metamorphism was simply recrystallization of original components. The possibility cannot be dismissed that at least some of the rocks termed meta-arkose in the area contain feldspar which was introduced during or formed by metamorphism; this possibility is so difficult of proof that in practice it must be ignored.

Schists described in this publication are differentiated qualitatively by prefixing one or more mineral adjectives to the noun, or rock name, the most important mineral qualifier being placed next to the noun. Thus, an albite-biotite-muscovite schist would contain a greater percentage of muscovite than biotite and a greater percentage of biotite than albite. Some writers place the qualifiers in opposite order, but as Knopf points out:<sup>7</sup>

Here one stands on an impregnable principle in English: The most important qualifier stands next to the thing qualified. In a mica-quartz schist quartz predominates over mica; mica-quartz schist is therefore an unnecessary term as it is synonymous with mica schist [on the principle that all schists are quartzose by definition]. In a quartz-mica schist, mica predominates over quartz.

Obviously all the minerals composing the rock cannot be prefixed to the rock name without making a useless and unwieldy term. Likewise following a rule that requires prefixing all minerals composing more than 5 percent of the rock to the rock name is too rigid a system to be generally applicable. The best solution is to use the important or diagnostic mineral qualifiers to supplement the noun, despite the accompanying introduction of the personal element. Thus, in this report a schist composed of 4 percent sericite, 4 percent biotite, 4 percent chlorite, and the remainder quartz is termed a sericite-biotite-chlorite schist; a schist composed of 4 percent chlorite, 15 percent sericite, and the remainder quartz is termed a sericite schist. In the writer's opinion the chlorite, although an important foliate mineral in the first example, is not necessary in identi-

fication of the second example, although, percentagewise, it is the same in both rocks. Some geologists might prefer to call the second example a chloritic sericite schist, but in this report minerals not necessary to characterize the rock are eliminated, and complete mineral composition can be found in the tables of modes.

Some authors (Billings, 1937, p. 491; Kruger, 1946, p. 167) have proposed a semi-quantitative terminology for schists based on a system of prefixes that express percentages of quartz and feldspar. Thus, a mica schist would contain less than 60 percent of quartz plus feldspar; a mica-quartz schist would contain 60 to 80 percent of quartz plus feldspar; and a quartz-mica schist or quartzite would contain over 80 percent of quartz plus feldspar. This system is clearly useful in classifying rocks which have been studied in thin section, and it may also be useful in the field in areas of homogeneous rock units. It is not useful in the field for rocks such as those of the Van Horn area where there were rapid variations in the arenaceous and argillaceous components of the original sediments, causing the present quartz-mica ratio to vary from place to place in one map unit, one outcrop, or even one thin section.

"Amphibolite" is used in this publication for an amphibole-plagioclase rock of metamorphic origin which may or may not have a schistose structure; for the most part these rocks do not have a well-developed schistosity. For strongly schistose amphibole-rich rocks, which in this area are restricted in occurrence, the name "amphibole schist" or "hornblende schist" is employed. These rocks are commonly rich in quartz and contain biotite as a prominent varietal mineral. In the discussion of amphibolites on later pages it has been necessary to consider also rocks of low amphibole and high quartz content—not because they are amphibolites by definition, but because they are transitional types which it is necessary to understand before the amphibolites themselves can be interpreted.

<sup>7</sup> Adolph Knopf, personal communication to P. T. Flawn, February 1952.



## NORTHWEST VAN HORN MOUNTAINS (MICA MINE AREA)

Peter T. Flawn

### SUMMARY

The Van Horn Mountains are a block-faulted range that rises about 10 miles south of Van Horn and extends southward to the Sierra Vieja (fig. 1). Pre-Cambrian rocks of the Carrizo Mountain group are exposed in a horst that forms a northwestern extension of the main mountain mass, and the area of exposed pre-Cambrian rocks is known as the Mica Mine area. The horst is bounded on the southwest and northeast by normal faults that trend approximately northwest-southeast, and along both faults pre-Cambrian and Permian rocks are raised against Cretaceous sandstone. Pre-Cambrian rocks have been exposed by removal of the unconformable Permian cover.

### PRE-CAMBRIAN ROCKS

*General features.*—The Carrizo Mountain group of the Mica Mine area consists of a thick sequence of meta-arkose, feldspathic metaquartzite, and feldspathic muscovite schist containing thin beds and lenses of biotite schist and amphibolite. Amphibolite and biotite schist comprise less than 10 percent of the section. The metasedimentary rocks are intruded by pegmatites which have been described in detail by Flawn (1951b). For the most part these rocks strike east of north and dip steeply southeast (Pl. 4). Four units were mapped in the area: (1) feldspathic metaquartzite and meta-arkose, (2) feldspathic muscovite schist, (3) biotite schist and amphibolite, and (4) pegmatite. The massive metaquartzite and meta-arkose form the center of the overturned southwesterly plunging anticline that is the major structure in the area. The muscovite schist occurs stratigraphically above the metaquartzite—meta-arkose section and is repeated on the north and south limbs of the fold. Biotite schist and amphibolite occur within the muscovite schist. Pegmatites intrude both the muscovite schist and the massive metaquartzite—meta-arkose but are more numerous in the schist. Pegmatite intrusion and local folding make it difficult to de-

termine thicknesses of units. The writer estimates a minimum thickness of 1,500 feet of muscovite schist and 900 feet of metaquartzite—meta-arkose.

The rocks of the Mica Mine area are of medium metamorphic grade and show the highest degree of metamorphism in the Van Horn area. They fall within the amphibolite facies of the Eskola classification. Almandine garnet and anthophyllite occur in amphibolites in the sequence, and the quartzo-feldspathic rocks show complete recrystallization and complete reconstitution of intergranular material to form oriented mica plates. No relict sedimentary structures except large-scale stratification are visible. Foliation is approximately parallel to the original bedding.

*Feldspathic metaquartzite and meta-arkose (pCCq) (Table 2, modes I, II, III, and V; Table 3, chemical analysis 1.)*—Feldspathic metaquartzite and meta-arkose with varied content of biotite and muscovite occur throughout the metasedimentary sequence and comprise 30 to 40 percent of the exposed pre-Cambrian rocks. They occur as thin beds (up to 3 feet thick) within the schist areas and as massive beds (up to 30 feet thick), separated by thin layers of schist, in the quartzite areas. Compared to the associated muscovite schist, these rocks are resistant to weathering and form blocky ledges and rough steep hogbacks that can be followed through the entire exposure of pre-Cambrian rocks (Pl. 20). In general the rock is fine- to medium-grained, hard, and weathers dark brown on the outcrop. In fresh sample it is a pink or buff rock in which mica plates, magnetite grains, and sporadic larger grains of quartz and feldspar are visible.

The mica content of the quartzites is varied, and all gradations between quartzite and mica schist are present. If the rock possesses a visible schistosity, it is here designated a schist. The mica content of the quartzites averages about 5 percent but is locally as high as 10 percent. Where the mica content exceeds 10 percent the rock is schistose.

**Petrography.**—In thin section the rock shows a well-developed granoblastic fabric—a mosaic of quartz, microcline, and plagioclase, usually albite (twinned or untwinned, average  $An_{5-10}$ ). The average grain size of the mosaic is 0.2 to 0.5 mm. with some grains reaching 3 to 5 mm. The mica plates show a preferred orientation, but no mineral segregation into bands, that is, development of gneissic structure, has taken place. Table 2 gives the modes of some representative metaquartzites and meta-arkoses. Most of the feldspar occurs as an integral part of the mosaic, but some small round inclusions of feldspar are present within quartz. This may indicate a tendency toward development of a "sieve" or diablastic fabric.

The high feldspar content of these rocks suggests there may have been an introduction of feldspar or a feldspathization, perhaps in connection with pegmatite emplacement. Further, sporadic feldspar grains show evidence of growth and are poikilitic. However, most of the feldspar is present in a simple mosaic with straight-line boundaries, and recrystallization of feldspathic sandstone or arkose provides a satisfactory explanation for the origin of these rocks.

Mica, either biotite or muscovite, or both, is well oriented. The biotite is green-brown and is variably altered to bleached biotite or bauerite. The bleached biotite takes on a "sickly" faded look but retains high birefringence.

Zircon, in quantity less than 1 percent, is present in all the quartzo-feldspathic rocks. It shows evidence of attrition but retains the crystal form.

Magnetite or ilmenite occurs in scattered grains and in some rocks is surrounded by red iron oxide. In some rocks the opaque mineral occurs in thin plates within the biotite cleavage. This suggests that iron or iron and titanium in excess of that needed by biotite during growth was excluded or rejected. Leucoxene is present in some thin sections, as are a few grains of apatite.

**Feldspathic muscovite schist (pCCms)** (Table 2, mode IV; Table 3, chemical analyses II, III).—Feldspathic muscovite schist, frequently biotitic, makes up 50 to 60 percent of the exposed pre-Cambrian section. It forms glittering white outcrops of soft rock that crumble into micaceous sand under the hammer. The schist crops out in two irregularly shaped areas that roughly comprise the northern and southern thirds of the exposed pre-Cambrian rocks and are separated by a high ridge of massive metaquartzite. To the north, east, and south the schist disappears beneath Permian and Cretaceous strata; to the west alluvial deposits mask its faulted boundary.

**Petrography.**—Except for the higher mica content and schistosity, this rock is in every way similar to the quartzo-feldspathic rocks discussed previously. The muscovite content is rarely over 30 percent and averages 15 to 25 percent. Feldspar, magnetite or ilmenite, and zircon are present.

The average grain size of the mosaic is 0.2 to 0.5 mm., with mica laths (in section) averaging 1 by 0.2 mm.

Table 2. Estimated<sup>8</sup> modes of representative rocks of the metaquartzite-muscovite schist sequence of the northwest Van Horn Mountains.

	I	II	III	IV	V*
Quartz	70	50	64	60	46.2
Microcline	9	37	15	10	31.4
Plagioclase	15	5	15	5	9.7
Muscovite	5	6		25	12.7
Biotite		2	5		
Magnetite or ilmenite	1		1		
Zircon	tr	tr	tr	tr	tr
Totals	100	100	100	100	100.0

\*Mode determined by Rosiwal analysis.

- I, Muscovitic feldspathic metaquartzite; average grain size 0.1 to 0.2 mm. (Maximum grain size 4 mm.).
- II, Biotitic-muscovitic meta-arkose; average grain size 0.2 to 0.4 mm.
- III, Biotitic meta-arkose; average grain size 0.2 mm.
- IV, Feldspathic muscovite schist; average grain size 0.5 mm.
- V, Muscovitic meta-arkose (slightly schistose); grain size 0.2 mm. (photomicrograph in Pl. 30, A).

**Biotite schist (pCCbsa).**—Intercalated with the quartzite and muscovite schist are thin lenses and beds of biotite schist, commonly associated with amphibolite. The contacts of these units are obscure. In some places seemingly discontinuous lenses of biotite schist or amphibolite are successive outcrops of a continuous bed. Elsewhere a number of biotite schist or amphibolite lenses occur along the same horizon; these are perhaps remnants of a once continuous layer that has been squeezed into lenses by tectonic action. Biotite schist occurs in layers that range from less than 1 foot to 25 feet thick. The maximum thickness of 25 feet of biotite schist is in the biotite

<sup>8</sup> Modes were determined by visual estimation, observing (a) the slide as a whole under low-power magnification and (b) randomly selected portions of the slide under higher power magnification. The personal error in these estimated modes is a function of the amount of mineral present and is a maximum in slides composed more or less equally of three or more minerals. Maximum error is probably about plus or minus 5 percent, and error of this magnitude must be expected in the values for albite and potassium feldspar where both make up significant portions of the rock. The estimated modes are presented to give the reader a general picture of the rocks studied. Modes used in connection with chemical analyses were determined by Rosiwal analysis (asterisked in tables). Rosiwal modes are given to the nearest tenth, but it is doubtful if any figures to the right of the decimal are significant within the limits of accuracy of the method.

schist—amphibolite sequence in the southern Mica Mine area (fig. 18, b).

The biotite-bearing rocks of the Mica Mine area have a varied mineralogy (Table 4) and seem to represent a transition between the potash-rich muscovite-microcline-quartz rocks on the one hand and the hornblende-plagioclase rocks on the other. For purpose of petrographic description three major varieties of biotite-bearing rocks are distinguished: (1) biotite schists associated with muscovite-bearing rocks; (2) biotite schists associated with amphibolite; and (3) altered biotite schists. Rocks of the third category are of minor importance and are derived from (1) or (2).

(1) Biotite schists associated with muscovite-bearing rocks:

The biotite content of the normal muscovite schist may increase locally to form a biotitic muscovite schist or a biotite-muscovite schist. This biotite is a green-brown variety that occurs with muscovite as parallel plates in a

mosaic of quartz and feldspar. Rarely, biotite is the sole micaceous constituent (Pl. 30, B).

(2) Biotite schists associated with amphibolite:

The common association of biotite schist and amphibolite in beds and lenses in the quartzo-feldspathic rock sequence has a definite bearing on the problem of origin of the amphibolites of this area. Not uncommonly an amphibolite bed 5 or 10 feet thick is separated from muscovite schist by several feet of biotite schist or biotite-albite schist. Biotite schists associated with amphibolites fall into two groups: (a) biotite-quartz schist and (b) biotite-plagioclase rocks with or without amphibole.

(a) Biotite-quartz schist in beds 6 inches to 25 feet thick forms glittering black outcrops. Biotite plates several millimeters in diameter, red-stained quartz, and white feldspar are visible in the hand specimen.

Table 3. Chemical analyses of quartzo-feldspathic rocks (R. M. Wheeler, analyst).<sup>a</sup>

	I	II	III	IV	V	VI
SiO <sub>2</sub>	78.15	77.12	78.37	81.89	75.71	79.00
Al <sub>2</sub> O <sub>3</sub>	11.09	13.69	12.57	9.10	11.4	11.38
Fe <sub>2</sub> O <sub>3</sub>	1.41*	0.80*	1.52*	0.17	2.4	0.68*
FeO	nd	nd	nd	0.16		nd
MgO	0.25	1.45	0.97	0.02	0.1	0.25
CaO	0.42	0.37	0.35	0.64	1.6	0.80
Na <sub>2</sub> O	1.64	1.91	1.85	0.11	2.0	2.45
K <sub>2</sub> O	5.56	3.00	3.35	7.11	5.6	3.45
H <sub>2</sub> O—	nd	nd	nd	0.21	0.6	nd
H <sub>2</sub> O+	nd	nd	nd	0.03		nd
Ignition loss	0.95	1.38	1.56	nd	nd	1.08
TiO <sub>2</sub>	0.11	0.13	0.17	0.06		0.14
P <sub>2</sub> O <sub>5</sub>	0.02	0.02	0.01	0.07	tr	
MnO	0.01	0.02	0.03	0.26	0.2	nd
CO	nd	nd	nd	0.28	0.4	nd
BaO	nd	nd	nd	0.03	nd	nd
Totals	99.61	99.89	100.77	100.14	99.8	99.23

\*Total iron reported as Fe<sub>2</sub>O<sub>3</sub>.

nd = not determined.

I, Meta-arkose, Mica Mine area.

II, Feldspathic biotitic muscovite schist, Mica Mine area.

III, Feldspathic muscovite schist, Mica Mine area.

IV, Quartz orthoclase (microcline) granulite with a little muscovite (metamorphosed arkose), from Lewisan (Richey and Thomas, 1930, p. 8).

V, Average of three analyses of arkose (Petijohn, 1949, p. 259).

VI, Representative pegmatite, Mica Mine area (30 percent pink microcline perthite; 40 percent white plagioclase, An<sub>7</sub>; 20 percent quartz; 10 percent muscovite).

<sup>a</sup> This table has been published in slightly different form in an earlier paper on the pegmatites of the Mica Mine area (Flawn, 1961b).

**Petrography.**—Thin section shows parallel plates of biotite in a mosaic of quartz and albite. There is a wide variation in size among the grains of the mosaic (0.5 mm. is a fair average). The rock is composed of 40 to 60 percent quartz, 10 to 20 percent albite, and 30 to 40 percent biotite (olive-brown variety). Microcline is present in some sections. One section shows 3 percent garnet restricted to a narrow zone parallel to the foliation. Apatite, sphene, leucoxene, magnetite or ilmenite, rutile, and carbonate occur in minor quantities.

- (b) The biotite of the biotite-plagioclase schist reflects a potassic phase of the general amphibolite assemblage. Hornblende and/or anthophyllite, epidote, and sphene may accompany biotite in this phase (Pl. 30, C and D). The biotite occurs in small flakes (1 mm. or less and makes up less of the total mineral assemblage than in (a) above. A striking example of the biotite-anthophyllite-bearing rock is at F.5—18.2, Plate 4. This rock occurs in a bed 5 feet thick and contains fan-shaped groups of anthophyllite blades up to 10 cm. in length in a ground-mass of biotite, oligoclase, and quartz.

**Petrography.**—Thin section shows a mosaic of albite-oligoclase averaging 0.5 mm. in grain size

and making up 50 to 75 percent of the rock. The plagioclase is more or less altered to sericite. Biotite, an olive-brown to red-brown variety, makes up 10 to 30 percent of the rock and shows parallel orientation. The biotite laths average 0.2 by 1 mm. Some specimens were observed to contain blue-green hornblende or anthophyllite. The hornblende occurs in poikilitic crystals or as subhedral prisms aligned with the biotite. The anthophyllite occurs in bladed or fan-shaped porphyroblasts as much as 10 to 20 cm. in length. Minor quartz, ilmenite or magnetite, sphene, leucoxene, apatite, and carbonate are present. Platy ilmenite (associated with leucoxene) occurs in biotite cleavages in some sections.

### (3) Altered biotite rocks:

The biotite of the previously discussed rocks shows a varied amount of alteration. When the alteration is advanced a fibrous pale green mineral is visible in the hand specimen.

**Petrography.**—Under the microscope this alteration is seen to involve color fading, development of more fibrous habit, and development of variable birefringence (although the birefringence remains high). The end-product of this process is bleached biotite, or bauerite, and in many rocks only relicts of the original biotite are present. Rutile and sphene appear in these altered biotite rocks.

**Amphibolite (pECbsa).**—There are four main varieties of amphibolite in the Mica Mine area: (1) hornblende-plagioclase

Table 4. Estimated modes of representative biotite-bearing rocks from the pre-Cambrian of the northwest Van Horn Mountains.

	I	II	III	IV	V
Quartz .....	55	17		35	5
Biotite .....	30 ob <sup>a</sup>	20 rh <sup>b</sup>	10 ob	15 ob	30 rb
Plagioclase .....	12	15	55	20	55
	(albite)	(oligoclase)	(oligoclase)	(altered)	(albite)
Microcline .....		48			
Almandine .....	3				
Zircon .....	tr	tr			
Apatite .....		tr	1		
Magnetite or ilmenite .....			4	1	4
Sphene .....				2	2
Hornblende .....				20	
Anthophyllite .....			30		
Epidote .....				7	
Leucoxene .....					3
Carbonate .....					1
Totals .....	100	100	100	100	100

<sup>a</sup>Olive-brown.

<sup>b</sup>Red-brown.

I, Garnetiferous albite-biotite schist; average grain size 0.4 mm. (irregular).

II, Quartz-biotite-microcline schist; average grain size 0.2 mm. (photomicrograph in Pl. 30, B).

III, Biotite-anthophyllite amphibolite; average grain size 0.5 mm., porphyroblasts 4 cm.

IV, Biotite-hornblende-albite schist; average grain size 0.2 to 0.5 mm. (photomicrograph in Pl. 30, C).

V, Quartz-biotite-albite schist; average grain size 0.2 to 0.3 mm.

rock, (2) almandine-hornblende-plagioclase rock, (3) anthophyllite-hornblende-plagioclase rock, and (4) epidote-hornblende-plagioclase rock, commonly containing streaks and layers of pure epidote rock or epidotite. The distribution of these rocks is shown in figure 18. The amphibolites are in beds that range from less than 5 to 60 feet thick. Maximum thickness of a single amphibolite layer is reached in the biotite schist—amphibolite section of the southern part of the area (fig. 18, b).

(1) The mineralogically simple hornblende-plagioclase amphibolite is a massive to slabby green-black rock in which minute prisms of hornblende are visible. In some rocks the hornblende shows a fair lineation and in others it occurs in a mat of non-lineated prisms parallel to the general

foliation of the area. The average length of the hornblende prisms is 1 to 3 mm., but local coarsenings are common. Hornblende may comprise as much as 70 percent of the rock and plagioclase is the only other major mineral.

*Petrography.*—Under the microscope this rock shows poikilitic hornblende prisms in a mosaic of untwinned plagioclase. The hornblende is a blue-green variety with  $Z \wedge C = 16$  to 18 degrees,  $\beta = 1.665$  to 1.672, and negative optic sign. These determinations, unless otherwise stated, hold true for blue-green hornblende of all amphibolite types in the Mica Mine area. The hornblende averages 30 to 50 percent of the rock but in places is as high as 70 percent. The plagioclase (oligoclase-andesine) has the same percentage range as the hornblende (average, 30 to 50, maximum, 70). It invariably shows some degree of alteration to sericite. An inverse zoning can be seen in most sections. Quartz, if present at all, is usually in amounts less than 10 percent, but

Table 5. Estimated modes of representative amphibole-bearing rocks from the pre-Cambrian of the northwest Van Horn Mountains.

	I	II	III*	IV	V*	VI*	VII	VIII	IX	X
Plagioclase	40 (andesine)	30 (oligoclase-andesine)	35.5 (andesine)	50 (andesine)	10.6 (oligoclase)	8.7 (albite)	50 (oligoclase)			20 (badly altered)
Hornblende	52	45	38.8		7.2	tr	25	53		25
Anthophyllite			21.6	40						
Cummingtonite									8	
Clinocllore				4						
Biotite										20
Epidote					51.4	86.8	20			8
Almandine		15		tr					5	
Sphene					2.8	4.5	tr			2
Leucoxene					tr					
Magnetite or ilmenite	5	7	3.1	4	0.6 (ilmenite)		3 (ilmenite)	20	2	tr
Apatite	3	3	0.9	2			2	1		tr
Quartz					27.3			25	85	25
Calcite					tr					
Totals	100.0	100.0	99.9	100.0	99.9	100.0	100.0	100.0	100.0	100.0

\*Mode determined by Rosiwal analysis.

- I, Amphibolite; average grain size 0.3 mm. (photomicrograph in Pl. 31, B).
- II, Almandine amphibolite; average grain size 0.1 to 0.2 mm.; porphyroblasts 5 mm. to 1 cm. (chemical analysis in Table 6).
- III, Anthophyllite amphibolite; average grain size 0.1 to 0.2 mm.; porphyroblasts 2 cm. (photomicrograph in Pl. 31, A; chemical analysis in Table 6).
- IV, Anthophyllite amphibolite; average grain size 0.3 mm.; porphyroblasts 1 cm.
- V, Epidote amphibolite; average grain size 0.1 to 0.2 mm. (photomicrographs in Pl. 31, D; chemical analysis in Table 6).
- VI, Epidotite; average grain size 0.1 mm. (photomicrograph in Pl. 31, C; chemical analysis in Table 6).
- VII, Epidote amphibolite; average grain size 0.1 to 0.2 mm.
- VIII, Magnetite-hornblende gneiss; average grain size 0.1 mm. (photomicrograph in Pl. 33, C and D).
- IX, Almandine cummingtonite metaquartzite; average grain size 0.3 mm. (photomicrograph in Pl. 33, B).
- X, Epidote-biotite-albite-hornblende schist; average grain size 0.1 to 0.2 mm. (photomicrograph in Pl. 30, C).

quartz-rich layers containing as much as 25 or 30 percent quartz occur in some thin sections. The quartz is easily distinguished from the altered plagioclase. Magnetite or ilmenite (4 to 5 percent) and apatite (1 to 2 percent) are invariably present. The average grain size of the mosaic is 0.2 to 0.4 mm. and the hornblende prisms average 1 to 2 mm. in length. (See Table 5, I, for mode.)

Several interesting deviations from the normal amphibolite occur in the biotite schist-amphibolite sequence of the southern Mica Mine area. A thin bed (less than 1 foot thick) of magnetite-hornblende gneiss occurs in association with biotite schist in this area. Megascopically the rock is a fine-grained heavy dark green slabby gneiss.

*Petrography.*—Thin section (Table 5, mode VIII, and Pl. 33, C and D) shows a mosaic of quartz containing oriented prisms of poikilitic hornblende and layers of magnetite grains. The prismatic shape of the hornblende is not well developed, but the orientation is definite. This hornblende, a green variety with  $Z \wedge C = 18$  degrees and  $\beta = 1.659$ , makes up to 40 to 60 percent of the rock and is distributed in layers. It is of special interest because it shows a well-developed

001 parting (Pl. 33, D). The magnetite occurs in discrete rounded grains and masses of grains concentrated in layers. Magnetite makes up 10 to 15 percent of the rock. The quartz grains show alignment of their long axes and undulatory extinction. Apatite is present in small quantity in some thin sections.

Associated with the hornblende-magnetite gneiss is another unusual rock—an almandine-cummingtonite quartzite. The rock occurs in a 2-foot layer of thin-bedded (2 to 3 inches) brown quartzite with garnets 1 to 2 mm. in diameter protruding above the bedding plane surfaces.

*Petrography.*—Quartz, showing undulatory extinction, forms a mosaic which makes up 85 percent of the rock. Skeletal garnet crystals (Pl. 33, B) occur throughout the mosaic and comprise about 5 percent. Also scattered through the quartz mosaic are small prisms of colorless cummingtonite showing fair lineation,  $Z \wedge C = 18$  degrees,  $\beta = 1.663$ , positive optic sign,  $\Delta = 0.021$ ,  $2V \sim 80^\circ$ ; it makes up about 8 percent of the rock. Magnetite grains make up as much as 2 percent of the slide.

(2) Almandine amphibolite was observed in one outcrop (F.0—19.3, Pl. 4).

Table 6. Chemical analyses of amphibolites and allied rocks (R. M. Wheeler, analyst).

	I	II	III	IV	V	VI	VII	VIII
SiO <sub>2</sub>	60.13	42.73	45.55	61.92	41.08	48.12	47.51	48.38
Al <sub>2</sub> O <sub>3</sub>	12.98	23.67	12.89	14.93	18.23	12.80	16.87	12.76
Fe <sub>2</sub> O <sub>3</sub>	12.43*	4.43	13.70	7.60	13.28	1.60	4.41	8.91
FeO		5.75	5.83	0.57	0.51	3.25	7.99	4.43
MgO	5.10	7.20	9.45	1.52	1.29	2.55	4.27	6.29
CaO	0.56	9.29	6.35	11.52	19.38	10.77	8.07	7.65
Na <sub>2</sub> O		1.30	1.76	0.14	0.05	0.60	3.26	1.13
K <sub>2</sub> O	5.85	0.37	0.32	0.29	0.32	3.60	3.16	1.67
H <sub>2</sub> O—	nd	nd	nd	nd	nd	1.75		
H <sub>2</sub> O+	nd	nd	nd	nd	nd	3.20	0.99	6.00
Ignition loss	1.44	1.00	0.70	0.98	2.48	nd	nd	nd
TiO <sub>2</sub>	1.34	2.56	2.72	0.83	1.89	0.78	2.65	2.07
MnO	0.22	0.39	0.27	nd	nd	0.09	tr	
P <sub>2</sub> O <sub>5</sub>	0.01	0.66	0.62	0.28	0.64	0.65	0.55	0.64
Cr <sub>2</sub> O <sub>3</sub>							nd	nd
NiO							nd	nd
CO <sub>2</sub>	nd	nd	nd	nd	nd	9.19	nd	nd
SO <sub>4</sub>	nd	nd	nd	nd	nd	0.24	nd	nd
S	nd	nd	nd	nd	nd	0.88	nd	nd
BaO	nd	nd	nd	nd	nd	0.01	nd	nd
SrO	nd	nd	nd	nd	nd	0.24	nd	nd
Totals	100.06	99.93	100.16	100.58	99.15	100.36	100.16	100.27

\* Total iron reported as Fe<sub>2</sub>O<sub>3</sub>.

nd = not determined.

- I, Garnetiferous biotite schist, Mica Mine area (see Table 4 for mode).
- II, Almandine amphibolite, Mica Mine area (see Table 5 for mode).
- III, Anthophyllite amphibolite, Mica Mine area (see Table 5 for mode).
- IV, Epidote amphibolite (containing 27.3 percent quartz), Mica Mine area (see Table 5 for mode).
- V, Epidotite, Mica Mine area (see Table 5 for mode).
- VI, Marine marlstone (Pettijohn, 1949, p. 287).
- VII, Dolerite (Washington, 1917, p. 476, No. 70).
- VIII, Basalt tuff (Washington, 1917, p. 894, No. 75).

Here the normal green-black amphibolite contains porphyroblasts of garnet averaging between 5 mm. and 1 cm. in diameter and making up 10 to 15 percent of the rock. They weather out in perfect dodecahedrons. The garnet is deep red and has a specific gravity of 4.14.

*Petrography.*—About 40 to 50 percent of the rock consists of lineated prisms of blue-green hornblende in a mosaic of plagioclase (oligoclase-andesine). There is no distortion or bending of the hornblende prisms where they abut the garnet. Inclusions of magnetite in the garnet show a lineation at an angle to the lineation of the rock as a whole and may be the result of a crystallographic control or a rotation of the garnet. The plagioclase makes up about 30 percent of the slide and is partly altered to sericite. Magnetite or ilmenite makes up 5 to 8 percent of the rock, and apatite, in rounded grains, comprises as much as 3 percent (Table 5).

In several slides the hornblende is optically anomalous. A single prism abruptly changes from blue-green to colorless along a transverse line. This change in color is accompanied by an increase in  $Z \wedge C$  from 17 to 21 degrees and a change in optic sign from negative to positive (Pl. 32, C). The writer has no satisfactory explanation of this phenomenon.

(3) In contact with the almandine amphibolite is an anthophyllite amphibolite, different from the biotite-anthophyllite rock previously described. In hand specimen the rock is massive, green-black, with bladed porphyroblasts of anthophyllite, on the order of 1 mm. wide by 15 mm. long, showing fair lineation.

*Petrography.*—Thin section shows a mosaic (0.1 to 0.2 mm.) of andesine containing oriented prisms of blue-green hornblende. The plagioclase and hornblende each make up about 40 percent of the slide. Large poikilitic porphyroblasts of anthophyllite constitute the remaining 20 percent of the rock. The anthophyllite blades, averaging about 1 cm. in length, show no particular orientation and cut across the lineation of the hornblende. The high  $\beta$  index (1.660) of the anthophyllite indicates that it is a high iron variety (Winchell, 1951, p. 426). The optic sign is positive. (For a chemical analysis of this rock, see Table 6, analysis III.) A pleochroic green core was observed in one anthophyllite crystal (Pl. 32 D). Apparently this represents a period of growth of the mineral during which the coloring element (perhaps ferrous or ferric iron and alumina or some combination thereof) was incorporated in the lattice. Magnetite or ilmenite and apatite are the important accessory minerals in this rock (Table 5, mode III).

In contact with the rock just described is another anthophyllite rock which is composed of 50 percent andesine and 40 per-

cent anthophyllite and contains no hornblende. Tiny garnets (1 mm.) make up about 1 percent of this rock (Table 5, mode IV).

It is interesting to note here that within the same exposure of amphibolite there are three distinct varieties: almandine amphibolite, anthophyllite-hornblende amphibolite, and anthophyllite amphibolite (without hornblende). The relations are obscured by colluvium, but the three rock types are apparently in contact along planes parallel to the general foliation of the area. Individual thicknesses are difficult to determine here. The aggregate thickness is about 30 feet.

(4) Discontinuous layers and lenses of epidote-bearing amphibolite are distributed through a more or less linear zone in the northern schist outcrop (fig. 18, a). With the appearance of a substantial epidote content the normal green-black amphibolite takes on a waxy green cast. Locally thin bands of more hornblende-rich, plagioclase-rich, or epidote-rich rock give this epidote amphibolite a layered appearance.

*Petrography.*—The epidote amphibolite consists of a mosaic of quartz and oligoclase containing blue-green poikilitic hornblende prisms, grains and granular masses of epidote, and grains of sphene. There is some tendency for the hornblende and quartz to be concentrated in layers.

The rock is composed of 10 to 30 percent well-lineated prisms of blue-green hornblende, 10 to 50 percent plagioclase, and a variable amount of epidote and quartz. The oligoclase may be twinned and, as in the other amphibolites, partly altered to sericite. Quartz, if present, is in amounts less than 10 percent, although in one section (Table 5, mode V) it reaches as high as 30 percent. Epidote, distinctly yellow in thin section, ranges from 10 to 70 percent, at which point the rock may be classed as an epidotite. The epidote occurs as small discrete equant grains (0.05 to 0.1 mm.) and groups of grains in a mosaic and clearly originated through metamorphism rather than hydrothermal alteration. In one section masses of epidote surround plagioclase (Pl. 33, A) and seem to have grown at the expense of the plagioclase. Sphene makes up 1 to 3 percent of the rock. One section showed aggregates of sphene surrounding ilmenite and flooded with leucoxene (Pl. 32, A and B). Ilmenite is a common accessory and in some samples makes up as much as 5 percent of the total composition. The modes and photomicrographs of epidote amphibolites are given in Table 5, modes V and VII, and Plate 31, D, and Plate 32, A and B).

Yellow-green streaks show up in the darker hornblende-rich rocks, and these streaks develop locally into layers of waxy

yellow-green rock consisting almost entirely of epidote. These layers are half an inch to 2 inches thick and commonly discontinuous. The rock conforms to the description of an epidotite (Flawn, 1951a).

*Petrography.*—The epidotites of the Mica Mine area contain 80 to 90 percent granular epidote in grains 0.04 to 0.06 mm. in diameter and 8 to 10 percent albite or albite-oligoclase, commonly altered. Sphene makes up 2 to 4 percent of the rock. Dark green hornblende is present in amounts up to 5 percent. The fabric is crystalloblastic (Table 5, mode VI, and Pl. 31, C).

It is interesting to note that in the Mica Mine area, rocks containing a large amount of epidote have a more sodic plagioclase than associated rocks with low epidote content. A discussion of the mineralogy and origin of the amphibolites in the pre-Cambrian rocks of the Van Horn area is given in a separate section (pp. 136–147).

*Pegmatite (Table 3, analysis VI).*—The writer has described the pegmatites of the Van Horn Mountains in detail in an earlier paper (Flawn, 1951b). Zoned and unzoned perthite-quartz-plagioclase-muscovite pegmatites in the form of tabular bodies, irregular-branching tabular bodies, elongate lenses, irregular masses without definite shape, lit-par-lit zones, small augen, and stringers are distributed throughout the metasedimentary sequence. The great majority of the pegmatites are tabular or lens-like bodies that conform to the foliation of the host rock. Zoned bodies have a core of perthite and quartz and a plagioclase-quartz-perthite-muscovite wall zone. The pegmatites contain numerous schist inclusions, and some show evidence of contamination by biotite schist and amphibolite. About 80 pegmatites more than 1 foot thick were mapped. The field, petrographic, and chemical evidence indicates that these pegmatites were emplaced in an essentially closed system, in part by forcing aside the host rock (dilation) and in part by digestion of the host rock (see Flawn, 1951b).

*Quartz veins.*—Veins of white quartz containing variable amounts of biotite and hematite occur within the Mica Mine area. They are mostly restricted to a north-south zone east of Mica Mine No. 1 (Pl. 4), indicating an old locus of fissuring, and seldom exceed a thickness of 2 to 4 feet. The location of minor quartz veins is in places controlled by the hanging wall or

footwall of pegmatites, and the veins are seemingly later than the pegmatites.

The veins probably are the product of high temperature hydrothermal solutions carrying iron and silica. The reaction of these iron-bearing solutions with the potash and alumina of the wall rocks formed biotite, commonly in coarse sheaf-like masses. Locally coarse leaves of biotite have been wrapped around quartz augen. These discontinuous and distorted masses of quartz and biotite conform to the structure of the metamorphic rocks and may be interpreted as the product of pre-metamorphic or syn-metamorphic hydrothermal solutions.

Plates of barite up to 2 inches wide occur in the west fault of the Mica Mine horst and are well shown where the fault is exposed in the quarried face of a pegmatite along the road about 1 mile southeast of the mill. Barite was not observed to occur elsewhere in the area. The age of the barite mineralization is probably Tertiary (younger than the fault zone in which it occurs).

#### PERMIAN ROCKS (Php and Ph)

Permian rocks rest on the pre-Cambrian rocks of the Mica Mine area with marked angular unconformity. On the basis of lithologic character and megafauna, the Permian section of the Mica Mine area is assigned to the Hueco limestone and correlated with the Wolfcamp series. Two lithologic units can be distinguished within the Hueco limestone in this area: a conglomeratic sandstone that will hereafter be called the Powwow member by analogy with the basal Permian strata of that name in the Hueco Mountains<sup>10</sup> and an overlying compact aphanitic gray cherty limestone.

The Powwow member is a transgressive facies extremely varied in thickness. The thickness is controlled by the topography of the pre-Permian surface. On pre-Cambrian hills the succeeding limestone member rests directly on the pre-Cambrian surface, while in low places on the old surface as much as 250 feet of conglomeratic sandstone and conglomerate intervenes. The Powwow is a fine- to coarse-

<sup>10</sup> Discussion of use of the name Powwow in the Van Horn area is given in the section on the Sierra Diablo foothills (p. 98).



grained red and brown micaceous feldspathic sandstone containing sporadic pebbles of quartz, feldspar and pegmatite. In the southern part of the Mica Mine area, 20 to 30 feet of boulder conglomerate is present at the base of the Powwow. Boulders of schist, quartzite, and pegmatite

reach diameters of 3 to 4 feet. The Powwow member grades into the overlying limestone through a 20 to 30-foot zone of interbedded sandstone and silty limestone.

Conformably overlying the conglomeratic sandstone is a compact aphanitic gray cherty limestone in beds 6 inches to

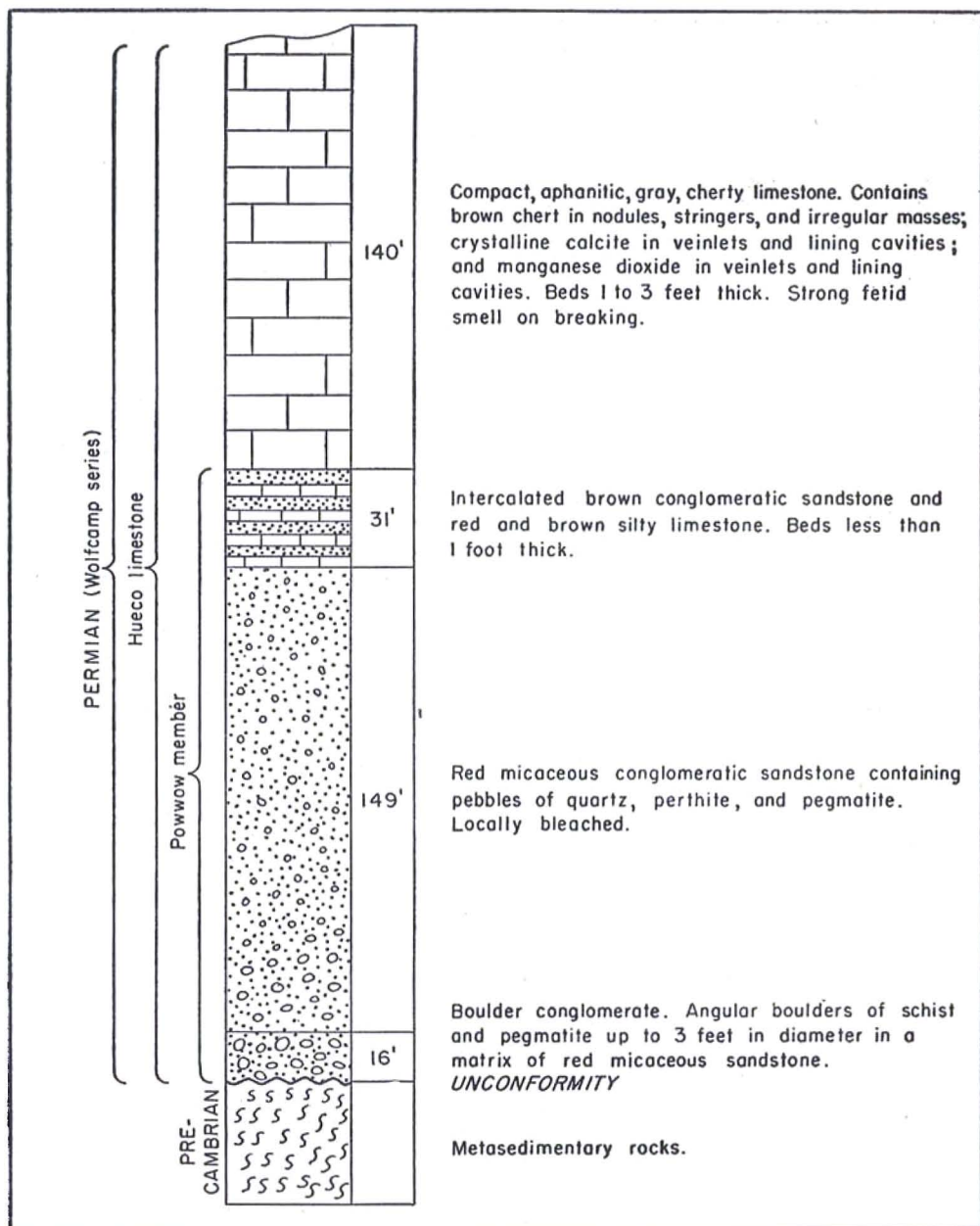


FIG. 4. Columnar section, showing representative sequence of basal Permian rocks (Powwow member of Hueco limestone, and overlying beds) in Mica Mine area, northwest Van Horn Mountains.

6 feet thick which forms bold cliffs around the exposed pre-Cambrian rocks. The limestone contains abundant brown chert in stringers, nodules, and irregular masses. Crystalline calcite occurs in veinlets and cavity linings, and nodules of manganese dioxide are common in cavities. Silicified echinoid spines and plates are numerous throughout the section. Baker (1927, p. 10) refers to this limestone as "the lower great limestone member of the Eagle, Van Horn, and Wiley mountains" and states that its "full thickness is perhaps about 1000 feet." However, in the immediate vicinity of the Mica Mine area the thickness of the limestone does not exceed 250 feet. A section measured east from a point located by coordinates K.6—9.3, Plate 4, is representative of the Permian rocks in the Mica Mine area (fig. 4).

#### CRETACEOUS ROCKS (Kcx)

In the Mica Mine area Cretaceous rocks are for the most part in contact with older rocks only along normal faults. Permian Hueco limestone has been raised against Cretaceous Cox sandstone along many normal faults, and pre-Cambrian rocks have been raised against Cretaceous rocks along parts of the two main normal faults that form the horst. The oldest Cretaceous formation in the area is the Cox sandstone whose upper part is probably of late Trinity age. The rock is a medium- to coarse-grained sandstone; well indurated (locally it is an orthoquartzite) and well sorted. It is composed mostly of quartz with less than 5 percent altered feldspar and less than 1 percent magnetite. The grains are sub-round. Bands of chert pebbles and cross-bedding are common. Thin beds of silty limestone and of conglomerate with limestone and chert pebbles occur within the sandstone, and masses of oyster shells occur locally in the limestone beds. Just east of the Mica Mine area the Cox sandstone is cut by a series of closely spaced normal faults and is present as a jumble of slickensided blocks. A complete section of Cox sandstone is not present in the Mica Mine area, and therefore it is difficult to estimate the thickness of the formation in this area. Baker (1927, p. 12) states that there is 1,500 feet of Cox sandstone in the eastern Van Horn Mountains, a distance of

about 5 miles from the Mica Mine area. The Cox sandstone is overlain by Finlay limestone (Fredericksburg) east of the Mica Mine area.

#### TERTIARY IGNEOUS ROCKS

Trachyte and analcite-bearing diabase dikes ranging from 1 to 4 feet thick occur in the Mica Mine area. From the field evidence these intrusives cannot be assigned a definite age. The trachytes cut Permian rocks. On the basis of similarity to the rocks described by Lonsdale (1940) and Baker (1927), these dikes are classed as Tertiary (?). Tertiary volcanic rocks, tuffs, and flows occur in the Van Horn Mountains east of the Mica Mine.

#### STRUCTURE

*Pre-Cambrian structures.*—The largest structural feature in the pre-Cambrian rocks of the area is an overturned anticline whose axis strikes northeast-southwest and plunges southwest (G.0—14.0 to K.0—15.5, Pl. 4). Both limbs dip 35° to 45° southeast. This structure conforms to the regional northeastward "grain" of the pre-Cambrian rocks. It may be that the amphibolite belts in the north and south parts of the Mica Mine area represent the same beds repeated on opposite flanks of this fold; however, there are significant mineralogical differences between the amphibolites on the north and south. Small open folds (amplitudes of less than 30 feet) are present but not common. Severe contortion is present locally but is not a prominent feature. The more micaceous rocks commonly show a small-scale folding or rucking, with the amplitude of the tiny plications less than 1 cm. This rucking is an  $S_3$  structure, because it deforms pre-existing bedding ( $S_1$ ) and bedding plane-foliation ( $S_2$ ) (cf. Turner, 1948, pp. 177–179). Distortion of foliation is also found in the vicinity of pegmatite contacts and is probably related to pegmatite emplacement.

*Younger structures.*—The Mica Mine horst is bounded by two parallel northwest-trending normal faults about three-fourths of a mile apart. Southeast of the Mica Mine area the east fault drops Tertiary volcanic rocks against Finlay lime-

stone (Fredericksburg), and the fault is therefore younger than the volcanic rocks. In the immediate vicinity of the Mica Mine area Cox sandstone (Trinity) has been thrown down against Hueco limestone (Wolfcamp) and pre-Cambrian rocks. Permian rocks in the horst have been raised high above the surrounding Cretaceous rocks, and at the northern limit of the pre-Cambrian exposure the highest point on the Permian-pre-Cambrian contact (elevation 4,838 feet) is about 350 feet above the Cretaceous sandstone against the fault about 1,000 feet to the east (elevation 4,481 feet). To this figure must be added

the thickness of the entire Permian section (a minimum of 250 feet) and an unknown thickness of Cretaceous rocks. Displacement on the faults bounding the horst, therefore, exceeds 700 feet and is probably in the neighborhood of 1,000 feet. At the north end of the horst the structure is terminated by a north-south fault that intersects both northwest-trending faults, and those faults change direction to a more northerly trend. The down-faulted Cretaceous rocks north, east, and south of the horst are broken by a number of normal faults of small displacement.

# NORTHEAST VAN HORN MOUNTAINS

Peter T. Flawn

## SUMMARY

The northeast Van Horn Mountains rise in a line of rugged hills about 10 miles south of Van Horn and about 1 mile due west of Lobo. This area is about 5 miles northeast of the Mica Mine area previously described. This part of the Van Horn Mountains is a block-faulted complex of pre-Cambrian, Permian, Cretaceous, and Tertiary rocks. Pre-Cambrian rocks of the Carrizo Mountain group are exposed, mostly in deep valleys, beneath unconformably overlying Permian rocks on up-thrown fault blocks. This area was mapped by D. L. Taylor in 1950.

## PRE-CAMBRIAN ROCKS

Two lithologic units, meta-arkose and pegmatite, were mapped in the Carrizo Mountain group of the northeastern Van Horn Mountains. These crop out in a number of discontinuous exposures along faults, where the cover of Hueco limestone has been stripped back (Pl. 5). Foliation is more or less parallel to bedding in the few places where bedding can be seen. In general, the rocks strike east of north and dip south, but in the westernmost exposure (Pl. 5) the strike is varied, probably as a result of local folding. Metamorphic grade probably corresponds to that in the Mica Mine area.

*Meta-arkose* (pCCma) (Table 7, modes I, II).—Meta-arkose is the only metasedimentary unit exposed in the northeastern Van Horn Mountains and is similar to that found in the northwest Van Horn Mountains and the Wylie Mountains to the southwest and northeast. It is a massive fine-to coarse-grained brown to buff rock with sporadic grains of quartz and feldspar reaching 4 to 5 mm. in diameter. Locally the rock is slightly schistose, but foliation has not developed to a point where the rock may be termed a gneiss. Thin beds of biotite schist are included within the unit.

*Petrography.*—Under the microscope the rock shows a poorly sized mosaic of quartz and microcline. The mosaic has straight-line boundaries, and all the original interstitial material has recrystallized to form oriented plates of muscovite and biotite (green-brown to dark olive-

brown). Quartz ranges from 40 to 55 percent and microcline ranges from 35 to 50 percent of the rock. Small amounts of albite, magnetite or ilmenite, zircon, and apatite are also present. Grain size ranges from 0.05 to 2 mm., and the fabric is granoblastic. This rock is a recrystallized arkose.

A thin layer of amphibolite, too small to map, crops out at B.O.—3.6, Plate 5. Whether this rock is of sedimentary or igneous origin has not been determined. No trace of an igneous fabric remains, if one was ever present, and field relations are obscure. The quartz content is appreciable (at least 10 percent).

*Petrography.*—This rock contains oriented laths of dark brown biotite and blue-green hornblende ( $Z \wedge C = 17^\circ$ ,  $\beta = 1.689 \pm .002$ , negative optic sign) in a mosaic of altered plagioclase (kaolinized) and quartz. Small grains of sphene occur in masses and strings. Apatite, magnetite or ilmenite, and chlorite are present (Table 7, mode IV).

*Pegmatite.*—Two pegmatites intrude the meta-arkose in this area. These bodies are conformable elongate lenses and are in all respects similar to the perthite-quartz-plagioclase-muscovite pegmatites in the Mica Mine area of the northwest Van Horn Mountains. No internal zoning was distinguished. Several small quartz-tourmaline masses are present in the area.

Table 7. Estimated modes of pre-Cambrian rocks of the northeast Van Horn Mountains.

	I	II	III
Quartz . . . . .	55	43	10
Microcline . . . . .	36	50	..
Plagioclase . . . . .	3		48
			(oligoclase)
Muscovite . . . . .	5	5	
Magnetite or ilmenite . . . . .	1	tr	1
Zircon . . . . .	tr	tr	
Biotite . . . . .	tr	2	5
Apatite . . . . .			1
Chlorite . . . . .			3
Hornblende . . . . .			30
Sphene . . . . .			2
Epidote . . . . .		---	
Totals	100	100	100

I, Muscovitic meta-arkose; grain size 0.04 to 2 mm.

II, Muscovitic meta-arkose; grain size 0.05 to 0.5 mm.

III, Amphibolite; grain size 0.1 to 0.2 mm.

### YOUNGER ROCKS

The Permian and Cretaceous rocks in the northeast Van Horn Mountains are similar to those in the northwest Van Horn Mountains described in the preceding section.

In addition there are tuffs and flows of the Tertiary volcanic sequence, the details of which were not worked out by Taylor.

### STRUCTURE

Pre-Cambrian rocks in this area maintain, for the most part, their regional northeast strike and southeast dip. Foliation is approximately parallel to the original stratification, although this stratification is

evident only where schistose beds occur within the massive rocks.

Three north-south faults, downthrown to the east, have thrown Permian against pre-Cambrian, and Tertiary against Permian and pre-Cambrian (Pl. 5). There is also an east-west structural trend marked by two faults of "dog-leg" plan downthrown to the north; these have thrown Tertiary and Cretaceous rocks against Permian and pre-Cambrian rocks with displacements on the order of hundreds of feet. Detailed mapping was restricted to the area of exposed pre-Cambrian rocks, and no attempt is made to present a broader structural analysis of this very complex area.

## WYLIE MOUNTAINS

Peter T. Flawn

### SUMMARY

The west scarp of the Wylie Mountains rises from the basin fill 4 miles southeast of the town of Van Horn. Pre-Cambrian rocks are exposed in a series of spurs along the base of the scarp on the upthrown side of a fault (Pl. 6). Pre-Cambrian rocks of the Carrizo Mountain group and unconformably overlying Hueco limestone have been raised along two intersecting faults, one striking north-northwest along the west scarp of the range and the other striking east-west along the southern limit of the range.

### PRE-CAMBRIAN ROCKS

*General features.*—Three rock units can be distinguished in the Carrizo Mountain group of the Wylie Mountains, namely (in order of decreasing age) mica schist, meta-arkose, and amphibolite. They are exposed in a long, narrow arcuate outcrop along the west and south scarp of the mountains, between the faults and the unconformably overlying Hueco limestone. The mica schist has a small outcrop and occurs stratigraphically beneath the meta-arkose which makes up the bulk of the pre-Cambrian exposure. Amphibolite occurs in small masses that intrude<sup>11</sup> the schist and meta-arkose. Schistosity is restricted to the thin outcrop of mica schist and to thin layers within the massive meta-arkose. Where present, it is approximately parallel to the bedding.

Metamorphism in the Carrizo Mountain group of the Wylie Mountains is probably of slightly lower grade than in the Mica Mine area, although there is no precise mineralogical indication of the metamorphic grade. There are indications of incipient retrogressive metamorphism in this area. The over-all grain size of the rocks is smaller than that in the Mica Mine area, and the meta-arkose shows cataclastic effects not observed in similar rocks southwestward along the strike in the Van Horn Mountains. In the mica schist of the Wylie

Mountains chlorite has formed at the expense of biotite. The amphibolite has a relict igneous fabric and is similar to that of the Carrizo Mountains rather than that of the Mica Mine area.

*Biotite - muscovite schist* (pECbms) (*Table 8, mode I*).—Mica schist in the Wylie Mountains crops out only in valleys at the western base of the scarp, and even there it is largely concealed by unconsolidated basin fill. Exposed thickness does not exceed 30 feet. The rock is a fine-grained light-colored glittering schist with the mica unevenly distributed in layers. Mica plates reach 1 mm. in diameter. The mica schist grades into the overlying meta-arkose through a zone of schistose, micaceous meta-arkose.

*Petrography.*—Under the microscope the rock shows a mosaic of quartz containing oriented plates of muscovite, biotite (olive-brown to green-brown varieties), and chlorite (clinocllore). About 85 percent of the rock is quartz. The chlorite has formed at the expense of biotite and the muscovite is partly altered to sericite. Untwinned feldspar, sphene, apatite, rutile, leucoxene, and zircon are present in minor quantities. The grain size of the quartz mosaic ranges from 0.02 to 0.20 mm., and the mica laths average 0.05 by 0.2 mm. The fabric is lepidoblastic. Layers of varied grain size and mica content are interpreted as relict bedding.

*Meta-arkose* (pECma) (*Table 8, mode II*).—Meta-arkose forms projecting spurs beneath the scarp of Hueco limestone and makes up over 90 percent of the pre-Cambrian rocks exposed; in most of the area it is the only unit present. The rock is medium to coarse grained; buff, brown, or red; schistose, slabby, thin bedded, or massive, and is plainly bedded. The rock is more massive toward the top of the exposed section. Schistosity, where developed, is parallel to the bedding within the unit and to the foliation of the underlying schist. Within the meta-arkose, concentrations of biotite are common along bedding planes and result in thin layers of dark glittering biotite schist, usually less than 6 inches thick. Thin layers of amphibolite occur conformably within the meta-arkose section.

*Petrography.*—In thin section the rock is a mosaic of quartz and feldspar that shows a wide

<sup>11</sup> Amphibolites of igneous origin are metamorphic rocks and were not intruded in their present form. However, for brevity these meta-igneous rocks will be referred to as intrusive to avoid repeated references to "the original igneous rock."

range in size of constituent grains (0.01 to 0.25 mm.) and contains sporadic grains of feldspar, quartz, and fragments of larger-grained quartz mosaics up to 2 mm. in diameter. In the general mosaic the feldspar is mostly microcline with minor plagioclase. The sporadic large feldspar grains are microcline-micropertthite and albite. The rock is composed of about 50 percent feldspar, 45 percent quartz and less than 5 percent of biotite (green-brown variety, partly bleached), muscovite, ilmenite or magnetite, leucoxene, and zircon.

Table 8. Estimated modes of representative rocks from the pre-Cambrian of the Wylie Mountains.

	I	II*	III	IV	V
Quartz	85	45.0		37	15
Microcline		50.5			
Plagioclase	5		52		25
Muscovite	2				
Biotite	4	4.5	3	30	4
Chlinoclare	3		1	tr	
Sphene	tr		2	2	1
Apatite		tr		tr	1
Zircon ..	tr	tr			
Rutile ..	tr			tr	
Leucoxene	tr	tr			
Magnetite or ilmenite		tr	1	1	tr
Hornblende			30		50
Epidote			10	30	4
Totals	100	100	100	100	100

\*Mode determined by Rosiwal analysis.

I, Muscovite-chlorite-biotite schist; average grain size 0.02 to 0.2 mm.; chlorite laths up to 0.1 by 4 mm.

II, Biotitic meta-arkose; grain size 0.01 to 1 mm.

III, Epidote amphibolite; grain size 0.01 to 2 mm.

IV, Biotite-epidote-quartz rock; grain size 1 to 2 mm.

V, Schistose amphibolite; grain size 0.01 to 1 mm.

This rock superficially resembles the metarhyolite of the Carrizo Mountains to the west and may be confused with sheared rhyolite even in thin section, but it is here interpreted as a meta-arkose for the following reasons:

(1) It shows bedding, and round grains of probable detrital origin can be seen in the hand specimen.

(2) In thin section it shows a wide and virtually continuous range of grain size. In the metarhyolite of the Carrizo Mountains there is a sharp break between the fine-grained, sheared ground-mass and the broken and sheared phenocrysts.

(3) It is similar in appearance and mineral composition to meta-arkoses in the northeast and northwest Van Horn Mountains and is on strike with them. The latter are metamorphosed clastic sediments which range from meta-arkose to feldspathic metaquartzite.

(4) There are no indications that strong shearing stresses have affected the rock. The rhyolite is characterized by rotation and crushing of the phenocrysts, conversion of microcline to sericite, banding and lineation. These are not criteria of origin, but they serve to emphasize the present differences between the two rocks in structure and texture.

*Amphibolite* (p<sub>f</sub>Ca) (Table 8, modes III, V).—Four mappable bodies of massive fine- to coarse-grained dark green-black rock intrude the schist and meta-arkose of the Carrizo Mountain group in the Wylie Mountains. This amphibolite occurs in four small bodies that, as exposed, have a roughly equant shape (Pl. 6). The bodies are probably short, thick lenses and apparently cut across the bedding-foliation structure in the meta-arkose which they intrude. The rock is generally massive with non-oriented hornblende prisms visible to the naked eye; locally, in particular around the margins of the bodies, a poor foliation has developed. A number of thin sills (generally less than 2 feet thick) of schistose green-black rock (too small to map) intrude the meta-arkose along bedding planes.

*Petrography*.—A thin section of the massive rock shows a mosaic of andesine containing matted masses of blue-green hornblende. The plagioclase is cloudy with incipient sericite and is characterized by the indistinct zoning common in the plagioclase of metamorphic rocks. Sporadic large grains of plagioclase show a ghostly polysynthetic twinning that is interpreted as relict from an original igneous fabric. Andesine makes up about 55 percent of the rock. Masses of small non-lineated prisms of blue-green hornblende ( $Z/\wedge C = 20$  to  $21^\circ$ ,  $\beta = 1.664 \pm .002$ , negative optic sign) constitute about 35 percent of the rock and have a shredded or matted appearance. Sporadic larger poikilitic grains of hornblende with good cleavage and a yellow-green to grass-green pleochroism are prominent. These larger grains of hornblende have a shredded periphery and may also be interpreted as relict from an earlier igneous fabric. Epidote occurs in grains and groups of grains throughout. Biotite (yellow-brown to dark olive-brown), ilmenite, sphene, leucoxene, apatite, and chlorite are present in minor quantities. The grain size of this rock ranges from 0.01 to 2 mm., plagioclase and epi-

dote constituting the finer grains. The chlorite, a clinocllore, occurs in plates and sheaves and was formed at the expense of the hornblende. The fabric is dominantly crystalloblastic but shows minor cataclastic effects (crushing, shredding). The rock is an epidote amphibolite that originated through metamorphism of a basic igneous rock, probably of the diorite or gabbro family.

A dark green fine-grained schistose amphibolite from a 2-foot sill in the meta-arkose was examined under the microscope. The section shows a fine-grained mosaic (0.03 to 0.05 mm.) of andesine (25 percent) and quartz (15 percent) containing masses of small prisms of blue-green hornblende unevenly distributed in layers. Although the hornblende in this rock possesses a fair lineation, it also exhibits the shredded appearance noted in the massive amphibolite. Sporadic larger hornblende crystals showing shredded borders probably are relicts from a previous igneous fabric. Hornblende makes up about 50 percent of this rock. Dark brown biotite, epidote, apatite, ilmenite, and sphene are present in minor quantities. The fabric is mainly crystalloblastic but crushing and shredding of grains indicates subordinate cataclasis.

*Quartz veins.*—Quartz-tourmaline veins and masses of quartz-tourmaline are common throughout the pre-Cambrian of the Wylie Mountains. The tourmaline, a brilliant black variety with E = pale pink-brown and O = deep gray-black, occurs in veinlets and masses of fine needles within the quartz. Tourmaline needles also are found on bedding plane and joint surfaces. Masses of quartz-tourmaline reach 4 feet in diameter. Smaller stringers without tourmaline are also present and commonly are contorted. Biotite has formed along the contact between the quartz veins and the country rock. This probably results from reaction between the potash and alumina of the country rock and the iron and silica in the vein-forming solutions.

#### PERMIAN ROCKS (Php AND Ph)

Hueco limestone composes a large part of the Wylie Mountains and forms a steep cliff on the western face of the mountains. As in the Van Horn Mountains, the basal Powwow member and an overlying gray cherty limestone are present.

The Powwow member (Php) in the Wylie Mountains is a medium- to coarse-grained soft red feldspathic sandstone, mostly conglomeratic, which probably represents a reworked regolith. Thickness, controlled by the pre-Hueco topography, is varied. An old pre-Hueco valley is well shown on the map (B.9—7.8, Pl. 6) by

the wedge of this clastic rock that occupies it. The sandstone grades upward into the overlying limestone through a zone of interbedded red to brown sandstone and brown silty limestone. Baker (1927, map) mapped the Powwow member of the area as Van Horn sandstone, which it closely resembles.

The limestone (Ph) overlying the Powwow member is a compact aphanitic gray limestone containing stringers, nodules, and irregular masses of brown chert; crystalline calcite in veinlets and as lining of cavities, manganese dioxide in veinlets and lining cavities. Echinoid spines and plates are common. Freshly broken limestone is dark gray to black with a strong fetid odor. It occurs in beds 6 inches to 6 feet thick, forms steep cliffs, and is in all respects similar to the limestone in the northwest Van Horn Mountains (pp. 34–36).

Two University of Texas master's degree candidates, E. F. McGee and H. Hay-Roe, mapped in the Wylie Mountains during the summer of 1951 and were kind enough to permit the writer to make advance use of some of their information. According to their measurements the Powwow member of the Hueco limestone ranges from 15 to 150 feet in thickness and averages about 60 feet in this area. They divided the overlying limestone into two members: (1) a lower gray-brown limestone, 660 feet thick, and (2) a black limestone, 80 feet thick. Aggregate thickness of the Hueco limestone in the western Wylie Mountains is 736 feet plus or minus 30 feet. A water well (Harper Mountain well) drilled about 1 mile east of the northern limit of the pre-Cambrian exposure encountered meta-arkose at 655 feet.

#### TERTIARY ROCKS (Tv)

Tertiary volcanic rocks (not differentiated by the writer) crop out to the south of the area on the downthrown block of the east-west fault. They are in direct fault contact with pre-Cambrian meta-arkose.

#### STRUCTURE

*Pre-Cambrian structures.*—The limited outcrop of Carrizo Mountain group in this area makes it difficult to interpret the structure. In the southern part of the ex-



posure the rocks strike northwest and dip southeast, except for changes caused by local folds. Folding increases to the north, and strikes range from northeast to northwest. Both north and south dips were measured in this area.

*Younger structures.*—The western face of the Wylie Mountains is a fault scarp caused by a north-northwest-trending normal fault, downthrown to the west, on which Hueco limestone is downfaulted against the Carrizo Mountain group. Baker

(1927, p. 42) estimates a minimum displacement of 300 feet.

A second normal fault trends east-west along the southern edge of the mountains and has dropped Tertiary volcanic rocks against meta-arkose of the Carrizo Mountain group and omits a Permian and Cretaceous sequence of unknown thickness. The normal faulting is younger than the early Tertiary volcanism and is probably of Miocene age or later (Baker, 1927, p. 37; King, 1935, p. 259).

## EAGLE MOUNTAINS

Peter T. Flawn

### SUMMARY

The Eagle Mountains rise from basin fill about 18 miles southwest of Van Horn. The range is made up chiefly of Permian, Cretaceous, and Tertiary (intrusive and extrusive) rocks, but on the northeast side pre-Cambrian rocks of the Carrizo Mountain group crop out in a semi-circular area between basin fill and unconformably overlying Hueco limestone (Pl. 7). They are cut off on the south by the Rhyolite fault (Gillerman, 1948, p. 516), a normal fault, trending east-west through the mountain block, which throws Permian against pre-Cambrian and Cretaceous against Permian (H.O.—2.3, Pl. 7).

### PRE-CAMBRIAN ROCKS

*General features.*—The exposure of Carrizo Mountain group in the Eagle Mountains is about 15 miles northwest of the line of strike which connects exposures of the group in the Van Horn and Wylie Mountains, and its rocks differ from those of the two preceding areas in both lithology and grade of metamorphism. They are much more similar to those in the Carrizo Mountains 6 miles to the northeast along the strike. In the Carrizo Mountain group of the Eagle Mountains five units are mappable, which comprise the following sequence, beginning with the lowest and oldest: (1) feldspathic metaquartzite; (2) meta-arkose; (3) mixed unit<sub>1</sub>, of interbedded metaquartzite, phyllite, and sericite schist, (4) mixed unit<sub>2</sub>—interbedded slate, phyllite, and limestone. These are intruded by (5) amphibolite.

The group forms a more or less conformable sequence that strikes east of north and dips steeply south, with about 5,000 feet of metasediments exposed. In general foliation is parallel to bedding, but there are local deviations related to small folds. The rocks show retrogressive changes, largely cataclastic, superimposed on a regional metamorphism.

*Feldspathic metaquartzite* (pCCq) (Table 9, modes I, II).—Feldspathic metaquartzite is the major lithologic unit in the Eagle

Mountains and the oldest rock exposed. The rock is a fine-grained hard brown quartzite that forms rough blocky ridges and makes up about 60 percent of the pre-Cambrian exposure. It comprises a thickness of 3,200 to 3,400 feet in continuous outcrop. Commonly the metaquartzite is micaceous (sericitic), and dark thin bands or lines of magnetite (or ilmenite) grains locally give it a striped appearance. Bedding is well preserved, and the sericite flakes are oriented parallel to the bedding. Cross-bedding is common and indicates that tops of the beds are to the southeast. Phyllite layers are interbedded.

*Petrography.*—In thin section the rock consists of a mosaic of quartz and feldspar containing oriented flakes of sericite, biotite, and chlorite. Quartz makes up from 70 to 80 percent of the rock, and microcline and albite range from 5 to 15 percent each. Mica usually is less than 5 percent, although one section showed a maximum of 10 percent sericite. Magnetite or ilmenite, apatite, zircon, sphene, leucoxene, and rutile are present as accessory minerals.

Recrystallization has not proceeded to the stage reached in the feldspathic metaquartzites of the Van Horn Mountains. The chloritic and sericitic material is more or less intergranular and no mica plates have formed. In one section the interfingering of biotite and chlorite, the bleached and faded appearance of the biotite, and the distribution of leucoxene and rutile within the biotite-chlorite areas suggest that the chlorite has formed at the expense of the biotite—a common retrograde metamorphic reaction. Locally the rock shows evidence of considerable shearing, namely, areas of crushed quartz and microcline augen partly converted to sericite. The fabric ranges from granoblastic to lepidoblastic, and the grain size ranges from 0.05 to 0.2 mm. Micro-layers of varied mica content and grain size are interpreted as original stratification. The rock was originally a feldspathic sandstone.

*Meta-arkose* (pCCma) (Table 9, mode III).—Conformably overlying the metaquartzite is a bed of fine-grained massive brown biotite-rich meta-arkose about 50 feet thick (maximum). The randomly oriented biotite plates are barely visible to the naked eye, and the rock is not foliated. To the west, contacts are obscure and the unit apparently pinches out; to the east it disappears beneath basin fill; the outcrop forms an elongate wedge which

tapers to the west. Thin beds of meta-quartzite and phyllite and thin layers of amphibolite are interlayered with the meta-arkose. It is separated from the next meta-sedimentary unit by an amphibolite sill.

*Petrography.*—Thin section shows poorly sized grains of quartz and twinned albite in a finer matrix of quartz, albite, and non-oriented biotite flakes (olive-brown variety). Epidote, chlorite (clinocllore), magnetite or ilmenite, and apatite are also present. The rock has not thoroughly recrystallized to an equigranular mosaic, and there is evidence of a relict clastic fabric. Sporadic grains of albite, some of which are sub-round or round, reach a diameter of 0.5 mm., although the average range in grain size is from 0.02 to 0.1 mm. The rock is composed of about 40 percent albite, 40 percent quartz, and 15 percent biotite. Originally this rock probably was a fine-grained ferruginous quartz-albite sediment, an albite-rich arkose.

*Mixed unit (pECm<sub>1</sub>) (Table 9, modes IV, V, VI, VII, VIII).*—This mixed unit makes up about 30 percent of the exposed area. An amphibolite sill is intruded along its lower contact, and it is overlain unconformably by the Hueco limestone. The unit consists of alternating thin beds of fine-grained brown metaquartzite, brown to gray phyllite, and fine-grained mica schist which average 2 to 5 feet thick. This unit is incompetent, and local folds and S<sub>3</sub> structures are common. Near the Rhyolite fault on the south the phyllite members are strongly crinkled and contorted. Folding makes it difficult to estimate the thickness of this unit, but 600 feet is a fair minimum figure.

Thin discontinuous layers (2 to 4 feet thick) of aphanitic white siliceous rock crop out near G.0—2.8, Plate 7. In the hand specimen this rock resembles novaculite. However, in the field the "novaculite" occurs in discontinuous bodies and cuts across the bedding. It is probably a metamorphosed vein rock that has been crushed and recrystallized.

*Petrography.*—Thin sections of the fine-grained schistose quartzite from this unit show grains of quartz (50 to 85 percent), albite (5 to 40 percent) and microcline (less than 5 percent) in part in a mosaic and in part surrounded by masses of sericite, chlorite, biotite, and finer crushed quartz (Table 9, modes VI, VIII). The chlorite (penninite) and biotite occur together and comprise about 7 or 8 percent. Sericite amounts to 15 percent in one slide where no biotite or chlorite is present. The biotite is partly bleached and has apparently altered in part to chlorite. Sphene, rutile, magnetite or ilmenite, apatite, and tour-

maline are present in minor quantities. Commonly the sphene and rutile are associated with the chlorite and probably formed from the titanium released by the alteration of the biotite. The rock has been subjected to shearing stress. The biotite is smeared out, and the streaks bend around mineral grains. Zones of finer material which are interpreted as crush-zones occur within the rock. Grain size ranges from 0.05 to 0.2 mm. The fabric is compound and shows elements of the original clastic fabric, subsequent recrystallization to a granoblastic or lepidoblastic fabric, and final development of mortar structure by incipient mylonitization.

A phyllite thin section shows a micro-layered rock composed of smeared, partly bleached biotite (30 percent), chlorite (penninite, 20 percent), and quartz (30 percent). Layers are defined by grain size and by biotite-chlorite content. Helicitic garnets almost completely altered to chlorite occur in elongate quartz "eyes" of relatively coarse grain. Almost completely sericitized feldspar, epidote, fibrous sericite, and tourmaline are present in minor quantities. The epidote occurs in a cross-cutting veinlet. The grain size of the rock ranges from 0.01 to 0.1 mm. Garnets average 1 mm.

The rock has a faded appearance that makes mineral identification and quantity estimation difficult. Originally the rock was a biotite-almandine schist, and the almandine garnet remnants show well-developed helicitic structure. A relatively coarse quartz mosaic crystallized in the pressure shadows of the garnets (photomicrograph, Pl. 36, B). Biotite is partly altered to chlorite, and porphyroblasts of chlorite can be seen growing across the foliation of the rock. The almandine garnet is likewise altered to chlorite, and each garnet relict is enveloped and veined by a mass of chlorite. The fabric is compound—a relict porphyroblastic fabric with a superimposed diaphoritic or retrograde fabric.

In thin section the "novaculite" is composed of about 98 percent quartz and feldspar (N < quartz) in a mosaic averaging 0.01 to 0.02 mm. Sporadic porphyroblasts of muscovite in poikilitic grains constitute 2 percent of the rock. Traces of biotite, chlorite, and zircon are present. The amount of feldspar in the fine-grained mosaic is difficult to estimate but is about equal to the quartz.

*Mixed unit (pECm<sub>2</sub>) (Table 9, modes IX, X).*—This unit is composed of dark slate, dark phyllite, and black limestone and is separated from the previously discussed unit by the Rhyolite fault. Its outcrop is bounded by the fault, the basin fill, and the unconformably overlying Hueco limestone. The exposure is almost completely concealed by colluvium from the massive Hueco cliff. The limestones of the mixed unit are aphanitic gray to black rocks with thin siliceous bands or laminae. They occur with dark slate and phyllite in beds less than 5 feet thick. Two of these impure limestones were thin sectioned.

**Petrography.**—Under the microscope the rocks show carbonate (55 to 75 percent) and quartz (10 to 30 percent) in a fine-grained mass. A fine opaque black sooty material, probably carbonaceous, occurs between the grains and may make up as much as 5 percent of the rock. Oriented biotite flakes, partly bleached, range from 1 to 10 percent. Sericite (up to 4 percent) is present in one of the slides. Magnetite or ilmenite and leucoxene are present in amounts less than 1 percent. Small blebs of opaque sulfides make up about 3 percent of one section. In reflected light these blebs are seen to be an intergrowth of three sulfides tentatively identified as pyrite, pyrrhotite, and chalcopyrite. Veinlets of carbonate cut the rocks. The rocks show a micro-layering defined by the quartz and/or carbon content of the layers. The grain size ranges from less than 0.01 to 0.05 mm. These rocks were originally carbonaceous silty black limestones containing iron sulfide and interbedded with black shales.

**Amphibolite (p<sub>F</sub>Ca) (Table 9, modes XI, XII, XIII).**—Two major sill-like bodies of amphibolite occur in the Eagle Mountain area; a number of smaller amphibolite bodies also occur but these were not mapped. The largest body is about 150 feet thick. The amphibolite is a green-black rock with grains less than 2 mm. in diameter. Small prisms of hornblende can be discerned with the naked eye, and local coarsenings are present. In some places the rock has been altered to a fine-grained apple-green epidotite. In general the rock is massive, although schistose outcrops are present.

The intrusive relation of the amphibolite to the metasedimentary rocks is well shown at two localities (G.4—3.5 and C.5—4.5, Pl. 7) where streams have cut steep-sided gullies.

**Petrography.**—The amphibolite was studied in three thin sections. It is composed mostly of non-oriented or poorly oriented laths and needles of hornblende in a plagioclase mosaic. Biotite (red-brown variety) is present in two of the sections and comprises as much as 10 percent of the slide. In the slide that does not contain biotite, quartz makes up 15 percent of the rock. Chlorite, a clinocllore, ranges from 3 to 10 percent. Epidote, magnetite or ilmenite, apatite, sphene, and rutile are present in minor quantities. Tourmaline makes up about 2 percent of the quartz-bearing amphibolite and apparently has replaced quartz and hornblende. Grain size ranges from 0.01 to 1 mm. Oligoclase-andesine comprises 10 to 45 percent of the bulk mineral composition of this rock. The plagioclase of the quartz-bearing amphibolite is slightly more sodic than the plagioclase in the other two rocks examined. In all three specimens the plagioclase occurs in an untwinned mosaic and in large subhedral grains that show a ghostly polysynthetic twinning. These subhedra are relicts

from the original hypidiomorphic granular igneous fabric. The plagioclase has partly altered to sericite or to sericite and epidote.

Hornblende makes up 35 to 60 percent of the rock. It occurs in large grains with straight-line boundaries and in masses or "fels" of fine needles commonly associated with masses of fine biotite flakes. The larger grains have a core of faded, "sickly" hornblende, unevenly pleochroic in pale grass-green, surrounded by a border of blue-green hornblende. The needles of hornblende are the blue-green variety. Commonly the blue-green borders of the large grains have a matted appearance. The larger grains are relicts of the original pale grass-green hornblende of the igneous rock which have escaped conversion to the blue-green metamorphic hornblende. Optical properties of the two hornblendes differ slightly. Both varieties are optically negative. The grass-green variety has a slightly larger extinction angle (by 2 or 3 degrees), smaller optic angle, and a slightly higher birefringence. The blue-green variety has  $Z \wedge C = 17$  to 18 degrees and  $\beta = 1.667 \pm .002$ . (It was not possible to distinguish the two varieties of hornblende with the immersion technique.)

The amphibolite has a compound fabric. The original igneous fabric, which was hypidiomorphic granular, has not been completely erased by metamorphism. Metamorphism has partly broken down the large hornblende grains into masses of small needles and has partly recrystallized the plagioclase. Epidote and chlorite indicate a trend toward a metamorphic grade that is lower than that indicated by the andesine plagioclase and more nearly in line with the associated phyllites and sericite schists. It is not possible to distinguish a progressive and a retrograde metamorphic fabric, and the amphibolite probably experienced only the later cataclastic metamorphism. Evidence to support this conclusion was found in the study of the Carrizo Mountain amphibolites and is presented in a following section.

