Geology and Quicksilver Deposits of the Terlingua District Texas

GEOLOGICAL SURVEY PROFESSIONAL PAPER 312

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By ROBERT G. YATES *and* GEORGE A. THOMPSON

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A detailed study of the geology of a mining district that has produced 150,000 flasks of quicksilver

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GEOLOGY AND QUICKSILVER DEPOSITS OF THE TERLINGUA DISTRICT, TEXAS

By Robert G. Yates and George A. Thompson

ABSTRACT

The Terlingua quicksilver district, which has produced more than 150,000 flasks of quicksilver, is in the southern part of the Big Bend region of southwestern Texas. It is a narrow, east-west area about 20 miles long and lies mainly in southwestern Brewster County. The district is connected by graded road with the nearest railroad, 84 miles north of its center.

Quicksilver minerals were first discovered in the district in the latter part of the 19th century, but there was no substantial production until 1900. Although there are about 20 mines and many prospects, more than 90 percent of the quicksilver came from the Chisos-Rainbow, Mariposa, and Study Butte mines. The most productive years were during World War I; since 1946 the district has been idle. Future production depends upon the discovery of new ore bodies—which will be costly—and the working of deposits now considered of too low grade to be profitable.

The area is mountainous and arid; its sparse vegetation is typical of desert regions. The altitudes range from 2,100 feet to 4,200 feet. Only two streams cross the district, and considerable stretches of these are dry during summer months. Because of the concentration of the scanty rainfall into torrential showers, and because of the wide range in hardness between different rocks, erosion is vigorous and has carved a rugged terrain.

The rocks consist of marine sedimentary rocks of Cretaceous age, and lavas and associated clastic beds and hypabyssal intrusive rocks, all of Tertiary age. Cretaceous sedimentary rocks, beginning with the oldest, are: Devils River limestone (1,500+ feet thick), Grayson formation (80 to 200 feet), Buda limestone (50 to 100 feet), Boquillas flags (about 1,100 feet), Terlingua clay (about 1,000 feet), Aguja formation (about 800 feet of sandstones and clays), and Tornillo clay (600 to 1,000 feet). All are fossiliferous. Rocks of Tertiary age, collectively termed Chisos volcanics, include tuffs, clays, conglomerates, and lavas, ranging from trachytes through andesites to basalt. Intrusive rocks are in the form of dikes, sills, laccoliths, and plugs and range in composition from rhyolite to basalt. Many igneous rocks have a high content of soda, represented in their mineral compositions as soda orthoclase, sodic pyroxenes, and analcite.

Domes, grabens, and breccia pipes are unusually abundant and well formed. The Terlingua uplift, an irregular dome with a structural relief of several thousand feet, underlies about half the district and is believed to have been formed by igneous uplift. Smaller domes, found throughout the district, are clearly the result of igneous intrusions. The grabens are bounded by normal faults, which together include most of the normal faults of the district. The vertical displacement of the grabens below adjacent blocks is as much as 2,000 feet. Masses of breccia with a pipelike or chimneylike shape have been designated descriptively as breccia-filled pipes, or simply breccia pipes. They range from 75 feet to 500 feet in diameter, and one has been explored vertically for more than 800 feet. The nature of the breccia and its walls indicate that the pipes were formed by collapse of bedded rocks into solution caverns.

Quicksilver minerals have been found in veins and tabular and pipelike bodies in both sedimentary and igneous rocks. Cinnabar is the principal ore mineral but there are minor quantities of native mercury, chlorides of mercury, and other rare mercury minerals. Associated minerals are calcite, clay, pyrite, hydrocarbon compounds, and, less commonly, several other minerals. The deposits are classified as: deposits formed in altered rock along the contact between the Devils River limestone and Grayson formation (limestone-clay contact deposits), deposits in calcite veins in the Boquillas flags, deposits in breccia pipes, and deposits in igneous rocks. Their distribution is directly related to fractures and breccia pipes and to the physical and chemical character of enclosing sedimentary rocks and is believed to be indirectly related to the Terlingua monocline and the igneous rocks in the district.

The quicksilver deposits were formed from hydrothermal solutions of igneous origin at temperatures below 300°C and pressures locally as high as 30 atmospheres. Deposition of mercury minerals is believed to have been from hydrothermal solutions as cinnabar and as primary chlorides. Mineralizing solutions ascended breccia pipes and fractures and the ore minerals were deposited in parts of these channels lying less than 2,000 feet below the surface.

INTRODUCTION

LOCATION, CULTURE, AND ACCESSIBILITY

The Terlingua quicksilver district is in Trans-Pecos Texas—the extreme western part of the State that lies between the Rio Grande and Pecos River—in the Big Bend region, which lies within the great southward bend of the Rio Grande, so conspicuous on any map of the State. The district is in the southern part of the Big Bend region and is a narrow belt, 20 miles long, that extends eastward from eastern Presidio County into southwestern Brewster County (fig. 1).

Quicksilver minerals have also been found at several places in the Big Bend region outside the Terlingua district, but these places are not described.

The population of the district has never been large and has been directly related to the highly fluctuating mining activity. Mining was greatest during World Wars I and II. Shortly after the end of each war many mines closed and the mine workers departed.

At the close of World War II the district contained three small company towns, which supported post

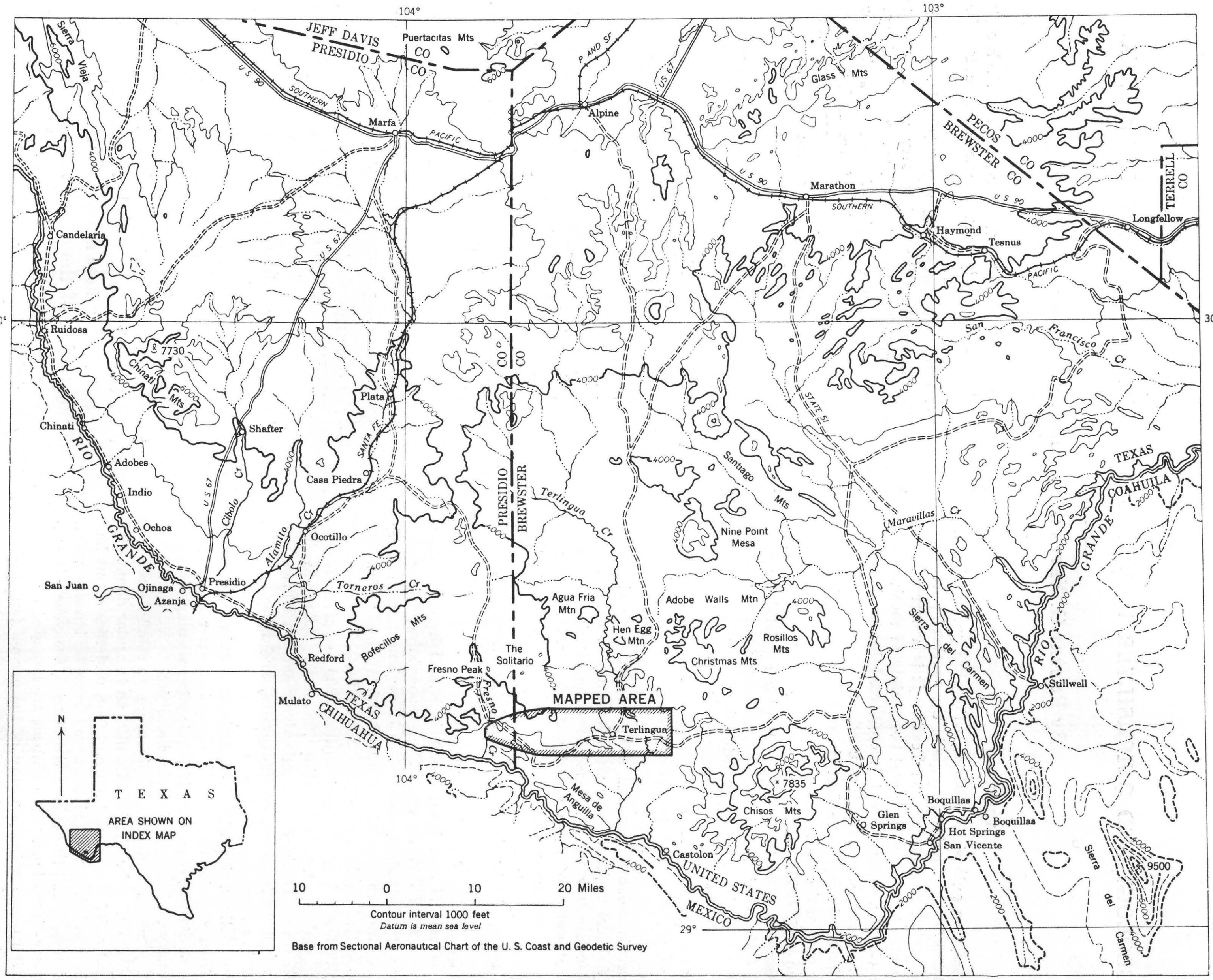

FIGURE 1.—Index map of the Big Bend region.

offices and a combined population of several thousand. By early 1947 the mines had closed, only one post office was open, and the population had shrunk to a few hundred inhabitants. The largest town, Terlingua, is a short distance east of the center of the district and is connected by graded but unsurfaced roads with the other two towns, Study Butte, at the eastern end of the district, and Bueno Suerte, at the western end of the district.

Terlingua is 84 miles by road from the Southern Pacific Railway and U. S. Highway 90 at Alpine. The Alpine-Terlingua road is a fair, graded road but is impassible for short periods during and immediately after heavy rains. The district is also accessible from Marathon, a town likewise on the Southern Pacific Railway and U. S. Highway 90, by State Highway 277, which is the principal access road to the Big Bend National Park.

PHYSICAL FEATURES

GEOGRAPHIC SETTING

Trans-Pecos Texas is an arid, mountainous region and has more geographic affinity to Mexico and New Mexico than it has to the rest of Texas. An excellent summary statement of the general physical features of Trans-Pecos Texas is given by Philip B. King (1937, p. 4) who describes them as follows:

> It [Trans-Pecos Texas] is a region of rugged sierras, of high plateaus and broad cuestas, and of gently sloping intermontane plains. The mountains have no timber except in sheltered valleys and on the higher summits.
>
> In the clear air of the desert the mountain masses loom with sharp outlines and clear detail from a distance of many miles, and the plains that surround them are deceptively foreshortened. More than half of the region is a lowland. These intermontane areas are either bolsons (structural depressions filled by mountain waste) or destructional plains that slope upward as pediments toward the mountain masses from which they have been carved.
>
> Ephemeral streams, which are dry gravel beds most of the year, discharge from the mountains and flow across the plains. Some of these drain into bolsons with no outlet to the sea, such as the Salt Basin, in the northwestern part of Trans-Pecos Texas. Most of the drainage channels, however, lead to the two master streams of the area, the Rio Grande and its major tributary, the Pecos River. Their waters flow to the Gulf of Mexico. The Rio Grande is noteworthy more for its persistence through long stretches of desert land than for its breadth or volume. In its southeastward course across the area the river traverses a succession of desert basins and passes from one to the next through separating mountain barriers in which it has cut narrow and imposing canyons.

The southern part of the Big Bend region corresponds only in small part to King's description. In contrast to the plains of west Texas, it is dominantly a mountainous region, having some of the most rugged topography within Trans-Pecos Texas, but it lacks the broad, sloping intermontane plains that characterize the larger area. Instead, the mountains are surrounded by areas of low relief that are as finely dissected as the mountains themselves. These intermontane areas are either bare rock or are covered by only a thin mantle of debris. The thick bolson deposits that are characteristic of much of Trans-Pecos Texas are entirely lacking.

The contrast between the typical Trans-Pecos Texas topography described by King and that of the southern Big Bend region is particularly evident when one approaches the Terlingua quicksilver district from the north. Stretching southward from Alpine is a broad upland plain (hereafter referred to as Nine Point Mesa Plain) having an average altitude of about 3,500 feet. The general low relief of this plain is broken here and there by isolated mesas and an occasional peak. South of Adobe Walls Mountain (fig. 1) the landscape changes abruptly; the broad plain is replaced by many intermontane areas of lower altitude bounded by mountains that are no longer mesalike, but rugged and closely spaced. This is what is locally called "Terlingua Country," which can be roughly defined as the southern drainage basin of Terlingua Creek. The land-forms are no longer smoothly contoured but give the impression of harshness. Close inspection shows that the surface is almost everywhere cut by gullies and canyons. This, the southern Big Bend region, is an area of active erosion where waste from both mountains and intermontane areas is being transported out of the region.

TOPOGRAPHY OF THE DISTRICT AND BORDERING AREAS

The Terlingua quicksilver district, whose boundaries are geologic and not geographic, is only a small part of the Big Bend region. It is therefore desirable to define its limits before describing its physical features. The district contains a belt of quicksilver deposits that extends east and west from the town of Terlingua. In 1902 the district was loosely defined by the publication of a topographic map, the "Terlingua District quadrangle." [1] Since then the belt of quicksilver deposits has been found to extend beyond the west boundary of this map. What is here considered as the Terlingua quicksilver district (as shown on pl. 1) includes all the area covered by the "Terlingua District quadrangle" plus the more recently discovered western extension of the district. This expanded district lies wholly within the boundaries of the Terlingua quadrangle, a topographic map that includes the area covered by the "Terlingua District quadrangle," with which it should not be confused.

The physical features of the quicksilver district cannot be adequately described without including features that lie either outside of or extend beyond the defined

[1] Prepared and published by the U. S. Geological Survey in cooperation with the University of Texas Mineral Survey.

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limits of the district. Fortunately, the local setting can be given by a description of that part of the southern Big Bend region that borders the quicksilver district. The district and this bordering area are referred to collectively as the "Terlingua area." The Terlingua area can be fairly well defined geographically and in general corresponds to what is referred to locally as the "Terlingua Country." It is bounded on the north by the plains of Nine Point Mesa, on the northeast by the Christmas Mountains, on the east by the Chisos Mountains, on the south by the Rio Grande, and on the west by the Bofecillos Mountains, and the lava plateau of eastern Presidio County (see fig. 1). It lies in the eastern two-thirds of the Terlingua quadrangle, the western part of the Chisos Mountains quadrangle, and extends for a short distance north into the areas covered by the Tascotal Mesa and Aqua Fria quadrangles.

Although mountainous, the Terlingua area is surrounded by areas that are in general topographically higher. Most of the central part of the area lies between altitudes of 2,500 feet and 3,500 feet, whereas the bordering country, averaging more than 4,000 feet in altitude, reaches a maximum of 7,835 feet above sea level in the Chisos Mountains. The relief within the Terlingua area exceeds 3,000 feet, with Fresno Peak in the Solitario area having the maximum altitude of 5,131 feet, and the Rio Grande, where it leaves the area, having the minimum altitude of less than 2,100 feet.

The mountains, arranged without apparent system, consist of flattopped domes, broad mesas, and monolithic masses of igneous origin that are either knoblike or sprawling. There are both large and small examples of these three kinds of mountains. The Solitario is the best example of a dome mountain and is larger than all other mountains of this type, as well as those of the other types. Mesas are largest and most prominent in the southwestern part of the region and are exemplified by Mesa de Anguila (fig. 1) and Lajitas Mesa (pl. 1). The mountains of igneous origin are smaller than those of the other two types and are most abundant in the northeastern part of the region. Good examples of igneous mountains are Hen Egg Mountain, Sawmill Mountain, and Bee Mountain.

Because of the lack of systematic arrangement of the mountains, the intermontane areas are irregular in size and shape. This is particularly pronounced in the northeastern part of the district where the mountains are intruded igneous masses that are much more resistant to weathering than the soft sedimentary rocks that floor the intervening areas. The broadest intermontane area is in the southern part of the Big Bend east of the Mesa de Anguila. Even here the surface is not a smooth plain, but its general low elevation is broken by mesalike hills and entrenched stream channels.

Although the Solitario, the principal topographic feature of the Terlingua area, lies completely outside the Terlingua quicksilver district, it requires more than casual mention because of its influence on the topography, as well as the geology of the western half of the district. The southern edge of the Solitario is about 3 miles north of the north border of the district at its west end. The Solitario is an almost perfectly circular topographic feature, 7.5 miles in diameter, of two concentric parts. The outer part, or rim, consists of an arrangement of hogback hills, from 4,600 feet to 5,100 feet in altitude, which have steep to gentle outward slopes and much shorter clifflike inward slopes. The rim encloses a central basin, which is a moderately smooth surface with an average altitude of about 4,400 feet, that is broken by low hills. The interior basin is drained by several stream channels, which are enclosed in deep, narrow canyons where they cross the rim. The north flank of the Solitario descends fairly gently to the plain of Nine Point Mesa, the west and southwest flanks descend steeply to Fresno Canyon, and the eastern flank descends with moderate steepness into the drainage basin of Terlingua Creek. The southeast flank is less well defined as it merges with a high, intricately dissected, plateaulike surface that extends southeastward into the Terlingua quicksilver district.

This plateaulike surface that extends southeastward from the Solitario is the principal topographic feature of the Terlingua district. It has a general southeasterly slope and is recognizable as far east as the town of Terlingua where its southern and northeastern boundaries join. Its southern boundary is a well-defined, southward-facing escarpment, whose general east-west alinement is locally sinous and broken by reentrants. These are narrow, steep-walled canyons such as Croesus Canyon and broad, northwesterly trending, flat-bottomed valleys such as Long Draw (pl. 1). The northeastern boundary is less well defined but can be arbitrarily fixed as parelleling the Long Draw and lying about 1 mile northeast of it. Its surface is dissected by many canyons and spotted with small buttes that rise above its general level. Besides the valleys that cross it in a northwestern direction, it is also crossed by one wide valley of northeastern trend; this, Lowes Valley, has a broad, flat floor and cliff walls. The most prominent feature that projects above the general level of the plateaulike surface is Black Mesa, a roughly circular, flat-topped mountain that borders the southeast side of the Lowes Valley.

The country south of this plateau projecting from the Solitario is topographically lower and has little local relief. In general, it is an irregular arrangement of low cuestas with steep northerly slopes and gentle southerly slopes. Many small canyons and ravines floored with dry stream channels cross the area. Southward and eastward the stream channels converge into gravel-strewn plains. This cuesta area extends along the southern border of the Terlingua quicksilver district from Contrabando Mountain eastward (see pl. 1).

Contrabando Mountain and Contrabando dome, two contrasting features form the western part of the southern border. Contrabando Mountain has a narrow, flat top and is a low northwestern extension of Lajitas Mesa, which is just south of the district. Contrabando dome is a low, circular arrangement of hills that have gentle outward slopes and steeper slopes toward the stream valleys that cut back into the interior of the dome.

The eastern one-third of the Terlingua district is in contrast to the western two-thirds. The plateaulike surface extending from the Solitario converges with an intermontane surface whose average altitude lies between 2,500 and 2,700 feet. Above this surface project numerous isolated mountains that are roughly circular in form. Almost all these mountains are igneous masses, representing intrusion into soft sedimentary rocks that have since been eroded away.

Terlingua and Fresno Creeks are the only permanent streams in the Terlingua area, and even long stretches of them are dry during the more arid months. All the runoff reaches the Rio Grande by way of these streams except for local areas adjacent to the Rio Grande that are drained by small intermittent streams. Terlingua Creek, crossing the central part of the region in a southerly direction, drains most of the area, although Fresno Creek, also flowing south, drains a much smaller area along the western border of the region.

During and immediately after rain storms Terlingua Creek is a boiling torrent, but during most of the year long stretches of its channel are completely dry. Between the dry stretches are infrequent spring-fed ponds from which water trickles downstream to be almost immediately lost in the gravels of the stream bed. These are the watering holes for the few cattle and goats that are grazed in the district. One of these permanently flowing sections of Terlingua Creek furnishes the water supply for the Two-Forty-Eight mine.

Springs are very rare in the Terlingua area and none have more than feeble flows. A more common, but less trustworthy, water supply is from the tanks, or tinajas, as they are called locally. These are both artificial and natural. The artificial tanks are storage basins for rainwater formed by dams built across small ravines. The natural tanks are depressions in drainage channels formed by solution of limestone and plunge basins below small waterfalls. Some tanks are large enough to store water sufficient to last between rains.

CLIMATE AND VEGETATION

The climate of the Terlingua district is arid or semiarid. No adequate rainfall records have been kept and there are no accurate data. The annual rainfall at Marathon and stations nearby is about 17 inches; and as the vegetation in the Terlingua district is representative of a more arid climate, it is probable that the rainfall in the Terlingua district is considerably less. Much of the rainfall occurs during the late summer months and is often torrential. Summer rain storms may occur without warning at any time. They are highly local; one storm may occur within an area of only a few square miles, while the sun shines brightly in adjoining areas.

The mean annual temperature is probably about 70°F. Daytime summer temperatures are high; temperatures of 100°F. are usual and temperatures above 110° are frequent. Only during short periods are the summer nights hot enough to make sleeping difficult. The winter climate is particularly invigorating: days usually are warm and sunny; the nights, however, are cold and temperatures below 20° have been recorded. Snow occasionally falls on the higher peaks and more rarely an inch or more covers the entire district.

The vegetation of the Terlingua district is scanty and consists mostly of plants especially adapted to survive in a climate where water is scarce and evaporation high. Members of the cactus and yucca families are most abundant and are found throughout the district. The cacti are mostly small forms that grow close to the ground and include representatives of both the *Opuntia* and *Cereus* groups. The commonest plants are many species of yucca, the amaryllid, lechuguilla (*Agave lecheguilla*) and, the lily, sotol (*Dasylirion wheeleri*). Lechuguilla grows particularly well on limestone slopes and in many places these sharp-spined plants are so closely spaced that walking is difficult. Sotol requires more soil than lechuguilla and individual plants are widely spaced. Prickly pear (*Opuntia*) and ocotillo (*Fouquieria splendens*) grow on both the hills and on the valley flats. Creosote bushes (*Covillea*) are common on the broad flats and flood plains of the larger streams, and mesquite (*Prosopsis juliflora*) and catclaw (*Acacia*), both thorny shrubs, grow along stream courses. The wax plant is locally abundant enough to be harvested and treated to obtain the thin coating of wax that covers it. The only trees in the district are a few cottonwoods that grow along Terlingua and Fresno Creeks.

PREVIOUS WORK

The Terlingua quicksilver district apparently escaped the attention of geologists until the close of the 19th century, when the district was visited by W. P. Blake. Blake's interest was concentrated on the recently discovered quicksilver deposits, and he gives an excellent summary (Blake, 1896) of the geology of the deposits that were known in 1895. By 1902 increasing interest in the deposits led the Texas Mineral Survey to send B. F. Hill to make a study of the area. His report (Hill, 1902) contributes some valuable historical information on what is now the central part of the district.

The work of J. A. Udden, (1907a, 1907b, 1911) and Udden and others, (1916), beginning a short time after Hill's report was published, described the stratigraphy of the Big Bend region and was the first serious attempt to correlate the deposition of cinnabar with structural features. Unfortunately, a paucity of published maps detracts from the value of Udden's work; however, of all the early work in the district, Udden's is outstanding. Adkins (Sellards, Adkins, and Plummer, 1933) in 1933 revised and adjusted Udden's stratigraphy into closer correlation with that of the rest of Texas.

Various phases of the geology of the district have been discussed by F. L. Ransome, (1917), H. W. Turner (1905), and J. T. Lonsdale (1940). The work of Ransome is in part based upon data gathered by H. D. McCaskey in 1910. The igneous rocks of the area have been excellently described by J. T. Lonsdale (1940).

In 1934 Clyde P. Ross, assisted by C. H. Coldwell, W. E. Cartwright, H. E. Stocking, and J. A. Connors, made a study of the Terlingua quicksilver district and the surrounding region. A brief preliminary report (Ross, 1941) on this work was published in 1941. A more extensive manuscript by Ross is in the files of the Geological Survey and was available to the authors. Parts of it referred to as "written communication," have been incorporated herein.

PRESENT INVESTIGATION AND ACKNOWLEDGMENTS

The fieldwork upon which this report is based was done between April 1942 and March 1945. Yates, accompanied by J. F. McAllister, first entered the area in April 1942 to examine several prospects at the request of the War Production Board. Shortly thereafter the War Production Board requested additional examinations, covering most mines and prospects in the district. In July the party was joined by Thompson. In November McAllister was transferred to another assignment, but Thompson and Yates remained in the field until late December.

Thomspon returned to the district in February 1943 and was joined by Randall E. Brown in April and by Yates in July. Brown left in August but Thompson and Yates remained until February 1944. Jaime Fernandez Concha assisted in the fieldwork during August and September 1943. During this field season the United States Bureau of Mines carried on an exploratory drilling program from June until October, testing favorable structures at the Chisos and Fresno mines. Geological guidance for this program was given by Thompson and Brown.

Thompson and Yates returned to the district in the spring of 1944 to map the areal geology; Yates remained only 2 weeks and Thompson 6 weeks. In December Yates, accompanied by Edgar H. Bailey, returned to the district and completed the mapping of the areal geology by March 1945.

All those who shared in the fieldwork contributed greatly to this report, and although their names do not appear on the title page, their individual contributions are credited on the maps. Particular mention should be made, however, of the contributions of James F. McAllister and Edgar H. Bailey. McAllister had a large share in the mapping of the Chisos mine and several prospects, and Bailey mapped a considerable part of the areal geology. Their ideas and suggestions on the interpretation of the geology were valuable.

The manuscript report by Clyde P. Ross, mentioned in the preceding section, proved of immeasurable value. The sections on stratigraphy, mining history, and mine production, as well as miscellaneous mine descriptions, are largely revised from Ross's manuscript. Ross's observations and conceptions of the geologic problems were of great initial help to the authors in their study of the area. The opportunity to do detailed mapping resulted in the confirmation of many of Ross's interpretations, which were, of necessity, based upon a less extensive study. However, our studies revealed new evidence that conflicts with some of Ross's published ideas (Ross, 1935a, 1935b, 1937, 1941). Unless otherwise noted, the present interpretations are based on an independent study of the field evidence for which the authors assume full responsibility.

The mining men of the district were, almost without exception, extremely cooperative and hospitable to the field party. They gave freely of their time and information, contributions without which the fieldwork would have been difficult. To list all those to whom the writers are indebted is not possible, but special thanks must be given to the Messrs. W. D. Burcham, Harris S. Smith, and Charles Worthington.

GENERAL GEOLOGY

STRATIFIED ROCKS

The writers' principal interests in the district were the structure and quicksilver deposits, and studies were concentrated on these phases. This specialized approach would not have been possible without the excellent background of stratigraphy supplied by the manuscript report of Clyde P. Ross. The descriptions that follow are mainly condensations of those of Ross, and the measured stratigraphic sections, fossil collections, and chemical analyses are direct quotations.

Although the strata in the Big Bend region range in age from early Paleozoic to Tertiary, almost all the stratified rocks exposed in the Terlingua quicksilver district are of Cretaceous age. Rocks of Paleozoic age doubtless underlie all the Cretaceous rocks, but as these rocks are exposed only in the Solitario, they are not discussed in this report. Lavas and associated clastic beds of Tertiary age, although very abundant east and west of the mapped area, are only sparsely represented.

The Cretaceous rocks in the Terlingua district fall naturally into distinct lithologic units that are easily recognized and mapped. Although these units are easily distinguished in the field, a comparison of the several reports on the district leads to confusion because of the duplicity of names. This duplicity has resulted mainly from the attempts to apply formational names that have been used in the eastern part of the State without consideration of differences in lithologic character.

The Cretaceous stratigraphic units in the Terlingua district were first named and defined by Udden (1907a). Except for the Buda limestone and the Del Rio clay (of former usage), Udden used local names to describe the strata. After later studies, Adkins (Sellards, Adkins, and Plummer, 1933) revised Udden's stratigraphy by redefinition and by substituting outside names for some of Udden's local names. The usage of Ross favors the return to some of the local names, a return that the writers of this paper have followed (table 1).

Although Adkins' studies established a fairly complete correlation between the local units and better known stratigraphic units in the eastern part of the State, it seems desirable to deviate somewhat from it. This largely results from the fact that the field mapping of geologic boundaries requires lithologic, rather than paleontologic units. If the paleontologic boundaries are not also lithologic boundaries, their mapping is difficult if not impossible. With a few exceptions Adkins' terminology has been retained, but his formational boundaries have been shifted in several places.

TABLE 1.—*Stratigraphic names in the Terlingua district*

<table>
<tr><th colspan="3"></th><th>Udden (1907a, p. 21–60)</th><th>Sellards, Adkins, and Plummer (1933)</th><th colspan="2">Names used in this report</th></tr>
<tr><td colspan="3" rowspan="2">Rocks of Tertiary age</td><td>Surface flows</td><td rowspan="2">Volcanic rocks</td><td colspan="2" rowspan="4">Chisos volcanics</td></tr>
<tr><td>Burro gravel and tuff</td></tr>
<tr><td rowspan="9">Upper Cretaceous</td><td rowspan="3">Navarro group</td><td rowspan="7">Gulf series</td><td>Crown conglomerate</td><td>Crown conglomerate</td></tr>
<tr><td>Chisos beds</td><td>Chisos beds</td></tr>
<tr><td>Tornillo clays</td><td>Tornillo formation</td><td colspan="2">Tornillo clay</td></tr>
<tr><td>Taylor group</td><td>Rattlesnake beds</td><td>Aguja formation</td><td colspan="2">Aguja formation</td></tr>
<tr><td rowspan="2">Austin group</td><td rowspan="2">Terlingua beds</td><td>Taylor formation</td><td colspan="2">Terlingua clay</td></tr>
<tr><td>Terlingua formation (restricted)</td><td rowspan="2">Boquillas flags</td><td>Upper member</td></tr>
<tr><td>Eagle Ford group</td><td>Boquillas flags</td><td>Boquillas flags</td><td>Lower member</td></tr>
<tr><td rowspan="2">Washita group</td><td rowspan="4">Comanche series</td><td>Buda limestone</td><td>Buda limestone</td><td colspan="2">Buda limestone</td></tr>
<tr><td>Del Rio clay</td><td>Grayson formation</td><td colspan="2">Grayson formation</td></tr>
<tr><td rowspan="2">Lower Cretaceous</td><td rowspan="2">Fredericksburg group</td><td rowspan="2">Not differentiated in the Terlingua district</td><td>Georgetown limestone</td><td colspan="2" rowspan="2">Devils River limestone</td></tr>
<tr><td>Edwards limestone</td></tr>
</table>

DEVILS RIVER LIMESTONE

DISTRIBUTION AND CHARACTER

The Devils River limestone, the oldest rock exposed in the Terlingua district, is a thick sequence of limestone beds of uniform character that are so resistant to erosion that they form spectacular cliffs and gorges. It is the most abundant rock in the district and, although not exposed in the eastern third of the district, its exposures total more than half of the area of the central and western thirds of the district.