A green schist crops out along the eastern margin of the area and is partly obscured by basin deposits. This is a chlorite-albite-quartz schist containing minor amounts of biotite, magnetite or ilmenite, sphene, apatite, epidote, and leucoxene (Table 9, mode XIV). The chlorite has apparently formed at the expense of biotite. The long axes of the quartz and feldspar are aligned, and the chlorite is bent around these grains. This rock probably is a metamorphosed shale or possibly a dacitic tuff.

In the same area is a small outcrop of an aphanitic white rock with black spots 2 to 3 mm. in diameter (Table 9, mode XV). In thin section this rock shows a sutured mosaic of quartz and albite (0.02 to 0.25 mm.) containing large porphyroblastic radiating masses of tourmaline (E = pale pink; O = gray) several mm. in diameter. Rutile or cassiterite occurs within the tourmaline. Apatite, zircon, and muscovite are also present. The tourmaline and rutile (or cassiterite) were probably introduced by hydrothermal agencies. Osann (1893, p. 136) described a similar rock "from the railroad near Van Horn" as a "tourmaline hornfels." He was not able to determine positively whether the yellow mineral

Table 9. Estimated modes of pre-Cambrian rocks from the Eagle Mountains.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
Quartz .....	80	78	38	90	35	70	30	85	30	10	15	...	...	50	50
Microcline.....	15	...	...	...	...	5	5	...	...	...	...	...	...	...	...
Plagioclase.....	...	5ab	40ab	6ab	45ab	15ab		...	...	...	10olig	40an	45ab	45ab	35ab
Muscovite.....	...	...	2	...	...	...	...	...	...	...	...	...	...	tr	...
Sericite.....	5	10	...	...	10	1	5	15	4	...	...	...	...	...	...
Biotite.....	...	2	15	1	7	4	30	...	1	10	...	2	10	tr	...
Hornblende.....	...	...	...	...	...	...	...	...	...	...	60	40	35	...	...
Apatite.....	...	...	...	...	tr	tr	...	...	...	...	3	1	tr	...	tr
Zircon.....	tr	tr	...	tr	tr	...	...	...	...	...	...	...	...	...	tr
Chlorite.....	...	...	2c	1	1	3p	20	...	...	...	5c	10c	3	5c	...
Sphene.....	...	...	...	...	...	1	...	...	...	...	1	1	...	...	...
Rutile.....	...	...	...	...	tr	tr	...	tr	...	...	...	tr	...	...	tr
Magnetite or ilmenite.....	tr	2	2	...	1	tr	...	...	tr	1	2	5	4	tr	...
Garnet.....	...	...	...	...	...	...	5	...	...	...	...	...	...	...	...
Epidote.....	...	...	3	...	...	...	5	...	...	...	2	1	3	tr	...
Tourmaline.....	...	...	...	...	...	...	...	tr	...	...	2	...	...	...	15
Carbonate.....	tr	...	...	...	...	...	...	...	60	76	...	...	...	tr	...
Leucoxene.....	...	3	...	...	...	...	...	...	...	tr	...	...	...	...	...
Iron sulfides.....	...	...	...	...	...	...	...	...	...	3	...	...	...	...	...
Carbon.....	...	...	...	...	...	...	...	...	5	...	...	...	...	...	...
Totals .....	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

ab = albite  
olig = oligoclase  
an = andesine  
p = penninite  
c = clinoclase

- I, Feldspathic metaquartzite; average grain size 0.05 to 0.2 mm.  
 II, Sericitic feldspathic metaquartzite; average grain size 0.1 mm.  
 III, Biotitic meta-arkose; grain size 0.02 to 0.1 mm.  
 IV, Aphanitic white siliceous rock; average grain size 0.01 to 0.02 mm.  
 V, Sericitic meta-arkose; grain size 0.05 to 0.2 mm.  
 VI, Feldspathic metaquartzite; grain size 0.05 to 0.2 mm.  
 VII, Chlorite-biotite phyllite; grain size 0.01 to 0.1 mm.; porphyroblasts 1 mm.  
 VIII, Sericitic metaquartzite; grain size 0.02 to 0.2 mm.  
 IX, Slaty black limestone; grain size 0.01 to 0.04 mm.  
 X, Pyritiferous black limestone; grain size less than 0.01 to 0.05 mm.; biotite laths → 0.3 mm.  
 XI, Amphibolite; average grain size 0.20 mm.  
 XII, Amphibolite; grain size 0.5 to 1 mm.  
 XIII, Amphibolite; grain size less than 0.01 to 5 mm.  
 XIV, Chlorite-albite schist; average grain size 0.1 mm.  
 XV, Tourmaline-albite-quartz rock; grain size less than 0.01 to 2 mm.

is rutile or cassiterite but stated "in all likelihood this mineral is cassiterite. . . ."

*Quartz-tourmaline veins.*—Masses of white quartz containing black tourmaline and ilmenite occur throughout the area. These masses are broken lenses and veins, and locally fractures in individual tourmaline crystals are filled with quartz. The broken and crushed nature of these masses suggests they may be a product of a pre- or syn-metamorphic period of hydrothermal activity.

#### PERMIAN ROCKS (Php AND Ph)

As in the Van Horn and Wylie Mountains, the Carrizo Mountain group of the Eagle Mountains is unconformably overlain by Hueco limestone. The basal Powwow member (Php) here consists of a fine- to coarse-grained red to brown conglomeratic sandstone with boulder conglomerate locally at the base. The conglomerate consists of quartzite boulders up to 2 feet in diameter and is restricted to the topographic lows of the old pre-Permian surface. Thickness of the member varies between 20 and 30 feet. It grades up into compact aphanitic gray cherty limestone that forms cliffs around the pre-Cambrian exposure.

Gillerman (1948, p. 511) has observed between 400 to 1,000 feet of the upper limestone member of the Hueco in the Eagle Mountains, but in the vicinity of the pre-Cambrian exposure no more than 200 or 250 feet is present. At the northwestern limit of the pre-Cambrian area (B.0—5.0, Pl. 7) a thrust fault repeats the Hueco and greatly increases its thickness. The existence of this fault was called to the writer's attention by P. W. Beckley.<sup>12</sup>

#### CRETACEOUS ROCKS (Kcx)

The Cox sandstone overlies the Hueco limestone of the Eagle Mountains with slight unconformity.<sup>13</sup> In the vicinity of the pre-Cambrian area the Cox is composed of medium- to coarse-grained brown sandstone containing thin beds of siltstone and beds of chert-free light-gray limestone 4 to

5 feet thick. Chert pebbles are common in the sandstone. The Cox sandstone of this area is very similar to that of the Van Horn Mountains.

With the exception of two Tertiary dikes too small to map, no younger rocks are present in the vicinity of the pre-Cambrian area.

#### STRUCTURE

*Pre-Cambrian structures.*—The major pre-Cambrian structure is a homocline which strikes northeast and dips steeply southeast. Small-scale local folds are mostly restricted to the relatively incompetent mixed units. In the area located by coordinates G.0—2.9, Plate 7, is a prominent overturned isoclinal fold, probably formed by drag. Near it, schistosity transects bedding and is apparently an axial plane cleavage. This is the only observed deviation from the prevailing bedding-plane schistosity, although crenulations and chevron folds ( $S_3$  structures) are present in the phyllite members of the mixed units.

*Younger structures.*—The Carrizo Mountain group in the Eagle Mountains is exposed on the upthrown side of the Rhyolite fault, an east-west-trending normal fault. Gillerman (1948, p. 512) has recognized two ages of Tertiary normal faulting in the Eagle Mountains: a northwest-trending series and a younger east-west-trending series, to which the Rhyolite fault belongs. The latter involve Tertiary igneous rocks farther west, which are downthrown southward in the order of hundreds of feet, and also show large components of horizontal displacement, the south side moving to the east.

Beyond the northwest limit of the pre-Cambrian area a low-angle thrust fault lies within the Hueco limestone and dips gently westward approximately parallel to the bedding; it apparently carries the rocks of the upper plate eastward over the lower. It has formed near the top of the formation, as a slice of Cox sandstone is present beneath it at one locality (B.8—5.2, Pl. 7). Farther north, the Hueco-Cox contact is repeated by the fault, but the displacement is apparently not great (P. W. Beckley, personal communication, August 1951). Gillerman (1948, p. 512) interprets

<sup>12</sup> Personal communication from Philip W. Beckley, Surface Geological Company, San Angelo, Texas, August 1951.

<sup>13</sup> Philip W. Beckley, Surface Geological Company, San Angelo, Texas, reports 5 to 15° angular discordance in the general area (personal communication, 1950).

the low-angle thrust faults of the Eagle Mountains as earlier than the Tertiary igneous activity and normal faulting.

Southward, the thrust fault ends against a small northwest-trending normal fault

with a vertical displacement of about 30 feet. Its relation to the thrust fault suggests that it is a tear fault, but within the small exposure its horizontal displacement could not be determined.

## CARRIZO MOUNTAINS

Peter T. Flawn

### SUMMARY

The Carrizo Mountains are a mass of rugged hills about 3 miles due west of Van Horn. In this paper the name is restricted to the mountain area between the Southern Pacific Railroad on the south and the Texas and Pacific Railroad on the north, although the U. S. Geological Survey's old topographic map of the Van Horn quadrangle (edition of 1906) includes the hilly country north of the Texas and Pacific Railroad in the Carrizo Mountains. The greater part of the Carrizo Mountains is composed of barren northeast-trending ridges of the Carrizo Mountain group. These pre-Cambrian rocks are bordered by scarps of Permian limestone on the south near Bass Canyon (topographically a pass rather than a canyon) and on the north near the Texas and Pacific Railroad. The Permian on the south lies unconformably on the pre-Cambrian but on the north is down-dropped against it along the Hillside fault. To the east and west the pre-Cambrian rocks disappear beneath unconsolidated basin deposits. U. S. highway No. 80 crosses the Carrizo Mountains just south of the Texas and Pacific Railroad, and many of the characteristic rock types appear in the road cuts (see Appendix, I).

### PRE-CAMBRIAN ROCKS

*General features.*—The Carrizo Mountain group of the Carrizo Mountains is made up of metasedimentary and meta-igneous rocks which are tilted steeply to the southeast and strike generally northeast. Thirteen metasedimentary units and three intrusive meta-igneous units have been distinguished and mapped on the basis of contrasting lithologic character and topographic expression (Pl. 1). The metasedimentary units are of formation rank but have not been named because of their small areal exposure and the paucity of available geographic names. Some of these different units are rather similar; several of them, for example, are designated as metaquartzites, although they occur as separate bands in different parts of the area. The bands probably are distinct units

in the sequence and not the same bed repeated by isoclinal folding. In succeeding descriptions, the titles of the rock units correspond to the lithologic designations and letter symbols used on the accompanying geologic map (Pl. 1).

The original sedimentary rocks in the Carrizo Mountain group in this area have undergone two periods of metamorphism and have been injected several times by igneous rocks, so that a great deal of their original stratigraphic character has been disturbed and destroyed. In particular, thicknesses in the incompetent units have been greatly increased as a result of crumpling. Original sedimentary structures such as cross-bedding are best preserved in the quartzo-feldspathic units, where there has been little metamorphic change other than recrystallization.

In order to present an over-all picture of the stratigraphy of the Carrizo Mountain group in the area, the writer has estimated thicknesses of the different units that are of at least the approximate order of magnitude. These are illustrated in the stratigraphic column of Table 10. The sequence is formed of about 19,000 feet of sedimentary rocks, but this figure includes many thin amphibolite sills too small to map. Intercalated in the sequence are five large sill-like bodies of amphibolite with a combined thickness of 5,600 feet and two sills of metarhyolite with a combined thickness of 2,100 feet. The nature and thickness of the large intrusive bodies of metarhyolite and amphibolite in the northwest part of the area are uncertain, but outcrops of each have a minimum breadth of over a mile (Pl. 1).

Foliation in the rocks of the group ( $S_2$ ) is closely parallel to the general homoclinal structure and to the bedding where this can be observed. On the map (Pl. 1), strike and dip of bedding is not differentiated from that of foliation. In many places in the area, but particularly toward the northwest, the foliation has been deformed by crenulation and chevron folds, which are  $S_3$  structures. These may be related to northwestward thrusting of the rocks of the group on the Streeruwitz thrust fault.



The rocks are now in the greenschist facies (Turner, 1948, p. 93), having retrogressed from a higher regional metamorphic grade. The retrogressive metamorphism apparently resulted from dislocation during the time in which the Carrizo Mountain group was thrust northwestward over the Allamoore formation along the Streeruwitz fault.

In the following pages the pre-Cambrian rocks of the Carrizo Mountains are described in order of stratigraphic succession, beginning with the lowest, which are exposed in the northwestern part of the

mountains, and progressing southeast down the dip.

#### METASEDIMENTARY ROCKS OF MAIN SEQUENCE

*Meta-arkose* (pECq<sub>1</sub>).—This unit occurs in the extreme northwestern part of the Carrizo Mountains in several irregular disconnected blocks that appear to be roof pendants in a large intrusive mass that is now amphibolite (D.0—10.0, Pl. 1). The stratigraphic relations of the unit are obscured by large-scale intrusion and over-

Table 10. Stratigraphic column of the Carrizo Mountain group in the Carrizo Mountains.

Thick- ness (feet)	Unit	
META-IGNEOUS ROCKS		
	pECg	Granodiorite: limited in occurrence; apparently the youngest pre-Cambrian intrusion and probably a late phase of the amphibolite
	pECa	Amphibolite: intimately intrudes all older rocks in the sequence
	pECmr	Metarhyolite: intrudes metasedimentary rocks and is intruded by amphibolite
METASEDIMENTARY ROCKS		
3400 min.	pECq <sub>6</sub>	Metaquartzite and sericite schist: in fault contact with pECm <sub>4</sub> and concealed by bolson deposits to west; may be faulted part of pECq <sub>5</sub> : stratigraphic relations uncertain
—?—?—?—?—?—?		
?	pECls	Limestone: limited outcrop between metarhyolite sill and bolson deposits; stratigraphic relations uncertain
—?—?—?—?—?—?		
2700 min.	pECq <sub>5</sub>	Metaquartzite and meta-arkose: in direct contact with pECm <sub>4</sub> ; partly concealed by Paleozoic rocks and bolson deposits; forms light-gray hills
400±	pECm <sub>1</sub>	Mixed unit: directly overlies pECq <sub>4</sub> ; intruded by metarhyolite, amphibolite, granodiorite, and Tertiary diabase, in part concealed by Paleozoic rocks and bolson deposits
300±	pECq <sub>4</sub>	Metaquartzite and meta-arkose: in part directly overlying pECm <sub>3</sub> , in part separated from it by amphibolite intrusion; forms ridges to east. becomes more micaceous and less resistant to west
2000±	pECm <sub>3</sub>	Mixed unit: separated from pECm <sub>2</sub> by metarhyolite sill; intruded by thin amphibolite sills
500±	pECm <sub>2</sub>	Mixed unit: intimately penetrated and stoped by amphibolite intrusion; loses identity as a unit to west; lies between metarhyolite and amphibolite intrusions
600±	pECp	Phyllite: discontinuous outcrop between pECq <sub>3</sub> and amphibolite intrusion; intimately penetrated and stoped by amphibolite
1700±	pECq <sub>3</sub>	Meta-arkose: in part directly overlying pECm <sub>1</sub> , in part separated from it by amphibolite; intruded by amphibolite; forms prominent ridge
1700±	pECm <sub>1</sub>	Mixed unit: directly overlies pECq <sub>2</sub> ; intruded by thin amphibolite sills: forms broad lowland
1800±	pECq <sub>2</sub>	Meta-arkose and metaquartzite: intruded by amphibolite along lower contact; forms prominent white ridge
—?—?—?—?—?—?		
3700± max.	pECcm <sub>5</sub>	Chlorite-mica schist: surrounded by intrusive amphibolite and metarhyolite; stratigraphic relations uncertain
—?—?—?—?—?—?		
?	pECq <sub>1</sub>	Meta-arkose: occurs mostly as roof pendants in a large amphibolite intrusive; stratigraphic relations uncertain

lap of bolson deposits. Another metasedimentary unit, chlorite-mica schist (pCCms) crops out north and southeast of the meta-arkose unit. Toward the southeast, at two places where original relations have not been disrupted by intrusions (G.0—11.0 and F.0—10.0, Pl. 1), the meta-arkose dips beneath the chlorite-mica schist with apparent conformity and is evidently older. To the north the meta-arkose is so separated from the chlorite-mica schist by intrusive rocks, or so concealed by alluvium, that the relations of the two units are not clear.

For the most part the meta-arkose is fine grained, light gray, and slightly schistose, but it includes thin layers of sericite schist and phyllite. The sericite content of the rock imparts a foliation that is parallel to the bedding, resulting in a slabby, platy outcrop.

*Petrography.*—In thin section the meta-arkose shows a granoblastic mosaic of quartz and feldspar. Cataclasis is indicated by areas of crushing and shearing. In general the feldspar is albite, accompanied by microcline in some sections. It is difficult to identify and correctly estimate percentages of feldspar in these rocks because of fine grain size, crushed areas, and finely divided sericite. Sericite makes up as much as 15 percent of the rock and occurs as layers of fine fibers or as fine intergranular fibers that appear as a braided network. Chlorite (clinochlore), magnetite or ilmenite, leucoxene, apatite, zircon, rutile, and tourmaline are present in minor amounts. Grain size ranges from less than 0.01 mm. to 0.5 mm. and averages 0.1 to 0.2 mm. Estimated modes of representative rocks are given in Table 11.

*Chlorite-mica schist (pCCms).*—Chlorite-mica schist forms a low hilly area of dark-colored rocks in the northwest Carrizo Mountains (E.0—13.0 to F.0—10.0, Pl. 1). The outcrops are surrounded by metarhyolite hills to the north, east, and south and by amphibolite hills to the southwest. Profuse intrusion has separated the chlorite-mica schist into five isolated masses surrounded, for the most part, by intrusive metarhyolite and amphibolite, and stratigraphic relations are not clear. Maximum thickness included between the bordering intrusive rocks is roughly 3,700 feet. This unit corresponds to the "chlorite schist" of King and Knight (1944).

The unit is composed of a wide variety of metasedimentary types. The most abundant is fine-grained lustrous dark sericite-chlorite-biotite schist, which forms most of the low hilly ground within the outcrop

area. Thin beds of dark slate and phyllite occur within the schist, and thin limestone beds (less than 5 feet thick) are rarely present. On a prominent ridge in the southern half of the principal exposure are more resistant coarser meta-arkose beds with intercalated highly crinkled phyllite layers. Flattened pebbles in some of the meta-arkose beds indicate their original conglomeratic nature. The phyllitic rocks were probably shales or tuffs.

Bedding ( $S_1$ ) is particularly well preserved in the more competent arkosic members, but it is obscure in the phyllitic and highly schistose members. Schistosity ( $S_2$ ) is broadly parallel to the bedding, but locally it transects bedding at small angles. Where the unit abuts more competent metarhyolite, it is strongly crinkled and contorted, apparently by a later structure ( $S_3$ ) resulting from mashing of incompetent schist against the metarhyolite, during the northward thrusting. Lineation, interpreted here as a lineation, was measured at one place (E.3—13.5, Pl. 1) and is parallel to lineation within the metarhyolite. The nature and origin of the lineation are discussed in the section on structure.

*Petrography.*—Under the microscope the schist shows elements of lepidoblastic and cataclastic fabrics. Oriented plates and smeared out masses of biotite, chlorite, and sericite occur in a strained and crushed mosaic of quartz and feldspar. In some sections the green-brown biotite is partly bleached to a red-brown variety and in other sections has gone over to chlorite (penninite). The feldspar is chiefly albite, but microcline was observed in one section. Zircon, magnetite or ilmenite, leucoxene, and tourmaline are present as accessory minerals. Micro-folding and micro-thrust-faulting were observed in association with the  $S_2$  structures. Average grain size ranges from less than 0.01 to 0.5 mm., although sporadic larger pebbles are present in the meta-arkose beds. Estimated modes of representative rocks of the unit are given in Table 11.

The fine grain size and the general smeared and crushed appearance of the rock, the faded and "sickly" character of the biotite, and the disequilibrium indicated by its partial conversion to chlorite indicates retrogressive metamorphism.

*Meta-arkose and feldspathic metaquartzite (pCCq<sub>2</sub>).*—This unit forms a prominent white ridge that trends northeast-southwest through the entire mountain mass and is offset by a fault at the northeast end (O.0—14.5 to G.0—8.2, Pl. 1). Beds are vertical or dip steeply southeast. The unit is separated from older sedi-

mentary rocks of the sequence by a thick amphibolite sill intruded along its lower contact. The thickness of the unit varies as measured across the outcrop because of the somewhat irregular trace of the intrusive contact, but 1,800 to 2,000 feet is a fair maximum thickness. Rocks of the unit are fine-grained thin-bedded light gray feldspathic metaquartzite and meta-arkose. Bedding and cross-bedding are visible and indicate that the top of the unit is toward the southeast. Foliation parallel to the bedding causes the rock to break into thin slabs and plates, on the surfaces of which is a sericitic sheen.

*Petrography.*—Thin sections of representative rocks from the unit show a cataclastically altered granoblastic mosaic of quartz and feldspar, containing a variable amount of sericite. Partly bleached biotite, chlorite (penninite), magnetite or ilmenite, leucoxene, apatite, zircon, carbonate, and rutile are present as minor constituents. The feldspar is albite or albite and microcline and makes up 20 to 57 percent of the bulk mineral composition. The fine grain size, fine sericite, and cataclastic alteration make it difficult to separate the two feldspars. The grid twinning of the microcline is vague and obscure. Estimated modes are given in Table 11.

*Mixed unit* (pCCm<sub>1</sub>).—This unit forms a northeast-southwest-trending lowland that extends through the entire mountain mass and is known locally as Cat Draw (O.0—14.0 to H.0—8.0, Pl. 1). The rocks directly overlie the quartzo-feldspathic unit previously described (pCCq<sub>2</sub>) and consist of a sequence of intercalated thin beds of fine-grained gray and blue quartzite, light-gray sericite schist, dark phyllite, dark lustrous slate, thin-bedded blue chert, thin-bedded to laminated brown and black cherty limestone, and thin layers of amphibolite. The abundant limestone beds, commonly showing intricate folding, distinguish this mixed unit from others in the sequence. Intrusion of amphibolite, complicated small-scale folding, and contortion have greatly increased the thickness of the original sedimentary unit which now has a thickness of about 1,700 feet. In the unit as a whole foliation is parallel to the bedding. The unit corresponds to the "limestone and slate" of King and Knight (1944).

*Petrography.*—These rocks are very fine grained to cryptocrystalline and yield little additional information under the microscope. Estimated modes of three specimens from the unit are given

in Table 11. Two thin sections of limestone from the unit were examined. The rocks are composed chiefly of calcite in a twinned mosaic. Grains range from 0.05 to 0.2 mm. to 1 to 2 mm. Quartz occurs in scattered grains and patches of grains and in places makes up as much as 15 percent of the slide. Albite, sericite, and iron oxide are present in minor amounts.

*Meta-arkose* (pCCq<sub>3</sub>).—In the northeastern part of the area, meta-arkose directly overlies the mixed unit previously described (O.0—13.0, Pl. 1); in the southwest part of the area the meta-arkose is separated from the mixed unit by an amphibolite sill about 700 feet thick which intrudes both the mixed unit and the meta-arkose (J.0—9.0, Pl. 1). Two other major amphibolite intrusions occur within the meta-arkose. The unit is composed of two distinct lithologic types, a gray meta-arkose and a reddish brown meta-arkose (not differentiated on Pl. 1), and has a thickness of about 1,700 feet, although measurements vary in different parts of the area because of the intrusions.

The gray meta-arkose comprises approximately the lower 800 feet of the unit and is fine-grained, thin- to medium-bedded sericitic rock with platy or slabby outcrop. Pebbles, stratification, and cross-bedding are prominent, and cross-bedding indicates that the top of the unit is to the southeast, in normal order. Lying with sharp contact on the gray meta-arkose is about 250 feet of hard, red-brown meta-arkose in beds up to 2 feet thick, which form a blocky resistant outcrop on the crest of a ridge. Bedding and cross-bedding are present but are less well developed than in the gray meta-arkose. During field work, this ridge-making member was suspected of being a meta-igneous unit, perhaps originally a soda aplite. This was disproved by discovery of relict sedimentary structures. The red-brown meta-arkose member grades up into the top member of the unit, a softer, less brittle, gray to buff sericitic meta-arkose that is similar to the lower member of the unit. The gray sericitic meta-arkose is plainly foliated when examined under the microscope, but the foliation is not obvious in the field except in sporadic thin mica-rich layers. The red-brown meta-arkose is not foliated.

P. B. King (personal communication, 1951) informed the writer that in an ex-

posure once present in a road cut along U. S. highway No. 80 (0.5—12.9, Pl. 1) the meta-arkose of this unit showed ripple-marks which may have been relict sedimentary structures. When the writer viewed this surface in 1950 it had been damaged (possibly by the eager hammers of itinerant geologists), and no reliable deductions could be made as to the nature of the ripples (whether sedimentary structures or tectonic pseudo-ripples). However, cross-bedding is distinct, particularly in smooth outcrops in streams south of the road and in a series of observations indicated a normal section.

*Petrography.*—Estimated modes of representative rocks of this unit are given in Table 11. The gray meta-arkose is composed of grains of feldspar, quartz, and quartz mosaic (0.2 to 0.5 mm.) in a matrix of fine quartz (less than 0.02 mm.) and finely divided sericite. The finely comminuted quartz and sericite have flowed around the larger grains as a result of incipient mylonitization. Sericite comprises as much as 15 percent of the rock. The feldspar, albite and microcline, is difficult to assess quantitatively in the slides examined. Albite and microcline together constitute about 30 percent of the rock. Magnetite or ilmenite, zircon, and rutile are present in small quantities. The fabric is cataclastic.

The hard brown or red-brown meta-arkose associated with the gray rock is also cataclastic (photomicrograph, Pl. 34, A). Strained grains of quartz with sutured edges, albite, and perthite occur in a fine crush matrix. Partly bleached biotite, magnetite or ilmenite, zircon, and apatite also are present. Grain size ranges from less than 0.01 mm. for the crush material to 0.5 mm. for the uncrushed grains. This rock, like the above, shows the mortar structure of incipient mylonitization. Where crushed material is at a minimum, the rock shows a sutured mosaic of albite and quartz.

*Phyllite* (pCCp).—Directly over the meta-arkose (pCCq<sub>3</sub>) is a blue-gray phyllite about 600 feet thick. This forms a narrow lowland between the meta-arkose ridge and a massive amphibolite ridge (P.0—13.0 to M.O—10.0, Pl. 1). Amphibolite intrusions occur along both hanging and footwall contacts and within the phyllite, where there are also thin layers of chlorite-epidote schist (probably sheared amphibolite sills). Locally the rock is slaty. The slaty cleavage must be approximately parallel to the bedding as it is parallel to the plane of the contact with the underlying meta-arkose; however, bedding laminae are not evident in the phyllite itself.

*Petrography.*—In thin section the phyllite is seen to be a very fine lepidoblastic mass of quartz, finely divided opaque mineral (probably magnetite), biotite, and sericite. Traces of apatite and leucoxene are also present. The biotite is a faded green-brown variety occurring in masses and scattered plates. It makes up approximately 25 percent of the rock. Grain size is less than 0.02 mm. The phyllite contains unusual spherical masses a few millimeters in diameter, which protrude like porphyroblasts on cleavage surfaces. Thin sections reveal that the masses are poor in mica and rich in magnetite; they may be relicts of former porphyroblasts destroyed during retrogressive metamorphism.

*Mixed unit* (pCCm<sub>2</sub>).—This unit is mappable only in a small area in the northeast part of the mountains, where it occurs between a thick amphibolite sill on the footwall contact and a thick rhyolite sill on the hanging wall contact (P.0—11.0 and Q.0—12.0, Pl. 1). It is obscured by remnants of unconformably overlying Van Horn sandstone north of U. S. highway No. 80 and by recent alluvium south of the highway. To the southwest the unit is intimately penetrated by amphibolite and loses its identity. Some of the beds crop out within the amphibolite and are traceable for short distances as thin partitions within the meta-igneous rock. On aerial photographs these partitions, lighter in color than the amphibolite, stand out remarkably and give the amphibolite a striped appearance.

The mixed unit is composed of about 500 feet of thin-bedded fine-grained gray metaquartzite, brown cherty limestone, gray sericite schist, and blue to green slaty rocks which in places have been thrown into small folds. Apparently these rocks were first intruded by rhyolite along the hanging wall contact and then by amphibolite along both contacts and throughout the unit. The unit is probably a part of the mixed unit stratigraphically above and to the southeast (pCCm<sub>3</sub>) and was separated from it by the two intrusions.

*Petrography.*—A thin section of a limestone member of this unit was examined. The rock is composed of 95 percent calcite with small amounts of chlorite, muscovite, quartz, and iron oxide in an uneven-sized mosaic ranging from less than 0.02 mm. to 0.5 mm. (Table 11). The fabric is granoblastic.

*Mixed unit* (pCCm<sub>1</sub>).—Southeast of the rugged metarhyolite ridge that culminates in Hackett Peak is a lowland developed

on another mixed unit (P.0—10.0 to I.0—6.0, Pl. 1). This consists of fine-grained sericitic quartzite, fine-grained biotite-sericite schist, and phyllite. One bed of brown cherty limestone 5 feet thick is present about midway in the unit, and some of the schists contain calcite. Thin sills of amphibolite occur throughout, and a rhyolite dike 4 feet thick cuts across the metasediments in the southwest part of the area (J.0—7.0, Pl. 1). Present thickness of the unit is about 2,000 feet but it has been thickened by local folding and contortion. Foliation is approximately parallel to the original bedding, but it is locally distorted by  $S_8$  structures (crenulations), particularly near the contact with the metarhyolite.

*Petrography.*—Estimated modes of representative rocks of this unit are given in Table 11. The schistose rocks are composed of oriented plates and fibers of biotite, chlorite, and sericite in a mosaic of quartz and feldspar with or without calcite. In some sections biotite has a "digested" appearance and in others seems to have gone over to chlorite. Except where partly bleached, the biotite is a dark brown variety. Partial bleaching results in a faded fibrous red-brown variety. The chlorite is penninite and occurs as discrete plates or as fibers and masses with biotite. Sericite occurs in fibers, streaks, and matted layers. In most sections the feldspar is albite. Microcline and microcline-micropertite accompany albite in one section. Where cataclastic phenomena are pronounced the feldspar occurs as lenticular crushed areas of low relief. Quartz makes up a large proportion of the fine-grained mosaic but also occurs in coarser "eyes" and layers. Magnetite or ilmenite, brown iron oxide, and apatite occur in minor amounts.

All the rocks of the unit are micro-layered, with numerous mica-rich, quartz-rich and carbonate-rich layers. This layering is either the result of a tectonic unmixing associated with metamorphism or is an original sedimentary feature. In the schistose rocks small rucking and chevron folding of the more micaceous layers are common, and in the quartz-feldspathic rocks crushing, straining, and development of augen are characteristic. These fabrics are a combination of lepidoblastic and cataclastic elements and may be classed as compound fabrics. Grain size ranges from less than 0.02 mm. in phyllitic rocks to 0.05 to 0.1 mm. in the schists and quartzites.

One thin section of the limestone from this unit was examined. The rock is composed equally of twinned calcite and quartz with the minerals distributed in layers. Sericite, magnetite or ilmenite, and red iron oxide are also present. Grain size ranges from 0.05 to 0.20 mm. (photomicrograph, Pl. 36, C).

*Feldspathic metaquartzite and metaarkose* (pCC<sub>q4</sub>).—This unit directly over-

lies the mixed unit previously described (Q.0—10.0 to J.0—6.0, Pl. 1). It is made up of light-gray sericitic feldspathic metaquartzite that forms a prominent ridge in the northeastern part of the outcrop. To the southwest the mica content increases and the unit becomes more schistose, losing its ridge-making character, probably because of an increase in content of argillaceous material in the original sediment. Bedding and cross-bedding are visible and the latter indicates a normal southeast dip; the unit is about 300 feet thick. Foliation has developed that is about parallel to the bedding but which locally cuts the bedding at small angles. To the northeast a north-east-trending fault horizontally displaces the quartzite ridge.

*Petrography.*—In thin section the rock shows a granoblastic-cataclastic fabric. Quartz comprises most of the slide and occurs as grains within the mosaic, in crushed areas, and as secondary quartz in veinlets parallel to the schistosity. Albite is the principal feldspar, although a few grains of microcline were noted. Sericite is present as fine fibrous intergranular material. Magnetite or ilmenite, leucocoxene, tourmaline, apatite, and zircon are present as accessory minerals. The tourmaline appears to be a secondary mineral introduced by the hydrothermal agencies that operated throughout the area. The grain size ranges from less than 0.01 mm. in the crush areas to 0.3 mm. (Table 11).

*Mixed unit* (pCC<sub>m4</sub>).—This unit is separated from the meta-arkose previously described (pCC<sub>q4</sub>) by intrusive bodies of metarhyolite and amphibolite (P.0—9.0 to K.0—6.0, Pl. 1). The area of exposure is complicated by metarhyolite, amphibolite, and granodiorite intrusions (pre-Cambrian), Tertiary diabase intrusions, and faulting, and is obscured by unconformably overlying Van Horn sandstone, Hueco limestone, and bolson deposits. Intricate small-scale folding is common, and the beds are contorted locally. The unit is roughly 4,000 feet thick. The rocks are chiefly fine-grained schists and phyllites, but fine-grained schistose quartzites are present. Thin sills of amphibolite are common, and massive irregular-shaped granodiorite intrusions occur just north of Bass Canyon. These bodies have acted as irregular competent buttresses within the incompetent beds of the unit, and this, together with faulting, has brought about a strong contortion of the schists. Elsewhere foliation is approximately parallel to the bed-

ding. Throughout most of the unit the strike is east of north, but at the southern limit of the exposure the strike swings to west of north, conforming with the succeeding unit.

In the vicinity of M.0—5.9, Plate 1, is a thin conglomerate member containing flattened chert pebbles with a long axis of about 2 inches and a short axis of about half an inch. The outcrop of this member is largely obscured by colluvium.

**Petrography.**—The sericite schists are fine-grained light-gray rocks that have a lustrous or silvery sheen in outcrop. They are composed of sericite and quartz, or sericite, quartz, and albite. The sericite occurs in fibers, layers, and fibrous masses, commonly showing micro-folding and thrust-faulting (Pl. 35, A). Magnetite or ilmenite, chlorite, partly bleached green-brown biotite, epidote, apatite, carbonate, and rutile are present in small quantities. Grain size is for the most part less than 0.1 mm. Fabric is lepidoblastic-cataclastic.

Interlayered with the sericite schists and phylites are fine-grained green schistose rocks that may be cataclastically altered amphibolite sills. They are composed largely of epidote, albite, and quartz with small needles of amphibole that is probably actinolite. Biotite, a partly bleached olive-brown variety, apatite, sphene, magnetite or ilmenite, and carbonate are present in minor amounts. The fabric is crystalloblastic-cataclastic, and the grain size ranges from less than 0.02 to 0.2 mm. Flowage structures and comminuted grains are the principal cataclastic features. Estimated modes of representative rocks of this unit are given in Table 11.

A hard brown rock crops out at K.6—5.5, Plate 1, and forms a ridge extending northeast. In the field this rock appears to be a fine-grained quartzite, but thin section shows a sutured granoblastic mosaic of albite (65 percent) and quartz (35 percent). Traces of apatite, muscovite, and magnetite or ilmenite are present. Grain size ranges from 0.05 to 0.5 mm. Intergranular crushing is marked. Good sizing of grains and essentially biminerale composition indicate that this rock may be cataclastically altered soda aplite, perhaps a phase of the granodiorite with which it is in contact. If this rock is meta-arkose, the original sediment was well sorted in contrast to the typical meta-arkose of the area.

**Feldspathic metaquartzite and meta-arkose (pCCq<sub>2</sub>).**—This unit forms a series of low gray hills at the southeast end of the pre-Cambrian exposure (N.0—4.0, Pl. 1). In Bass Canyon the rocks are in contact with the schists of the mixed unit just described (pCCm<sub>4</sub>) but to the northeast the contact is offset, distorted, and obscured by down-faulted Van Horn sandstone and Hueco limestone, intrusions of Tertiary diabase, and unconsolidated bol-

son deposits. Southward, these rocks disappear beneath unconformably overlying Hueco limestone. As exposed, the unit has a minimum thickness of about 2,700 feet. To the northeast it strikes east of north, but to the south the strike swings through north-south to west of north and indicates the first major deviation encountered in the usual northeast strike and southeast dip of the rocks. The greater part of the unit is composed of fine-grained light gray sericitic feldspathic metaquartzite and sericitic meta-arkose. On the outcrop the rock breaks into thin slabs that gleam with sericite. The foliation is parallel to the contacts of the unit and is essentially a bedding plane foliation. Relict sedimentary structures are not apparent. Intercalated with the sericitic meta-arkose and metaquartzite are beds less than 1 foot thick of very fine-grained white, blue, and gray quartzite or chert and thin layers of sericite schist. The number of schist layers increases westward toward the contact with the underlying mixed unit. Near this contact is a 3 to 5-foot layer of almandine-mica schist with small unaltered idiomorphic garnets 1 to 2 mm. in diameter. This is the only garnet-bearing schist observed in the Carrizo Mountains. The layer, extremely contorted, is a thin incompetent body between competent quartzites.

**Petrography.**—Estimated modes of two rocks of the unit are given in Table 11. In thin section the quartz-feldspathic rocks show a granoblastic mosaic of quartz and feldspar. Sericite occurs as oriented flakes and as fine intergranular material. The feldspar is albite, microcline, and microcline-micropertite. Biotite, a fibrous partly bleached red-brown variety, zircon, apatite, magnetite or ilmenite, leucosene, rutile, and calcite are present in small quantities.

The almandine-mica schist is composed of about 85 percent sericite and biotite showing extreme micro-folding and thrust-faulting. The mica flows around the garnet porphyroblasts (photomicrograph, Pl. 36, A). The garnets occur as idiomorphic crystals and show no diaphthoritic effects. Long laths of chlorite (penninite) have grown in the pressure lees of the garnet porphyroblasts, but this chlorite does not appear to have been derived from the garnet. Small amounts of magnetite or ilmenite, quartz, and feldspar are present.

This almandine-mica schist presents certain contradictions. The biotite is a "sickly" faded mineral typical of diaphthoritic rocks, but the idiomorphic garnets show no evidence of retrograde phenomena and indicate a higher metamorphic grade than is

characteristic of the Carrizo Mountain sequence in general. It is possible that the soft incompetent mass provided by the very highly micaceous matrix (which shows extreme deformation) has absorbed the crushing and shearing stresses which seem to have been responsible for the retrogressive phenomena elsewhere in the sequence and thus has protected the garnets from cataclasis, much as conglomerate pebbles are protected or cushioned in a soft clay matrix.

#### METASEDIMENTARY ROCKS OF UNCERTAIN STRATIGRAPHIC RELATIONS

In outlying parts of the Carrizo Mountains, mainly to the north, east, and south, are relatively small outcrops of additional pre-Cambrian rock units which, because of a variety of reasons, chiefly aberrant structure, cannot be fitted into the homoclinal sequence just described.

*Limestone* (pCCl).—A fine-grained hard brown calcareous rock crops out at the easternmost salient of the mountains (Q.0—9.0, Pl. 1). It is bordered on three sides by unconsolidated bolson deposits and is bounded by intrusive metarhyolite on the fourth; it occurs in an area of metarhyolite and amphibolite intrusions, quartz-tourmaline veins, and contorted beds. Southeastward along the strike, the outcrop is obscured by bolson deposits, down-faulted younger rocks, and Tertiary intrusions. The rock is unique in the sequence and its stratigraphic relations have not been established.

*Petrography*.—In thin section the rock shows a granoblastic mosaic of albite and calcite, containing poikilitic porphyroblasts of pink chlorite identified as delessite. The carbonate and albite occur in patches. Biotite, apatite, muscovite, rutile, leucoxene, and tourmaline are present in small quantities. The mosaic averages 0.05 to 0.2 mm. in grain size with the porphyroblasts attaining a maximum diameter of 2 mm. (Table 11).

*Feldspathic metaquartzite and feldspathic sericite schist* (pCCq<sub>6</sub>).—This unit forms an area of light-gray hills in western Bass Canyon at the extreme southwest limit of the pre-Cambrian exposure (L.0—4.0, Pl. 1). It is overlapped to the west and south by Hueco limestone and unconsolidated bolson deposits. The rock is a fine-grained light-gray sericitic metaquartzite, with distinct schistosity, that

weathers into thin plates and slabs. Relict sedimentary structures are not distinct, although banding in the rock that generally parallels the schistosity may be interpreted as bedding. The unit may be a structurally dislocated part of metaquartzite and metaarkose (pCCq<sub>5</sub>), which it resembles lithologically.

Structure of the unit differs from that of the adjacent metasedimentary rocks to the north, as it does not share their prevailing southeast dip and northeast strike; instead its rocks strike northwest and stand vertical or dip northeast. Relations with the adjacent rocks of the sequence are obscured by intrusions and contortion of the beds. The simplest and most satisfactory interpretation seems to be that it is separated from mixed unit pCCm<sub>4</sub> to the northeast by a fault, along which it has been moved horizontally northwestward.

Partial confirmation of this interpretation is afforded by the unit's petrographic character. Unlike the quartzo-feldspathic rocks near by to the north, it lacks indications of cataclastic alteration and contains plates of muscovite rather than fibrous intergranular sericite. It thus possesses a higher metamorphic grade than the rocks to the north, which is more like that of the rocks to the southeast in the Van Horn Mountains. The fault, if present, may be younger than the metamorphism and may have brought rocks of two metamorphic grades into contact. Such displacement need not have been large, as the rocks of the main sequence in the Carrizo Mountains themselves show southeastward increase in metamorphic grade and decrease in retrogressive metamorphism.

*Petrography*.—Under the microscope the rock shows a mosaic of quartz and albite (partly altered to sericite), containing oriented fibers of sericite and muscovite plates. The mica is unevenly distributed in layers. Magnetite or ilmenite, zircon, and apatite are present in small amounts. The fabric is granoblastic to lepidoblastic, depending on the amount of muscovite. Grain size ranges from 0.05 to 0.2 mm. (Table 11).

*Allamoore formation(?)* (pCAIs(?)).—In the northern Carrizo Mountains, between the Texas and Pacific Railroad and the Hillside fault, are a number of outcrops of associated metarhyolite and limestone. Most of the outcrops are small and surrounded by alluvium so that a con-

TABLE 11  
ESTIMATED MODES OF REPRESENTATIVE METASEDIMENTARY ROCKS IN THE CARRIZO MOUNTAINS

LOCATION ON MAP (PLATE I)	UNIT ON MAP (PLATE I)	QUARTZ	ALBITE	MICROCLINE	MICROPHERITE	SERICITE OR MUSCOVITE	BIOTITE	CHLORITE	CARBONATE	MAGNETITE OR ILMENITE	RED OR BROWN IRON OXIDE	LEUCOXENE	APATITE	ZIRCON	TOURMALINE	RTILITE	GARNET	SPHENE	AMPHIBOLE	EPIDOTE	IRRESOLVABLE GROUND-MASS	AVERAGE GRAIN SIZE	ROCK NAME	
(E 4-13.6)	pC0cm5	69	3			20	5			3	Tr <sup>1</sup>											0.5 to 2 mm	BIOTITE-SERICITE SCHIST	
(F 4-14.0)		80					3	10		7	Tr											0.2 to 0.5 mm	BIOTITE-CHLORITE SCHIST	
(H 9-12.9)		57	10			2		3		Tr	1											0.5 to 1 mm	CHLORITE-ALBITE SCHIST	
(I 5-12.9)		72				15	10			3	Tr											< 0.2 mm	BIOTITE-SERICITE SCHIST, APPROACHING SLATE	
(G 3-13.4)		75				18	3	3			1				Tr							< 0.1 to 1 mm	SERICITE SCHIST	
(F 3-12.7)		83				9		5		2			1	Tr		Tr							< 0.5 mm	CHLORITE-SERICITE-ALBITE SCHIST
(H 7-12.8)		65	30			5	Tr	Tr				Tr			Tr								< 0.2 to 2 mm	SERICITIC META-ARKOSE
(F 3-12.4)		43	50			4				1	2				Tr								2 to 3 mm	SERICITIC META-ARKOSE
(H 1-12.6)		2	Tr			Tr		Tr	98	Tr	Tr												1 to 2 mm	LIMESTONE
(G 3-11.5)	pC0q1	58	30			6			2	Tr	Tr	Tr	Tr	Tr	3	Tr						1 to 2 mm	SERICITIC META-ARKOSE	
(E 8-10.8)		74	25			1				Tr	Tr	Tr	Tr	Tr								1 to 2 mm	META-ARKOSE	
(D 3-11.1)		55	40					3	Tr	Tr		2	Tr	Tr								1 to 2 mm	META-ARKOSE	
(E 1-11.1)		76				15	7		2		Tr	Tr	Tr	Tr								< 0.1 to 5 mm	CHLORITE-SERICITE-ALBITE SCHIST, APPROACHING SLATE	
(J 7-11.5)	pC0q2	63	4	20		10			2	1			Tr									1 mm	SERICITIC FELDSPATHIC METAQUARTZITE	
(G 0-9.2)		48	35			15		1		1	Tr			Tr								0.5 to 2 mm	SERICITIC META-ARKOSE	
(H 0-10.8)	pC0m1	43	54				1	1		1	Tr		Tr			Tr						1 to 2 mm	META-ARKOSE	
(K 2-11.0)		1	2						97													1 to 2 mm	LIMESTONE	
(I 4-9.5)		14				Tr			65		1											0.5 to 2 mm	LIMESTONE	
(N 9-13.3)		1	1											Tr							98	CRYPTO- CRYSTALLINE		SLATE
(D 0-12.8)	pC0q3	53	28			15				3				Tr		Tr						2 to 5 mm	SERICITIC META-ARKOSE	
(L 7-11.2)		49	50									1	Tr	Tr	Tr	Tr						2 mm	META-ARKOSE	
(J 5-9.1)		45	45		5		2			2				Tr								< 0.1 to 5 mm	META-ARKOSE	
(L 6-9.8)	pC0p	60	Tr			5	25			10		Tr	Tr									< 0.2 mm	BIOTITE-PHYLLITE	
(P 6-11.8)	pC0m2	1				2		2	95	Tr												< 0.1 to 5 mm	LIMESTONE	
(N 6-9.2)	pC0m4	46				2			50	1	1											0.5 to 2 mm	QUARTZ LIMESTONE	
(K 8-7.5)		24	30				25	2	15	2				Tr						2		0.5 to 5 mm	CALCITE-QUARTZ-BIOTITE-ALBITE SCHIST	
(L 1-8.0)		50	35			10	2	3						Tr								0.5 mm	SERICITE-ALBITE SCHIST	
(Q 0-10.6)		75				20						5		Tr								< 0.2 mm	SERICITE-PHYLLITE	
(J 5-7.4)		65		10		20	2	3						Tr								0.4 to 0.5 mm	SERICITE-ALBITE PHYLLITE	
(P 6-9.5)	pC0q4	79	12	Tr		7			Tr			1	Tr	Tr	1							< 0.1 to 3 mm	SERICITIC FELDSPATHIC METAQUARTZITE	
(K 8-5.6)		32	65			2	Tr			1												0.5 to 5 mm	META-ARKOSE OR META-ALPITE	
(L 3-5.1)	pC0m5	44	35	5		10	2			1	3		Tr									0.5 to 2 mm	SERICITIC META-ARKOSE	
(L 1-6.1)		72	15			3	2	3	1	3						Tr				1		0.2 to 5 mm	CHLORITE-MICA-ALBITE SCHIST	
(L 8-5.7)		50				45	Tr	2		3						Tr						1 mm	SERICITE SCHIST	
(N 8-7.8)		15	20				Tr												25	40		0.2 mm	ALBITE-ACTINOLITE-EPIDOTE SCHIST (SHEARED AMPHIBOLITE?)	
(L 1-5.7)		25	40			Tr	Tr		Tr	Tr				Tr						5	30	< 0.1 to 2 mm	EPIDOTE-ALBITE SCHIST (SHEARED AMPHIBOLITE?)	
(O 3-4.7)	pC0q5	70	20			8	1		1					Tr		Tr						0.5 to 2 mm	SERICITIC FELDSPATHIC METAQUARTZITE	
(N 3-5.6)		2				66	20	5		1								5				5 to 2 mm	ALMANDINE-MICA SCHIST	
(L 2-5.3)	pC0q6	69	15			15			1				Tr	Tr								0.5 to 2 mm	FELDSPATHIC MUSCOVITE SCHIST	
(L 2-3.5)		60		35		5			Tr	Tr		Tr	Tr	Tr		Tr						1 mm	SERICITIC META-ARKOSE	
(R 0-9.3)	pC0i	47				Tr	1	3	45			2	1		Tr	1						0.5 to 2 mm	CALCITE-ALBITE ROCK	

1 Tr = Trace < 1%

2 < 0.2 mm = less than 0.2 mm

< 0.1 to 1 mm = grain size range from less than 0.1 to 1 mm



tinuous view of the relations between the limestone and metarhyolite cannot be obtained. As exposed, most of the limestone occurs as roughly tabular bodies in straight-line contact with the metarhyolite (Pl. 1). The rhyolite in this area is completely mylonitized, and the attitude of schistosity and lineation changes rapidly from one outcrop to another. Under the microscope some of the metarhyolite (mylonite) in this area proves to have been re-brecciated (photomicrograph, Pl. 35, B), possibly by movement along the Hillside fault.

The limestone is in part characterized by chert bands and sedimentary laminae, similar to the limestone in the Allamoore formation, and is in part a massive dirty brown rock containing fine irregular siliceous fragments. Under the microscope this latter "limestone" proves to be a very fine metarhyolite breccia cemented and/or partly replaced by calcium carbonate. It is worth noting that the banded limestone not only resembles some limestone in the Allamoore formation but is dissimilar to limestones in the Carrizo Mountain group.

King (King and Knight, 1944) suggested that this rather chaotic area may be an exposure of the Streeruwitz thrust fault close to the Hillside fault which displaces it. Certainly there is evidence of extreme tectonic activity in this area, and King's explanation seems to be the correct one. Thus, part of the limestone belongs to the Allamoore formation beneath the Streeruwitz thrust fault and part is pseudo-limestone that originated through deposition of carbonate in permeable breccia zones.

#### META-IGNEOUS UNITS

*Metarhyolite* (pCCr).—The metasedimentary rocks of the Carrizo Mountain group are intruded by metarhyolite. These siliceous rocks were first described petrographically by Osann (1893, p. 138) who designated them as "pressed quartz porphyries." They were later studied by King (1940, p. 146; King and Knight, 1944) who believed that they represented lava flows in the lower part of the Carrizo Mountain group.

In the Carrizo Mountains the metarhyolite occurs in four bodies (Pl. 1). The largest is an irregular mass in the north-

west part of the mountains, which crops out in low hills southeast of Allamoore and in higher ridges beyond. This is being worked for crushed stone by Gifford-Hill & Company at their Holley plant  $2\frac{1}{2}$  miles east of Allamoore; many characteristic phases of the metarhyolite are exposed in their quarry and in near-by cuts along U. S. highway No. 80 (Appendix, I). Farther southeast, in the central part of the mountains, is a long sill-like body of about 2,100 feet thick, which projects in a line of red jagged ridges, the highest of which is Hackett Peak. In the southeast part of the mountains are two smaller sill-like bodies, the northwestern 1,200 feet thick and the southeastern 300 feet thick. Metarhyolite also occurs in discontinuous outcrops in the Sierra Diablo foothills north of the Texas and Pacific Railroad (Pls. 2 and 3), where it lies with thrust contact on the Allamoore formation.

The metarhyolite is generally a hard, blocky or slabby siliceous rock of red, pink, brown, buff, or gray color. It consists of an aphanitic ground-mass which contains phenocrysts generally less than 2 mm. in diameter, now largely broken. An exceptionally coarse phase occurs in the Sierra Diablo foothills 4 miles northwest of Allamoore (P.O.—6.0, Pl. 3), in which some of the phenocrysts reach a diameter of 1 cm. (p. 74). The texture and appearance of the rock is similar in all the bodies in the Carrizo Mountains, but microscopic study indicates that the feldspar in the southeastern bodies is microcline, whereas that in the northwestern bodies of the Carrizo Mountains and in the Sierra Diablo foothills is microcline-microperthite and albite. This difference may have resulted from subsequent introduction of sodium and albitization of original potassium feldspar.

Cataclastic metamorphism has produced a well-developed planar structure, or schistosity, in the metarhyolite, on the surface of which the original phenocrysts and other mineral aggregates have been crushed, streaked, and drawn out to form a pronounced lineation (Pl. 22). The schistosity generally strikes east of north and dips southeast, with strikes varying from nearly north to almost due east. Near the Hillside fault north of the Texas and Pacific Railroad the schistosity is more disturbed and

strikes northwest into the fault. The lineation, where measured, plunges southeast in the plane of the schistosity.

Locally, schistosity has developed to such an extent that the rock has become a fine-grained sericite schist or phyllite, which is shown by microscopic examination to contain remnants of broken microcline phenocrysts. In places, especially in the northwest part of the Carrizo Mountains and in the Sierra Diablo foothills, the metarhyolite is converted into mylonite, in which the phenocrysts are nearly or completely destroyed, and a strong layered structure has developed. In the same area are occasional small outcrops of rocks that have the appearance of limestone but which are shown by microscopic examination to be carbonate-cemented metarhyolite breccia. In the southeastern bodies the metarhyolite is less strongly layered than farther northeast, and lineation is not conspicuous. Phyllitic bands are also uncommon, except in part of the southeasternmost major sill (P. 6—9.2, Pl. 1), where the microcline has been almost wholly converted to sericite.

Superficially, the metarhyolite seems to be an extrusive rock, because of its stratified appearance and the occurrence of beds of sericite schist and phyllite, which could represent metamorphosed pyroclastic rocks. Detailed study demonstrates that the metarhyolite intrudes the metasedimentary rocks of the sequence; contacts are irregular in detail. The sill-like bodies to the southeast are for the most part conformable to the enclosing metasedimentary rocks, but they branch or pinch out along the strike and contain occasional inclusions of metasedimentary rocks. In one of the mixed units (pECm<sub>3</sub>) south of Hackett Peak a rhyolite dike cuts across the bedding, extending toward the large metarhyolite sill to the northwest (J.5—6.2, Pl. 1).

The metarhyolite is younger than the metasedimentary rocks which it intrudes, and it is intruded in turn by the amphibolite, the largest bodies of which are along contacts between the metarhyolite and the metasedimentary rocks. The close resemblance between all the metarhyolite bodies in different parts of the sequence, and the lack of any coarse-grained phases, suggests that they were intruded at approximately the same level in the crust, probably after

the metasedimentary rocks had been tilted and reduced by erosion. After intrusion, the metarhyolite was strongly altered by cataclastic metamorphism. Whether it was also affected by the progressive regional metamorphism that is evident in the adjacent metasedimentary rocks is uncertain, for if this ever existed, all traces of it have now been erased. More probably, the metarhyolite was intruded after the metasedimentary rocks had been subjected to progressive regional metamorphism, which may have accompanied the tilting referred to above.

The cataclastic metamorphism resulted from strong dislocative movements, that were perhaps related to the displacement of the Carrizo Mountain group on the Streeruwitz overthrust. It will be recalled that the cataclastic effects are generally greatest nearest the overthrust. The dislocative movements created the widely developed planar structure and lineation and locally produced sericite schists and mylonites. The lineation is interpreted as an *a* lineation, parallel to the *a* fabric axis, or direction of transport.

*Petrography.*—Microscopic study shows the metarhyolite to be composed of a fine crush matrix of quartz and feldspar containing phenocrysts of quartz and feldspar in various stages of reduction. The grain size of the ground-mass ranges from cryptocrystalline to 0.05 mm. The index of refraction of the ground-mass is less than quartz and less than the cementing medium (about 1.54). The feldspar ranges from microcline and microcline-micropertite to albite. In the southeastern sill and in Hackett Ridge the feldspar is microcline with an indistinct twinning. To the northwest the feldspar is microcline-micropertite and albite. The albite shows a "chessboard"<sup>14</sup> twinning. Sericite occurs in streaks and layers and is usually wrapped around the broken feldspar phenocrysts. Magnetite or ilmenite, zircon, biotite (partly bleached), apatite, chlorite, sphene, rutile, tourmaline, calcite, leucoxene, and iron oxides are present in small quantities. The fabric is wholly cataclastic. Some specimens show almost complete reduction of the phenocrysts and are ultra mylonites. Estimated modes are given in Table 12 (photomicrographs, Pl. 34, B, C, D; Pl. 35, B, C, D).

Some of the rocks listed in Table 12 have more quartz than is normal in rhyolites. Probably a good deal of this is secondary quartz which has replaced portions of the ground-mass; small quartz veinlets are common in the metarhyolite. The crushing and comminution of grains in mylonitization results in increased surface area and

<sup>14</sup> The writer could not locate in the literature a reference to "chessboard twinning," but Professor Adolph Knopf (personal communication, January 1952) says it has long been regarded as the result of replacement of microcline by albite.

TABLE 12  
ESTIMATED MODES OF METARHYOLITE IN THE CARRIZO MOUNTAINS

LOCATION ON MAP (PLATE I)	OUTCROP AREA	IRRESOLVABLE GROUND-MASS	QUARTZ	ALBITE	MICROCLINE	PERTHITE	SERGITE	BIOTITE	MAGNETITE OR ILMENITE	RED OR BROWN IRON OXIDE	ZIRCON	APATITE	LEUCOMENE	SPHENE	RUTILE	CARBONATE	TOWMALINE	CHORTITE	GRAIN SIZE	REMARKS
(Q 4-91)	SOUTHEAST CARRIZO MOUNTAINS		20		60		15	2	2			Tr	1						gr moss = .02 mm p → 1 mm	PARTIAL RECRYSTALLIZATION FOLLOWING CATACLASIS
(Q 4-94)		40 (FLOWAGE)	40		3		15					Tr						2	gr moss → isohop p → 5 mm	INTRODUCED QUARTZ IN VEINLETS PARALLEL TO SCHISTOSITY
(N 1-84)		90 (FLOWAGE)	5		5		Tr		Tr	Tr			Tr						gr moss - crypto p → 2 mm	
(P 5-88)		74 (FLOWAGE)	5				20		1		Tr		Tr						cryptocrystalline to 01 mm	INTERLAYERED SERGITE AND CRYPTOCRYSTALLINE MATERIAL. SOME SECONDARY QUARTZ
NORTHWEST END HACKETT RIDGE	HACKETT RIDGE	82 (FLOWAGE)	3		15			Tr	Tr	Tr	Tr	Tr	Tr						gr moss - crypto p → 2 mm	SAMPLE FROM DIKE 3 FEET WIDE
MIDDLE HACKETT RIDGE		92	1		3		3		1		Tr								gr moss < 01 mm p → 5 mm	MICROCLINE AUGEN CONVERTING TO SERGITE
GORGE IN HACKETT RIDGE		92 (FLOWAGE)			6		2				Tr	Tr	Tr		Tr				gr moss < 02 mm p → 1 to 2 mm	QUARTZ VEINLETS, MICROCLINE CONVERTING TO SERGITE
(N 1-95)		82 (FLOWAGE)	10		5		Tr		1				Tr				1		gr moss → isohop p → 5 mm	REMARKABLE LAYERING AND FLOW STRUCTURE
(Q 2-115)		75	4		15		4		2		Tr		Tr				Tr		gr moss < 01 mm p → 2 to 3 mm	MICROCLINE CONVERTING TO SERGITE
(J 5-79)		85 (FLOWAGE)	3		5		5		2								Tr		gr moss < 01 mm p → 5 mm	OPAQUE MINERAL IN BROKEN GRAINS, SECONDARY OR RECRYSTALLIZED QUARTZ PRESENT
(L 3-144)	NORTHWEST CARRIZO MOUNTAINS		47 (MOSTLY QUARTZ)				50		1			Tr	1	Tr			1		.02 to 04 mm	SERGITE IN CRINKLED LAYERS, ROCK IS A PHYLLITE-SHEARED AND RECRYSTALLIZED METARHYOLITE
(K 5-146)			35		60		4		Tr			Tr					1		.02 mm	QUARTZ IN LAYERS AND CRUSH ZONE
(J 2-146)					90		8		1		Tr						Tr		gr moss < 02 mm p → 1 mm	NOTE EMBAYED QUARTZ PHENOCRYSTS; FLOWAGE STRUCTURES PRESENT
(I 8-147)					65		30		3			Tr					Tr	1	gr moss < 02 mm p → 5 to 1 mm	FLOWAGE STRUCTURES PRESENT
(I 3-155)		70 (FLOWAGE)	4	5		15	5		1		Tr								< 01 mm	
(I 1-156)		75	10		15		Tr		Tr		Tr								gr moss crypto. p → 2 mm	
(L 0-138)		65	25		5				Tr	1	Tr	Tr	Tr		Tr		3		gr moss < 02 mm p → 2 mm	SOME SECONDARY QUARTZ
(J 3-131)			43		2		50	5	Tr		Tr								.02 to 04 mm	ROCK IS A SERGITE SCHIST-SHEARED RHYOLITE + RECRYSTALLIZED AND INTRODUCED QUARTZ, FELDSPAR CONVERTING TO SERGITE
(K 5-142)			30		67		2		1		Tr								.02 to 04 mm	ROCK IS PARTLY RECRYSTALLIZED MYLONITE
(L 4-146)		85	5		2		5		3					Tr					gr moss < 02 mm p → 1 mm	
(I 2-150)			67		45		15	2	1	Tr			Tr						gr moss = 02 to 04 mm p → 1 to 2 mm	QUARTZ IS UNSTRAINED AND PROBABLY MOSTLY SECONDARY; SERGITE SURROUNDS FELDSPAR AUGEN
(C 9-147)			94	1			3	1		1		Tr	Tr						gr moss < 02 mm p → 1 to 2 mm	PHENOCRYSTS ALMOST COMPLETELY REDUCED; ROCK IS A MYLONITE
BETWEEN EAGLE FLAT & ALLAMORE, NORTH OF USMC		70 (FLOWAGE)	7		20		2		1			Tr	Tr					Tr	gr moss < 01 to 02 mm p → 1 cm	FELDSPAR AUGEN → 1 CM VISIBLE IN HAND SPECIMEN

1 p = phenocrysts  
 1 → = up to, as much as  
 1 crypto = cryptocrystalline  
 1 < 01 mm = less than 01 mm.

increased permeability. Solutions can be expected to move toward these crushed areas and effect replacement and recrystallization of the mylonitized rock.

Some of these rocks deserve individual mention. One specimen from near the Hillside fault is a re-brecciated mylonite (photomicrograph, Pl. 35, B). The original rhyolite was mylonitized during the thrust-faulting, transected by small quartz veinlets, and then brecciated again, probably by movement along Hillside fault. A specimen from Hackett Ridge (photomicrograph, Pl. 35, D) shows a remarkable interlayering of cryptocrystalline material that is almost isotropic and coarser quartz-feldspar layers and elongate lenses. Flowage structure is pronounced.

*Amphibolite* (pCCa).—Bodies of amphibolite intimately intrude the older metasedimentary rocks and metarhyolite of the Carrizo Mountain group. (These rocks are the "greenstone intrusives" of King and Knight (1944). The amphibolite occurs for the most part in elongate sill-like bodies which, although locally discordant, in general conform to the regional structure. A large irregular discordant mass of amphibolite exposed on the northwest edge of the Carrizo Mountains is an exception to this rule. The thickness of the tabular bodies ranges from less than 5 feet to 1,800 feet. The magma that gave rise to these rocks was a dioritic magma that intimately soaked or penetrated the metasedimentary host rocks. Thin discontinuous bands of country rock commonly are included within the amphibolite bodies. This is well illustrated by the thin-bedded mixed unit designated on the map as pCCm<sub>2</sub>. Southwest of the highway the unit is intimately penetrated by amphibolite, and beds of the metasedimentary unit show up as light-colored bands within the dark intrusive body.

The rock is fine to coarse grained, green to black, and schistose to massive. Sills less than 10 feet thick are commonly schistose, and the schistosity conforms to that of the metasedimentary rocks. Light-colored feldspar-rich facies of this rock were mapped in two places. Microscopic study discloses that the amphibolites of this area are characterized by a relict igneous fabric (hypidiomorphic granular) on which is imposed a compound crystalloblastic-cataclastic metamorphic fabric. It should be noted that green rocks in the Allamoore formation just north of the Streeruwitz thrust fault that megascopically resemble the amphibolites of the Carrizo Mountains

are altered diabasic rocks which contain pyroxene and show no marked cataclastic effects.

The amphibolite intrudes the metarhyolite in sills parallel to the planar structure that was developed in the rhyolite during the cataclastic metamorphism, and along the contacts between metarhyolite and metasedimentary rocks. The magma that gave rise to the amphibolites, then, must have been intruded during the retrogressive or cataclastic metamorphism, after the development of planar structure and schistosity within the rhyolite but before the end of the metamorphic period, because the amphibolite itself has a partly cataclastic fabric. It is this late cataclastic metamorphism that converted the original igneous rock, probably a diorite, into amphibolite. The youngest pre-Cambrian meta-igneous rock in the area is granodiorite, which shows only incipient cataclastic metamorphism. The granodiorite is probably a late phase of the diorite magma intruded at the close of the cataclastic metamorphism, but there is no real evidence to support this inference.

The igneous rock from which the amphibolite was derived was more likely diorite than gabbro or diabase because even in the least metamorphosed samples, taken from the interior of the large amphibolite mass in the northwestern Carrizo Mountains, there is no trace of an original pyroxene. The pyrogenic ferromagnesian mineral that now occurs as armored relicts in these rocks is hornblende. The mineralogic and fabric evidence obtained by microscopic study of these disequilibrium rocks with their relict igneous features indicates that the original igneous rock was a hornblende-andesine rock with a hypidiomorphic granular fabric and an average grain size of 2 to 5 mm.

*Petrography.*—In thin section all but the most highly sheared specimens show a relict igneous fabric. A crystalloblastic-cataclastic fabric (with crystalloblastic and cataclastic elements probably developed concomitantly) has been superimposed on the original hypidiomorphic granular fabric. There is extreme variation in grain size. The relict igneous fabric is shown by the subhedral outlines of plagioclase laths (commonly showing a ghostly polysynthetic twinning) and amphibole grains (Pl. 36, D). The original grain size was 2 to 5 mm. The rock is in disequilibrium. The original amphibole subhedra have developed ragged fibrous edges of blue-green hornblende and a faded, patchy green to blue-green pleo-

chroism. Small prisms and felty masses of blue-green hornblende occur throughout the rock. The original calcic plagioclase was converted to a fine granular mixture of albite or oligoclase and epidote or zoisite. Some of the albite has recrystallized to form a mosaic with quartz. Most of the plagioclase in these rocks is albite, but alteration has not proceeded equally throughout the area and oligoclase and andesine are found in the less altered amphibolites that in general show more pronounced relict igneous features. Biotite (dark brown to red-brown variety) is present as oriented plates or fibrous masses and probably in part formed at the expense of amphibole. Sericite is commonly present as a product of feldspar alteration. Ilmenite, commonly armored by sphene and leucoxene, is present in nearly all slides. Apatite and carbonate are common accessory minerals, although the carbonate is probably secondary. Scapolite was found in one sample, and tourmaline was found in another. In the section examined, scapolite seems to replace plagioclase. The introduction of scapolite and tourmaline was probably caused by halogen-bearing solutions. Osann (1893, p. 137) described scapolite in one of these rocks. Quartz is present in nearly all sections examined (Table 13).

The amphibole of these rocks merits special mention. The least metamorphosed specimen of amphibolite examined came from the interior of the large amphibolite mass in the northwestern Carrizo Mountains. The amphibole in this rock is colorless to pale green in thin section. There is no pyroxene or biotite in this relatively unmetamorphosed sample, but biotite is present in more typical amphibolite in the area. Comparison of the relatively unaltered rock with the common amphibolite indicates that in the process of metamorphism the colorless amphibole has been converted to a blue-green hornblende ( $Z \wedge C = 19$  to  $21^\circ$ ,  $\beta = 1.651 \pm .002$ , negative optic sign), biotite, and chlorite.

The leucocratic facies of the amphibolite mapped (pECaf, Pl. 1) consist principally of albite, commonly showing a micrographic texture. The over-all hypidiomorphic fabric of this rock has been modified by crushing.

**Granodiorite (pECg).**—Three irregular masses of granodiorite intrude metasedimentary rocks in the southern Carrizo Mountains and form steep hills on the north side of Bass Canyon (Pl. 1). It is not clear in the field whether the granodiorite is younger or older than the amphibolite. The rock is badly fractured and has been affected by cataclasis, although to a lesser degree than the amphibolite. The granodiorite is probably a late phase of the diorite intrusions that gave rise to the amphibolite and is closely related to the diorite in time of intrusion.

The granodiorite is a massive fine-grained brown to bronze rock that forms steep hills and ridges. Jointing and frac-

turing cause rough slopes covered with loose rock fragments.

**Petrography.**—Three thin sections show a considerable variation in the amounts of the principal minerals that compose the rock. The dominant minerals are albite (40 to 70 percent), quartz (10 to 20 percent), and microcline (5 to 20 percent). The albite ( $An_{3-6}$ ) surrounds and embays microcline remnants. Pale olive-brown to black biotite (4 to 10 percent) occurs in "nests" of small flakes between feldspar subhedra and may be a deuteric mineral. A deeply colored blue-green hornblende ( $Z \wedge C = 17^\circ$ ,  $\beta = 1.702 \pm .002$ , negative optic sign) is present in skeletal and poikilitic prisms in one slide where it is partly altered to a fibrous orange mineral. Epidote (2 to 5 percent) occurs in grains scattered through the plagioclase and is probably the result of release of calcium by the feldspar in an incipient metamorphic reaction. Sphene, apatite, zircon, and magnetite or ilmenite are present as accessory minerals. The fabric is hypidiomorphic granular with later cataclastic effects indicated by intergranular crushed areas and strained and bent minerals. Grain size is 0.5 to 2 mm.

This rock is more or less mineralogically similar to the amphibolite, except for the presence of microcline, but chemically it is richer in alkali elements. Taken individually, one of the slides studied might be termed quartz diorite rather than granodiorite, but there is after all no fixed boundary between the two types in nature. This rock is not a normal granodiorite as the term is applied to the great batholithic masses in western United States, and the nature of the minerals present and the variations in mineral content, together with the geologic setting, suggest that the granodiorite is the result of local fractionation of the diorite magma that is now amphibolite. Minor cataclastic elements in the fabric of the rock indicate that it was emplaced at the close of the last metamorphism, thus pointing to a close time as well as spatial relation between the granodiorite and amphibolite.

#### QUARTZ VEINS

Broken and sheared masses of vein quartz occur throughout pre-Cambrian rocks of the Carrizo Mountains. Black tourmaline, platy ilmenite, and, in some places, pink feldspar (microcline) are present with the quartz. (The feldspar-bearing veins were called "pegmatite" by some of the early workers in the area.) These veins are the result of high temperature hydrothermal activity before the dislocation and thrusting, perhaps related to pegmatite emplacement to the south in the Van Horn Mountains. At one locality at the easternmost projection of the mountains (Pl. 1) there has been extensive tourmalinization and silicification of the country rock; tourmaline also occurs as a

TABLE 13  
ESTIMATED MODES OF AMPHIBOLITE IN THE CARRIZO MOUNTAINS

LOCATION ON MAP (PLATE 1)	QUARTZ	PLAGIOCLASE	HORNBLende	EPIDOTE	BIOTITE	MAGNETITE OR ILMENITE	CHLORITE	SPHENE	LEUCOXENE	APATITE	RTILe	CARBONATE	SERICITE	ZOISITE	TOURMALINE	SCAPOLITE	AVERAGE GRAIN SIZE	REMARKS
BASS CANYON		55 OLIG <sup>1</sup>	40 (BG <sup>2</sup> Z A C 18*)		3	2				Tr							1-3 mm	
BASS CANYON	10	27 OLIG	25 (BG Z A C 18*)	30		4		2		2							< 0.2 mm to 1 cm	LARGE POIKILITIC HORNBLende
CANYON NORTH OF BASS CANYON	3	50 AB	30 (BG Z A C 18*)	5	7	2	2			1							< 0.2 to 2 mm	HORNBLende CONVERTING TO BIOTITE & CHLORITE, PLAGIOCLASE CONVERTING TO ALBITE & EPIDOTE
CANYON NORTH OF BASS CANYON	1	45 AB	25 (PALE Z A C 21*)	15	5	Tr	5	5									< 0.2 to 2 mm	ILMENITE CONVERTING TO SPHENE PALE, FAINTLY PLEOCHROIC HORNBLende
(P 6-12 6)		55. OLIG. AN <sub>20</sub>	25 (BG Z A C 18*)	3	3	3	8	2		Tr							1 mm	MASSSES OF SMALL PRISMS OF BLUE-GREEN HORNBLende AROUND PALE GREEN HORNBLende
(M 2-14 0)		45 ALTERED	20 (PATCHY PLEOCHROISM)	10		2	12	1		Tr				10			5 to 1 mm	
(Q 3-9 2)	15	20 AB	25 (ACTINOLITE)	40	Tr												0.2 mm	ACTINOLITE-EPIDOTE SCHIST = SHEARED AMPHIBOLITE
(Q 0-9 7)	6	32 AB	30 (PALE AND BG IN PATCHES)	10	3	2	8			Tr		4				5	0.2 to 2 mm	NOTE FADED PATCHY PLEOCHROISM IN HORNBLende - BLUE-GREEN AND PALE GREEN
(K 7-5 9)	4	40 OLIG.	35 (BG Z A C 18*)	8		3	8			Tr		1					0.2 to 3 mm	
(I 1-7 4)	3	44 AND	30 (WEAK BG Z A C 18*)	10	4		5	4									< 0.2 to 5 mm	SOME HORNBLende IN FIBROUS, FELTY MASSES
(L 6-9 7)	32	3	15 (MINUTE PRISMS)	50				Tr		Tr							1 mm	EPIDOTE SCHIST = SHEARED AMPHIBOLITE ?
(K 5-10 9)		74 AB AN <sub>6</sub>			2	4	3			Tr	1	10	3		3		5 to 2 mm	SODA-RICH PHASE OF AMPHIBOLITE
(I 4-10 0)	20	80 AB				Tr					Tr		Tr				5 to 2 mm	MICROGRAPHIC SODA-RICH PHASE OF AMPHIBOLITE
(I 1-8.8)		60 AB AN <sub>6</sub>	30 (BG Z A C 17*)	4	Tr	4				1							1 mm	EPIDOTE IN LARGE GRAINS; WEAK, PATCHY, UNEVEN PLEOCHROISM IN HORNBLende
(H 9-13 7)	30	45 AB			3	4	15	2	Tr	Tr	Tr						0.2 to 1 mm	HORNBLende AND BIOTITE CONVERTING TO CHLORITE
(E 5-16 1)	5	66 AB	5 (BG Z A C 17*)	3	15	1	4			1							1 to 2 mm	
(F 2-12 2)		58 AB	10 (COLORLESS Z A C 19-21*)	15	10	3		3		1							< 0.1 to 2 mm	COLORLESS TO VERY PALE GREEN AMPHIBOLE
(E 7-11 5)	15	83 AB			Tr	Tr	2	Tr		Tr							1 to 2 mm	SODA-RICH PHASE OF AMPHIBOLITE

<sup>1</sup> AB = ALBITE  
OLIG = OLIGOCCLASE  
AND = ANDESINE  
<sup>2</sup> BG = BLUE-GREEN

secondary mineral in many metasedimentary rocks throughout the area. Locally massive hematite is associated with quartz veins, and one of these has been prospected near the Texas and Pacific Railroad (O.6—14.8, Pl. 1). Where quartz veins are in contact with limestone layers, chiefly in Cat Draw, siderite has formed. Other narrow quartz veins containing small amounts of iron and copper sulfides and capped by small gossans occur in the area. These veins are concordant with the regional foliation and are probably younger than the metamorphism. (Copper mineralization to the north is younger than the Hazel formation.) These copper-bearing veins have been extensively prospected.

#### PRE-CAMBRIAN (?) ROCKS

*Van Horn sandstone* (pCv).—Discontinuous remnants of basal arkosic Van Horn sandstone crop out along the east edge of the Carrizo Mountains, south of the Texas and Pacific Railroad. These remnants form low dark red hills which are composed of pebble and cobble conglomerate that lies unconformably on the metamorphic rocks. This conglomerate resembles that in the lower part of the Van Horn sandstone in the main areas of exposure north of the railroad (see section on Sierra Diablo foothills). It is composed of round, smooth pebbles and cobbles of red rhyolite, vein quartz, hard quartzite, and hard red sandstone (resembling the Hazel sandstone) set in a soft red to brown sandstone matrix. Most of the rounded fragments have been fractured during deformation of the enclosing rock, and whole specimens are usually difficult to extract. The cobbles and pebbles are set free by weathering and cover the outcrops of the formation. About 30 feet of conglomerate appears to be preserved. It occupies low areas on a former pre-Cambrian surface, much as does the Powwow member of the Hueco limestone, and the thickness is not constant.

Northeast of Bass Canyon (P.1—7.2, Pl. 1) a more nearly complete section of Van Horn sandstone has been preserved under an unconformable Permian cover in a down-faulted block. Here the conglomerate previously described grades upward into a red, violet, and brown medium-

grained conglomeratic feldspathic sandstone or arkose. The rock is cross-bedded and contains pebble layers and strings.

The Van Horn sandstone and the basal Powwow member of the Hueco limestone are very similar, and it is difficult to separate the two where they are in juxtaposition. Baker (1927) during the reconnaissance of the area confused the two, identifying the Powwow as Van Horn sandstone in the southern Bass Canyon area and in the Wylie Mountains. Both units are unfossiliferous red to brown conglomeratic sandstones. However, a number of features serve to distinguish them from each other:

(1) The Powwow is a softer, more friable rock than the Van Horn sandstone and is generally not well bedded. Moreover, the Van Horn sandstone is markedly cross-bedded, while cross-bedding in the sandstone of the Powwow is indistinct.

(2) The clastic material making up the sandstone of the Powwow is derived from rocks directly beneath. Thus where this unit overlies schist it is a micaceous sandstone; where it overlies rocks intruded by pegmatite (as in the Mica Mine area) the sandstone contains pebbles and cobbles of pegmatite and perthitic feldspar; and where it overlies quartzite it is quartz sandstone. The grains in the Powwow are subangular to angular. Where boulder conglomerate is present at the base of the Powwow, angular boulders of soft rocks such as mica schist are present. The Van Horn sandstone, on the other hand, contains at the base well-defined layers of smooth round cobbles and boulders of red rhyolite and vein quartz. These cobbles and boulders are evidently the abrasion-resistant remnants of a considerably water-worn sediment.

(3) The sandstone of the Powwow member grades into the overlying Hueco limestone through a zone of interbedded sandstone and silty limestone as much as 30 feet thick. Flat coiled gastropods are present in the upper sandstone and limestone layers. The Van Horn sandstone is unfossiliferous throughout.

Separating the two units is difficult where the Powwow overlies the Van Horn sandstone. The problem then is one of separating a red or brown sandstone from a re-worked red or brown sandstone, because

the Powwow here is derived in part from reworking the underlying Van Horn sandstone. Angular discordance between the pre-Cambrian (?) Van Horn sandstone and the Permian Powwow member is not a satisfactory criterion because of poor bedding. However, with careful searching it is possible to find weathered fragments of the older Van Horn sandstone as pebbles in the lower part of the Powwow, and, as the observer proceeds from the Van Horn sandstone into the Permian section, the line between the two units can be drawn where these fragments first appear. It is, of course, difficult to see weathered pebbles of red Van Horn sandstone in the red sandstone matrix of the Powwow member, and separation can be made only in well-exposed colluvium-free outcrops.

The age and history of nomenclature of the Van Horn sandstone is discussed by King in a later section.

#### PERMIAN ROCKS

*Hueco limestone* (Php and Ph).—Unconformably overlying the rocks of the Carrizo Mountain group and the Van Horn sandstone is the Hueco limestone, of basal Permian (Wolfcamp) age, which is similar to the formation as described in the Van Horn, Eagle, and Wylie Mountains. The Hueco limestone forms a steep cliff on the south side of Bass Canyon and comprises the southern part of the Carrizo Mountains. Discontinuous outcrops of the limestone are present along the west edge of the mountains and dip steeply toward the bolson. Northeast of Bass Canyon a down-faulted block is capped by the limestone. North of the Texas and Pacific Railroad, the Hueco limestone forms a steep scarp on the downthrown side of Hillside fault.

The Powwow member in this area is a soft micaceous red conglomeratic sandstone. South of Bass Canyon it ranges from 120 to 200 feet thick. The limestone is a compact, aphanitic, gray cherty cliff-making limestone that attains a maximum thickness of about 200 feet on the south side of Bass Canyon.

#### CRETACEOUS ROCKS (Kcg AND Kcx)

Basal Cretaceous limestones and sandstones unconformably overlie the Permian rocks on the downthrown side of Hillside fault. These rocks are described in the section on the Sierra Diablo foothills.

#### TERTIARY (?) INTRUSIVE ROCKS (Ti?)

A number of small dikes and sills of diabase occur within the area of pre-Cambrian rocks. These intrusives are black to brown, fine-grained to aphanitic rocks that commonly weather into a soft crumbly gray rock. The largest body is a sill on the east side of the Carrizo Mountains (0.5—7.5, Pl. 1) which has been intruded along the unconformity between the Van Horn sandstone and the Carrizo Mountain group. This sill is 10 to 15 feet thick. About 1 mile north a smaller sill has been intruded along this same contact.

*Petrography.*—Under the microscope these intrusive rocks show the characteristics of an altered diabase. Twinned laths of labradorite (about An<sub>64</sub>) partly altered to sericite compose 65 to 75 percent of the rock. Phenocrysts of plagioclase occur sporadically. The pyroxene of the original diabase has been replaced by a fibrous brown mineral with positive elongation and varied birefringence. This mineral was not positively identified. Magnetite, red and brown iron oxides, and carbonate occur between the plagioclase laths. Long needles of apatite are characteristic of these rocks. The fabric is ophitic to sub-ophitic, and the grain size averages 0.2 to 0.5 mm. These rocks are similar to the Tertiary intrusives described by Baker (1927) and Lonsdale (1940) and are probably of the same age.

#### STRUCTURE

*Pre-Cambrian structures.*—The major pre-Cambrian structure of the Carrizo Mountains is a great northeast-striking and southeast-dipping homocline which, as exposed, includes about 19,000 feet of metasediments, a minimum of 5,600 feet of intercalated amphibolite sills, and a minimum of 2,100 feet of intercalated metarhyolite sills. The homocline is interrupted to the northwest by intrusions of amphibolite and metarhyolite whose relations are obscured by unconsolidated bolson deposits. At the southeast end of the mountains in the Bass Canyon area, the strike swings from east of north to west of north. Here again relations are obscured by younger deposits, but the structure



seems to be an east-plunging syncline whose south limb has been displaced north-westward.

King (King and Knight, 1944, map section V-V'), in a preliminary map of the northern part of the Carrizo Mountains, suggested that the major structure in the Carrizo Mountains may be an over-turned syncline rather than a simple homocline. The axis of the hypothetical syncline extended roughly northeast-southwest through Cat Draw (pCCm<sub>1</sub>, Pl. 1). This hypothesis was considered for the following reasons:

(1) Two quartzo-feldspathic units (pCCq<sub>2</sub> and pCCq<sub>3</sub>, Pl. 1) of similar appearance lie on either side of Cat Draw and were interpreted as the same bed repeated by folding.

(2) Enclosed between the quartzo-feldspathic ridges are metasedimentary rocks and amphibolites that were believed to show only low-grade metamorphism, and these were interpreted as being high in the sequence.

(3) Metarhyolite and amphibolite to the northwest were interpreted as largely surficial lavas in stratigraphic sequence below the quartzo-feldspathic unit.

(4) Metarhyolite appears southeast of the southeastern ridge of quartzo-feldspathic rocks (at the limit of the preliminary map) and appeared to be equivalent to the northwestern metarhyolite and in harmony with the synclinal interpretation.

According to the synclinal hypothesis, the metasedimentary rocks could be interpreted as a younger infold in an older meta-igneous complex, and during the early stages of the work in the area, this appeared to be a logical picture. However, detailed mapping shows that the synclinal hypothesis is incompatible with a number of facts:

(1) Both the metarhyolite and amphibolite are younger than the metasedimentary rocks and intrude them.

(2) Units are present on the southeast limb of the proposed syncline which are not repeated on the northwest side of the axis (pCCp and pCCm<sub>2</sub>, Pl. 1). (King recognized some of these units during his earlier work in the area and realized at that time that these rocks did not fit the synclinal hypothesis.)

(3) When examined in detail the quartzo-feldspathic rocks that form ridges on either side of the hypothetical syncline are not lithologically similar, and cross-bedding indicates that both units are right side up with their tops to the southeast.

Northwest of the Carrizo Mountains and 1 to 2 miles north of the Texas and Pacific Railroad the trace of the Streeruwitz overthrust fault crops out in an arc whose chord strikes roughly northwest-southeast. The fault plane is marked by intense cataclasis, and metarhyolite klippen are found as much as a mile and a half north of the trace of the fault. Unfortunately in an area 2 to 3 miles wide between the exposed fault plane and the northwestern outcrops in the Carrizo Mountains the Carrizo Mountain group is covered by unconsolidated bolson deposits. The fault plane apparently dips south or southeast at a low angle, and the direction of thrust was from this same direction; the rocks of the Carrizo Mountain group have moved north or northwest over the Allamoore formation.

Exposures of pre-Cambrian rocks in the southeastern Carrizo Mountains are not sufficient to determine the relations between the major homoclinal structure and the possible syncline suggested by the change in attitude of the rocks in that area. In the eastern part of Bass Canyon the strike shows a gradual smooth change from east of north to west of north and indicates an open syncline plunging steeply to the east (Pl. 1). If this indicated syncline is a major structure, and not merely a flexure within the homocline, the entire homoclinal sequence may constitute its north limb. Rocks in western Bass Canyon strike west of north and are delimited on the northeast by an inferred fault that trends northwest. These rocks may be part of the concealed south limb of the indicated syncline that was displaced to the northwest.

The minor structures within the Carrizo Mountain group, such as small-scale complex folding within incompetent units, are the result of the interlayering of competent and incompetent units and the consequent absorption of the applied stresses by adjustment within the incompetent units.

Bedding (*S*<sub>1</sub>) and foliation (*S*<sub>2</sub>) are generally parallel, and therefore the folia-

tion conforms to the major homoclinal structure. The planar structure or schistosity developed in the metarhyolite and amphibolite is approximately parallel to that developed within the metasedimentary rocks.  $S_3$  structures are prominent in certain areas, particularly where incompetent units are in contact with massive competent units such as the metarhyolite. Lineation in the metarhyolite plunges fairly uniformly southeast, although strike and dip of schistosity in this unit is varied by broad open folds. The origin of the schistosity and lineation is discussed in the section on metamorphism.

Two northeast-trending faults displace pre-Cambrian metasedimentary units and metarhyolite in the northeast Carrizo Mountains (Pl. 1). In both these faults the southeast side has apparent horizontal displacement to the southwest on the order of 1,200 to 1,500 feet. The age of this faulting is not apparent, but is probably pre-Cambrian and may have been caused by adjustments

during the period of thrust faulting. The northeast trend shown by these faults is not characteristic of younger structures.

*Younger structures.*—The Hueco limestone that unconformably overlies the Carrizo Mountain group of the Carrizo Mountains is displaced by a number of north-trending normal faults that are downthrown to the east. The displacement on these faults is less than 100 feet. In the eastern and southern parts of the mountains the Hueco dips gently south except where it is disturbed by the normal faulting. Along the western edge of the mountains the Hueco dips steeply away from the mountains into the bolson to the west. Apparently a post-Permian uplift of the Carrizo Mountains, probably in Tertiary time, caused sharp folding of Hueco on the west side of the mountains and normal faulting to the east and north. The Carrizo Mountains were thus last uplifted as a triangular block, hinged on the west and faulted on the east and north.

## SIERRA DIABLO FOOTHILLS

Philip B. King

### TOPOGRAPHIC SETTING

The Sierra Diablo foothills are a belt of country 7 miles wide, extending southward from the scarps of the Sierra Diablo to the Texas and Pacific Railroad and the alluvial area of Eagle Flat. Rising above the foothills on the north and east are scarps of the Sierra Diablo and Beach Mountain, surmounted by cliffs of flat-lying Paleozoic limestone—of Permian age in the Sierra Diablo and of Ordovician age in Beach Mountain. Below the cliffs on the west side of Beach Mountain, and for short distances in the Sierra Diablo, are red ledges of an older formation, the Van Horn sandstone, which form some of the most striking scenic features of the area. Within the foothills themselves are occasional outliers of flat-lying Permian and Cretaceous limestones and sandstones which rise above their surroundings as buttes and mesas.

Most of the foothills are, however, made up of much more deformed older rocks, of pre-Cambrian age. One of the most conspicuous units in the older rocks is a fine-grained, homogeneous red sandstone, a part of the Hazel formation, which has been carved into gently sloping pediments. The pediments are partly covered by alluvium in the Eagle Flat drainage to the west but are dissected into a network of low hills and shallow valleys in the Salt Basin drainage to the east. More resistant rocks of the succession, conglomerates of the Hazel formation and limestones of the Allamoore formation, project in ragged strike ridges several hundred feet high, not unlike those of the deformed Paleozoic rocks of the Marathon basin.

The most extensive belt of these ridges lies two or three miles south of the Sierra Diablo scarp and immediately north of the alluvial area of Eagle Flat, where they form a chain of low hills. The hills have been split into three groups by two belts of alluvium along major drainage courses leading from the Sierra Diablo scarp to Eagle Flat. So far as known, these hills have been given no names by the local residents, or at least no distinctive names, yet they must be referred to constantly in the descriptions which follow. The writer there-

fore ventures to create the following titles for them:

The western of the three groups of hills will hereafter be called the *Streeruwitz Hills*, after W. H. von Streeruwitz, sagacious geologist of the Dumble Survey, who in 1890 (Von Streeruwitz, 1891, pp. 681-682) demonstrated that they contained "micaceous schistose rocks, similar if not identical with those of the Carrizo Mountains," a concept fundamental to the more extensive interpretations made in this report.

The central group of hills are termed the *Bean Hills*, after the old Bean ranch (now Canning ranch) which lies on their eastern side.

The eastern group of hills are termed the *Millican Hills*, after the old Millican ranch (now Garren ranch) which lies in their midst. This usage serves to perpetuate in the geological record the name "Millican," used by Richardson (1914, p. 4) for a formation that included rocks herein termed the Allamoore and Hazel formations. For a number of reasons that will become apparent later, the writer, to his reluctance, has found it necessary to abandon further use of the name Millican as a stratigraphic term.

### PRESENT INVESTIGATION

The reader will be better able to evaluate the geological conclusions contained in this chapter if the manner in which the investigation was made is set forth.

Field work on the pre-Cambrian rocks of the Sierra Diablo foothills was one phase of a wider investigation of the Sierra Diablo region made for the U. S. Geological Survey with the assistance of J. Brookes Knight, the chief purpose of which was to obtain information on the stratigraphy, paleontology, and structure of the Paleozoic rocks, because of their significance in exploration for oil and gas. In the course of this work incidental study was made of pre-Cambrian, Cretaceous, Quaternary, and other rocks of the area. The main emphasis of field work on the pre-Cambrian rocks, like that on the others, was on

their stratigraphy and structure, and less attention was paid to their petrography.

A collection of some 51 specimens was made from the pre-Cambrian rocks, which it was planned would serve as a basis for a later cursory petrographic study. However, these collections appear to have been lost, and this section on the pre-Cambrian rocks of the Sierra Diablo foothills is out of balance with sections by Flawn on pre-Cambrian rocks elsewhere in the region, which are supported by elaborate petrographic work. This circumstance is to be regretted, but it should be borne in mind that these younger pre-Cambrian rocks are more susceptible to ordinary methods of stratigraphic study and analysis than the metamorphosed and injected pre-Cambrian rocks farther south that have been investigated by Flawn.

Initial field work on the pre-Cambrian of the Sierra Diablo foothills was done in 1931, when a reconnaissance was made of the Streeruwitz Hills. The writer's interest in this area had been excited because Von Streeruwitz (1891, pp. 681-682) had there reported the occurrence of schist, otherwise known only south of the Texas and Pacific Railroad, as in the Carrizo Mountains. Mapping was done on the old, highly inaccurate Sierra Blanca 1:125,000 topographic sheet, enlarged to a scale of 1:31,250, supplemented by free sketching of topographic and geologic details. During this season, evidence was gathered which strongly suggested that the schistose rocks on the south were overthrust on the sedimentary rocks on the north, and the following interpretation was made of the sequence (Darton and King, 1933, p. 21; Sellards, 1933, pp. 38-40):

*Table 14. Sequence of pre-Cambrian rocks of Sierra Diablo foothills as interpreted in 1931.*

Van Horn sandstone

Unconformity

Millican formation:

Upper limestone, in synclines lying on red sandstone, as in northern Bean Hills and on Tumbledown Mountain.

Red sandstone, conspicuously exposed on lower slopes of Sierra Diablo; Hazel sandstone of Dumble.

Massive conglomerate, forming high ridges 3 miles northwest of Eagle Flat section house, and elsewhere.

Lower limestone, forming a belt in south part of Sierra Diablo foothills.

Overthrust; sequence broken

Carrizo Mountain schist; with mylonite near overthrust.

Igneous rocks were found interlayered with the limestone but were believed to be for the most part intrusive sills, like the basic intrusives ("greenstone" or amphibolite) in the Carrizo Mountain schist to the south.

During 1933 and 1936, a few weeks were devoted to extending the reconnaissance mapping of the pre-Cambrian rocks eastward across the Millican Hills to Tumbledown Mountain. Many interesting local relations were established, but it was found that the structure was so complex that no solution to the geological puzzles could be obtained without much more detailed surveys.

Opportunity for such work came in 1938, when about five weeks were devoted to detailed mapping of the Millican Hills. Surveys were made on the Van Horn 1:125,000 topographic sheet, enlarged to a scale of 1:20,833, topographic and geologic details being filled in by an elaborate system of pacing traverses. This method proved to be highly satisfactory, as the topographic base had a high degree of intrinsic accuracy, however generalized it might appear when so greatly enlarged. It was also attempted to extend similar detailed mapping westward into the Bean Hills but with disappointing results, as the Sierra Blanca base map did not lend itself to the same use as the Van Horn map.

During 1938, the metarhyolites of the Carrizo Mountain group were reviewed with Earl Ingerson and their mylonitic and cataclastic structure verified, thereby strengthening the interpretation that they lay in thrust contact on the limestones to the north. The mineral deposits of the †Millican formation were reviewed with S. J. Lasky, as well as the rocks in which they occur. The volcanic rather than intrusive nature of the igneous rocks associated with the limestones had already been suggested by petrographic work by C. S. Ross, and this was confirmed by observations in the field in company with Lasky; their age was established by discovery of their fragments in the succeeding conglomerates.

As a result of these conferences, and the writer's own detailed surveys, it was now possible to revise the section of 1931 and to create the classification which has appeared in subsequent publications, and with minor modifications in the present

section. The supposed upper limestone was shown to be identical with the lower and to have attained its present position above the red sandstone by overthrusting or overfolding. The conglomerate was found to be interbedded so intimately with the red sandstone as not to constitute a separate formation. The sequence now became (King, 1940, pp. 143-156; King and Knight, 1944):

Table 15. Sequence of pre-Cambrian rocks of Sierra Diablo foothills as interpreted in 1938.

Van Horn sandstone  
Unconformity  
Hazel sandstone, made up of red sandstone, interbedded with and underlain by conglomerate.  
Unconformity  
Allamoore limestone, made up of interbedded limestone, volcanics, and phyllite.  
Overthrust; sequence concealed  
Carrizo Mountain schist; in this area metarhyolite, partly mylonitized, and basic sills ("greenstone").

In 1951, during preparation of the present report, the earlier mapping was reviewed with the aid of air photographs that had become available in 1948. Surveys were replotted and corrected with the aid of a stereoscope on prints enlarged to a scale of 1:13,615. During this work, the validity of the detailed mapping in the Millican Hills on the Van Horn topographic base was abundantly demonstrated, and little or no revision was required. More revision was needed of the vertical faults and fractures north of the Millican Hills, as it had proved impossible to locate these accurately at all places by ground surveys alone. Resulting changes in representation of these features may be perceived by comparing the present map with that published in 1944. Review on the air photographs also demonstrated the inadequacy of the reconnaissance mapping on the Sierra Blanca topographic base. Many problems in the area of the Sierra Blanca map were solved by the new work, but many additional problems were raised which could not be settled without additional ground surveys; these it was not feasible to undertake.

In short, replotting of the ground surveys on the air photographs indicates that the representation on the eastern of the two maps (Pl. 2) accompanying this chapter has a high degree of accuracy, but that the representation on the western of the two

maps (Pl. 3) is unreliable. The general distribution of the rock types in the western area has been established, but not enough information has yet been obtained successfully to interpret their stratigraphy and structure. All the mineral deposits of economic interest lie in the area of the eastern sheet (with the exception of a recently discovered talc deposit), and the rocks of the area of the western sheet appear to be relatively barren.

## PRE-CAMBRIAN ROCKS

### CARRIZO MOUNTAIN GROUP<sup>15</sup>

*Introduction.*—The Carrizo Mountain group is exposed here and there at the south edge of the Sierra Diablo foothills, next to the alluvial area of Eagle Flat, where it forms yellowish or pinkish hills, whose light color contrasts with adjacent darker hills of limestone and conglomerate. The most extensive outcrops are in the southern Streeruwitz Hills northwest of Eagle Flat section house (Pl. 3), where the occurrence of schist (metarhyolite) was noted by Von Streeruwitz (1891, pp. 681-682). Smaller outcrops occur at the south edge of the Millican Hills 2 miles northeast of Allamoore (E.5-2.5 and F.5-2.5, Pl. 2), where the occurrence of metarhyolite was noted by Richardson (1914, p. 7); he observed its resemblance to rhyolites of the Carrizo Mountains but unfortunately grouped it on his geologic map with the Tertiary intrusives. Among other exposures are some outliers within the Millican Hills, entirely surrounded by outcrops of Allamoore formation, of which the largest is 2 miles west of the Garren ranch house (B.0-6.0, Pl. 2).

The Carrizo Mountain group of the Sierra Diablo foothills consists of metarhyolite and minor amounts of amphibolite, which are identical with metarhyolite and amphibolite of the Carrizo Mountain group in the Carrizo Mountains. The latter are described by Flawn elsewhere in this report.

The metarhyolite and amphibolite lie against the Allamoore formation on the north, and their foliation generally dips away from it toward the south. Many lines of evidence, discussed under the heading of

<sup>15</sup> The U. S. Geological Survey classes the Carrizo Mountain as a formation rather than a group; see introduction, pp. 20-22.

structure, indicate that the Carrizo Mountain group has moved over the Allamoore formation along the sole of a great, low-angle fault, here termed the Streeruwitz overthrust. The outliers of Carrizo Mountain within the Millican Hills are believed to be klippen of the overthrust.

*Metarhyolite* (pCCr).—In most exposures in the Sierra Diablo foothills, the metarhyolite is a pink, siliceous rock that splits into blocks along numerous clean-cut joints. In many places, these blocks strew the surface to such an extent that ledges in place are difficult to discover. The rock contains relict phenocrysts less than one-fourth inch in diameter, mainly of pink feldspar, now more or less crushed and broken. Nearly all the metarhyolite exhibits a well-developed foliation, on the surface of which are lineations formed of streaks of light and dark minerals. In places lineation dominates over foliation, so that the rock is made up of closely packed, rod-like structures, without any clear planar element. As shown on the geologic map, foliation generally dips south, and lineation plunges south or south-southwest, but in places, especially near the sole of the overthrust, foliation shows rolls and minor contortions, and lineation trends in aberrant directions.

Parts of the metarhyolite close to the sole of the Streeruwitz overthrust have been altered to compact, aphanitic, siliceous mylonite, made up of straight, parallel, light and dark laminae no more than a few millimeters thick. Outcrops show that the mylonite is interlayered with the metarhyolite in layers a few feet thick, but in many places mylonite is preserved only in float blocks, and relations are obscure. Close to the sole of the overthrust the metarhyolite contains inclusions of brown, highly siliceous carbonate rocks, similar in appearance to altered limestone in the Allamoore formation beneath the thrust sheet. This is either hydrothermally altered limestone intercalated tectonically in the metarhyolite or is carbonate-cemented metarhyolite microbreccia. Farther back from the trace of the overthrust, the metarhyolite contains occasional interbedded layers of silvery, lustrous, sericitic schist.

A rhyolite porphyry which is coarser and more massive than the rest occurs in three low hills that project from the alluvium

4½ miles northwest of the village of Allamoore (P.5—6.5 and Q.5—6.5, Pl. 3). The dominant rock consists of pink feldspar phenocrysts as much as half an inch in diameter, set in a dark gray or blue-gray, fine-grained ground-mass. Foliation is expressed only by rude layering, on the surface of which lineation is faintly developed; in some places the phenocrysts have been broken and strung out in the direction of lineation. The porphyries are associated with fine-grained massive rocks, consisting largely of ground-mass and containing very few phenocrysts, and with thinly fissile schist.

Specimens of various phases of the metarhyolite from the Sierra Diablo foothills have been examined under the microscope by Flawn, who reports as follows (memorandum of February 1952):

A specimen of the normal phase of the metarhyolite from directly over the Streeruwitz overthrust in outcrops 2 miles northeast of Allamoore contains 80 percent fine-grained (less than 0.02 mm.) crushed ground-mass of feldspar and quartz, showing flow structure and possessing a cataclastic fabric. Fourteen percent of the rock is relict phenocrysts, of which 5 percent are albite (chessboard twins cut by veinlets of the same feldspar), 9 percent micropertthite (albite in irregular veins in potassium feldspar; may be microcline with vague distorted twinning), and 5 percent quartz (severely strained, in streaks, eyes, and elongate grains). Minor constituents are calcite, zircon, and red iron oxide. Secondary quartz occurs in veinlets.

A specimen of the coarse phase of the metarhyolite from 4½ miles northwest of Allamoore consists of 70 percent ground-mass, formed of fine-grained (0.01 to 0.05 mm.) feldspar and quartz. Both indices of refraction of the feldspar are consistently less than 1.530, indicating that it is potassium feldspar. Broken and crushed phenocrysts with diameters up to 5 mm. make up 20 percent of the rock. Identification of the feldspar of the phenocrysts is difficult. Some show an anomalous twinning that may be a vague and distorted microcline quadrille; others show chessboard twinning of the sort that has been interpreted as indicating replacement of microcline by albite; still others are microcline-micropertthite. Determinations on two phenocrysts gave the lower index of refraction as about 1.530, indicating that at least part of the phenocrysts are albite. Coarser eyes of quartz and grains of calcite occur in pressure lees of the phenocrysts. The quartz of the eyes and of the grains in the ground-mass makes up about 7 percent of the rock. Minor constituents of the rock include magnetite or ilmenite (small scattered grains), sericite (fibers commonly wrapped about the phenocrysts), chlorite (associated with an opaque mineral from which iron was derived), and traces of apatite and sphene.

A specimen of the fine-grained brown carbonate rock, from an outcrop surrounded by metarhyolite 2 miles northeast of Allamore shows a compound fabric which includes cataclastic, crystalloblastic, and diablastic (hornfels) elements. Grain size is 0.02 to 2 mm. Albite makes up 57 percent (grains in a mosaic with calcite showing bent twin lamellae; also as fresh twinned grains in veinlets with tourmaline and calcite); quartz 20 percent (severely strained grains and in larger masses showing relict crush-suture fabric); tourmaline 8 percent (zoned prisms and groups of prisms). Minor constituents are reddish iron oxide and apatite. The rock may have formed by high-temperature hydrothermal activity near the fault zone, with replacement of original limestone by sodic solutions during the same period as that which albitized the phenocrysts in the metarhyolite.

*Amphibolite (pCCa).*—The metarhyolite is interbedded with thin to thick bodies of amphibolite, which form sills lying parallel to the foliation. Most of these, too small to show on the map, are thin beds or streaks a few feet thick, with well-marked foliation and lineation parallel to that in the enclosing metarhyolite.

Among the thicker bodies, two in the southern Streeruwitz Hills are differentiated on the map. The largest (D.5—8.5, Pl. 3) is actually a complex of many smaller sills, separated by sheets and leaves of metarhyolite. Close to the metarhyolite the amphibolite is as strongly foliated as in the smaller bodies, but the interior parts are more massive. Specimens from the sill were studied under the microscope by C. S. Ross, who reports as follows (memorandum of June 21, 1938):

One specimen is a highly ferro-magnesian rock, composed dominantly of plagioclase and hornblende. The ground-mass is moderately coarse-grained, and a few plagioclase phenocrysts are present. The rock seems to be a hypabyssal type, of andesitic character. Abundant secondary minerals are epidote, calcite, chlorite, and part of the hornblende. Alteration is marked, but less extreme than in the next specimen. In the latter, alteration is so thorough that the original character is not clearly determinable, although it may have been similar to the first specimen. It is now composed of some primary hornblende, secondary hornblende, clinozoisite, quartz, and chlorite. Sphene is very abundant. The alteration is hydrothermal rather than dynamic.

*Quartz and quartz-feldspar veins.*—Both metarhyolite and amphibolite contain vein material, generally in narrow stringers and irregular blebs a few inches thick but partly in more massive bodies several feet thick. The dominant mineral is milky or

vitreous quartz, but in places this is associated with pink feldspar, muscovite, specular hematite, and martite. Some of the veins and adjacent host rocks contain undeformed cubes of pyrite. Narrower quartz veins also traverse the adjacent altered limestones of the Allamore formation.

Structural relations of the veins are complex. Although they occur to some extent in the amphibolite, they appear to be most common in the metarhyolite, perhaps because this rock was more brittle and susceptible to fracture. Many veins follow the foliation of the enclosing rocks or spread through them irregularly; some of these are slickensided parallel to the prevailing lineation. Other veins lie on joints that cross the foliation, and some form the cement of brecciated metarhyolite. Still other cross-joints break and offset the veins and show no mineralization except for scant coatings of specular hematite or chlorite.

*Interpretation of Carrizo Mountain group.*—According to observations of Flawn, the metarhyolite of the Carrizo Mountains intrudes a thick sequence of sedimentary rocks, also a part of the Carrizo Mountain group; no remnants of this earlier host rock remain in the metarhyolite of the Sierra Diablo foothills.

Succeeding rocks and structures developed under the influence of dynamic forces, in part at least related to development of the Streeruwitz overthrust. Differential movement within the metarhyolite produced foliation and cataclasis; phenocrysts and other mineral aggregates were drawn out in the direction of transport, or a structural axis, to create the all-pervading lineation. Less competent zones were converted to mylonite and schist. Close to the sole of the overthrust, continued movements contorted the previously formed foliation and skewed the lineation into aberrant trends.

After the beginning of the dynamic period, amphibolite was injected in the metarhyolite as sills parallel to the foliation. Further movements crushed and foliated the thinner bodies between the enclosing, more competent masses of metarhyolite but produced little change in the thicker bodies.

Introduction of vein material succeeded that of the amphibolite and took place during the waning stages of the dynamic epoch.

The earliest veins are probably those parallel to the foliation, as their slickensides attest continuation of differential movements like those which produced the lineation in the enclosing rock. Later veins follow the cross joints, but joints continued to open after the period of vein formation, as many of the veins are broken and offset by the latest, little-mineralized joints.

#### ALLAMOORE FORMATION

*Introduction.*—The Allamoore formation crops out mainly well south of the Sierra Diablo scarp, near Eagle Flat, where it occurs in a belt about 5 miles wide that trends west-northwest. The formation projects in low, barren, sub-parallel ridges.

The most prominently exposed parts of the Allamoore are its limestone beds and units, but these are interlayered with great masses of volcanic rocks, including flows, pyroclastics, and perhaps shallow intrusives. There are also many thin units of argillaceous rocks, now altered to phyllite.

As the Allamoore is exposed mainly to the south where deformation of the pre-Cambrian rocks is greatest, the formation is nearly everywhere tilted at high angles and complexly folded and faulted (fig. 10). Determination of stratigraphic sequence is therefore difficult, and estimation of total thickness almost impossible. On Tumbledown Mountain (R.5—8.5, Pl. 2), where relations are unusually well shown, about 1,630 feet of the formation is exposed but neither the top nor base is present, and the sequence is at least partly duplicated by thrusting. Any traverse across the strike of the formation will cross a wide expanse of steeply dipping beds that can hardly have been produced by repetition of a few thin layers; the formation is probably as much as several thousand feet thick.

*Limestone (pCals).*—Limestones of the Allamoore formation stand in jagged ledges and ridges. They are characteristically seamed by bands of chert a quarter to half an inch thick, lying parallel to the bedding and disposed at intervals of a few inches (Pl. 23, A). Differential weathering of chert and limestone gives the ledges a striking ribbed appearance. The chert appears to be a primary or diagenetic feature; it at least antedates the pre-Cambrian orogeny, for where the rocks are strongly deformed, chert seams are sliced and

broken, while the less brittle intervening limestones are deformed by flowage.

The limestones themselves, where least altered, are mainly thin bedded and compact, with occasional more granular or more crystalline layers. Most of the limestone is blue, gray, or brown, but some is reddish or purplish. Some limestone beds are very thinly and evenly laminated by light and dark seams; others up to 8 feet thick are massive and contain no chert. At a few places the limestones are interbedded with intraformational limestone-pebble conglomerate.

A specimen of dark gray, fine-grained, little altered limestone of the Allamoore formation from Tumbledown Mountain (bed 5 of Tumbledown Mountain section) was analysed by K. J. Murata in the chemical laboratory of the U. S. Geological Survey with the following results (memorandum of March 4, 1937):

Table 16. Analysis, in percent, of limestone from Allamoore formation (K. J. Murata, analyst).

Inorganic insoluble . . . . .	6.69
Organic insoluble . . . . .	0.05
Soluble $R_2O_3$ . . . . .	0.97
$CaCO_3$ . . . . .	83.82
$MgCO_3$ . . . . .	9.32
$MnCO_3$ . . . . .	0.06
$Ca_3(PO_4)_2$ . . . . .	none
Soluble CaO other than carbonate . . . . .	none
Soluble $SiO_2$ . . . . .	none
Total . . . . .	100.91

The analysis indicates that the limestone is only slightly magnesian. According to Richardson (1904, p. 25) "A partial analysis, by Mr. George Steiger, of a sample collected 3 miles northeast of Eagle Flat, shows considerable magnesian content." So far as the present analysis shows, there is nothing to distinguish this specimen from similarly analysed Paleozoic limestones of the same region, except perhaps the appreciable content of manganese. According to Mr. Murata, the organic matter indicated by the analysis is apparently similar to the bituminous material which darkens the Paleozoic limestones.

The organic matter in the limestones seems to prove existence of life during formation of these ancient rocks, yet searches for fossils that have so far been made reveal nothing but possible algal remains. Many of the chert-banded or laminated limestones have a crinkled, wavy, or dome-



like structure similar to the *Cryptozoon* or stromatoporoid growths in the older Paleozoic rocks, and in places they rise into low mounds or reefs (Pl. 23, B). Other beds resemble the mottled limestones of the older Paleozoic rocks which were perhaps formed by algal growth. Many of the observed structures in the limestones of the Allamoore formation closely resemble those from the Belt series of Montana that have been described and figured as fossil algae by C. L. and M. A. Fenton (1937, pp. 1941-1965).

Mention should also be made of various obscure objects which occur here and there in the limestones, that might once have been fossils. They lie in rock now so altered and silicified that if organic structure once existed it has since been destroyed. Part of the material may once have been shells, shell fragments, or broken algal crusts, but so far as can be determined, most of the objects are of inorganic origin.

On a high knob in the northern Millican Hills  $1\frac{1}{4}$  miles east of the Garren ranch house and south of the Anaconda no. 2 prospects (I.5-7.5, Pl. 2) are limestones of surpassing interest, for they show many features that suggest an organic and possibly algal origin. The limestones of the knob dip north, away from the Hazel formation and toward volcanic rocks. Near the north base of the knob the limestone is blue-gray or brown and seamed by chert, much as it is elsewhere. About halfway up the slope to the south is a brown limestone which encloses angular fragments of blue-black, crinkled limestone, apparently of organic origin. Near by are some blue, thin-bedded, mottled limestones, made up of winding bluish bodies enclosed in a sparse yellow matrix. On the northwest tip of the hill are structures that look like *Cryptozoon* and stromatoporoid reefs. The rock contains great reefy heads 10 feet or more across, composed of dark, bituminous, papery, laminated limestone. The laminae run in waves a foot or so across, whose crests are rounded and troughs acute. Between the reefy masses, and ending abruptly against them, are layers of straight-bedded, thinly laminated, siliceous rock. Above them are breccias or conglomerates, full of fragments of the laminated reef limestones.

Similar reefy structures of probable organic origin are described below, in bed 5 of the Tumbledown Mountain section and are illustrated in Plate 23, B.

Intraformational conglomerates occur in the limestones at several localities a mile or two southeast of the Garren ranch house. They are composed of limestone pebbles and flags up to several inches across, set in a limestone matrix. The limestone conglomerates are easily deformed by pressure, and in places the pebbles have been mashed. Their outcrops are not far south of the contact between the Allamoore and Hazel forma-

tions, and the adjacent conglomerates of the latter contain boulders of the older conglomerate.

Structures which have the superficial appearance of fossils were observed in the limestone in the hills immediately west of the Canning ranch house (P.5-11.5, Pl. 3) and on a ridge crest near a prominent synclinal fold  $1\frac{3}{4}$  miles southeast of the Garren ranch house (H.5-4.5, Pl. 2). At the first locality the structures are globular, siliceous masses from the size of a pea to the size of a walnut ( $\frac{1}{8}$  to  $\frac{1}{2}$  inch in diameter). At the second they are spherical bodies of about the same size, composed of white, finely crystalline calcite, in part with a thin siliceous shell. The structures at both localities are probably inorganic, although some of them have tantalizing suggestions of shell structure.

*Volcanics* (pCAv).—Volcanic rocks probably make up from one-fourth to one-half of the total volume of the Allamoore formation, but they are much less conspicuous than the limestones, as they have been worn down generally to soil-covered slopes, sags, and valleys. Their best exposures are in creek banks and prospect holes. In a few places, more massive parts of the volcanics project in rugged black hills, covered by ledges and boulders. The volcanics are interbedded with the limestone in units a few feet to hundreds of feet thick and in places also contain thin limestone beds. Volcanic activity and limestone deposition were thus essentially contemporaneous.

Some of the volcanic rocks are very massive and weather to brown or black, bouldery surfaces; when fresh, such rocks are dark green or red. Diabasic structure is prominent in places, and in others amygdulites are abundant. Superficially these massive igneous rocks resemble the intrusive amphibolites in the Carrizo Mountain group that are described by Flawn elsewhere in this report. They differ in the occurrence of amygdulites, which indicate a surface or near-surface rather than a deep-seated origin; and in the fact that they are diabasic rather than dioritic. Specimens examined by Flawn contain pyroxene rather than amphibole.

A considerable part of the dark massive igneous rocks were no doubt originally spread out as subaerial or subaqueous lava flows, but little remains of primary flow structures except for the rather common amygdulites. Other parts may have originated as welded pyroclastics, and some of the thicker, more massive bodies may have been shallow, sill-like intrusives. In the openings at the Anaconda no. 2 prospect in

the Millican Hills (J.5—7.5, Pl. 2), diabasic rocks are crossed by aphanitic bands that may be dikes.

Some of the other, less massive volcanic rocks are probably of pyroclastic origin, for they show well-developed sedimentary structures but are made up in large part of igneous detritus. Coarser varieties include dark red, brown, or green sandstones with pebbly seams of igneous fragments and interbedded layers of volcanic conglomerate. Finer beds include brown or green siliceous shales, thinly laminated pink siliceous rocks, and light green schistose laminated rocks, all probably derived from different sorts of tuffs. Interbedded with the pyroclastics are thin beds of reddish limestone that contain angular igneous fragments.

Specimens of the volcanic rocks have been examined under the microscope by C. S. Ross (memorandum of June 21, 1938) and P. T. Flawn (memorandum of February, 1952), whose reports are as follows:

One specimen examined by Flawn from about 2½ miles northwest of Eagle Flat section house (Pl. 3) "is an altered diabase composed of 74 percent plagioclase (considerably altered but index of refraction indicates it is probably andesine or labradorite), 7 percent augite, 5 percent magnetite or ilmenite and iron oxide, 3 percent carbonate, 2 percent chlorite, 7 percent fibrous radiating mineral that may be chlorite, 2 percent of an unidentified low-birefringent, high relief fibrous radiating mineral that, except for structure, resembles apatite, and traces of epidote and zoisite. Fabric is sub-ophitic or diabasic; grain size is 0.2 to 0.4 mm. Rock is probably a shallow intrusive."

Another rock from the same locality examined by Flawn "is very hard, green, vesicular, and aphanitic, consisting of about 5 percent quartz (as angular fragments, veinlets, and spongy cavity fillings), 5 percent carbonate (masses of dirty, brown-stained grains), and 90 percent of gray-green cryptocrystalline ground-mass. The rock is an altered and indurated pyroclastic."

A considerably more altered rock from the vicinity, examined by Ross, is of less certain origin. It is a "very strongly laminated rock, with abundant augen-like inclusions that themselves have a fine schistose structure. The ground-mass is very fine-grained, with abundant ferromagnesian minerals and dark pigmenting material that forms wavy parallel stringers. The augen are in part calcitic and in part a material that is probably a light-colored chlorite aggregate. It is not clear how much of this lamination is due to shearing. The structure of the ground-mass material could be produced by compaction of a vesicular pyroclastic aggregate, followed by thorough recrystallization. On the other hand, a distinct parallelism of the chloritic material in

the augen indicates a rather definite shearing. Probably both factors played a part."

Still another specimen studied by Ross is a pyroclastic rock from 2 miles northwest of the Canning ranch house (C.5—14.5, Pl. 3). It is "a volcanic tuff of rhyolitic character. The minerals in the rock fragments are very fine-grained, and the only recognizable primary minerals are feldspar and possibly some quartz. However, much of the quartz is in aggregates that seem to represent sandstone and perhaps novaculite fragments that have been incorporated with the tuff. Secondary calcite is abundant. The rock is much altered."

Typical outcrops of the volcanics may be seen in the northern Millican Hills in the vicinity of the Anaconda no. 2 prospect a mile east of the Garren ranch house (H.5—7.5, Pl. 2). The prospect is on low, rounded, greenish hills of igneous rock. The pits expose the following rock types: (1) Massive, diabasic rock, dark greenish-gray when fresh, weathering dark reddish brown. (2) Similar rock, but containing amygdulæ, some of which are filled with green chloritic mineral. (3) Augite rock of light olive-green color, with dark brown weathered surface and schistose chlorite on joints. (4) Olivine rock of dark green color. (5) Aphanitic bands, which may be dikes, in the more granular rock. In the vicinity of the pits the volcanics are interbedded with thin lenses of limestone, some of which are of orange-red color.

North of the volcanics at the prospect is a thin bed of white, laminated, calcareous phyllite, followed by 150-foot unit of limestone in 2-foot beds, interbedded with pink, thinly laminated siliceous rock, perhaps an altered tuff. Between this and the succeeding Hazel formation is dark red, gritty sandstone, probably a pyroclastic and believed to be part of the Allamoore formation. The conglomerates of the Hazel formation in this vicinity contain fragments of many of the rock types just described.

Half a mile west of the Anaconda no. 2 prospect are other prominent exposures of the volcanics. To the north, in contact with the Hazel formation, is massive, bouldery igneous rock which weathers maroon-red. A little to the south are interbedded lenses of limestone 2 to 3 feet thick; these are highly tuffaceous, of deep red color, with seams of igneous grits. Near by are beds of buff siliceous laminated rock.

The volcanics are also well exposed at Buck Spring, 3½ miles southeast of the Garren ranch house (J.5—3.5, Pl. 2), which issues in a gorge carved in the limestones and volcanics. At the spring is a belt of volcanics 300 feet wide, standing nearly vertical and in sharp contact with limestones on the south. Part is a massive amygdaloidal igneous rock, but there are interbedded greenish pebbly and gritty layers, made up of igneous detritals, and thin limestone lenses.

In places, the more massive volcanics have a deceptively youthful appearance. In the western Millican Hills 2¼ miles west of the Garren ranch house (A.5—7.5, Pl. 3) is a black, bouldery knob which looks very much like a recent basalt plug. Most of the rock on the knob is dark amygdaloidal igneous rock, showing no trace of deformation. However, toward the edges of the body the same rock is strongly sheared and jointed, and

mapping discloses that the rock on the knob is merely a massive phase of a more extensive band of outcrop of a volcanic unit of the Allamoore formation.

In the southern Streeruwitz Hills northwest of Eagle Flat section house, the geologic map (Pl. 3) shows several wide bands of volcanics interbedded in limestones of the Allamoore formation immediately north of the trace of the Streeruwitz overthrust. There is some question whether these are interbedded volcanic units or whether they are intrusive sills related to the amphibolites that intrude the metarhyolite of the Carrizo Mountain group a short distance to the south. The thickest igneous body shows no evidence of cataclastic alteration like that in the adjacent amphibolite, but on a conical hill near the west end of the exposure it is foliated and phyllitic near its contact with the limestone on the south. In the interior of the body the rock is massive fine-grained greenstone. The specimen examined under the microscope by C. S. Ross, which has the appearance of an extrusive igneous rock, seems to have come from one of these igneous bands.

*Phyllite (pCap).*—Phyllite is almost as widely distributed as limestone and volcanic rocks in the Allamoore formation but has considerably less volume; it generally forms units less than a hundred feet thick. Like the volcanics, its beds are poorly resistant to erosion and are commonly worn down to low ground between the limestone ledges. In many places the phyllite and volcanics are closely associated, and a single interval between the limestones may consist in one place of phyllite, in another of volcanics, and in others may contain both rocks.

The original argillaceous constituents of the phyllite have been thoroughly altered to foliated, sericitic or talcose minerals. Most of the rock is gray to dark gray, but parts are black and apparently graphitic, and others are calcareous. Bedding is indicated by alternation of the gray, black, and calcareous varieties, generally in layers a few inches thick. Bedding is intensely contorted and is crossed by strongly marked slaty cleavage roughly parallel to the axial planes of the folds (Pl. 24, A). The rock weathers to white or ashen colors and splits into flakes, plates, or papery sheets parallel to the cleavage.

The phyllites were originally shale units of the Allamoore formation and except for greater alteration are not unlike the calcareous shales and thin interbedded limestones of the early Ordovician formations of the Marathon region. The rather intimate association of phyllite and volcanic

units in the Allamoore is curious and perhaps significant; the argillaceous sediments may in part have had a volcanic source.

*Tumbledown Mountain section.*—Some of the finest exposures of the Allamoore formation in the region are on Tumbledown Mountain, a high western spur of Beach Mountain  $1\frac{1}{2}$  miles northeast of the Yates ranch house (R.5—8.5, Pl. 2; Pl. 11). The Allamoore of the mountain has a synclinal structure and lies on the Hazel formation, probably as a result of thrusting on a "surface of movement"; another "surface of movement" within the Allamoore divides it into at least two parts. The syncline is bordered by later high-angle faults on the east and south, and the folded rocks are overlain unconformably on the east by the Bliss (?) sandstone (Lower Ordovician).

The Allamoore formation of Tumbledown Mountain is much less altered than farther south, and in the upper beds the structure is simple and plain. The mountain is therefore one of the few places where a stratigraphic section of the Allamoore can be described and measured (fig. 5). Although this section is at least partly duplicated by faulting, and although it has no top or base, it is of interest in showing a representative succession of the rock types of the formation (Table 17, p. 80).

*Blackshaft mine area.*—Northeast of the Millican Hills in the midst of the Hazel formation, a thin bed of Allamoore formation crops out from the Blackshaft mine (M.5—9.5, Pl. 2) for a mile and a half westward and northwestward past the St. Elmo and Sancho Panza mines. The formation in this vicinity is of interest, as it is the host of productive ore deposits.

In an earlier publication the writer (King and Knight, 1944) termed the bed a tuffaceous member of the Hazel formation, but Sample and Gould (1945) interpreted it, probably correctly, as part of the Allamoore formation on the sole of a thrust sheet.

The bed of Allamoore formation lies on and is overlain by Hazel formation and is probably separated from the Hazel beneath by a "surface of movement." The upper contact with the Hazel may approximate the original unconformable surface between the two formations, but it has also been subjected to some movements, as in

mine workings the Hazel forms a smooth strong surface and rests on contorted and schistose Allamoore. The bed shows great contortion, shearing, and pinching and swelling, and is much more metamorphosed than the enclosing more competent Hazel formation. It varies considerably in make-up along its course and is a complex of limestone, carbonaceous shale, tuff, and igneous rock.

At the Blackshaft mine, where the bed is about 5 feet thick, it consists of soft, contorted, schistose rock, probably originally tuffaceous, of limestone, and of platy, rotten, black graphitic schist, in places resembling anthracite coal. The schist is veined by calcite and contains sulfides.

On the ridge west of the St. Elmo mine the bed is highly mineralized cherty limestone, with some associated fine-grained igneous rocks, possibly of extrusive origin.

At the open cuts of the Sancho Panza mine, where the bed is about 10 feet thick, it is gray, finely granular, siliceous rock, perhaps an altered limestone or tuff, marked by many wavy, irregular laminae which are evidently not stratification. Similar siliceous rocks appear in pits a short distance to the northwest, where they are associated with greenish tuffaceous clastics. About a quarter of a mile northwest of the open cuts is a considerable body of coarse-grained, diabasic igneous rock. Sample and Gould (1945) suggest that this might be a young intrusive, perhaps of Tertiary age, but it seems more likely that it is one of the volcanic members of the Allamoore formation.

**Rock alteration.**—Most of the rocks of the Allamoore formation have been more or less changed from their original character, perhaps mainly as a result of the deformation to which they have been subjected, but probably with the aid of hydro-

Table 17. Stratigraphic section of Allamoore formation on Tumbledown Mountain.

	Estimated thickness (in feet)
Bliss (?) sandstone at top of section	
Unconformity	
Allamoore formation:	
(10) Brown, thinly laminated limestone, with siliceous bands, forming massive ledges. Exposed only in small patches in core of syncline, beneath Bliss (?) sandstone	100
(9) Dark greenish or dark reddish, amygdaloidal igneous rock, probably a lava flow or flows; in part interbedded with underlying sandstone	200
(8) Medium to coarse-grained, maroon-red sandstone, in part filled with dark grains a few millimeters across, perhaps igneous detritals. The sandstone is well laminated, the gritty beds alternating with the finer grained beds. The sandstone is darker and less reddish on freshly broken surfaces	300
(7) Very massive, jagged-surfaced brown limestone, perhaps dolomitic. Forms top of resistant beds of mountain, the beds above being carved into a canoe-shaped basin between the enclosing limestone ridges	30
(6) Siliceous beds, strikingly banded by light buff siliceous layers, and red-brown sandy-calcareous layers, the respective layers being a fraction of an inch to 6 inches thick. Some bedding surfaces show faint small-scale ripple marks	200
(5) Main limestone body of the mountain. Pale gray or pale brown limestone, with some dark gray or blue-gray limestone, the latter thinly laminated and possibly bituminous; the chemical analysis by K. J. Murata was from such rock. Chert is common in many beds but particularly in the more massive layers. Some of the chert bands in the massive layers follow a series of zig-zags, the points of which are hardly rounded; these seem not to be due to crumpling and may be original in the deposit, and perhaps caused by organic growth. At one place the top bed consists of massive pinkish limestone with some laminated structure that resembles <i>Cryptozoon</i> , whose upper surface rises into knobs and points that are overlapped by the succeeding siliceous beds of member (6) (Pl. 23, B).	250
(4) Blue-black, fissile phyllite, sericitic and graphitic, with some blue-black hornstone and gray calcareous layers. Bare exposures at southwest end of mountain show intensely contorted bedding caused by prominent slaty cleavage. Exposed only on south and southwest sides of mountain; pinches out between member (5) and underlying Hazel formation on north	100
(3) Greenstone, either an intrusive or a massive flow. Dense, fine-grained, tough rock, blue-black where fresh, dark olive-green where weathered; some fragments in float are amygdaloidal. Crops out only on south side of mountain.	200
Surface of movement	
(2) Reddish sandstones of pyroclastic origin, with some interbedded lava. The member is identical in appearance to bed (8) and quite different from bed (3), which overlaps it in places	250
(1) Lower limestone, similar to bed (5); exposed only on lower western slopes of mountain	50-150
Surface of movement	
Hazel formation at base of section; overlain by bed (3) on south side of mountain; by bed (1) on west end; and by bed (5) on north side.	

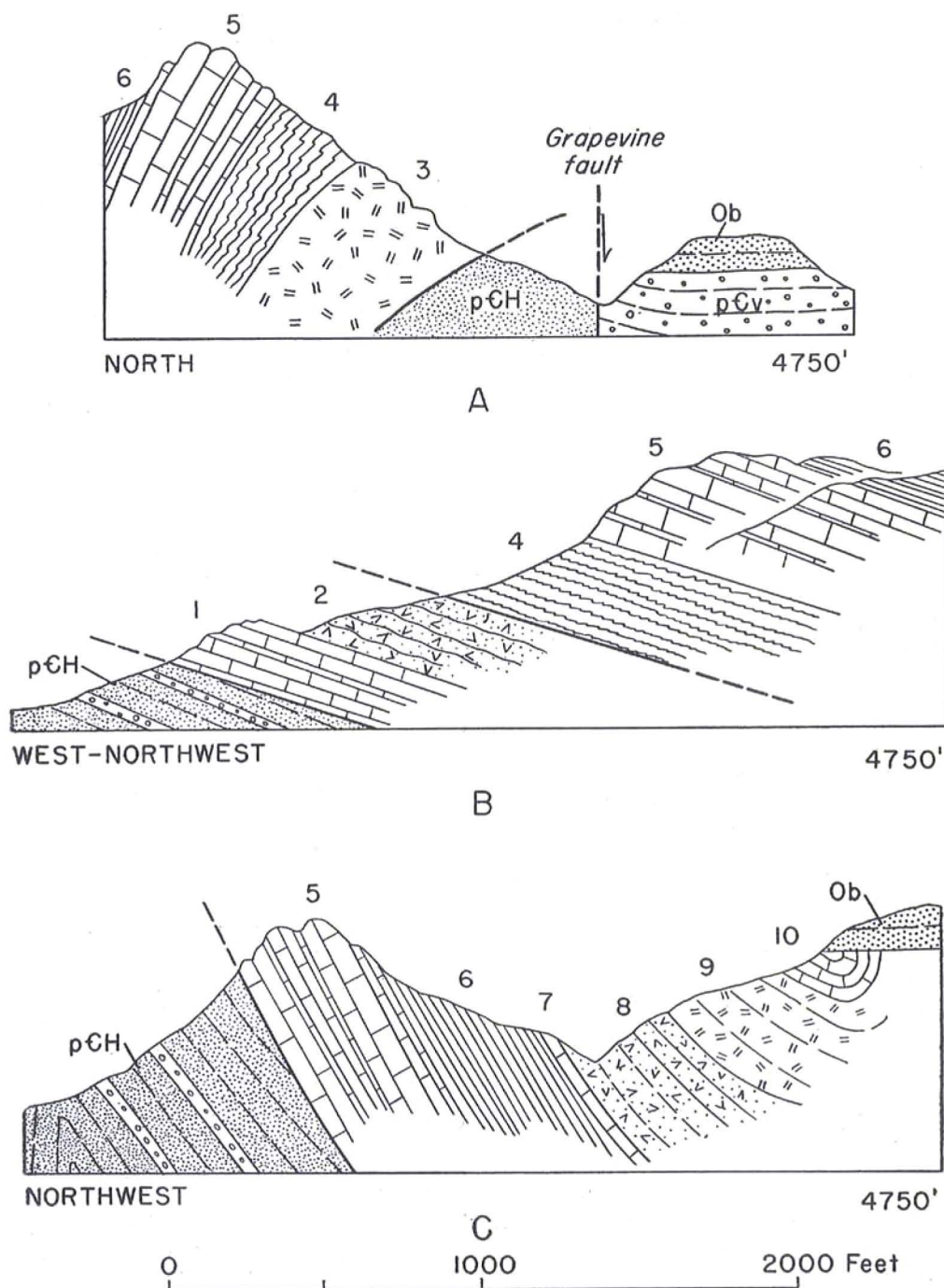


FIG. 5. Profiles showing stratigraphic section of Allamoore formation on Tumbledown Mountain (Q.5—8.5, Pl. 2). A, South side of mountain; B, west end of mountain; C, north side of mountain. Numbers refer to units in section as described in Table 17. pCH = Hazel formation; pCv = Van Horn sandstone; Ob = Bliss (?) sandstone. Note "surface of movement" between Allamoore formation and underlying Hazel formation in all profiles, and that between beds 2 and 4 of profile B.

thermal solutions. Alteration is least toward the north, as on Tumbledown Mountain, and increases southward to a maximum near the outcrops of metarhyolite of the Carrizo Mountain group that forms the overriding body of the Streeruwitz overthrust.

The limestones exhibit various types of alteration. Perhaps the most striking is marmorization, which occurs in small, erratically placed areas, perhaps related to intense flowage or squeezing, or to hydrothermal activity. The limestones are recrystallized to marbles of sugary texture, mostly white, but with reddish and bluish streaks, possibly inherited from original bedding. Striking specimens of "red, white, and blue" banded rock may be collected. Where the limestone was originally impure or shaly, it has been rendered schistose, and the original bedding laminac have been thrown into "jackknife" folds.

Over a wide area immediately north of the trace of the Streeruwitz overthrust the limestones have been extensively silicified into rocks resembling those classed as jasperoid in other areas. Thoroughly silicified limestones have lost all trace of bedding and are traversed by many quartz veinlets. Their weathered surfaces are brown and felty and are recessed around quartz veins and siliceous knots like other calcareous or carbonate-bearing rocks. However, they probably actually contain little lime, for they break with conchoidal fracture into dark gray, steel-hard chips.

Where cherty limestones have been sheared, the chert layers are sliced, offset, and broken along innumerable planes of fracture cleavage, while the intervening less brittle limestone has accommodated itself by flowage around the chert. Where shearing is greatest, such rocks have been converted into a rubble of angular chert fragments, set in a reconstituted limestone matrix.

The more massive diabasic volcanics may have undergone considerable internal mineralogical change, but little of this is apparent to the unaided eye, and even the amygdules show little indication of compression. By contrast, the fine-grained tuffaceous volcanics and the phyllite units are highly contorted and have been rendered thoroughly schistose.

Silicification of the limestone near the Streeruwitz overthrust is well displayed near the metarhyolite outcrops 2 miles northeast of the village of Allamoore (E.5—2.5 and F.5—2.5, Pl. 2). Here, the limestones are silicified for half a mile north of the metarhyolite, but alteration seems to be greatest on the hill summits, presumably nearest the eroded sole of the overthrust, and is less in the valleys, where there are occasional outcrops of blue-gray limestone of more nearly normal aspect.

The silicified rock is dense and very hard when broken but weathers to a brown, felty, calcareous-appearing surface, with an irregular network of more siliceous ridges and occasional quartz veins. Bedding is nearly destroyed, and the rock weathers into irregular ledges and craggy blocks. Some of the altered rock is distinctly granular and might have been derived from sandstone rather than limestone; there are a few patches of schist, probably derived from volcanics.

Close to the metarhyolite is much cream-colored, streaky, massive marble, which at one locality is interbedded with blue, blue-green, or blue-gray calcareous schist, containing blebs of bright blue mineral. In places the blue schist weathers out in "pencils" and "logs" that are probably of tectonic origin. The blue mineral has been identified as an amphibole by Horace Winchell of Yale University, who made the following tests on it:

CO<sub>2</sub> present by acid test.

Fe<sup>2+</sup> and Fe<sup>3+</sup> present in HCl solution.

X-ray pattern shows most of lines of tremolite-actinolite, with remarkably good agreement indicated.

Fibrous habit typical of amphibole.

No tests for Na, hence for glaucophane; could be this.

Two specimens of altered limestone from near the Streeruwitz overthrust in the hills 2 miles northeast of Allamoore were examined under the microscope by Flawn (memorandum of February 1952), who reports as follows:

"One specimen, which looks like layered petrified wood in hand specimen, and weathers to a gray, rough, slaggy surface, is a tourmaline-biotite-albite limestone. It has a granoblastic to crystalloblastic fabric, with grains 0.04 to 0.2 mm. in diameter. Carbonate comprises 84 percent and forms a fine mosaic. There is also 8 percent albite (scattered grains showing secondary overgrowths), 3 percent green-brown biotite (patches), 2 percent tourmaline (green, brown spongy crystals, 2 percent of opaque mineral (spongy, poor-reflecting grains), 1 percent sericite, and traces of apatite and leucoxene."

"The other specimen is a fine-grained banded pure calcite marble of light buff or pink color, with a granoblastic fabric. Calcite comprises nearly the whole rock and is a mosaic of twinned and untwinned grains between 0.04 and 0.1 mm. in diameter; there are traces of sericite."

#### *Interpretation of Allamoore formation.*

—The limestones of the Allamoore formation were probably laid down in a marine environment. They differ little in chemical composition from marine limestones of Paleozoic age that occur in the same region

and like them contain appreciable amounts of bituminous material, as well as reefy structures of possible algal origin. The intraformational conglomerates suggest, however, that the water was relatively shallow. The phyllites and the finer-grained, well-bedded pyroclastics also have the appearance of water-laid sediments, and the phyllites are comparable to the less altered marine shales of the Paleozoic rocks. There is, however, no evidence that the lava flows were erupted under water. Pillow structures have not been observed, although it is possible that other features characteristic of subaqueous eruption might be discovered by further study. As the water in which the nearly contemporaneous interbedded sediments were laid down was probably relatively shallow, the flows may have been built up on the sea floor to such an extent that they projected above the surface.

The rocks of the Allamoore formation have many of the characters of eugeosynclinal deposits as described and defined by Kay (1951, pp. 4-5, 69-77). Large volumes of lavas, pyroclastics, and other volcanic rocks are diagnostic of the eugeosynclinal facies. Limestones, it is true, are more characteristic of the miogeosynclinal facies, but those of the Allamoore are highly cherty and are interlayered with bedded siliceous rocks like those common in eugeosynclinal deposits.

*Stratigraphic relations.*—The base of the Allamoore is nowhere exposed. It is in contact on the south with the possibly older metarhyolite of the Carrizo Mountain group, but this has been emplaced by movement on the Streeruwitz overthrust and overlies rather than underlies the Allamoore. Farther southeast, in the Carrizo Mountains, the metarhyolite intrudes a thick sedimentary sequence, described by Flawn elsewhere in this report. The relation of the sedimentary rocks of the Carrizo Mountain group to those of the Allamoore formation have not been determined; the first may represent a downward continuation of the second, or the two might be far apart in age.

The Allamoore formation is also in contact with the Hazel formation. From structural relations alone it is not possible to determine the original nature of the succession, for either formation may overlie the other. However, the conglomerates of the

Hazel indicate clearly that this is the younger formation, as they consist in large part of fragments of limestone, volcanics, and other rocks identical with those in the Allamoore and derived from its erosion.

The conglomerates show, further, that the Hazel lies unconformably on the Allamoore, and their great thickness and the coarseness and angularity of their fragments suggest that the Allamoore depositional epoch was closed by orogeny, which probably continued into the initial phases of Hazel deposition. This is further attested by the fact that some of the limestone fragments in the conglomerates are marmorized in the same manner as parts of the limestone still in place in the Allamoore.

The nature of the deformation caused by the pre-Hazel orogeny is somewhat obscure, as a considerable part of the structure now visible in the Allamoore is shared with the adjacent Hazel and is the result of a later, post-Hazel orogeny. The contact between the two formations is strongly discordant in most places, but it is generally sheared and faulted along a "surface of movement," so that it is difficult to determine the original degree of angular divergence between them, or the amount of irregularity of the surface on which the conglomerate was deposited.

At several localities there is a suggestion that the angular discordance between the Allamoore and Hazel is not entirely caused by the "surface of movement" which separates them but results in part from original angular unconformity.

North of the Anaconda no. 2 prospect a mile east of the Garren ranch house (H.5-7.5, Pl. 2) conglomerates of the Hazel formation are in contact within short distances with reddish tuffaceous sandstone, limestone, and massive, bouldery lava. The conglomerate includes fragments of these rocks, as well as of others seen in place deeper in the Allamoore in the same vicinity. Southeast of the Garren ranch house the conglomerates of the Hazel contain boulders of the limestone-pebble conglomerate that is interbedded in the limestones of the Allamoore formation near by, as though they were derived from uptilted ledges of this rock.

In the southern Streeruwitz Hills northwest of Eagle Flat section house the Allamoore is bordered on the north by coarse, massive conglomerate of the Hazel formation which projects in a high, dark ridge. Strikes and dips of the two formations are nearly parallel, but successive limestone, volcanic, and phyllite members of the Allamoore are truncated by the conglomerate toward the west (C.5-10.5, Pl. 3), and the conglomerate itself wedges out against the Allamoore toward the east (F.5-10.5, Pl. 3). These relations may be the result of faulting along a "surface of movement" but they may in part be caused by original angular discordance between

the Allamoore and Hazel and by irregular deposition of the conglomerate against a surface of considerable relief.

#### HAZEL FORMATION

*Introduction.*—The Hazel formation crops out in many parts of the deformed area immediately north of the trace of the Streeruwitz overthrust, where its rocks are intimately infolded with the Allamoore formation. Unlike the Allamoore, however, it is also exposed much farther north, in areas of less deformation. Outcrops extend around the south and east sides of the scarps of the Sierra Diablo, where they reach to within a few miles of Victorio Peak, and a large inlier also occurs in the interior of the range near Sheep Peak. Not all these northern outcrops are shown on the geologic map (Pl. 2); for the whole extent of the formation the reader should refer to the general geologic map of the Sierra Diablo region (King and Knight, 1944).

The Hazel formation consists of two sorts of rock, red sandstone which characterizes the upper and northern part, and conglomerate which characterizes the lower and southern part. The two rocks are intimately interbedded. Adjacent to the Allamoore formation are thick, massive layers of solid conglomerate, but farther away and higher in the sequence conglomerate beds become thinner and more sandy and are separated by increasingly thicker beds of red sandstone, which finally dominate altogether. The conglomerate may also wedge out northward in the sandstone, away from the uplifted masses of Allamoore formation from which it was derived, although this relation is difficult to prove because of the complex structure.

The Hazel is clearly a very thick formation, but structural relations are such that only incomplete estimates of thickness can be made. Extending northward from the Allamoore formation in the central Streeruwitz Hills there appears to be a continuous, steeply dipping succession at least 5,000 feet thick; of this, more than half is conglomerate. On the eastern scarps of the Sierra Diablo near the Pecos mine, north of the map area, at least 2,250 feet of gently dipping sandstone is exposed.

*Conglomerate (pCHc).* The conglomerate of the Hazel formation is one of the more resistant rock units of the pre-Cam-

brian succession and in places forms ridges as high as, or higher than, those of the limestones of the Allamoore formation. In the southern belts of outcrop in the Streeruwitz and Millican Hills it projects in high, irregular ridges, covered by deep brown or black-surfaced, craggy ledges or blocks. Farther north it is less consolidated and forms fewer ledges, although it still rises in high hills.

The conglomerate consists almost entirely of fragments derived from the Allamoore formation, and particularly of its limestones. All types of limestone are present, including the chert-seamed, laminated, and carbonaceous varieties, as well as a lesser number of marmorized pieces. There are also occasional cobbles of bright red, jaspery limestone or chert. Almost as abundant as the limestone fragments are those of volcanic rocks, including massive, diabasic or amygdaloidal lavas, and coarse to fine pyroclastics. The finer pyroclastics in some of the fragments appear to have been rendered schistose before having been incorporated in the conglomerate.

In a few places the conglomerate also contains cobbles and boulders of red granite and coarse rhyolite porphyry. These are especially abundant between Carrizo Spring and Tumbledown Mountain in the eastern Millican Hills (N.5—3.5 and P.5—8.5, Pl. 2), but a few were seen in the northwestern Streeruwitz Hills (N.5—14.5, Pl. 3). The granite and porphyry are unlike the igneous rocks in the Carrizo Mountain group but closely resemble those in boulders of the succeeding Van Horn sandstone. Like those in the Van Horn they resemble pre-Cambrian granite and porphyry exposed some distance to the northwest, in the Pump Station Hills and southern Hueco Mountains. The known distribution pattern of boulders in the Hazel does not, however, suggest a northwestward source, and they may have been derived from other areas, as yet unknown, where they are now concealed by younger sediments.

Fragments in the conglomerates are of all sizes, ranging from fine grits and pebbles up to large blocks, mainly of limestone, 6 feet or more across. The large blocks are most abundant in the lower part, near the contact with the Allamoore formation, but they are surprisingly common hundreds or even thousands of feet above the base. The fragments are generally



poorly rounded and many are angular, in this respect differing notably from those in the overlying Van Horn sandstone; the difference in rounding provides a ready means of distinguishing the Hazel from the Van Horn in the field.

The conglomerate matrix is variable. That in the lower and southern conglomerate beds, which are most resistant to erosion, may originally have been highly calcareous, but it generally has been silicified and impregnated with iron on weathered surfaces (Pl. 24, B). In the higher and more northern conglomerate beds the matrix contains a larger proportion of sand and arkose, causing the rock to be softer and less coherent (Pl. 25).

Most of the fragments lie helter-skelter in the conglomerate, pieces of all sizes, shapes, and composition being mingled without sorting. Little or no grain gradation is visible from base to top of a single layer, and in the more massive phases bedding itself is difficult to see. In the higher conglomerates there are occasional finely gritty seams and lenses or thin interbedded layers of red sandstone. It is rather surprising, however, that sediments transitional from conglomerate to sandstone are small in volume. There are no coarse sandstones or pebbly sandstones of any thickness near the conglomerates. Instead, many of the coarse conglomerate beds are inserted abruptly between red sandstones that are as fine and silty as any elsewhere in the area.

The thickness of the conglomeratic part of the Hazel formation seems to vary from place to place along the outcrop, but it is uncertain how much of this is the result of original differences in amount of conglomerate deposited, and how much the result of structural complication. In the central Streeruwitz Hills, next to the southern outcrop belt of the Allamoore formation, conglomeratic beds are at least 3,000 feet thick, of which the lower half is solid conglomerate and the upper half is interbedded conglomerate and sandstone. Conglomerate of similar structural relations in the southern Millican Hills is about 2,000 feet thick.

Adjacent to other belts of Allamoore formation farther north, conglomeratic beds of the Hazel formation are more variable and in places much thinner. Such variations may be seen on the map along the edges of the belt of Allamoore which extends east and west from the Garren ranch house in

the northern Millican Hills. In these northern belts the conglomerate may have been partly cut out along the "surface of movement" between the two formations, but at least some of the variations may be original.

Conglomerate occurs in two areas that are surrounded by outcrops of the Allamoore formation, one lying north and east of the Dwees ranch house in the southern Millican Hills (B.5—4.5 to E.5—4.5, Pl. 2) and another 2 miles northwest of the Canning ranch house in the northeastern Bean Hills (N.5—13.5, Pl. 3). These conglomerates are probably part of the Hazel, although they differ somewhat from the usual conglomerates of that formation; they seem to be synclinal remnants deeply infolded in the Allamoore, on which they rest unconformably and without an intervening "surface of movement." Near the Dwees ranch house the matrix is a brown-weathered limestone, which encloses fragments of limestone a few inches to a foot across, and a few fragments of brown-red volcanics. The rock is greatly sheared and bedding is almost obliterated.

In two places the southern outcrops of Allamoore formation are succeeded on the north by thick, massive conglomerates. One is in the central Streeruwitz Hills northwest of Eagle Flat section house (C.5—10.5 to F.5—10.4, Pl. 3), the other in the southern Millican Hills between the Garren ranch house and Carrizo Spring (E.5—5.5 to N.5—3.5, Pl. 2); the latter outcrops are crossed by the county road  $2\frac{1}{2}$  miles north of the village of Allamoore.

The conglomerate of both areas is presumably the basal unit of the Hazel formation, although it is so discordant with the Allamoore on the south as to suggest that the two formations are separated in both places by a marked unconformity or "surface of movement." In the central Streeruwitz Hills the lower massive conglomerate is about 1,500 feet thick and is succeeded by an equal thickness of interbedded conglomerate and sandstone. In the southern Millican Hills the massive conglomerate is about 2,000 feet thick and is succeeded by sandstone, with only a little interbedding at the contact. In both areas, the matrix is now thoroughly silicified and deeply crusted by iron, so that the rock projects in massive ledges in which bedding is scarcely apparent (Pl. 24, B). Most of the fragments are a few inches to a foot in diameter, but there are some larger angular blocks. In the Streeruwitz Hills the pieces are mainly blue and gray cherty limestone like those in the Allamoore, but there are some of bright red siliceous jasper and of a schistose rock that may have been derived from altered pyroclastics. The pieces in the Millican Hills are similar but include some boulders of limestone-pebble conglomerate. Granite porphyry occurs in 1-foot boulders near Carrizo Spring, but nowhere else in the two areas. Near the middle of the unit in the Streeruwitz Hills are lenses of thin-bedded brown sandstone and toward the top are thicker layers of red pebbly sandstone. The succeeding conglomerates interbedded with red sandstone have a sandy, less coherent matrix than

that below; even these higher beds contain occasional limestone blocks 2 to 4 feet across.

The conglomerate of one of the more northern belts is well exposed in the northeastern Millican Hills, east of the Anaconda no. 1 prospect and south of the Blackshaft mine (J.5—7.5 to N.5—7.5, Pl. 2), where it is deeply dissected by Hackberry Creek and its tributaries. One of the most striking outcrops is on Hackberry Creek half a mile southeast of the Blackshaft mine (N.5—8.5, Pl. 2), where the channel drops abruptly 50 feet or more over a vertical bed of conglomerate 275 feet thick, lying in red sandstone.

In the northeastern Millican Hills about 65 percent of the fragments are limestone, 30 percent are lavas and pyroclastics, and 5 percent are minor constituents. The limestone and volcanic fragments are mostly pebbles and cobbles, but there are occasional boulders and blocks of limestone as much as 4 feet across. Large blocks are not confined to the conglomerate nearest the Allamoore, but occur far distant from it and presumably high above the base of the Hazel formation. The volcanics include red diabasic lavas, dark aphanitic basalts, and red tuffaceous sandstones. The minor constituents include red granite porphyry and marmorized limestone. The porphyry fragments are conspicuous but never dominant constituents; some fragments reach 2 feet in diameter and unlike comparable pieces in the Van Horn sandstone are only moderately rounded. The fragments of white, crystalline, marmorized limestone contrast notably with those of the less altered limestones with which they are associated. In the northeastern Millican Hills the fragments lie in a sandy or gritty matrix, containing numerous small chips or angular grains of a composition similar to that of the larger pieces. During field work, numerous attempts were made to employ graded bedding for determination of tops and bottoms of beds, but usually with indifferent results. Many gradations from coarse to fine and fine to coarse were observed, but they provided conflicting evidence, even within the same outcrop.

*Red sandstone (pCHs).*—Red sandstone forms the most conspicuous and extensive outcrops of the Hazel formation. It crops out on smoothly rounded red surfaces, only lightly masked by vegetation. These extend to considerable heights on the scarps of the south and east sides of the Sierra Diablo, where they are surmounted by light gray cliffs of the Hueco limestone (Pl. 28, B). At the bases of the scarps the slopes flatten into broad pediments, capped in many places by benches of Quaternary gravels, but mostly carved into an intricate network of hills and valleys, such as those between Beach Mountain and the Hazel mine (O.5—13.5, Pl. 2). The hills are dome-like, with rounded crests that descend into steep slopes near the incising streams. The dissected hills have an especially pleasing as-

pect toward sunset, when lights and shadows bring out details of their modeling.

The red color of the sandstones is universal, ranging from brick-red in the northern exposures to a darker maroon-red farther south. Most of the sandstones are very fine grained, verging on or grading into siltstones. They coarsen somewhat toward the south, where there is more variation in texture from bed to bed; here some of the coarser layers are traceable in long strike ridges. Part of the rock is rather loosely consolidated, but most is fairly hard and well-cemented, so that it has a conchoidal fracture. The following reports on microscopic study of specimens of the sandstone are available.

(1) G. B. Richardson (1914, p. 4), locality not stated: "The texture is characteristically sedimentary and the rock is composed chiefly of subangular or rounded grains of quartz and sub-ordinate feldspar, with some flakes of muscovite and rather abundant interstitial calcite, the minerals being coated with a thin film of red pigment—ferric oxide—that gives the uniform color to the rock."

(2) S. J. Lasky (memorandum of October 28, 1938), from near Hazel mine: "A fine-grained, argillaceous, calcareous sandstone, slightly feldspathic, with angular grains and a red iron-oxide pigment in the matrix."

(3) Charles Milton (memorandum of September 26, 1951), from hillside northwest of Garren ranch house: "Consists of evenly-sized angular to sub-angular particles of quartz and alkalic plagioclase, with a small amount of potassic microcline feldspar and colorless mica in worn wisps, and a few opaque grains of hematite. Calcite, which makes up 5 to 10 percent of the rock, is interstitial."

Bedding of the sandstone is indicated in most places by thin, closely spaced, dark laminae. These are commonly cross-bedded on a small scale, and in places there are ripple marks on the bedding surfaces. In the structurally complex areas attempts were made during field work to use cross-bedding and grain gradation as evidence for tops and bottoms of beds, but uniformly successful results could not be obtained in the time available. Over most of the area the rock does not split along bedding planes, for these are thoroughly welded together; instead, it breaks into angular blocks along innumerable vertical or inclined joints, so that in many places the bedding may be determined only by close scrutiny. Richardson (1914, p. 4) reported that the sandstone beds near the Hazel mine stood nearly vertical, whereas outcrops in

this vicinity show faint but persistent bedding which lies nearly flat.