It is a medium- to thick-bedded, fine-grained limestone, light to dark gray on freshly broken surfaces, and gray on weathered surfaces except where stained brown through the oxidation of pyrite, of which it contains small amounts. The chemical analysis given below (table 2) shows that it is a relatively pure limestone, very low in magnesia content, and contains only about 1 percent of silica. The calcium carbonate occurs mainly as shells and shell fragments; the carbonate is recrystallized, but not extensively. Although the organic character of the limestone is evident in the field where some beds can be seen to consist almost entirely of oysterlike fossils, it is strikingly evident when the limestone is studied under the microscope. Much of the matrix material around megascopic fossils was seen to be tests and fragments of tests of Foraminifera, notably species of *Globigerina* or similar genera. The silica in the rock analyzed is probably disseminated in small grains throughout the rock; however, some beds contain variable amounts of small and irregular concretions of chert.

Joints are well developed and the joint pattern has been accented by solution along joint planes. In places this solution of the limestone has progressed far enough to produce caverns and sinkholes.

The base of the Devils River limestone is nowhere exposed in the Terlingua district; consequently, its local thickness could not be measured. Although several sections contain more than 500 feet of beds, they doubtless represent only a small part of the total section, because south of the district, in cliffs of the Mesa de Anguila, the thickness is more than 1,500 feet and even here the base is not exposed. The base is exposed, however, in the rim of the Solitario. Here the Devils River limestone rests conformably upon impure limestone containing Glen Rose fossils (Sellards, Adkins, Plummer, 1933, p. 305), which in turn rests conformably upon a coarse sandstone and conglomerate. The conglomerate rests in angular discordance upon beds of Paleozoic age.

TABLE 2—*Analysis of sample of Devils River limestone collected by Clyde P. Ross from Canyon Group of claims in the northeast part of sec. 42, Block G–12.*

[Analyst, Charles Milton, November 1936]

	Percent
SiO_2	1.08
Fe_2O_3	.56
MgO	.06
CaO	54.62
CO_2	42.85
H_2O	.65
Total	99.82

The contact of the Devils River limestone with the overlying Grayson formation is in all its many exposures sharp and conformable. This division between the two formations is not, however, so abrupt a change from limestone to clay as the sharp contact suggests, because the uppermost beds of Devils River limestone are argillaceous and the lowermost beds of the Grayson formation are calcareous. These slightly argillaceous beds of Devils River limestone appear to be confined to the uppermost 50 feet of the formation, which, in some places, is also thinner bedded and less resistant to solution. Many quicksilver deposits occurred in this part of the Devils River limestone.

This uppermost 50 feet of the formation has locally been termed the Georgetown limestone (see table 1), a distinction that has not been made on the district map (pl. 1) because a consistent mapping of this subdivision would be extremely difficult. A subdivision based on the above described differences in lithologic character could have been made in the vicinity of California Mountain (pl. 1), but at other places in the district the differences are too vague for accurate mapping purposes. Under these circumstances it seems best to call the entire unit the Devils River limestone, a general term proposed by Udden (1907b, p. 56) for a similar sequence of limestone beds without mappable subdivisions in Val Verde County, Tex.

AGE

According to Ross, "Previous investigators (Sellards, Adkins, and Plummer, 1933, p. 271, 346; Hill, 1902, p. 16) consider that none of the beds of the Devils River limestone appear to be younger than Georgetown and that the oldest beds are probably of Fredericksburg age." Fossils are sparse and poorly preserved.

Of the six collections of fossils (table 3) obtained from beds assigned to the Devils River limestone, three collections are regarded by J. B. Reeside, Jr., as of undeterminate age and the same is true of specimen TT 506 examined by L. G. Henbest. Reeside lists one collection (USGS 16847) from high in the formation as definitely of Edwards age, and another (USGS 16850) from the lower part of the Devils River as probably of Edwards age.

TABLE 3.—*Fossil collections from the Devils River limestone in the Terlingua region, Texas*

[Numbers, except TT 506, are U. S. Geological Survey Mesozoic locality numbers]

16846. Top of large sinkhole near Colquitt-Tigner mine.
Kingena wacoensis (Roemer)
Neithea sp., fragments

16847. Top of Black Mesa.
Neithea duplicicosta (Roemer)
Lucina acutilineolata (Roemer)
Toucasia cf. *T. texana* (Roemer)
Eoradiolites? sp., fragments
Boring, undetermined

16850. From base of scarp on the north side of the Rio Grande at the east end of the Grand Canyon of Santa Helena.
Gryphaea marcoui Hill and Vaughan
Exogyra texana Roemer
Pholadomya near *P. sanctisabae* (Roemer)
Lucina? sp., molds
Cardium? sp., molds
Turritella? sp., molds

16967. Crosscut of the 200 foot level off the Contratira (Subia winze) Mariposa mine. (Collected by H. D. McCaskey.)
Ostrea (*Exogyra?*) sp.

16980. Main shaft dump, Colquitt-Tigner mine. (Collected by H. D. McCaskey.)
Pecten sp.

TT 506. Canyon group of claims (studied by L. G. Henbest).
Globigerina sp.
Textularian? (not *Haplostiche texana*)
Echinoderm plates

GRAYSON FORMATION

DISTRIBUTION AND CHARACTER

Conformably overlying the Devils River limestone is an almost structureless clay that had long been known as the Del Rio clay (Hill, 1902, p. 18–19). Adkins (Sellards, Adkins, and Plummer, 1933, p. 270, 271, 386–387, 391–393) proposed extending to the Terlingua area the name Grayson formation, a name long used for beds of similar stratigraphic position farther north.

The clay of the Grayson formation crops out in the same general part of the district as the Devils River limestone, but because it is much thinner and has been extensively eroded, it covers a much smaller area. It is mainly along the flanks of folds and beneath the talus slopes of buttes and mesas that the Grayson formation has been able to resist erosional stripping. It is not only easily eroded but is a constant hazard where it forms the walls of mine workings because it loses all coherency and completely disintegrates upon wetting.

Underground the clay appears as a massive rock, except near the top and bottom of the formation where more calcareous beds give the rock a poorly bedded character. In surface exposures the bedding is more pronounced, for individual beds weather variously from gray to rusty brown. This is due to the oxidized pyrite that is present in small quantities throughout

TABLE 4.—*Analysis of sample of clay of the Grayson formation collected by C. P. Ross from road to the Mariposa mine in sec. 39, Block G–12*

Analyst, Charles Milton, November 1936]

	Percent soluble in HCl	*Percent insoluble in* HCl
SiO_2	0. 16	44. 87
Al_2O_3	1. 14	15. 09
Fe_2O_3	. 29	2. 75
CaO	12. 77	. 23
MgO	1. 56	. 59
Na_2O	----------	None
K_2O	----------	2. 10
H_2O	----------	6. 25
TiO_2	----------	1. 12
CO_2	11. 94	----------
Subtotal	27. 86	73. 00
Total	----------	100. 86

the rock and is abundant in certain beds. The pyrite is best seen in mine workings and in drill cores; it is never seen in weathered rock. As indicated by the following analysis (table 4) the rock is calcareous. The calcium carbonate content of individual beds ranges from about 10 percent to more than 90 percent.

Although the character of the Grayson formation (Late Cretaceous) is constant throughout the district, its thickness varies considerably. In and near sec. 42, Block G–12, it is about 200 feet thick. A diamond-drill hole on the Canyon group of claims penetrates 195 feet of clay before entering the Devils River limestone. Beneath California Mountain the Grayson formation is about 185 feet thick. In sec. 70, Block 341, farther east, the thickness is a little less than 100 feet. North of Clay Mountain the formation appears to be 80 feet thick.

AGE

Numerous and well-preserved fossils are common in the Grayson formation. Adkins (Sellards, Adkins, and Plummer, 1933, p. 393) reported that the basal and middle parts of the formation contain an abundance of echinoderms (mostly *Heteraster*), *Gryphaea mucronata*, pyritized micromorphs of ammonites and gastropods, and *Haplostiche texana*. In the upper beds he noted a zone of abundant *Exogyra cartledgei* Böse.

Hill (1902, p. 19) reports that the most common fossils in the formation include *Nodosaria* [*Haplostiche*] *texana*, *Exogyra arietina*, *Exogyra drakei*, *Gryphaea pitcheri* (*mucronata*), and numerous echinoderms.

According to Ross (written communication):

Two specimens of Del Rio clay [now called the Grayson formation] were examined by Henbest for possible microfossils. One of these from an especially calcareous bed on the Canyon group of claims was found to contain abundant Foraminifera, but these cannot be identified closely enough to be of value in age determination. The microfossils in a specimen of typical Del Rio clay [now called the Grayson formation] from an outcrop on the road east of California Mountain are regarded by Henbest as indicative of Comanche age.

Fossil collections from the Grayson formation in the Terlingua quicksilver district

[Material submitted by C. P. Ross to J. B. Reeside, Jr., for identification. Numbers are U. S. Geological Survey Mesozoic locality numbers]

16836. From the northwest part of Reed Plateau (pl. 1) close to the Walker prospect.
Exogyra arietina Roemer
Exogyra cartledgei Böse

16973. Nodular limestone in Grayson formation and separated by fissile shale from base of Buda limestone on California Mountain. (Collected by H. D. McCaskey.)
Exogyra cartledgei Böse

16975. Near top of Grayson formation on the southwest slope of California Mountain. (Collected by H. D. McCaskey.)
Haplostiche texana (Conrad)

16977. From the upper few feet of Grayson formation on California Mountain. (Collected by H. D. McCaskey.)
Haplostiche texana (Conrad)

BUDA LIMESTONE

DISTRIBUTION AND CHARACTER

In the Terlingua district, it is almost axiomatic that wherever there is the Grayson formation there is Buda limestone. Preservation of the easily eroded clay of the Grayson for any length of time, is possible only where the clay is protected by the more resistant Buda limestone. In turn, the Buda, because of its relation to the Grayson, characteristically forms hogbacks and is the capping rock in mesas and buttes.

The Buda limestone is a distinct, easily defined stratigraphic unit. It is a white, well-bedded and well-jointed limestone commonly 90 feet thick, but locally as much as 100 or as little as 50 feet thick. Its tendency to fracture conchoidally, coupled with a spherical weathering of joint blocks, produces a characteristic gravel-like detritus.

The limestone contains more than 96 percent calcium carbonate as can be seen from the analysis in table 5 quoted from Udden (1907a, p. 28).

TABLE 5.—*Analysis of Buda limestone one mile east of Boquillas*

	Percent
Silica	2.35
Alumina	.21
Ferric oxide	.24
Lime	53.90
Magnesia	.15
Carbonic acid	42.23
Water (hygroscopic)	.18
Water (combined)	.33
Sulphur	tr
Total	99.59

AGE

Identifications by J. B. Reeside, Jr., of five fossil collections submitted by C. P. Ross are listed below:

Fossil collections from the Buda limestone, Terlingua quicksilver district

[Numbers are U. S. Geological Survey Mesozoic locality numbers]

16838. From one-quarter mile east-northeast of Coltrin Camp on the southwest side of Reed Plateau. (Collected by W. E. Cartright.)
Budaiceras cf. *B. mexicanum* Böse
Stoliczkaia sp.

16839. From the margin of the Buda limestone on Reed Plateau, north of the center of sec. 69, Block 341.
Neithea sp., fragment
Cardium, apparently unnamed
Nerinea? sp., fragment
Budaiceras mexicanum Böse

16851. Close to the east end of the exposure of Buda limestone on the northeast side of Reed Plateau.
Sponge?
Borings of worms?
Holaster sp.
Astarte sp., fragment
Nemodon? sp., possibly new
Neithea subalpinus Böse
Turbo? sp., unnamed
Glauconia? sp., fragment
Schloenbachia? sp., probably unnamed
Budaiceras cf. *B. hyatti* (Shattuck)

16971. Forty-six feet below top of exposed Buda limestone about 2 miles southwest of Tres Cuevas Mountain in the northwest quarter of sec. 57, Block G 12. (Collected by H. D. McCaskey.)
Budaiceras sp.

16978. Location unknown. (Collected by H. D. McCaskey.)
Budaiceras sp., fragment

A specimen of Buda limestone from the Chisos mine consists, according to Henbest, largely of the following Foraminifera: *Globigerina* or *Globerigerinella*, *Guembelina*?, *Textularia*?, and dissociated chambers of globerigerinids. Similar but even less closely identifiable forms were found by Henbest in two other specimens of Buda limestone.

BOQUILLAS FLAGS

DISTRIBUTION AND CHARACTER

The rocks described on the preceding pages, the Devils River limestone (Lower Cretaceous), and Grayson formation, and Buda limestone (Upper Cretaceous), are predominantly limestones. The deposition of the lowermost beds of the Boquillas flags, which overlie the Buda limestone with apparent conformity, marks a change in conditions of sedimentation. The Upper Cretaceous rocks contain, as one goes up in the section, decreasingly less limestone and increasingly more clay and sand. This change in rock character represents a progressive change from a marine to a continental environment of sedimentation, a change that culminated in the deposition of volcanic rocks, which continued to be deposited well into Tertiary time.

As a result of these progressive changes in environment, the upper Cretaceous units grade one into the other; consequently, they are not easily delineated and have therefore been variously defined and named. The writers in mapping the upper Cretaceous rocks divided them into formations solely on the basis of lithologic character; consequently, formational boundaries are not always in agreement with those of earlier workers, who established some boundaries on the basis of fauna in the desire to have formational divisions that would agree in time span with those previously established elsewhere in Texas.

The Boquillas flags, which consist of about 1,000 feet of flaggy limestone and shaly beds, are widely distributed throughout the district (pl. 1), and are particularly well exposed east of the Chisos mine and in the Contrabando dome south of the Fresno mine. Although the basal beds immediately overlying the Buda limestone are dominantly limestones, their thin-bedded character contrasts so sharply with the thick-bedded Buda limestone that the contact between the two is readily recognized and easily mapped. The formation as mapped includes all the beds considered by Ross (1941, p. 121) as belonging to the formation, but it is divided into an upper and lower member, the plane of division being the top of a thin sandy limestone bed that represents a faunal zone characterized by an ammonite (*Crioceras*), found nowhere else in the formation.

The lower member of the Boquillas is dominantly limestone, the beds ranging from 6 inches to 3 feet thick, separated by thinner layers of limy shale. The limestones are yellow to creamy white on weathered surfaces and gray to black on fresh fractures. Individual beds are faintly laminated and the rock can be readily split along the laminations, to produce flagstones, or "flags," a property for which it was named. Many limestone beds are sandy, containing small amounts of detrital quartz grains; others are argillaceous. The analyses quoted below show the siliceous and argillaceous character of the flaggy beds and also the presence of "organic" or carbonaceous matter, which is the pigmentation that gives the rock its black color.

The selected analyses in the following table give some idea of the variations in composition of the flags.

The shaly intercalations are nearly black on fresh fracture, and likewise bituminous; they weather to light yellow or buff. The upper part of the Boquillas contains more shale than the lower part.

The typical flagstone of the formation is an impure limestone, yellow to creamy white on weathered surfaces, and gray to black on fresh fractures. The flags range from a few inches to a few feet in thickness, and can be cleaved into large flat slabs from 1 to 5 inches thick. Some of the flaggy beds are sandy. The flaggy beds are intercalated with thin layers of shaly material, which is also calcareous and generally contains some bituminous matter. Most of the shaly material is nearly black on fresh fracture but weathers to light yellow or buff. The quantity of shaly material increases upward in the formation to where the flags disappear, and there is a gradation into the overlying Terlingua clay.

TABLE 6.—*Analyses of flaggy limestone from the Boquillas flags (Udden, 1907a, p. 30, 40)*

O. H. Palm, analyst]

	South of Cuesta Blanca	*Cuesta Blanca*	*Near Colquitt-Tigner mine*
Silica	19. 34	7. 80	20. 72
Alumina	3. 00	1. 30	. 16
Ferric oxide	2. 16	1. 30	. 45
Lime	39. 50	49. 20	43. 15
Magnesia	1. 00	. 15	. 52
Carbonic acid	31. 50	38. 50	34. 20
Organic matter	. 90	1. 10	---------
Water (hygroscopic)	. 30	. 20	. 10
Water (combined)	2. 00	. 50	. 32
Totals	99. 70	100. 05	99. 62

The upper limit of the lower Boquillas is placed at the top of a 1- to 2-foot bed of sandy limestone about 500 feet above the top of the Buda limestone. This bed contains abundant fossils, determined by Adkins (Sellards, Adkins, and Plummer, 1933, p. 451) as belemnites, later found by L. W. Stephenson (oral communication, 1955) to be *Sciponoceras* cf. *S. gracilis* (Shumard), *Crioceras* n. sp., and *Scaphites* aff. S. *vermiculus*. The most distinctive of these fossils, is the large uncoiled ammonite, *Crioceras*, which was seen at no other horizon in the formation.

The bed, because of its arenaceous composition, forms low hogbacks and is easily recognized as a dark line on the air photographs. Its characteristic fossils distinguish it from all other similar beds.

The beds above the *Crioceras* zone resemble those below except there is a tendency for the limestone beds to be more shaly, and they are also farther apart. This change is progressive and results in a gradation into the overlying formation, the Terlingua clay.

The upper limit of the Boquillas flags is not as definite as the lower limit. In mapping this boundary the writers followed C. P. Ross, who said (written communication),

For purposes of mapping, it [the upper contact] is placed at the base of the dark, dominantly shaly beds, in which flagstones are absent or so thin and sparsely distributed as to be relatively inconspicuous. Nearly everywhere the contact as thus defined can be recognized with sufficient precision for mapping. Even where shaly beds are exceptionally abundant in the upper part of the Boquillas flags they can be distinguished from similar but generally less calcareous material above by the fact that, on the whole, they weather to a lighter, more yellowish color and have a conspicuous amount of flaggy beds interbedded with them.

The great number of faults that cut exposures of Boquillas flags in the Terlingua district make an accurate measurement of the thickness of the formation extremely difficult. Ross made what he considered a fairly accurate measurement of the whole formation in the northwest part of sec. 300, Block G–4, where he found the thickness to be 1,090 feet.

The subdivision of the Boquillas flags into upper and lower members was prompted by a desire to increase the degree of accuracy and attendant economic usability of the district geologic map and still keep formations lithologically distinctive from those above and below. This purpose could be best served by the selection of a plane of division somewhere near the middle of the formation. The presence of an easily recognized faunal zone near this position in the section was indeed fortunate. In a sense it is also fortunate that this zone is the one selected by Adkins (see table 1) as the division between his Boquillas flags and Terlingua formation. Its selection, therefore, gives a common boundary, albeit a boundary used in this report between members of a formation and a boundary used by Adkins between two formations. Adkins' usage is in keeping with the commendable desire to correlate a certain thickness of strata in the Big Bend region with rocks deposited (Eagle Ford) in eastern Texas during the same period of time. The writers, however, favor making this faunal zone a boundary between formational members rather than between formations because of the similarity of rocks above the zone to those below. Accordingly, this division of the Boquillas flags into members is not a subdivision of Adkins' Boquillas flags, which includes only the lower member; instead it is an extension of his and Udden's definition of the formation to include rocks considered by them as more properly belonging to an overlying formation.

Beds mapped as Boquillas flags therefore include the lower part of what Adkins called Terlingua formation (restricted).

AGE

The Boquillas flags are everywhere fossiliferous, but distinctive, well-preserved fossils are not common. The most conspicuous and most abundant macrofossils are shells of *Inoceramus,* of which there are at least six species present in the formation. Some of these shells are more than 30 inches wide and 3 inches thick. Besides the inocerami, there are other pelecypods, a few ammonites, and many Foraminifera.

The collections of macrofossils made during the investigation of C. P. Ross have been studied by L. W. Stephenson and the following data are taken from Ross's report.

Inoceramus labiatus Schlotheim, of Eagle Ford age, has been identified from sec. 70, block 341 (USGS coll. 16837), from Long Draw, from Fossil Knobs (USGS colls. 16843, 16844), and from six collections of unknown locations (USGS colls. 16966, 16968, 16969, 16970, 16983, 16984), made by H. D. McCaskey. All the collections containing *I. labiatus* are from beds clearly belonging to the Boquillas flags. In addition to *I. labiatus*, the collections from Fossil Knobs contain *Inoceramus* cf. *I. latus* Sowerby, *Crioceras* sp., and problematical markings, such as are usually termed fucoids. The fossils in these collections are regarded as of Eagle Ford age by Stephenson.

A collection (USGS coll. 16842) from the lower part of a measured (by C. P. Ross) section of Boquillas flags in sec. 30, block G–4, contains *Inoceramus* sp. (many fragments) and *Ostrea* sp. It is regarded by Stephenson as of Eagle Ford age.

Material from this measured section was searched for Foraminifera by Lloyd G. Henbest who reports that most of the collections from the Boquillas flags do not contain diagnostic Foraminifera. Most of the assignments of Austin age to certain of the collections were made because of the presence of "species of *Hastigerinella* of supposed restriction to rocks of Austin age."

The samples from the lower beds contain no diagnostic Foraminifera. A sample collected about 150 feet above the base contains *Guembelina* of the Eagle Ford and no forms restricted to rocks of later age. A collection from about 400 feet above the base of the section measured by Ross is regarded by Henbest as of either Eagle Ford or Austin age. The collections from the next 200 feet of beds are for the most part not diagnostic. One from about 650 feet above the base of the section was reported to represent possibly late Austin age but more likely represents early Taylor age. However, a collection made about 100 feet higher in the section is reported by Henbest to contain *Hastigerinella alexanderi* (smaller than typical specimens) and to resemble forms of Austin age. Collections made at still higher horizons within the Boquillas flags proved not to be diagnostic.

A specimen collected half a mile southwest of the Rainbow shaft in beds regarded as close to the top of the Boquillas flags is thought by Henbest to be of Taylor age.

In summary, the fossil evidence indicates that the beds designated as the lower member of the Boquillas are clearly of Eagle Ford age and that the beds designated as the upper member of the Boquillas are probably predominantly of Austin age, although it is possible that the uppermost beds mapped as Boquillas may be as young as Taylor.

TERLINGUA CLAY

DISTRIBUTION AND CHARACTER

Terlingua clay as mapped in the district consists of about 1,000 feet of soft structureless clay and a few thin beds of impure limestone. Included are only the upper three-fourths of the formation Udden (1907a, p. 33–41) called Terlingua beds; the bottom fourth of the formation is included in the writers' upper Boquillas. Likewise, it only includes the upper half of what Adkins (Sellards, Adkins, and Plummer, 1933, p. 271) called Terlingua formation (restricted), but includes in addition all of Adkins' Taylor formation.

Although the units of Udden and Adkins have a greater value in age correlations than the present division, they lack lithologic unity in the Terlingua district. As lithologic unity was of primary cartographic importance in this study, the changes in formational boundaries appear to be justified.

The Terlingua clay is only in the eastern part of the district and is locally well exposed on Terlingua Creek and some of its branches. Because it is soft and almost unconsolidated when once exposed, it erodes rapidly to produce low rounded hills. In the immediate valley of Terlingua Creek this characteristic topography has not developed because the hills of Terlingua clay are capped and protected by a mantle of caliche-cemented gravels, which were once continuous across the stream valley.

The Terlingua clay as here mapped consists of soft, structureless, gray clay that weathers a dirty yellow-brown, a minor quantity of shaly marl, and a few thin beds of impure limestone. Exposed clay swells on weathering to produce a peculiar popcornlike surface, a phenomenon suggestive of a bentonitic composition. As stated in the preceding discussion, the lower boundary of the formation is placed "at the base of the dark, dominantly shaly beds, in which flagstones are absent or so thin and sparsely distributed as to be relatively inconspicuous." The shaly beds at the base become less calcareous and lose their well-defined bedding planes as they grade upward into the structureless clay. Although the same clay continues upward into what has been mapped as Aguja formation, which is composed of sandstone and clay, the lowermost sandstone bed, with which the clay is intercalated, indicates a change in conditions of sedimentation sufficient to justify a formation boundary at this horizon.

Except in areas where the clay is baked, measurements of the attitude of bedding must be made on the shaly and limestone layers. The baking of the clay by underlying igneous intrusions has made apparent the otherwise invisible bedding planes in the rock. An excellent example of this is just north of Study Butte where structureless Terlingua clay can be traced laterally into baked rocks so well bedded that they can easily be mistaken for Boquillas flags.

Because of the paucity of measurable bedding planes it is difficult to make more than an estimate of the total thickness of the Terlingua clay. A planetable traverse made by C. P. Ross over the long ridge northwest of Dawson Creek yielded the data for estimating the presence of 465 feet of beds. This traverse covered only the upper part of the formation and must be several hundred feet short of including the total thickness. Another partial section, south of Cuesta Blanca, contains about 600 feet of beds. At several other places in the district several hundred feet of beds can be measured, but nowhere in the district is there a complete, unfaulted section. An estimated total thickness of 1,000 feet seems reasonable.

AGE

Fossils collected by C. P. Ross and identified by L. W. Stephenson, Lloyd G. Henbest, and J. B. Reeside, Jr., indicate that the greater part of the Terlingua clay is of Taylor age, although the lowest beds may be as old as Austin rocks.

In Long Draw three-quarters of a mile northeast of the Colquitt-Tigner mine a collection (USGS coll. 16835) from a fault block of Terlingua clay contains *Inoceramus* sp., *Gryphaea* sp., and Foraminifera regarded by Henbest as of Taylor age.

Two small hills on either side of the highway half a mile southwest of Study Butte yielded the following (USGS coll. 16845):

Echinoid of the family Spatangidae
Inoceramus deformis Meek?
Inoceramus (2 sp.)
Ostrea congesta Conrad
Spondylus sp.
Baculites sp.
Texanites sp. (=*Mortoniceras* Meek)
Crioceras? sp.

According to L. W. Stephenson, who made the identifications, this collection is indicative of Austin age. It is not possible to tell the exact stratigraphic position of the clay in these hills within the Terlingua because they are isolated outcrops. It is likely, however, that they are low in the section, for the beds from which the fossils came are flaggy layers lithologically similar to the Boquillas flags.

Beds of the Terlingua just east of Sierra Aguja (about 7 miles south of Terlingua) yielded *Inoceramus* cf. *I. vanuxemi* Meek and Hayden (USGS coll. 16986), regarded by Stephenson as of Taylor(?) age.

A collection made near the top of the Terlingua clay northeast of Leon Mountain, yielded *Exogyra ponderosa erraticostata* Stephenson. This fossil is regarded as of late Taylor(?) age by Stephenson. The same species was found in similar stratigraphic position in the southwestern part of sec. 252, Block G–4 (USGS coll. 16841).

The clay exposed in the southeast corner of sec. 297, Block G–4, just below the contact with the Aguja, yielded fossils that are, according to Reeside, fragments of a thick-shelled form of *Inoceramus* (*Haploscapha*) sp., *Ostrea congesta* Conrad, *Spondylus guadalupae* Roemer?, *Anchura*, *Natica*, and other gastropods represented by internal molds, a smooth small *Baculites*, and two small corroded ammonite specimens. This assemblage suggests Austin rather than Taylor age, but is inconclusive, especially as the identification of *Spondylus guadalupae* is not definite. Foraminifera contained in 5 collections from this locality have been examined by Henbest, who regards them as of early Taylor age. Of the 9 collections made from exposures of the Terlingua in the fault zone along Long Draw, 7 are regarded by Henbest as of early Taylor, and 2 are regarded by him as of Taylor age, without closer assignment. One of the collections of early Taylor age, from a point 0.2 mile S. 55° W. of the main shaft of the Rainbow mine, is reported to contain *Planoglobulina*, highly ornate, angular *Guembelina*, and *Kyphopyxa christneri*. Two collections made near the west end of Study Butte are reported as probably of Taylor age.

A collection of foraminiferal material made from near the base of the exposed section of Terlingua clay on the ridge near Dawson Creek is reported as probably lower Taylor, and another collection from near the middle of the section is reported as probably Taylor. The collection of supposed early Taylor age contains, according to Henbest, *Kyphopyxa christneri* which is limited to the upper Austin and lower Taylor. *Epistomina* sp. is also present.

A collection made directly above the top of the Boquillas flags sec. 300, Block G–4, is reported by Henbest to contain *Hastigerinella alexanderi* Cushman, a species representing a forerunner of *Planulina taylorensis*, and two or three species of *Guembelina*. He regards the assemblage as indicative of Austin age, although the species of *Guembelina* look like forms from the Taylor. Another collection from slightly higher beds is assigned an Austin age by Henbest because of the presence of *Hastigerinella watersi* (smaller than usual for this species). The *Guembelina* present agree with this assignment, but a species of *Globorotalia*, ordinarily regarded by Henbest as Taylor or younger, is also present.