The total thickness of the red sandstone has not been determined but probably reaches thousands of feet. The thickness locally exposed on the east-facing escarpment of the Sierra Diablo from the Pecos mine northward (north of Pl. 2) can be estimated, as south-dipping lines of bedding show up faintly but distinctly on the red sandstone slopes below the cliffs of Hueco limestone. Measurements in this area yield the following results:

also extends in ramifying stringers through the rock. Specimens of this material from near the Garren ranch house were examined under the microscope by Charles Milton, who reports as follows (memorandum of September 26, 1951):

The black material on high magnification resolves itself into aggregates of tourmaline. The tourmaline is stubby prismatic, brownish-green, weakly pleochroic. It is unquestionably authigenic. With the tourmaline is fine black dust of

Table 18. Estimated thickness of red sandstone of Hazel formation near Pecos mine

	Thickness (in feet)
Hueco limestone, with Powwow member at base, forming cliffs at top of escarpment.	
Unconformity	
Red sandstone of Hazel formation:	
(4) Youngest and highest beds, which come in southward, between Pecos mine and Hazel mine; thickness undetermined	?
(3) Beds exposed on escarpment above Pecos mine, disregarding those below and to east on pediment. Tracing of bedding indicates that base of this unit rises to base of Hueco a little beyond Bat Cave, 2 miles to the north	750
(2) Thickness of beds on escarpment north of Bat Cave	1,000
(1) Older and lower beds, exposed mainly on pediment north of last locality; much more than	500
Total thickness, more than	2,250

**Rock alteration.**—Rock alteration is generally less severe in the Hazel formation than in the Allamoore formation. This is partly because the formation generally lies farther from the center of strong deformation, and partly because its sandstones and conglomerates are both much more competent than any of the rocks in the Allamoore.

In many places in the strongly deformed areas to the south the conglomerate has been sliced along a multitude of closely spaced shear or cleavage planes. These are most prominent in the matrix but are likely to cut through the fragments as well. Flattening of the fragments is rare and is confined to the most strongly deformed areas.

The sandstones are relatively little altered, and pressures were evidently dispersed along innumerable clean-cut vertical and inclined joints. Because the sandstone has not been readily sheared or squeezed in the strongly deformed areas, it has probably been sliced by many minor thrust planes. These are especially abundant in the belt of sandstone in the Millican Hills that extends eastward from the Garren ranch house (F.5—6.5, Pl. 2), where they are marked by slickensided surfaces, commonly coated with a black highly polished substance a few millimeters thick, which

hematite, identified as such from its appearance in polished section. It is believed that the tourmaline-hematite aggregate accounts for the blackness in hand specimen and the opacity in thin section. Graphite and carbonaceous matter were considered as a possibility, but were not found by chemical or microscopic study. Some veinlets of quartz and calcite also traverse the rock.

It is of interest to note that Flawn has observed quartz-tourmaline veins in the Carrizo Mountain group of the Carrizo Mountains. The relation between the introduction of tourmaline in the Carrizo Mountains and the Millican Hills is uncertain. Flawn interprets the quartz-tourmaline veins as probably caused by pre- or syn-metamorphic hydrothermal activity, whereas the tourmalinized slickensided surfaces appear to have formed during the late stages of the orogenic epoch.

Near some of the large, high-angle faults north of the Millican Hills, notably the Grapevine fault (N.5—9.5, Pl. 2), the sandstone appears to have been mashed and reconstituted. Near such faults it loses its flinty, conchoidal aspect and becomes massive, soft, and earthy.

Near many faults, joints, and fractures in the northern area the sandstone is decolorized. For several inches or feet away from the fracture the red rock has been bleached to buff or yellow. The bleaching

may be related to ascent of mineralizing solutions, as it is best developed near prospective or productive veins; it is considered as a favorable indication of mineralization by the local prospectors. Bleaching of the red sandstone was also noted immediately beneath the unconformity at the base of the Hueco limestone in the buttes 3 miles south-southeast of the old Circle ranch house (E.5—12.5 to G.5—12.5, Pl. 2); this either took place during the pre-Hueco erosion interval or during later circulation of ground water.

*Interpretation of Hazel formation.*—

From the foregoing description, it is evident that the Hazel formation is an unusual deposit. The thick, coarse, poorly rounded and sorted conglomerates, lying in or wedging into fine-grained or silty red sandstones, certainly must be "tectonic sediments," formed not merely from destruction of a deformed terrane after the close of a period of orogeny but from active erosion of rising folds and fault blocks while orogeny was still in progress. They are remarkably similar to late Cretaceous and Tertiary conglomerates and sedimentary breccias in southern Nevada and the Mojave Desert region of California, which the writer has seen under the guidance of C. R. Longwell, D. F. Hewett, and L. F. Noble. One of these, the Overton fanglomerate of the Muddy Mountains of Nevada, is related by Longwell (1949, pp. 933-940, 963-964) to the advance of the Glendale thrust, and in fact contains outlying klippen of the thrust, buried in their own debris. Like the conglomerate of the Hazel, the fanglomerate of the Overton is interbedded with, and wedges into, fine silty sediments. The conglomerate of the Hazel also strongly resembles the Etholen conglomerate (Huffington, 1943, pp. 1007-1009; Smith and Albritton, 1949, p. 1921), lying in the midst of the Cretaceous in the Sierra Blanca area, not far to the west in Trans-Pecos Texas. The coarse, angular limestone fragments of the Etholen have a different source from those of the Hazel, as many of them contain Permian fusulinids.

The origin of the fine-grained, silty red sandstones of the Hazel formation is perhaps more perplexing than the conglomerates. Their well-marked laminae, and associated ripple marks and cross-bedding,

suggest subaqueous deposition, but if they are marine, the environment was wholly different from the supposed marine deposits of the preceding Allamoore. They somewhat resemble the poorly fossiliferous red siltstones and fine sandstones of the Lower Cambrian Rome formation of the Southern Appalachians, which have been interpreted as marine deposits derived from weathering of the regolith of the continental interior. They also somewhat resemble, except in color, the fine-grained Tertiary intermontane deposits which occur in many places in the Cordilleran province, some of which are associated with "tectonic sediments" of the sort already noted.

The origin of the red color of the sandstones of the Hazel formation is uncertain. The writer has heard the origin of "red beds" debated since his student days, but to his knowledge no completely satisfactory explanation has yet been offered. It is certainly remarkable that the two red formations of the section in the Van Horn region—the Hazel and Van Horn—should lie one on the other, even though the environments in which the two were deposited were not entirely the same.

*Stratigraphic relations.*—The Hazel formation is overlain by various much younger strata, including those of Permian and Cretaceous age, but the next youngest formation which succeeds it is the Van Horn sandstone. Even with the Van Horn, its relations are strongly unconformable, and the Hazel and Van Horn epochs are separated by a major period of orogeny, by which the Hazel and Allamoore formations were strongly deformed, and by a prolonged period of erosion, during which they were deeply cut. Emplacement of the Carrizo Mountain group along the Streeruwitz overthrust probably took place during this orogeny, as the conglomerates of the Van Horn are the first in the sequence to contain fragments of lineated and mylonitized metarhyolite. The Van Horn of the Sierra Diablo foothills lies not only on the Hazel but in places on the Allamoore; in the eastern Carrizo Mountains, as shown by Flawn, it lies also on the Carrizo Mountain group.

Despite the marked unconformity between the Hazel and Van Horn, their sediments are surprisingly alike. There are, of course, differences in their characters

in detail, but both include red, unfossiliferous clastics and coarse conglomerates made up of fragments of the older rocks. Both were probably laid down in continental environments, near areas of considerable relief.

Some of the best exposures of the contact between the Hazel and Van Horn may be seen along Hackberry Creek near the Yates ranch house (O.5—6.5, Pl. 2), between the Millican Hills and Beach Mountain (Pl. 11). In this vicinity, Richardson (1914, p. 4) reported that the gently dipping Van Horn lies in almost vertical beds of the Hazel, but this is true only locally; dips are generally lower than vertical, although the structure is highly complex.

The contact between the two formations is well exposed on the north side of a ravine leading into Hackberry Creek from the west, near the road to the Yates ranch house and half a mile to the south (O.5—5.5, Pl. 2). Here, the beds of the Hazel dip 60° north and are truncated by an

undulatory erosion surface. The overlying Van Horn lies nearly flat and contains at the base rounded boulders of the Hazel a foot in diameter.

As shown on the map (Pl. 2), the contact along Hackberry Creek has a sinuous course, the sinuosities being the result of partial stripping of a moderately hilly surface of Hazel on which the Van Horn was deposited. In places, hills of the Hazel project 50 feet into the Van Horn, which dips away from them at angles as much as 10° (fig. 6, A). The Van Horn is not conspicuously more conglomeratic near the hills than elsewhere, and its cross-beds maintain their usual southward dip.

The terrain west of the Hazel-Van Horn contact seems to be an exhumed part of the pre-Van Horn landscape. Here, a long, rugged slope rises westward from Hackberry Creek to the summits of the Millican Hills, at about the same angle as the dip of the Van Horn to the east (fig. 6, B). The slope is truncated at the summit of the hills by a nearly level surface, which may represent a much later peneplain, perhaps of Tertiary age.

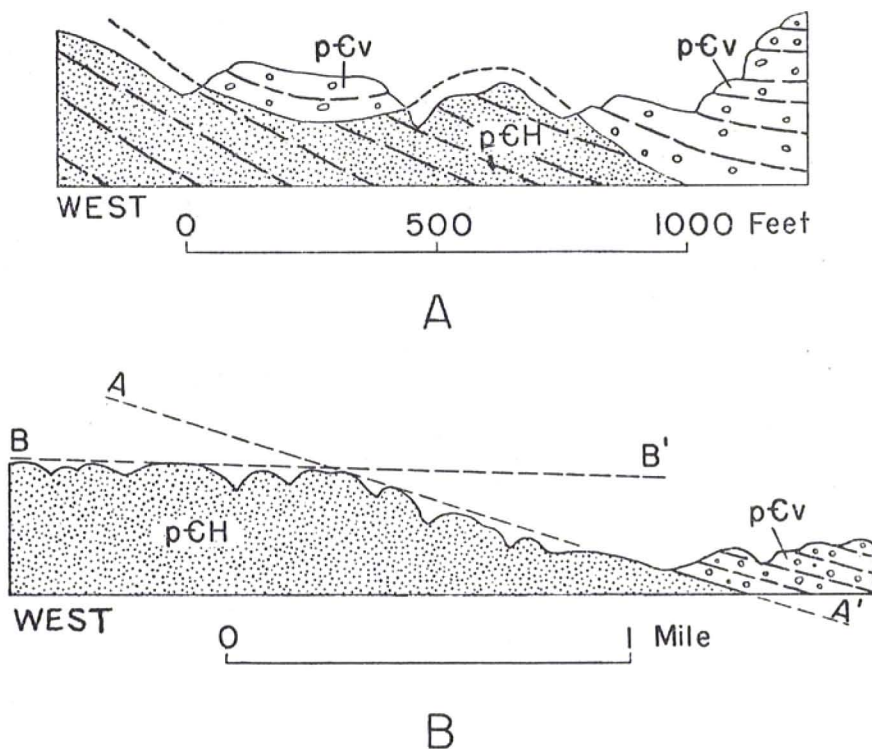


FIG. 6. Sections showing unconformable relations between Van Horn sandstone (pCv) and Hazel formation (pCH) northwest of Yates ranch house. A, Hill of Hazel formation buried by Van Horn sandstone and partly resurrected, half a mile northwest of Yates ranch house (O.5—6.5, Pl. 2); B, sketch section westward from Yates ranch house and valley of Hackberry Creek, to summit of Millican Hills, showing resurrected surface on which Van Horn sandstone was deposited (A-A'), truncated by a later surface at the summit of the hills (B-B'), which is probably of Tertiary age.



## PRE-CAMBRIAN (?) ROCKS

## VAN HORN SANDSTONE (pCv)

*Introduction.*—The Van Horn sandstone is exposed in relatively small areas in the Sierra Diablo foothills, the wide dispersal and isolation of the outcrops being due in no small measure to its unconformable relations with various formations that overlie it. All its outcrops are shown on the accompanying maps (Pls. 1, 2, 3), except for a few small areas in the Baylor Mountains, which are shown on the general geologic map of the Sierra Diablo (King and Knight, 1944). The most extensive outcrops are in the Red Valley northwest of the town of Van Horn and southwest of Beach Mountain (K.5—2.5 to R.5—2.5, Pl. 2), which Richardson (1904, p. 28) designated as the type area of the formation. It is also exposed on the northwest corner of Beach Mountain south of the B-Bar ranch house (S.5—10.5, T.5—11.5, Pl. 2; Pl. 28, A); on the southeast corner of the Sierra Diablo between the Hazel and Pecos mines (N.5—18.5, O.5—16.5, Pl. 2), and on the south-facing scarp of the Sierra Diablo 4 to 7 miles west of the old Circle ranch house (M.5—18.5 to R.5)—18.5, Pl. 3; Pl. 27, A; fig. 7). Flawn has found some outliers of the formation in the eastern Carrizo Mountains, south of the Texas and Pacific Railroad.

The Van Horn is characteristically a coarse, red, arkosic sandstone in thick or massive beds, mostly friable and poorly consolidated, cross-bedded in many places, and containing occasional scattered pebbles. No fossils are known. The sandstones are interbedded with and are underlain by thin to thick beds of conglomerate, made up

of rounded pebbles, cobbles, and even boulders, that are made up not only of the older rocks of the immediate area but also of granite and rhyolite porphyry unlike any exposed in the vicinity. The greatest thickness of the formation preserved at any one place is about 800 feet, but it is generally much thinner.

The red, massive, clastic rocks of the Van Horn form some of the most striking outcrops in the region (Pls. 11, 27, and 28, A). Its sandstones project in great rounded ledges, largely barren of vegetation, and on the faces of escarpments rise in picturesque towers, prows, and battlements. Tables, pedestals, and other fantastic erosion forms are common. The massive ledge-making beds are commonly separated by others less resistant to erosion, generally more conglomeratic, which form intervening shelves, in places overhanging. Widely spaced joints, commonly set at right angles, are worn into creases or crevices that extend across the outcrops and are prominently visible from adjacent mountain tops or in air photographs. Stream channels across the outcrops form rounded swales on the shelves but descend across the ledges, with many swirls and potholes, in narrow slots that follow one of the prevailing joints.

*Conglomerate.*—The conglomerates of the Van Horn form beds a few feet to several hundred feet thick, which are commonly thickest and coarsest at the base and thinner and finer grained higher up. Basal conglomerates are of variable thickness. In the section 4 miles west of the old Circle ranch house (Q.5—18.5, Pl. 3), described below, they are more than 300 feet thick (beds 1 to 5), but they thin both eastward

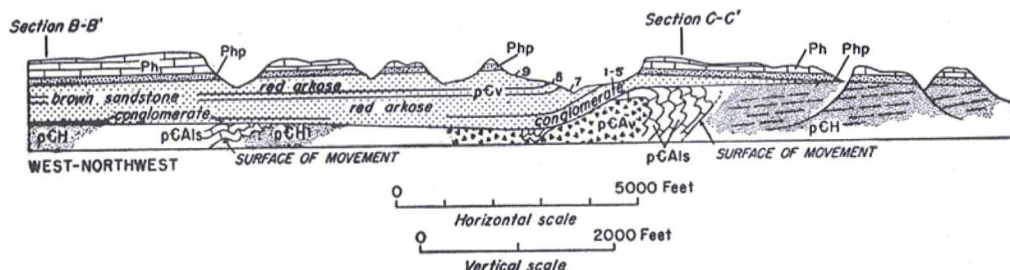


FIG. 7. Profile showing rocks exposed on south-facing escarpment of the Sierra Diablo,  $2\frac{1}{2}$  to 6 miles west of old Circle ranch house (T.5—17.5 to N.5—18.5, Pl. 3). Numbers indicate beds in measured section of Van Horn sandstone which is described in text. pCAv = volcanic member of Allamoore formation; pCAIs = limestone member of Allamoore formation; pCH = red sandstones of Hazel formation; pCv = Van Horn sandstone; Ph = Hueco limestone, with Php, Powwow member, at base.

and westward—to the east and up the dip apparently against a buried hill of limestone of the Allamoore formation (fig. 7). In some other places, as near the Yates ranch house, there is no well-defined basal conglomerate, although conglomerate beds and dispersed pebbles are common throughout the section.

Fragments in the conglomerate are made up of pebbles, cobbles, and boulders, those in the basal beds 4 miles west of the old Circle ranch house (bed 1 of section) being as much as 2 feet in diameter (Pl. 26, A). The great majority are smoothly and perfectly rounded, and some have almost polished surfaces; a few of obvious local derivation show somewhat less rounding. Many of the fragments have been shattered, sheared, and offset by subsequent deformation, but many of these were afterward recemented. The fragments are set in an arkosic sandy matrix, ordinarily somewhat less consolidated than the adjacent sandstones, in some being closely packed, in others widely dispersed in the matrix. Weathering of the poorly consolidated matrix sets free vast quantities of the rounded fragments, which strew the outcrops of the formation.

The fragments in the conglomerate consist of a wide variety of older rocks, but the dominant ones, especially in the northern and northwestern exposures, are red granite and red rhyolite porphyry. They are prominently displayed in outcrops 4 miles west of the old Circle ranch house (Pl. 26, A), where a suite of specimens was collected from boulders near the base (bed 1 of section). These rocks were examined under the microscope by C. S. Ross, who reports as follows (memorandum of June 21, 1938):

(A) Strongly porphyritic rock. Phenocrysts are sodic plagioclase, microcline, and quartz. Both feldspar and quartz have been somewhat rounded by resorption. Magnetite forms large, irregular grains. The ground-mass is a very fine, equigranular mass of interlocking grains of quartz and feldspar. On the whole, the rock is fresh, but a little sericite has developed, especially in the plagioclase.

(B) Related to preceding, but phenocrysts are very sparse. The magnetite grains are altered to hematite, and abundant hematite pigment has developed in the ground-mass of nearly equigranular feldspar and quartz grains.

(C) Dominantly phenocrysts of microcline and minor amounts of sodic plagioclase. A small proportion of interstitial material is quartz and feld-

spar. This tends to be micrographic in habit, with the late feldspar continuous with that of the phenocrysts. Feldspar somewhat altered to sericite; hematite pigment present; no ferromagnesian minerals.

(D) Probably belongs to same group as first three, but feldspar phenocrysts are surrounded by very abundant micrographic intergrowth of feldspar and quartz. The only other primary minerals are magnetite and a green biotite. The rock is more altered than others of the group, and secondary chlorite, serpentine-like mineral, and abundant pigment have developed.

(E) Very coarse-grained granitic rock, composed of microcline, quartz, and sodic plagioclase. No interstitial fine-grained material. Rock fresh except for hematite, some of which seems to be introduced.

These rhyolites and granites differ greatly from any igneous rocks exposed in place in the Van Horn region. They are unlike the metarhyolites of the Carrizo Mountain group, except possibly the coarse phase  $4\frac{1}{2}$  miles northwest of Allamoore. Moreover, fragments clearly derived from the metarhyolites are also present in the Van Horn. The rhyolites and granites most closely resemble pre-Cambrian rocks exposed some distance northwest of the Van Horn region, such as the red rhyolite porphyry of the Pump Station Hills (described elsewhere in this report) and the coarse red granite at the south end of the Hueco Mountains (King, King, and Knight, 1945, sheet 1).

Mr. Ross was asked whether there was petrographic evidence to justify comparison of the fragments in the Van Horn sandstone with rocks exposed to the northwest. He comments that it is very probable that specimens examined by him from the Van Horn sandstone, the Pump Station Hills, and the Hueco Mountains are related. The rock from the Pump Station Hills "shows alteration similar to that in specimen (D), and traces of the same micrographic structure that characterizes specimens (C) and (D). The rocks from both the Van Horn sandstone and the Pump Station Hills were originally very low in dark minerals."

Metarhyolite derived from the Carrizo Mountain group is a significant but never dominant constituent of the conglomerates of the Van Horn. This fact was first noted by Dumble (1902) who mentions "fragments of material resembling silicified wood \* \* \* identified by Dr. Osann as belonging to the quartz porphyries." The

fragments show the same lineation and cataclastic structure as the rock in the parent ledges. The metarhyolite has been observed in nearly every outcrop of the formation but is perhaps commonest in the southern exposures.

Other fragments include fine to coarse-grained basic igneous rocks, probably derived from the volcanics and amphibolite intrusives of the Allamoore formation and Carrizo Mountain group; limestone, chert, and jasper from the Allamoore formation; red sandstone from the Hazel formation; and vein quartz.

The following notes, arranged from northwest to southeast, record the composition of the conglomerates in different outcrops of the formation:

(1) Seven miles west of old Circle ranch house near tank at summit of Sierra Diablo escarpment (north of Pl. 3), conglomerate beds 5 feet thick in upper part of formation: 90 percent of fragments are red sandstones of Hazel formation, the remainder being chert and limestone of Allamoore formation and red granite and rhyolite porphyry; the latter are rounder than the others.

(2) Five and one-half miles west of old Circle ranch house on Sierra Diablo scarp (N.5—18.5, Pl. 3), 100-foot bed of conglomerate at base: Fragments include some of lineated metarhyolite.

(3) Four miles west of old Circle ranch house, at measured section (Q.5—18.5, Pl. 3): Lower thick conglomerates (beds 1 to 5) largely made up of red granite and rhyolite porphyry, in rounded boulders as much as 2 feet across (Pl. 26, A). Higher conglomerates (beds 7 to 9) contain same rocks and also basic igneous rocks, vein quartz, and limestone of Allamoore formation.

(4) Spur of Sierra Diablo south of Pecos mine (N.5—18.5, Pl. 2), conglomerate at base: Rounded and polished cobbles as much as 1 foot in diameter, dominantly of red rhyolite porphyry but including quartzite, basic igneous rock, and chert.

(5) Buttes northwest of Baylor Mountains (north of Pl. 2): Conglomerate at base consists of well-rounded pebbles and cobbles of chert, red sandstone, limestone, vein quartz, basic igneous rock, and schist. In higher beds, besides these, are pebbles of chert, red rhyolite porphyry, and lineated metarhyolite.

(6) South end of Baylor Mountains, 3 miles east of B-Bar ranch house (east of Pl. 2), thin conglomerates in upper part of formation: Fragments include red sandstone of Hazel formation and lineated metarhyolite.

(7) Northwest corner of Beach Mountain, south of B-Bar ranch house (T.5—11.5, Pl. 2); no thick conglomerate at base, but many thin beds throughout the sandstone, as well as isolated pebbles and small cobbles: Fragments consist of chert and limestone of Allamoore formation, red sandstone of Hazel formation, vein quartz, basic igneous rock, some red rhyolite porphyry, and lineated metarhyolite.

(8) North of Yates ranch house and one-fourth mile south of Grapevine Spring (P.5—7.5, Pl. 2); occurrence of conglomerate similar to that of (7): Fragments are dominantly basic igneous rocks and vein quartz, but there are also pebbles of red sandstone and buff chert.

(9) Near old nitrate prospect at west end of Red Valley (K.5—18.5, Pl. 3), probably high in formation, scattered pebbles generally less than an inch in diameter: Black, gray, and red chert, vein quartz, and igneous rocks.

(10) North of Hillside siding and southwest of Threemile Mountain (P.5—14.5, Pl. 1), 5-foot conglomerate bed, probably high in formation: Pebbles as much as 2 inches in diameter of vein quartz, igneous rock, and chert, some of the latter green-colored.

*Sandstone.*—The sandstones of the Van Horn are dominantly red but are generally of a slightly darker hue than those of the Hazel—most are maroon-red, some even purplish-red. The strong tints seem to die out upward, and the highest beds of the formation, where present, are orange-red or red-brown. The sandstones are coarse-grained, grains commonly being a millimeter in diameter, with scattered still larger grits and small pebbles; they contrast with the fine silty red sandstones of the Hazel. The grains consist of quartz and feldspar, apparently in about equal proportions, with at some localities an appreciable amount of mica. In most of the rock, beds are 3 to 10 feet thick, but some are even thicker. Within many layers are well-marked cross-beds, upon which systematic observations were made during field work (fig. 8). It was found that the greater number of these slope southward, the remainder sloping southeastward or southwestward but never northward. These dips are maintained even where the enclosing strata are inclined in opposing directions.

In some of the higher parts of the formation are interbedded members of buff or brown sandstone in layers a foot or two thick, which appear to be more cleanly washed than the rest and to contain more quartz than feldspar. On the south-facing scarp of the Sierra Diablo west of the old Circle ranch house, one of these units near the middle of the formation (bed 8 of section) can be traced for more than 2 miles (fig. 7). Others are common in the outcrops south of Threemile Mountain and east of Hillside siding. In outcrops near a tank at the summit of the Sierra Diablo



escarpment 7 miles west of the old Circle ranch house (north of Pl. 3), the massive arkosic sandstones are interbedded with 5-foot layers of soft flaggy sandstone and greenish clay shale, which are nearly unconsolidated and contain apparent fucoid markings.

The Van Horn sandstone in outcrops east of Hillside siding and south of Threemile Mountain (Q.5—14.5 to S.5—12.5, Pl. 1) deserves special notice, as it is of somewhat different aspect from that characteristic of the formation. It may either be a higher part of the formation than preserved elsewhere or a southern facies of the formation.

In this area, the sandstones lie in straight, blocky ledges a few feet thick, rather than great, rounded ledges as elsewhere; they are orange-brown or red-brown rather than red. The rock in most beds is coarse and gritty but does not

appear to be as feldspathic as elsewhere; some beds are rather quartzitic. Conglomerate is absent, except for a single 5-foot bed near Hillside siding, in which the pebbles are less than 2 inches in diameter.

*Sections of Van Horn sandstone.*—Only one section of the Van Horn sandstone was measured, at a locality on the south-facing escarpment of the Sierra Diablo 4 miles west of the old Circle ranch house (Q.5—18.5, Pl. 3). The section begins at the base of the scarp and proceeds northward up a valley on the west side of a prominent mesa of Hueco limestone (Table 19, p. 94).

At the northwest corner of Beach Mountain (T.5—11.5, Pl. 2), 300 or 400 feet of Van Horn sandstone is exposed on the steep slopes, below cliffs of Bliss (?) sand-

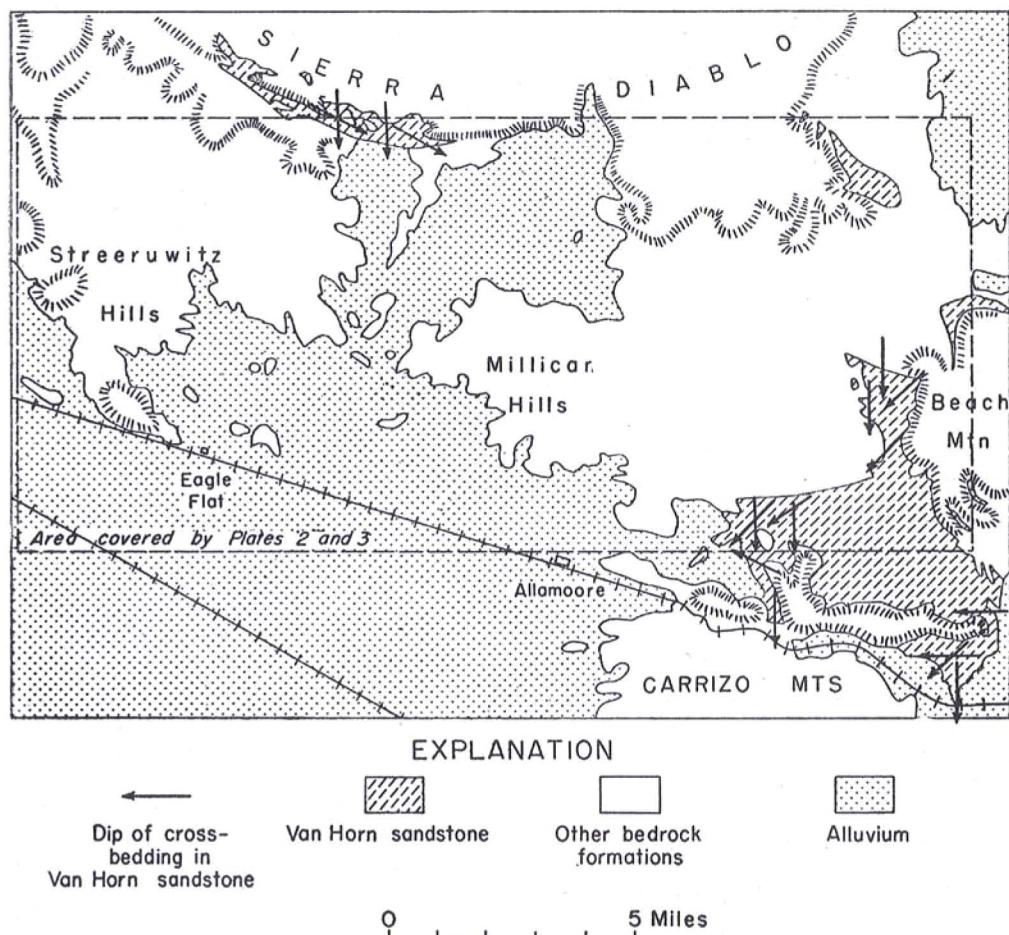


FIG. 8. Map of Sierra Diablo foothills, showing outcrops of Van Horn sandstone and observed directions of dip of its cross-bedding. Note absence of northward dips.

stone and El Paso limestone and above red sandstones of the Hazel formation. The Van Horn is, however, discordant with the Bliss (?) and its beds are truncated eastward (fig. 9, C). In a reentrant valley on the north side of the mountain a mile to the east, it is little more than 75 feet thick.

suggests that these lands were no longer in the process of active uplift. The Van Horn is almost certainly of continental origin.

The present distribution of the Van Horn in widely scattered, basin-like remnants might suggest that it was laid down in several disconnected areas, were it not that

Table 19. Stratigraphic section of Van Horn sandstone west of old Circle ranch house.

	Thickness (in feet)
Hueco limestone at top of section, with Powwow member at base.	
Unconformity	
Van Horn sandstone:	
(9) Friable, arkosic sandstone, vermilion or brownish, in part cross-bedded, containing ferruginous nodules. There are some thin conglomeratic beds containing rounded pebbles of rhyolite, granite, and limestone of Allamoore formation	200
(8) White or buff sandstone, spotted with limonite flecks, in 1 to 3-foot beds, resembling the near-by Cox sandstone (Cretaceous). Cut by two sets of joints at nearly right angles, which impart to outcrops of member an angular or sawtoothed appearance. Bed is traceable for at least 2 miles westward along escarpment	20
(7) Friable, arkosic sandstone, similar to bed (9) but redder colored (Pl. 27, A)	200
(6) Thinly and regularly bedded brown sandstone	4
(5) Conglomerate of igneous pebbles, interbedded with layers of red arkose several feet thick. Most of cobbles are red granite and rhyolite porphyry, but some are basic igneous rocks and vein quartz	300
(4) Arkosic and pebbly red sandstone	20
(3) Similar to bed (1)	3
(2) Pebbly arkose	4
(1) Coarse conglomerate of ovoid and spherical, well-rounded boulders as much as 2 feet across, closely packed, but with some arkosic matrix in the interstices (Pl. 26, A). Boulders are mostly red granite and rhyolite porphyry (see petrographic report by C. S. Ross)	8
Unconformity	
Allamoore formation at base of section: Massive greenish igneous rock at foot of scarp, either thick flow or intrusive sill. To east, the Van Horn lies on limestones of the Allamoore, and beyond on red sandstones of the Hazel formation (fig. 7).	

Total thickness of Van Horn sandstone

759

The thickness of the Van Horn can be estimated fairly closely on the west side of Beach Mountain three-fourths mile south of the Yates ranch house (P.5—5.5, Pl. 2). Here, 250 feet is exposed below the Bliss (?) on the steep slope east of Hackberry Creek. The base of the formation crops out across the creek not far to the west, so that the total thickness cannot exceed 325 feet. Farther south in the Red Valley the formation may be much thicker, as it crops out over wide areas and in places dips as steeply as 45°.

*Interpretation of Van Horn sandstone.*—The Van Horn sandstone is a post-orogenic deposit, rather than a syn-orogenic deposit like the Hazel formation. Its base lies on a deformed and deeply eroded terrane of the older rocks; its sediments were derived from lands of considerable relief, but the perfect rounding of its included fragments

its conglomerate fragments are chiefly not of local origin, and its cross-beds maintain their southward dip regardless of the dip of the beds into the basins (fig. 8). The present basins are thus probably remnants of an originally more extensive deposit, which was fragmented by subsequent down-folding, down-faulting, and erosion. The original depositional area was probably a trough extending east and west between deformed and uplifted Allamoore and Carrizo Mountain rocks on the south and highlands of granite and rhyolite porphyry on the north. The dip of the cross-beds, and the dominant granite and porphyry fragments, suggests that the basin was filled mainly by sediments brought in from the north, with only minor contributions from other directions.

The Van Horn sediments closely resemble those of the Triassic Newark group

of the eastern states, and the Pennsylvanian Fountain formation of Colorado, which likewise are red, thick-bedded, arkosic, conglomeratic deposits. They are also strikingly like the Miocene deposits along the San Andreas fault zone from Cajon Pass westward, in southern California (Noble, 1933, pp. 12-13), which are thick-bedded, arkosic, and conglomeratic but flesh-colored rather than red. Many of these comparable deposits contain vertebrate bones, plants, and other fossils indicative of a continental environment.

*Stratigraphic relations.*—In most places the Van Horn sandstone is followed by the very much younger Hueco limestone, of Permian age, but in a few places, as on Beach Mountain, it is overlain by early Paleozoic rocks, the Bliss (?) sandstone, of Ordovician age.

The Van Horn and Bliss (?) were not differentiated in earlier reports (Dumble, 1902; Richardson, 1904, 1914) and were thought to be gradational deposits, but they are actually quite distinct and the contact between them can be located with confidence in all exposures. A marked change in sedimentation took place from Van Horn to Bliss (?) time—from coarse, arkosic, continental, unfossiliferous deposits in the Van Horn, to fine-grained, cleanly washed, quartzose, marine, fossiliferous deposits in the Bliss (?).

The Bliss (?) lies unconformably on the Van Horn and in nearly all exposures can be seen to truncate the tilted beds of the underlying formation at a low angle. Typical examples are shown on the accompanying figure 9. Relations are well shown on the north face of Beach Mountain east of its northwest corner (T.5—11.5, Pl. 2), where there is an angular divergence of 20° between the bedding of the two units, causing more than 200 feet of beds of the Van Horn to be cut out in a distance of a mile along the scarp (fig. 9, C). Sandstones of the Van Horn for a few feet below the base of the Bliss (?) are commonly bleached from red to yellow, either by pre-Bliss weathering or by later circulation of ground water along the contact.

The most striking manifestations of unconformity are on Tumbledown Mountain (R.5—8.5 and S.5—9.5, Pl. 2) where the Van Horn is dropped against the Alla-

moore along two faults, the Dallas and Grapevine, which moved between Van Horn and Bliss (?) time. The faulted terrane is truncated by Bliss (?) deposits, which lie on the Van Horn on the downthrown sides and on the Allamoore on the upthrown sides, in the angle between the two faults. The Dallas fault has not moved since Bliss (?) time (figs. 9, B; and 15), but the Grapevine fault was displaced again in the same direction later.

*Age.*—Dumble (1902, pp. 1-3) and Richardson (1914, p. 4) have previously interpreted the Van Horn as being of "Potsdam" or "Upper Cambrian (?)" age, a conclusion based partly on the marked unconformity between it and the underlying pre-Cambrian rocks and on the occurrence of *Scolithus*, or worm tubes, in the supposedly conformably overlying Bliss (?). With the discovery of a notable unconformity between the Van Horn and the Bliss (?) a Cambrian age for the Van Horn became less plausible, as it has little resemblance to rocks of known Cambrian age elsewhere. The writer (King, 1940, p. 153) has therefore termed it "Cambrian or pre-Cambrian" in an earlier publication, but he now prefers to term it "pre-Cambrian (?)," to express the stronger presumption that it is of late pre-Cambrian age.

Arguments favoring a later age for the Van Horn are relatively insubstantial. It is true that it lies with marked unconformity on the Hazel and Allamoore formations, which expresses a time of orogeny and deep erosion, but these events need not necessarily mark the end of pre-Cambrian time. It is poorly consolidated, but so also is the still older Hazel formation in regions of slight deformation. It is the next formation below the fossiliferous Bliss (?), but the unconformity between them indicates that there was a large time hiatus between Van Horn and Ordovician time.

Arguments favoring an earlier age are stronger. There is a well-marked unconformity between the Van Horn and Bliss (?), involving tilting, faulting, erosion, and changes in sedimentation. The Van Horn is unfossiliferous. It was laid down in a continental environment in a region of considerable relief, unlike any

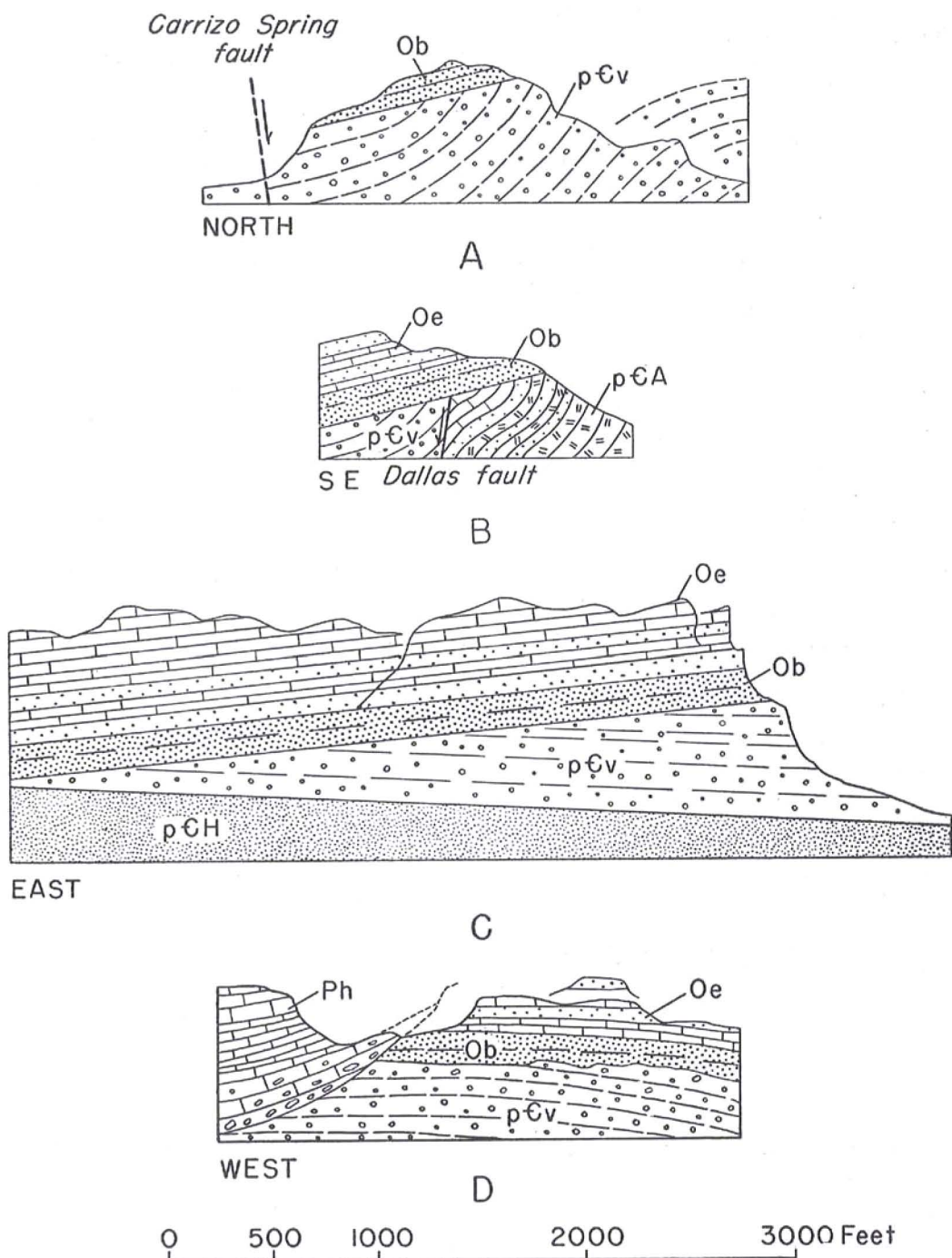


FIG. 9. Sections showing unconformity between Van Horn sandstone and Bliss (?) sandstone. A, West side of Beach Mountain,  $1\frac{1}{4}$  miles southeast of Yates ranch house (Q.5—3.5, Pl. 2); B, south of Dallas prospect on Tumbledown Mountain (S.5—8.5, Pl. 2); C, eastward from northwest corner of Beach Mountain (T.5—11.5, Pl. 2); D, in southern Baylor Mountains, 3 miles east of B-Bar ranch house (east of Pl. 2). pCH = Hazel formation; pCA = Allamoore formation; pCv = Van Horn sandstone; Ob = Bliss (?) sandstone; Oe = El Paso limestone; Ph = Hueco limestone.

near-by Cambrian deposits. Its deposits are much more like those of the Hazel than those of the Paleozoic, and they seem to mark a resumption of conditions very similar to those of Hazel time after an intervening period of orogeny.

It is admitted that these arguments are more weighty against the Van Horn being of Late Cambrian age, than against its being a continental facies of the Early Cambrian, if such should have been laid down in the region. The dilemma is comparable to that in the Lake Superior region, where coarse, red, unfossiliferous clastics which lie next beneath the fossiliferous Cambrian have generally been assigned to the upper Keweenaw, or late pre-Cambrian, but which, in their terminal parts at least, may be continental Early Cambrian (Raasch, 1950, pp. 148-150).

## PALEOZOIC AND YOUNGER ROCKS

### INTRODUCTION

After Van Horn time, various younger deposits, of Paleozoic and Mesozoic age, were spread over the pre-Cambrian rocks herein described. Apparently the area became increasingly positive with time, as successive transgressive units overstep those beneath, each in turn resting on the pre-Cambrian. There are three transgressive systems—the Ordovician, with the Bliss (?) sandstone at the base; the Permian, with the Powwow member of the Hueco limestone at the base; and the Cretaceous, with the Campo Grande<sup>16</sup> limestone at the base.

As descriptions of the Paleozoic and Cretaceous rocks have appeared in other publications, or will be published later, it is unnecessary to describe them in detail. Nevertheless, some remarks are desirable regarding the different units which come in contact with the pre-Cambrian formations.

### ORDOVICIAN ROCKS

*Bliss (?) sandstone* (Ob).—The Bliss (?) sandstone contains the oldest identifiable fossils in the Sierra Diablo region, and is the next youngest formation above the Van Horn sandstone. Within the map area, it is exposed in a semicircle around the north and west sides of Beach Moun-

tain, where it forms shelves and thin ledges about halfway up the face of the escarpment. A few small outcrops also occur in the Baylor Mountains, farther northeast (King and Knight, 1944).

Sections measured by the writer in Beach Mountain show that the Bliss (?) maintains a nearly constant thickness of 115 to 120 feet. The main part of the formation consists of white or light brown, quartzitic, quartzose sandstones, in beds a few inches to a foot thick, which are commonly laminated, cross-bedded, and ripple-marked. Many of the sandstone beds contain vertical worm tubes, or *Scolithus*, and in the upper part the tubes are abundant in nearly every layer (Pl. 26, B). Between the sandstone layers, especially in the upper part, are partings of softer, more marly sandstone, of gray, brown, purplish, or greenish color. The greenish material was suspected to contain glauconite, but C. S. Ross reports as follows on a specimen examined by him (memorandum of November 19, 1940):

No glauconite was observed. The green color appears to be caused by a high iron clay that is interstitial to sand grains. Clays rich in nontronite may be green.

To the writer, the Bliss (?) sandstone of Beach Mountain appeared not to be calcareous, although he noted calcareous beds in the upper part in the Baylor Mountains. On the other hand, Cloud and Barnes (1948, p. 67) state that "tests with dilute HCl show that most beds are slightly calcareous, and one 10-inch bed of dolomite was seen near the middle at the north end of Beach Mountain."

The basal few feet of the Bliss (?), lying unconformably on the Van Horn sandstone, is a conglomerate consisting of rounded pebbles less than an inch to as much as 3 inches in diameter, mostly of vein quartz but with a few of chert, quartzite, and schist. At some places, the matrix is reddish, probably because it contains reworked red detritus from the Van Horn.

The Bliss (?) appears to be sharply separated from the El Paso limestone above. The thin-bedded, non-calcareous or poorly calcareous sandstones of the Bliss (?) are succeeded abruptly by thick-bedded dolomitic limestones and dolomitic sandstones of the El Paso. The El Paso may lie disconformably on the Bliss (?), a possibility confirmed by Cloud and Barnes, who found detritus reworked from the Bliss (?) in the basal El Paso.

<sup>16</sup> At the time Plates 1 and 3 of this paper were sent to the engraver it was thought that the approved spelling had been changed to Campogrande. Unfortunately the writers were mistaken; the correct spelling is Campo Grande, two words, and the spelling on the maps is in error.



Various collections of fossils have been made in the Bliss (?) of the Beach Mountain area, the most extensive being those of Cloud and Barnes (1948, p. 68). In the upper 4 feet of the formation these authors cite *Clarkoceras* sp., *Lytospira* sp., *Ophileta* sp., *Helicotoma* sp. cf. *H. uniangularata* (Hall), various other gastropods, *Hystriocurus* sp., and archaeostracan crustaceans. These are of Early Ordovician aspect. Nineteen feet lower the beds contain numerous unidentifiable gastropods and *Lingulepis*, generally considered to be an index fossil of the Upper Cambrian.

Cloud and Barnes (1948, pp. 68-69) tentatively conclude that all the Bliss (?) of the Beach Mountain area is of Early Ordovician age and is probably equivalent to the Tanyard formation of the Ellenburger group in the Llano area. Although they recognize differences between it and the type Bliss of the Franklin Mountains to the west, they state that "the burden of proof perhaps rests with those who would dispute the correlation of these two stratigraphically commensurate basal sands." However, Bridge (Kelley, 1951, p. 2205), after reviewing other and later evidence, concludes that "the Bliss sandstone at the type locality in the Franklin Mountains and north and west of this locality is Upper Cambrian." A separate name for the Early Ordovician sandstones on Beach Mountain seems unwarranted as both it and the type Bliss are probably part of a single transgressive series and are not far apart in age. It therefore seems appropriate to term the beds of Beach Mountain the Bliss (?) sandstone, a conclusion with which Mr. Bridge agrees.

*El Paso and Montoya limestones* (Oe and Om).—The El Paso limestone, which succeeds the Bliss (?) on Beach Mountain, is a mass 1,115 feet thick of calcitic and dolomitic limestone, with several thick beds of calcareous or dolomitic sandstone in the lower part. Its fossils indicate that it is of Early Ordovician (Beekmantown) age and equivalent to various formations of the Ellenburger group of central Texas. The El Paso of Beach Mountain has been described in great detail by Cloud and Barnes (1948, pp. 66-71, 352-361), and it is unnecessary to add further observations.

On the summit of Beach Mountain, at the extreme east edge of the map area (T.5—6.5 and T.5—7.5, Pl. 2), the El

Paso limestone is overlain by massive dolomitic limestone and cherty limestone belonging to the Montoya limestone, of Late Ordovician (Cincinnatian) age.

#### PERMIAN<sup>17</sup> ROCKS

*Hueco limestone* (Ph and Php).—In most of the Sierra Diablo foothills, the next formation above the pre-Cambrian rocks is the Hueco limestone, of Wolfcamp (early Permian) age (Pl. 28, B). In the Sierra Diablo region the Hueco lies with major unconformity on all the older rocks of the section, including not only the pre-Cambrian but also the Ordovician, Silurian, and Devonian systems and the Mississippian and Pennsylvanian series (Pl. 19, C). The general features and map relations of the Hueco in this region have been set forth elsewhere (King, 1942, pp. 556-562; King and Knight, 1944), but some further details pertaining to the Sierra Diablo foothills are here given.

Sections measured by J. B. Knight indicate that the formation is 565 feet thick on Threemile Mountain (T.5—15.5, Pl. 1.), 370 feet thick in the southern Streeruwitz Hills northwest of Eagle Flat section house (G.5—6.5, Pl. 3), and 430 feet thick in the southeastern part of the Sierra Diablo north of the Hazel mine (P.5—14.5, Pl. 2). This is not the full thickness of the formation, as the Hueco in this area is either the highest formation present or is overlain unconformably by Cretaceous rocks.

At the base of the Hueco is a clastic member, which forms slopes and thin ledges below the surmounting limestone cliffs. For this, the name Powwow member is used, on recommendation of Prof. R. K. DeFord of The University of Texas, supplanting the term "basal clastic member" used in previous reports. The name Powwow is derived from the Hueco Mountains (King and King, 1929, p. 911; King, 1934, p. 743; King, King and Knight, 1945, sheet 2), where the member is a thin, discontinuous body of conglomerate and red beds that occupies the same position at the base of the Hueco limestone as do the clastics in the Sierra Diablo.

The Powwow member is thickest in the south, as on the ridges between Threemile Mountain and the Gifford-Hill rock crusher

<sup>17</sup> The U. S. Geological Survey classes the Wolfcamp series, of which the Hueco limestone is a part, as of Permian (?) age.

(T.5—15.5 and H.5—16.5, Pl. 1) and the southern Streeruwitz Hills (G.5—6.5 to D.5—9.5, Pl. 3), where sections 103 to 184 feet thick have been measured; in places in the southwest part of the Red Valley it may be as much as 250 feet thick (K.5—1.5, Pl. 2). In the central Streeruwitz Hills the member is erratically developed, as a result of overlap on a hilly surface of the pre-Cambrian rocks, and in places it is absent. Along the south-facing escarpment of the Sierra Diablo, at the north edge of the map area, it is less than 100 feet thick.

The member consists of conglomerate, arkose, red and buff sandy shale, and thin varicolored argillaceous or earthy limestones, passing up into interbedded gray limestones and fossiliferous marls. Conglomerate fragments are mostly poorly rounded fragments derived from the immediately subjacent pre-Cambrian rocks, but where the member overlies the Van Horn sandstone it contains many rounded cobbles reworked from that formation. Fossils in the upper part include echinoid spines, euomphalid and bellerophonitid gastropods, *Composita*, and productids; many of them weather free on the slopes.

An unusual facies of the Powwow member occurs between Threemile Mountain and the Gifford-Hill rock crusher, immediately north of the Hillside fault. Just north of the fault and  $1\frac{1}{2}$  miles east of the rock crusher (K.5—16.5, Pl. 1) it is a coarse, bouldery conglomerate, made up of angular fragments of metarhyolite of the Carrizo Mountain group. Similar fragments occur in the member for half a mile north of the fault. In this vicinity the Powwow member lies, not on metarhyolite, but on Van Horn sandstone, but the metarhyolite is extensively exposed immediately south of the fault. Evidently the metarhyolite fragments were eroded from a scarp along the Hillside fault that had been raised during the pre-Hueco deformation.

The main body of the Hueco limestone above the Powwow member projects in light-colored cliffs and mural escarpments that are prominent along the Texas and Pacific Railroad west of Threemile Mountain and northwest of Eagle Flat section house, as well as on the southern scarps of the Sierra Diablo from the Hazel mine westward. Away from the cliffs, it forms step-like ledges or the surface of flat-topped table-lands.

In most of the Sierra Diablo foothills the limestone is gray, fine-textured, and calcitic, in part cherty, with a few dolomitic beds and marly units. Northeastward, however, in the angle of the Sierra Diablo between the old Circle ranch house and the Hazel mine (Pl. 2), it passes into a monotonous sequence of thin-bedded, dolomitic limestone. The calcitic limestones contain an assemblage of fossils similar to that in the upper part of the Powwow member. Foraminifera are nearly absent, except for the minute *Staffella*, which abundantly dots the surface of some of the limestones. Northeastward in the dolomitic facies, fusulinids become abundant, almost to the exclusion of any other fossil. Some of these collected near the old Circle ranch house have been identified by Dunbar and Skinner (1937, p. 722, localities 94–96).

#### CRETACEOUS ROCKS

*Introduction.*—Cretaceous rocks of the Sierra Diablo region, like the Permian rocks (Hueco limestone) lie unconformably on the preceding formations. In the Sierra Diablo foothills they rest in part on the Hueco but in part overstep it and rest on the pre-Cambrian. Their most extensive outcrops are in mesas along the south edge of the Sierra Diablo escarpment which extend northwestward, beyond the map area, from the vicinity of the Keene ranch house (J.0—16.0, Pl. 3). Small, widely dispersed outliers occur in the Streeruwitz and Bean Hills, and there are several larger ones east of the Gifford-Hill rock crusher near the Texas and Pacific Railroad (I.5—16.5 to L.5—16.5, Pl. 2). Two formations are present in the Sierra Diablo foothills, the Campo Grande limestone below and the Cox sandstone above; they are part of the Comanche series and are probably late Trinity in age.

*Campo Grande limestone* (Kcg).—Most of the Cretaceous rocks in the map area belong to the Campo Grande limestone, made up of several beds of massive ledge-making light gray limestone, in part sandy or conglomeratic, and of nodular limestone and marl. At the base is a conglomerate containing chert and limestone fragments, largely derived from the Hueco limestone. Some beds contain poorly preserved oysters, *Trigonia*, echinoid fragments, and rudistids, and at one locality the foraminifer *Haplostiche* (*Nodosaria*). In the Streer-

uwitz Hills the Campo Grande limestone is 100 to 140 feet thick, but near the Gifford-Hill rock crusher only 30 to 60 feet is present.

*Cox sandstone* (Kcx).—The succeeding Cox sandstone is most prominently displayed northwest of the map area, as on Dome Peak 5 miles northwest of the Keene ranch house, where 605 feet was measured. Within the map area the largest outcrop is on the high butte immediately east of the Gifford-Hill rock crusher (1.5—16.5, Pl. 1) which is made up of 410 feet of the formation. The Cox includes numerous sandstone beds 5 to 10 feet thick, which form prominent massive ledges and weather out in great cubical blocks that strew the slopes below. The sandstones are buff or brown, coarse grained, saccharoidal, and in part cross-bedded. Many contain small spherical ferruginous concretions, and some contain seams of chert pebbles. Between the sandstone ledges, and making up nearly half the formation, are beds of poorly consolidated thin-bedded sandstone or sandy shale, of gray, purple, or red color, in which there are a few layers of nodular argillaceous or earthy limestone. Within the map area the Cox sandstone is unfossiliferous.

#### TERTIARY (?) INTRUSIVE ROCKS (Ti)

In the western part of the map area are a few small bodies of intrusive igneous rock that are probably of Tertiary age and related to larger intrusive bodies in the immediate region.

One of these lies in metarhyolite of the Carrizo Mountain group of the southern Streeruwitz Hills, 2½ miles west-northwest of Eagle Flat section house (D.5—7.5, Pl. 3). It is made up of massive, unsheared, spotted igneous rock, unlike any of the pre-Cambrian rocks in the vicinity and megascopically resembling the alkalic igneous intrusives of the Diablo Plateau to the north.

Farther north, a mile northwest of the Keene ranch house (1.5—17.5, Pl. 3), two small plugs and associated sills penetrate the Campo Grande limestone. These were not seen by the writer during field work but were discovered on the air photographs, where they stand out prominently; they were later visited by Flawn. According to Flawn, the rock is a black aphanitic basalt that contains sparse small phenocrysts of

black glassy augite and spinel, mostly less than 5 mm. in diameter. Associated with the plugs or laccoliths are a number of thin basalt sills, commonly less than 5 feet thick, containing numerous phenocrysts of olivine, spinel, and augite as much as 1 to 2 cm. in diameter and containing sporadic augite phenocrysts as much as 4 to 5 cm. The vesicular nature of phases of this rock indicates that it was intruded near the surface.

There is a possibility that other bodies of Tertiary intrusives may exist amidst the pre-Cambrian volcanic rocks of the Allamoore formation in the Sierra Diablo foothills. As already noted, Sample and Gould (1945) regard igneous rocks near the Sancho Panza mine as probably much younger than the Allamoore, and a body of dark, amygdaloidal rock 2¼ miles west of the Garren ranch house has a fresh, un-sheared appearance, much like a young basalt plug. In addition, Flawn suggests that diabase near the talc prospect in the Streeruwitz Hills northwest of Eagle Flat section house may be of Tertiary age, on account of its un-sheared appearance and its nearly circular, plug-like outline. The writer has considerable reservations regarding the youth of these and other possible Tertiary bodies in the Allamoore and believes that decision can only be made after regional study. The volcanic rocks which are part of the Allamoore formation probably include not only bedded deposits but also shallow intrusives of various forms. Moreover, the interiors of the more massive bodies have very often been little sheared by subsequent movements, and although they are actually ancient, they have preserved much of their original structure and texture.

## STRUCTURAL GEOLOGY

### INTRODUCTION

The rocks of the Sierra Diablo foothills show an unusually complex and varied structure for so small an area. The numerous unconformities in the rock sequence and the contrasts in structure between formations of different ages indicate that the complexity and variety was the result of an eventful tectonic history. The nature of the different structures and the times during which they were formed are indicated in Table 20.



Table 20. Tectonic history of Sierra Diablo foothills.

Heading in text	Age	Kind of structure	Associated unconformity	Associated tectonic sediments
Streeruwitz overthrust  Folds and thrusts in Allamoore and Hazel formations	post-Allamoore, early Hazel	Uplift, marmorization, and (?) folding; not separable in field from next succeeding structures.	Probable angular unconformity at base of Hazel formation; lies on Allamoore formation.	Conglomerates of Hazel formation with fragments of Allamoore formation, in part marmorized; synorogenic.
	post-Hazel, pre-Van Horn	Thrusting and cataclasis of Carrizo Mountain group near Streeruwitz overthrust; intense folding and thrusting of Allamoore and Hazel formations.	Major angular unconformity at base of Van Horn sandstone; lies on all older formations.	Conglomerates of Van Horn sandstone, including fragments of cataclastically altered metarhyolite of Carrizo Mountain group; post-orogenic.
		Strike-slip movements on Grapevine and other high-angle faults.		
Structures of late pre-Cambrian (?) rocks	post-Van Horn, pre-Bliss (?)	Tilting, local faulting on Dallas, Grapevine, and other (?) faults.	Minor angular unconformity at base of Bliss (?) sandstone.	
Paleozoic and Mesozoic structures	late Pennsylvanian, pre-Hueco	Broad folding, local faulting on Hillside, South Diablo, Sulphur Creek, and other (?) faults.	Major angular unconformity at base of Hueco limestone; lies on all older formations.	Conglomerate, sandstone, and red beds of Powwow member of Hueco limestone; post-orogenic.
	post-Permian, pre-Cretaceous	Broad warping, possible local faulting on South Diablo fault.	Major erosional unconformity at base of Cretaceous; lies on Hueco and pre-Cambrian.	
High-angle faults and related features	late Tertiary and early Quaternary	Block faulting along west-north-westerly and northerly fault systems.	Unconformity at base of unconsolidated deposits.	Bolson deposits of Salt Basin and Eagle Flat; syn-orogenic.
	late Quaternary	Renewed movement on northerly fault systems.		Younger fanglomerates of Salt Basin.

In the descriptions which follow, the structural features will be taken up under the headings indicated in the first column of the table, which are largely in chronological order.

#### STREERUWITZ OVERTHRUST

A major feature, and probably the master structure of the pre-Cambrian rocks of the Sierra Diablo foothills, is the Streeruwitz overthrust, which emerges along the south edge of the foothills and forms the contact between the Carrizo Mountain group on the south and the Allamoore formation on the north.

The Streeruwitz overthrust is named for the Streeruwitz Hills, in the south part of which it crops out for a distance of  $2\frac{1}{2}$  miles (C.5—8.5 to G.5—9.5, Pl. 3; P. 9, section A—A'); in turn the hills are named in honor of W. H. von Streeruwitz who made the first geological observations there (1891, pp. 681—682; 1892, section O—P, Pl. 26). East of the Streeruwitz Hills the overthrust is largely covered by the alluvium of Eagle Flat, but it emerges at the base of the Millican Hills at two places northwest and northeast of Allamoore (U.5—4.5, Pl. 3; E.5—2.5 and F.5—2.5, Pl. 2; Pl. 9, sections D—D' and E—E'). Farther north in the Millican Hills are several patches of metarhyolite of the Carrizo Mountain group lying amidst the Allamoore formation (U.5—7.5, Pl. 3; C.5—6.5, Pl. 2; Pl. 9, section D—D'), which are interpreted as klippen of the overthrust. Features similar to those along the overthrust in the Sierra Diablo foothills occur at one locality in the northern Carrizo Mountains (L.5—15.5 and M.5—15.5, Pl. 1) and may mark another place of emergence of the overthrust.

Many lines of evidence, from both major and minor features, indicate that the contact between the Carrizo Mountain group and Allamoore formation is one of overthrust:

(1) The contact separates two different sequences, that on the south (Carrizo Mountain) being dominantly metamorphic and igneous and that on the north (Allamoore and Hazel) being dominantly sedimentary. These differences are not as absolute as they appeared in Richardson's time (1914, pp. 3—4), as the rocks to the north

are partly igneous and metamorphic and the rocks to the south are partly sedimentary. Considerable differences in both habit and facies nevertheless exist.

(2) The rocks of the Allamoore and Hazel formations north of the contact strike west-northwest parallel with the trace of the contact, whereas the rocks of the Carrizo Mountain group south of the contact strike northeast over wide areas. The northeast-striking rocks of the group in the Carrizo Mountains are separated from outcrops of the contact by a mile or more of younger rocks, so that exact relations cannot be established, but their pattern suggests that they strike up to and are truncated by the contact. The contact thus apparently brings rocks of unlike structure into juxtaposition.

(3) The contact involves great stratigraphic displacement. The rocks next to the Allamoore are metarhyolites that are intrusive in the lower part of the sedimentary sequence of the Carrizo Mountain group. In the Carrizo Mountains, Flawn has found that this sequence is 19,000 feet thick and dips away from the contact, so that the highest beds are exposed farthest away toward the southeast. Somewhat tenuous evidence suggests that even the highest beds are stratigraphically beneath the Allamoore.

(4) The southern rocks (Carrizo Mountain) are superimposed on the northern (Allamoore). The contact between them dips south at a low angle, and klippen occur a mile or more to the north.

(5) The Allamoore and Hazel formations for 3 miles or more north of the contact are violently deformed, apparently under the influence of stresses directed from the south; farther north the deformation fades out.

(6) Indications of large-scale transport of the Carrizo Mountain group are afforded by its minor structures. Its rocks for some distance south of the thrust are cataclastically altered, with strongly developed lineation and streaks of mylonite. Lineation trends generally southward, normal to the trace of the thrust and apparently parallel to the *a* fabric axis, or direction of transport.

(7) Greatest alteration of the Allamoore formation is close to the fault con-

tact, where its limestones are extensively silicified and marmorized, probably by a combination of dynamic and hydrothermal processes.

The actual contact between the Carrizo Mountain group and Allamoore formation is visible on ravine banks and hillsides at a number of places in the southern Streeruwitz Hills and northeast of Allamoore but affords little conclusive evidence for or against the overthrust interpretation. There is no sharply marked, clean-cut surface of movement, such as one would find on a younger fault or one of less complex history. Near the contact the metarhyolite is strongly silicified and lineated, and the limestone is contorted, schistose, and marmorized, but the contact itself is likely to be masked by schistose amphibolite or by quartz veins. In places, hydrothermal alteration of both metarhyolite and limestone is so great that they are difficult to differentiate. In others, the metarhyolite contains inclusions of brown, highly silicified carbonate rocks, perhaps in part incorporated tectonically and derived from limestones of the Allamoore formation below the contact. Aberrant dips of foliation and trend of lineation in the metarhyolite close to the contact attest further movement after the formation of the cataclastic structures.

The most interesting manifestations of thrusting are the klippen in the western Millican Hills, within the area of Allamoore formation (Pl. 9, section D-D'). These range from patches a few acres or less in extent, to hills as much as half a mile long, all composed of metarhyolite like that in the main area of the Carrizo Mountain group, a mile or more to the south. The largest mass is  $1\frac{3}{4}$  miles west of the Garren ranch house (B.5—6.5, Pl. 2). The klippen apparently mark a belt of major downfolding of the thrust sheet that trends east and west. Superimposition of metarhyolite on Allamoore is plain in the smaller klippen but is somewhat more obscure in the larger, as a result of complex folding and confusing dips. However, trends of ledges of the Allamoore around the largest klippe, as revealed by ground surveys and air photographs, suggest that it lies in a sharply depressed syncline, probably overturned northward on the south side. In another large klippe

a mile to the west (U.5—7.5, Pl. 3), the Allamoore is overturned southward on the metarhyolite.

Direct evidence indicates that the Streeruwitz overthrust is older than the Hueco limestone, as an outlier of the Hueco lies across its trace in the southern Streeruwitz Hills (E.5—8.5, Pl. 3). Indirect evidence demonstrates that it is also older than the Van Horn sandstone, as the Van Horn lies unconformably on all the older formations, truncates structures associated with the overthrust, and contains fragments of metarhyolite that was lineated and mylonitized during the thrusting.

#### FOLDS AND THRUSTS OF ALLAMOORE AND HAZEL FORMATIONS

*Introduction.*—The Allamoore and Hazel formations of the Streeruwitz, Bean, and Millican Hills, for 3 miles or more north of the trace of the Streeruwitz overthrust, are intensely folded and faulted, apparently by stresses directed from the south (fig. 10). Farther north, in the Hazel formation, the disturbance decreases, and on the eastern and southern scarps of the Sierra Diablo the sandstones of the Hazel dip at low angles.

As indicated by the coarse, thick conglomerates of the lower part of the Hazel formation, made up almost entirely of angular fragments of the Allamoore formation, the Allamoore was considerably deformed immediately before and during the early part of Hazel time. Part of the complex structure now visible in the Allamoore formation of the disturbed belt was probably produced by this deformation but cannot now be unraveled from the dominant structure, shared by both Allamoore and Hazel formations, which is of post-Hazel and pre-Van Horn age. The two sets of structures will therefore be described together.

Interpretation of the structure of the disturbed belt is rendered difficult by lack of guide fossils and by uncertainty as to the true nature of the stratigraphic succession. One stratigraphic fact on which much interpretation is dependent is proved by the conglomerates of the Hazel formation, namely, that the Hazel is younger than and originally overlay the Allamoore. This determines the nature of at least the

larger features, for where Allamoore now overlies Hazel it must have attained this position by overthrusting or overfolding.

Nevertheless, numerous details are difficult to interpret. In places, but particularly in outcrops of the Allamoore, strikes and dips are almost meaningless, for if one so desires he can discover nearly every angle or direction within short distances. Plunges of folds are also not especially helpful. Where a contact curves across the axis of a fold, instead of a consistent low plunge in one direction, one is likely to encounter high, irregular dips. Moreover, the map pattern indicates that plunges are not consistent throughout the area but reverse themselves within short distances along the strike. Observations on cleavage and graded bedding might provide helpful clues; in this respect the field work on which this report is based is admittedly weak. Where such observations were made, results were so conflicting or inconclusive that more time would have had to be devoted to them than was available for the field work.

over, there is reason to suppose that over wide areas bedding has been rotated more than  $180^\circ$ , and in such places use of an overturned symbol would be devoid of meaning.

(2) Throughout the disturbed belt there are many indications of folds of anticlinal and synclinal habit, but there is good evidence that some of these have been rotated more than  $180^\circ$ , so that an apparent syncline is actually the inverted nose of a recumbent anticline. Without creation of special symbols and making possibly unwarranted interpretations, it appears impracticable to indicate such possibilities on the map. All folds with apparent anticlinal and synclinal structure are therefore shown as anticlines and synclines, regardless of their possible true character and prior history. Some hint of the probable nature of these structures is given on the structure sections (Pl. 9).

(3) As indicated in discussing the stratigraphic relations of the Allamoore and Hazel formations, the contact between them is complex. In places there may be still

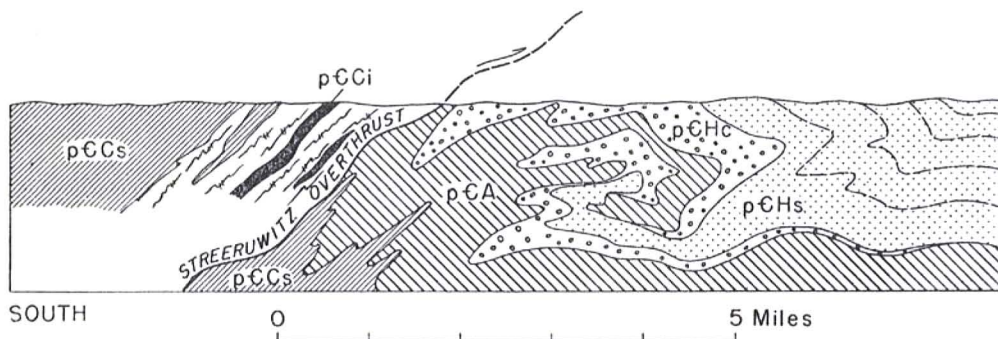


FIG. 10. Synoptic section, showing general structure of pre-Cambrian rocks in Millican Hills. The master structure is the Streeruwitz overthrust, which has carried rocks of the Carrizo Mountain group over the Allamoore and Hazel formations and has intensely folded them for several miles north of the contact. The section is based on features in various parts of the outcrop area, some of which are also shown on sections D-D' and E-E' of Plate 9. pCCi = igneous rocks of Carrizo Mountain group; pCCs = sedimentary rocks of Carrizo Mountain group; pCA = Allamoore formation; pCHc = conglomerate of Hazel formation; pCHs = sandstone of Hazel formation.

The complexities of the structure have necessitated the adoption of several conventions on the geologic maps:

(1) No overturned beds are differentiated. Indication of beds believed to be overturned would introduce a large subjective element, and it therefore appeared best to indicate strikes and dips as they were actually observed in the field. More-

preserved the original irregular unconformable surface of the Allamoore on which the Hazel was deposited, but where the contact is exposed there is generally evidence of movement between them of undetermined magnitude, no doubt resulting from differences in competency of the rocks of the two formations. In some places, where the Allamoore overlies the



upper part of the Hazel formation, the two are undoubtedly separated by a low-angle fault of large displacement. Differentiation of these possibilities from place to place along the contact would be so subjective that it seems undesirable to attempt it on the map. To indicate the special nature of the contact it is differentiated from others as a "surface of movement," shown by a special symbol.

The closest field study of the disturbed belt was made in the Millican Hills, and although even here some details still defy explanation it is thought sufficient to provide interpretation of at least the larger features. This area will therefore be described in some detail in the pages that follow, after which interpretations will be suggested for other areas where less decisive information has been obtained.

**Millican Hills.**—The Millican Hills are formed of limestone, volcanics, and phyllite of the Allamoore formation, and of conglomerate and red sandstone of the Hazel formation, which crop out in successive belts striking generally west-northwest, in which the beds dip steeply, at diverse angles, and in various directions. The rocks of the hills are considerably altered by dynamic and hydrothermal processes, in the manner indicated in the descriptions of the respective formations, but little of the original sedimentary struc-

ture is lost except near the Streeruwitz overthrust on the south. Cleavage and schistosity apparently were formed by progressive metamorphism during a single cycle.

In the south part of the hills, immediately north of the Streeruwitz overthrust, is a belt of Allamoore formation 1 to 2 miles wide, which extends from a point south of the Canning ranch house, 8 miles east-southeast to Buck Spring (Q.5—8.5, Pl. 3, to K.5—3.5, Pl. 2).

Within the southern belt of Allamoore formation, sharply depressed synclines preserve outliers of conglomerate of the Hazel formation north of the Dwees ranch house (C.5—4.5, Pl. 2) and klippen of metarhyolite of the Carrizo Mountain group west of the Garren ranch house (B.5—6.5, Pl. 2). Elsewhere, intense folding is indicated by winding outcrops of the limestone, volcanic, and phyllite units of the Allamoore and in places is visible in cross section on the sides of the ridges, as 2 miles southeast of the Garren ranch house (fig. 11). Nevertheless, relations are generally so complex that the broader pattern is obscure. Several high-angle faults a mile or more in length break the rocks of the belt (A.5—6.5 and G.5—3.5, Pl. 3), trending west-northwest nearly parallel to the regional strike. These are not Tertiary normal faults, as adjacent steeply folded beds conform to them; more probably they were created by strike-slip movements late in the orogenic epoch.

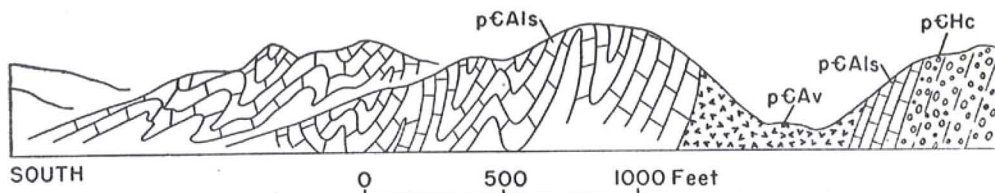


FIG. 11. Profile, based on field sketch, showing folding in limestones of Allamoore formation 2 miles south-southeast of Garren ranch house (G.5—4.5, Pl. 2). pCAIs = limestone unit of Allamoore formation; pCAv = volcanic unit of Allamoore formation; pCHc = conglomerate of Hazel formation.

ture is lost except near the Streeruwitz overthrust on the south. Tourmaline-bearing, slickensided surfaces are common in the sandstones and conglomerates, and in places in the limestones, suggesting that the rocks were deformed under high temperature. There is, nevertheless, no discernible trace of the cataclastic metamorphism that is prominent in the metarhyolites of

External relations of the southern belt of Allamoore formation are more informative than the internal. Between Buck Spring and Carrizo Spring at its southeast end (L.5—3.5, Pl. 2) the Allamoore formation stands in several anticlines, whose flanks dip steeply and whose crests plunge eastward beneath the basal conglomerates of the Hazel formation. Here, the Allamoore is

rooted in place beneath the Hazel, and there is no intervening "surface of movement." West-northwestward along the contact, relations between the two formations become more discordant. Two miles west-northwest of Buck Spring at the Cooper Hill prospects (F.5—4.5, Pl. 2) the contact dips south but the adjacent conglomerate dips north. The presence of an intervening "surface of movement" is indicated by fracture cleavage in the conglomerate and schistosity in the marmorized limestones, both of which dip south parallel to the contact. Movement cannot have been great, as

the conglomerate contains boulders of limestone pebble conglomerate like that seen in place in the adjacent Allamoore.

Relations are much more discordant beyond. Northwest of the Cooper Hill prospects the Allamoore formation extends for nearly a mile over the Hazel formation in a recumbent anticline, or "subsidiary nappe" (fig. 12; Pl. 9, section D-D'), plunging to the west, every detail of which is well exposed in the hills west of the Garren ranch house (D.5—6.5, Pl. 2). This feature is on a scale small enough to be apprehended readily yet is apparently comparable to

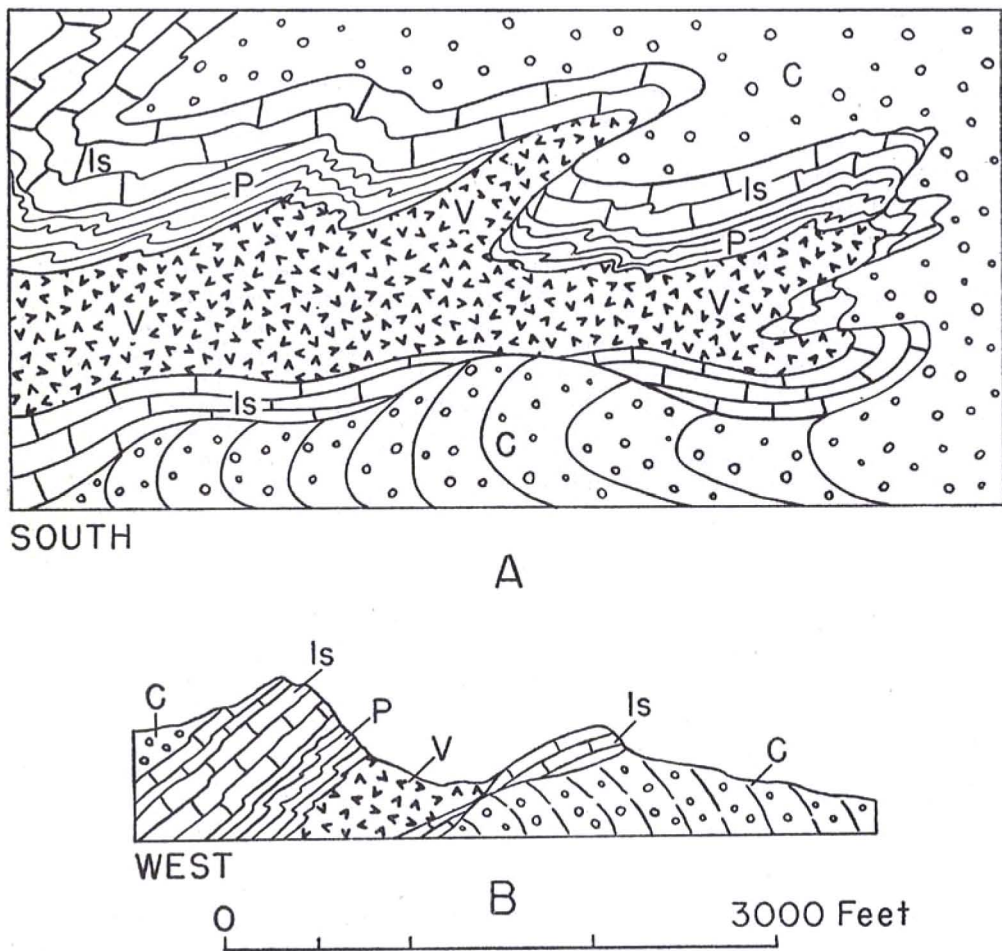


FIG. 12. Sections of the "subsidiary nappe" a mile west of the Garren ranch house (C.5—6.5 to E.5—6.5, Pl. 2). This structure, which is on a relatively small scale, is believed to resemble some of the larger structures of the Millican Hills and to provide a key for their interpretation. A, North-south section, combining features observed at various places along the plunge of the structure; B, east-west section, which crosses the preceding section near its center. V = volcanic unit of Allamoore formation; P = phyllite unit of Allamoore formation; Is = limestone unit of Allamoore formation; C = conglomerate of Hazel formation.

larger and more complex features elsewhere in the area, described below. The "subsidiary nappe" has a carapace of limestone which is traceable, with some interruptions caused by piercement structure, from the lower limb on the east to the upper limb on the west. Its core is formed of volcanics and phyllite. It is enveloped by conglomerate of the Hazel formation which appears to be accordant above and discordant below. Accordance above is indicated by conformity of dip between limestone and conglomerate and by the presence in the conglomerate of limestone and volcanic fragments like those in place in the "subsidiary nappe." Discordance below is indicated by marked differences in attitude of bedding of the limestone and conglomerate, although within a few feet below the contact the discordant conglomerate beds are sharply bent into parallelism with the overlying limestone. At the place of bending they contain numerous tourmalinized slickensided surfaces. The cause of the recumbent folding in the "subsidiary nappe" is readily apparent, for on its back, a short distance to the west, reposes one of the larger klippen of the Streeruwitz overthrust (Pl. 9, section D-D').

A northern belt of Allamoore formation  $3\frac{1}{2}$  miles in length extends east and northwest of the Garren ranch house (D.5—9.5 to J.5—7.5, Pl. 2). The rocks of the northern belt are like the southern, and the belt belongs to the same formation as it is physically attached to its parent by an "umbilical cord"—a narrow curved belt of limestone, plunging westward,  $1\frac{1}{2}$  miles northwest of the Garren ranch house (B.5—8.5, Pl. 2).

Internally, the northern belt of Allamoore formation consists of sinuous outcrops of various limestone, volcanic, and phyllite members, of most complex structure, which north of the Garren ranch house (F.5—8.5, Pl. 2) are split by seven or more north-trending tear faults with considerable strike-slip displacement.

Externally, the northern belt has the form of a syncline, which is nested in a syncline of conglomerate of the Hazel formation that comes to the surface up the plunge to the east, beyond the Anaconda no. 1 prospect (Pl. 9, section E-E'). This apparent structure is questionable as the conglomerate is stratigraphically higher than the Allamoore. Proof of this succession is afforded

locally by fragments in the conglomerate like those which occur in place in the northern belt of the Allamoore and by graded bedding in the conglomerates on the north flank which indicate that tops of the beds are away from the Allamoore. Moreover, the apparent syncline in the conglomerate has vertical dips on its north flank and low dips on its south flank (K.5—7.5, Pl. 2; Pl. 9, section E-E'), or the opposite of what should be expected from the general northward asymmetry of the disturbed belt. The northern belt of Allamoore formation is thus not truly a syncline, as it appears to be, but is the inverted nose of a recumbent anticline, or nappe, on a much larger scale than the "subsidiary nappe" but rooted in the same manner in the southern belt of the formation.

The enveloping Hazel formation is discordant with the Allamoore formation of the northern belt, but it is uncertain how much of this resulted from original angular unconformity and how much from later dislocation; the whole contact is indicated on the map (Pl. 2) as a "surface of movement." Near the two Anaconda prospects at the eastern end of the belt, the dislocation is probably slight, as conglomerates at the base of the Hazel contain fragments of rock types that occur in the near-by Allamoore. Westward along both north and south sides of the belt the conglomerates thin out, and a mile north of the Garren ranch house (F.5—9.5, Pl. 2) the Allamoore is in contact with red sandstones. Here, marked differences in dip between the two formations indicate a large degree of structural discordance.

An unusual complication exists on the hill slope above the county road at the Garren ranch house, where limestones at the top of the Allamoore formation dip  $20^\circ$  northwest beneath the conglomerate of the Hazel formation. Relations are much more complex than the local outcrop would indicate, as the contact can be traced in a spiral, first northwestward, then southwestward along the "umbilical cord" and southeastward through the "subsidiary nappe," to the anticlines of the southern belt at Buck Spring. The limestones at the Garren ranch house, to attain their present position below the conglomerate, and their low dip, must have

been rotated nearly  $360^\circ$ . In this vicinity the south flank of the nose of the recumbent anticline of the northern belt must have been rolled back beneath itself, in the manner suggested in figure 10 (right center). This may have resulted from forward thrust of the "subsidiary nappe" after the larger and higher fold had been created.

Another, narrower belt of Allamoore formation,  $1\frac{1}{2}$  to 4 miles northwest of the Garren ranch house (C.5—10.5, Pl. 2, to T.5—11.5, Pl. 3) has no visible attachment to the southern belt. Its steeply dipping rocks afford no indication of its true nature, but it may well be the nose of another recumbent anticline that originally lay higher than that of the belt just described.

The conglomerates and red sandstones of the Hazel formation which enclose the Allamoore formation of the Millican Hills share its complex deformation. One belt lies north of Buck Spring and the Cooper Hill prospects and extends southwest from the Garren ranch house (E.5—6.5 to L.5—5.5, Pl. 2), between the southern and northern belts of the Allamoore. Next to the Allamoore on the south is a solid mass of conglomerate 2,000 feet thick, which dips northward beneath a wide band of red sandstone; this in turn dips northward at angles of about  $30^\circ$  beneath conglomerates which border the northern belt of Allamoore formation (Pl. 9, section E—E'). The whole suggests a homoclinal sequence, and it contains no hint of any reversal or indications of great internal stress, save for some tourmalinized slickensided surfaces in the red sandstone immediately above the southern conglomerate. Nevertheless, the northern conglomerate occupies the same stratigraphic position as the southern, immediately adjacent to the Allamoore, and it is presumably likewise a basal deposit of the Hazel, but now inverted.

Explanation of the structure of the Hazel in this belt is elusive, but the tourmalinized slickensided surfaces may mark a zone of reversal or thrusting. Determination of tops and bottoms of beds in the belt would be helpful, but observations which have been made of graded bedding in the sandstones and conglomerates did not yield conclusive results.

As already noted, the conglomerates to the north, east of the northern belt of Allamoore, form an apparent syncline which, from its relations to the Allamoore, appears actually to be the nose of a recumbent anticline. This plunges westward beneath the Allamoore at the Anaconda no. 1 prospect (J.5—7.5, Pl. 2), but farther east it plunges eastward toward Hackberry Creek (N.5—7.5, Pl. 2) and passes uniformly beneath the Van Horn sandstone at the foot of Beach Mountain. Along Hackberry Creek near the Yates ranch house it spreads out into a series of low, broad folds  $1\frac{1}{2}$  miles wide. If these structures conform to those already described, all the beds contained in them must be inverted (Pl. 9, section F—F').

*Area north of Millican Hills.*—On the north flank of the northern conglomerate belt of the Millican Hills, bedding of the Hazel formation stands nearly vertical for half a mile or more across the strike. Tops of beds are to the north, away from the false synclinal axis, as indicated by occasional observations on graded bedding and by the gradual diminution of the conglomerate component at the expense of the red sandstone component, so that this finally dominates altogether toward the north. South of the Blackshaft and St. Elmo mines there are, however, a number of tight isoclinal folds (K.5—8.5, Pl. 2). North of the mines the red sandstones and interbedded conglomerates flatten abruptly to nearly horizontal attitudes, forming the "north edge of the steep dip zone" of the map (Pl. 2).

Near the "north edge of the steep dip zone" at the Blackshaft, St. Elmo, and Sancho Panza mines a thin layer of Allamoore is tectonically interlayered in the Hazel formation (J.5—10.5 to L.5—9.5, Pl. 2). To the southeast this dips steeply northward or locally is overturned and dips southward, but to the northwest it dips at low angles eastward or northeastward, with many wrinkles and offsets. The layer of Allamoore is no more than 10 feet thick and is highly sheared and metamorphosed. In places, as between the Blackshaft and St. Elmo mines, it disappears altogether, leaving only a decolorized plane of shearing in the red sandstone. In mine workings, the hanging



wall of Hazel formation, overlying the Allamoore, is shown to be a strong, firm, smooth surface. The footwall is less definite and includes horses of underlying sandstone; in places it is marked by grooves or steps parallel to the strike.

Apparently the Allamoore and that part of the Hazel lying above it has been carried over the Hazel beneath along a thrust plane, or "surface of movement" (Sample and Gould, 1945). The smooth hanging wall of Hazel formation above the Allamoore suggests that it is likewise a "surface of movement," but displacement on it must have been less than on the one below, as the overlying Hazel contains coarse conglomerates such as might have been deposited on or not far above the top of the Allamoore formation. As the "surface of movement" involves at least several miles of horizontal displacement, it must extend for long distances in the Hazel formation beyond the points of disappearance of the Allamoore formation, but the red sandstones contain no structures that hint of dislocations of such magnitude.

Farther east, the Allamoore formation is exposed on Tumbledown Mountain (Q.5—8.5 to R.5—8.5, Pl. 2), where it again overlies red sandstones and thin interbedded conglomerates of the upper part of the Hazel formation. The Allamoore and underlying Hazel are folded into an eastward-plunging syncline (Pl. 9, section G—G'), which is more open and regular than most Allamoore structures. The Allamoore is, however, separated from the Hazel by a thrust plane, or "surface of movement," as different units overlie the Hazel from place to place, and as there is an intervening slice of Allamoore at the west end of the mountain (beds 1 and 2 of Table 17) which is discordant with the Hazel below and main body of the Allamoore above.

The broader relations of the structure on Tumbledown Mountain are obscured by later high-angle faults and by overlap of the Van Horn sandstone and younger formations. Correlation with structures in the Millican Hills to the west is uncertain. The syncline of Tumbledown Mountain lies on the approximate prolongation of the false syncline of the northern belt of conglomerate and Allamoore formation of the Millican Hills, but it differs from the false

syncline in that neither the Allamoore nor the Hazel which compose it seem to be inverted.

North of the "north edge of the steep dip zone" only red sandstones are visible, to the farthest exposures of Hazel formation on the east face of the Sierra Diablo 10 miles to the north. The sandstones at first lie nearly horizontal, but beyond the Hazel mine they rise northward at angles of 5° to 30°, with the uniform southward dip of the bedding faintly but distinctly visible on the slopes of the Sierra Diablo escarpment.

*Streeruwitz Hills.*—The Allamoore and Hazel formations were not studied in as much detail in the Streeruwitz and Bean Hills as in the Millican Hills, and their structure therefore cannot be as certainly interpreted. However, many of the same structural units described in the Millican Hills seem to exist also in this area.

Immediately north of the trace of the Streeruwitz overthrust in the central Streeruwitz Hills is a southern belt of Allamoore formation about a mile wide which is bordered on the north by massive conglomerate of the Hazel formation (B.5—11.5 to C.5—10.5, Pl. 3), like that north of the southern belt of the Millican Hills near Buck Spring and the Cooper Hill prospects. Both conglomerates and Allamoore dip 45° to 60° south, but the contact between them is discordant, causing units of the Allamoore to be cut out against the conglomerate on the west and conglomerate to be cut out against the Allamoore on the east. It is uncertain whether this is the result of an original angular and erosional unconformity or is due to a "surface of movement" between the two formations, but it has been tentatively mapped as the latter.

Northward in the Streeruwitz Hills the conglomerate is followed by red sandstone which contains several thick interbedded conglomerate members. Dips are northward, flattening to nearly horizontal at the north edge of the hills. One of the conglomerate bands in the northwest part of the hills (A.5—14.5, Pl. 3) encloses a narrow mass of limestone half a mile or more long, partly concealed by Permian and Cretaceous rocks on the west. In 1931, the limestone mass and its flanking conglomerate were interpreted as the projecting crest of a sharp anticline. This interpretation is

retained on the present map, although review of air photographs failed to show any curving of beds over the crest of the anticline, down its assumed plunge to the east. Other interpretations are therefore possible:

(1) There may be a continuous upward sequence in the Hazel formation from the southern belt of Allamoore formation to the north edge of the Streeruwitz Hills. The conglomerate that contains the limestone mass may be a sedimentary lens high in the sequence. The limestone mass itself may be a klippe of a contemporaneous advancing thrust sheet, buried in its own debris, after the fashion of the limestone klippen in the Overton fanglomerate of southern Nevada (Longwell, 1949, p. 935).

(2) A more likely possibility is that the conglomerate and the limestone mass are the inverted nose of a recumbent anticline, in the same manner as the northern limestone belts of the Millican Hills. If this be the case, there must be undetected reversals or thrusts in the sandstone and conglomerate south of it, between it and the southern belt of Allamoore formation. As indicated in the discussion of the Millican Hills, such reversals would be difficult to detect, even after detailed field work.

*Bean Hills.*—The Bean Hills, which lie between the Streeruwitz and Millican Hills, are a depressed part of the structure, as folds plunge toward the hills from the east and west. Many structural elements characteristic of the Millican and Streeruwitz Hills are not visible here and are perhaps buried, whereas novel and probably higher structural elements make their appearance.

In the northeast part of the Streeruwitz Hills along the road north of the Dwecs ranch house (N.5—12.5 to H.5—14.5, Pl. 3) the Allamoore formation lies on the Hazel formation in two broadly folded synclines that plunge eastward toward the Bean Hills. Structurally these bodies of Allamoore differ from the northern belts of Allamoore in the Millican Hills, as they do not lie in recumbent folds on inverted conglomerate of the lower part of the Hazel. They resemble the body of Allamoore on Tumbledown Mountain, as they are a transported mass lying on red sandstones of the upper part of the Hazel, from

which they are separated by a "surface of movement" along which there has been great horizontal displacement.

The synclinal bodies of Allamoore formation in the northeastern Streeruwitz Hills are the western edge of a large body of Allamoore formation which occupies most of the northern Bean Hills, with a width of a mile or more and a length of 5 miles along the strike (H.5—14.5 to Q.5—12.5, Pl. 3; Pl. 9, sections B-B' and C-C'). Along its northern side contorted beds of the Allamoore lie discordantly on gently dipping red sandstones of the Hazel.

North of the large transported mass of Allamoore formation are smaller and more isolated masses. One is in the northern Streeruwitz Hills (E.5—14.5 to G.5—14.5, Pl. 3), another east of the Keene ranch house (L.5—16.5 to O.5—17.5, Pl. 3), and a third on the Sierra Diablo scarp west of the old Circle ranch house (R.5—17.5, Pl. 3). In each, limestones and volcanics of the Allamoore formation are intricately folded and contorted, yet they overlie or adjoin red sandstones of the Hazel formation that dip gently or lie nearly horizontal (Pl. 9, sections A-A', B-B', and C-C'). Presumably these masses were derived by thrusting from the south along a "surface of movement," but the nearest autochthonous body of Allamoore is the southern belt of the formation, next to the Streeruwitz overthrust and  $3\frac{1}{2}$  miles distant.

It may be that the overthrust masses of Allamoore formation in the Bean Hills and to the north are forward parts of the overriding block of the Streeruwitz overthrust, but this is unlikely for a number of reasons: They lack the cataclastic and hydrothermal alteration characteristic of rocks near the Streeruwitz overthrust. There are only two sorts of klippen in the Sierra Diablo foothills—those to the south made up of metarhyolite of the Carrizo Mountain group, which are related to the Streeruwitz overthrust, and those to the north made up of Allamoore formation. If all were part of the same overriding block there should be klippen of rocks intermediate between the metarhyolite and the Allamoore. More probably the masses of Allamoore rode forward on one or more subsidiary thrusts that lay in front of and beneath the Streeruwitz overthrust.

STRUCTURES OF LATE PRE-CAMBRIAN (?)  
ROCKS

The Van Horn sandstone, of probable late pre-Cambrian age, does not share the complex structure of the earlier pre-Cambrian rocks. As indicated in the stratigraphic description, it lies on the deeply eroded surface of the Carrizo Mountain group and the Allamore and Hazel formations and truncates their folds and faults.

*Age of structures.*—The Van Horn itself was tilted and faulted before Early Ordovician (Bliss ?) time, as shown where the contact is exposed in Beach Mountain and the Baylor Mountains (fig. 9). Tilting generally amounts to only a few degrees but is as much as  $20^\circ$  on the north face of Beach Mountain (fig. 9, C) and even greater locally. Faulting is shown on Tumbledown Mountain where the Van Horn was dislocated by the Dallas and Grapevine faults before Bliss (?) time (fig. 9, B). Steep dips in the Van Horn near the Carrizo Spring fault zone farther south (fig. 9, A) suggest that this also may have been dislocated in pre-Bliss (?) time. Details of the faulting will be described under the heading of "High-angle faults and related features" (p. 117).

Over wide areas the Van Horn is overlain by the Hueco limestone, of Permian age, from which it is separated by a marked angular and erosional unconformity. The Hueco truncates the several widely dispersed, basin-like areas in which the Van Horn is now preserved, indicating that fragmentation of the original Van Horn basin of deposition had been accomplished by Hueco time. It is impossible to determine how much of the disturbance of the Van Horn beneath the Hueco was produced during pre-Bliss (?) time, and how much produced during the much younger deformation, immediately before the Hueco. The paleogeologic map (Pl. 19, C) indicates that the basin-like areas in which the Van Horn is preserved below the Hueco conform broadly to the structures of the succeeding pre-Hueco Paleozoic formations, suggesting that they were at least partly formed during the pre-Hueco deformation.

*Tilting and warping.*—The Van Horn sandstone is tilted or broadly warped. The maps (Pls. 1, 2, and 3) generally record

dips of  $5^\circ$  or  $10^\circ$  and some areas of horizontal beds. Locally in the Red Valley the beds are tilted as steeply as  $45^\circ$ . These structures are not original depositional features, as cross-bedding maintains a rather uniform southward inclination, regardless of the dips of the enclosing layers (fig. 8). In the Red Valley, where the formation is most extensively exposed, there appear to be several broad folds, or eastward-plunging noses. In the north part, as near Carrizo Spring (N.5—3.5, Pl. 2), dips are northeastward or eastward; near Threemile Mountain (T.5—15.5, Pl. 1) dips are generally to the southeast; south of Threemile Mountain they are again to the north.

*Jointing.*—Although the Van Horn was faulted as early as pre-Bliss (?) time it is not possible to determine how much of the jointing in the formation dates from that period. The formation is actually less jointed than the thinner-bedded sandstones and limestones which overlie it, probably because its massive sandstones did not respond as readily to fracture. Joints are spaced tens of feet apart, but individual joints are strongly exposed, probably because they are sought out by erosive forces. Fracture patterns of the Van Horn sandstone are prominently visible when its outcrops are observed from an adjacent mountain top, or in air photographs. The joints seem to belong to the same systems as those of the younger rocks (Pl. 10).

PALEOZOIC AND MESOZOIC STRUCTURAL  
FEATURES

The general nature of the Paleozoic and Mesozoic structural features of the Sierra Diablo and Guadalupe Mountains region has been described and illustrated elsewhere (King, 1942, pp. 614–617; 1948a, pp. 104–108), and present remarks will be devoted mainly to local relations.

*Pre-Hueco structures.*—A great deal of the complexity of the map pattern of the pre-Hueco Paleozoic rocks in the Sierra Diablo region results from the unconformity at the base of the Hueco limestone, which causes it to lie, at one place or another, on all the older rocks of the section. The unconformity resulted from folding, faulting, and deep erosion of the underlying

rocks—events that were of late Pennsylvanian age, as rocks of early Pennsylvanian age lie beneath the unconformity in the northern Sierra Diablo.

The pre-Hueco deformation is strikingly demonstrated by the distribution of the Ordovician rocks in the Sierra Diablo foothills. On Beach Mountain, they comprise the Bliss (?) sandstone, El Paso limestone, and Montoya limestone, a mass nearly 2,000 feet thick (Pl. 28, A). Three miles to the northwest, on the southeast corner of the Sierra Diablo, the Hueco limestone lies on red sandstones of the Hazel formation (Pl. 28, B), and all the Ordovician rocks are missing, as well as the Van Horn sandstone beneath them. A paleogeologic map of the surface on which the Hueco was deposited (Pl. 19, C) indicates that Beach Mountain lay near the southwest end of a broad syncline that plunged northeastward, whereas the southeast corner of the Sierra Diablo lay on the crest of the next broad anticline to the northwest.

Abrupt truncation of pre-Hueco formations near some of the west-northwest-trending faults of the area, notably the Sulphur Creek, South Diablo, and Hillside faults, suggests that these were dislocated during the pre-Hueco deformation. These relations will be discussed under the heading of "High-angle faults and related features" (pp. 116–117).

*Pre-Cretaceous structures.*—The Cretaceous, like the Hueco, lies unconformably on the older rocks of the region, but it is questionable whether this was a product of more than gentle warping and accentuation of earlier structures. The Cretaceous lies on the pre-Cambrian in the western part of the Sierra Diablo foothills (Pl. 19, D), but the Hueco of this area lies also on the pre-Cambrian, and the removal of the earlier Paleozoic formations was accomplished in pre-Hueco time. Erosion after the Hueco and before the Cretaceous needed only to remove the few hundred feet of Hueco to reveal the pre-Cambrian.

Sharper flexing and faulting seems to have taken place locally on the north side of this uplifted area near the South Diablo fault zone, as described below under the heading of "High-angle faults and related features" (pp. 115–116).

#### HIGH-ANGLE FAULTS AND RELATED FEATURES

*Introduction.*—The Sierra Diablo foothills are traversed by steeply dipping faults of probable later Cenozoic age, which dislocate all the pre-Cambrian, Paleozoic, and Cretaceous formations. These belong to a system of faults of general west-northwest trend which characterizes much of the interior of the Sierra Diablo. They are one part of the extensive fault complex of northern Trans-Pecos Texas, whose general character has been described and illustrated elsewhere (King, 1948a, pp. 117–118, Pl. 21; 1948b.)

For convenience of reference, the larger and longer faults of the foothill area have been named for adjacent geographic features (King and Knight, 1944). The rocks of the south part of the Sierra Diablo are broken by the Sulphur Creek, Sheep Peak, Circle Ranch, and South Diablo faults (Pl. 2), all of which extend considerable distances northwestward beyond the map area, and one of which, the South Diablo fault, has a length of more than 30 miles. Southeastward, they are at least partly continuous with faults in the north part of Beach Mountain, such as the Grapevine fault, which extend eastward beyond the map area. Along the south edge of the Millican Hills, and extending eastward beyond the map area, is the Carrizo Spring fault zone (Pl. 2); still farther south, along the north side of the Carrizo Mountains, is the Hillside fault (Pl. 1). In the Red Valley between, are many minor faults trending north and south nearly at right angles to these two major faults. In the Streeruwitz Hills to the west (Pl. 3) are many unnamed minor faults, of short length and small displacement.

East of the map area, other faults of general northerly trend outline the Salt Basin—a long intermontane depression deeply filled by Tertiary and Quaternary unconsolidated deposits—and form the base lines of the Sierra Diablo and other ranges. One member of this system crosses the extreme northeast corner of the map area (S.5—18.5 to T.5—14.5, Pl. 2). Relatively recent movements on the faults bordering the Salt Basin are indicated by fresh scarps on the upthrown sides and active alluvial fans on the downthrown. A considerable antecedent history is suggested by the more mature

erosion of the higher parts of the escarpments which border them, and they may have originated farther back in the Cenozoic, perhaps during later Tertiary time.

*Topographic expression of faults.*—Unlike the faults which border the Salt Basin, the faults of the Sierra Diablo foothills and elsewhere in the interior of the Sierra Diablo show no fresh, active fault scarps, and the latest movements on them must antedate the present erosion cycle.

The faults in the southeastern corner of the Sierra Diablo (Pl. 2)—the Sulphur Creek, Sheep Peak, and Circle Ranch faults—mainly involve the Hueco limestone and are followed on their upthrown sides by maturely dissected topographic scarps whose height approximates the fault displacement. In places, as at Cox Mountain north of the map area, the downthrown sides preserve Cretaceous rocks which are less resistant to erosion than the Hueco, and these may have covered much of the Sierra Diablo region at the time of faulting. The scarps in the Hueco limestone were probably created by removal of this poorly resistant superjacent material, and they are resequent fault-line scarps.

The scarp of the South Diablo fault has had a similar history. In the extreme north part of the map area west of the old Circle ranch house (Pl. 3), the fault is bordered on its upthrown side by a scarp of Van Horn sandstone and Hueco limestone 800 feet high, but Cretaceous rocks remain on its downthrown side (Pl. 9, sections B-B' and C-C'; fig. 13) and must have been stripped from the upthrown side. Southeastward, the scarp on the upthrown side is much more deeply dissected. Along Deer Creek at the old Circle ranch house (D.0—

18.0, Pl. 2) it has been cut back nearly 2 miles from the trace of the fault.

Southeast of the Sierra Diablo the Sulphur Creek, Sheep Peak, Circle Ranch, and South Diablo faults pass into a network of low hills carved from red sandstones of the Hazel formation, through which it is difficult to trace them on the ground. On air photographs many of the faults stand out prominently, because they are expressed by alignment of minor valleys and ridges and by low but persistent scarps. They have been drawn on the map (Pl. 2) on this basis. The topographic features along the faults in this area have been produced by crushing, jointing, and fracturing of the red sandstones. Such structures are manifested on the ground by bleaching of the sandstones and the presence of springs. Grapevine and Cowan Springs (P.5—8.5 and M.5—10.5, Pl. 2) lie in the zone of fracturing produced by the Circle Ranch and Grapevine faults.

Topographic discontinuities along the Carrizo Spring and Hillside faults are entirely the result of differential erosion of contrasting rocks on the upthrown and downthrown sides. The Carrizo Spring fault zone in part of its course separates the unlike topography of the deformed Allamoore and Hazel formations in the Millican Hills on the north, from the mesas and hogbacks of tilted massive red rocks of the Van Horn sandstone in the Red Valley on the south. On the northern, or downthrown, side of the Hillside fault is a wall-like scarp as much as 500 feet high, formed of Hueco limestone and Cretaceous rocks, whereas the upthrown rocks of the Carrizo Mountain group on the south are worn down to rugged hills. The

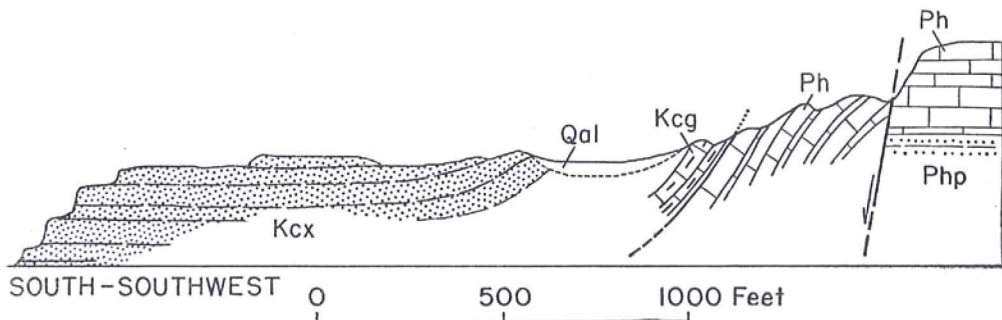


FIG. 13. Field sketch of South Diablo fault  $3\frac{1}{2}$  miles northwest of Keene ranch house (north of Pl. 3), where the surface rocks are of Permian and Cretaceous age. Ph = Hueco limestone, with Php, Powwow member, at base; Kcg = Campo Grande limestone; Kcx = Cox sandstone; Qal = alluvium.

scarp on the Hillside fault is an obsequent fault-line scarp.

South of the Sierra Diablo foothills is the intermontane basin of Eagle Flat which, like the Salt Basin to the east, is deeply filled with unconsolidated bolson deposits. Unlike the Salt Basin, it is not bordered by an even base line or topographic scarp. Alluvium extends finger-like for many miles northward into the frayed bed-rock foothills. Along the south base of the high mesa northwest of Eagle Flat section house are low ridges and knobs of down-faulted Hueco limestone, tilted steeply towards Eagle Flat (A.5—7.5, G.5—5.5, Pl. 3). These may be part of a general line of faulting which separates alluvium-covered pediments of the foothills to the north from thick bolson deposits of the structural basin of Eagle Flat to the south. The fault line may continue eastward from the section house, south of widely spaced outliers of foothill rocks and a little north of the Texas and Pacific Railroad. If such faults exist they are relatively ancient features whose scarps have now been so eroded and masked by alluvium that they can no longer be traced.

*Fault pattern.*—So far as the major faults can be traced on the ground and in air photographs, they run nearly straight, or diverge in gentle curves. They are spaced a mile or two apart and separate blocks that have been differentially raised or lowered, and tilted. Within some of the blocks are minor faults of shorter length and less displacement than the major faults, which either branch from them or lie parallel with them.

Numerous minor faults branch north-eastward and southeastward from the South Diablo fault west of the old Circle ranch house (L.5—18.5 to S.5—17.5, Pl. 3). The Circle Ranch fault, the next to the northeast, is actually part of a zone, and the fault so designated on the map (E.5—17.5 to G.5—15.5, Pl. 2) is probably not continuous through the whole length of the zone, within and northwest of the map area. On the escarpment west of the old Circle ranch house (U.5—18.5, Pl. 3, to A.5—18.5, C.5—18.5, Pl. 2) the zone is expressed by four or five minor breaks in the Hueco limestone, with maximum displacements of less than 100 feet.

The general course of the faults in the Sierra Diablo foothills, and elsewhere in the interior of the Sierra Diablo, is west-northwest. This must be a fundamental trend, or "grain," as the dominant joints of the area trend in the same direction (Pl. 10) and show no apparent relation to the larger and more recent northerly faults that define the eastern edge of the Sierra Diablo and its adjacent ranges.

Near Beach Mountain in the east part of the area, this trend is modified. The Grapevine fault, for example, has the characteristic west-northwest trend to the west but curves into an east-northeast course to the east (M.5—10.5 to T.5—8.5, Pl. 2) and so continues beyond the map area. The Carrizo Spring and adjacent faults farther south also pursue an east-northeast course. That the modified trend reflects a change in the actual "grain" of the rocks is shown by the fact that major joints of the area also trend east-northeast (Pl. 9). In the north part of the same area there is also a suggestion of an opposite tendency. The Dallas fault, and others east and west of it (O.5—10.5 to S.5—10.5, Pl. 2, and east of the map area), trend north-northwest but apparently curve in this direction into the west-northwest system. The reason for these departures from the normal "grain" of the Sierra Diablo foothills is not evident.

*Fault habit.*—All the major faults of the area, with the notable exception of the Hillside fault, are downthrown to the south, causing the formations to descend southward in steps from the heights of the Sierra Diablo. Within the Sierra Diablo, the step-like descent is somewhat modified by gentle northward tilting of the blocks between the faults. Displacements on the faults are generally no more than a few hundred feet. One of the largest, the South Diablo fault, is downthrown about 800 feet to the south in the area 4 miles west of the old Circle ranch house, but the downthrow decreases to 350 feet 2 miles south-southeast of the ranch house.

The Hillside fault near the Gifford-Hill rock crusher appears to be downthrown as much as 1,000 feet to the north, so that Cox sandstone, Campo Grande limestone, Hueco limestone, and Van Horn sandstone of the downthrown side lie against rocks of the Carrizo Mountain group on the up-

thrown side. About half a mile east of the rock crusher, however, Flawn has discovered a small patch of Powwow member of the Hueco formation on the south side of the fault, lying on Carrizo Mountain group. This is either part of a wedge in a broad fault zone, or the post-Cretaceous movements on the fault are relatively small, the greater part of the displacement having taken place in pre-Hueco time. Farther east on the Hillside fault, Van Horn sandstone is exposed on both sides, and the displacement is probably less than 600 feet.

On some of the faults in the interior of the Sierra Diablo the rocks on the downthrown side are dragged up steeply against the plane, whereas the adjacent rocks on the upthrown side are little disturbed. Within the map area, drag was observed on the Sheep Peak fault  $2\frac{1}{4}$  miles east of the old Circle ranch house (I.5—17.5, Pl. 2), on the Circle Ranch fault 1 mile south-southeast of the old Circle ranch house (E.5—16.5, Pl. 2), and on the South Diablo fault  $1\frac{3}{4}$  miles northeast of the Keene ranch house (M.5—18.5, Pl. 3). Similar drag on the South Diablo fault continues beyond the map area to the northwest (fig. 13). On the Circle Ranch fault, the southward lowering of the Hueco limestone caused by drag is actually much greater than the displacement caused by breakage on the fault itself.

The planes of the faults, where visible, stand nearly vertical or dip steeply toward the downthrow, and they are thus normal faults. Steep dips toward the downthrow have been observed on the Sheep Peak fault south of Sheep Peak (north of Pl. 2), on the South Diablo fault north of the Keene ranch house (north of Pl. 3), and on the Hillside fault east of the Gifford-Hill rock crusher (H.5—16.5, Pl. 1). Steep or vertical dips on the Grapevine, Carrizo Spring, and related faults may be inferred by the manner in which they cross the steep western scarp of Beach Mountain (R.5—7.5 and R.5—4.5, Pl. 2). The only exception is a fault on the apparent southeastward prolongation of the Sheep Peak fault; where this is exposed on the Sierra Diablo escarpment  $1\frac{1}{4}$  miles northwest of the Hazel mine (M.5—14.5, Pl. 2) its plane dips  $60^\circ$  toward the northern, or upthrown, side (fig. 14, B).

*Age of faulting.*—The large, obvious displacements on the faults in the Sierra Diablo foothills took place in post-Cretaceous time, as Cretaceous formations are present in places on the downthrown sides. The deep erosion of their scarps and the presence in places of obsequent fault-line scarps indicate that they are by no means recent features. Their movements thus antedated the latest movements of the faults along the edges of the Salt Basin, although they may be nearly contemporaneous with the initial movements of these faults and hence perhaps of late Tertiary age.

There is, however, evidence that the faults of the Sierra Diablo foothills possessed a considerable antecedent history and that at least some of them were displaced in Mesozoic, Paleozoic, or even pre-Cambrian time. On one fault, the Dallas, faulted rocks are overlain unconformably by younger formations which are not faulted, but in most places earlier movements are suggested merely by stratigraphic anomalies near the faults. These anomalies might be coincidental and might in part have resulted from intersection by the younger faults of earlier and different structural features, but the cumulative effect of the anomalies is such as to suggest that both younger and older features had common origins.

Evidence of earlier movements on or near the faults of the Sierra Diablo foothills is as follows:

- (1) Along the South Diablo fault, pre-Cretaceous and post-Permian structures occur west of the old Circle ranch house. Relations are strikingly displayed  $3\frac{1}{2}$  miles to the west (R.5—15.5 to R.5—18.5, Pl. 3; Pl. 9, section C-C'), where the scarp on the north is formed by 900 feet of Van Horn sandstone and overlying Hueco limestone, whereas to the south Campo Grande limestone forms a low mesa and lies directly on red sandstones of the Hazel formation. Although the latest displacement on the fault is downward to the south, earlier down-faulting or downflexing to the north is indicated. The earlier structure did not, however, exactly coincide with the present fault in all places, as  $2\frac{1}{2}$  miles farther west (M.5—18.5, Pl. 3; Pl. 9, section B-B') the Hueco and Van Horn extend a short distance south of it.



A similar anomaly occurs in the southern Streeruwitz Hills, in the butte north of the Texas and Pacific Railroad. On its north side, the Hueco limestone is broken by a fault trending east and west, on the northern or downthrown side of which,  $2\frac{1}{4}$  miles northwest of Eagle Flat section house (D.5—7.5, Pl. 3), is a small remnant patch of basal conglomerate of the Campo Grande limestone. The Hueco beneath the remnant is less than 150 feet thick, yet it is more than 350 feet thick immediately south of the fault; the fault must have been downthrown to the south in pre-Cretaceous time.

(2) Pre-Hueco, and probably late Pennsylvanian, structures occur near many of the faults of the area.

Where the Sulphur Creek fault crosses the Sierra Diablo escarpment 1 mile north of the Hazel mine (N.5—15.5, Pl. 2) the Hueco limestone of the northern or upthrown side is underlain by 750 feet or more of Van Horn sandstone, but on the downthrown side it lies on red sandstones of the Hazel formation (fig. 14, A; Pl. 9, section F-F'; Richardson, 1914, section E-E'). The Van Horn is folded into an east-plunging syncline, on the south flank of

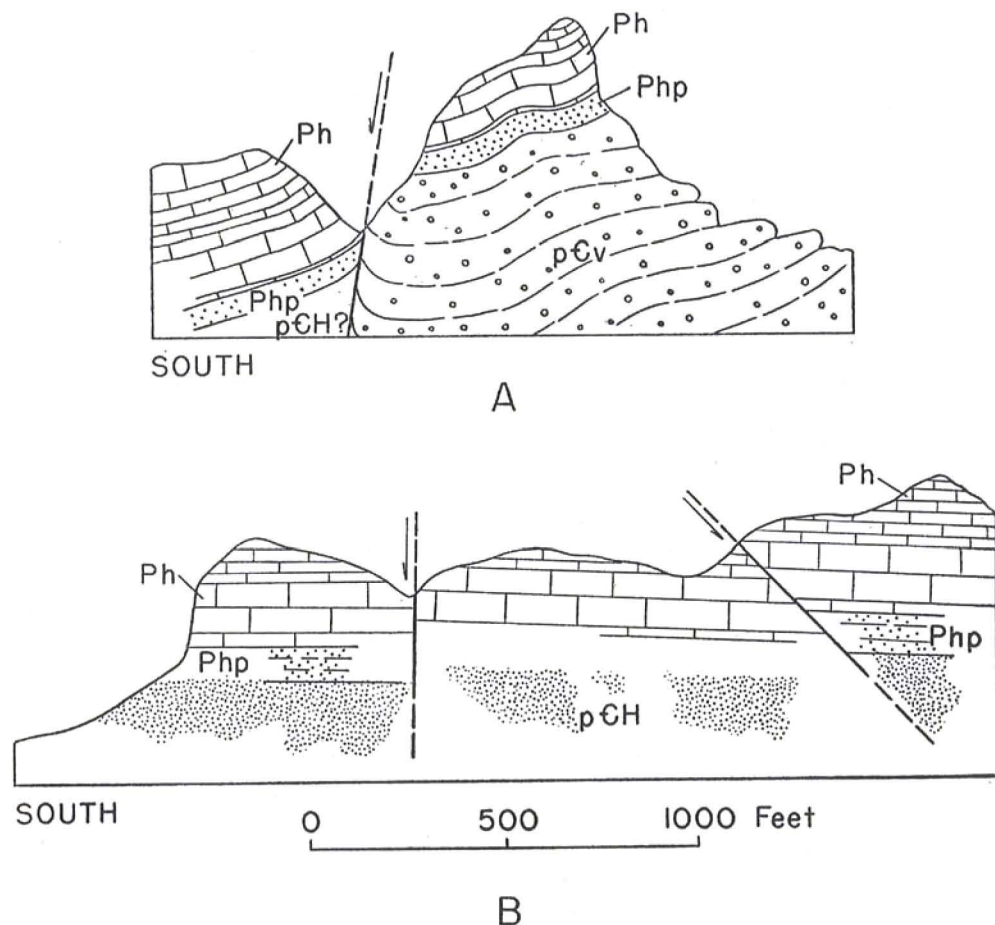


FIG. 14. Field sketches of Sulphur Creek and Sheep Peak faults. A, Sulphur Creek fault on promontory of Sierra Diablo  $1\frac{1}{2}$  miles north of Hazel mine (O.5—16.5, Pl. 2); note apparent absence of Van Horn sandstone beneath Hueco limestone on downthrown side, suggesting an opposite downthrow on fault in pre-Hueco time. B, Sheep Peak fault and a minor fault to south on escarpment of Sierra Diablo  $1\frac{1}{4}$  miles northwest of Hazel mine (M.5—14.5, Pl. 2); note north dip of Sheep Peak fault, a departure from usual high angle of dip of faults in this area. pCH = red sandstone of Hazel formation; pCv = Van Horn sandstone; Ph = Hueco limestone, with Php, Powwow member, at base.



which, close to the fault, the beds are steeply upturned. Locally at least, the south flank of the syncline appears to have been displaced by movements on the Sulphur Creek fault which were the opposite of the latest movements. Eastward, however, the paleogeologic map (Pl. 19, C) indicates that the syncline diverges northward from the course of the Sulphur Creek fault.

Pre-Hueco movements may have taken place along the South Diablo fault in the same area as the pre-Cretaceous movements described above, as the Hueco on the escarpment to the north lies on Van Horn sandstone, yet some miles to the south and southwest lies on the Hazel and Allamoore formations. There is no clear evidence to indicate that this structure was any more than a broad flexure.

Along the western part of the Hillside fault, the Powwow member at the base of the Hueco limestone on the northern or downthrown side contains large quantities of coarse angular fragments of metarhyolite of the Carrizo Mountain group. It does not lie on the metarhyolite but on Van Horn sandstone, although it is faulted against the metarhyolite on the south. The fragments in the Powwow member indicate that the metarhyolite projected as a scarp along the Hillside fault during early Hueco time and was perhaps raised by faulting immediately before.

The local pre-Hueco structure on the Hillside fault appears to be part of a much broader feature (Pl. 19, C). To the north, the Hueco lies on the Van Horn sandstone and not far away on the Ordovician. To the south, in the Carrizo, Wylie, Eagle, and Van Horn Mountains it lies, with a few exceptions, on the Carrizo Mountain group, indicating a general uplift of this southern area in pre-Hueco time. The truncation of the earlier formations south of the Hillside fault was not complete, however, as Flawn has found a few thin remnants of Van Horn sandstone in the eastern part of the Carrizo Mountains.

(3) Faulting before Bliss (?) and after Van Horn time is clearly shown on the Dallas and Grapevine faults near Tumbledown Mountain (S.5—9.5 and Q.5—7.5, Pl. 2). The Dallas fault, which trends north-northwest, drops Van Horn sandstone down on the east against Allamoore formation on the west, with a displacement

of at least 500 feet, yet when the fault is traced southward it passes beneath Bliss (?) sandstone which is not displaced (fig. 15). Slight recurrent movements are suggested by strong joints along the same trend which extend upward into the Bliss (?) and El Paso; during a visit in 1951 the author saw what appeared to be a few feet of displacement in the Bliss (?) near the workings of the Dallas prospect north of the point of overlap. The Grapevine fault on the south side of Tumbledown Mountain, which trends nearly east-west, was displaced in a like manner in pre-Bliss (?) time, so that the Bliss (?) lies on Van Horn sandstone on the south and Allamoore formation on the north. Here, however, the earlier faulting has been obscured by later displacements in the same direction.

Farther south on the west face of Beach Mountain, near the Carrizo Spring fault, the Van Horn is locally steeply upturned and truncated by the Bliss (?) (fig. 9, A), and similar steep dips in the Van Horn, but without a cover of Bliss (?), occur near the fault farther west. These structures suggest that movement may have taken place during pre-Bliss (?) time on the Carrizo Spring fault also.

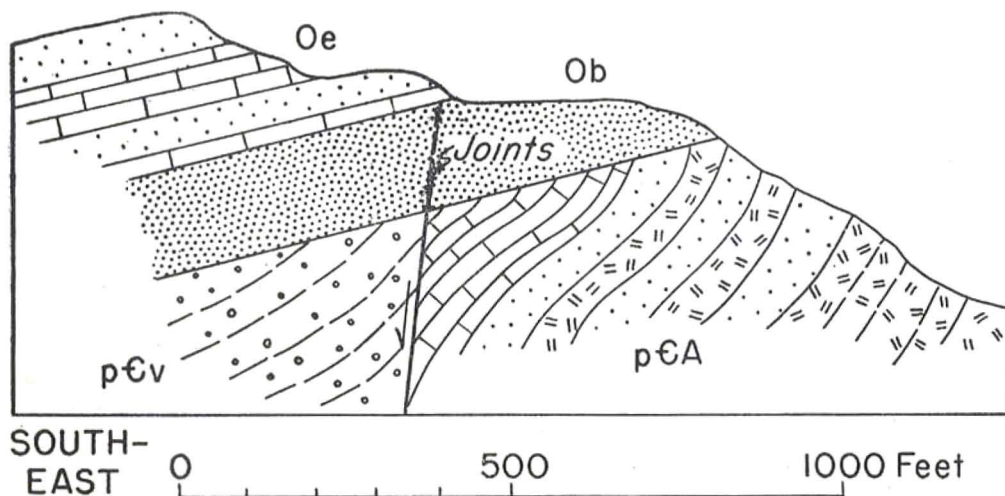
(4) Besides the early structures just described, which are of post-Van Horn and pre-Bliss (?) age, there are others of apparent early date near the high-angle faults in the pre-Cambrian area whose age is less certain.

Along the Grapevine fault half a mile northeast of the Blackshaft mine (M.5—9.5, Pl. 2), the "north edge of the steep dip zone" in the Hazel formation is offset northwestward on the north side by about 2,200 feet, so that for a short distance vertical beds on the north lie against horizontal beds on the south (Pl. 9, section F-F'). This could not have been produced by nearly vertical downdrop on the south, such as has displaced the Van Horn and younger formations on the same fault farther east, but must have resulted from a sinistral<sup>18</sup> strike-slip, or transcurrent, movement.

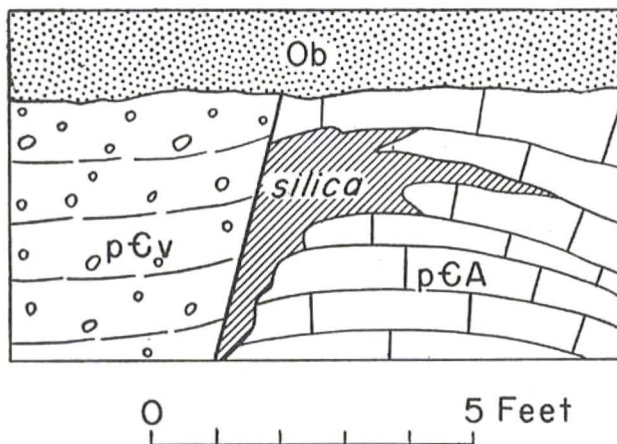
<sup>18</sup> As pointed out by E. M. Anderson (1942, p. 55) "from whichever side the observer views a fault-plane, motion on the distant side will appear in the one class to be towards the right, and in the other class towards the left. \*\*\*\* The two classes of fault planes may well be termed 'dextral' and 'sinistral'."

Other west-northwest-trending faults in the pre-Cambrian area seem to show evidence of transcurrent movement. A minor fault a mile northeast of the Grapevine fault also offsets the "north edge of the steep dip zone" but by a smaller amount

and in a dextral direction. In the southern Millican Hills two faults in the Allamoore formation on the western prolongation of the Carrizo Spring fault zone (A.5—5.5 and G.5—3.5, Pl. 2) involve highly folded beds in such a manner that they cannot



A



B

FIG. 15. Field sketches of Dallas fault in outcrops south of Dallas prospect (S.5—8.5, Pl. 2), where it is overlain unconformably by the Bliss (?) sandstone. A, General view of locality; note joints without displacement which continue up into Bliss (?) sandstone. B, detailed view of contact. pCA = Allamoore formation; pCv = Van Horn sandstone; Ob = Bliss (?) sandstone; Oe = El Paso limestone.

have formed by mere vertical displacement. Similar faults are also indicated on the map in the Bean and Streeruwitz Hills (K.5—12.5 and F.5—10.5, Pl. 3), but their relations are less clear.

The transcurrent movements on the west-northwest-trending faults may have taken place during the post-Van Horn, pre-Bliss (?) dislocations just described. This seems to be hardly likely, as large-scale transcurrent movements are produced during times of orogeny by compressive forces. The Van Horn is a post-orogenic deposit which has been tilted and block-faulted but apparently not strongly compressed. It is therefore possible that the transcurrent movements took place before Van Horn time, in the waning stages of the post-Hazel orogeny.

We have thus traced the history of the west-northwest-trending faults of the Sierra Diablo foothills well back into pre-Cambrian time. The ancient origin of these features would seem to account for the west-northwest "grain" which is possessed by all the rocks of the area. The long history of this "grain" should give pause to anyone who should attempt to interpret the mechanism of the faulting in the area in terms of pattern alone. Stresses at an early period created the pattern, yet the pattern was renewed in younger rocks during successive periods, under the influence of quite different stresses.

*Joints.*—The writer has made systematic observations on joints in the Sierra Diablo and southern Guadalupe Mountains, some of the results of which have already been published (King and Knight, 1944, inset map; King, 1948a, pp. 114–117, 119–120, 123–124, Pls. 20 and 21). The Sierra Diablo foothills were included in the area thus studied, and details of the results obtained here are shown on Plate 10.

All the rocks of the Sierra Diablo foothills are cut by joints. Those in the highly deformed Carrizo Mountain group, Allamore formation, and Hazel formation trend in diverse directions, dip at all angles from horizontal to vertical, and are so complex that it was not considered worth while to observe or analyse them. Those in the Van Horn and younger formations stand about vertically and are arranged in systematic patterns that are susceptible of measurement and study. Similar joints also occur in the gently dipping part of the

Hazel formation, along with other joints inclined at lower angles. The steeply dipping joints in this part of the Hazel formation were also included in the study.

Most of the joints in all the rocks are straight and smooth, even where they cut through irregularly bedded rocks, or alternations of hard and soft layers. At the surface, some of the joints are open fissures, but these have probably been widened by weathering, and most of them are probably tight and narrow at depth. Single joints commonly extend across the entire breadth of any exposure, and where several sets are present they commonly cross one another without deflection. Spacing of the joints depends on the nature of the rock; they are widely spaced in massive rocks, such as the Van Horn sandstone, and are closely spaced in thin-bedded brittle rocks, such as the Ordovician and Permian limestones.

Nearly all the joints dip steeply or are nearly vertical. During the course of the work, conspicuous deviations of the joints from vertical were conscientiously noted, but it was found that such deviations were so slight and so uncommon that they could well be ignored. The most significant feature of the joints appeared to be their trend in horizontal plan, and on this the largest number of observations was made. In the Sierra Diablo foothills, trends of 1,265 joints were measured, at 156 stations.

These observations are shown on Plate 10, where the trends of the joints are summarized by two methods:

(1) Joints at individual stations are shown by lines of various lengths, radiating from the point of observation. Records made at the stations commonly consisted of measurements at two or more points in the immediate vicinity, at each of which all joints were recorded, and notations made on the prominence of each; observations at a station may include as many as 20 individual measurements. It is not possible to show all these measurements on the map; the joints at each station have accordingly been summarized, and the most abundant five or six have been plotted, with the lengths of the lines indicating relative prominence of each. On the compilation sheet from which Plate 10 was prepared, the joints were further differentiated according to the formations in which they occur, in an effort to discover whether there

were any significant differences in pattern in rocks of successive ages. So little discernible difference was found that it did not appear to be worth while to include this differentiation on the final map. The user of the map can observe to some extent the joint patterns in rocks of different ages by noting the formations in which the respective stations are located.

(2) Joints in different units are further summarized statistically in the form of rosettes, which are overprinted at various places on the map. Units are differentiated by age and locality. Separate statistical summaries were made for the Hazel formation, the Ordovician rocks, the Hueco limestone, and the Cretaceous rocks. The occurrence of joints in the different stratigraphic units was further subdivided according to locality. Thus, different rosettes were prepared for the Hueco limestone in the southeast part of the Sierra Diablo, the Streeruwitz Hills, and the ridges south of the Red Valley.

Each rosette shows the relative abundance and prominence of the different joints measured in each unit. Tallies were made (a) of the number of joints observed in each  $5^\circ$  of arc and (b) of the relative prominence of the joints observed. The two tallies were combined, giving greater weight to the first factor than the second; actually, the two corresponded closely, for the most abundant joints also proved to be the most prominent joints. The combined tallies were converted into percentages of joints in each  $5^\circ$  of arc, in terms of the total number recorded in the unit. As originally worked out, wide variations were found between percentages at some of the adjacent points on the arcs, which apparently resulted from a personal equation in making the observations. The percentages were therefore evened by means of moving averages. Each figure used in plotting the rosettes is thus the average of the original percentage for the direction shown and the percentage of the two directions lying  $5^\circ$  on each side of it.

Observations on the trends of the joints amplify and fill in the "grain" of the rocks which is otherwise partly suggested by the fault pattern. Like the faults, the dominant joints trend west-northwest, both near the faults and in areas where few or no faults are present. In the eastern part of the area, where the faults change their trend to east-

west or east-northeast, the dominant joints likewise change their direction. In the western part of the Red Valley, where minor faults trending north and south are present, joints of similar trend are also prominent.

After the dominant west-northwest set, the next most abundant is a set which trends nearly at right angles, or north-northeast. Ordinarily this set is not followed by any faults. Of the remaining joints, the rosettes indicate that the greater number commonly lie about midway in the angles between the two dominant sets. The characteristic joint pattern of the area thus consists of two dominant joint sets at nearly right angles and two subordinate sets which bisect the angle between them.

A similar pattern occurs in the southern Guadalupe Mountains where, however, the dominant joint set trends north-northwest rather than west-northwest. In the southern Guadalupe Mountains much of the jointing seems to have originated during the Cenozoic uplift which produced the present mountains, and the joint pattern seems to be related to the strains thereby set up (King, 1948a, pp. 123-124).

The origin of the joint pattern in the Sierra Diablo foothills is less obvious. Patterns in rocks of different ages, which are separated by significant times of disturbance or orogeny, seem to be essentially alike. This may be because the dominant pattern in all the rocks is less closely related to the earlier orogenies than it is to the latest upheaval of the area. This does not seem likely, because the latest upheaval was primarily along faults of the northerly-trending system, with which the joints are not parallel. Moreover, evidence along the faults of the foothill area indicates that the dominant west-northwest "grain" of the rocks originated early in their history, and perhaps as early as late pre-Cambrian time. It would thus appear that joints related to this "grain," and perhaps others, were formed long before the latest upheaval of the area and were renewed in successive younger rocks as they were laid down unconformably on the older.

The joints may be related to regional structure. The map (Pl. 19, B) showing contours on the top of the pre-Cambrian rocks indicates that in a belt extending west-northwest or northwest through the Van Horn area these rocks lie much higher than on either side. The continuity of this

high-standing belt is much disordered by the northerly-trending faults which cross it, but it may have been a single long, broad uplift or positive area before the faulting and during Mesozoic and Paleozoic time. It is possible that the dominant west-northwest-trending joints and faults of the Sierra Diablo foothills were controlled by this uplift and were formed parallel to its axis during its several periods of movement. If this interpretation is correct, the joints and faults have the same mechanical relation to the early west-northwest-trending pre-Cambrian uplift of the Van Horn area as do those of the Guadalupe Mountains to its later north-northwest-trending uplift.

*Fractures.*—The geologic maps (Pls. 2 and 3) differentiate, besides the faults, another class of structures that are designated as "fractures." These have been traced largely from air photographs where they are expressed in the same manner as the faults—by alignment of minor valleys and ridges. They differ from faults in that they show no clear evidence of displacement. They may be faults of small displacement or strong lines of jointing on which there has been no displacement.

The fractures as mapped are therefore probably heterogeneous, but they include one well-characterized group of structures which seem to be different from any others in the area—the "fractures of Hazel type."

Fractures of Hazel type are vertical mineralized fractures or fissure veins in which the ore bodies of the Hazel mine and those of similar mines and prospects are located (Pl. 12 and fig. 19). They cut gently dipping red sandstones of the Hazel formation not far from the bases of the escarpments of the Sierra Diablo. In plan, the fractures are clustered in zones, in which they lie parallel or en echelon, or diverge from each other at acute angles; in places, minor fractures branch off at wider angles. Surface outcrops of the fractures are commonly indicated by bleaching of the red sandstones immediately adjacent. In vertical section they are zones a few feet to 40 feet wide of bleached, brecciated, and sliced country rock, interlaced with a gangue of barite, calcite, and quartz, which contains sulfides of copper, silver, and other metals.

Areal mapping discloses that fractures of Hazel type form two zones—one a system of en echelon fractures  $3\frac{1}{2}$  miles in

length, trending nearly east and west, extending from the Mohawk mine to the Hazel mine (H.5—12.5 to O.5—13.5, Pl. 2), and the other a set of similar fractures about 2 miles in length, trending north-northeast, on which the Pecos mine and Eureka prospect are located (north of Pl. 2; see fig. 19 and map of King and Knight, 1944).

The relation of fractures of Hazel type to the high-angle faults and joints of the same area is uncertain. They run across the dominant west-northwest "grain" of the country rock, apparently without offsetting it or being offset by it, yet the dominant "grain" seems to have originated in late pre-Cambrian time and to have been subjected to intermittent movement until the late Tertiary. Thus, one of the Hazel fractures is crossed without offset by a west-northwest-trending fault near the Marvin-Judson prospect (L.5—12.5, Pl. 2), and another is crossed without offset by the west-northwest-trending Cox Mountain fault near the Pecos mine. First movements on the west-northwest "grain" produced transcurrent faults with considerable strike-slip displacement, and the fractures of Hazel type must be younger than these movements. Later movements on faults of the west-northwest "grain" were dominantly vertical and might have displaced the vertical fractures of Hazel type without offsetting them laterally.

In the present discussion, the fractures of Hazel type are treated as structural features and not as ore bodies. The mineral deposits which they contain are described in the section on "Economic Geology." A distinction must be made between the time of formation of the fractures and the time of emplacement of the mineral deposits; the deposits were introduced into zones of weakness already formed and are younger—perhaps much younger.

The faults and joints of the west-northwest "grain" must be different from the fractures of Hazel type, as few of them show any significant mineralization. Evidently they were less susceptible to the circulation of mineralizing solutions. Possibly they are tighter, straighter, cleaner breaks than the fractures of Hazel type and were accompanied by less slicing and brecciation of the country rock.

# PUMP STATION HILLS

Philip B. King and Peter T. Flawn

## INTRODUCTION

Rhyolite of probable pre-Cambrian age is exposed in an area of about 12 square miles in the Pump Station Hills, near the center of the Diablo Plateau, 55 miles northwest of Van Horn and 40 miles north of Sierra Blanca (Darton, Stephenson, and Gardner, 1937; King, 1948a). Hueco Pump Station on the Pasotex pipe-line lies near the center of the hills, and they are crossed by the county road leading north from Sierra Blanca.

The pre-Cambrian nature of the rocks of this area was first recognized by N. H. Darton, during his reconnaissance work for the geologic map of Texas. Previously published geologic maps had grouped the igneous rocks of the Pump Station Hills with the near-by intrusives of Tertiary age (Richardson, 1904; Beede, 1920).

## RELATIONS TO SURROUNDING ROCKS

The rhyolite projects in low rounded hills, on which there are no prominent ledges. Much of the surface of the hills is masked by colluvium made up of rhyolite fragments, and the intervening and surrounding valleys are covered by alluvium. Outcrops are insufficient to determine decisively the relation of the rhyolite to the surrounding sedimentary rocks. About 2 miles to the south on the Sierra Blanca road are indistinct ledges of Cretaceous limestone and sandstone, and the same rock forms low hills south of the pipe-line about a mile east of the pump station. Several miles to the north and east are outcrops of Permian limestone. These rocks have not been seen in contact with the rhyolite and are separated from it by areas of alluvium.

The rhyolite hills are very different in appearance from the jagged buttes and peaks formed by the near-by Tertiary alkalalic intrusives, and they have the appearance of a long-eroded surface, perhaps the exhumed summit of a pre-Cambrian ridge. Structurally this may be related to Paleozoic deformation, as it lies at the upper end of a considerable flexure in the Permian rocks which extends southeast into

the northern Sierra Diablo where it has been called the Babb flexure. Deep drilling in this part of the Diablo Plateau would undoubtedly bring to light many interesting features, but at present the wells that have been drilled are spaced many miles apart, and subsurface data are scanty. A well drilled 7 miles northeast (A. and E. Jones No. 1 E. C. Mowry, T. D. 3,840 feet) encountered Devonian, thick Silurian, Montoya, and topmost El Paso.

## LITHOLOGY

The rock is a dark red rhyolite porphyry. Phenocrysts of pink feldspar and clear glassy quartz occur in an irresolvable maroon ground-mass. Phenocrysts range in size from 2 mm. to 1 cm. and range in amount from less than 5 to 40 percent of the rock. Dark green rocks containing red feldspar phenocrysts in an aphanitic green ground-mass are locally found within the outcrop. In one place this green rock crops out along a linear fissure zone. It is probably an altered phase of the normal red rock. The rocks are well jointed but show no discernible attitude or structure.

The rhyolite is very similar to the rhyolite found as cobbles in the Van Horn sandstone (Table 21, mode IV) and to

Table 21. Estimated modes of pre-Cambrian rhyolite near Hueco Pump Station.

	I	II	III	IV
Ground-mass	80	80	82	75
Quartz			10	10
Albite			7	14
Potassium feldspar	15	15		
Apatite	tr			tr
Zircon			tr	tr
Opaque	1	1	1	1
Chlorite	1	4		
Sericite	tr			
Sphene	tr			
Calcite	2		tr	
Totals	100	100	100	100

- I, Near Hueco Pump Station west of road.
- II, Near Hueco Pump Station west of road.
- III, Near Hueco Pump Station east of road.
- IV, Cobble from Van Horn sandstone, east edge Carrizo Mountains.

the cataclastically altered rhyolite of the Carrizo Mountain group in the northwest part of the Carrizo Mountains.

*Petrography.*—In thin section the rhyolite shows altered phenocrysts of feldspar in a ground-mass of altered feldspar microlites (maximum size 0.04 mm.). Sericite and chlorite are the principal alteration products. Calcite replaces feldspar to a limited extent. Quartz comprises as much as 10 percent of the rock but is not present in all

samples. Magnetite, apatite, and sphene are present in minor amounts.

The altered character of the rock makes it difficult to determine the feldspar. The greater part of the feldspar in the phenocrysts is albite that shows an erratic and disrupted "chessboard" twinning, suggesting a replacement of microcline by albite. The low index ( $N_x$ ) is about 1.530. The feldspar constituting the ground-mass is too altered to give a satisfactory determination. Perthitic feldspar was observed in one slide. Most of the rock is albite rhyolite.

## GENERAL PROBLEMS OF PRE-CAMBRIAN ROCKS

### STRUCTURAL AND STRATIGRAPHIC PROBLEMS

Philip B. King

#### STRUCTURAL HISTORY

*Introduction.*—In chapters which have gone before, the structural history of the pre-Cambrian rocks has been set forth in piecemeal fashion under discussion of the different rock units; part has been summarized in Table 20 (p. 101). Under the present heading the structural history in the different areas will be reviewed, and an attempt will be made to coordinate them into a single sequence.

*Structural history of south part of Van Horn pre-Cambrian area.*—Flawn's study of the Carrizo Mountain group in the southern part of the Van Horn pre-Cambrian area indicates the following sedimentary, metamorphic, and structural history (Table 22, p. 126).

*Structural history of north part of Van Horn pre-Cambrian area.*—King's study of the Sierra Diablo foothills in the northern part of the Van Horn pre-Cambrian area indicates the following sedimentary, metamorphic, and structural history (Table 23, p. 127).

*Structural history of pre-Cambrian rocks northwest of Van Horn area.*—Northwest of the Van Horn area in Trans-Pecos Texas, pre-Cambrian rocks crop out in the Pump Station Hills, the south end of the Hueco Mountains, and in the Franklin Mountains (fig. 1). These are considerably different from those of the Van Horn area, and outcrops are so small and scattered that it is difficult to make out a structural history. The sequence in the principal area of the Franklin Mountains is, moreover, in need of modern detailed study, which might alter published conclusions. The following very tentative sequence (Table 24, p. 128) is compiled from Richardson (1909, pp. 3, 6-7) and King (1935, pp. 226-227) and from notes given to King by N. H. Darton in 1930.

*Correlation of structural events in the different areas.*—Correlation of events between the three different areas is beset with uncertainties. Few connections can be traced between them, because the southern and northern parts of the Van Horn

area are separated by the Streeruwitz overthrust, and the two parts of the Van Horn area are in turn separated from the pre-Cambrian areas to the northwest by a cover of younger rocks. There are, moreover, only slight physical resemblances between the three sequences, yet the physical features are the only ones on which a correlation can now be based. A tentative correlation between the structural histories of the different areas based on such physical features is given in Table 25 (p. 129).

Reference to Table 25 indicates that the last major structural event in the south part of the Van Horn area was emplacement of the Streeruwitz overthrust, and that this can be dated in the north part of the Van Horn area as of post-Hazel and pre-Van Horn age. Cataclastic and retrogressive metamorphism of the rocks of the Carrizo Mountain group took place at this time, and detrital fragments of rocks thus altered appear in the succeeding Van Horn sandstone.

Lower in the columns, another possible comparison can be made between the rhyolite intrusives of the south part of the Van Horn area and the rhyolite eruptives and possible intrusives northwest of the Van Horn area. Flawn has pointed out a petrographic resemblance between rhyolites of the Carrizo Mountain group in the Carrizo Mountains and rhyolites in the Pump Station Hills. The rhyolites to the northwest are older than the Van Horn sandstone, as it contains their detrital fragments. Tenuous evidence suggests that they may also be older than the Hazel formation, as the Hazel contains detrital fragments of red granite, and red granite intrudes the rhyolite of the Franklin Mountains.<sup>19</sup> The Hazel is a non-igneous forma-

<sup>19</sup> Richardson (1909, p. 7) classed the granite of the Franklin Mountains as "post-Carboniferous." King, however, observed the Bliss lying unconformably on red granite at the head of McKilligan Canyon. According to N. H. Darton (notes of 1930) there appear to be two granites in the Franklin Mountains: a red granite of pre-Cambrian age, presumably younger than the rhyolite and Lanoria quartzite, and a granite porphyry of late Cretaceous or Tertiary age, which invades the Paleozoic as well as the pre-Cambrian rocks.



Table 22. Sedimentary, metamorphic, and structural history of south part of Van Horn pre-Cambrian area, by Peter T. Flawn.

Sedimentation	Igneous activity	Metamorphism	Deformation
Van Horn sandstone (local) Unconformity			
No sedimentary record	Quartz veins during late stages of cataclasis, and after.	Late stages of cataclastic metamorphism; diorite altered to amphibolite.	Climax of movements on Streeruwitz overthrust.
	Intrusion of diorite in sills and irregular bodies along pre-existing foliation.		
		Cataclastic and retrogressive metamorphism; development of foliation, lineation, and mylonite in metarhyolite; retrogression of metamorphic facies in sedimentary rocks in northwest part of area.	Initiation of movements on Streeruwitz overthrust.
	Intrusion of rhyolite, mainly in sills.		
	Injection of pegmatite to southeast, possibly related to granitic batholith at depth.	Regional progressive metamorphism of low to medium grade, increasing in intensity to southeast.	Tilting of sedimentary rocks into homoclinal sequence of northeast strike and southeast dip; overturned folds in southeast.
Carrizo Mountain group (19,000 feet plus): Quartzofeldspathic arenaceous sediments, with interbedded argillites and some carbonates; volcanics near base of exposed section in Carrizo Mountains (chlorite-mica schist).	Volcanics in lower part (chlorite-mica schist of Carrizo Mountains).		

Table 23. Sedimentary, metamorphic, and structural history of north part of Van Horn pre-Cambrian area, by Philip B. King.

Sedimentation	Igneous activity	Metamorphism	Deformation
Unconformity (with Bliss (?) sandstone)			Tilting and block faulting.
Van Horn sandstone (800 feet plus): Continental, post-orogenic; fragments of cataclastically altered meta-rhyolite from south and rhyolite and granite from north.			
Major unconformity	Quartz veins	Low-grade progressive metamorphism, dying out to north; axial plane cleavage in phyllites; marmorization in limestone; tourmaline veins in sandstone.	Major orogeny. Strong folding and thrusting of Allamoore and Hazel formations, dying out to north; emplacement of Streeruwitz overthrust; transcurrent faults in late phases.
Hazel formation (many thousands of feet): Subaqueous, perhaps intermontane red sandstone; syn-orogenic conglomerate, with fragments from Allamoore formation, and a few of granite, probably from north.			
Unconformity		Metamorphism at least locally; marble and possibly schistose pyroclastics in conglomerate of Hazel formation.	Strong deformation of unknown character, masked by post-Hazel orogeny.
Allamoore formation (many thousands of feet): Cherty limestones, phyllites, volcanics; marine, eugeo-synclinal facies.	Volcanics interbedded in Allamoore formation: Pyroclastics, flows, and shallow intrusives. Diabase a prominent component.		

Table 24. Sedimentary and structural history of pre-Cambrian rocks northwest of Van Horn area (compiled from Richardson (1909) and King (1935)).

Sedimentation	Igneous activity	Metamorphism	Orogeny
Erosional unconformity (with Bliss sandstone)	Granite, and probably rhyolite, are older than Hazel formation as granite fragments occur in its conglomerate.	No metamorphic history recorded	Distinct angular unconformity between Bliss sandstone and underlying rhyolite and Lanoria quartzite (observations of N. H. Darton, 1930). In parts of Franklin Mountains and in Hueco Mountains Bliss lies on granite which presumably intrudes these formations.
	Intrusions of red granite (unconformable below Bliss in Franklin and Hueco Mountains).		
Rhyolite flows (Franklin Mountains)	Rhyolite eruptions; thick flows with basal agglomerate in Franklin Mountains; rhyolites elsewhere not determined as extrusive or intrusive.		
Erosional unconformity			Unconformity between rhyolite flow and Lanoria quartzite is of undetermined significance; apparently slight where observed.
Lanoria quartzite (1500 feet plus): Gray, quartzose, fine grained, medium bedded. Known only in Franklin Mountains.			

Table 25. Tentative correlation of structural events in different parts of Van Horn region.

South part of Van Horn area	North part of Van Horn area	Northwest of Van Horn area
	Tilting and faulting	
Van Horn sandstone	Van Horn sandstone	
Major orogeny; emplacement of Streeruwitz overthrust; cataclastic and retrogressive metamorphism.	Major orogeny; emplacement of Streeruwitz overthrust; low-rank progressive metamorphism.	
	Hazel formation	
Diorite intrusions Beginning of orogeny	Orogeny; local metamorphism	
	Allamoore formation	
Rhyolite intrusions		Granite intrusions Rhyolite eruptions
Major orogeny; progressive regional metamorphism		Slight unconformity
Carrizo Mountain group		Lanoria quartzite

tion, and it seems unlikely that rhyolites were forming south and northwest of it while it was being deposited.

Unfortunately, no rhyolite is present in the sequence in the north part of the Van Horn area, so that it cannot be determined by what measure the rhyolite precedes the Hazel formation. The underlying Allamoore formation contains volcanic units but no massive rhyolite bodies. The rhyolites must either be equivalent to the Allamoore, or be older.

Accepting the rhyolites as a datum throws new light on the relation of the Allamoore formation and Carrizo Mountain group. The writer (King, 1940, p. 146) suggested earlier that: "The rocks of sedimentary origin in the Carrizo Mountain schist may not be very different in age from those of the Allamoore limestone \* \* \*. They may have formed dur-

ing the same cycle of deposition, with the sedimentary rocks of the Carrizo Mountain representing the initial deposits, and those of the Allamoore limestone the later deposits. \* \* \* The types of rocks present, and the degree of metamorphism and deformation are similar." It was therefore inferred that the two units were laid down nearly contemporaneously in different environments that were widely separated before the telescoping movements on the Streeruwitz overthrust; also that the post-Allamoore and pre-Hazel orogeny and accompanying metamorphism was the same as the orogeny which tilted and regionally metamorphosed the Carrizo Mountain group.

This interpretation has been greatly weakened by Flawn's detailed work in the Carrizo Mountains. Metasedimentary rocks (second and third meta-arkoses and first

mixed unit) are not synclinally infolded in an older extrusive meta-igneous sequence (metarhyolite and amphibolite) as was supposed in 1940; instead the meta-igneous rocks are intrusive, the structure is essentially homoclinal, and the metamorphic history is complex.

Moreover, if the rhyolites are contemporaneous with or older than the Allamoore, the post-Allamoore and pre-Hazel orogeny cannot be the same as that which tilted and regionally metamorphosed the Carrizo Mountain group. The rhyolite of the Carrizo Mountain group was injected after the tilting and regional metamorphism of the sedimentary part of the group.

The Allamoore and Carrizo Mountain were therefore laid down during separate cycles of deposition, and the orogeny at the end of Allamoore time is different from and younger than the orogeny at the end of deposition of the Carrizo Mountain sediments. There were, therefore, three orogenies in the Van Horn area, rather than two. It is perhaps odd that the Carrizo Mountain should show the structural and metamorphic effects of only the oldest and youngest orogenies, but the Carrizo Mountain was not in juxtaposition with the Hazel and Allamoore before overthrusting took place, and the second orogeny may not have extended into the Carrizo Mountain area, or was blended with the initial effects of the third orogeny.

Some confirmation of the conclusion that the Carrizo Mountain is older than the Allamoore may be had in the differences between the sediments of the two units. The Allamoore consists largely of limestone and volcanic rocks, both of which are unimportant in the Carrizo Mountain. It contains no sand other than detrital material of volcanic origin, whereas the Carrizo Mountain contains thick bodies of quartzo-feldspathic sandstone. These differences indicate either that the two units were formed at the same time in areas widely separated geographically, or that they are of different ages.

Correlation between the Van Horn area and the Franklin Mountains involves greater hazards than those just discussed because of the distance and lack of continuity. Accepting the rhyolite as a datum suggests the possibility that the Lanoria

quartzite is nearly equivalent to the Carrizo Mountain group. The Lanoria is separated from the succeeding rhyolite flows by an unconformity, and the Carrizo Mountain was tilted before being intruded by rhyolite. The structural break between the Lanoria and rhyolite appears to be less than that between the Carrizo Mountain and rhyolite, but this may be because the Carrizo Mountain developed in a more mobile area.

Richardson (1909, p. 3) describes the Lanoria quartzite as a gray, medium-bedded, quartzose sandstone, and Darton (notes of 1930) describes it as a thinly laminated white or pinkish sandstone with some interbedded reddish shaly layers. It appears to be much grayer and much less red than the sandstones of the Hazel formation, but it is seemingly less feldspathic than the sandstones of the Carrizo Mountain.

The correlations just outlined are subject to so many imponderables that they will no doubt be extensively revised as further information is obtained. More information is especially desirable on the relative ages of the different rocks. Specimens of limestone from the Allamoore formation and Carrizo Mountain group have been submitted by Flawn to Dr. J. Lawrence Kulp of Lamont Geological Observatory, Columbia University, for age determinations by the strontium method, but work on these is still in progress. Perhaps other means of age determination by radioactive methods will be devised in the future that can also be applied to the rocks of the Van Horn area and adjacent regions.

#### STRUCTURAL PATTERN

The Streeruwitz overthrust and features associated with it have every appearance of a major structure on the border between a stable region or cratonic area, on the north, and a mobile belt on the south (Pl. 19, A). In the southern Appalachians, mylonites and cataclastic structures like those on the Streeruwitz overthrust occur in crystalline rocks near the great thrusts of the Blue Ridge and Piedmont provinces (Crickmay, 1933; Oriel, 1950, p. 44). These are separated from the flat-lying sedimentary rocks of the Cumberland Plateau in the stable region on the northwest by a belt 50 miles or more in width, the Valley and Ridge

province, made up of strongly folded and faulted sedimentary rocks. In the Van Horn area the comparable belt of strongly folded and faulted Allamoore and Hazel formations is, rather surprisingly, only a few miles in width.

In the southern Appalachians, as in the Van Horn area, there is doubt as to correlation between the highly metamorphosed and injected crystalline rocks within the mobile belt and the sedimentary rocks which border them on the northwest. The crystalline rocks are generally considered to be older, although there is a possibility—as in the case of the Carrizo Mountain and Allamoore—that they are at least in part equivalent.

#### REGIONAL RELATIONS

A comprehensive review of the pre-Cambrian rocks in the region surrounding the Van Horn area appears to be somewhat futile at this time, as it would furnish only disconnected items whose relations to other items is not evident. Some of these uncertainties will no doubt be cleared up with further research, although many features will probably forever remain obscure.

Further clues as to regional relations will no doubt be obtained by study of other areas of pre-Cambrian outcrop, although all the outcrops of the region are now known in a general way, and it appears unlikely that any others will yield features as varied as those in the Van Horn area. Clues as to relations between the outcrops may be obtained when more deep wells penetrate the pre-Cambrian, and geophysical surveys may reveal gravity and magnetic anomalies that cannot be caused by Paleozoic and younger rocks alone but must express structures in the pre-Cambrian beneath. Greatest progress will be made, however, when more age determinations by various radioactive methods become available, as these will knit together items already known, as well as those remaining to be discovered. Physical features which are apparently similar and equivalent may turn out to have been formed under like conditions at quite different times, and dissimilar physical features may turn out to have formed at the same time in different environments.

The pre-Cambrian rocks of New Mexico and Arizona have been summarized by Darton (1925, pp. 15–37; 1928, pp. 3–5),

and further details of the older pre-Cambrian rocks of Arizona have recently been given by Anderson (1951, pp. 1331–1346). An area in central New Mexico which contains ancient metasedimentary and metavolcanic rocks intruded by granite has been described by Stark and Dapples (1946, pp. 1127–1143) and by Reiche (1949, pp. 1186–1198). In Arizona, a complex of older pre-Cambrian metasedimentary and metavolcanic rocks, widely intruded by granite, is overlain unconformably by younger pre-Cambrian sedimentary rocks of the Grand Canyon series and Apache group. The Grand Canyon series and Apache group have many resemblances to the Allamoore and Hazel formations, although they differ in being little deformed, or at most tilted and faulted, rather than strongly folded. In particular, the chert-banded Mescal limestone of the Apache group, as described and figured by Darton (1925, p. 32), strikingly resembles the limestones of the Allamoore formation; like the limestones of the Allamoore it is at least locally associated with lavas. If the Carrizo Mountain group is older than the Hazel and Allamoore, as it appears to be, it may be equivalent to the complex of older pre-Cambrian rocks of Arizona.