Henbest notes that the collections of Taylor age generally have more nearly complete microfaunas than those made in older beds. He determines as lower Taylor (lower half) collections with *Kyphopyxa christneri* (Carsey) plus one or more forms of Taylor age. Those collections reported simply as of Taylor age contain nothing to indicate the exact part of the Taylor to which they are most likely equivalent in age. Several collections reported as lower Taylor also contain *Vaginulina regina* Plummer of which Henbest says (written communication):

> "This form is limited to the Austin and lower chalky layers of the Taylor, according to Plummer. A variety of this species has been recorded from the Eagle Ford by Moreman. One or two of the collections that contain *V. regina* also carry *Hastigerinella alexanderi* Cushman, currently regarded as an indicator of Austin age."

AGUJA FORMATION

DISTRIBUTION AND CHARACTER

The beds of sandstone and clay that overlie the Terlingua clay are here termed Aguja formation as proposed by Adkins (Sellards, Adkins, and Plummer, 1933, p. 505–508), who made the proposal because Udden's original name, Rattlesnake beds, (Udden, 1907a, p. 41–54) is preemployed by a formation in Oregon of Pliocene and Pleistocene(?) age.

The Aguja formation is widely, but irregularly, distributed in the Terlingua district. It occupies considerable areas in the eastern part of the district but has been eroded in the western part. Because it is composed of soft clays interlayered with much more resistant sandstone, its topographic expression lacks the smooth contours of the Terlingua clay.

As mapped, the base of the Aguja formation is the base of the first sandstone bed overlying the Terlingua clay. The upper boundary of the Aguja formation, which is the base of the overlying Tornillo formation, is of only local importance in the area mapped (pl. 1), because beds mapped as Tornillo were found only in the southeastern corner of the district. Here the change from dull to brightly colored rocks—a criterion useful in areas outside the district—is not sharp; so some finer basis of separation had to be sought. A thin tuffaceous bed was decided upon as the boundary, and all beds below it are included in the Aguja formation. These beds apparently contain no tuff.

In contrast to the underlying formations of clays and limestones, the Aguja formation can be described as the "sandstone formation" of the Cretaceous rocks. Although it contains argillaceous beds in an abundance equal to that of the sandstone beds, the latter are conspicuous and characterize the formation; argillaceous beds are most abundant in the upper part of the formation. Near the base of the formation the sandstone beds are interbedded with clays that resemble the underlying Terlingua clay. Also near the base of the formation are two or more thin limestone beds that contain abundant fossils. Coaly beds are found near the base but are more abundant in the upper part of the section.

The sandstone of the Aguja formation is of medium grain and has considerable range in color. Beds are commonly light gray or light brown; yellow and reddish beds are fairly rare. Crossbedding may or may not be present, and where it is not present, the rock is massive or shows fairly well developed normal bedding. Beds containing roughly spherical concretions, ranging from a few inches to more than 3 feet in diameter, are common.

The principal component of the sandstone is quartz in poorly rounded grains, with lesser quantities of plagioclase, chert, biotite, kaolinized material that may have been potash-feldspar, and fossil fragments. The maximum grain size is a little more than 1 millimeter and the average grain size less than 0.5 millimeter. Most cementing material is argillaceous, a little is calcareous.

The clay beds in the lower part of the formation resemble the Terlingua clay and those in the upper part resemble those in the Tornillo formation. On the whole, they are more silty and arenaceous than those in either of these formations and locally have a shaly structure. Coaly material is common throughout the clay beds, and although some coal from the Aguja formation has been mined and used locally, there is none within the district (pl. 1) that appears suitable for shipment. Plant fragments and silicified tree trunks are common.

The only place in the Terlingua district where the thickness of the Aguja formation can be measured is in the valley of Dawson Creek in the southeast corner of the district. Even here exposures are incomplete and even an estimate of the total thickness requires projections. C. P. Ross, in making a planetable traverse across these beds, found that the lower 260 feet consists of sandstone alternating with clay, and also three thin limestone beds. Above this lies 30 feet of black, highly carbonaceous shaly clay and then 400 feet of crossbedded sandstone. The rest of the Aguja is largely concealed. The writers would add an additional 100 feet of clay beds to the section, because it is that distance to the tuffaceous bed, that they use as the upper limit.

AGE

Fossils are abundant in the thin limestone beds of the lower part of the Aguja formation and, except for saurians, are rare in the upper part of the formation. The fossils found in the lower part of the formation indicate that these lower beds are of late Taylor age. Rocks in the upper part of the formation represent an indefinite length of Navarro time. Fossils collected by C. P. Ross and identified by L. W. Stephenson are given in table 7.

Another collection (USGS coll. 16840) made high in the lower 260 feet unit in the same section, contains *Ostrea pratti* Stephenson. Stephenson regards this as of late Taylor(?) age and notes that its known range in North Carolina corresponds to the range from upper Taylor to lower Navarro.

A collection of fossils (USGS coll. 16852) from beds near the base of the Aguja formation in the southwestern part of sec. 252, Block G–4, contains very abundant *Ostrea cortex* Conrad. Stephenson states that this is a characteristic fossil of the Escondido formation of Maverick and Uvalde Counties. The Escondido is a formation of the Navarro group approximately equivalent to the Kemp clay, the uppermost formation (Maestrichtian) of the group. Because fossils of late Taylor age have been identified from the lower Aguja, this suggests that *O. cortex* may have a lower range in west Texas than it has in Maverick and Uvalde Counties or else it suggests—a less likely possibility—that the base of the Aguja is stratigraphically higher here than at other fossil localities in the Terlingua district.

Rather high in the section associated with fossil tree trunks are saurian bones. Udden (1907a, p. 51–54)

TABLE 7.—*Fossils from measured section of Aguja formation near Dawson Creek*

FIRST LIMESTONE BED

Pelecypoda:
- *Anomia* sp.
- *Cymbophora* (both large and small species)
- *Corbula* sp.
- Unidentified pelecypod

Gastropoda:
- *Monodonta?*
- *Polinices* sp.
- *Gyrodes* sp.
- *Pugnellus* sp.
- *Volutomorpha* sp.

Cephalopoda:
- *Eutrephoceras* sp.
- *Baculites* aff. *B. taylorensis* Adkins

Vertebrata:
- Shark teeth (2 or 3 species)

SECOND LIMESTONE BED

Pelecypoda:
- *Exogyra* sp.
- *Anomia* sp.
- *Aphrodina* sp.
- *Cymbophora* sp.

Gastropoda:
- *Volutoderma* sp.
- *Morea* sp.

Cephalopoda
- *Eutrephoceras* sp.
- *Baculites* aff. *B. taylorensis* Adkins
- *Placenticeras* sp.

found this characteristic of the formation. According to S. W. Williston, the saurians include *Claosaurus*, *ceratopsid?*, *Dryptosaurus* (several teeth), crocodile (new), and several fresh-water turtles.

TORNILLO CLAY

DISTRIBUTION AND CHARACTER

The formation next above the Aguja has been named the Tornillo by Udden (1907a, p. 54) and this name has been universally adopted. In the area mapped, the Tornillo is exposed only in the extreme southeastern corner (pl. 1).

As the name indicates, the Tornillo is composed largely of clay, which is locally sandy. In exposure the rock is variegated with dull, merging colors, such as yellow, brown, red, blue gray, and olive green. It contains a few layers of sandstone that resemble the beds in the Aguja. Much of the clay is tuffaceous, and some beds are composed almost entirely of tuffaceous material, although the igneous character of the formation is not as obvious as that of the overlying Chisos volcanics. Udden estimates that the thickness is at least 600 feet and possibly as much as 1,000 feet.

What is probably the characteristic chemical composition of the formation is shown in table 8.

TABLE 8.—*Analysis of Tornillo clay from east of Rough Run, 2 miles east of Dogie Mountain.*[1] *From Udden, (1907a, p. 56)*

[O. H. Palm, analyst]

Silica	64. 14
Alumina	18. 81
Ferric oxide	6. 05
Lime	. 74
Magnesia	. 30
Potash	1. 28
Soda	. 58
Water (hygroscopic)	
Water (combined)	2. 50
Total	100. 40

[1] About 5 miles east of Bee Mountain.

AGE

Udden (1907a, p. 60) reports silicified wood and saurian bones from the Tornillo clay but other macrofossils have not been recorded. According to C. P. Ross (written communication), "The Tornillo clay near Dawson Creek contains sparsely distributed Foraminifera which, according to Henbest, include poorly preserved specimens of *Globotruncana?*, *Guembelina*, and *Globigerina*. The species of the first two genera are indicative of Cretaceous age with fair assurance, but the species of *Globigerina* are two generalized to be of value." The formation presumably is to be correlated with some part of the Navarro group; Adkins (Sellards, Adkins, and Plummer, 1933, p. 271) places it at the top of this group.

CHISOS VOLCANICS

CHARACTER AND DISTRIBUTION

The group of lava flows and clastic rocks termed collectively the Chisos volcanics, although abundant both to the east and west, are present only locally in the Terlingua district. The principal occurrence within the district is at the Fresno mine in the extreme western part, where they unconformably overlap Boquillas flags. Doubtless these flows and related clastic rocks once covered the entire district because remnants of them are preserved in breccia pipes and related collapse structures. These structures are described in considerable detail in a later part of this report.

In the study of a much larger area than that covered by this report C. P. Ross (written communication) found that the succession of clastic and volcanic strata overlying the Tornillo had great enough lithologic affinity for him to propose extending Udden's definition (1907a, p. 60–68) of Chisos beds to cover all these post-Tornillo beds. This is the sense of Chisos volcanics in this report, for the fragmentary exposures of the Chisos volcanics in the Terlingua district permit the use of only such loose terminology.

Ross's studies of the Chisos volcanics in and about the Chisos Mountains and west of Fresno Creek (fig. 1) led him to the conclusion that, although clastic beds predominate in the lower part of the sequence, and flows above, there are at several horizons within the lavas clastic deposits that are lithologically indistinguishable from those below. The clastic beds range from fine nodular clay through sandy beds to coarse conglomerate, and their colors are mainly white and pale shades of buff, purple, brown, green, and gray; a few are brick red. Most of the clay beds are found east of the Chisos Mountains and were not recognized within the Terlingua district; conglomerate is found throughout the region, but is nowhere abundant in the district; the sandy tuffaceous beds are the most abundant clastic rocks in the district. The sandy beds are composed of grains and fragments of both sedimentary and volcanic rocks and an abundance of glass shards and pumice fragments. Much of the rock is cemented by calcite. The conglomerates are similar in character.

Lava flows were distinguishable in the Chisos volcanics in the Terlingua district only at the Fresno mine and possibly at Black Mesa. These are rhyolites. The conglomerates and blocks of collapse breccia, however, include, besides rhyolites, andesites, basalt, and trachyte.

No conception of the total thickness of the Chisos volcanics could be gained from a study of those in the

Terlingua district. Studies by C. P. Ross (written communication) in the Chisos Mountains and west of Fresno indicate that the aggregate original thickness of the flows and intercalated clastic beds must have been fully 2,000 feet.

AGE

The age of the Chisos volcanics cannot be closely estimated from the occurrences of these rocks within the Terlingua district. At the Fresno mine the volcanics rest in angular unconformity on the Boquillas flags; elsewhere in the district breccia blocks of the Chisos are in structures that are younger than the intrusive rocks. Just south of the southeast corner of the mapped area (pl. 1) and south of Dawson Creek, the Chisos volcanics overly the Tornillo rocks in apparent conformity. The presence of tuffaceous material in the Tornillo suggests that the conformability is real. This locally confirms Udden's (1907a, p. 66) interpretation of a gradation between beds of the Tornillo and Chisos.

The stratigraphic relations west of Fresno Canyon are different. Here the Tornillo is absent and the Chisos rest unconformably upon Boquillas or older rocks. This unconformity represents too great a stratigraphic break to be considered a local condition. Consequently, the basal beds of the Chisos here are either younger than the basal beds of the Chisos Mountains or else there was a pre-Chisos post-Boquillas structural deformation in the western part of the district but not in the eastern part.

Although no fossils indigenous to the Chisos volcanics have been found in the Terlingua district, they have been found in similar volcanic sequences farther north. About 60 miles north of Terlingua, in Sheep Canyon in the Alpine quadrangle, Goldich and Elms (1949) found a collection of gastropods in a fresh water limestone that have been identified as Eocene in age, on the basis of abundant *Goniobasis*. This limestone is in a sequence of volcanic flows and associated clastic rocks that rest unconformably upon the Boquillas flags. Higher in the same volcanic sequence gastropods were found that were tentatively assigned to the Oligocene. Similar fossils from similar volcanic sequences have been found still farther north.

It is very probable that the Chisos volcanics are at least in part equivalent to these volcanic rocks to the north. From the evidence at hand, it seems probable that they range through the uppermost Cretaceous well into the Tertiary.

INTRUSIVE IGNEOUS ROCKS

The Terlingua quicksilver district is in a province of alkalic igneous rocks where the sedimentary strata are intruded by many sills, laccoliths, dikes, and plugs that range in composition from rhyolite through analcite syenite to olivine basalt. The intrusive rocks appear to have solidified at shallow depths; consequently, most are fine grained, but some are aphanitic and a few are medium grained The rocks can be broadly classified into those that contain analcite and those that are analcite-free. The analcite-free rocks are rhyolite, quartz soda syenite, soda trachyte, soda latite, and olivine basalt. The analcite rocks include analcite syenite, analcite-plagioclase syenite, analcite syenogabbro, and analcite basalt. As almost all the rocks are sodium-rich, all probably belong to the same general period of igneous activity.

DISTRIBUTION AND FORM

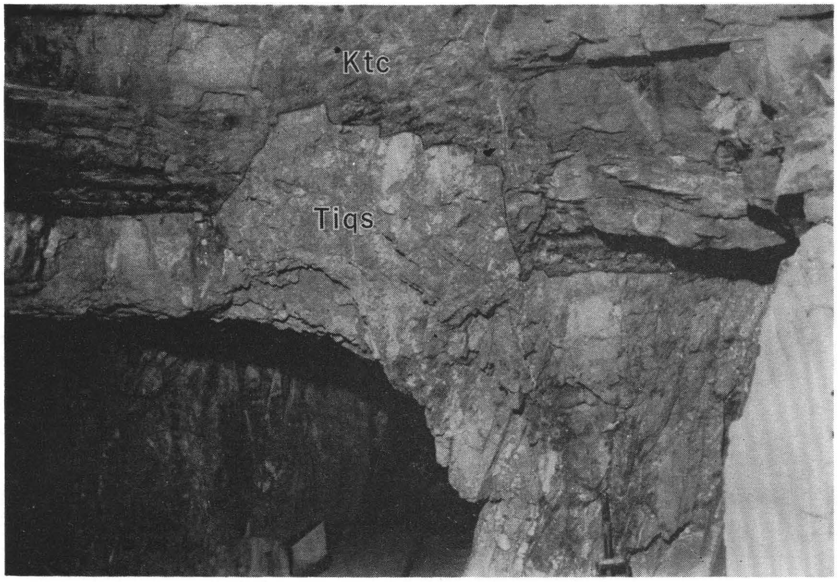
Although intrusive igneous rocks are found in many places in southwestern Texas, they are more numerous and varied in the Terlingua region than elsewhere. The eastern part of the Terlingua quicksilver district extends into an area where they are particularly abundant. Throughout the rest of the district they occur less abundantly.