The larger pattern of pre-Cambrian structure in the region adjacent to the Van Horn area is still elusive. An attempt to portray the pre-Cambrian “grain” of Texas was made by Rettger (1932), but this was based on the assumption that pre-Cambrian structures closely parallel those in the overlying Paleozoic rocks, which may or may not be correct. Pre-Cambrian structures might cross the Paleozoic structures that have been superimposed on them at any angle, and even if Paleozoic structures were broadly controlled by pre-Cambrian structures there are probably significant local deviations.

If the Van Horn area marks the border between a pre-Cambrian stable region and mobile belt, it would be of interest to determine more of the outlines and extensions of each. Judging from the low degree of metamorphism and the local nature of the deformation in the rocks of the north part of the Van Horn area, they are of relatively late pre-Cambrian age, and the stable region and mobile belt indicated in the Van Horn area may also be primarily a feature of the later pre-Cambrian. The pre-Cambrian rocks of the Llano region of

central Texas might be a part of the stable region, as radioactive determinations made at Barringer Hill indicate an age of 1,040 million years, or about the same as that of the Laurentian intrusives in the Grenville province of the Canadian shield (Holmes, 1937, pp. 204-206); rocks of similar age have also been determined in the Pikes Peak area of Colorado.

The old notion that the North American continent grew outward from a nuclear stable area by peripheral accretion of successive mobile belts along its borders has recently been revived by Wilson (1948, p. 721):

The symmetry of the North American continent is well known. It consists of a large and central shield area, over much of which pre-Cambrian rocks are exposed. There are four systems of mountains around the shield, cut out of later sedimentary rocks, in each case folded tangentially or parallel with the margins of the shield. The Appalachian Mountains, folded in late Paleozoic time, and the Cordillera, of Mesozoic and Tertiary age, are well known. Their inner margins are thrust over the covered shield. The fact that these mountains form a V or U-shaped margin to the shield has often been mentioned, as has the similar arrangement of the foliation within the shield. Less studied, but comparable in size with the Appalachians, are the East Greenland Mountains and those that cross North Greenland and Ellesmere Island. \*\*\*\*\* When these northern mountains are considered, it can be seen that the continent has the shape of an irregular polygon rather than a U or a V. The orogenic forces that produced these successive additions around the margins of the continent must presumably have acted inwards towards its center. It is here suggested that the same radial and inward forces acted to form tangentially folded ranges of mountains during pre-Cambrian time as have acted since.

The Van Horn pre-Cambrian area, and the supposed stable region that possibly embraces the Llano and Pikes Peak areas, lies far south of the Canadian shield for which the above theory was proposed by Wilson. If the continent developed by outward growth from the Canadian shield alone, the existence in pre-Cambrian time of a stable region farther south would be unlikely. If the theory of peripheral accretion is accepted it is more probable that the continent developed from several separate nuclei, as suggested by Kay (1951, p. 97), which were welded by orogenies into a single large stable region before Paleozoic time.

#### STRUCTURE OF THE PRE-CAMBRIAN SURFACE

The structure of the surface of the pre-Cambrian in the region surrounding the Van Horn area has been contoured in generalized form by Moss (1936, pl. 4, p. 948), and later in more detail by John Emery Adams as part of a research project for the Standard Oil Company of Texas. Contours made by Adams on the top of the pre-Cambrian in northwestern Trans-Pecos Texas are reproduced in Plate 19, B, of the present paper with his kind consent.

Adams' work shows that the Van Horn pre-Cambrian area lies at the crest of a broad domical area, oriented northwest-southeast, on the summit of which the top of the pre-Cambrian rises to about 6,000 feet above sea level. On the northeast flank the top of the pre-Cambrian slopes beneath the Paleozoic rocks of the Delaware basin, and on the southwest it slopes more abruptly beneath the thick geosynclinal Mesozoic sediments of the deformed belt of the Eagle and Quitman Mountains. This is the Van Horn "dome" or "uplift" of Baker (1927, p. 41; 1935, p. 182), who has termed it "the highest uplift in Texas."

The area of high-standing pre-Cambrian rocks is domical only in the broadest sense. In detail, the pre-Cambrian rocks come to the surface in a number of closely adjacent, but distinct, mountain uplifts, separated by down-faulted areas. Detailed contours on the pre-Cambrian would show complex offsetting of the surface from one fault block to the next. Adams (1944) has properly criticised the concept of the Van Horn area as "the highest structural point in Texas," pointing out the different results that can be obtained by application of several criteria and concluding that the Franklin Mountains, a much narrower and more localized uplift farther west, contains the "highest structural point."

The Guadalupe Mountains now stand several thousand feet higher than the Sierra Diablo, yet they expose only later Paleozoic rocks, whereas the latter exposes older Permian, older Paleozoic, and pre-Cambrian rocks. Structure contours drawn on the top of the pre-Cambrian indicate that the pre-Cambrian in the south part of the Sierra Diablo stands higher than in any other area in trans-Pecos Texas. Most of this uplift resulted from the greater structural height of the Sierra Diablo in early Mesozoic time, for the range was not uplifted as much as the Guadalupe

Mountains in Cenozoic time (King, 1948a, p. 108.)

The area of high-standing pre-Cambrian rocks may have had a much more domical form before it was disrupted by the later Cenozoic faulting; during parts of Paleozoic, Mesozoic, and early Tertiary time it may have been the dominant structural feature of this part of Texas. It evidently originated after pre-Cambrian time, as it includes part of the pre-Cambrian mobile area on the southeast and part of the pre-Cambrian stable area on the northwest. Its origin was probably complex. Much of its development may have been relatively passive, as Paleozoic and later sediments were deposited over it to less thickness than elsewhere, or if deposited, were partly or wholly removed by erosion (Pl. 19, C and D). On the broader feature more active but lesser features were superimposed—the folds of late Paleozoic time, others of early Tertiary time, and finally the normal faults of later Cenozoic time.

## PROBLEMS OF METAMORPHISM

Peter T. Flawn

### SUMMARY OF METAMORPHISM

The pre-Cambrian rocks of the Van Horn area present different metamorphic facies from one area to another—one in the Carrizo Mountain group in exposures in the northwest and northeast Van Horn Mountains and the Wylie Mountains, another in the Carrizo Mountain group of the Eagle and Carrizo Mountains, and a third in the Allamoore and Hazel formations of the Sierra Diablo foothills.

*Southeastern metamorphic facies of Carrizo Mountain group.*—Outcrops in the northwest and northeast Van Horn Mountains and the Wylie Mountains lie in a northeast-southwest line, nearly parallel with the strike of the rocks. At each locality the rocks are chiefly meta-arkose, feldspathic metaquartzite, and feldspathic muscovite schist—essentially a quartzo-feldspathic sequence. These have been thoroughly recrystallized, with complete reconstitution of intergranular material to form plates of biotite and muscovite. Associated with these rocks in the northwest Van Horn Mountains are almandine- and anthophyllite-bearing para-amphibolites. The facies is made up of medium grade metamorphic

rocks, in the almandine zone of regional metamorphism, or amphibolite facies of Eskola. Fabrics are crystalloblastic, and the rocks consist for the most part of mineral assemblages that are in equilibrium.

The rocks have been so thoroughly altered that original bedding ( $S_1$ ) is no longer visible, although the larger stratification is indicated by interbedding of mineralogically contrasting layers. Foliation ( $S_2$ ) is more or less parallel to the stratification.

*Northwestern metamorphic facies of Carrizo Mountain group.*—Outcrops in the Eagle and Carrizo Mountains lie 12 to 15 miles northwest of the line of strike which connects the preceding exposures and are themselves essentially along the regional strike. Slate, phyllite, chlorite schist, and limestone occur between thick quartzo-feldspathic members in a metasedimentary sequence. The metaquartzite and meta-arkose units show some intergranular chloritic and sericitic material, not reconstituted into mica plates. All the rocks of the sequence are fine grained, and cataclastic fabrics dominate. Microscopic examination shows disequilibrium relations and an over-all smeared, comminuted, and faded appearance. Helicitic garnets in phyllite in the Eagle Mountains are almost completely converted to chlorite. Biotite partly converted to chlorite is seen in most rocks. A perceptible northwestward increase in cataclastic features is seen within the breadth of the Carrizo Mountains. This facies is made up of diaphoritic or retrograde rocks, which had previously possessed a higher grade of regional metamorphism. The earlier metamorphism is probably correlative with the metamorphism of the preceding facies but is not as intense and seldom exceeds the stage of biotite formation.

Relict sedimentary structures ( $S_1$ ), such as bedding laminae, cross-bedding, and pebbly seams, are well preserved in many of the quartzo-feldspathic rocks of the sequence. Foliation ( $S_2$ ) is more or less parallel to the original stratification of the rocks, except for a few local deviations. In some of the schist or phyllite units, foliation is distorted by rucking, crinkling, and chevron folding ( $S_3$ ), the axes of which lie in planes that cross the planes of the foliation at wide angles. Such structures occur locally in the Van Horn Mountains, but they



are most abundant in those parts of the Eagle and Carrizo Mountains where retrogressive metamorphism is most intense, and especially where incompetent units abut against competent and massive metarhyolite intrusions.

Intrusive rhyolite and diorite, now altered to metarhyolite and amphibolite, show strong cataclastic structures. The metarhyolite has a pronounced foliation, in the plane of which is a conspicuous lineation that plunges southeast, formed by streaking and drawing out of relict phenocrysts and other mineral aggregates. Intense shearing and dislocative movements have converted parts of the metarhyolite into sericite schist, or to mylonite. The amphibolite, which is younger than the metarhyolite, in places contains similar but less pronounced cataclastic structures. The cataclastic metamorphism of the metarhyolite and amphibolite is clearly contemporaneous with the retrogressive and cataclastic metamorphism of the adjacent metasedimentary rocks. Whether the metarhyolite, like the adjacent metasedimentary rocks, had earlier passed through a progressive regional metamorphism is uncertain; if its effects were once present they have now been erased. More probably the rhyolite was intruded into the metasedimentary rocks after they had undergone their first metamorphism.

*Metamorphic facies of Allamoore and Hazel formations.* The Allamoore and Hazel formations of the Sierra Diablo foothills, although strongly deformed, do not show as obvious a development of metamorphic minerals and structures as do the rocks of the Carrizo Mountain group. The most striking manifestations of metamorphism are in the phyllites and fine-grained pyroclastic sediments, whose original constituents have been converted into strongly foliated minerals such as sericite and chlorite. Locally, also, the limestones have been recrystallized into banded marbles. However, microscopic examination of other rocks from the southern outcrops of the two formations indicates that many of them have had a more complex history than would be suspected from superficial examination, and that they have been subjected to alteration at relatively high temperatures. Limestones of the Allamoore formation are found to contain biotite, muscovite, and albite as metamorphic products, and the Hazel formation shows black, slickensided surfaces

which consist largely of tourmaline. Petrographic study of the Allamoore and Hazel formations is incomplete, and the extent of their metamorphic features, either geographically or stratigraphically, has not been determined. In exposures to the north, the two formations appear to have been little altered.

Foliation in the phyllites, pyroclastics, and limestones of the Allamoore formation is primarily an axial-plane cleavage, which crosses stratification at wide angles. No cataclastic structures appear to be present, although they are prominent in the metarhyolite of the Carrizo Mountain group immediately to the south. The occurrence of fragments of marmorized limestone and possibly of schistose pyroclastics, derived from the Allamoore formation, in conglomerates of the succeeding Hazel formation suggests that there may have been two periods of metamorphism, one preceding and one following Hazel time. Nevertheless, no superimposed metamorphic structures are visible in the Allamoore formation itself, and so far as one can determine, its structures were created by low-rank progressive metamorphism, during a single cycle.

*Albitization.*—Petrographic study suggests that there was an introduction of sodium, manifested as the mineral albite, into the rocks in the general vicinity of the Streeruwitz overthrust. Albite is a prominent constituent of Allamoore limestone near the overthrust and occurs (a) in a mosaic with and apparently replacing calcite and (b) in cross-cutting veinlets. Also suggestive of albitization is the presence of "chessboard" albite in the metarhyolite near the overthrust (and its absence in metarhyolite in the southeastern Carrizo Mountains). This sodium metasomatism is probably a late feature of the cataclastic metamorphism and perhaps belongs to the same period of hydrothermal activity responsible for the introduction of tourmaline in this same area. Albite rhyolite in the Pump Station Hills also shows indications of albitization, but correlation of sodium metasomatism in the two widely separated areas is tenuous at best.

*Interpretation of metamorphic structures.*—Parallelism of foliation and stratification has been considered anomalous, but it is actually widespread in metamorphic terranes. Axial plane cleavage and other marked deviations from parallelism are

likely to occur mainly on the borders of a deformed belt, as in the Allamoore formation of the Van Horn area. In the Carrizo Mountain group foliation and stratification are generally parallel in both the higher-rank metamorphic rocks to the southeast and in the lower-rank metamorphic rocks to the northwest, where two sets of metamorphic structures have been superimposed. It has been thought that bedding plane foliation indicates geothermal metamorphism, or recrystallization caused by deep burial, which depressed the rocks into higher temperature levels of the crust and subjected them to pressure from a thick load of overlying rocks, without accompanying tangential shearing stresses. Turner (1948, pp. 176, 278), following Sander, suggests that a pre-existing set of S-planes such as stratification renders the rock sufficiently anisotropic as to exert control on subsequent development of slip surfaces. In the Carrizo Mountain group, original stratification may thus have controlled not only the formation of schistosity during the regional metamorphism but also the development of slip surfaces during the later cataclastic metamorphism.

It may appear anomalous that original sedimentary structures are best preserved in the Carrizo Mountain group in its northwestern exposures, where retrogressive metamorphism is superimposed on progressive metamorphism. It is inconceivable that a rock which has been transformed into a thoroughly crystalloblastic schist and then retrograded to a fine-grained phyllite should show any trace of its original structure. However, nothing as extreme as this has taken place in the area. Regional progressive metamorphism decreased in intensity northwestward, and in the area of greatest retrogressive metamorphism it scarcely passed the stage of biotite formation. Moreover, the sedimentary structures are best preserved in the quartzo-feldspathic rocks, which reacted by simple mass recrystallization. The structure and metamorphism of the interbedded schist-phyllite-slate units is much more complex, and a great deal of the applied stress during the retrogressive metamorphism may, in fact, have been dissipated in them.

One of the manifestations of rock failure in the schist-phyllite-slate units is the development of rucking, crinkling, and chevron folding ( $S_3$ ), which deforms the foli-

ation. In other areas similar structures have sometimes been interpreted as formed during a phase closely succeeding the development of the foliation, or even to be a mere "fracture cleavage" formed by a component of the same force which produced the foliation. In the Van Horn area, at least, the  $S_3$  structures appear to be much younger than the foliation, and to be contemporaneous with the retrogressive metamorphism. Regionally, they are best developed toward the northwest where retrogressive metamorphism is greatest, and specifically they are best developed where incompetent units are crowded against competent metarhyolite intrusions. The structures are therefore younger than the metarhyolite, and the metarhyolite, as here interpreted, is itself younger than the regional metamorphism.

The lineation in the metarhyolite of the northwest part of the Carrizo Mountains appears to be the result of strong northwestward dislocative movements that were contemporaneous with the retrogressive metamorphism of the near-by metasedimentary rocks. The lineation is interpreted as an  $a$  lineation, parallel to the  $a$  fabric axis, or direction of transport. According to Turner (1948, p. 180):

In mylonites and similar rocks which originate locally by intense cataclastic deformation in planar zones such as slickensides, where considerable displacement is accomplished by relatively rapid movement within a small thickness of deformed rock, a linear structure (*Rillung*) parallel to the direction of movement, i.e., to the  $a$  axis of the fabric, is typically conspicuous.

As to the ultimate cause of the two metamorphisms:

The profuse intrusion of pegmatites in the northwest Van Horn Mountains indicates the possibility of a subjacent batholith in the southeastern part of the area, and this batholith, if present, may have provided the heat necessary for the regional metamorphism. Whether the regional metamorphism was directly or only indirectly related to the tilting and other deformation of the rocks of the Carrizo Mountain group has not been established.

The retrogressive and cataclastic metamorphism has a striking areal relation to the Streeruwitz overthrust which bounds the Carrizo Mountain group on the north and increases in intensity toward it. The lineation in the metarhyolite, a cataclastic structure, plunges southward or southeastward, approximately at right angles to the

trace of the overthrust, and perhaps parallel to its plane. It would seem that the cataclastic metamorphism took place at the same time as the emplacement of the Carrizo Mountain group on the Streeruwitz overthrust and was caused by the same forces.

The amount of time which elapsed between the regional metamorphism and the later cataclastic metamorphism is uncertain. The two may be related parts of a continuous kinetic-thermal system, during operation of which there was a thermally dominated environment in the southeast part of the area, nearest the hypothetical batholith, while the stress component of regional metamorphism increased northwestward, where it culminated in cataclastic metamorphism and overthrusting. However, intrusive rhyolite and diorite in the northwest part of the area experienced the cataclastic metamorphism but are apparently younger than the regional metamorphism. Also, the Streeruwitz overthrust, to which the cataclastic metamorphism is related, can be dated as younger than the unmetamorphosed Hazel formation. The cataclastic metamorphism thus seems to be a late feature in the structural and metamorphic history of the area and may also have been of relatively local extent.

#### MINERAL RELATIONS IN THE MICA MINE AREA

The Mica Mine area is unique among exposures of pre-Cambrian rocks in the Van Horn area in that it presents a sequence of rocks of varied mineralogy, regionally metamorphosed to the amphibolite facies and not complicated by subsequent retrogressive metamorphic reactions. Eight chemical analyses (Tables 3, 6) were made in connection with the detailed study of pegmatites and amphibolites in the area, and a discussion of the mineral relations is in order.

The study of metamorphic rocks has been facilitated in recent years by use of the facies classification developed by Eskola (1915, p. 114). The classification of metamorphic rocks into metamorphic facies is based on the thesis that:

In any rock of a metamorphic formation which has arrived at a chemical equilibrium through metamorphism at constant temperature and pressure conditions, the mineral composition is controlled only by the chemical composition.

Thus a metamorphic facies includes rocks that have reached equilibrium during metamorphism under a particular set of physical conditions.

Whether or not a particular assemblage of minerals constitutes an equilibrium assemblage is a difficult problem. A partial solution to this problem is found by applying the mineralogical phase rule.<sup>20</sup> Turner (1948, p. 50) says:

A general agreement . . . between the number of observed associated minerals in a series of rocks and the number required by the mineralogical phase rule may . . . be interpreted with some assurance as indicating a general approach toward equilibrium.

The chief difficulty in applying the mineralogical phase rule lies in determination of the number of participating components. Substitution of one component for another may decrease the number of phases. Other difficulties arise from consideration of the mobility of certain components since, ideally, the maximum number of phases in equilibrium is equal to the number of inert components. Because the ideal mobile condition is rarely attained, the principal mineral phases may be accompanied by small amounts of other phases due to the limited mobility of the corresponding components (Turner, 1948, p. 53). It should be noted that in application of the phase rule only the chief mineral constituents are considered, and minor constituents are a factor only in so far as they contain components in common with chief minerals; for example, if calcite is present as a minor constituent an amount of CaO equivalent to the CO<sub>2</sub> must be subtracted in calculations from the total CaO.

Water, as one component, is considered to be everywhere present, and the existing phases are those which can exist in the presence of water. The number of *solid* phases, then, is one less than the number of components.

Eskola (1915, p. 138) treats the rocks of the Orijärvi region as members of a six-component system but states that limited isomorphous substitution of Fe and Mg compounds may result in a seven-component system with six stable minerals.

<sup>20</sup> Goldschmidt's mineralogical phase rule (a restatement of Willard Gibbs's phase rule to apply to metamorphic rocks) is given by Turner (1948, p. 48): "The maximum number of crystalline minerals that can coexist in stable equilibrium is equal to the number of individual components that are contained in the minerals (provided the singular transition points are omitted from consideration)."

Turner (1948, p. 78) following Eskola, discusses the rocks of the amphibolite facies as members of a six-component system. Turner (1948, pp. 77-88) includes four subfacies under the amphibolite facies:

- (1) Cordierite-Anthophyllite Subfacies (essentially a contact-metamorphic facies formed under a low shearing stress)
- (2) Staurolite-Kyanite Subfacies (rocks formed by medium to high-grade metamorphism involving strong deformation under high pressure and shearing stress—the product of regional metamorphism)
- (3) Sillimanite-Almandine Subfacies (a product of high-grade regional metamorphism characterized by the presence of sillimanite)
- (4) Almandine-Diopside-Hornblende Subfacies (a subfacies probably developed under high pressure at great depth)

It should be noted that these subfacies of Turner (1948) have genetic implications, such as that of depth, not present in the original facies classification of Eskola. Although the critical minerals staurolite and kyanite are not present in the Mica Mine area, the rocks are probably isogradic with the Staurolite-Kyanite Subfacies of Turner. The absence of these critical minerals is a reflection of the chemical composition of the rocks.

*Mineral assemblages in the Mica Mine area.*—The major metamorphic mineral assemblages in the Mica Mine area are as follows:

- I. Quartzite—muscovite schist sequence
  1. Quartz-microcline-albite-muscovite-biotite
- II. Biotite schist—amphibolite sequence
  1. Quartz-biotite—"albite-oligoclase".<sup>21</sup> almandine (Almandine is not everywhere present.)
  2. Quartz-biotite-oligoclase-anthophyllite
  3. "Oligoclase-andesine"-biotite-hornblende-anthophyllite (Biotite, hornblende, anthophyllite; biotite and anthophyllite; or biotite and hornblende may be absent. Quartz is present in some specimens.)
  4. Andesine-hornblende-almandine
  5. Oligoclase-hornblende-epidote-quartz (Quartz is extremely variable in amount and may be absent.)
  6. Epidote-albite-sphene (This assemblage is an extreme of number 5. Sphene has increased to almost 5 percent and can be considered a major mineral. Hornblende is present only in amounts near 1 percent. Epidote makes up about 90 percent of the rock and albite makes up about 5 percent of the rock.)

<sup>21</sup> Quotation marks enclose one mineral phase with a range in chemical composition.

Thus the maximum number of mineral constituents in any Mica Mine rock is five, with three and four the general rule. If, following Turner (1948, p. 78), these rocks are considered as a six-component system, it is reasonably certain that they are equilibrium assemblages.

In the following discussions of Mica Mine assemblages and construction of AKF and ACF diagrams, calculations are made following Eskola (1915). In analyses of Mica Mine rocks it is assumed for the purposes of calculation that the ignition loss is all water.

*The quartz-microcline-albite-muscovite-biotite assemblage.*—Analyses of representative rocks of this assemblage are given in Table 3. In general these rocks are characterized by an excess of alumina ( $\text{Al}_2\text{O}_3 : (\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO}) > 1$ ) and an excess of potash. Eskola (1915, p. 125) states that rocks containing an excess of potash contain biotite or muscovite and possibly microcline but no anthophyllite, almandine, cordierite, or andalusite. Rocks deficient in potash invariably contain at least one of the minerals of the last-mentioned group and no microcline.

Three analyzed samples from the quartzite-muscovite schist sequence and a representative analysis of pegmatite of the Mica Mine area are shown in an AKF diagram, figure 16. In the analyses of these three rocks all iron is reported as  $\text{Fe}_2\text{O}_3$ , and consequently in order to show the effect of possible combinations of amounts of ferrous and ferric iron in the rock, the analyses are plotted on the AKF diagram with the iron calculated respectively as ferrous and as ferric (fig. 16).

Figure 16 shows that three of the rocks are characterized by an excess of potash (shown by the presence of microcline), the remaining analysis, number 3, falling into the almandine-muscovite-biotite field. No almandine, however, was observed in this rock or in any of the sections studied from this sequence. It is suggested that the excess amount of  $\text{Al}_2\text{O}_3$  formed muscovite at the expense of microcline while the relatively high Mg content (with respect to Fe) is responsible for the presence of a high-magnesium biotite and the absence of almandine. The FeO and MgO in this instance act as a single component in the biotite. Eskola (1915, p. 123) says that it is the imperfect miscibility of the ferrous and magnesium compounds that causes the appearance of almandine. According to Eskola, MgO and FeO, in a rock too rich in the latter to form cordierite, behave as two

independent components and a new phase, almandine, appears without causing the disappearance of any other phase. Some question may be raised on the idea of limited miscibility of FeO and MgO since complete mutual substitution of FeO and MgO is known to take place in many minerals. The question here is the extent to which MgO can substitute for FeO in almandine. Since the work of Ford (1915) the series pyrope-almandine-spessartite has generally been considered a continuous solid solution series. Nevertheless (a) cordierite and almandine and (b) biotite and almandine occur together in equilibrium assemblages, and where this occurs MgO and FeO are acting as separate components. Bowen (1925, p. 283) says:

The grouping of, say, ferrous iron and magnesia as a single component may lead to no difficulties in the great majority of rocks, but in those few that are formed under conditions that lie within what may be termed inversion intervals, a number of phases too great for agreement with such grouping may be found even with perfect equilibrium.

Eskola (1915, p. 123), Barth (1936, p. 819), and Turner (1948, p. 49) all remark on the limited extent to which MgO can substitute for FeO in almandine *within the*

range of physical conditions corresponding to a medium to high grade of metamorphism. It seems certain, therefore, that under some conditions MgO and FeO do act independently. Further work is needed on the physical and chemical conditions that cause such behavior.

*The quartz-biotite-"albite-oligoclase"-almandine assemblage.*—An analysis of this rock is given in Table 6 and plotted on the ACF diagrams shown in figure 17. The rock is characterized by an excess of alumina and a deficiency of potash. Apparently the magnesia and ferrous iron are acting as separate components, and therefore almandine (in the presence of an excess of alumina) appears as a separate phase. Consequently this assemblage contains a high magnesium biotite and an essentially ferrous almandine. This rock falls within the biotite-almandine field of Turner's ACF diagram (fig. 17).

*The quartz-biotite-"albite-oligoclase"-anthophyllite assemblage.*—No analysis of this particular assemblage was made. It constitutes a more potassic and sodic phase of the following assemblage and contains relatively less alumina than the previous assemblages.

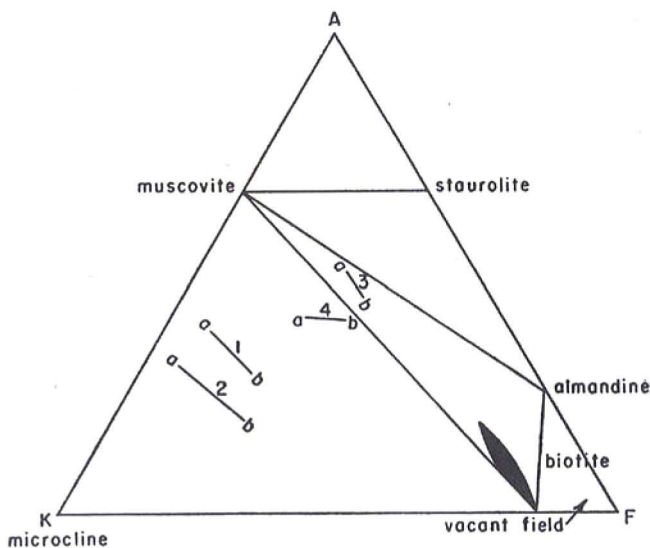


FIG. 16. AKF diagram for rocks with excess  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  (after Turner, 1948, fig. 20), on which are superimposed chemical analyses of rocks from the Mica Mine area (1 through 4).  $a$  = total iron calculated as  $\text{Fe}_2\text{O}_3$ ;  $b$  = total iron calculated as  $\text{FeO}$ . Rocks whose compositions fall within the field microcline-muscovite-biotite have excess  $\text{K}_2\text{O}$ . (1) Representative pegmatite (microcline perthite-albite ( $\text{An}_7$ )-quartz-muscovite). (2) Feldspathic quartzite (microcline-quartz-albite-muscovite). (3) Biotitic muscovite schist (quartz-muscovite-biotite). (4) Muscovite schist (quartz-muscovite-microcline). See Table 3 for chemical analyses.

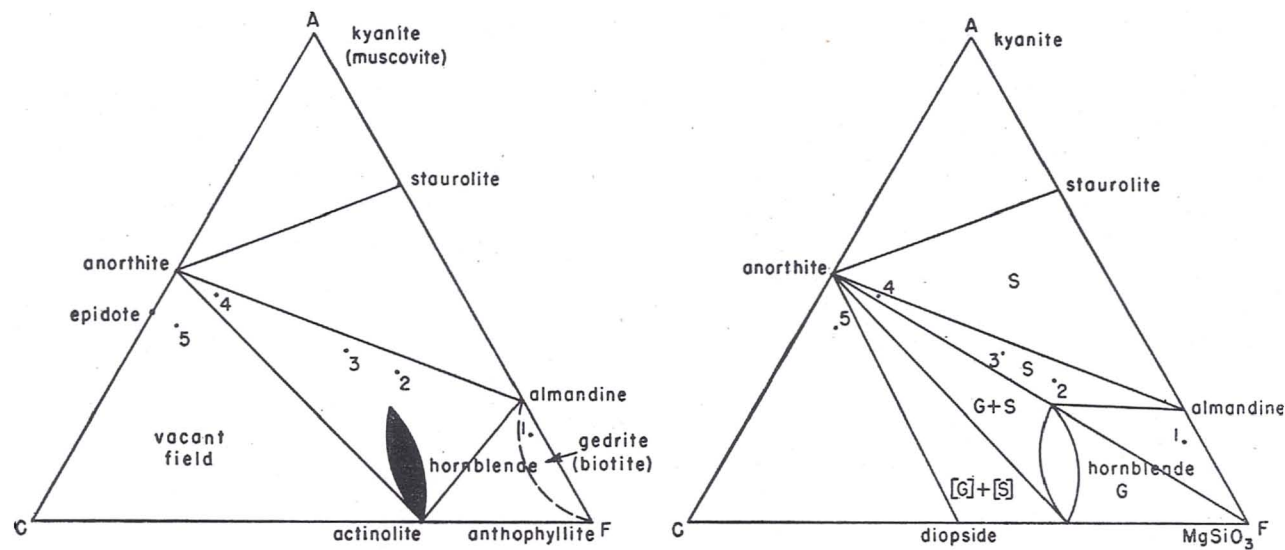


FIG. 17. ACF diagrams of amphibolite facies, on which are superimposed chemical analyses of rocks from the Mica Mine area (1 through 5). (a) Diagram for rocks with excess of  $\text{SiO}_2$  and deficiency of  $\text{K}_2\text{O}$  (after Turner, 1948, fig. 19). (b) Diagram showing rocks of the gabbro series, G, and rocks of the sedimentary series, S (after Vogt, 1927, fig. 104). (Note that in rocks low in  $\text{Na}_2\text{O}$  the place of anorthite may largely be taken by epidote.) (1) Quartz-biotite-albite-almandine schist. (2) Andesine-hornblende-anthophyllite amphibolite. (3) Andesine-hornblende-almandine amphibolite. (4) Quartz-epidote-oligoclase-hornblende amphibolite. (5) Epidote-albite-(sphen) epidote. See Table 6 for chemical analyses.

*The "oligoclase-andesine"-biotite-hornblende-anthophyllite assemblage.*—This assemblage shows a wide range in the minerals present. An andesine-hornblende-anthophyllite member of this assemblage was analyzed (Table 6) and plotted on ACF diagrams (fig. 17). The rock is deficient in alumina and contains a small amount of femic lime but no excess lime. (CaO in excess of ratio  $\text{CaO} : \text{Al}_2\text{O}_3 - (\text{K}_2\text{O} + \text{Na}_2\text{O}) = 1$  is called femic lime; rocks showing ratio of femic lime to magnesia more than 1:3 may be called rocks with excess lime.) As plotted on the ACF diagrams the rock falls into the almandine-anorthite-hornblende field and, on Vogt's diagram, is also within the sedimentary series. In the rock itself, however, anthophyllite and not almandine is present. Apparently in the absence of enough potash and alumina to form biotite, the magnesia and the ferrous iron act as a single component in the anthophyllite. Almandine ( $3\text{FeO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$ ) could not form in the presence of the high concentration of MgO and the deficiency of  $\text{Al}_2\text{O}_3$ , and its place was taken by anthophyllite ( $7(\text{Fe}, \text{Mg})\text{O} \cdot 8\text{SiO}_2 \cdot \text{H}_2\text{O}$ ). The almandine amphibolite in direct contact with this anthophyllite has an excess rather than a deficiency of alumina. Apparently, if sufficient water is available the alumina ratio is critical to the appearance of anthophyllite rather than almandine.

The high "A" rating which locates this rock on the ACF diagram is caused by the high ferric iron content which is calculated with the  $\text{Al}_2\text{O}_3$  to give the "A" value.

*The andesine-hornblende-almandine assemblage.*—Analysis of a sample from this assemblage is given in Table 6 and plotted on the ACF diagram in figure 17. The rock is characterized by an excess of alumina and an absence of femic lime. On the ACF diagram the rock falls into the anorthite-hornblende-almandine field and, on Vogt's diagram, into the sedimentary field.

*The oligoclase-hornblende-epidote-quartz assemblage.*—An analysis of this rock is given in Table 6 and plotted on the ACF diagram in figure 17. The assemblage has a deficiency of alumina and an excess of lime. On the ACF diagram this rock falls within the anorthite-hornblende-almandine field and, on Vogt's diagram, into the sedimentary series. There is, however, no almandine in the rock. Probably this is due to the low FeO content (a half percent by

weight) and the deficiency of alumina. The FeO and MgO act as a single component in the hornblende. Although in the presence of the large CaO content the rock must be classed as alumina deficient, the high  $\text{Fe}_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$  percentages give the rock a high "A" value. The  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  form epidote and because the ratio  $\text{CaO}/\text{Na}_2\text{O}$  is very high ( $\text{Na}_2\text{O} =$  a tenth percent by weight), epidote largely takes the place of anorthite.

It is recognized that generally with increasing metamorphic grade epidote disappears, reacting with sodic plagioclase to form a calcic plagioclase. The epidote amphibolite facies has thus been considered to be of lower grade than the amphibolite facies. Turner (1948, pp. 88-89), however, recognizes that epidote amphibolites with oligoclase or andesine are stable throughout much of the range of the amphibolite facies. The persistence of epidote resulting from an excess of lime over that which can enter the plagioclase demanded by the physical conditions during metamorphism. He therefore distinguishes an albite-epidote amphibolite facies of lower grade than the amphibolite facies, in which albite as well as epidote is a critical mineral. Thus in this oligoclase-hornblende-epidote-quartz assemblage here discussed the presence of epidote does not indicate a lower metamorphic grade. It is not reasonable to suppose that a thin bed of epidote amphibolite is at a metamorphic grade different from closely associated rocks above and below it in the stratigraphic sequence. The epidote is a result of an excess of lime, that is, its presence is controlled by the original chemical composition of the rock and not by the physical conditions of metamorphism.

The question might be raised as to why, in the presence of a large excess of lime, no diopside formed (as in the rocks of the Orijärvi region; Eskola, 1915). The answer must lie (presuming the physical conditions of metamorphism would permit the formation of diopside) in the presence of a large amount of ferric iron with relatively small amounts of MgO and FeO. In the presence of this large excess of  $\text{Fe}_2\text{O}_3$  with excess CaO and available alumina, epidote is the stable mineral and no lime is left for diopside.

*The epidote-albite-sphene assemblage.*—An analysis of this rock is given in Table 6 and plotted on the ACF diagrams in figure



17. The sphene is treated as a minor constituent and does not appear in the diagram. This rock has a deficiency of alumina and a large excess of lime. On the diagrams the rock falls into a vacant field unless epidote is substituted for anorthite, which causes the rock to fall nearly on the epidote-hornblende line, close to the epidote end. Small amounts of hornblende are present in this assemblage. Almost all the  $\text{CaO}$ , due to the large amount of  $\text{Fe}_2\text{O}_3$  and the lack of  $\text{Na}_2\text{O}$ , enters the epidote. The composition of the plagioclase is apparently not controlled by the temperature-stress conditions during metamorphism as suggested by Turner (1948, p. 81) but by the greater stability of epidote (rather than calcic plagioclase) in the presence of a large excess of lime, a large amount of ferric iron, and a lack of soda. The argument here is similar to that advanced in the foregoing section. There is no reason to suppose that this assemblage is at a lower metamorphic grade than the rocks closely associated with it. The reason for the difference between its mineral composition and that of rocks normally found in the amphibolite facies must lie in the chemical composition of the rock and not in special conditions of metamorphism.

It is noteworthy that the amphibolites of the Mica Mine area fall into the sedimentary range of Vogt's ACF diagram and confirm the hypothesis of sedimentary origin developed from field relations, although the writer does not regard the position of an analysis within an ACF diagram as conclusive proof of the original nature of the rock.

#### ORIGIN OF THE AMPHIBOLITES

*Origin of amphibolites in the Eagle, Carrizo, and Wylie Mountains.*—The origin of the amphibolites in the Eagle, Carrizo, and Wylie Mountains does not constitute a difficult problem. These amphibolites intrude the metasedimentary rocks and metarhyolite in the Carrizo Mountains and show a relict igneous fabric under the microscope. They occur in conformable sills and irregular discordant bodies and originated through metamorphism of an intrusive igneous rock, probably diorite. Mineralogy shows little variation from one area to another. Bleached and faded green hornblende subhedrons are converted

partly to masses of small prisms and needles of blue-green hornblende. Plagioclase is in part in relict subhedrons showing a vague polysynthetic twinning and almost completely altered to epidote and sericite and in part recrystallized to a fine mosaic. Most of the plagioclase is albite, but some rocks have an oligoclase or an andesine feldspar. Epidote is present throughout as a product of the breakdown of the high calcium plagioclase of the original igneous rock to a sodic plagioclase that was more stable in the metamorphic environment. Biotite, chlorite, magnetite or ilmenite, sphene, and apatite are characteristically present. The quartz content of the amphibolites shows wide variation; some rocks contain no quartz, and others may have as much as 30 percent quartz. Possibly much of the quartz within the amphibolites in these areas is secondary.

In many respects these rocks are strikingly similar to the "low-grade epidiorites" that have been thoroughly described by Wiseman (1934, pp. 357-378), the major difference being that Wiseman's rocks were originally diabases, rather than diorites, and show relict pyroxene and, locally, relict ophitic fabric.

*Origin of amphibolites in the northwest Van Horn Mountains.*—The amphibolites in the Mica Mine area of the northwest Van Horn Mountains are different from the amphibolites in other pre-Cambrian exposures in the Van Horn area. Distribution of the various amphibolite types in this area is shown in figure 18. The field relations are as follows:

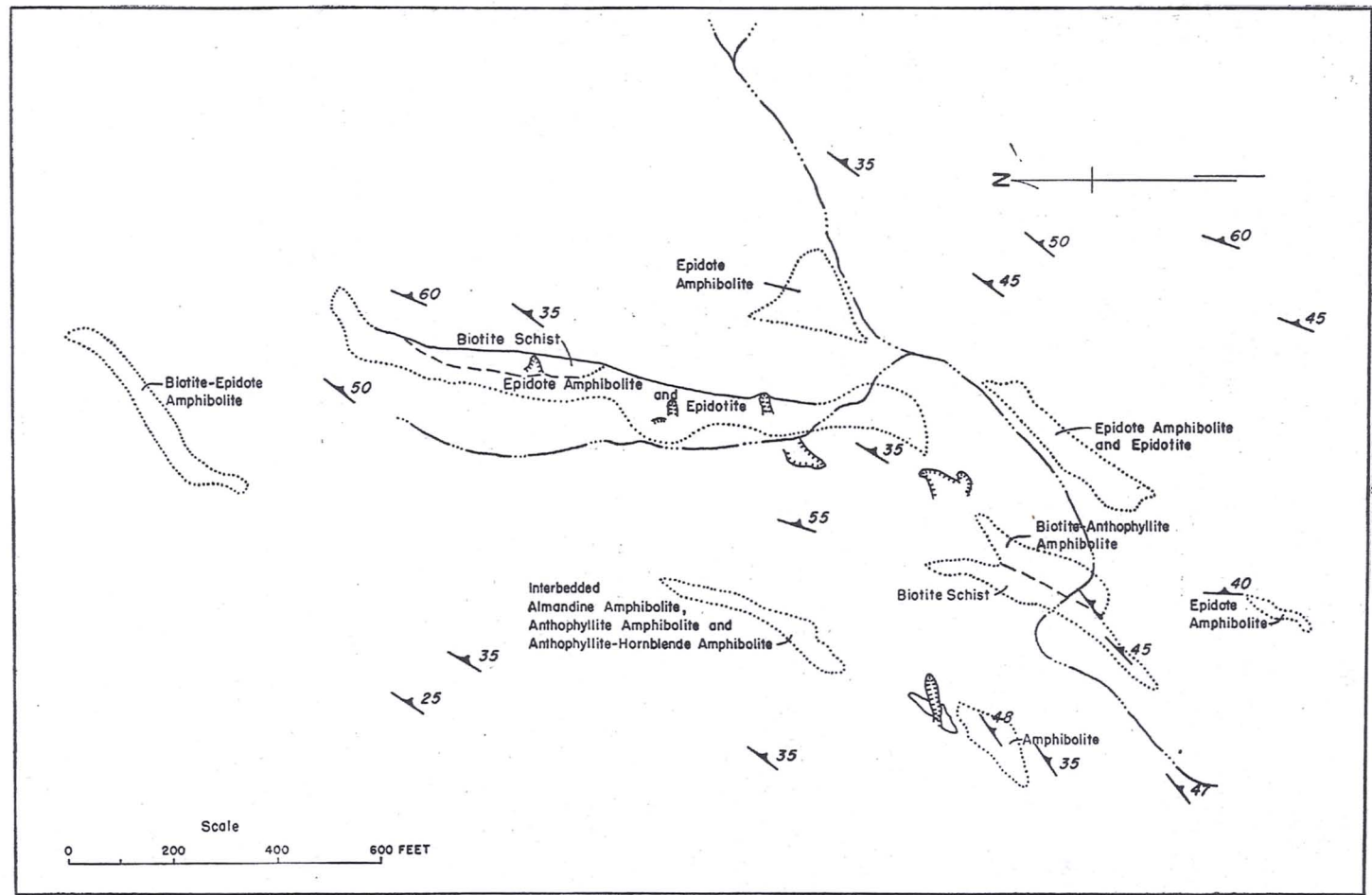
(1) Amphibolites and biotite schists occur together and are found in the more schistose parts of the quartzo-feldspathic sequence.

(2) Amphibolites and biotite schists occur in thin beds and in lenses along a common horizon. These beds and lenses are for the most part conformable within the sequence, but masses of epidote amphibolite east of the mill site show apparent intrusive relations.

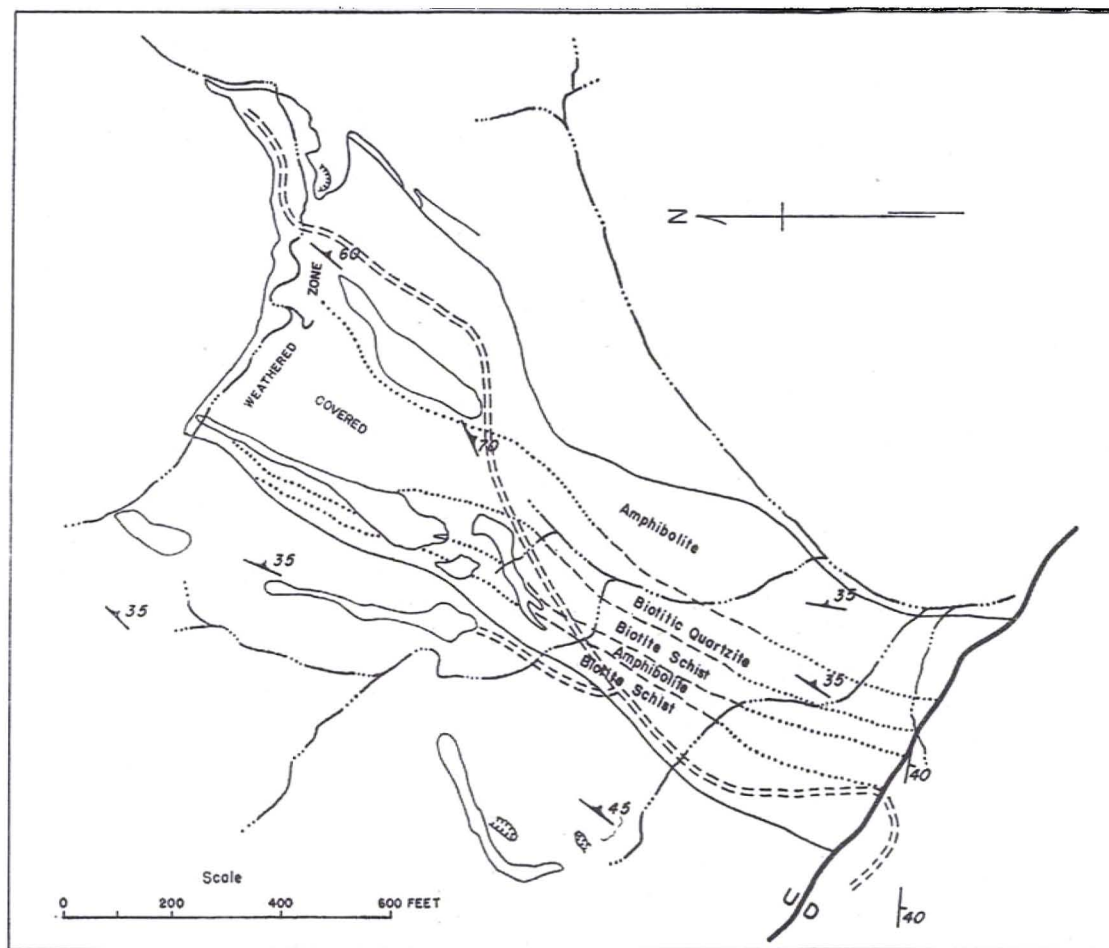
(3) A number of different mineral assemblages occur in close contact within the amphibolite-biotite schist sequence, and the percentages of minerals within a particular rock type or assemblage may vary widely. This is a reflection of variations in composition of the original rock, and the variations occur between layers parallel to the bedding-plane foliation.

(4) The transition from biotite schist to amphibolite is in some places effected through a biotite amphibolite of varied thickness. A biotite-muscovite schist commonly separates the muscovite schist from the amphibolite-biotite schist





(a)



(b)

FIG. 18. Sketch maps showing distribution of amphibolite types in the northwest Van Horn Mountains. (a) North end of Mica Mine area; (b) south end of Mica Mine area. (See Pl. 4.)

sequence. These transition rocks are not everywhere present, and the change from one petrographic type to another may take place across a bedding plane.

(5) In the southern amphibolite exposure the amphibolites and biotite schists are associated with sedimentary schists and quartzites different from the rocks of the normal muscovite schist-quartzite sequence. These rocks are magnetite-hornblende gneiss; almandine-cummingtonite quartzite; and almandiniferous biotite schist. These rocks, together with amphibolite, biotite schist, and a normal quartzite member, constitute a stratified series.

(6) The amphibolites commonly show a distinct thin banding, expressed by the mineral content of the respective layers.

*Hypotheses for consideration.*—Amphibolites may have formed in the following ways:

- (1) By thermal-kinetic (regional) metamorphism of sedimentary rocks: (a) impure carbonate rocks or marls; (b) tuffs or reworked tuffaceous material; (c) uncontaminated detritus from a basic igneous terrane.
- (2) By thermal-kinetic (regional) metamorphism of basic intrusive or extrusive rocks.
- (3) By action of hydrothermal or igneous agencies on carbonate rocks; additive (and subtractive) metamorphism.
- (4) By the action of a "basic front" produced by granitization; regional metasomatism.

In the Mica Mine area there is no relation between the intrusive pegmatite bodies and the amphibolites and no evidence of selective addition and subtraction of material within the amphibolite sequence. Where a pegmatite is in contact with amphibolite, a few inches of biotite amphibolite along the contact reflects the addition of potash. This is the only contact-metasomatic effect. Whatever changes in petrographic character that the amphibolites show are stratigraphic, vertically within the section, with lithologic continuity along the strike. A consideration of these points and the field relations previously summarized makes it necessary to discard the third and fourth hypotheses.

The lens-like character of some amphibolite exposures rules out the possibility that these rocks were extrusives or directly deposited tuffs, unless it can be demonstrated that an original continuous layer has been broken into lenses by diastrophism.

The general restriction of the amphibolites to the more schistose parts of the quartzite-muscovite schist sequence is not conclusive evidence of either sedimentary

or intrusive igneous origin. Intrusive rocks may have found easier access in the less massive parts of the section. If the amphibolites were originally sediments, the sediment belonged to the more argillaceous rather than the feldspathic arenaceous portion, and upon metamorphism the more argillaceous parts would be more schistose. However, this "preference" of the amphibolites for the more schistose parts is further reason for discarding the extrusive and directly-deposited-tuff hypotheses. There is no reason, other than coincidence, for a pyroclastic rock or a flow to "seek out" schistose rocks.

The localized deposition of uncontaminated detritus from a basic igneous terrane in lenses and thin beds within a thick body of quartz-alkali feldspar detritus would demand abrupt and recurrent changes of provenance and restricted transportation and deposition of the uncontaminated material. The hypothesis of origin from reworked tuffaceous material suffers from the same reasoning, that is, how could the material be transported and deposited in a relatively uncontaminated state? Fine sizes of the tuff might have separated out during transport and might thus have remained effectively separated from the dominant coarser quartz-feldspar detritus. But it seems unlikely that the entire quartzite-muscovite schist sequence would show no evidence of incorporation of tuffaceous material. The two hypotheses that best seem to satisfy the field and chemical data are (a) that of origin from basic igneous intrusives, probably doleritic or basaltic, and (b) that of origin from an impure carbonate or marl, in this case (see analyses, Table 6) a ferruginous, dolomitic marl.

*Hypothesis of origin from basic igneous intrusions.*—The igneous hypothesis satisfies the chemical data only in part (Table 6). The almandine amphibolite (Table 6, analysis II) has over 4 percent excess alumina, and this is not characteristic of igneous rocks. When applied to the field observations listed on pages 141, 144, the igneous hypothesis breaks down. Although the occurrence of the amphibolites in lenses and thin beds can be satisfactorily explained by intrusion of sills, the association with biotite schists and the peculiar schists and quartzites of the southern part of the area (both of sedimentary origin), the transition rocks, the stratified character of

the rocks, the distribution of the various types of amphibolites, the changes in composition across a bedding plane, and the occurrence of epidotites cannot be so explained. At one locality (up the canyon east of the main mill) a roughly circular outcrop of epidote amphibolite seems to have intrusive relations. However, this might also be explained by squeezing of an incompetent layer, because other outcrops of epidote amphibolite occur along the same stratigraphic horizon.

One explanation of the layers of unlike composition within a particular exposure, under the igneous hypothesis, would be by differentiation, in place, of the magma of the sill. But the difference in composition here is reflected in the calcium and aluminum content as well as in the iron and magnesium content, and sills of less than 5 feet in thickness do not in general show such differentiation. Differentiation cannot explain the difference in composition between two amphibolite outcrops separated by a narrow band of muscovite schist. Layers of unlike composition are common features of composite or compound sills (formed by successive injections of magma of different composition), but in these intrusions there is commonly a bilateral symmetry or at least a repetition of rock types.

As negative evidence, the lack of the igneous index elements chromium and nickel and the lack of relict igneous structure can be cited.

*Hypothesis of origin from impure carbonate rocks or marls.*—The existence of amphibolites of sedimentary origin, so called para-amphibolites, has been recognized for over half a century. Rosenbusch (1898, p. 514) and Grubenmann (1907, Part II, p. 81) have remarked on the origin of amphibolites from dolomitic clay marls. Eskola (1914, p. 119) notes amphibolites that have originated from calcareous shales probably mixed with volcanic material. The analyses of the rocks from the Mica Mine area (Table 6) show that the original sediment must have had substantial amounts of iron, magnesium, calcium, titanium, and phosphorus, and little sodium and potassium. The amounts of these elements vary considerably in the different types of amphibolite here described. Unfortunately the analysis of sedimentary rocks has not progressed to the point

where adequate analyses are available for comparison. It must also be remembered that during metamorphism the water, carbon dioxide, and other mobile components of sediments will escape, resulting in a relative enrichment of the remaining constituents. Thus a perfect correspondence of analyses between sedimentary rocks and their metamorphic equivalent should not be expected. An analysis of a marl is given in Table 6, analysis VI. The correspondence between this analysis and the analyses of the amphibolites is not as striking as the correspondence between the analysis of the dolerite or the basalt tuff and the analyses of the amphibolites. This particular marl is low in titanium, but sediments with high titanium content are not uncommon. (Clarke, 1915, gives analyses of some soils and clays.) That this titanium was indeed a constituent of the sediment is shown by the high titanium content of the associated biotite schist (Table 6, analysis I) which is definitely of sedimentary origin. If in the metamorphism of this marl (Table 6, analysis VI) about 9 percent carbon dioxide and about 5 percent water are eliminated, the relative concentration of the remaining elements is higher. In consulting Table 6 the wide range in composition of the closely associated amphibolites should be noted. This is understandable in sedimentary rocks but difficult to explain by the igneous hypothesis.

The next problem is the consideration of the conditions under which a sediment of the appropriate composition was deposited in beds and lenses in the quartz-alkali feldspar sequence. As previously stated, abrupt and repeated changes in provenance are unlikely and can be ruled out. The amphibolite-biotite schist sequence, then, must be the result of a change in the transportation-deposition system. The material from which the amphibolites were derived, especially the iron and aluminum, would be concentrated in the fine fraction which, in the Mica Mine area, normally bypassed the coarser quartz-feldspar detritus. A change in conditions of sedimentation, perhaps a deepening of the water, would cause the finer fraction to be deposited, with accompanying precipitation of carbonate, in an area it previously by-passed. A development of lateritic conditions in the source area would furnish iron and aluminum in the clay sizes.

The field relations summed up on pages 141, 144 can be explained by the sedimentary hypothesis (excluding tuffs which here are considered to be sedimentary rocks). The apparent intrusive relations shown locally might be explained by the mechanical effects of deformation on relatively incompetent units. Layers of varied composition, transitional rocks, and associated peculiar quartzites and schists would naturally result from sedimentary processes. The presence of biotite schists indicates the natural association of ferruginous shales with the ferruginous marls that give rise to the amphibolites. This association of biotite schist and amphibolite is a major point against the igneous theory. Variations in the amount of iron, calcium, and magnesium across a bedding plane or within a limited vertical range are common in sedimentary rocks. Eskola (1914, p. 118), discussing diopside amphibolites of sedimentary origin, remarked on the miniature bedding and individual layering shown by these rocks. Such a small-scale layering may be seen in the amphibolites of the Mica Mine area (Pl. 22, B).

Epidotite (Table 6, analysis V) occurs in streaks and layers within the epidote amphibolite. In classifications of metamorphic rocks these epidotites are grouped under the lime-silicates and considered to be of sedimentary origin (Rosenbusch, 1898, p. 527; Grubenmann, 1907, pp. 143, 150). An occurrence of epidote amphibolite and epidotite similar to that of the Mica Mine area was encountered by J. S. Flett (1946, pp. 45-54) among the "hornblende schists" of Old Lizard Head. Flett says:

The origin of these epidotic streaks is not very clear. Apparently they are not the remains of sedimentary intercalations, such as calcareous or dolomitic deposits, converted into calc-silicates, but they seem to be segregations formed during the process of metamorphism. No calc-silicate bands are known in the Old Lizard Head Series. Probably they represent feldspathic folia normally found in hornblende schist and their present conditions may be due to thermal action at two stages widely separated, . . . . .

However, there is no reason to rule out the hypothesis that the epidotites represent sedimentary intercalations in the Mica Mine area. And since the epidote amphibolites pass through all gradations to epidotites the sedimentary hypothesis, in the light of what has gone before, is a reasonable one.

It is not difficult to conceive of thin streaks of purer carbonate in a marl. An alternative hypothesis is that the epidotites are the product of hydrothermal alteration of the amphibolites, perhaps accompanying emplacement of the pegmatites.

*Conclusions on the origin of the amphibolites.*—The fact that amphibolite of meta-igneous origin occurs in areas of low metamorphic grade north and northwest of the Mica Mine area cannot fail to influence the observer to consider the hypothesis that all the amphibolites in the pre-Cambrian rocks of the Van Horn area are meta-igneous rocks, with the original igneous characteristics of the amphibolite in the higher grade metamorphic rocks of the Mica Mine area obliterated by this higher grade metamorphism. However, it must be remembered that there are differences in the mineralogy of the amphibolites of the two areas that result from a difference in the chemical composition of the rocks and cannot be explained solely by reference to the change in metamorphic grade. Moreover, it has been demonstrated that the amphibolite in the areas of pre-Cambrian rocks north of the Mica Mine area experienced only the late cataclastic metamorphism, while the amphibolites of the Mica Mine area are regionally metamorphosed rocks of medium grade, and this suggests that the northern amphibolites are younger than those of the Mica Mine area. This is significant but it cannot be regarded as conclusive because it is possible that a regional metamorphic environment of medium grade was maintained in the southeastern part of the area at the same time that retrogressive cataclastic metamorphism prevailed in the rocks of the thrust plate to the north.

The writer has considered alternative hypotheses objectively and concludes that the weight of the evidence indicates that the amphibolites of the Mica Mine area are para-amphibolites. There remains the possibility that amphibolites of both igneous and sedimentary origin are present in this area. The field relations and mineralogy of the epidote amphibolite east of the mill site are the most like the meta-igneous amphibolites to the north, but the relation of the epidote amphibolite to the biotite schist and to the other amphibolites in the area makes this correlation hazardous.

One final point concerning amphibolites in the Mica Mine area deserves clarification.

tion. The major structure in the area is interpreted as an overturned anticline, and, at first glance, it appears that the amphibolites on the north flank of the anticline should correlate with the amphibolites on the south flank (see Pl. 4). However, failure to obtain precise correlation of amphibolite types between these two areas can result from: (1) a change in composition

of the original rock over the distance between the two outcropping belts (the distance was greater before the folding) or (2) the presence of an off-setting structure not recognized in the relatively homogeneous quartzo-feldspathic rocks. In most areas of metamorphic rocks it is difficult to correlate thin or lenticular beds over any appreciable distance.

## ECONOMIC GEOLOGY

Philip B. King and Peter T. Flawn

### COPPER AND SILVER

#### GENERAL CONSIDERATIONS

**Introduction.**—Vein deposits containing metallic sulfide minerals occur in a number of places in the pre-Cambrian rocks of the eastern part of the Sierra Diablo foothills and to a lesser extent in the Carrizo Mountains and elsewhere. Ore has been produced intermittently from a number of mines since 1880, and the veins in other places have been explored by numerous prospects. The principal metals of the deposits are copper and silver, but some deposits also contain zinc and lead.

The most prolific mine in the district is the Hazel, which lies near the foot of the Sierra Diablo 10 miles northwest of Van Horn; it is one of the oldest mines in Texas and is the largest copper producer in the State. Production from the other mines has been considerably less. Total production of the district is difficult to estimate because records are fragmentary or lacking, especially for the period before 1900. A possible approximation is as follows:

Table 26. Estimated total production of Allamoore-Van Horn copper-silver district.

Mine	Ore produced (tons)	Copper (pounds)	Silver (ounces)
Hazel	110,000	1,500,000	4,000,000
Blackshaft	13,000	740,000	4,000
Sancho Panza	8,500	400,000	7,000
Pecos	100	4,000	100
Mohawk	300	12,000	300
St. Elmo	350	14,000	350
Hackberry	610	8,600	20,000
Totals	132,860	2,678,600	4,031,750

**Mining conditions.**—Ores of the district are of relatively low grade, and although some rich pockets were encountered in the early days of mining, the ores as a whole average  $2\frac{1}{2}$  to 3 percent of copper. Most of the production of the district is therefore marginal and is dependent on unusually favorable economic conditions, so that there has not been sustained production from any deposit. The low grade of the deposits is counterbalanced to some extent by the fact that the district is a relatively short

distance by rail from the American Smelting & Refining Company's smelter at El Paso. The present freight rate from Allamoore to the smelter, a distance of 110 miles, is \$3.77 per ton (plus 3 percent Federal tax) for ore valued at less than \$75.00 per ton. Most of the deposits lie within 10 miles of the rail shipping points of Allamoore and Van Horn, with which they are connected by Federal and State highways, and by good, though little improved, access roads.

Most of the ore bodies are in narrow, steeply dipping veins, so that they must be worked primarily by underground methods. The deepest workings of the district, at the Hazel mine, extend 746 feet below the surface, although most of the mining here has been at shallower depths. At only one mine, the Sancho Panza, is the structure such that the ore may be extracted from open cuts.

The climate of the district is such that mining may be conducted all year. As the climate is arid or semi-arid, with less than 12 inches of rainfall per year, water is scarce, and timber suitable for mining purposes is unobtainable locally. It is reported that failure of one of the mills that was set up in the area was largely due to lack of sufficient water. Most of the ores that have been mined were not milled before shipment but were sent to the smelter without beneficiation other than hand sorting.

**Ore bodies.**—The metallic mineral deposits of the district occur in four principal associations, of which only two have yielded production:

(1) The Hazel type of deposits includes the Hazel, Mohawk, and Pecos mines and the Marvin-Judson and Eureka prospects, all of which lie in the northern part of the district, near the foot of the scarps of the Sierra Diablo. These deposits are in vertical fissure veins or mineralized fractures, lying in gently dipping compact red sandstones of the Hazel formation. The veins are commonly indicated in surface outcrops by bleaching of the red sandstones immediately adjacent. They consist of zones a few

feet to 40 feet wide of bleached, brecciated, and sliced country rock, interlaced with a gangue of barite and other minerals, which contain sulfides of copper, silver, and other metals.

Areal mapping discloses that the Hazel type deposits are not haphazardly located but occur in two structural zones—one a system of en echelon fractures about  $3\frac{1}{2}$  miles in length, trending nearly east and west, on which the Hazel, Marvin-Judson, and Mohawk deposits are located (Pl. 2); and the other a set of similar fractures about 2 miles in length, trending north-northeast, on which the Pecos and Eureka prospects are located (north of Pl. 2; see fig. 19 and King and Knight, 1944).

(2) The Blackshaft type of deposits includes the Blackshaft, St. Elmo, and Sancho Panza mines and is confined to a belt about  $1\frac{1}{2}$  miles long immediately north of the Millican Hills (Pl. 2). The Blackshaft type of deposits are in crushed, sheared, and silicified limestone, phyllite, and igneous rock of the Allamoore formation, and associated fault gouge, which forms a bed a few feet thick along a "surface of movement," or low-angle thrust fault, enclosed by the Hazel formation. The bed is folded into an irregular syncline, so that it dips steeply in the southwest part and very gently in the northwest part, where it crops out over a wide area and is susceptible to open cut mining. The crushed and sheared rock of the Allamoore formation has been veined and replaced by gangue minerals and metallic sulfides, principally of copper, although there are occasional rich silver-bearing pockets.

(3) Other deposits have been prospected in the Allamoore formation and Carrizo Mountain group. These include the Anaconda no. 1 and no. 2, Cooper Hill, Bluebird, and Buck Spring prospects in the Millican Hills. In all of them, mineralization seems to have taken place in narrow, unsystematic veins and veinlets, and there is little evidence of replacement of limestones or other host rocks. Prospecting so far has failed to yield any sizeable ore bodies, and no ore is known to have been produced from the deposits.

(4) A different kind of deposit, at the Dallas prospect, is perhaps unique, as it occurs in veins in the Allamoore formation adjacent to a fault of pre-Ordovician (pre-Bliss ?) age, which has thrown the Van

Horn sandstone down against the Allamoore. No ore is known to have been produced from the deposit.

*Origin and age of deposits.*—In all the types of ore deposits just described, narrow, previously formed zones of weakness in the country rock have been veined and replaced by gangue and metallic minerals brought in by mineralizing hydrothermal solutions. The zones of weakness are of diverse character and lie in various sorts of country rock, but the ore deposits themselves are of such similar make-up as to suggest that they all were formed from a common cause and at about the same time.

The dominant occurrence of the deposits in the pre-Cambrian rocks, and the general lack of such deposits in the Paleozoic and Cretaceous rocks of the same area, might at first lead one to suppose that they were formed before Cambrian time. An even closer dating is suggested by the Dallas deposit, which is along a fault formed after Van Horn and before Bliss (?) time.

Much evidence suggests, however, that the deposits are actually considerably younger. Although metallic ore deposits are generally lacking in the younger rocks there is occasional indication of weak mineralization. The Bliss (?) and El Paso formations above the Dallas fault are broken by strong joints parallel to the fault which contain iron oxides probably weathered from sulfides. The Hueco limestone above the Pecos mine is cut by veins, following the Cox Mountain fault zone, that contain gangue minerals and iron oxides like those in the Bliss (?) and El Paso above the Dallas fault.

The zone of weakness in which the Blackshaft type ore deposits was emplaced was certainly formed in pre-Cambrian time, but there is much doubt about the age of the zones of weakness in which the Hazel type deposits were emplaced. As indicated in the discussion of the structure of the Sierra Diablo foothills, the age and origin of the Hazel-type fractures is something of a mystery. They run across the dominant west-northwest "grain" of the country rock, apparently without offsetting or being offset by it, yet the dominant "grain" seems to have originated in late pre-Cambrian time and to have been subjected to intermittent movement until the late Tertiary. First movements on the west-northwest "grain" produced transcurrent faults with



considerable strike-slip displacement, and the Hazel-type fractures must be younger than these movements. One fault which shows strike-slip displacement elsewhere in its course crosses a Hazel fracture near the Marvin-Judson prospect (L.5—12.5, Pl. 2) and does not offset it. Later movements on the west-northwest "grain" were apparently dominantly vertical and could displace the vertical Hazel-type fractures without offsetting them laterally. Whatever the age of the Hazel-type fractures, the ore deposits which they contain are younger, perhaps much younger.

In view of the wide extent and long history of the west-northwest "grain" throughout the area, it is surprising that joints and faults of this trend should show so little mineralization. Apparently they were much narrower and tighter than the fractures of Hazel type.

Regional considerations suggest that the metallic ore deposits of the district may have been emplaced during Tertiary time. Paleozoic and Cretaceous rocks contain mineral deposits in the Eagle and Quitman Mountains not far to the southwest in Trans-Pecos Texas (Baker, 1927, pp. 63-66), and similar deposits are widely distributed in adjacent parts of New Mexico and Chihuahua. Tertiary intrusive and volcanic rocks are also common throughout the region. The ore deposits may be principally in the pre-Cambrian rocks, not because the deposits are old, but because the pre-Cambrian rocks were lower and nearer the source of hydrothermal solutions, and because the pre-Cambrian rocks have been much more deformed and fractured than the Paleozoic and later rocks which overlie them.

**Ore reserves.**—Estimation of reserves of metallic ores in the district is difficult. The ore bodies occur erratically in narrow veins whose thickening and thinning cannot be predicted, or projected for any distance. Sample and Gould (1945) offer the following estimate, based on ore indicated or inferred in or adjacent to present mine workings (Table 27).

They concluded in 1945 that "the present outlook for substantial copper production from the district is not promising. \* \* \* The ore is low in grade and occurs in lenticular bodies which cannot be predicted from surface exposures or underground workings. Following the mineralized zone

underground seems to be the only sure method of staying in ore. Pinching, swelling, and cross-shearing in many places complicate exploration."

Table 27. Estimate of ore reserves of Allamore-Van Horn district, by R. D. Sample and E. E. Gould.

Mine	Indicated ore (tons)	Inferred ore (tons)	Grade (percent of copper)
Blackshaft	1,000	5,000	2½-3
St. Elmo		500	2½
Sancho Panza	100	2,000	2½-3
Hazel	1,000	10,000	2-3
Others		1,000	2-3
Totals	2,100	18,500	2½

On the other hand, Evans (1943) states that "The ore reserves of the district, and particularly in the south [Blackshaft] area, are believed to be much greater than was heretofore suspected," but his account is too brief to present evidence for this conclusion.

**Recommendations for further exploration.**—Sample and Gould (1945) recommend further exploration in the Blackshaft area: (1) in the vicinity of the Blackshaft mine to determine how deep the present mineralized zone continues below the lowest workings, (2) the areas around both the St. Elmo and Sancho Panza workings to determine the extensions of the several lenses. Sample and Gould did not make detailed recommendations regarding the Hazel mine, due to the inaccessibility of the underground workings.

Flawn, as a result of detailed surface surveys of the Hazel area and study of records regarding the underground workings, suggests the following as worthy of investigation there: (1) The undeveloped ground between the East and West shafts. Probably the most favorable area is 100 to 150 feet south of Tom Owens' house (Pl. 12), where sandstone on the surface shows extreme shattering and where, as projected, a number of fractures intersect. Such prospecting could be done economically by core drilling. (2) The lower levels of the mine. Von Streeruwitz records a vein width of over 40 feet below a depth of 500 feet. Although there is no reliable information as to the nature of mineralization at this depth, the unsubstantiated report that silver values de-

crease downward while copper values remain steady is worthy of investigation. If a strong wide vein containing 2 to 3 percent copper throughout extended laterally and downward from the lower levels of the main shaft it could probably be worked profitably under present economic conditions. As with most of the underground workings of the district, examination and exploitation of deeper levels of this mine would require dewatering.

In a larger view, further exploration of deposits of Hazel type would seem to offer greater promise than exploration of the other types listed. Deposits in the Allamoore formation and Carrizo Mountain group, although widely dispersed, have consistently failed to yield production. Deposits of Dallas and Blackshaft type are confined to very limited areas. The Dallas deposit has yielded little if any production. Much ore has been produced from the Blackshaft type deposits, and more could probably be developed in the immediate vicinity of the existing mines by following the recommendations of Sample and Gould. Nevertheless, the ore-bearing structure terminates laterally within short distances of the known deposits and does not reappear elsewhere; no similar structures have been discovered by detailed mapping of the Sierra Diablo foothills.

By contrast, the Hazel-type deposits are extensively distributed—yet they are not haphazardly located, as geologic mapping indicates that they all lie along two structural zones, one trending nearly east and west and the other north-northeast. The fractures on which the deposits occur, although probably not mineralized for their entire length, are each traceable for several miles on the surface. The fact that the vein system widens downward at the Hazel mine suggests that at this locality the surface lies near the top of an ore-bearing structure. It is possible that elsewhere along the two structural zones there may be other ore-bearing structures which do not reach as near the surface. Such possible hidden ore bodies could be searched for by very detailed geological mapping of the outcrops of the fracture zones, accompanied by microchemical testing and geophysical (especially electrical) surveying and followed by core drilling of favorable areas. Of the two structural zones, that trending east and west would seem to be the most favor-

able as it includes along its course the prolific Hazel deposit and as the known mineralization on the north-northeast zone appears to be weaker. The probable maximum reward of such exploration would be a deposit of about the rank of the Hazel, with the likelihood that anything discovered would be smaller, less prolific, and probably deeper.

A more remote possibility for exploration would be to drill below the Hazel formation in the fracture zone to determine the nature of mineralization in the Allamoore formation, on the chance that it might there have created larger ore bodies of replacement type. However, structural evidence suggests that the Hazel formation at the Hazel mine is at least several thousand feet thick, so that the Allamoore formation is probably beyond the reach of economical mining, and perhaps even beyond the reach of drilling. Moreover, mineralization of the Allamoore formation, where this unit is exposed in the Millican Hills, does not seem to have produced any replacement deposits.

*Outlook of district.*—The future possibilities of a district can be judged to some extent by its past record. Some deposits in the present district, such as that at the Hazel mine, have yielded spectacular rewards during short periods, as rich pockets were discovered and mined, but over the whole life of the district it is doubtful whether returns have greatly exceeded the capital invested. Even the modest revival of mining during World War II was not conducive to profitable operation on a long-term basis, as it was achieved by robbing and gouging of ores remaining in existing workings, with few discoveries of new deposits, and to the detriment of renewed mining in the deeper workings because of dumping of waste and removal of supporting ground. The average low grade of the ores and inconsistency of the deposits has prevented an orderly program of development and has kept operations in the district on a marginal basis. Considerations such as these prompted the generally unfavorable judgment expressed by Sample and Gould (1945), quoted under an earlier heading (p. 151).

Nevertheless, a mineralized district within short rail haul of smelters would seem to merit careful consideration, as deposits could profitably be worked there which could not be operated economically

in districts more remote. At least some of the capital invested in the district has been unwisely used, and the reputation of the district has not been such as to attract capital backed by experience and technical skills. Such experience and skills are vitally needed if the life of the district is to be prolonged. The ground has been rather thoroughly prospected, so that it is unlikely that any outcropping ore bodies have escaped notice. Discovery of hidden ore bodies can be accomplished only by scientifically and technically skilled exploration. Exploration along the lines suggested under the preceding heading might result in discovery of new ore bodies up to the rank of the original Hazel deposit, which would provide limited but profitable production of copper and other ores.

#### HAZEL MINE<sup>22</sup>

*Introduction.*—In preparation of this account, Flawn made a detailed plane-table survey of the surface of the property (Pl. 12) in 1951 and assisted Virgil E. Barnes in making a gravity meter survey of the property in 1952 (see Appendix, II). Underground workings were not inspected because they were under water, but all available published and unpublished reports and records were carefully examined, and much additional information was obtained from local operators.

Published reports include those of Von Streeruwitz (1890, pp. 224–235; 1891, pp. 665–713; 1892, pp. 383–389; 1893, pp. 141–167); Richardson (1914, p. 8); Sample and Gould (1945); and the yearly records in “Mineral Resources of the United States” and “Minerals Yearbook.” Unpublished records include notes made by P. B. King and S. J. Lasky during an examination of the property in 1938 and maps by the World Exploration Company made in 1928 to 1930. Permission to use the latter in this report has been granted by the Hazel Mining & Milling Company, the present owners. Additional information was obtained from interviews with A. P. Williams of Van Horn and others. Because of the current copper shortage, a separate report on the Hazel mine was published in advance of this text to aid in exploration of the property (Flawn, 1952).

*Location and access.*—The Hazel mine is 10 miles northwest of Van Horn and 9 miles northeast of Allamore, in red sandstone country at the foot of the southeastern angle of the Sierra Diablo (0.5–13.5, Pl. 2). It lies in Culberson County, a little east of the Culberson-Hudspeth County line. Present access is from Van Horn, from which it is 14.6 miles distant by road, via State highway No. 54 and a secondary road to the mine. A road from Allamore to the mine formerly existed but is now impassable to conventional vehicles.

The mine lies in section 14 of block 66, township 7, Texas and Pacific Railroad survey, which is a patented section owned by the Hazel Mining & Milling Company of Dallas, Texas (represented by R. B. Stichter, Jr.).

*History.*—The Hazel mine was discovered and located by Tom R. Owens in 1856, who sank a shaft 20 feet deep (pit just north of Owens' house of Pl. 12) but was shortly thereafter driven out of the country by hostile Apache Indians. Owens served as captain of artillery in the Confederate Army during the Civil War but returned thereafter, relocated the claim, and did additional development work. According to the late Jim Bean of Van Horn, Texas, T. R. Owens and a man named Miller were located on the east end of the vein, and W. H. Winn and C. S. Phinney were located on the west part of the vein in 1884, and only a few prospect pits had been made prior to this date. Shortly thereafter the property was sold to Messrs. Shriver and Andrews of San Antonio, Texas.

Shriver and Andrews operated the property until 1896, with a Mr. H. J. Clifford as mine superintendent. This period appears to have been the most profitable in the mine's history, and between 1880 and 1896 it is estimated that 80,000 tons of high-grade silver and copper ore were produced (Sample and Gould, 1945). In 1889, 10 carloads of ore a week were shipped for 10 consecutive weeks (Von Streeruwitz, 1890, p. 224). By 1890, over 200 carloads had been shipped, with vast quantities of low-grade ore left on the dump (Von Streeruwitz, 1891, p. 698). In 1892 the mine, “although not worked to its full capacity, clears \* \* \* about \$6,000.00 per month from the argentiferous copper ores shipped, besides dumping immense quanti-

<sup>22</sup> By Peter T. Flawn.

ties of ores which are regarded as \* \* \* not fit for shipment [but containing] up to 23 ounces of silver to the ton" (Von Streeruwitz, 1893, p. 151). Much of the ores are said to have been shipped to a smelter in Pueblo, Colorado, for processing. By 1891, three shafts had been put down to depths of 575, 375, and 42 feet respectively, and the main shaft was eventually carried to 746 feet, apparently before 1900.

Between 1896 and 1912 the Hazel mine was operated intermittently, without any consistent production; during this period it was purchased by a group of Dallas men. About 1912, Sutton, Steele & Steele began operations at the mine with Walter Case as superintendent and built a 100-ton reduction mill using a dry-concentration process. Equipment consisted of a Blake crusher, 12 Sutton, Steele & Steele classifiers, 5 Sutton, Steele & Steele concentration tables, and a Sutton, Steele & Steele dielectric separator. Crude ore and concentrates were shipped until May 1914, when the mine closed, although sporadic smaller shipments continued through 1917. According to local sources, mill recovery was very poor.