The igneous rocks are exceptionally well exposed. They are more resistant to erosion than any of the sedimentary rocks except the Devils River limestone; consequently, in the eastern part of the district, where the Devils River limestone is not exposed, they stand out in bold relief against the softer, more rapidly eroded sediments. In places the sedimentary rocks have been so recently and rapidly removed that the intrusive bodies appear in almost their original shapes. Contacts between igneous and sedimentary rocks, however, are not everywhere exposed; but available exposures do show that both concordant and discordant intrusive relations exist.

The concordant intrusions are laccoliths and sills. In general, the laccoliths are larger than the sills, and some have sills associated with them. The division between the two is not sharp, but for purposes of this report a laccolith is defined as a concordant, almost flat-lying body whose intrusion caused a pronounced bowing of the overlying beds. In most laccoliths the bowing is concentrated along their peripheries; above their relatively flat tops bowing is less.

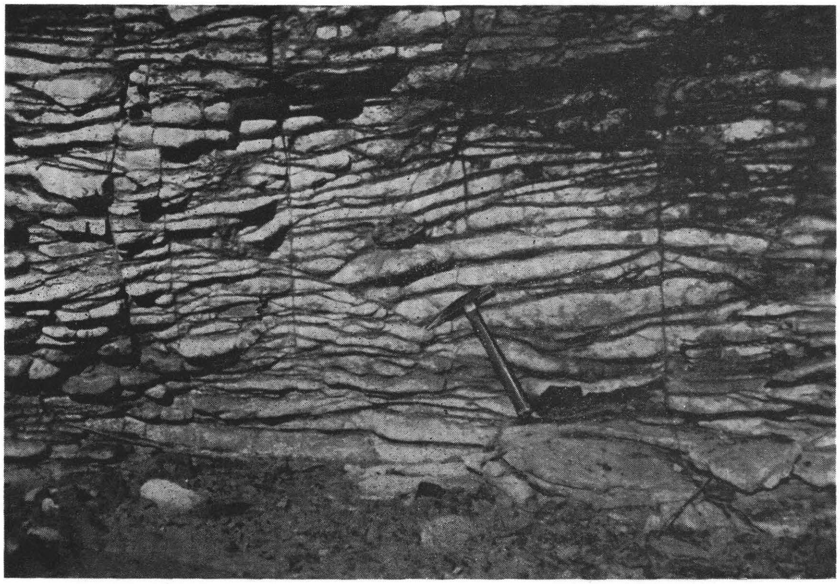
The discordant intrusions are dikes and plugs.[2] The dikes range from stringers less than 1 inch thick to dikes more than 20 feet thick and more than 1 mile long, but average about 5 feet thick and one-fourth mile long. Intermediate between dikes and plugs are

[2] The term "plug" is used in this report without genetic implications for any discordant, roughly cylindrical igneous intrusion that may or may not have been connected with the surface at the time the rock was in a molten state. Thus, we recognize that some features called plugs may be eroded volcanic necks.



A. UPPER CONTACT OF BODY ON 150-LEVEL

Note steplike character of contact. Ktc, Terlingua clay; Tiqs, intrusive quartz syenite.



B. FLOW STRUCTURES NEAR UPPER CONTACT OF INTRUSIVE BODY

Lenticular banding accentuated by oxidation of iron minerals along and near parting planes.

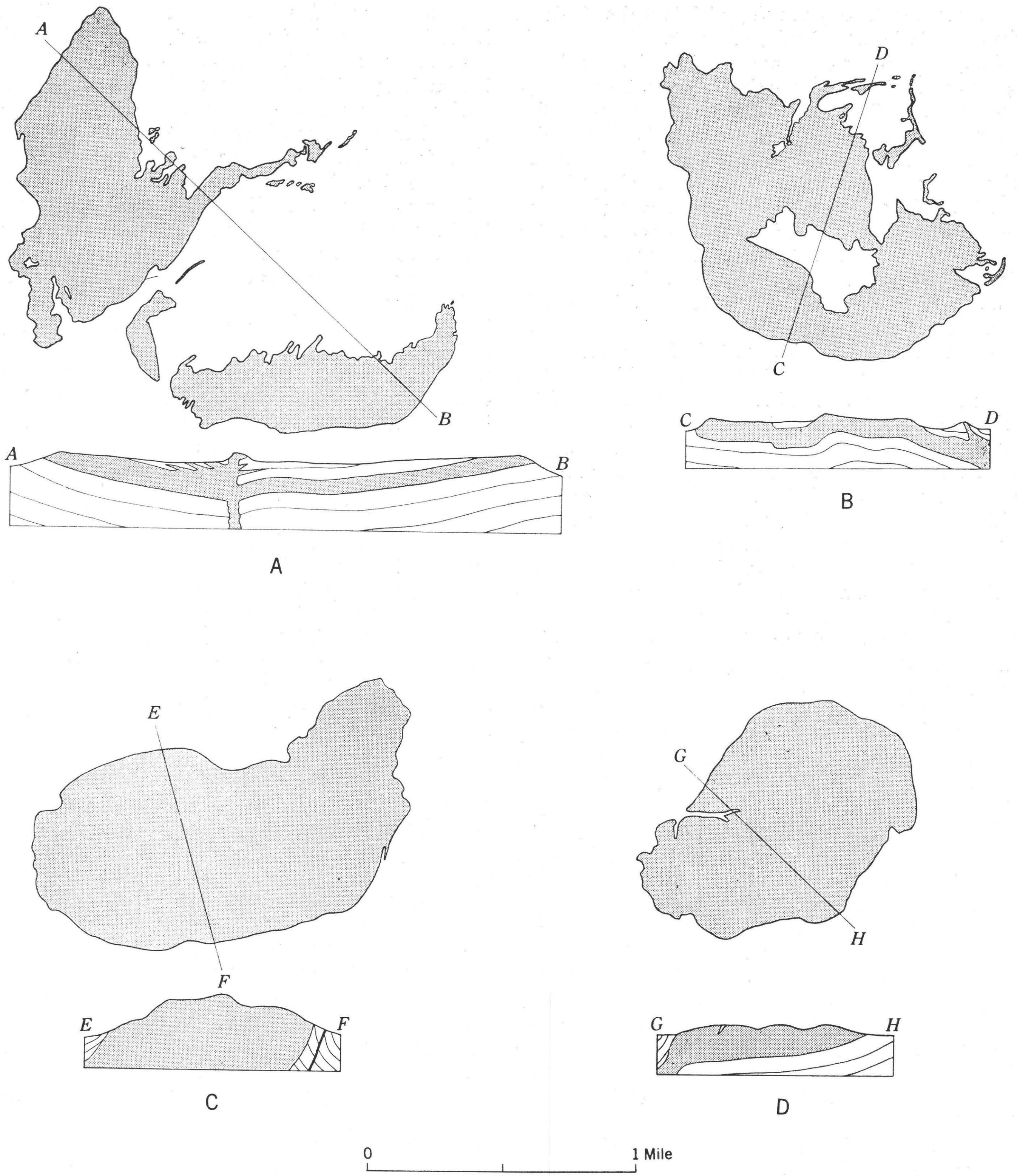


FIGURE 2.—Outline map and sections of intrusive rocks in the eastern part of the Terlingua district. The sections are hypothetical, being based upon surface data and analogy with the known subsurface extent of other intrusive rocks in the district. *A*, Analcite syenogabbro of Leon Mountain; *B*, soda trachyte body 1 mile north of Maverick Mountain; *C*, soda trachyte of Maverick Mountain; and *D*, analcite syenogabbro of Cigar Mountain.

the igneous rock to break along joints and slide down the slopes to form the jumble of blocks.

Sills, or flat-lying concordant intrusives with no appreciable thickening in their central part, occur west and south of Sawmill Mountain, northwest of Bee Mountain, between Willow and Maverick Mountains (see fig. 2*B*), at Contrabando Mountain, in the vicinity of the Chisos mine, and at many other places in the district. They range in thickness from a few inches to more than 200 feet, and in outcrop area from a few square feet to more than 1 square mile. Their compositions range from rhyolite to analcite basalt.

Some intrusive bodies are in part concordant and in part discordant. An excellent example is the body of fine-grained quartz syenite at Study Butte, which has been described by Ross (1937) as a sphenolith (a wedge-shaped intrusion), and which can be studied from drill-hole records and mine workings.

The outcrop of the intrusive body at Study Butte is about 2,700 feet long and about 400 feet wide and trends east. In general, both its north and south contacts with the enclosing Terlingua clay dip to the north. A few hundred feet to the north of the outcrop of the body and immediately south of it the clay beds are horizontal; whereas those beds adjoining and immediately north of the body dip steeply to the south. A monoclinal fold coinciding with these southward-dipping beds extends eastward from the southeastern corner of the outcrop and may extend westward from the outcrop, but this cannot be determined because the rocks west of the intrusion are covered by a thin mantle of alluvium. Except at the east end of the intrusion, the relations between intrusive and intruded rock are discordant on the surface. Data obtained from mine workings and drill-core records show that beneath the surface their relations are both concordant and discordant. To the north the intrusive is a sill, but its south part is dikelike and cuts across the bedding.

Figure 3 shows the probable way in which the Study Butte intrusion was emplaced. A sill-like intrusive advanced southward following bedding planes and locally quitting them to follow joint planes (see pl. 3*A*). As it advanced southward it thus came closer and closer towards the surface. It made room for itself by lifting the overlying strata, except near its southern end where both sill and dike mechanisms of lifting and dilatation were operative.

The amount of lifting was less where the sill became a dike; consequently a monoclinal fold was formed in the overlying beds. Much of this fold has been removed by erosion but that which remains extends eastward to Maverick Mountain, thus indicating that the intrusion likewise extends this far.

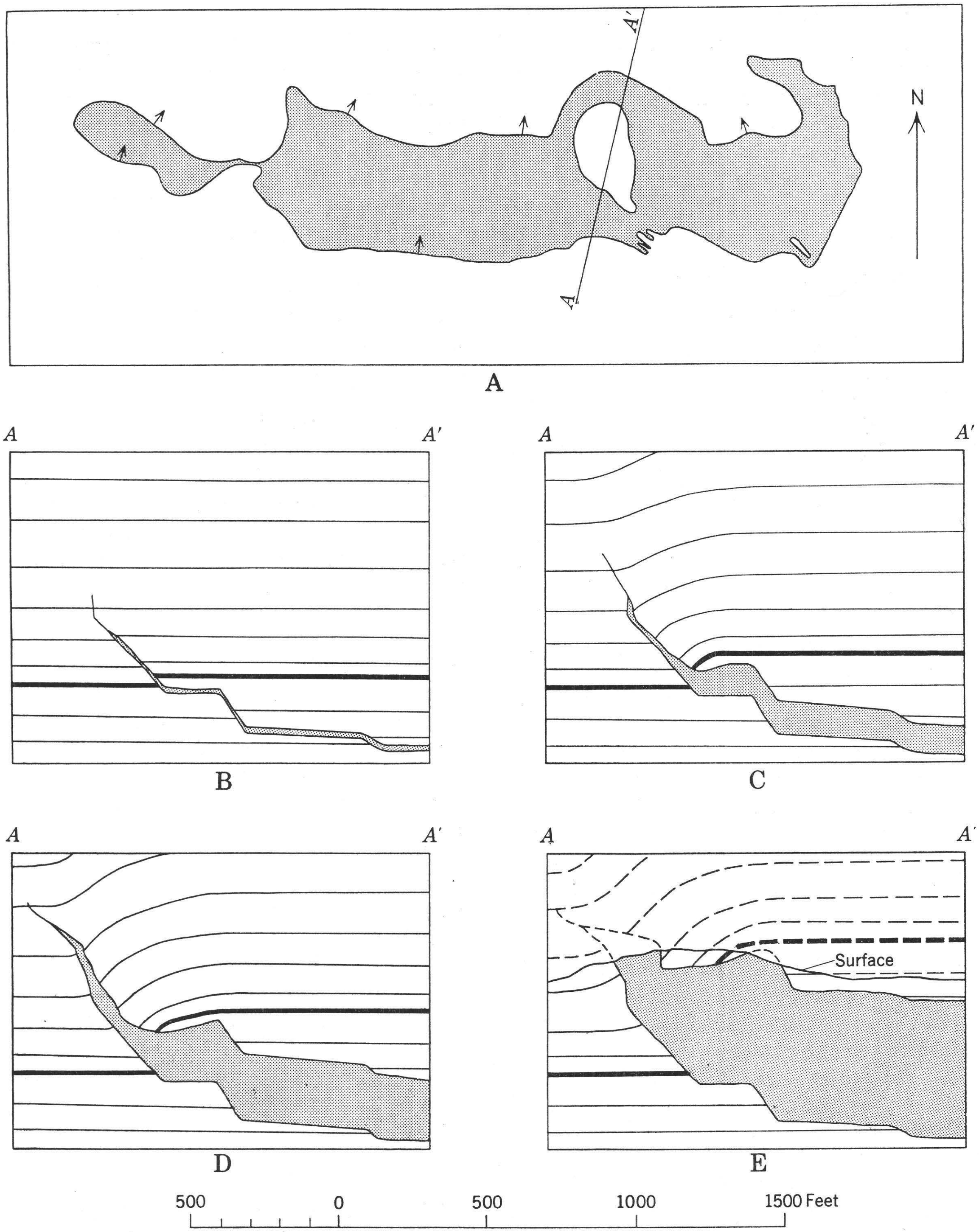
It seems probable that the intrusive bodies at Maverick Mountain (see fig. 2*C*), Willow Mountain, the unnamed mountain between Maverick and Willow Mountains, possibly Cigar Mountain, and many smaller bodies were emplaced in a manner similar to that at Study Butte. They all are sill-like bodies that show discordant relations with the intruded rocks along at least one side. If the body at Cigar Mountain is of this type and not a laccolith, the inferred dikelike projection along its western side is not necessarily a deep-rooted feeder but may be a connection with a lower sill-like mass that lies to the west of Cigar Mountain. This inference invites the speculation that many isolated sills are more extensive than their outcrops indicate, and that they were not fed through deep-rooted dike conduits, but through relatively short connections with other, deeper sills. Thus, apparently independent centers of intrusion may be more directly connected than surface outcrops indicate.

Dikes are most numerous in the northeastern part of the district (pl. 1), but a few are in the vicinity of California Hill and Contrabando dome. Those in the vicinity of Contrabando dome are of both silicic and mafic varieties of rocks, whereas those in the northeastern part of the district are mainly of mafic varieties. For the most part, the rhyolite dikes tend to be short and thick and grade into shapes that can be best classified as plugs. The mafic dikes, in contrast, tend to be long and thin with very sharp walls. Many of the rhyolite dikes contain near their borders numerous angular inclusions of baked sedimentary rocks that were plucked from their walls.