In the early 1920's the mine was leased by M. F. Drunzer, who did some underground work and in 1927 and 1928 shipped 12,360 tons from the old dumps; this averaged 0.5 percent copper and 9 ounces of silver per ton.

In 1928, the mine was acquired by the World Exploration Company which reconditioned the buildings, built a 65-foot headframe and 150-ton ore bin, enlarged the old shaft to 4½ by 10½ feet in the clear, and timbered and lagged a three-compartment shaft to the 340-foot level. A 100-ton flotation mill was completed in January 1930, which was equipped with 2 Sturtevant crushers (still on property), a Colorado Iron Works 6 by 6 ball mill, a Dorr duplex 5½ by 18-foot classifier, 3 MacIntosh flotation machines, an Oliver filter, and 2 Dorr thickening tanks. The mill operated for about 8 months at the rate of 31 tons per day, after which it was shut down, reportedly for lack of water. Between May and October 1930, 4,616 tons of ore were treated to yield 238.5 tons of concentrates, containing 23,262 ounces of silver and 102,583 pounds of copper. Operations of the World Exploration Company ceased at the end of 1930.

Between 1935 and 1937 the mine was operated by the Hazel Mine & Development Company, which shipped 1,034 tons of ore. Between 1938 and 1945 it was leased by A. P. Williams, who had been mechanical engineer for the World Exploration Company, and 4,396 tons of ore were shipped. In 1947, Drunzer again leased the property and made a small shipment of ore.

*Production.*—Available records indicate shipments from the Hazel mine amounting to 37,615 tons of ore, which contained 996,207 pounds of copper and 675,173 ounces of silver, but this includes very little of the rich production between 1880 and 1896, when it is estimated that 80,000 tons of high-grade silver and copper ore were produced. It would be hazardous to make a close estimate of the total production of the mine, but it may well have amounted to 110,000 tons, yielding 1,500,000 pounds of copper and 4,000,000 ounces of silver. Total value of ores shipped between 1927 and 1944 is estimated by Glen L. Evans as \$182,417.00.

Known production of the Hazel mine is listed in Table 28.

Table 28. Known production of the Hazel mine. (Compiled from U. S. Geological Survey, "Mineral resources of the United States"; U. S. Bureau of Mines, "Minerals Yearbook"; smelter records of American Smelting & Refining Company;<sup>1</sup> and miscellaneous sources).

Year	Ore (Short tons)	Copper (pounds)	Silver (fine ounces)
1856-1880 <sup>2</sup>	?	?	?
1880-			
1896	80,000 <sup>3</sup>	x	x
1891	600	42,000	353,370
1896-1905	?	?	?
1906	x	x	x
1907	0	0	0
1908	139	28,364	x
1909-1910	0	0	0
1911	x	x	x
1912	x	721	x
1913	x	34,665	x
1914	x	23,760	x
1915	x	x	x
1916	x	99,569	x
1917	x	x	x
1918-1919	0	0	0
1920	x	x	x
1921-1925	0	0	0
1926	x	10,000 apx.	x
1927	2,360 <sup>4</sup>	19,676	27,353
1928	14,810 <sup>5</sup>	180,000 apx.	123,670 apx.
1929	6,813	225,980	41,307
1930	4,616 <sup>6</sup>	102,583	23,262
1931	0	0	0

Table 28—(Continued)

Year	Ore (Short tons)	Copper (pounds)	Silver (fine ounces)
1932	x	x	x
1933	0	0	0
1934	941 <sup>7</sup>	28,800	13,359
1935	625	10,832	10,386
1936	223	7,079	3,251
1937	186	4,192	2,255
1938	373	7,217	8,183
1939	1,742	25,459	32,690
1940	1,055	33,000	18,093
1941	268	12,799	1,839
1942	469	28,242	2,081
1943	1,218	45,645	5,801
1944	326	4,909	3,579
1945	397	13,732	1,963
1946	0	0	0
1947	454	6,983	2,731
1948	0	0	0
Totals	37,615 <sup>8</sup>	996,207	675,173

? — Nothing known about status of mine.

x — Mine known to have shipped ore; figures lacking.

0 — Mine known to have been idle.

<sup>1</sup>From unpublished notes of Glen L. Evans.

<sup>2</sup>Mine located in 1856 but not developed until after Civil War.

<sup>3</sup>Estimate by Sample and Gould (1945); all ore shipped contained better than 23 ounces of silver per ton; by 1890 over 200 carloads had been shipped and there were extensive workings, including a 575-foot shaft.

<sup>4</sup>Dry silver ore with less than 0.5 percent copper, from old dump.

<sup>5</sup>10,000 tons from old dump contained 9 ounces of silver and 0.42 percent copper; 4,810 tons of siliceous ore from underground contained 7.63 ounces of silver and 1.53 percent copper.

<sup>6</sup>4,616 tons of ore produced; concentrated before shipment to 238.5 tons.

<sup>7</sup>In 1934, American Smelting & Refining Company received 855 tons, containing 27,960 pounds of copper and 11,286 ounces of silver.

<sup>8</sup>Does not include 80,000 tons estimated production between 1880 and 1896.

**Workings.**—The workings of the Hazel mine consist of three main shafts, a considerable length of drifts and cross cuts, and two open stopes. These are illustrated on Plates 13 to 16.

During the last two decades the deeper workings of the mine have been full of water, apparently as a result of gradual seep and runoff rather than large underground flows, but the water has been lowered from time to time by pumping. The mine below the 400-foot level has not been worked since the early 1900's and has apparently been under water since that time. At the time of King's and Lasky's visit in 1938, water level stood at a depth of 175 feet from the surface in the East shaft and at higher

levels in some of the adjacent shafts. In June 1944, water level was at 165 feet in the East shaft but by March 1945, had been lowered to 225 feet (Pl. 15 and Sample and Gould, 1945). In 1951, water level was within 30 feet of the surface. There is a noticeable difference in water level in the separate workings, indicating the tightness and impermeability of the country rock and vein.

The high water levels of recent decades have greatly hindered surveys of the mine and examination of its ores, so that a considerable part of the descriptions which follow have necessarily been compiled from earlier records.

The East shaft is the most important entry and is the site of the headframe and hoist house. In 1891, it was 575 feet deep and was deepened to 746 feet before 1900, although it has since not been worked below the 400-foot level. It is reported that operations in the lowest workings were abandoned because at that time cost of hoisting made it necessary for the deeper ores to be worth more than \$35.00 per ton to yield a profit. When surveyed by Von Streeruwitz in 1891 (Pl. 13) there was drifting and cross-cutting from 10 levels, each 60 to 70 feet apart, with about 600 feet of drifts and cross-cuts from the 7th to the 10th levels. Probably not much work was done later on these lower levels, and they have been full of water since about 1900. The upper six levels were reconditioned by the World Exploration Company in 1928. Most of the high-grade silver ore came from the first four levels, above 200 feet, and was worked through two large stopes, now open at the surface. The East stope is 200 feet deep, and the ore was drawn, at least in part, through the 4th level. The West stope is connected with the East shaft at the 2nd level; it is reported to have contained sporadic pockets of silver ore assaying 1,800 to 2,000 ounces per ton. Recent robbing of pillars and gouging have left the upper four levels of the mine in a dangerous condition, and waste has been dumped into stopes, cross-cuts, and down the shaft. The collar and lagging at the top of the shaft are rotted and weakened. Most of the dump surrounding the East shaft is the product of operations since 1928. The earlier dumps contained low-grade ore and were shipped and sold in 1927 and 1928.

The Middle shaft is 350 feet west of the East shaft on the southeast corner of the West stope. In 1891 it was 42 feet deep, with 40 feet of drifts. Six hundred feet west of the East shaft, immediately west of the West stope, is a shaft about 200 feet deep, inclined steeply to the south, which intersects drifts on the 3rd and 4th levels. This was put in after the survey by Von Streeruwitz, but its date of completion is unknown. Farther west, and 150 feet east of the West shaft, is the Bonanza shaft, said to have been sunk a few hundred feet on rich chalcocite ore; 50 feet to the east is a concreted ventilation raise. Many other pits and shallow shafts lie between the East and West shafts.

The West shaft is 1,800 feet west of the East shaft. By 1891 this had been sunk vertically 375 feet and there were 350 feet of drifts and cross-cuts. Little additional work has been done, except for a 25-foot stope west of the entry (G. L. Evans, personal communication, 1951). At the surface, this is a timbered double-compartment shaft, without headframe. It is surrounded by its original dump. The shaft itself was not put down in ore, and the dump shows little evidence of mineralization.

*Geology.*—The Hazel mine lies in red sandstone of the Hazel formation, which in the vicinity lies nearly horizontal or dips at a low angle to the south. According to interviews by Glen L. Evans with miners who had seen the lowest workings, the main shaft encountered "granite" near its bottom. Descriptions of this "granite" indicate that it is probably conglomerate of the Hazel formation; the shaft thus reached the lower part of the formation, although it probably ended far above its base. North of the mine at least 2,250 feet of red sandstones without conglomerate emerge; probably the conglomerate in the shaft fingers out in sandstone in this direction. Presumably the Hazel formation at the mine is underlain by Allamoore formation, but this must be far below the surface.

The Hazel is overlain unconformably by the Hueco limestone, which caps the escarpments of the Sierra Diablo to the north (Pl. 29). Not far to the northwest, the Hueco is broken by west-northwest-trending faults of the Sheep Peak fault zone (fig. 14, B), but although the mine lies on their southeastward prolongation no evidence of them could be found near

it, either on the ground or in air photographs (Pl. 2).

The mine lies in the Hazel fracture zone, a system of steeply dipping, decolorized fissures, arranged en echelon, and trending nearly east and west. The fracture zone may be plainly traced on air photographs for about 3 miles westward to the Mohawk mine. Near the Hazel mine the fracture zone shows considerable complexity in detail, with a number of main fractures offset en echelon, and with three or four minor fractures branching off northwestward (Pl. 12). There is no evident displacement on the fracture zone, although slickensides and mullion structure are reported in the underground workings.

Near the fractures of the Hazel zone the red sandstone country rock has been brecciated and bleached to yellow or gray. At the surface near the mine, the bleached sandstone is less than 7 feet wide and occurs in discontinuous patches and feathery projections. A typical outcrop of the principal mineralized fracture occurs in a small open cut 200 feet east of the East shaft. It consists of two main fractures 7 feet apart, connected by diagonal, interlacing cross-fractures, enclosing moderately crushed country rock. Bleaching of the red sandstone extends 1 to 2 feet away from the two bordering fractures and is irregular between them. The crushed country rock is traversed by barite veinlets a few inches wide, containing chalcopyrite and tetrahedrite; the metallic minerals form only a small percentage of the total volume.

Beneath the surface in the mine, the altered rock of the fracture zone solidly fills the space between the red sandstone walls. It widens downward until it attains a breadth of over 40 feet at a depth of 500 feet (Von Streeruwitz, 1892, p. 387), suggesting that the present surface of the ground lies near the top of the fissure system.

*Ore body.*—The only geologist who has been able to study the Hazel ore body to any depth was Von Streeruwitz, whose report is as follows (1892, pp. 387–389):

The gangue is nearly perpendicular. Its width to a depth of about 500 feet averages 34 feet, below this depth it widens to over 40 feet. Its longitudinal extension may be traced for several miles, and its nearly uniform thickness is ascertained for 1,800 feet by the present workings shown in the accompanying sketch [Pl. 13]. The gangue is in a fissure between a fine-grained red

sandstone \*\*\*\*\* which also forms the walls, and which, in the vicinity of the gangue, is more or less metalliferous. The gangue is a whitish-gray calcareous silicate, more or less impregnated through nearly its whole width with copper and silver sulfide and other metal combinations, and numerous richer veinlets fill the space between the two principal veins, known as the north and south veins.

The north vein runs from the outcrop to the whole depth reached at the time I made the examination (June, 1891) down to 575 feet practically perpendicularly. The south vein also runs perpendicularly to about 150 feet, when it changes its dip slightly to the north and joins the north vein at about 453 feet from the surface.

At about 300 feet from the surface another vein was struck on the south side, which joins the north vein at about 500 feet. A vein running in at 360 feet through the south wall dips nearly parallel with the north vein to the full depth of the shaft, thus forming the south vein in the deeper parts of the mine. The strike of the gangue and the veins is nearly true east and west.

The east shaft, on which most of the work has been done, is sunk on the south vein, reaching the depth of 575 feet. From this shaft every 50 feet crosscuts are made to the north vein, determining the average width of the gangue from wall to wall to be about 35 feet. From these crosscuts as well as directly from the shaft, more or less extensive drifts are run in the north and south veins, \*\*\*\*\* and the quantity and quality of ore struck by shafting and drifting in the veins is highly promising to actual mining and stoping. \*\*\*\*\*

The middle shaft is 300 feet west from the east shaft on the north vein. It is 42 feet deep, and was last June a drift about 40 feet in a material of the same character as the east shaft. The walls, as well as the gangue material in all the shafts and drifts, are sound and solid, and therefore very little timbering is required. Up to the time I made an examination of this mine no obnoxious gases were noticed, except those resulting from the blasts, and very little water was struck in the shafts and drifts.

The principal ores of the main veins, as well as the veinlets and pockets, are silver-bearing copper glance, gray copper, silver copper glance, silver glance, native silver, chlorides with more or less copper. Lead, antimony, and arsenites are found in traces, and traces of gold are not infrequent, and strongly ferruginous specimens assayed 0.95 of an ounce in gold and 13 ounces in silver. The gray copper yields very high assays up to 2,000 ounces in silver, and assays of some of the copper glance exceed 600 ounces to the ton.

These as well as the other combinations mentioned above are deposited through the vein material (calc-silicates, frequently heavy spar) widening out occasionally to pockets of considerable size, and resulting in those ores which stand shipping without concentration.

The whole gangue between the east and west shaft may be regarded as filled in with low grade ore through which the richer veins, pockets and veinlets are dispersed, and I regard it as anything but an exaggeration to estimate the value of the

ores of this mine as far as it is opened for work at 20,000,000 ounces of silver.

Summarizing the above report and later data: In the vicinity of the East shaft there are two main veins in the fracture zone, the north and the south. The north vein is essentially vertical at least to 575 feet, the lowest depth reported on. The south vein is perpendicular from the outcrop to a depth of 150 feet, where it changes to a steep north dip and joins the north vein at a depth of 400 feet. At a depth of 300 feet a third vein comes in from the south, dips steeply north, and joins the two main veins at a depth of 400 feet, just below the 8th level. The gangue between these veins is brecciated and filled with narrow anastomosing veinlets of sulfides. Mr. A. P. Williams states that in the drifts west of the East shaft, the main sulfide veins averaged 2 to 3 inches wide, with small pockets of ore where the east-west veinlets were intersected by cross fractures. In the open slope west of the main shaft was a massive body of copper-silver sulfide and barite 2 to 3 feet wide. In this area the east-west veins were intersected by a number of northeast-trending veinlets that were also mineralized.

Assay maps made by the World Exploration Company between 1928 and 1930 (Pl. 16) indicate that this company left 10,000 to 15,000 tons of broken low-grade ore, with 1 to 2 percent copper and 3 to 5 ounces of silver per ton in slopes between the 4th and 6th levels. This ore body apparently results from convergence of the north and south veins and is about 25 feet wide.

The interlacing veinlets pinch and swell along the strike, resulting in ore pockets and relatively barren areas; this has made it difficult to stay in ore or to calculate reserves. The ore is sharply contained within the massive sandstone walls on each side of the fracture zone, and is not disseminated in the country rock beyond.

*The ore.*—The following copper and silver-bearing minerals were reported by Von Streeruwitz from the Hazel mine:

- silver-bearing copper glance (chalcocite)
- gray copper (tetrahedrite)
- silver copper glance
- silver glance (argentite)
- native silver
- chlorides with more or less copper
- traces of lead
- traces of gold
- traces of antimony and arsenites

S. J. Lasky (memoranda of August 25 and October 28, 1938) reported that a steely mineral occurring as threads in the bleached rock is tennantite; also that specimens reported to have come from the upper levels of the mine were steely chalcocite; in addition, he noted pyrite, galena, chalcopyrite, and a trace of bornite. Lasky also reports as follows on a black rock found in certain parts of the vein:

The black rock that accompanies the stronger parts of the vein and that the miners say they use as a guide to ore seems to be crushed rock and vein matter that owes its color to comminuted sulfides. \*\*\*\*\* Some of this black rock has a streaked structure resembling flowage and has about the texture and hardness of some slate. In it are breccia pieces of both vein matter and of wall rock, and the adjacent wall rock is also brecciated in some places. A thin section of the black rock shows breccia pieces of rock and calcite, and grains of quartz (presumably from the original sandstone), in a cryptocrystalline matrix made gray to black by opaque dust. Examination of a polished section cut from the same fragment as the thin section fails to give any clue as to the identity of the opaque dust, the only mineral identifiable being the irregular grains of pyrite that can be seen in the hand specimen, but I obtained a good microchemical test for arsenic. Though a test for copper is negative, the positive test for arsenic would seem to indicate that some of the opaque dust is tennantite, presumably powdered so fine as not to be apparent on polished surface, perhaps because of having been gouged out during polishing.

Specimens of massive sulfide were collected by Flawn on a dump near the West shaft and three polished specimens were examined under the microscope. All consisted largely of anisotropic chalcocite intimately penetrating and penetrated by barite. Fine brecciation and flowage structures are present in all three samples. Small irregular patches of bornite (0.01 to 0.02 mm.) occur within the chalcocite and are commonly separated from the chalcocite by a very thin border of gray mineral that is probably tetrahedrite. Small masses of covellite and tiny clusters of pyrite grains occur sporadically within the chalcocite and bornite. The reported distribution of copper values in the mine and the anisotropic character and steely appearance of the chalcocite indicate it is a primary mineral.

Gangue minerals are calcite, barite, and quartz, the latter probably being derived from the original sandstone.

Three polished sections of massive metallic fragments from the dump near the East shaft show a fine intergrowth (in part a

microbreccia) of barite and a large number of metallic minerals. Chalcocite, tetrahedrite-tennantite(?), bornite, an unidentified strongly anisotropic brownish-gray mineral, chalcopyrite, native silver, pyrite, marcasite, covellite, and an unidentified pale silver-white mineral (antimony?) are present in approximately that order of abundance. The extremely fine grain size makes identification of the unknowns very difficult. Pyrite is apparently early and occurs in fractured grains which locally have been drawn out into lenses. Chalcopyrite is in part early in fractured grains and in part late in narrow veinlets parallel to the flowage structure. Bornite occurs in spongy intergrowths with tetrahedrite-tennantite(?) and in veinlets parallel to existing flowage structure. Chalcocite and the unidentified brownish-gray mineral seem to have come in late and "healed" the microbreccia, but the relations of the chalcocite and the brownish-gray mineral to the bornite-tetrahedrite-tennantite(?) intergrowths is not apparent. Native silver was the last ore mineral deposited and occurs in fractures that crosscut the earlier structures and grain boundaries. Marcasite, covellite, and the unidentified pale silver-white mineral (antimony?) are present in minute quantities. Possibly some argentite is included in what is here called tetrahedrite-tennantite (see p. 157) because the two minerals, both gray, are not easily distinguished in such a fine-grained intergrowth. A thorough study of the relations of mineral paragenesis and fracturing or brecciation would perhaps aid in the search for high-grade silver ore in the Hazel mine.

Assays of the ores are erratic and characterized by sporadic high silver values. The bulk of the high-grade silver ore came from the open stope west of the East shaft where assays as high as 1,800 to 2,000 ounces per ton have been reported. Probably the main ore minerals here were tetrahedrite-tennantite. Silver values drop to the west, and in the vicinity of the West shaft the principal sulfide is chalcocite. Most of the bleached altered sandstone gangue between the East and West shafts will assay 1 to 5 ounces of silver. An unsubstantiated report handed down from one of the early miners states that work on the East shaft stopped at 746 feet because of a decrease in silver values downward; in the early days of the mine it was necessary to



have a silver content above 23 ounces per ton to make shipping ore. The copper content of the ore apparently remained fairly constant with increased depth.

*Sequence of mineralization.*—On account of the inaccessibility of the underground workings, Flawn was unable to make first-hand observations leading to conclusions on the paragenesis of the ores. From the information available it appears that brecciation and movement occurred in the Hazel fracture zone both before and after mineralization. Thus, during underground examination King observed brecciated ore made up of angular fragments of wall rock and sulfides, cemented by calcite, and Lasky found that the black "slaty" rock that commonly accompanies the ore is finely comminuted sulfide dust.

The relation of barite to the copper-silver minerals is worthy of further study. Barite invariably occurs with the ore, although the converse is not true. Flawn has observed breccia fragments of gray sandstone surrounded by a thin coating of sulfides and the whole completely enveloped by barite; the space between the barite-coated fragments is filled by sulfide. Apparently the sulfide mineralization both preceded and followed barite mineralization, although there may have been changes in the nature of the precipitated sulfide over the period of deposition. There might thus have been a change from tennantite and tetrahedrite in the early stages to chalcocite (primary) in the final stage.

Two types of altered sandstone are present in the fracture zone—a soft crumbly yellow to buff rock and a hard gray rock containing sulfides that are visible as black spots. Probably wall-rock alteration proceeded in that sequence, first with bleaching of the red iron oxide pigment and leaching of the cement of the sandstone, then in some places, impregnation by sulfides. Both types of altered wall rock are veined by calcite and barite.

*Existing structures and equipment.*—Equipment now on the ground at the Hazel mine is in a very dilapidated and partly demolished condition (Pl. 29, B), and it is doubtful if much could be salvaged were operations to be resumed.

Three buildings are standing, the power house, bunk house or office, and hoist house, the latter partly dismantled. The timber in the 65-foot headframe is considerably deteriorated and needs repair, but the 150-ton ore bin is in good condition. The following equipment remains:

- (1) In hoist house:  
Fairbanks-Morse 60 H.P. gasoline hoisting engine (latest patent, 1909), drum and cable, presumably with ore bucket at end of cable in shaft.  
85 H.P. Bessemer gasoline engine (latest patent, 1899).  
Ingersoll-Rand compressor, Imperial type 10. Starting engine and compressor; 8 H.P. Ziegler-Schryer gasoline engine and size 45 Worthington compressor.
- (2) In power house:  
General Electric 2300-volt, 45.3-ampere alternating current generator.  
General Electric 125-volt direct current generator (exciter for large generator).  
Control panel.
- (3) At old mill site:  
Two Sturtevant Mill Co. 10 x 15 jaw crushers.  
Small gasoline engine.

#### OTHER MINES AND PROSPECTS

*Marvin-Judson prospect.*<sup>23</sup>—The Marvin-Judson prospect is 1½ miles west of the Hazel mine in red sandstone country not far from the base of the Sierra Diablo escarpment (L.5—12.5, Pl. 2). It lies in block 66, township 7, Texas and Pacific Railroad survey, a short distance west of the Hudspeth-Culberson County line.

Little is known of the history of the prospect, and there is no record of any shipments. It is reported to have been opened before 1900 and is shown on U. S. Army maps dated 1917; when first visited in 1936 it had long been idle. Workings at the prospect consist of a vertical shaft cribbed with railroad ties. The dump consists of bleached sandstone containing some barite gangue.

Study of air photographs indicates that the Marvin-Judson prospect lies at the western end of the same fracture as that on which the Hazel mine is located and near its intersection with a west-northwest-trending fault which has a pronounced scarp on its southwest side. Farther southeast the fault offsets the "north edge of the steep dip zone" of the Hazel formation by about 400 feet, apparently by dextral transcurrent movement, but according to observations by Flawn the Hazel fracture zone is not offset by it.

*Mohawk mine.*<sup>24</sup>—The Mohawk mine is 6½ miles north-northeast of Allamoore and 3 miles west of the Hazel mine in red sandstone country south of the Sierra Diablo escarpment (H.5—12.5, Pl. 2). It lies in

<sup>23</sup> From notes by P. B. King, 1936, and P. T. Flawn, 1951.

<sup>24</sup> From notes by P. B. King, 1936.

section 2, block 67, township 7, Texas and Pacific Railroad survey.

The Mohawk mine was operated mainly between 1922 and 1934 and apparently has since been idle. At the time of visit in 1936 it was leased by a Mrs. Kennery and had previously been operated by her brother. The mine has probably produced about 300 tons of ore. The following record of production is compiled from "Mineral Resources of the United States" and "Minerals Yearbook":

- 1922.—Producing.
- 1923.—Shipped several cars of dry silver ore.
- 1926.—Shipped small lot of silver-copper ore (Mohawk Mining Company's Little Lightning mine).
- 1927.—Shipped 2 cars of dry silver ore (Little Lightning mine).
- 1928.—Shipped 2 cars of silver-copper-lead ore (Little Lightning mine).
- 1929.—Shipped 1 car of silver-lead ore.
- 1930.—Shipped 76 tons of silver-lead-copper ore.
- 1934.—Shipped 4 tons of copper-lead ore containing 280 pounds of copper, 100 pounds of lead, and 79 ounces of silver.

Bed rock near the mine is red sandstone of the Hazel formation, which dips at a low angle to the south, but this is partly masked by gravel on the terrace to the west and by alluvium in the valley to the east. The sandstone is traversed by nearly vertical fractures or veins trending in various directions, near which the sandstone wall rocks have been bleached from red to yellow. The veins are 1 to 1½ feet wide and consist of mineralized gouge containing numerous sandstone fragments and wedges. The ore examined contains much pyrite and some chalcopyrite and barite; it is greatly stained by copper carbonates and iron oxides. It resembles ore from the Hazel mine but appears to be of much lower grade.

The principal vein trends N. 25°–30° E. and has been traced for nearly 1,200 feet. Near its south end is a 60-foot shaft; elsewhere it has been explored by horizontal adits in the hillsides. Rich ore is said to have been found near its north end, where several veins trending N. 60° E. intersect it. Farther northwest are two veins that trend N. 60° E. and N. 65° E. In the alluvial flat, the intersection of the two veins has been explored by a shaft 70 feet deep. At the time of visit in 1936, the two shafts were filled with water to within 16 feet of the surface.

Study of air photographs indicates that the Mohawk mine lies on the western prolongation of the same fracture system as that which passes through the Hazel mine. The N. 60° E. fractures of the Mohawk area are traceable about a mile northeastward, where they lie en echelon with the fractures which pass through the Hazel mine.

About a mile north of the Mohawk mine, also in red sandstones of the Hazel formation, are some pits which may be the Circle Ranch claim, operated by Brent Melton in 1923, from which one carload of good grade silver ore was shipped.

*Pecos mine.*<sup>25</sup>—The Pecos mine is 4 miles north of the Hazel mine on the lower east slope of the Sierra Diablo escarpment, in red sandstone country near a ranch windmill (north of Pl. 2; see map of King and Knight, 1944). It lies in the northwest part of section 23, block 54½, Public School Land survey.

The mine was first worked before 1917, was operated intermittently until 1936, and has since been idle. At the time of visit in 1936, it was leased and operated by the Leah brothers. The mine has probably produced about 100 tons of ore. The following record of production is from "Mineral Resources of the United States" and "Minerals Yearbook":

- 1917.—Shipped one car of ore.
- 1929.—Shipped one car of lead-copper-silver ore.
- 1935.—Shipped one car of copper-silver-lead ore.
- 1936.—Development work.

The Pecos mine is in gently dipping red sandstones of the Hazel formation and explores a system of steeply dipping, decolorized fractures that trend about N. 35° E. (fig. 19). During the earlier operations a 200-foot shaft was sunk near the windmill but was abandoned because of rock falls. At the time of visit in 1936, another shaft was being put down a few hundred feet to the north. The fractures are also explored by prospect pits for some distance northward and southward. The decolorized fracture zone is plainly traceable for nearly a mile on air photographs.

At the new shaft the main vein dips 70° to 80° west, and the decolorized zone along it is 5 to 10 feet wide. About 600 feet to the east is another vein nearly as wide as the first and dipping east, which converges

<sup>25</sup> From notes by P. B. King, 1936.

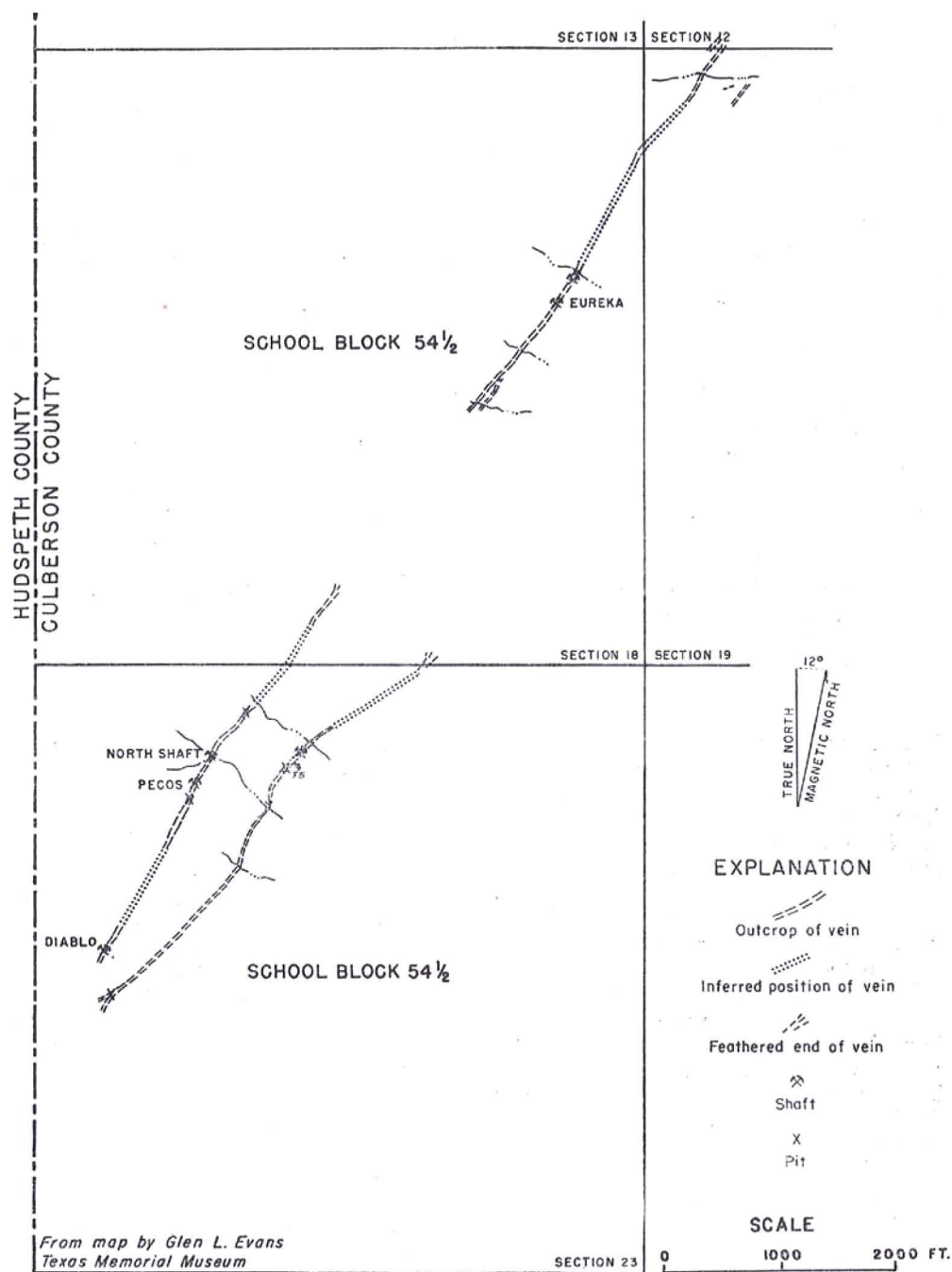


FIG. 19. Map showing copper-lead-zinc veins on east face of Sierra Diablo in vicinity of Pecos mine, Culberson County, Texas (from survey by Glen L. Evans, 1943).

southward with the first along the trace. At the surface the decolorized sandstone is yellow but changes to blue-gray at depth. Within the decolorized zone the operators describe thin streaks of strongly mineralized rock containing finely to coarsely crystalline masses of galena, chalcopryite, and other sulfides, with considerable barite gangue. Near the surface the copper sulfides are altered to green carbonate. Assays are reported to show the presence of lead, silver, copper, and zinc, the copper predominating, but with the different constituents showing great variation from place to place. According to Evans (1943):

Zinc and lead have been found in some quantity in the Pecos group of workings where they occur as complex sulfide ores, along with copper and silver, in a barite gangue. The zinc, because of difficulties produced by it in smelting processes, has proved detrimental to the ore. The smelter penalty on the contained zinc is reported to be the principal reason for suspension of operations at the Pecos mine.

On the Sierra Diablo escarpment above the Pecos mine the Hueco limestone is broken by the west-northwest-trending Cox Mountain fault, with a displacement of a few hundred feet. The beds on the downthrown side are sharply dragged and folded, but the fault plane stands nearly vertical. Farther north on the escarpment two lesser branches of the Cox Mountain fault also break the Hueco. All three faults are followed by calcite veins that contain limonite, probably altered from pyrite and other sulfides. It is reported that the Cox Mountain fault, and veined fractures related to it, is traceable down the slope through the red sandstone toward the Pecos mine, where they intersect the Pecos vein. The nature of the intersection has not been determined, but the Pecos vein does not appear to be offset laterally by the Cox Mountain fault. The weak mineralization in the Hueco suggests that the stronger mineralization in the Hazel might also have taken place in post-Hueco time.

*Eureka prospect.*—The Eureka prospect is a mile north-northeast of the Pecos mine (fig. 19), in red sandstone country on the lower east slope of the Sierra Diablo escarpment (north of Pl. 2; see map by King and Knight, 1944). It lies in the east part of section 18, block 54½, Public School Land survey. The history of the prospect is unknown. In 1945 it was under lease by Tom Suttlemyer, "who was preparing to

deepen the old shaft" (Sample and Gould, 1945). No shipments have been reported from the property.

The Eureka prospect has not been visited by the writers. It is on a mineralized fracture zone in the red sandstone of the Hazel formation which trends north-northeast (fig. 19), on the approximate northward prolongation of the vein at the Pecos mine.

*Dallas prospect.*<sup>26</sup>—The Dallas prospect is on a western spur of Beach Mountain, in the angle between Beach and Tumbledown Mountains (S.5—9.5, Pl. 2), and 2½ miles northeast of the Yates ranch house. It lies on Yates ranch property in block 66, township 7, Texas and Pacific Railroad survey.

Little is known of the history of the prospect. Von Streeruwitz (1891, p. 699) mentions promising indications of copper carbonate and sulfide on Tumbledown Mountain but does not report any development. The prospect is said to have been worked by a group of men from Dallas, Texas, but the time of operation is unknown. When first visited in 1933, the prospect had long been idle, and it has not been operated since.

The workings are on or near the Dallas fault, which drops gently dipping Van Horn sandstone down on the east against steeply tilted Allamoore formation on the west, with a displacement of about 500 feet, so that various limestone and volcanic units of the Allamoore abut in turn against the fault. The fault stands vertical or dips steeply eastward and trends generally north and south, although its course is somewhat irregular in detail. The Allamoore is sharply dragged close to the fault and is traversed by fractures that either branch from or lie parallel to the main break. Near the fault the limestone is irregularly silicified, and the Van Horn on the opposite side is bleached of its normal red color and somewhat silicified.

The Dallas fault is of pre-Early Ordovician age, as it passes beneath the Bliss (?) sandstone which forms the next projecting spur to the south. The Bliss (?) lies unconformably on the faulted rocks and is not displaced, although it is traversed by strong joints that extend upward from it and have created a shallow valley on the slope (fig. 9, B). The joints contain

<sup>26</sup> From notes by P. B. King and S. J. Lasky, 1938.

limonite veins, perhaps altered from sulfides. During a visit in 1951, it was observed that north of this locality and immediately east of the prospect workings the Bliss (?) was dropped against the Allamoore with a few feet of displacement, indicating a slight later recurrence of movement on the fault.

At the prospect, about a dozen openings have been made along or immediately west of the fault, beginning on the north side of the spur of Beach Mountain and extending about 1,000 feet southward across the south side of the spur and along the east side of the valley beyond. The openings are mostly small pits, but on the south side of the spur some adits and shafts have been driven in more than 25 feet. The workings explore the main fault and associated fractures in the limestone of the Allamoore immediately to the west. The mineralized veins, mostly in the Allamoore, are tight, narrow gouge zones, which show much copper carbonate on weathered surfaces. In a less weathered, deeper pit on the south side of the spur, the veins contain chalcopryite, chalcocite, calcite, and quartz, suggesting that the prevailing carbonates change to sulfides with depth.

The occurrence of an ore body on a fault of post-Van Horn and pre-Bliss (?) age suggests the possibility that mineralization may have taken place before Ordovician time, but the weak mineralization on joints in the overlying Bliss (?) indicates that the ore deposit may have been introduced long after creation of the fracture into which it was emplaced.

*Blackshaft mine.*<sup>27</sup>—The Blackshaft mine is 6 miles northeast of Allamoore, north of the Millican Hills, on the north side of Hackberry Creek (L.5—8.5, Pl. 2; Pl. 17). It lies in section 25, block 66, township 7, Texas and Pacific Railroad survey; it is in Hudspeth County, a short distance west of the Hudspeth-Culberson County line.

The Blackshaft mine is the second largest producer in the district and has a recorded production of 12,565 tons of ore. Total amount of metal produced is not known but may have been about 740,000 pounds of copper and 4,000 ounces of silver. Only scattered records are available as to the history of the mine. It was discovered and opened before 1890, as Von Streeruwitz

(1891, p. 699) reports that there was then a 50-foot shaft on the property with a "partly decomposed" dump. The following subsequent history has been compiled from "Mineral Resources of the United States" and "Minerals Yearbook":

- 1910.—Preparing to reopen.
- 1915.—Operating?
- 1917.—One car shipped (Texas Mining Company).
- 1918.—One car shipped (Texas Mining Company).
- 1929.—Operated from May to end of year; 1,000 feet of development work done; 1,187 tons of ore shipped, averaging 0.59 ounces of silver per ton and 3.19 percent copper.
- 1930.—734 tons of ore shipped containing 411 ounces of silver and 45,059 pounds of copper.
- 1936.—Development work.
- 1937.—Operated from May to end of year; shipped 4,000 tons of copper-silver ore.
- 1938.—54 tons of copper-silver ore shipped.
- 1941.—Operated 11 months by A. P. Williams; shipped 52 tons of ore containing 21 ounces of silver and 2,641 pounds of copper.
- 1943.—Shipped 399 tons of ore containing 98 ounces of silver and 20,584 pounds of copper.
- 1944.—Operated by M. F. Drunzer; shipped 3,799 tons of ore containing 1,269 ounces of silver and 232,977 pounds of copper.
- 1945.—Shipped 1,600 tons of ore containing 408 ounces of silver and 90,555 pounds of copper.
- 1946.—Shipped 80 tons of ore containing 18 ounces of silver and 5,644 pounds of copper.
- 1948.—Operated by A. P. Williams for last few months of year and several cars shipped.

During operations by M. F. Drunzer in 1944 and 1945, about two carloads of ore a week were being shipped to the smelter in El Paso. A special premium of 8 cents per pound was received on the copper, in addition to the regular premium of 5 cents per pound. No premium was received for the silica, although the ore is siliceous and is good smelting ore. An average analysis of 60 carloads is as follows:

Table 29. Average analysis, in percent, of ore from Blackshaft mine (from Sample and Gould, 1945).

Copper . . . . .	3.2
Silver . . . . .	2 ounces per ton
Zinc . . . . .	0.1
Iron . . . . .	1.3
Lime . . . . .	9.0
Alumina . . . . .	10.1
Silica . . . . .	54.2
Sulfur . . . . .	0.5
Arsenic . . . . .	0.1

<sup>27</sup> From Sample and Gould (1945) and notes by P. B. King and S. J. Lasky, 1938.

The country rock of the Blackshaft mine is red sandstone of the Hazel formation in which, in the vicinity, are a few thin interbedded layers of conglomerate. Lying in the sandstone is the ore-bearing bed or zone, made up of highly crushed and sheared Allamoore formation—a complex of shale, tuff, and limestone, in part converted into fault gouge. Shale and shaly gouge dominate near the main shaft, but tuffaceous rock is common farther east.

At the collar of the main shaft the zone is 5 feet thick, dips  $70^{\circ}$  N., and strikes N.  $70^{\circ}$  E. Eastward, it is traceable 800 feet, where it disappears in a dry wash and is not known to reappear. Westward it extends a few hundred feet to the gravel channel of Hackberry Creek, beyond which its position is indicated only by calcite veins and decolorized streaks in the red sandstone. Between here and the St. Elmo mine, ore-bearing material reappears in occasional small lenses.

Downward in the main shaft the  $70^{\circ}$  dip of the ore-bearing zone is maintained to the 80-foot level, below which it flattens to  $50^{\circ}$ , which inclination continues to the lowest workings (Pl. 17, section C-C'). In the workings, the hanging wall of the zone is a firm, smooth sandstone surface, but the footwall is less regular and definite and in places contains large horses of barren sandstone. The zone pinches and swells, partly by cross-faulting, so that the wall rock is as much as 15 feet apart in places and nearly closes in elsewhere.

The richest copper ore is in black, coal-like gouge between the crushed, schistose layers. This black, shaly gouge varies from a thin seam to lenses more than 10 feet thick. In places it fills the zone from wall to wall but thins rapidly within a few feet. The black layer is the one most sought by the miners as it is richest in copper sulfides (and has given the name to the mine); values decrease gradually away from it into the enclosing schistose layers. The rich layers usually lie near the firm, smooth hanging wall, and the ore zone is leaner toward the irregular and less definite footwall. Disseminated copper minerals are rare in the country rock. The lens-like shape of the ore bodies is probably due to movement along the undulating fault plane. Movement probably tended to open certain parts of the zone, into which the soft gouge was squeezed, and which in turn formed a

channel for circulation of mineralizing solutions. Much of the gouge assays more than 6 percent copper, but in mining its grade is reduced by admixture with the lower grade schistose rock.

The sulfide minerals in the ore vary somewhat. During examination in 1938, chalcopyrite, pyrite, and pyrrhotite were noted, but S. J. Lasky (memorandum of October 28, 1938) reports that "the principal mineral at the Blackshaft mine is bornite," and Medora H. Kreiger (memorandum of 1944) has identified chalcocite. Mrs. Kreiger reports as follows on study of thin sections and polished sections of black gouge collected by Sample and Gould:

The sulfide mineral is chalcocite. This determination was made by means of etch tests. No other sulfides were found on the one polished surface examined. Most of the chalcocite occurs in veinlets cutting across the rock structure. Brief examination of a thin section showed quartz veinlets, many of which cut across the structure of the rock. Associated with the quartz veinlets are tiny grains of a mineral of lower index than the quartz, which are probably feldspar. \*\*\*\*\* Some of the chalcocite occurs in the center of the quartz veinlets, but other veinlets are not associated with quartz. \*\*\*\*\* The main mass of the rock is a black, fine aggregate of dust-like particles with occasional small angular quartz grains.

From the surface the main inclined shaft follows the ore-bearing zone for 80 feet with a dip of  $70^{\circ}$  to the first level, then flattens to  $50^{\circ}$  for 55 feet to the second level, and so continues another 60 feet to the third level, the lowest in the mine (Pl. 18). The best ore was obtained in an area 100 feet west and 300 feet east of the main shaft. Drifts have been run along the ore zone for several hundred feet in either direction from the shaft on the first and second levels. On the third level, drifting extends only 50 feet to the west. There are also a few short drifts between the first level and the surface.

In the west drift on the second level the ore zone is made up largely of black gouge to a thickness of more than 15 feet for a distance of 100 feet, and this has been stoped from wall to wall. Farther west the zone pinches to a few inches, and the black gouge practically disappears. Along the east drift on the same level the ore zone follows the hanging wall, which is almost a smooth plane; the footwall weaves in and out, causing the crushed zone and gouge to thin and thicken from a few inches to more than

10 feet. About 500 feet from the main shaft the mineralization is very weak and drifting was discontinued. The richest ore shoots have been stoped from the second to the first level.

About 300 feet east of the main shaft, near the eastern end of the mineralized zone, an inclined shaft follows the zone downward for about 90 feet. The lower 20 feet was filled with water in 1944; above this the ore-bearing zone is 4 to 8 feet thick but shows only weak copper sulfide and carbonate mineralization in thin stringers in the schist.

West of Hackberry Creek, in one of the scattered lenses of ore-bearing material, is a shallow incline which shows very patchy low-grade copper mineralization.

*Hackberry mine.*—The Hackberry mine lies a short distance south of the Blackshaft mine across Hackberry Creek, in the north part of the Millican Hills. The deposit was discovered after the survey of the area was made by King in 1938 and has not been examined by him.

According to Sample and Gould (1945), "M. F. Drunzer, operator of the Blackshaft mine, is prospecting some small veins south of the Blackshaft which, according to assays, show promise of producing considerable amounts of silver with a fair amount of copper. Assays from surface workings show 200 ounces per ton of silver and 8 to 10 percent copper from a 6-inch width of vein. However, these veins are narrow and unless they widen downward, mining at depth will not be profitable." The "Minerals Yearbook" reports that in 1945 M. F. Drunzer and Lewis Stumberg shipped from the Hackberry mine 610 tons of dry silver ore with 19,547 ounces of silver and 8,633 pounds of copper.

The ores of the Hackberry mine are not in the same zone as those of the Blackshaft mine but are in veins that cut conglomerate and red sandstone of the Hazel formation.

*St. Elmo mine.*<sup>28</sup>—The St. Elmo mine is about half a mile west of the Blackshaft mine (K.5—8.5, Pl. 2; Pl. 17), in the southeast part of section 13, block 67, township 7, Texas and Pacific Railroad survey.

Little is known of the history of the mine. It was not mentioned by Von Streeruwitz, and the first recorded production was in 1929, when two carloads of copper ore

were shipped. In 1944 it was operated by John Heath and Lewis Stumberg of Van Horn, who shipped 10 carloads of ore which averaged less than 2½ percent copper. Total production of the mine has probably been about 350 tons of ore.

The St. Elmo mine lies in the same crushed and contorted zone of the Allamoore formation as that at the Blackshaft mine, although its structure is much more complex. On the ridge southeast of the mine the zone is overturned and dips 70° S., but it reappears in several folds to the north (Pl. 17, section B-B'). The workings consist of three shafts, the main one about 30 feet deep, with short cross-cuts which lead to ore lenses in the zone. The ore is similar to that at the Blackshaft mine but is consistently lower in grade.

*Sancho Panza mine.*<sup>29</sup>—The Sancho Panza mine is about a mile northwest of the Blackshaft mine and not far south of the old road from Allamoore to the Hazel mine, in low hills west of a main head branch of Hackberry Creek (J.5—9.5, Pl. 2; Pl. 17). It lies in section 13, block 67, township 7, Texas and Pacific Railroad survey.

The Sancho Panza mine has a recorded production of 8,396 tons of ore. Total amount of metal produced is not known but may have been about 400,000 pounds of copper and 7,000 ounces of silver. Known history and production of the mine is indicated in the list below, which was compiled principally from "Mineral Resources of the United States" and "Minerals Yearbook":

- 1887.—Operating, according to Mint Agent.
- 1890.—Numerous shallow diggings at Sancho Panza and Don Quixote prospects; ore to value of \$10,000.00 has been shipped, and considerable quantities of low-grade ore lie in scattered dumps (Von Streeruwitz, 1891, p. 699).
- 1922.—Producing.
- 1928.—3,000 tons of silver-copper ore shipped.
- 1939.—Operations began in September and small shipments continued rest of year.
- 1942.—Shipped 3,548 tons of silver-smelting ore, containing 2,335 ounces of silver and 172,801 pounds of copper.
- 1943.—Operated by M. F. Drunzer from January to June; shipped 1,727 tons of dry silver ore containing 739 ounces of silver and 75,607 pounds of copper.
- 1944.—Shipped 35 tons of ore.
- 1945.—Shipped 86 tons of ore containing 1,347 ounces of silver and 1,000 pounds of copper.

<sup>28</sup> From Sample and Gould (1945).

<sup>29</sup> From Sample and Gould (1945) and notes by P. B. King and S. J. Lasky, 1938).

1948.—Operated by A. P. Williams for last few months of year and several carloads of ore shipped.

The average copper content of the ores from the Sancho Panza mine is reported to be about  $2\frac{1}{2}$  percent, but there has generally been sufficient silica content to command a premium as fluxing ore.

The Sancho Panza mine is in the same bed or zone of crushed and sheared Allamoore formation as that of the Blackshaft and St. Elmo mines. Here, however, the bed and its enclosing red sandstone lie in the trough of a syncline and dip gently eastward, with minor wrinkles and rolls, and in places lie horizontal (Pl. 17, section A-A'). The main outcrop of the bed is on the ridge west of the workings, but it is brought to the surface for 1,500 feet or more to the east by minor folds. Because of the structure, the principal workings at the Sancho Panza mine are open cuts, and all the shafts and drifts are shallow.

Most of the ore has been mined from two open cuts, designated as Sancho Panza no. 1 and Sancho Panza no. 2 (Pl. 17). Sancho Panza no. 2 lies not far west of Hackberry Creek and has an area of about  $1\frac{1}{2}$  acres; it appears to have been the earliest worked but was considerably enlarged during World War II. Sancho Panza no. 1 lies about 1,400 feet to the northwest and has an area of less than an acre; it was apparently opened during World War II, as it was not seen by King in 1938 and 1939. The ore-bearing bed west and northwest of Sancho Panza no. 2 has been explored by numerous pits and a few shallow shafts, but apparently little or no ore has been mined from them.

The open cut of Sancho Panza no. 2 exposes an ore-bearing bed 4 to 6 feet thick that dips mainly at a low angle to the southeast and is overlain and underlain by red sandstone. The bed is a gray, fine-grained, siliceous rock which may have been formed by thorough silicification of a highly sheared limestone. The bed is made up of wavy, irregular lenses, and contains remarkably convoluted laminae that appear not to be bedding. Specimens of the rock collected by Sample and Gould were examined by C. S. Ross, who reports as follows (memorandum of 1944):

Specimens 1, 2, 3, and 5 all show evidence of closely spaced crush zones. These rocks have been thoroughly replaced by quartz and calcite, and

there is abundant apatite in no. 3, and possibly in the others. Replacement is so thorough that the nature of the original rock is somewhat problematical. However, there is no evidence of volcanic tuffs or other igneous rocks.

The bed is full of calcite stringers and lenses which contain scattered sulfides, such as chalcopyrite. Joints and fractures are coated with copper carbonate, which appears to be the principal source of copper in the ore. No mineralization is evident in the overlying or underlying sandstones.

Sample and Gould state that east of one of the open cuts (which one not specified) the ore-bearing bed has been mined from underground workings. The hanging wall of red sandstone is very pronounced and firm; the mineralized zone dips gently northeast and apparently pinches out down dip. Underground mining was discontinued when copper assays began to run less than  $2\frac{1}{2}$  percent.

Some of the workings west and northwest of Sancho Panza no. 2 expose siliceous rock like that in the open cuts, but this is overlain by tuffaceous clastics. The siliceous and tuffaceous rocks contain calcite veins and copper carbonates as impregnations and joint coatings. Near the northwest end of the area King in 1939 observed a shaft 25 feet deep (not identifiable on Sample and Gould's survey, Pl. 17) which follows a nearly vertical north-trending mineralized fracture in gently dipping red sandstone; this contains copper carbonate.

Throughout the area west and northwest of Sancho Panza no. 2 are many outcrops of fine-grained igneous rocks. A specimen from one of these, collected by Sample and Gould, was studied by C. S. Ross (memorandum of 1944) who reports that it is a diabasic rock that has been thoroughly altered to calcite and chlorite. These igneous rocks were interpreted by Sample and Gould as younger than the Allamoore formation with which they are associated, and they are indicated as doubtfully of Tertiary age on Plate 17. King, however, regards them as one of the volcanic units of the Allamoore formation.

*Anaconda no. 1 prospect.*<sup>30</sup>—The Anaconda no. 1 prospect is about 2 miles east of the Carren ranch house near the north edge of the Millican Hills (J.5—7.5, Pl. 2). It lies on Garren ranch property in

<sup>30</sup> From notes by P. B. King and S. J. Lasky, 1938.



block 67, township 8, Texas and Pacific Railroad survey. Little is known of the history of the prospect, and there is no record of any shipments from it; it is known to have been worked for a time by Tom Suttlemeyer. The prospect was idle when visited in 1933 and 1938.

The workings are in limestones and volcanics of the Allamoore formation near their contact on the north with conglomerates of the Hazel formation. They consist of half a dozen shallow pits and a short adit, distributed over a distance of about 1,000 feet, which explore a mineralized fracture, or group of closely spaced parallel fractures, trending N. 85° W.

The adit, which is about midway in the group of workings on the west side of a low hill, is in green aphanitic igneous rock a few feet from its contact with conglomerates of the Hazel formation. Along the fracture zone in the tunnel the igneous rock is much bleached, and there are veins of milky quartz, calcite, and a pink mineral which Lasky states (memorandum of October 28, 1938) "is simply pink, ferriferous, manganiferous calcite, rather than ankerite." The veins contain pyrite and a little chalcopryite, but the absence of copper carbonates on weathered surfaces suggests that the copper content of the sulfides is low.

A pit 5 feet deep in similar igneous rock farther east up the hill slope shows somewhat greater copper mineralization. The calcite veins are stained with copper carbonate and contain both chalcopryite and black mineral aggregates, regarding which Lasky states (memorandum of October 28, 1938): "The blebs of dark mineral that are associated with the chalcopryite give strong microchemical tests for copper and arsenic and are doubtless tennantite; a little bornite is present."

Pits west of the tunnel show narrow quartz and calcite veins that contain chalcopryite and are much stained by copper carbonate and iron oxide.

*Anaconda no. 2 prospect.*<sup>31</sup>—The Anaconda no. 2 prospect lies about half a mile west of Anaconda no. 1 in low, rounded, greenish hills of volcanic rock near the north edge of the Millican Hills (I.5—7.5, Pl. 2). It lies on Garren ranch property in block 67, township 8, Texas and Pacific Railroad survey. Little is known of the his-

tory of the prospect and there is no record of any shipment from it; it is known to have been worked for a time by Tom Suttlemeyer. The prospect was idle when visited in 1933 and 1938.

The prospect is in a wide band of volcanic rocks of the Allamoore formation, made up of massive amygdaloidal flows, with interbedded tuffs and impure limestones. No regular vein system is evident, and the openings are scattered haphazardly over a tract of 3 or 4 acres. The workings include several pits and two shallow shafts, the deepest extending about 40 feet. Little evidence of mineralization was seen in the dump of the deeper shaft, but the rock in pits farther west shows spectacular copper carbonate stains on joint faces. The rock is penetrated by minute irregular calcite veinlets, containing lenses and blebs of chalcopryite and specular hematite.

*Cooper Hill prospects.*<sup>32</sup>—The Cooper Hill prospects lie on the high ridge east of the county road 2½ miles northeast of Allamoore and 1 mile south of the Garren ranch house (E.5—4.5 to G.5—4.5, Pl. 2). They are on Garren ranch property in block 67, township 8, Texas and Pacific Railroad survey. No information is available as to when or by whom the prospects were worked.

The ridge consists in its northern part of massive conglomerate of the Hazel formation and in its southern part of limestone of the Allamoore formation, the latter being strongly sheared, marmorized, and overturned northward along the "surface of movement" which separates the two formations. For a distance of about three-fourths mile east of the county road the limestone immediately south of the contact has been explored by ten or more pits and short adits. Except for some copper carbonate stain in the rock on the dumps, little evidence of mineralization is visible. One of the prospects toward the west has broken into a cave, and cave onyx is present on the dump.

*Bluebird prospect.*<sup>33</sup>—The Bluebird, or John D., prospect is 2 miles northeast of Allamoore on a low ridge rising from the alluvial flat south of the Millican Hills (E.5—3.5, Pl. 2). It is on Garren ranch property and lies on the boundary between section 16 on the south and 9 on the north, of

<sup>31</sup> From notes by P. B. King and S. J. Lasky, 1938.

<sup>32</sup> From notes by P. B. King, 1938.

<sup>33</sup> From notes by P. B. King, 1936.

block 67, township 8, Texas and Pacific Railroad survey. At the time of visit in 1936 it was leased by Tom Suttlemeyer, but it was idle when visited again in 1938.

The prospect lies in nearly vertical beds of calcareous conglomerate of the Hazel formation. It is explored by a shallow pit which the prospector stated contained showings of silver chloride, but there seemed to be little evidence of mineralization.

*Buck Spring prospect.*<sup>34</sup>—The Buck Spring prospect is in the south part of the Millican Hills, near the head of a drainage which leads south past Buck Spring, and is 4 miles east-northeast of Allamoore (J.5—3.5, Pl. 2). It lies on Garren ranch property in section 14, block 67, township 8, Texas and Pacific Railroad survey. At the time of visit in 1936 it was leased by Tom Suttlemeyer, who was doing a little development work, but it was idle when revisited in 1938. Sample and Gould's map (1945) indicates a near-by Welge prospect, but no information on this is available.

The prospect lies in the Allamoore formation, whose beds of limestone, volcanics, and phyllite extend nearly vertically across the property.

On the north bank of a small wash, a shaft nearly 20 feet deep has been sunk in dense greenish tuff and talcose phyllite. The prospector stated that the rocks of the shaft contain silver and gold, with pockets of richer ore scattered through the leaner rock; very little evidence of mineralization could be observed. About 200 yards down the wash to the southeast is a vein of iron oxide  $1\frac{1}{2}$  feet wide, dipping southeast, in crumpled calcareous slate; the prospector stated that this contained some gold.

*Prospects in Carrizo and Eagle Mountains.*<sup>35</sup>—Numerous thin veins of quartz and carbonate traverse the rocks of the Carrizo Mountain group in the Carrizo and Eagle Mountains, and contain small quantities of copper sulfides, mostly chalcopyrite and bornite; on the surface these have weathered to malachite and other copper carbonates. These showings have been explored in times past by many shallow shafts, inclines, and adits, which are indicated on Plates 1 and 7. So far as known, no ore has been produced or shipped from

them. Richardson refers to the Maltby (Knight) prospect and the Hudson prospect in the Carrizo Mountains 5 miles west of Van Horn, but if the other workings were given names by their operators, the developments were so ephemeral that the names are no longer known to the local people.

Although these prospects are not themselves of commercial interest, they are significant in their indications of weak, but widespread and persistent, metallic mineralization in the pre-Cambrian rocks of the region.

*Unknown mines and prospects.*—Besides the mines and prospects already described, the "Mineral Resources of the United States" and "Minerals Yearbook" lists some properties with other names from the west Texas region which have yielded occasional small production. Some of these can safely be ascribed to mines and prospects already listed, and have been so assigned in the preceding text. Others are known to be outside the Allamoore-Van Horn district. Still others cannot be identified. These are listed below. They are either mines and prospects already described, mines and prospects outside the district, or mines and prospects within the district whose location is unknown to the writers.

1887.—Llewellyn and Gracie mines operating according to Mint Agent.

1906.—51,337 pounds of copper produced from miscellaneous shipments from State of Texas.

1908.—28,364 pounds of copper produced from 139 tons of ore from El Paso County (which at this time included Culberson and Hudspeth counties).

1915.—Producing mines were Allamoore, Hand of Fate, Pacific, and Texas.

1919.—One carload of copper ore shipped from Copper Queen mine, near Van Horn.

1920.—Three mines operating in Allamoore district produced 227 tons of ore, containing 2,800 ounces of silver and 14,436 pounds of copper.

1929.—Two carloads of silver-copper ore shipped from Roundtree property.

1932.—7,000 pounds of copper produced from ores of Allamoore district.

1933.—Two mines operating in Allamoore district produced 45 tons of ore containing 2,000 pounds of copper and 63 ounces of silver.

1943.—Michael Robert mine shipped 395 tons of dry silver ore containing 76 ounces of silver and 17,041 pounds of copper.

<sup>34</sup> From notes by P. B. King, 1936.

<sup>35</sup> From notes by P. T. Flawn, 1951; see also Von Streeruwitz (1891) and Richardson (1914, pp. 8–9).

MICA AND FELDSPAR<sup>33</sup>

*Introduction.*—The rocks of the Carrizo Mountain group in the exposure in the northwest part of the Van Horn Mountains (Pl. 4) are profusely intruded by mica and feldspar-bearing pegmatite, of which about 80 bodies more than 1 foot thick have been mapped by the writer. The conspicuous

mica content of the pegmatites has caused the place to be known locally as the Mica Mine area. The Culberson-Hudspeth County line bisects the mineral claims. The property consists of two patented mineral claims of one section each, M-864 and M-865, which essentially comprise the east and west halves of sections 334 and 335 and of sections 341 and 340 (fig. 20). These sections are part of the Scrap File Survey and do not carry a block designation.

<sup>33</sup> By Peter T. Flawn. Previous reports on the mica and feldspar deposits of the district include Von Streeruwitz (1891, 1893); Sterrett (1923, pp. 303-307); Baker (1927, pp. 7-8, 68); Redfield (1946); Holt and Bowsheer (1947); and Flawn (1951b).

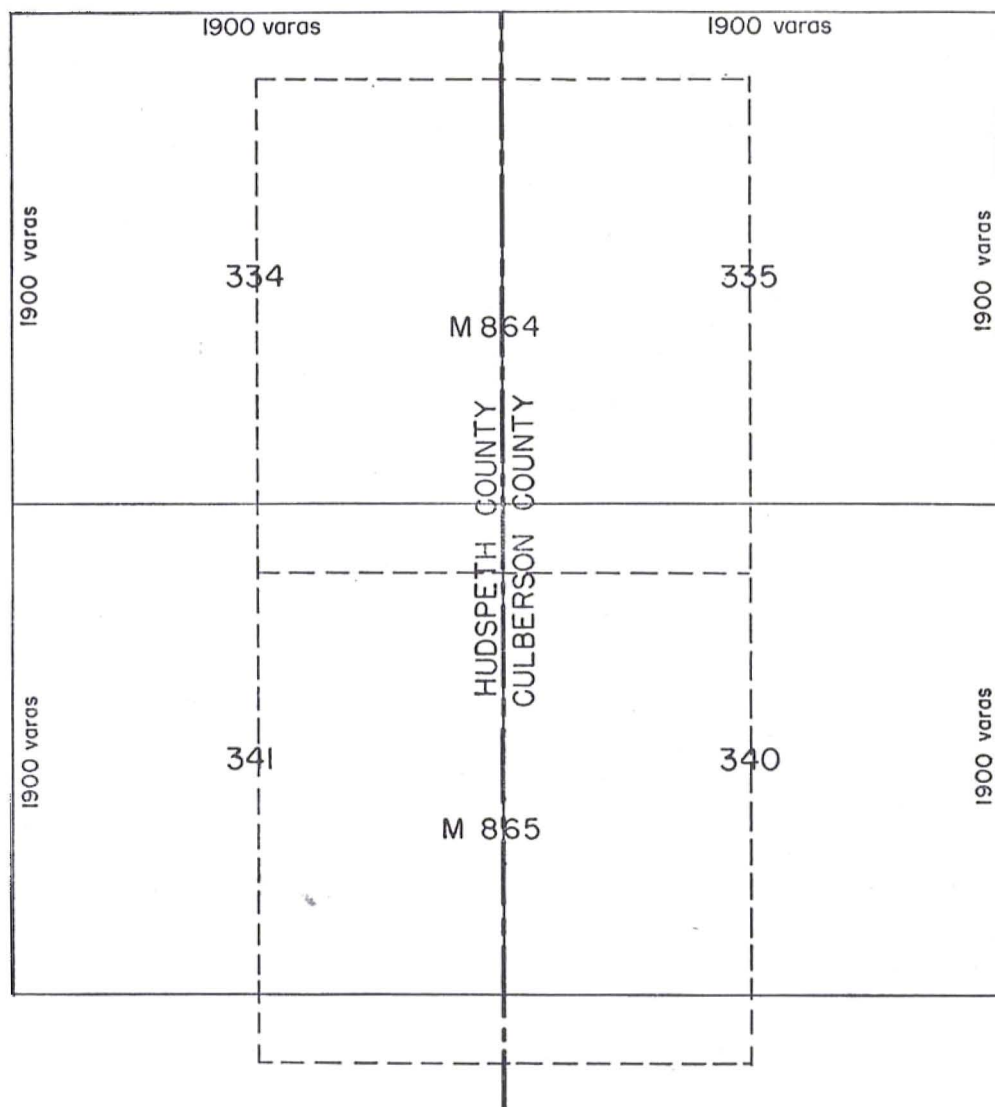


FIG. 20. Sketch map showing land subdivisions in the Mica Mine area, northwest Van Horn Mountains.

*History.*—Outcrops of mica were discovered in the area by Ben Kraus of Pecos, Texas, between 1890 and 1893. The deposits lay idle until 1910, when they were acquired by the Texas Mica Company, of Pecos, Texas, which purchased the two sections of land from the State. When examined by Sterrett in 1923, two cuts had been opened on the principal deposit, smaller pits had been dug elsewhere, and a small grinding mill had been erected for experimental purposes. Attempts were made to develop mica and micaceous rock suitable for giving a "micolithic" finish to cement and other structural material.

In 1920, the property was taken over by the Micolithic Company of Texas, a stock company with large capitalization. This company put in 5 miles of railroad to link the deposit with the main line of the Southern Pacific and installed a large steel-framed mill and warehouse, a diesel electric power plant, dwelling houses, and a pump house and pipe-line to furnish water from a well in the flat to the west. It was planned to develop a product for facing cutstone. The only traces of actual quarrying operations by this company are a few small pits in the more micaceous schists of the area.

The Micolithic Company went bankrupt in 1930, and its assets were taken over by the Rio Grande Quarries Company. The property and assets of this company were in turn sold, in 1940, to a syndicate of twelve members, represented by M. A. Baldwin and Dr. W. H. Scherer of Houston, Texas. During World War II they leased the property to the Texas Mica & Feldspar Company, which operated it for a short time. The lessees planned to produce sheet mica with the aid of a government subsidy which then existed, and it is reported that about \$5,000.00 worth of mica was sold as "strategic mica" during this period.<sup>37</sup> In 1951, the property was sold to the Neal ranch, and the installations dismantled and sold.

*Mica.*—The area has no future for production of sheet or scrap mica as a primary product, although scrap mica might be an important byproduct of other operations. Some of the pegmatites will yield an average of 5 to 8 percent scrap mica from a process separating run-of-mine pegmatite for feldspar. A good grade of "electrical"

mica occurs in the pegmatites in the immediate vicinity of the mill, but the existence of any sizeable reserves remains to be proved. A very small amount, too small for economic production, was classed as "strategic" during World War II.

During the operations of the Texas Mica & Feldspar Company the deposits were explored and tested by the U. S. Bureau of Mines, and its report presents results of power factor and flotation tests (Holt and Bowsher, 1947, pp. 6-7).

*Feldspar.*—A considerable tonnage of feldspar exists in the Mica Mine area. The average pegmatite contains 30 to 40 percent easily cobbled potash spar, and a number of pegmatites are large enough for quarrying operations. If it should prove feasible to mill and float run-of-mine pegmatite, a scrap mica and perhaps a clean quartz tailing would be salable in addition to the spar. Black tourmaline is the only deleterious constituent of the pegmatite and could easily be separated.

An important point for investigation is the iron content of the feldspar. The Bureau of Mines (Holt and Bowsher, 1947, p. 7) found 0.28 percent  $\text{Fe}_2\text{O}_3$  in a minus 20-mesh flotation concentrate, of which feldspar made up 51.8 percent of the product (7.4 percent mica, 32.2 percent quartz, 8.5 percent slime). These tests were run on mill tailings, and it was not specified from which pegmatite the tailings were derived. If the iron content of the feldspar has any relation to the color of the feldspar, it must be extremely variable throughout the area. It will be necessary to determine the iron content of the feldspar from individual pegmatites, and this will entail systematic sampling.

#### TALC<sup>38</sup>

*Eagle Flat prospect.*—Talc is being prospected in the western part of the Streeruwitz Hills 3.8 miles northwest of Eagle Flat section house and 1.9 miles due north of the Texas and Pacific Railroad. The workings are in section 22, block 57, Public School Lands, on the south side of a hill, and are visible from U. S. highway No. 80. The deposit was recently discovered by Sam Rossman of Pecos, Texas, and was explored early in 1952 by the Southwestern Talc Corporation, of Llano, Texas. At the time of visit in May 1952, the workings consisted

<sup>37</sup> Personal communication from H. O. DeBeck of the U. S. Bureau of Mines, 1949.

<sup>38</sup> From notes of P. T. Flawn, 1952.

of two bulldozer cuts and a number of churn drill holes; one carload had been mined and shipped to Llano, and tests were being made to determine the commercial possibilities of the ore.

The ore body is a phyllite unit of the Allamoore formation (pCAp of Pl. 3) which strikes nearly east and west and is bounded on the north and south by cherty limestones. The block of Allamoore formation which contains it has been overridden on the south by the Carrizo Mountain group along the Streeruwitz overthrust and in turn overrides the Hazel formation on the north along a "surface of movement."

The incompetent phyllitic body, enclosed as it is by competent limestone layers, has been tectonically thickened toward the west, has been highly contorted, and may have been subjected to differential movement and displacement. Eastward the phyllite unit terminates against conglomerates of the Hazel formation along the "surface of movement"; westward it is probably down-faulted against Hueco limestone, which crops out not far beyond the workings. Northwest of the workings is a nearly circular body of massive diabase which is either one of the igneous components of the Allamoore, or a much younger intrusive, of Tertiary age.

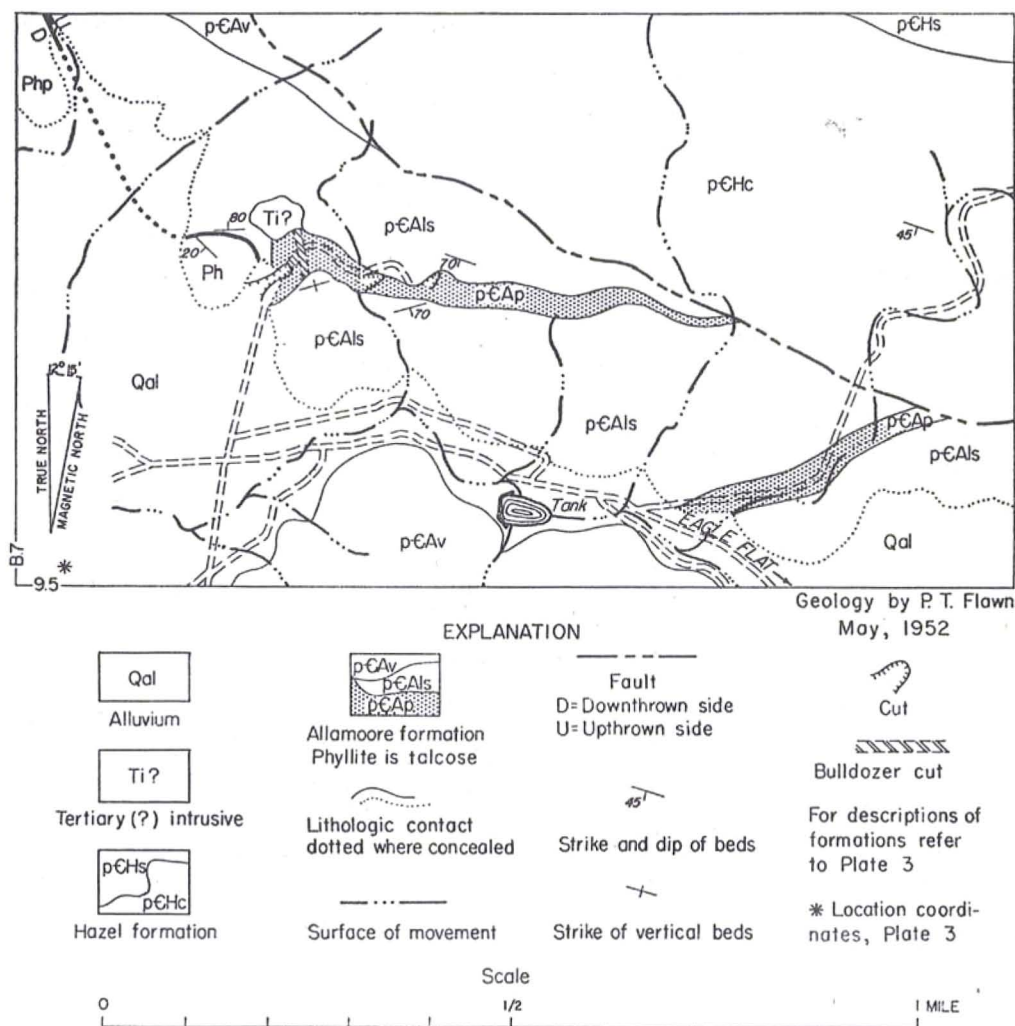


FIG. 21. Map showing revised geology at Eagle Flat talc prospect (from observations by P. T. Flawn, 1952).

Geologic mapping of the locality as shown on Plate 3 is based on reconnaissance work by P. B. King in 1931; a detailed survey would doubtless show significant revisions and modifications. Plate 3 was in the hands of the engraver by the time the locality was visited; figure 21 shows revisions of the mapping observed by Flawn on this visit.

The talc lies in a tabular, wedge-shaped phyllite body about 7,000 feet long, which strikes east-west and dips 70° to 85° south, tapering from a width of 400 to 500 feet on the west to 100 to 200 feet on the east. Specimens of soft, phyllitic rock collected from the body have been identified as talc by Dr. Joseph Weiss of the Department of Ceramic Engineering, The University of Texas. Further exploration of the body is desirable to determine tonnage of talc of requisite purity to be of commercial grade. A considerable amount of the material observed in the workings feels harsh, as though from impurities, and it is interbedded with layers of chert and lenses and streaks of light gray to brown dolomitic rock. At the southwest end of the body, near its contact with limestone of the Allamoore, blocks of chert have been tectonically included. One chert bed just east of the main bulldozer cut shows repeated small-scale isoclinal folding.

The origin of the mineral talc within the phyllitic body has not yet been determined. The carbonate beds which border it appear to be limestones rather than dolomites, so that the required magnesium was probably not derived from regional metasomatism. Possibly the phyllitic material from which the talc has formed was originally a fine-grained magnesium-bearing basic tuff.

Further exploration is desirable, not only of the body in which the talc is currently being prospected, but of the other phyllite units of the Allamoore formation which have been located and mapped by King on Plates 2 and 3. It is not impossible that, even if the present deposit is not of commercial grade, favorable conditions for commercial operation will be found in one of the other beds in the area. Talc possibilities of the area will be a subject of further investigation by the Bureau of Economic Geology.

#### CRUSHED STONE<sup>39</sup>

Crushed stone is produced by Gifford-Hill & Company, Inc., of Dallas, Texas, at its Holley plant 2½ miles east of Allamoore (H.5—16.5, Pl. 1). The plant and workings are in the northwest part of the Carrizo Mountains, immediately southwest of the Texas and Pacific Railroad, and between the railroad and U. S. highway No. 80. They lie near the center of block 67, township 8, Texas and Pacific Railroad survey. The plant was opened in 1926 and has been in nearly continuous operation since that date.

The stone used for crushing is metarhyolite of the Carrizo Mountain group, which forms low rounded hills in the vicinity and westward and rises into higher, more rugged ridges to the south. Immediately northeast of the plant, on the opposite side of the railroad, the metarhyolite abuts against the Hillside fault, and the Cox sandstone (Cretaceous) is dropped down against it.

The metarhyolite in the workings is a pink or reddish, siliceous rock, considerably more massive and blocky than it is elsewhere in the area. As elsewhere, it contains broken and drawn out phenocrysts; there is some layering defined by different colors and varying silica content; but the rock does not split readily along the layering. Large reserves of metarhyolite remain in the neighborhood, although most of it is more foliated, and hence more slabby and less massive than that now quarried, and lies farther from the railroad.

The stone is quarried from several large open cuts, three or four acres in extent and up to 50 feet deep, from which it is removed by power equipment. The plant has a capacity of 30,000 cubic yards per month and is equipped with an Allis-Chalmers 48 by 42 jaw crusher and a 4-foot Symonds cone crusher, which yield a finished product composed of minus 2-inch stone. The product is loaded for shipment directly into railroad cars on the siding at the plant.

The crushed metarhyolite makes a superior railroad ballast and has been used to ballast the line of the Texas and Pacific Railroad between Dallas and Sierra Blanca. The rock is also suitable for highway work and was used to a limited extent as sub-

<sup>39</sup> From notes of P. T. Flawn, 1951, and data furnished through the courtesy of Gifford-Hill & Company, Inc., of Dallas, Texas.

grade for U. S. highway No. 80 when this was relocated west of Van Horn in 1929. Little stone has been produced for highway purposes, however, as the volume of product would be small in comparison with the expense of adding new sizing and screening equipment.

#### NITRATE

The arid regions of the southwestern United States contain many deposits of nitrate salts in caves, recesses on canyon walls and cliffs, and in other places protected to a considerable extent from the weather. These are surface or near-surface accumulations which form coatings on rock walls or fragments, fillings of crevices and cracks, or result from falls onto the floors of caves or bases of cliffs, where they mingle with earthy matter. They do not penetrate more than a few inches into the rock masses and then only along deep cracks and fissures. These and other possible sources of nitrate were extensively investigated by the U. S. Geological Survey during World War I, and the results have been summarized by Mansfield and Boardman (1932). These authors list a number of deposits in the vicinity of Van Horn (1932, pp. 66-68), but only one of them was visited and examined by a U. S. Geological Survey geologist.