Small plugs occur in many parts of the district. Many probably have no great downward continuation, but are local protuberances from underlying sills and laccoliths. Some are along faults, but many are unrelated to faults. Sedimentary rocks in contact with them are invariably baked or discolored but do not always show evidence of physical deformation through brecciation and distortion of bedding planes.

Small irregular, pluglike intrusives of mafic igneous rock occur within the cylindrical bodies of breccia that are common in the district. These breccia pipes, which are not, at least directly, of igneous origin, are described in the chapter on structure.

The only large plugs are those that form Bee and Sawmill Mountains. Each is half a mile in diameter and cuts vertically across nearly horizontal Upper Cretaceous strata, which are locally turned up sharply against the plugs. Relations between intrusive and intruded rock are everywhere discordant. The plug at Bee Mountain is soda trachyte and that at Sawmill Mountain is an analcite syenite. Bee Mountain is



A. Map of the intrusive body. The intruded rocks are Terlingua clay.
B. An early stage in the emplacement of the partly sill-like and partly dikelike body.
C. Growth of the intrusion by thickening and spreading. The magma made way for itself by vertical lifting of the overlying rocks and thus created a monocline. Note that the vertical distance through the intrusion is uniform except beneath the fold, whereas the thickness varies.
D. Continued growth of the intrusion by vertical lifting accompanied by wedging open of the dikelike part at the left.
E. Present cross section of the intrusive body as determined from all available data, including surface, mine workings, and drill holes.

FIGURE 3.—The Study Butte quartz soda syenite intrusive body and theoretical cross sections showing progressive development of the intrusion and accompanying monocline.

a fairly homogeneous mass that shows well-developed columnar structure, particularly at its western side. The columns are vertical and extend the full exposed height of the plug, flaring somewhat downward. Sawmill Mountain consists of an outer shell of light colored syenite and an inner core of darker syenite containing more abundant ferromagnesian minerals and analcite. There is no indication that either of these bodies is a plugged conduit of a volcano now removed by erosion.

CONTACT METAMORPHISM

Sedimentary rocks adjoining the intrusive bodies were bleached and indurated by the heat of intrusion, but with few exceptions they were otherwise little changed. In a few places, limestone along contacts was silicified, notably that near intrusive rhyolite in Lowes Valley and that along the upper contact of the Wax Factory laccolith. Analcite was seen in a few places in sedimentary rocks adjoining analcite-bearing intrusive rocks. The development of typical contact metamorphic minerals was observed at only two places: C. P. Ross (written communication) noted that calcareous clay next to a small basalt intrusion in Long Draw had been changed to a calcite aggregate containing diopside, and the writers found small garnets in a recrystallized calcareous clay at the base of the quartz soda syenite intrusion at Study Butte.

The sedimentary rocks that were most affected by the intrusion of igneous rocks are the calcareous shales and clays; limestone underwent only minor changes, mainly recrystallization of calcite and bleaching. The most obvious change in both limestones and clays is a pronounced decrease in the intensity of color, or whitening of the rock, which resulted from the carbonaceous components being volatized and driven off.

The physical properties and appearance of the clay rocks have been considerably changed by the baking; the rocks have been hardened, made more brittle and more fissile, and those inconspicuously bedded have become well bedded. Some calcareous clays have developed a spotted appearance; this is particularly evident on weathered surfaces.

Under the microscope the principal change seen in the baked rocks is the recrystallization of calcite. In shales that were uniformly calcareous before baking, the calcite has been redistributed and recrystallized as irregular, somewhat spheroidal aggregates. The material between the calcite aggregates is mainly clay, partly in a finely crystalline state, which so contrasts with the amorphous clay of the unbaked rock that it indicates that there has been considerable recrystallization of the clay. Microfossils are exceptionally well preserved, although the calcite that composes and fills them is recrystallized.

The induration is not the result of the addition of new substances from the cooling igneous rocks, but of the reorganization of original constituents, mainly calcite and clay, into a rock of decreased porosity whose mineral grains are more tightly interlocked. Water, doubtless, was of great importance in this conversion. Some of this water was given off by the crystallizing magma, but probably most was already present in the pores of the rocks intruded. The intrusive material heated this water, which circulated through the sedimentary rocks, and by processes of solution and precipitation, redistributed the calcite in the sedimentary rocks. As the calcite was obviously redeposited by a replacement process, which requires removal of the clay minerals to make room for the calcite, there was likewise some slight redistribution of the components of the clay minerals.

The thickness of baked rock bordering the intrusive bodies varies greatly and depends upon the kind of igneous rock and its size or thickness, the kind of sedimentary rock, the attitude of the contact between igneous and sedimentary rocks, and doubtless upon other factors, such as the amount of water in the intruded rocks. Generally, but with notable exceptions, the more silicic the igneous rock, the broader the aureole of baked rock. Massive limestones are seldom bleached more than a few feet away from the igneous rock, whereas the most readily baked rocks, the calcareous shales and clays, were baked more than 100 feet from the contact. The size of the intrusive mass was of less importance than the attitude of the contact from which the heat was being transferred. Along vertical and steeply overhanging contacts of igneous rock there is a minimum of baked sedimentary rocks. This is particularly true along the peripheries of the large plug at Bee Mountain, where Terlingua clay only a few feet from the contact is apparently unaffected by intrusion. Conversely, the rocks that overlie even relatively thin sills are highly baked. There appears to be great variation in the thickness of baked rock that underlies flat-lying intrusive bodies, but in general it is less than that above the sill.

AGE

The intrusive igneous rocks include the youngest rocks in the district exclusive of Quaternary alluvium and can be considered of Tertiary age. They intrude not only Upper Cretaceous marine sedimentary rocks but also lavas and pyroclastic rocks that have been correlated with fossiliferous volcanic sediments of Tertiary age in neighboring areas.

Igneous intrusive rocks belong to a late stage in the structural history of the area. As they intrude the Chisos volcanics that rest on the beveled edges of the major fold in the district, they are later than the major folding. The major faults of northwesterly trend are later than the folding and some of these have been intruded by igneous rocks. Examples are at Cigar and Sawmill Mountains. Faults of diverse trends do cut the intrusive rocks, but all those observed were of minor displacements. Numerous dikes of northeasterly trend in the northeast part of the district suggest that the regional system of northeasterly fractures is earlier than the dikes and that it controls their locations. It seems probable that most of the intrusive rocks were emplaced after the major faults were established, and it seems equally probable that some fault movements were contemporaneous with, and a result of, intrusion.

PETROGRAPHY

The intrusive rocks of the Terlingua region have textures typical of small, near-surface intrusions, but have mineral assemblages that are uncommon. Fine-grained porphyritic textures are by far the most common, but aphanitic and medium-grained textures are moderately abundant. The rocks range from rhyolitic to basaltic; those of intermediate composition are the most abundant and present in the greatest variety. The rocks of intermediate composition are all sodium-rich, and many contain analcite. Alkalic feldspar, either orthoclase, soda orthoclase, or anorthoclase, is common to all the rocks except a few basalts. The ferromagnesian minerals in rocks that have alkalic feldspar dominant over calcic feldspar are soda varieties, as aegerine and riebeckite, whereas those in rocks that have dominant calcic feldspar are augite and olivine, which almost invariably occur together. Analcite is present in many, but not all, rocks with less than 60 percent silica,[3] and occurs as a replacement of calcic feldspar, as an intersertal mineral, and as a filling in vesicles.

[3] This generalization is made from an interpolation of analyses and modes of rocks of the Terlingua district presented by J. T. Lonsdale (1940).

CLASSIFICATION

Lonsdale (1940), who has made an intensive study of the igneous rocks of the Terlingua region, divides them into two main groups: those containing analcite and those containing no analcite. This division, which is followed in this report, although not ideal, is logical, because the elements that form the analcite are as clearly derived from the magma as are those that form the feldspar. This basic division is doubly useful, because the analyses of Lonsdale show that all the analcite-bearing rocks contain less than 60 percent of silica. It does not follow that all the igneous rocks in the district containing less than 60 percent silica are analcite-bearing. Lonsdale's subdivision of each of the two major groups is not strictly followed in this report, mainly because not all the rock types he describes are found in the area mapped. The refinements of his subdivisions are accordingly unnecessary, and perhaps would be confusing, in this much less detailed petrographic discussion, which is of necessity based upon relatively few thin sections and no new chemical analyses. The table given below is the classification that is followed here.

Because the intrusive rocks were formed under conditions intermediate between the deep-seated, or plutonic, environment and the surficial, or volcanic, environment, they have textural features characteristic of both environments, as well as those characteristic of their own. Textures are neither distinctly plutonic nor distinctly volcanic, but generally they approximate the texture—especially the grain-size—of one of these two groups. It must be remembered, however, that within the individual igneous masses variation in grain size is the rule, and any one igneous mass may have a phase most closely akin to its plutonic equivalent and another phase most closely akin to its volcanic equiva-

TABLE 9.—*The classification of igneous rocks in this report*

[The approximate percentage of a mineral is given only if it is essential to this classification of rocks; the percentage is not necessarily that of Lonsdale. The relative amoun of a mineral and whether the mineral is essential to the rock name are shown as follows: E, in large amount and essential; e, in small amount and essential; A, in inter mediate amount and not essential; a, in small amount and not essential]

Names used in this report	Correlative names used by Lonsdale (1940)	Abundance of principal minerals (numbers express percent). Quartz	Alkali feldspar	Plagioclase feldspar	Soda ferromagnesian minerals	Augite, olivin or both
ANALCITE-FREE ROCKS						
Rhyolite	Potassic rhyolite	E>10	E			
Quartz soda syenite	Soda rhyolite	e 3–10	E		A	
Soda trachyte	Soda trachyte	a<3	E		A	
Soda latite	Trachy-andesite		E 30–50	E 30–50	a	A
Olivine basalt	Olivine basalt		?	E		E
ANALCITE-BEARING ROCKS						
Analcite syenite	Analcite syenite		E<80	a<10	a	a
Analcite-plagioclase syenite	Analcite-plagioclase syenite		E<60	e 10–30	a	a
Analcite-orthoclase gabbro	Syenogabbro		e<25	E>30		E
Analcite basalt	Analcite basalt			E		E

lent. In such cases, simplification favors giving the mass the name of the dominant phase.

It is necessary because of gradations between rock types to subdivide them on the basis of relative amounts of mineral constituents in a somewhat arbitrary manner in order to emphasize interrelations and to avoid confusion and ambiguity that would result if more rigid rock definitions were strictly adhered to. The rhyolite, quartz soda syenite, and soda trachyte are all composed dominantly of alkalic feldspars and variable amounts of quartz, with plagioclase feldspar in effect absent. These three rocks are separated one from another partly on the basis of their quartz content. Those with more than 10 percent quartz are termed rhyolites; those with from 10 to 3 percent quartz are termed quartz soda syenite; and those with less than 3 percent quartz are termed soda trachyte. In addition, rhyolite is separated from quartz soda syenite and soda trachyte, which are gradational types and closely related, by the presence of orthoclase in contrast to soda orthoclase, the dominant feldspar of the two latter rocks. Sodium-rich ferromagnesian minerals are present in amounts as much as 20 percent in the quartz soda syenite and soda trachyte, but no visible ferromagnesian minerals are in the rhyolite. Only the quartz-poor soda rhyolites of Lonsdale are in the district, and these are included under quartz soda syenites in order to emphasize an affinity that is closer to trachyte than rhyolite. The closeness of the relation of the rhyolite to the other rocks in the district was not learned.

Felsic rocks containing roughly equal amounts (within 40–60 range) of alkali feldspar and plagioclase feldspar are termed "soda latite" in substitution for the trachy-andesite of Lonsdale. This substitution of names is made partly because latite is the commoner term, but mostly because trachy-andesite has not only been used according to the above definition but Rosenbusch has used it also for orthoclase-plagioclase rocks carrying a feldspathoid or aegerine or riebeckite. The term "trachy-andesite" has therefore been used to name two contrasting rock types that fall on both sides of the line used to differentiate the rocks of the Terlingua district into two main groups. Its retention might be confusing.

Gradational rock types are likewise included within the analcite group. As gradations exist between analcite syenite, analcite-plagioclase syenite, and analcite-orthoclase gabbro (syenogabbro), limits of mineral compositions must be defined. All contain alkalic feldspar and plagioclase in variable proportions; therefore the relative quantities of these minerals is a good basis for division, especially since the same ferromagnesian minerals are in all three. Plagioclase is less than 10 percent in analcite syenite, between 10 and 30 percent in analcite-plagioclase syenite, and more than 30 percent in analcite-orthoclase gabbro. Analcite syenite contains more than 80 percent alkali feldspar, and analcite-orthoclase gabbro contains not more than 25 percent alkali feldspar. With decreasing alkali feldspar, analcite-orthoclase gabbro grades into analcite basalt, the aphanitic equivalent of analcite gabbro. It is obvious from the foregoing that alkali feldspar, usually a soda variety, is an important constituent in practically all the intrusive igneous rocks in the Terlingua district.

ANALCITE-FREE ROCKS

RHYOLITE

Intrusive rhyolite occurs at Contrabando Dome, Contrabando Mountain, and Lowes Valley, as plugs, dikes, and sills. The rhyolite is a white to cream, fine to microgranular rock, which has in many places well-developed flow structures. It is commonly porphyritic, containing rhombs of glassy sanidine, rarely as large as 5 mm, and much less abundant subhedral to anhedral phenocrysts of quartz. No mafic minerals are megascopically visible.

In thin sections the phenocrysts are seen to be enclosed in a groundmass of very fine grained sanidine and quartz. No glass was noted. Granophyric quartz is common throughout the groundmass, and some intergrowths are almost as large as the sanidine phenocrysts. No plagioclase was detected but some sanidine phenocrysts show corroded centers, accompanied by what appears to be microcrystalline albite. Microscopic examinations revealed no mafic minerals except small quantities of iron oxide dusted through the rocks.

QUARTZ SODA SYENITE

Quartz soda syenite was found in only the eastern part of the district, and it is the rock that forms Study Butte, Willow Mountain, and a dike about half a mile northeast of Bee Mountain. It ranges in color from light gray to greenish gray and in texture from aphanitic glomeroporphyritic to medium-grained porphyritic. Although commonly a grained rock, most intrusions are partly aphanitic and these phases could be called quartz soda trachyte. Flow structures are particularly evident in weathered rock where they are outlined by films of iron oxide.

Under the microscope, the phenocrysts are seen to be soda sanidine and the groundmass largely laths of the same mineral in a trachytic or subtrachytic arrangement. The phenocrysts in the Willow Mountain body contain inclusions of aegerine augite, but inclusions are absent in phenocrysts from Study Butte. The Willow Mountain body has in the groundmass subhedral prisms of aegerine augite, which compose about 20 percent of the bulk of the rock. Anhedral quartz totaling as much as 5 percent of the bulk of the rock is intersertal to the feldspar. Magnetite and pyrite are rare accessories.