This is the so-called "Potash mine" (marked as "nitrate prospect," K.5-18.5, Pl. 1), which lies near the western end of the Red Valley 7 miles northwest of Van Horn, in a large outcrop of massive Van Horn sandstone that dips gently southeastward.<sup>40</sup> The deposit was being prospected in 1928 while King was in the area but was not visited by him until 1936, by which time operations had ceased. The following description of the deposit is based on an examination by W. B. Lang in July 1929 (Mansfield and Boardman, 1932, pp. 67-68):

The southeast end [of the sandstone outcrop] forms a cliff that has a prominent overhanging ledge, which at some places extends out 15 feet at a height of 8 to 12 feet. The overhang runs approximately 200 feet and has afforded and still affords resting place for bats. There is also abundant evidence of the use of the place as a shelter by Indians. The walls are scored, frescoed, and blackened, and the ground at the base contains charcoal, bones, and other organic remains.

<sup>40</sup> The sandstone is erroneously assigned to the Cretaceous in the report of Mansfield and Boardman.

Prospecting by digging, tunneling, and blasting had been carried on for a length of about 150 feet at the base of the cliff and to a depth of 2 or 3 feet, but was not in progress at the time of Mr. Lang's visit, though some shipments are reported to have been made. Samples collected by Mr. Lang gave the following results upon analysis:

Table 30. Analyses of samples from "potash mine" near Van Horn, Texas (E. T. Erickson, analyst).

Material	Soluble Salts (per-cent)	N <sub>2</sub> O <sub>5</sub> in Soluble Salts (per-cent)	K <sub>2</sub> O in Soluble Salts (per-cent)
(1) Surface soil and fresh bat guano	5.1	10 apx.	10 apx.
(2) Indian trash heap at east end	.4	1.5 apx.	5 apx.
(3) Detrital soil 5 feet from base of cliff at point of greatest overhang	.5	5.0 apx.	10 apx.
(4) Dug rock from trench prepared for shipment	2.4	5-10 apx.	10 apx.

The amounts of potash and/or nitrate examined are relatively insignificant, neither of these substances exceeding one-half of one percent. The organic and surficial origin of the nitrate is evident. The material in sight may continue to supply a few shipments, but the deposit is not commercial in any but the most limited sense.

#### TURQUOISE<sup>41</sup>

Turquoise has been obtained, according to Richardson, in the Carrizo Mountains about 5 miles west of Van Horn, at the Hudson prospect and at the Maltby or Knight prospect a mile to the southwest. At the Hudson prospect sky-blue and greenish-blue turquoise is said to form a seam about a millimeter thick along joint planes in the rock. The Maltby prospect, where traces of turquoise are also reported, has been worked primarily for copper and contains both copper arsenate and traces of silver and gold.

These old prospects, abandoned years ago, still remain south of U. S. highway No. 80 as shallow shafts and inclines, lying in sedimentary rocks of the first mixed unit of the Carrizo Mountain group. The most extensive openings are near L.7-12.4, Plate 1. No turquoise is now visible on any of the dumps, but as this is a semi-precious gem stone, and only a small quantity was originally present, it has probably long since been removed.

<sup>41</sup> From Richardson (1911, p. 9) and notes by P. B. King and P. F. Flawn, 1939 and 1951.



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## APPENDIX

### I. ROAD LOG ALONG U. S. HIGHWAY NO. 80 THROUGH THE CARRIZO MOUNTAINS

Peter T. Flawn

For the convenience of itinerant geologists, the following short road log describes road-cut exposures along U. S. highway No. 80 in the Carrizo Mountains between Van Horn and Allamore. The zero point is a roadside park 4.0 miles west of the intersection in Van Horn of U. S. highways No. 80 and No. 90. Most of the distance between Van Horn and the roadside park is traveled on unconsolidated bolson deposits. Low hills of Van Horn sandstone occur 500 feet north of the highway 2.4 miles west of Van Horn, and a prominent ridge of metarhyolite is crossed in a water gap 3.5 miles west of Van Horn. The log should be used in conjunction with Plate 1 and text descriptions.

#### Miles

- 0.0 Roadside park on north side of U. S. highway No. 80 4 miles west of Van Horn. Massive green rock exposed at picnic area is amphibolite (pECa), a meta-igneous rock intruded into the metasedimentary rocks of the Carrizo Mountain group.
- 0.5 Road-cut on north side of road exposes fine-grained gray sericitic meta-arkose (pECq<sub>3</sub>). Poorly preserved ripple-marks are visible in a single surface. Cross-bedding here is vague and is better displayed in a stream bed about 1,000 feet south of the road.
- 0.7 Road-cut on south side of road exposes fine-grained brown meta-arkose (pECq<sub>3</sub>).
- 0.8 Road-cut on north side of road is just west of Culberson-Hudspeth County line and

#### Miles

- near contact of pECq<sub>3</sub> and pECm<sub>1</sub>, a mixed unit. Road-cut exposes fine-grained white sericitic meta-arkose cut by numerous brown veinlets. On west end of outcrop, approximately on the lower contact of pECq<sub>3</sub>, is a massive brown carbonate-cemented chert breccia zone.
- 0.9 Road-cuts on both sides of road expose thinly intercalated fine-grained metaquartzite, chert, slate, and phyllite (pECm<sub>1</sub>).
- 1.8 Road-cut to north exposes amphibolite. White ridge trending southwest is pECq<sub>2</sub>. Scarp to north is Hueco limestone (Wolfcamp).
- 2.2 Beginning of exposure of metarhyolite which composes the remainder of the mountains. Note slabby, schistose outcrop in this road cut. High sericite content and schistosity is due to conversion of microcline to sericite during cataclastic alteration.
- 2.4 Broken and distorted zone in the metarhyolite. "Limestone" at west end of road-cut on the north side of the road is a metarhyolite microbreccia cemented by carbonate.
- 2.6 Metarhyolite showing lineation.
- 3.1 Exceptional development of lineation in metarhyolite.
- 3.5 Metarhyolite intruded by amphibolite on west end of road-cut on north side of road.
- 4.1 Beginning of massive "red" phase of metarhyolite, less sericitic and therefore less schistose than that seen to the east.
- 4.7 Last outcrop of metarhyolite along highway. Quarry and crusher of the Gifford-Hill Company to the north produce crushed metarhyolite. Hill behind rock crusher is Cox sandstone (Trinity) faulted down against metarhyolite of the Carrizo Mountain group.

### II. REPORT ON A GRAVITY SURVEY AT THE HAZEL MINE

Virgil E. Barnes and Peter T. Flawn

Observations of gravitational force in the vicinity of the Hazel mine and the Marvin-Judson prospect were made by V. E. Barnes<sup>42</sup> and P. T. Flawn January 15-18, 1952. The observations were made with a LaCoste-Romberg gravity meter, and the writers wish to express their gratitude to Dr. L. J. LaCoste for the loan of the instrument. The writers are indebted to Mr. Frederick Romberg<sup>43</sup> who examined the

data and helped make interpretations. These gravity data were published earlier in a separate report on the Hazel mine (Flawn, 1952).

The observations were reduced in the usual manner for latitude and elevation. A combination Bouguer and free air elevation correction of 0.06 mg./ft. was used, which corresponds to a density of 2.67 gms./cm.<sup>3</sup> Terrain corrections were not made, even though for some stations the need for such corrections is apparent. These stations are mostly situated on the fringe of the area

<sup>42</sup> Geologist, Bureau of Economic Geology.

<sup>43</sup> Manager, Southern Division, Geophysical Service, Inc., Houston, Texas.

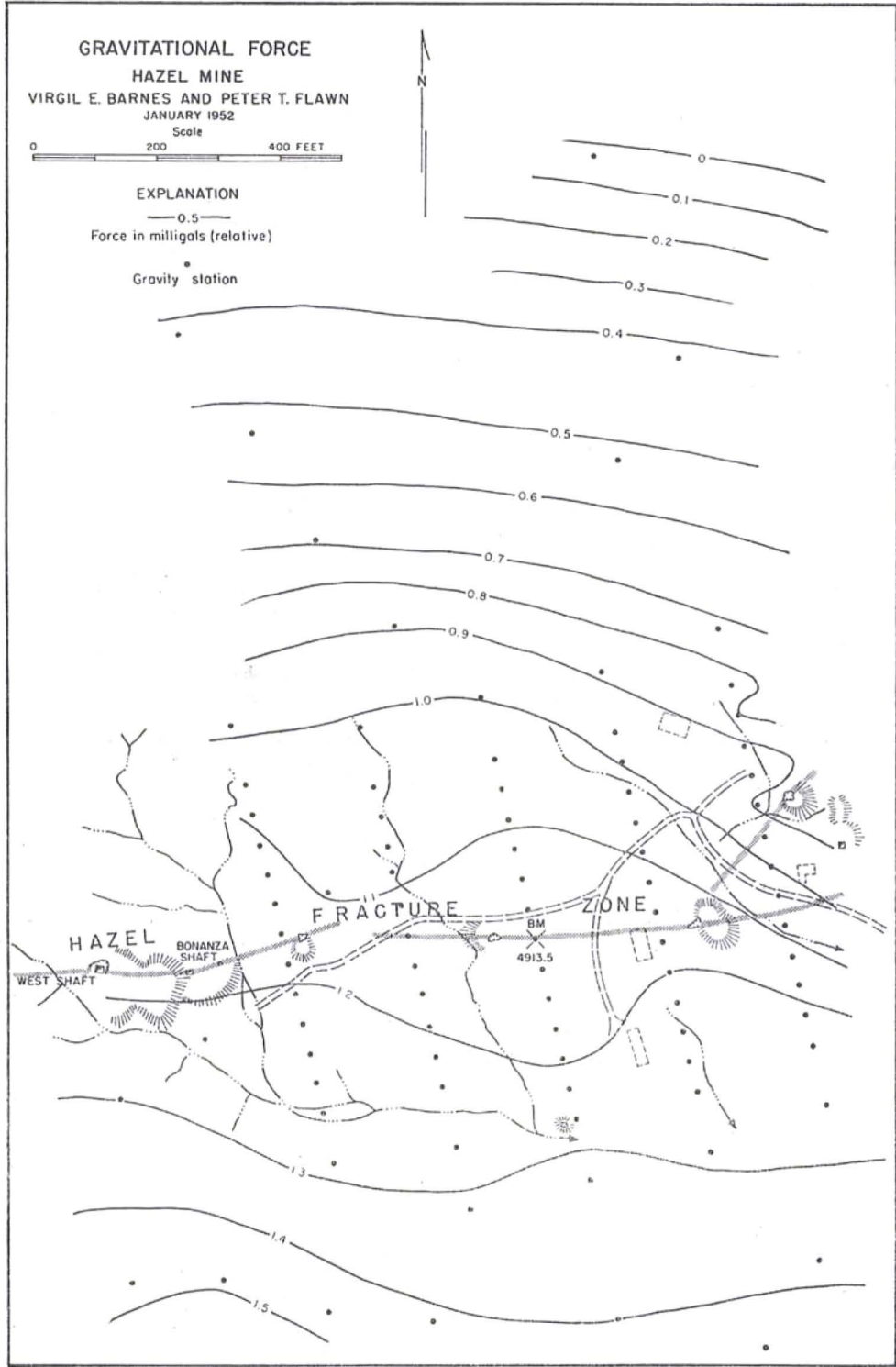


FIG. 22. Gravitational force map of the Hazel mine area.

and have been disregarded. Tie-ins and check readings show that the probable error of any station with respect to any other station is less than 0.04 mg. and that most of this error is due to insufficient accuracy in obtaining elevations. The elevations are least accurate in the areas of rough terrain which, as mentioned above, is mostly on the fringe of the surveyed area.

The locations of the stations and the contour lines for the force are shown in figure 22 for the Hazel mine and in figure 23 for

information about the regional gradient in this direction. If the gradient steepens in this direction the classical interpretation would be fulfilled. If this interpretation is correct the density contrast should be situated at a depth of 300 or 400 feet and the denser material should be north of the fault. Investigation of this anomaly should be included in an exploration program.

Another interpretation is possible because the Hazel sandstone in the vicinity of the vein is leached and less dense than

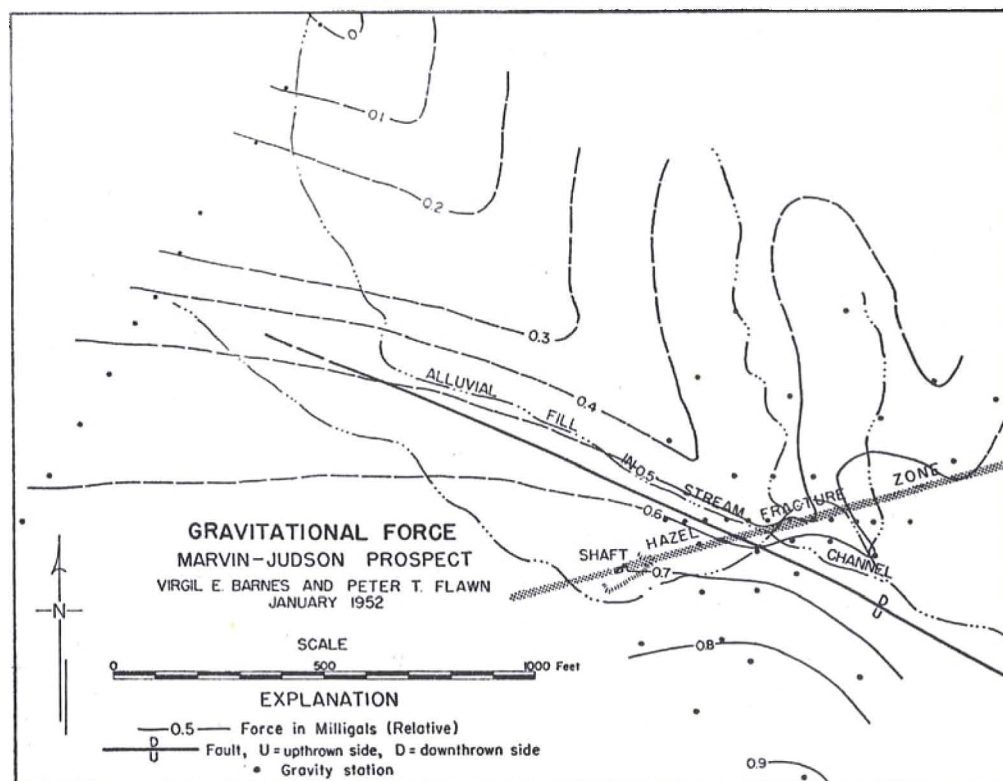


FIG. 23. Gravitational force map of the Marvin-Judson area.

the Marvin-Judson prospect. North of the Hazel mine fracture (fig. 22), the gravity gradient changes, steepening northward. Such a change in the vicinity of a known fault might indicate a difference of density of the rocks on opposite sides of the fault. For such a feature, however, the classical interpretation is a level gravity field on one side and a level gravity field on the other side at a different level, with a gradient in between. More gravity data should have been obtained to the south in order to give

normal. Density determinations made on nine specimens of the leached rock range from 2.32 to 2.60 gm./cm.<sup>3</sup> and the average is 2.49 gm./cm.<sup>3</sup>, giving a density contrast of about 0.2 gm./cm.<sup>3</sup> with the fresh rock. The leached zone averages about 34 feet thick, and the gravity anomaly (fig. 24) caused by such a zone will amount to about 0.1 mg. At least part of the flattening of the gravity gradient in the vicinity of the Hazel fracture zone could be caused by the presence of leached rock.

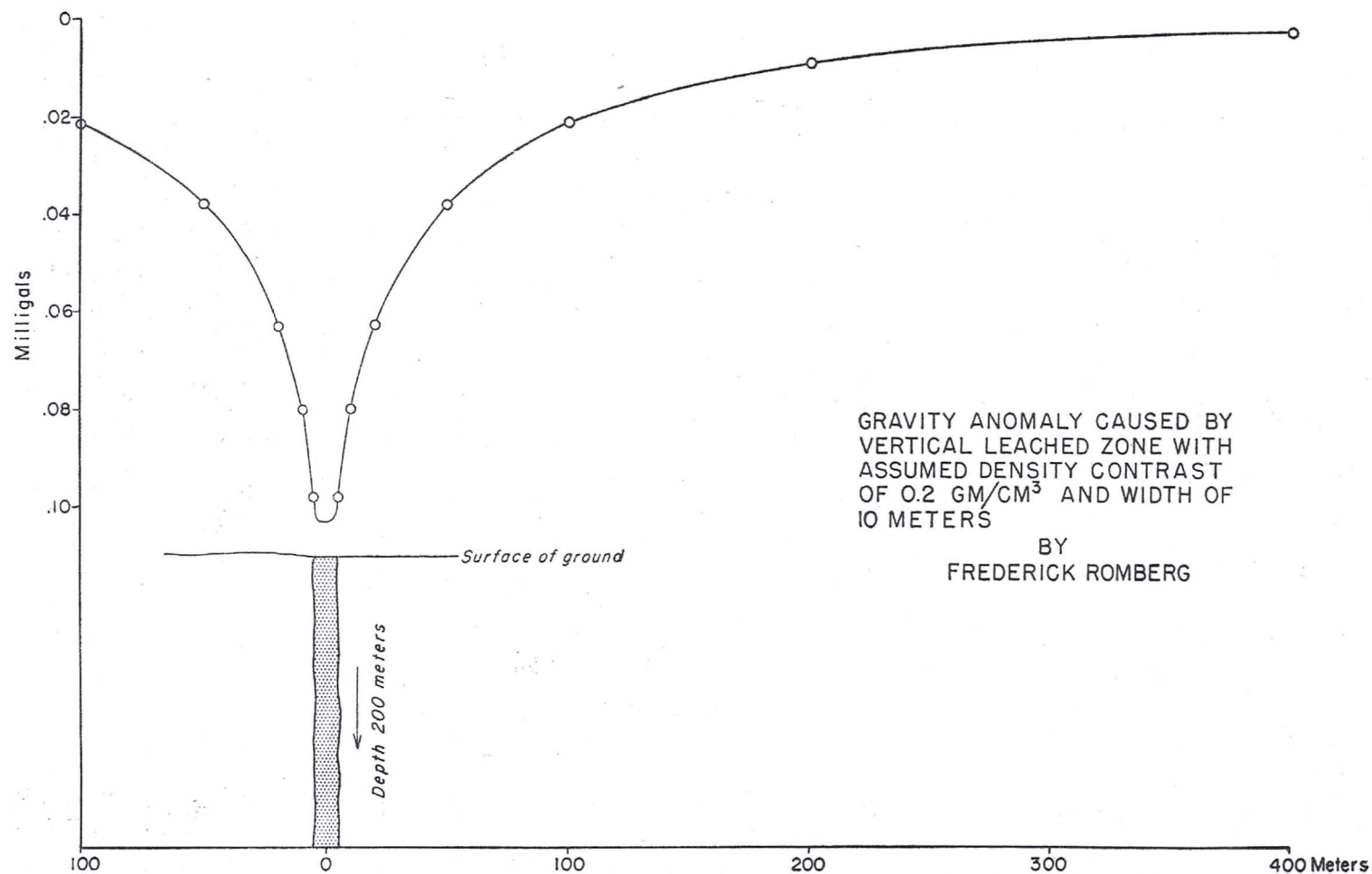


FIG. 24. Diagram showing gravity anomaly caused by a leached zone.

In the vicinity of the Marvin-Judson prospect (fig. 23) a negative gravity anomaly follows the main alluvium-filled valley. Removal of the regional gradient accentuates but does not change the position of the negative anomaly. Alluvium, being less dense than the Hazel sandstone, should cause a negative anomaly. The effect of 10 feet of alluvium can be estimated by assigning a density of 1.97 gm./cm.<sup>3</sup> to the alluvium and comparing it to the Hazel sandstone which has a density of 2.67 gm./cm.<sup>3</sup> This gives an anomalous density of 0.7 gm./cm.<sup>3</sup> Therefore 15 feet of alluvial fill would be sufficient to produce all of the anomaly found.

However, a portion of the anomaly could be explained by a density contrast produced in some other manner. For example, the Hazel sandstone beneath the alluvium could be brecciated and porous and thus have a lower than normal bulk density. Since the drain is following a fracture, this

might be true. There is no evidence of a density contrast on opposite sides of the fracture, and also there is no evidence of a density contrast on the opposite sides of the Hazel mine fracture in this area.

The gravity survey failed to reveal any sharp positive anomaly indicative of a concentrated heavy mass (ore minerals plus heavy gangue) in the vicinity of the Hazel mine or the Marvin-Judson prospect. However, this is not positive evidence of the absence of concealed ore bodies in these areas because the effect of local concentrations of heavy metallic sulfides and barite might be compensated by general deficiency in density of the fracture zone itself. Moreover, concentrations of copper-silver minerals that might be worked profitably may not cause a sufficient density contrast to produce a gravity anomaly. The gravity meter survey was undertaken in hopes that a near-surface lens of barite and metallic sulfides, similar to those encountered in the stopes east and west of the East shaft, could be detected.

**PLATE 20**

Rocks of the Carrizo Mountain group in the northwest Van Horn Mountains

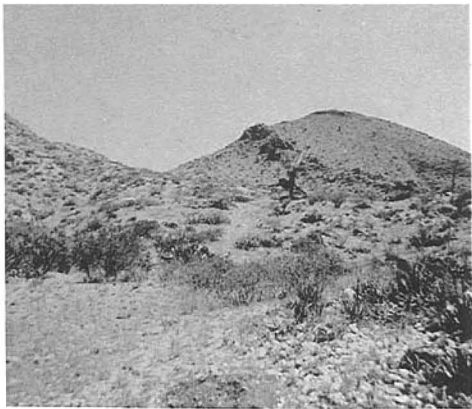
- A, B. Resistant beds of metaquartzite and meta-arkose in the canyon east of the north mill site (E.0—15.0; G.5—20.0, Pl. 4).
- C. Interbedded metaquartzite and muscovite schist cropping out on the north side of the canyon about 1,000 feet southeast of the Mica Mine No. 1 (G.5—14.0, Pl. 4).
- D. Resistant pegmatite in the canyon east of the north mill site (D.0—18.0, Pl. 4).

Photographs by P. T. Flawn





A



B



C

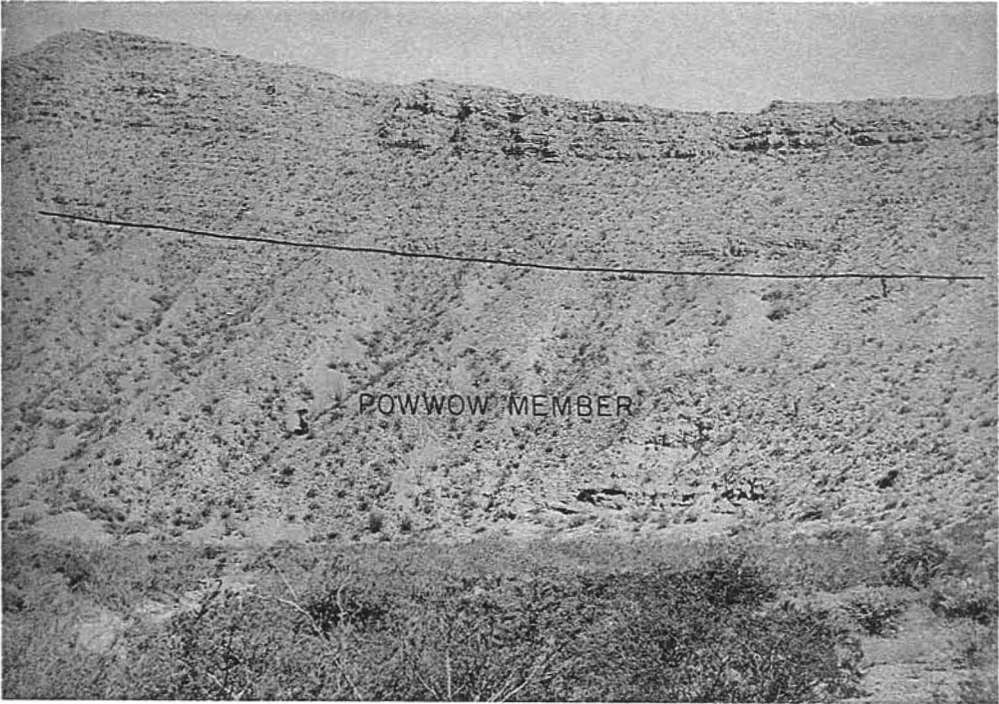


D

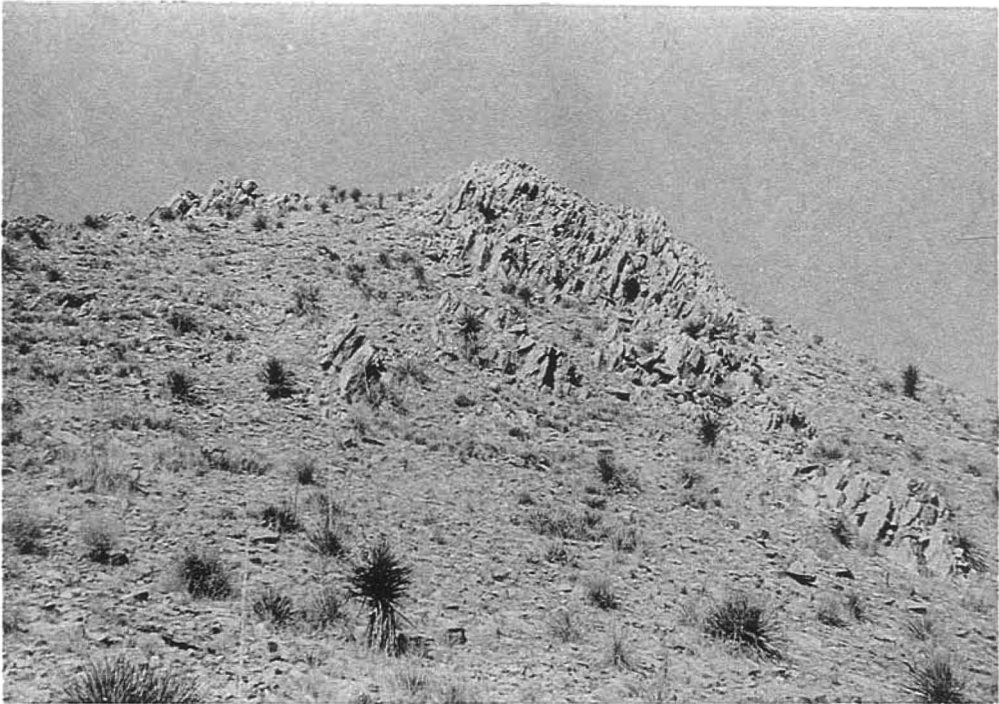
**PLATE 21**

- A. Basal section of the Hueco limestone at the south end of the Mica Mine area, northwest Van Horn Mountains (N.5—8.0, Pl. 4).
- B. Slabby metaquartzite unit in the Carrizo Mountain group of the Carrizo Mountains (unit pCc<sub>9</sub> of Pl. 1). Photograph taken on the south side of U. S. highway No. 80 about half a mile west of the roadside park west of Van Horn (Q.4—12.8, Pl. 1.)

Photographs by P. T. Flawn



A

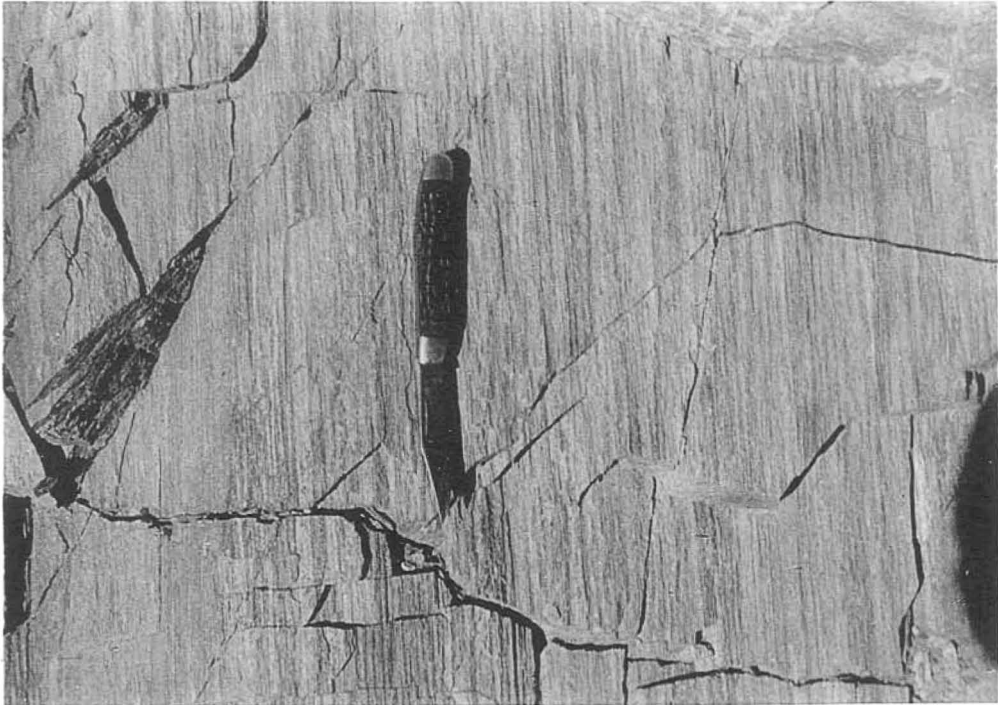


B

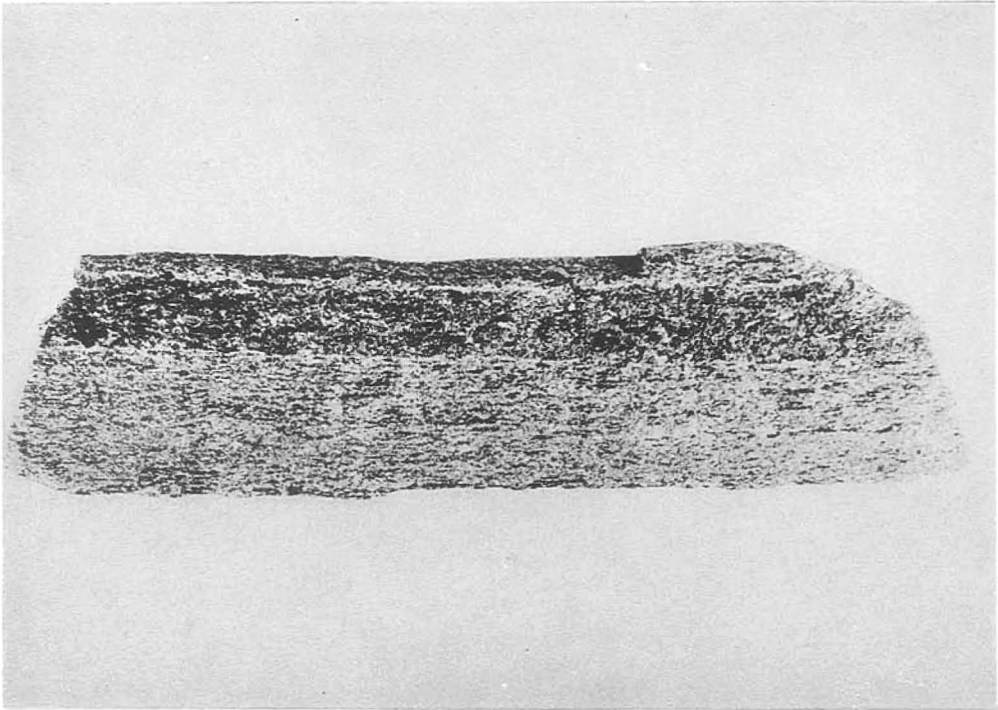
**PLATE 22**

- A. Lineation in metarhyolite of Carrizo Mountain group in road cut along U. S. highway No. 80 about 3 miles west of the roadside park west of Van Horn.
- B. Layering in epidote amphibolite, northwest Van Horn Mountains. Specimen (natural size) collected in the canyon east of the north mill site (G.O—20.5, Pl. 4).

Photographs by P. T. Flawn



A

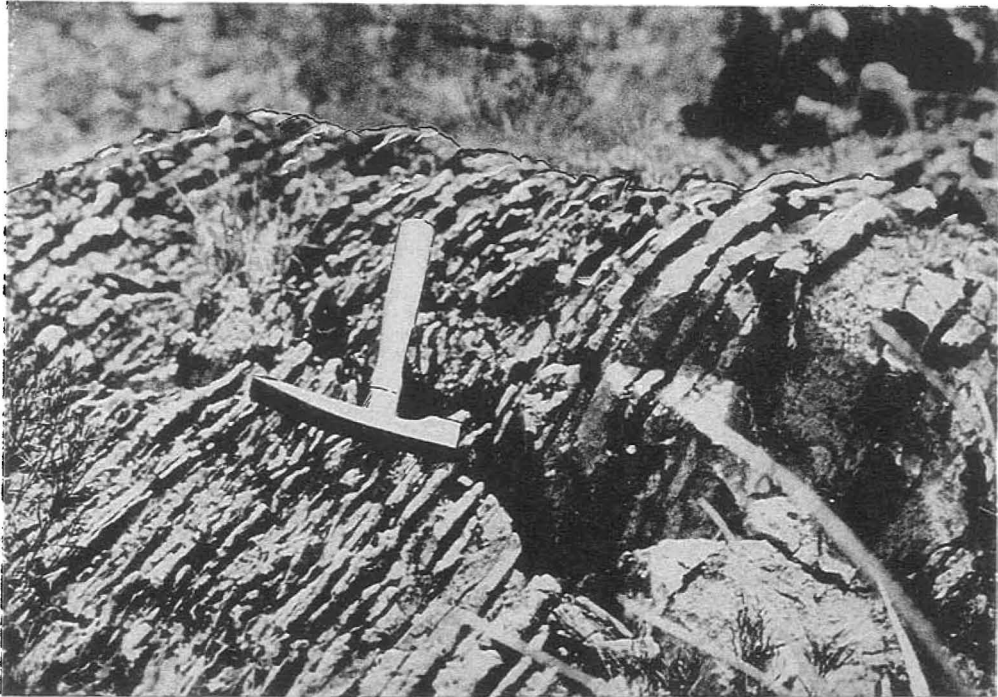


B

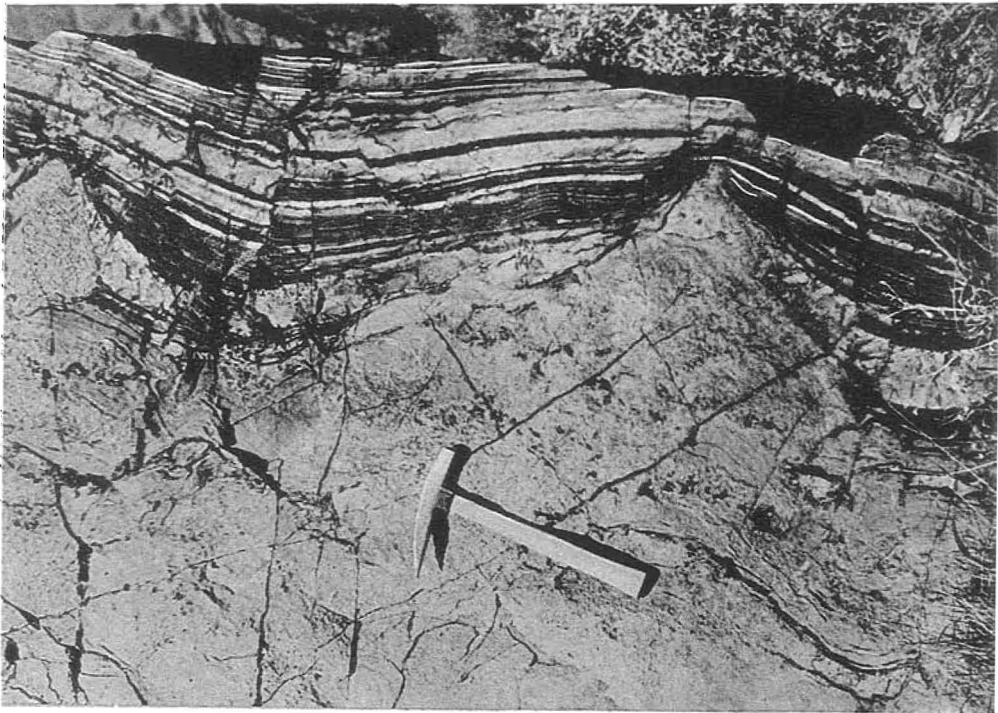
**PLATE 23**

## Limestones of Allamoore formation

- A. Limestone with closely spaced chert seams; 3 miles northwest of Eagle Flat section house (D.5—9.5, Pl. 3). Photograph by P. B. King.
- B. Massive limestone of possible algal origin, with an irregular upper surface on which bedded siliceous rock was deposited; contact of beds 5 and 6 of Tumbledown Mountain section (Q.5—8.5, Pl. 2). Photograph by Josiah Bridge.



A



B

**PLATE 24**

## Allamoore and Hazel formations

- A. Phyllite of Allamoore formation, showing folding and axial-plane cleavage; 3 miles northwest of Eagle Flat section house (D.5—9.5, Pl. 3).
- B. Massive conglomerate of Hazel formation, with siliceous and ferruginous matrix, possibly originally calcareous;  $3\frac{1}{2}$  miles northwest of Eagle Flat section house (E.5—10.5, Pl. 3).

Photographs by P. B. King





A



B

**PLATE 25**

## Conglomerate of Hazel formation

The two views are typical of the northern facies of the conglomerate, in which the matrix is more sandy and less consolidated than that shown in Plate 24, B. North base of Tumbledown Mountain near Dallas prospect (R.5—9.5, Pl. 2).

Photographs by P. B. King



A



B

**PLATE 26**

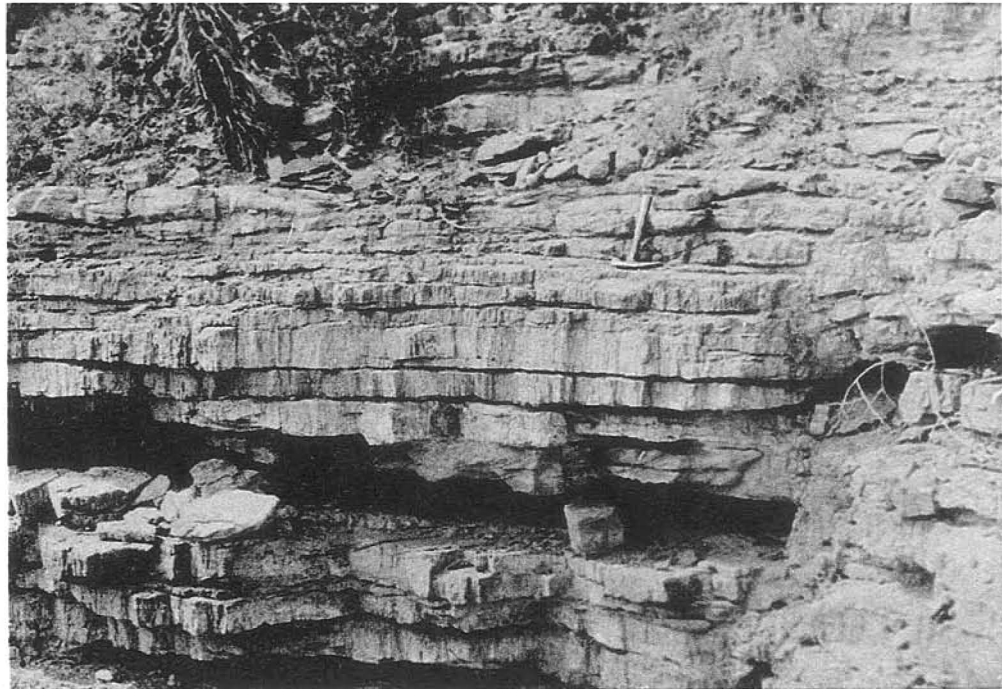
## Van Horn and Bliss (?) sandstones

- A. Basal conglomerate of Van Horn sandstone, containing rounded boulders of red granite and rhyolite porphyry as much as 2 feet across; bed 1 of section on south-facing escarpment of Sierra Diablo 4 miles west of old Circle ranch house (Q.5—18.5, Pl. 3).
- B. Thin-bedded sandstone of Bliss (?), with abundant *Scolithus* tubes; south end of Baylor Mountains 3 miles east-northeast of B-Bar ranch house (east of Pl. 2).

Photographs by P. B. King



A



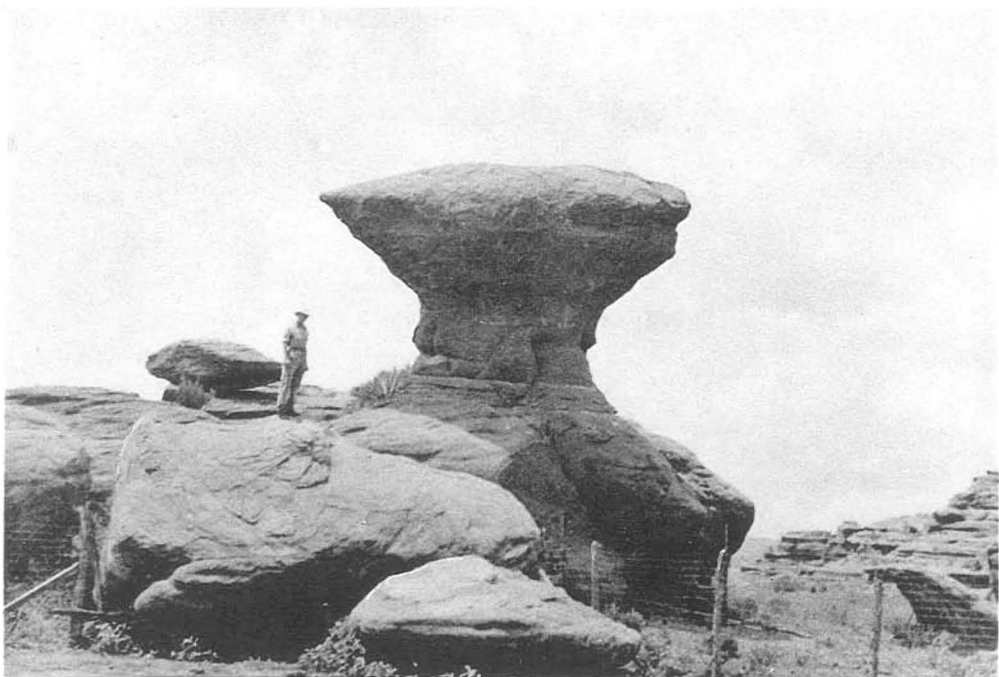
B

**PLATE 27****Outcrops of Van Horn sandstone**

- A. Weathering of massive sandstone and conglomerate beds; middle part of section on south-facing escarpment of Sierra Diablo 4 miles west of old Circle ranch house (Q.5—18.5, Pl. 3). Numbers indicate beds in measured section described in text (p. 94). Photograph by P. B. King.
- B. Pedestal rock in massive red sandstone near Yates ranch house (0.5—6.5, Pl. 2). Photograph by Josiah Bridge.



A



B

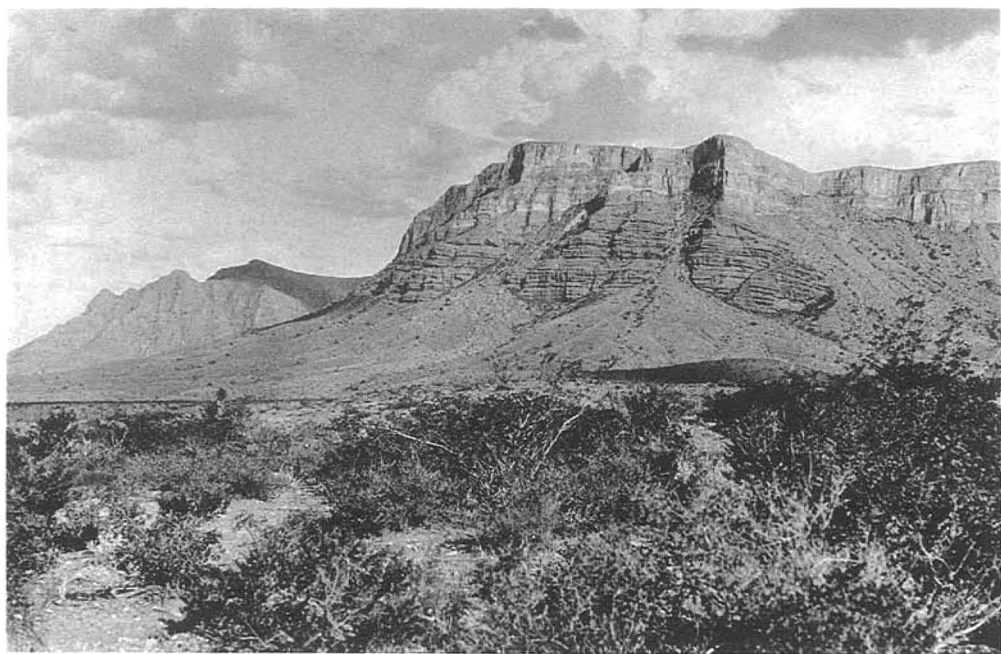
**PLATE 28**

## Escarpments of Beach Mountain and Sierra Diablo

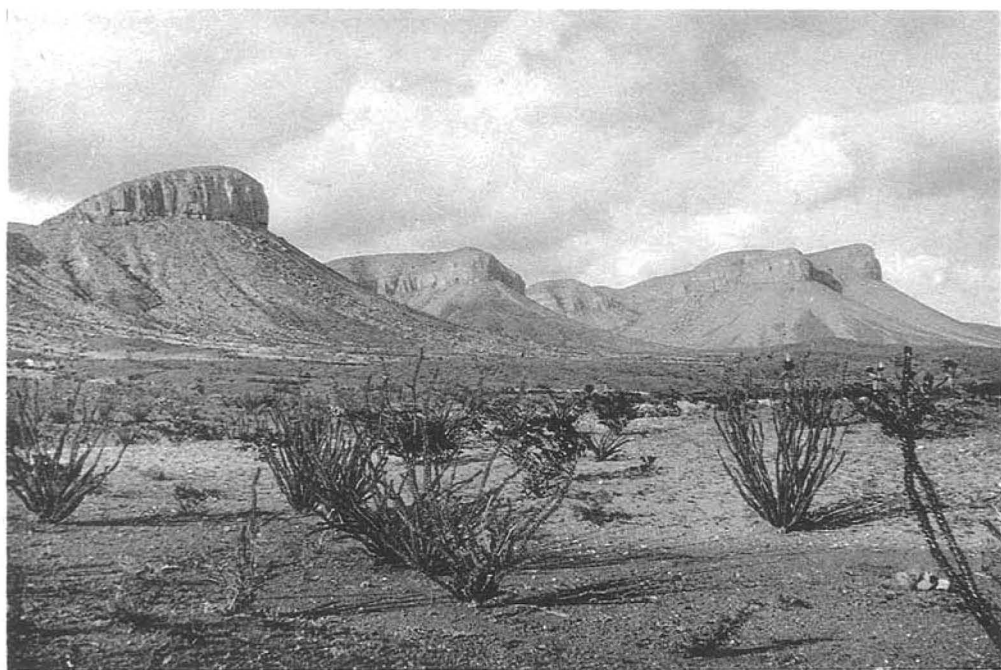
- A. Northwest corner of Beach Mountain (T.5—11.5, Pl. 2), showing El Paso limestone (light-colored cliffs) and Bliss (?) sandstone (slope below cliffs) lying on Van Horn sandstone (dark-colored ledges). View southeastward from near Hazel mine.
- B. South-facing escarpment of Sierra Diablo northwest of Hazel mine (L.5 to O.5—14.5, Pl. 2), showing Hueco limestone (light-colored cliffs) lying on red sandstone of Hazel formation (dark slopes); looking northeast. This locality is only 3 miles northwest of the first, yet all the Van Horn, Bliss (?), and El Paso exposed there have been cut out here by pre-Hueco erosion.

Photographs by P. B. King

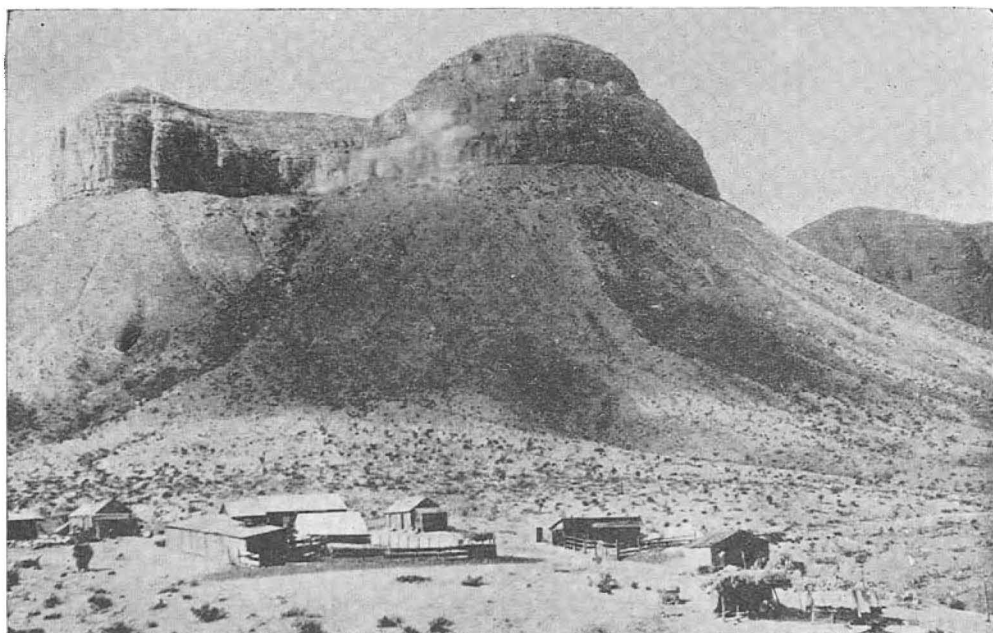




A



B



(A) The Hazel mine in 1889 (reproduced from a photograph by Rogers; Von Streeruwitz (1890), opposite p. 224).



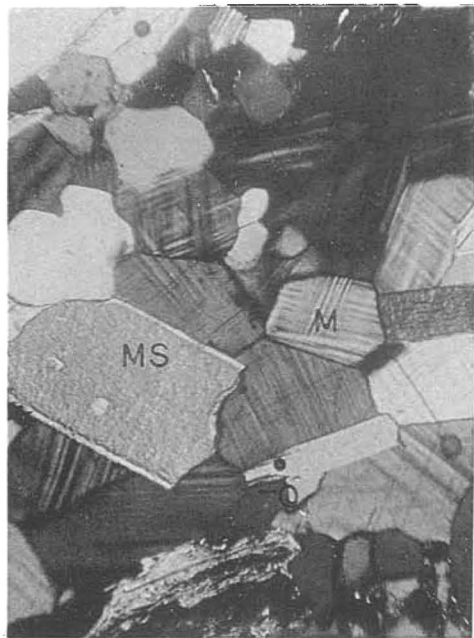
(B) The Hazel mine in 1951, view just east of that in (A) above. Compare with (A) above and note the increase in creosote bush and decrease in grasses. Photographs taken by P. T. Flawn, 1951.

**PLATE 30**

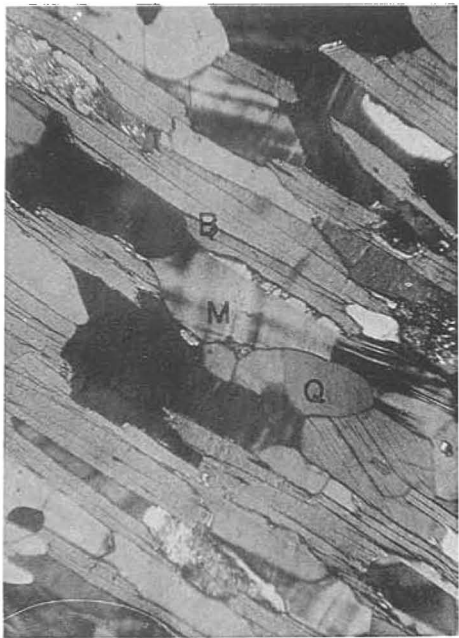
Photomicrographs of pre-Cambrian rocks from the northwest Van Horn Mountains  
All x70

- A. Muscovitic meta-arkose (slightly schistose in hand specimen). Crossed nicols. (See p. 27, Table 2, mode V.)
- B. Quartz-biotite-microcline schist. Crossed nicols. (See p. 29, Table 4, mode II.)
- C. Epidote-biotite-hornblende schist. (See p. 30, Table 5, mode X.)
- D. Biotite-hornblende schist. (See p. 30, Table 4, mode IV.)

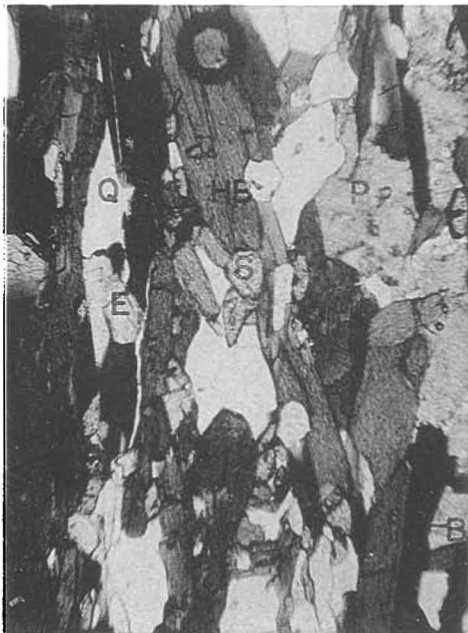
M, microcline; MS, muscovite; P, plagioclase; E, epidote; Q, quartz;  
S, sphene; HB, hornblende; B, biotite



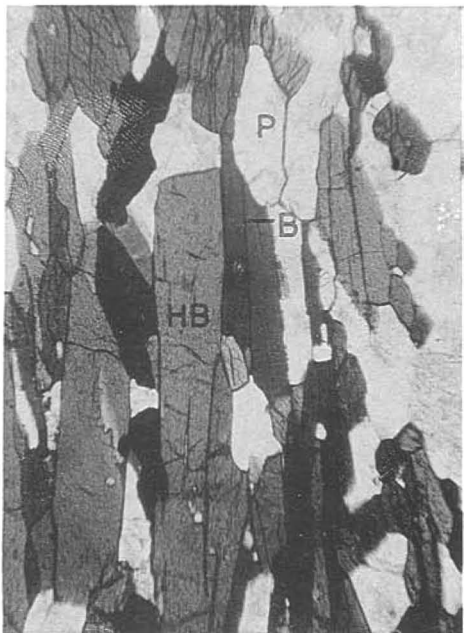
A



B



C



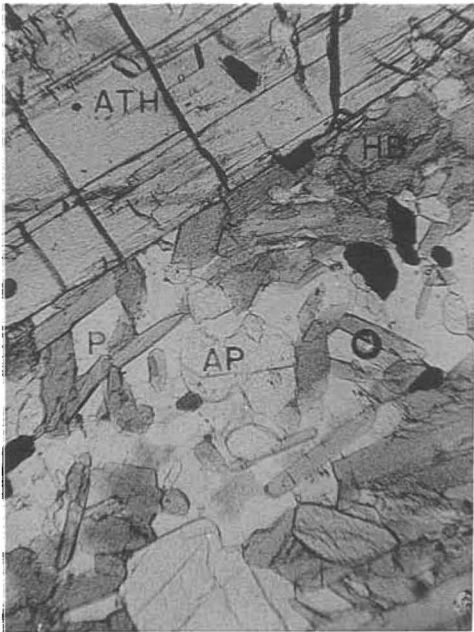
D

**PLATE 31**

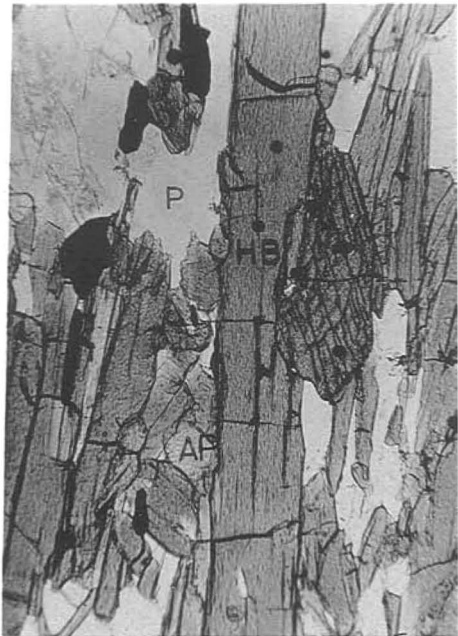
Photomicrographs of pre-Cambrian rocks from the northwest Van Horn Mountains  
All x70

- A. Anthophyllite amphibolite. (See p. 33, Table 5, mode III.)
- B. Normal amphibolite. (See p. 31, Table 5, mode I.)
- C. Epidotite. (See p. 34, Table 5, mode VI.)
- D. Epidote amphibolite. (See p. 33, Table 5, mode V.)

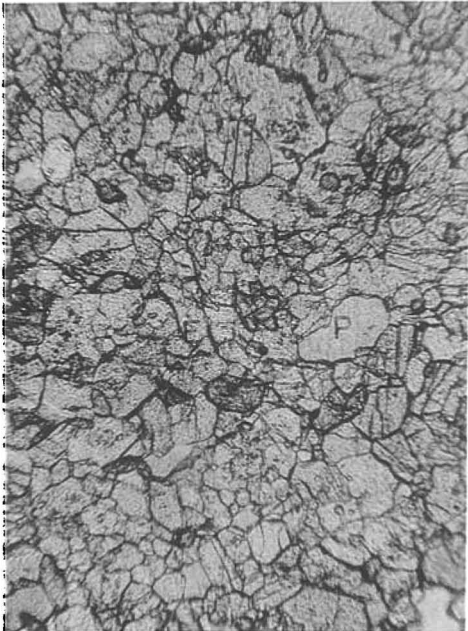
HB, hornblende; P, plagioclase; ATH, anthophyllite;  
AP, apatite; E, epidote; S, sphene



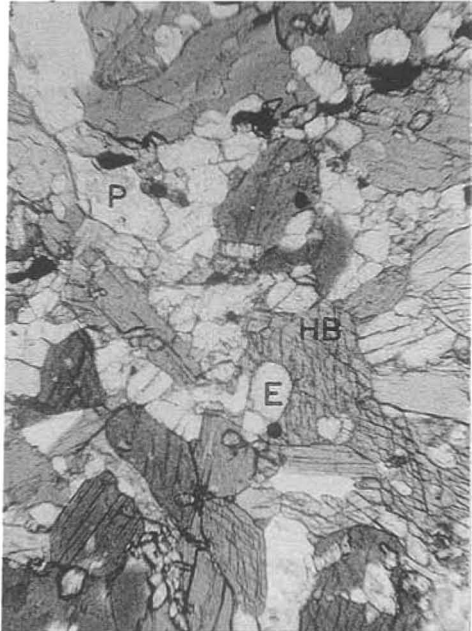
A



B



C



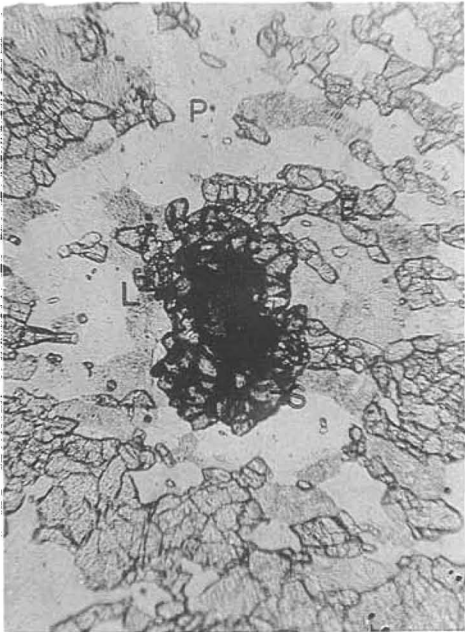
D

**PLATE 32**

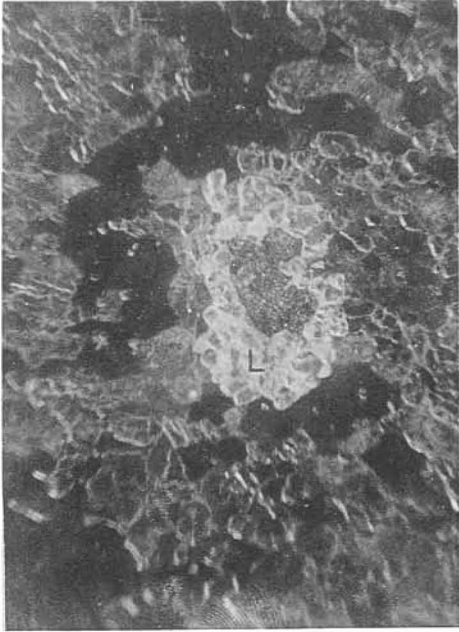
Photomicrographs of pre-Cambrian rocks from the northwest Van Horn Mountains  
All x70

- A. Epidote amphibolite; sphene enveloping ilmenite and flooded with leucoxene. (See p. 33, Table 5, mode V.)
- B. Same as (A) but by reflected light.
- C. Blue-green hornblende changing abruptly to colorless amphibole in amphibolite. (See p. 33.)
- D. Core of pleochroic green amphibole within anthophyllite in anthophyllite amphibolite. (See p. 33.)

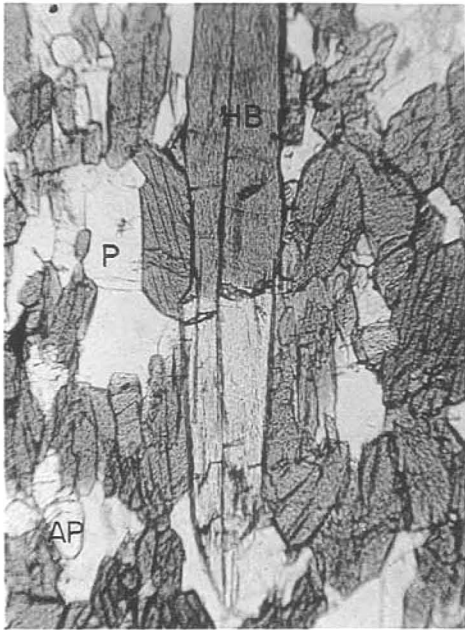
HB, hornblende; P, plagioclase; AP, apatite; ATH, anthophyllite;  
E, epidote; S, sphene; L, leucoxene



A



B



C



D

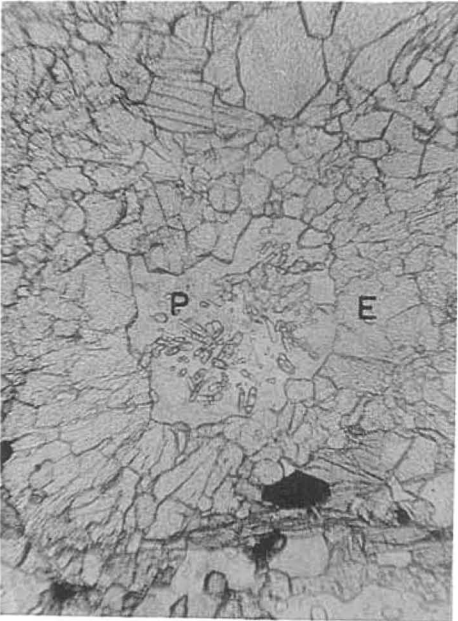


**PLATE 33**

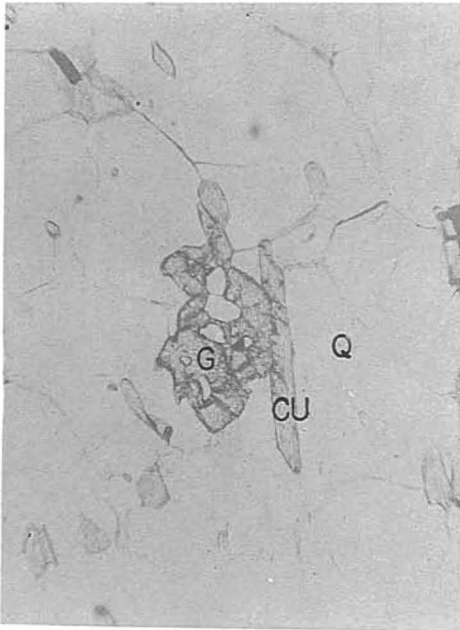
Photomicrographs of pre-Cambrian rocks from the northwest Van Horn Mountains  
All x70

- A. Plagioclase partly converted to epidote in epidote amphibolite. (See p. 33.)
- B. Almandine-cummingtonite quartzite; shows skeletal garnet. (See p. 32, Table 5, mode IX.)
- C. Hornblende-magnetite gneiss. (See p. 32, Table 5, mode VIII.)
- D. Same as (C); shows 001 parting in hornblende. Crossed nicols.

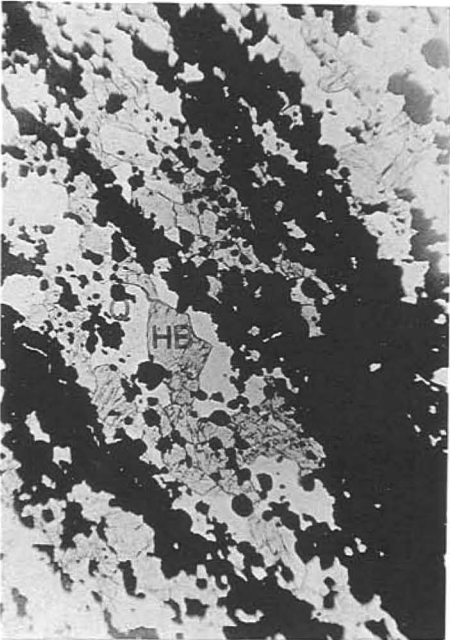
HB, hornblende; P, plagioclase; E, epidote; Q, quartz;  
CU, cummingtonite; G, almandine garnet



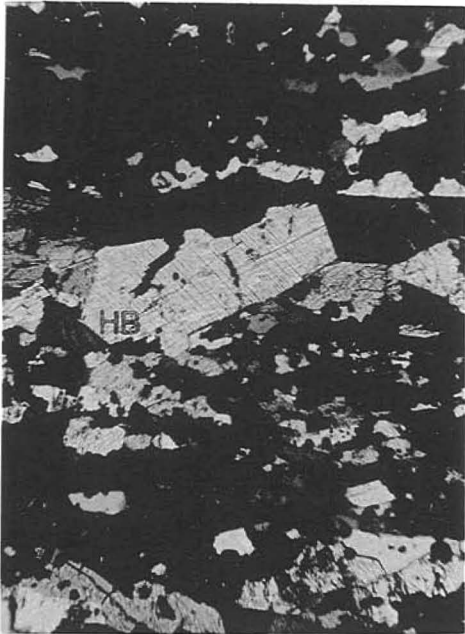
A



B



C



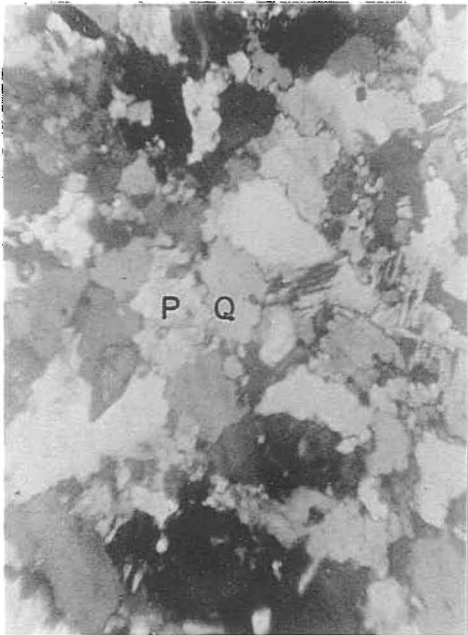
D

**PLATE 34**

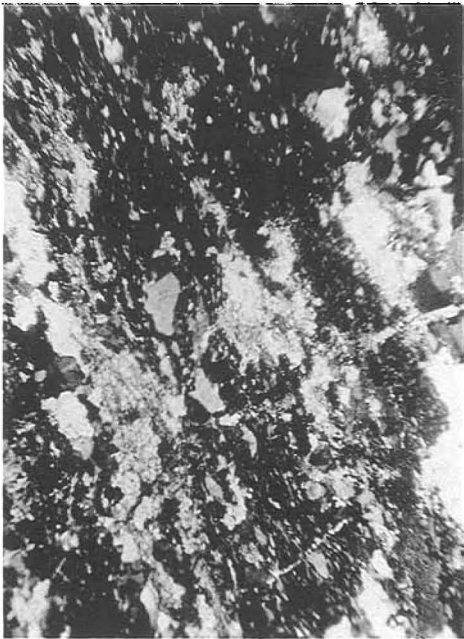
Photomicrographs of pre-Cambrian rocks from the Carrizo Mountains  
All  $\times 70$

- A. Meta-arkose. (See p. 55, Table 11; L.7—11.2, Pl. 1.)
- B. Calcite veining and replacing mylonitized metarhyolite. (See p. 62; M.5—15.2, Pl. 1.)
- C. Mylonitized metarhyolite. (See p. 62, Table 12; P.5—8.8, Pl. 1.)
- D. Metarhyolite. (See p. 62, Table 12; Q.4—9.4, Pl. 1.)

P, plagioclase; Q, quartz



A



B



C



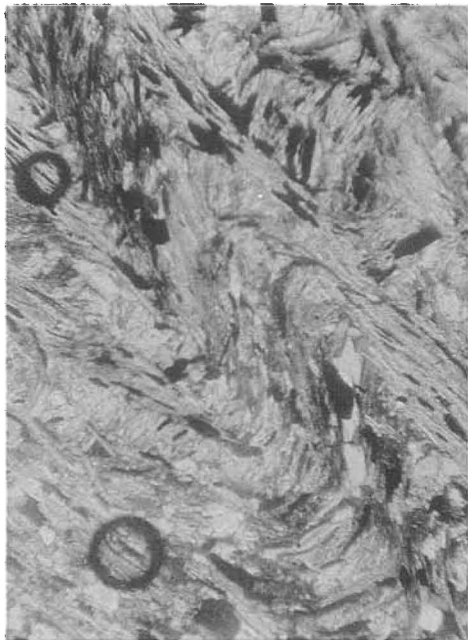
D

**PLATE 35**

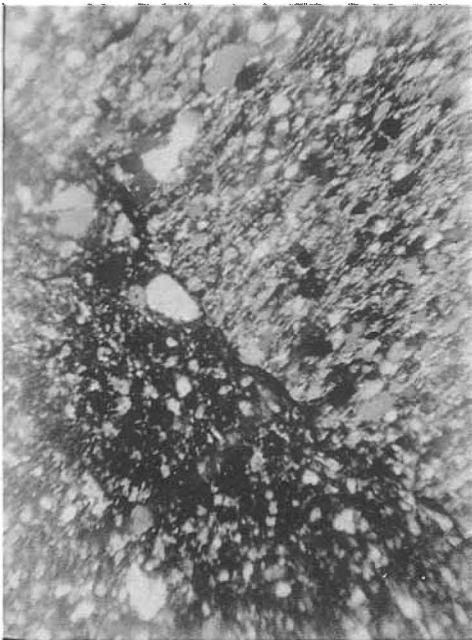
Photomicrographs of pre-Cambrian rocks from the Carrizo Mountains  
All x70 and all with crossed nicols

- A. Microfolding in sericite schist. (See p. 57, Table 11; L.8—5.7, Pl. 1.)
- B. Brecciated mylonite. (See p. 63, Table 12; K.5—14.2, Pl. 1.)
- C. Microcline augen converting to sericite in mylonite. (See p. 62, Table 12; Hackett Ridge gorge.)
- D. Metarhyolite; note flowage structure and layering. (See p. 63, Table 12; N.1—9.5, Pl. 1.)

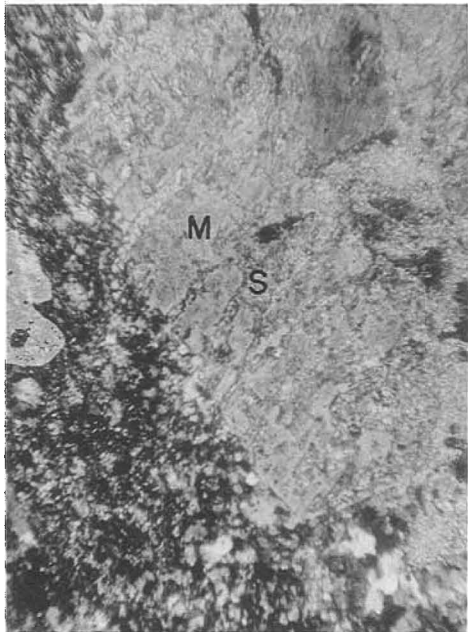
S, sericite; M, microcline



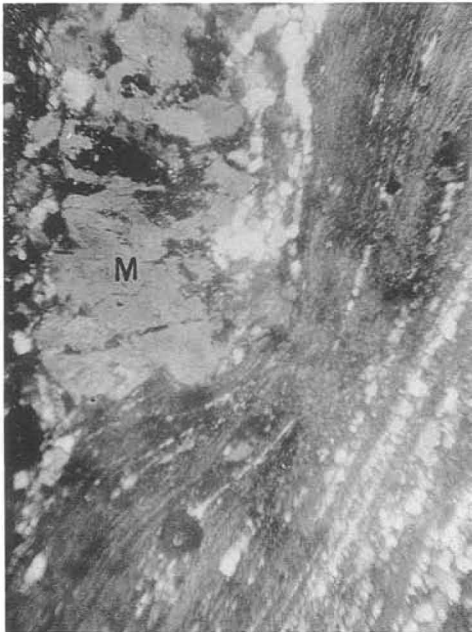
A



B



C



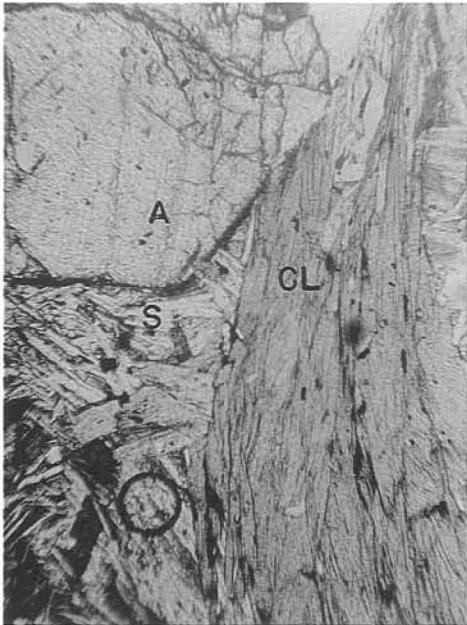
D

**PLATE 36**

Photomicrographs of pre-Cambrian rocks from the Carrizo and Eagle Mountains  
All x70

- A. Chlorite-almandine-mica schist, Bass Canyon, Carrizo Mountains. (See p. 57, Table 11; N.3—5.6, Pl. 1.)
- B. Helicitic almandine garnet converting to chlorite in phyllite, Eagle Mountains. (See p. 46, Table 9, mode VII; F.0—2.5, Pl. 5.)
- C. Limestone, Carrizo Mountains. (See p. 54, Table 11; I.4—9.5, Pl. 1.)
- D. Well-preserved relict igneous fabric in amphibolite, Carrizo Mountains. (See p. 64, Table 13; F.2—12.2, Pl. 1.)

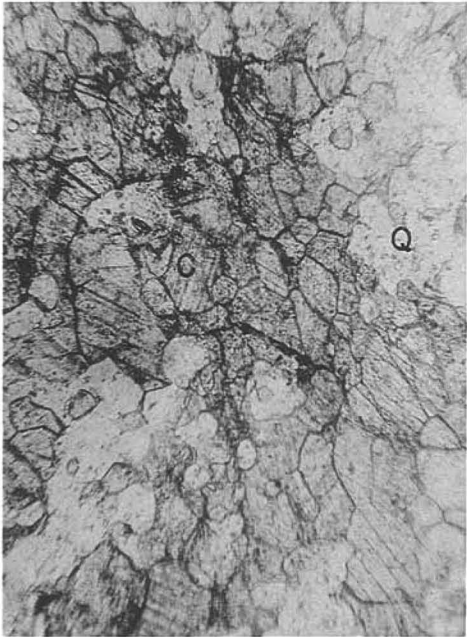
A, almandine; CL, chlorite; C, calcite; Q, quartz; P, plagioclase;  
HB, hornblende



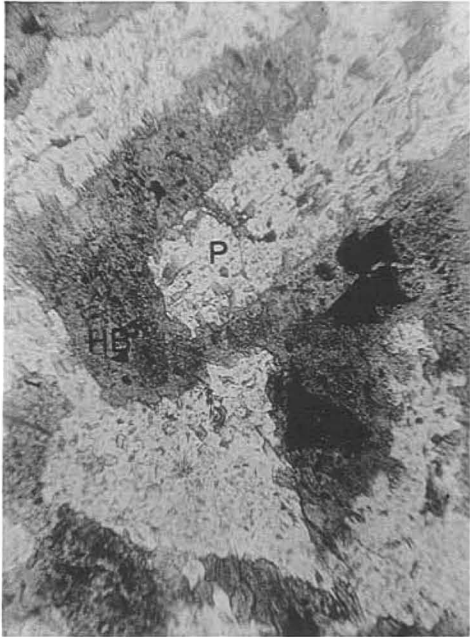
A



B



C



D



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