The quartz soda syenite of Study Butte differs from that of Willow Mountain by having a better developed trachytic structure and completely lacking any positively determinable mafic minerals. A few thin sections from Study Butte show pseudomorphs of hematite after pyrite, which in turn is after a prismatic mineral that may have been aegerine. Other thin sections show similarly shaped pseudomorphs of calcite and epidote. If all these various alteration products were derived from the deuteric alteration of the mafic minerals, the rock originally contained less than 10 percent of mafic minerals.

Most specimens from Study Butte show a fairly well developed orientation of the feldspar laths in the groundmass. This structure is particularly well pronounced near the borders of the intrusion. Many feldspar laths are slightly bent and cracked.

The Study Butte rock contains less than 5 percent quartz, which occurs both intersertal to the feldspar and as crystals of amethystine quartz lining the rare vugs. Some thin sections show intersertal glass in one part of the section and intersertal quartz in another part; an association difficult to interpret. Those sections (from near the borders of the rock) showing glass also show traces of an intergrowth of orthoclase and quartz, which is also intersertal to the groundmass feldspar. Although the soda sanidine phenocrysts appear to have the same composition as the groundmass feldspar, some have ragged borders, suggesting a reaction with the magma.

The rock at Study Butte is almost a monomineralic rock and if given a name better describing its hypabyssal character might be called a quartz bostonite.

SODA TRACHYTE

Large intrusive bodies of soda trachyte compose Maverick and Bee Mountains and the mountain north of Maverick Mountain. Several smaller bodies of this rock are found in the same general area. These rocks are all porphyritic, their groundmass textures ranging from aphanitic to medium grained. Phenocrysts are feldspar commonly arranged in clusters. The colors are gray, greenish-gray, and brown on fresh surfaces, and various shades of brown on weathered surfaces. Some of the rare vesicles are filled with calcite.

The groundmass is mainly lath-shaped soda orthoclase crystals, which are either unoriented or arranged in a subtrachytic or trachytic manner. Phenocrysts are soda orthoclase and anorthoclase and enclose small grains of the mafic minerals. The feldspar content of the rock ranges from 70 to 90 percent of the total rock volume. The remaining 10 to 30 percent consists of aegerine or aegerine augite, a little quartz, and traces of magnetite and apatite. The mafic minerals are euhedral prisms of aegerine augite, fringed anhedral crystals of the same mineral, and rare crystals of green augite surrounded by rims of aegerine augite. In the finer grained varieties, the mafic minerals of the groundmass are usually fine needles of aegerite. Quartz is in anhedral grains, interstitial to the groundmass feldspar.

In general, the soda trachytes differ little from the quartz soda trachytes. They contain a smaller amount of quartz and more abundant mafic minerals and are somewhat darker rocks.

SODA LATITE

Rocks classified as soda latite are found southwest of the Fresno mine in the Wax Factory laccolith, as intrusions near California Mountain, as small irregular bodies near the Chisos mine, as small dikes and sills south of Sawmill Mountain, and as several small dikes and sills elsewhere in the district. They are somewhat darker than the trachytic rocks, ranging from greenish gray to dark greenish gray, and are slightly porphyritic, with either feldspar, pyroxene, or amphibole phenocrysts. They range from aphanitic to fine grained.

There are two principal varieties of soda latite: hornblende soda latite, exemplified by the body at California Mountain, and augite soda latite, exemplified by the Wax Factory laccolith. Only one body having the composition of hornblende soda latite was noted, but examples of augite soda latite are common and of considerable compositional range. Neither variety was found in transition to soda trachyte. Soda trachytes, with only rare plagioclase phenocrysts, contrast with these rocks, which have 40 percent or more plagioclase.

Hornblende soda latite at California Mountain is a greenish-gray, fine-grained to aphanitic rock. Much of it is porphyritic, having bladed phenocrysts of green hornblende as long as 1 cm. Exposures are deeply weathered and some of the rock is hydrothermally altered to a pinkish-buff to dark-red rock, with white kaolinite, pseudomorphic after the hornblende phenocrysts. Phenocrysts of plagioclase are rare.

Under the microscope the specimens examined were seen to be somewhat altered and to contain abundant calcite, kaolinite, hematite, and jarosite. All plagioclase phenocrysts are zoned with labroadorite centers and more sodic borders (up to An_{38}). Many are rimmed by alkalic feldspar. The groundmass shows a pronounced alinement of small andesine laths with interstitial grains of soda orthoclase. Bright-red hematite, pseudomorphic after magnetite, is in euhedral to subhedral grains in considerable abundance. Apatite is fairly abundant in characteristic prisms. In the more highly altered varieties of the rock it is the only unaltered mineral. No hornblende was identified among the groundmass minerals but may be represented by some of the abundant fine-grained alteration products.

The augite soda latite southwest of the Fresno mine (Wax Factory laccolith) is more mafic than the hornblende soda latite at California Mountain and on the average is coarser grained. In general, it is a medium-grained dark greenish-gray rock; but it has a lighter, coarser-grained facies, as well as a black aphanitic facies. Textural and color differences seen in this rock in the field suggested that it may have differentiated to some extent within the laccolith, but unfortunately the intrusion was not well enough sampled to prove this hypothesis through laboratory study.

The rock at the Wax Factory laccolith lacks the trachytic texture of that at California Mountain and has its feldspar and mafic minerals arranged in an allotriomorphic granular texture, which preserves but few crystal outlines. Feldspar composes about 80 percent of the rock bulk and plagioclase and anorthoclase are present in roughly equal amounts. Plagioclase is equidimensional in habit and most grains are zoned, with labradorite centers similar to those in the California Mountain rock, but with more sodic borders (up to An_{27}), and armored with anorthoclase. Anorthoclase is likewise in small grains interstitial to the plagioclase and is easily recognized by its fine gridiron twinning. The only abundant mafic mineral is a gray, almost colorless, augite, which composes about 15 percent of the rock bulk. It is enclosed by the feldspar grains. Some augite is bordered by aegerine augite, and some is altered to hornblende, which in turn has locally been altered to biotite. Magnetite, mainly in euhedral grains, is about one-third as abundant as augite.

OLIVINE BASALT

Olivine basalt—black, aphanitic rocks slightly porphyritic, and having phenocrysts of augite or plagioclase or both—is fairly common as small dikes, sills, and irregular pluglike bodies. Some small bodies labeled basalt on plate 1 were not sampled and studied in thin section, but were named after only megoscopic examination, which would not detect alkalic feldspar or analcite in the groundmass of the rock. Accordingly, it is likely that analcite basalts and orthoclase-bearing alkalic basalts are included under the legend for olivine basalt.

The olivine basalt intruded into the breccia pipe that is on the road about one-half mile east of California Mountain is typical of those rocks of this group that most closely approach normal olivine basalt. This rock is black, aphanitic, and decidedly prophyritic, with phenocrysts of augite and plagioclase. Phenocrysts range from 1 to 10 mm in length. The rock contains xenoliths of a medium-grained light-colored rock composed of orthoclase, basic oligoclase, and quartz, surrounded by reaction zones of an intergrowth of diopside and feldspar.

In thin section the olivine basalt has an intergranular texture and is composed of short laths of labradorite (An_{53} to An_{67}) and equidimensional grains of augite, partly altered to chlorite and calcite. The groundmass also includes about 5 percent of subhedral to euhedral magnetite and a smaller amount of apatite in long prisms. Both augite and plagioclase are zoned with more sodic borders. No orthoclase was seen in this rock, but it may be present in the groundmass. Equant grains of olivine altered to serpentine minerals occur similarly to the augite, but in lesser abundance.

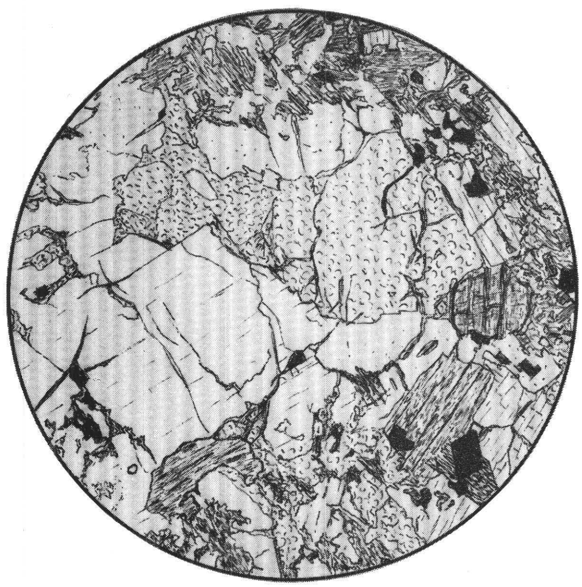
ANALCITE-BEARING ROCKS

Analcite rocks, ranging from analcite syenite to analcite basalt, are common in the Terlingua district. Besides analcite, these rocks all contain plagioclase augite, and olivine, and, with the possible exception of the olivine basalt, all contain alkalic feldspar. The analcite is interstitial, both as a replacement of feldspar and as a vesicle filling. Various occurrences of analcite in the rocks of the Terlingua district are illustrated in figure 4. In quantity analcite ranges from a few percent to as much as 30 percent of the rock volume. Where it is interstitial and a vesicle filling its relative abundance is partly a function of the quantity of open space present after the nonhydrous minerals crystallized. As the volume of open space varied greatly from place to place in any one rock mass, the analcite content varies accordingly.

Analcite, a hydrous sodium aluminum silicate containing 8 percent or more water, is usually regarded as having affinities with the zeolite group of minerals. It is fairly common as a filling in vesicles and cracks in mafic igneous rocks; it is less common as a groundmass mineral and as a replacement of plagioclase, nepheline, leucite, sodalite, and such in the alkalic rocks; it is relatively rare in sedimentary and metamorphic rocks. As late as 1893 (Lindgren, 1893, p. 289) it was considered a secondary mineral generally deposited by extraneous waters that circulated through cooling igneous rocks. According to Scott (1916, p. 35), this hypothesis was advanced to explain its common occurrence in rock openings, its freshness in

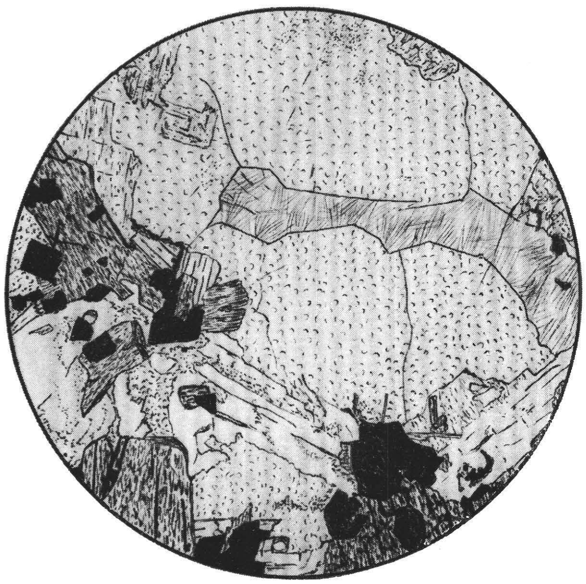
A

A. Analcite orthoclase gabbro sill in Two-Forty-Eight mine. Plagioclase (white) replaced by aggregate (irregular gray) of analcite and calcite. Bladed mineral, biotite, black, ilmenite altered to leucoxene. Plain light, × 130.



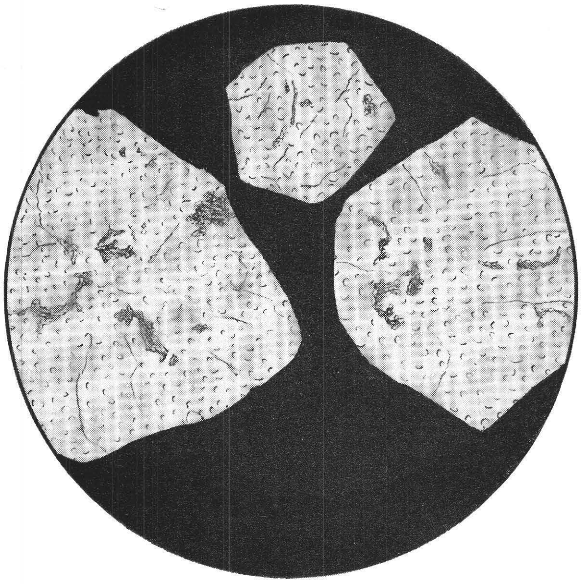
B

B. Analcite syenite from top of Sawmill Mountain. Analcite (patterned gray) replacing orthoclase (white) and cut by calcite veinlets. Note limited control of cleavage on replacing analcite. Dark-gray mineral with cleavage, aegerine augite; black, ilmenite. Plain light, × 130.



C

C. Analcite basalt sill southeast of Cigar Mountain. Analcite (patterned gray) filling with a later zeolite clouded with needles of an unknown mineral. Dark gray, augite; white, plagioclase; black, magnetite. Plain light, × 130.



D

D. Analcite in bituminous impregnated clay from Two-Forty-Eight mine. Gray inclusions in analcite are clouds of minute titanite crystals in bitumen stained areas. Plain light, × 30.

FIGURE 4.—Sketches made from photomicrographs of thin section of analcite-bearing rocks.

contrast to highly altered surrounding minerals, and its replacement relations with other minerals. At that time it was believed by many geologists that magmas were in effect dry and did not contain enough water to supply the high water-content of analcite. Since then it has been demonstrated conclusively that some magmas are hydrous enough to supply the water content of analcite. It is therefore possible for analcite to form from the alkali-rich and water-rich residuum produced during the final stages of crystallization of a magma. It is clear that the analcite in the igneous rocks in the Terlingua district crystallized from such a residuum.

The final crystallization of this residuum, or residual fluid, is in two not clearly separable stages: the first stage, the late magmatic stage, is crystallization from a water-rich magma; the second stage, the hydrothermal stage,[4] is crystallization from what is considered a water solution. An important difference between the two stages is the amount of water present, or in other words, the concentrations of the solutions. In the late magmatic stage, the solution (the magma) is of such a concentration that it is capable upon crystallization of filling with silicate minerals almost all the space it occupied as a liquid; the filling of this space is a process that does not require circulation of the residual fluid. In the hydrothermal stage, the solutions are not sufficiently concentrated to be capable of filling with silicate minerals more than a small part of the space they occupied as liquids; to fill the space with a solid requires a circulating supply of solution.

Because of this difference in the mechanisms of filling, one would expect that the form and the texture of the minerals developed during the late magmatic stage would contrast with the form and texture of the same minerals developed during the hydrothermal stage. In many igneous rocks, the two stages can be identified by interpretations of textures and structures; but in the analcite-bearing rocks in the Terlingua district, some modes of occurrence of analcite definitely indicate a hydrothermal origin; other modes of occurrence can be interpreted as either late magmatic or hydrothermal.

A consideration of the physical enrivonment in which the analcite crystallized suggests that analcite crystallizing from a melt need not be any different from that crystallizing from hydrothermal solutions. At the time the analcite crystallized, the rocks were in effect solid; certain parts of the rocks consisted of an open mesh of interlocking crystals of feldspar and ferromagnesian minerals through which was distributed the residual fluid. The space available for the crystallization of analcite was that between previously formed crystals: much of the analcite occurs in such interstitial space. If the residual fluid was essentially an analcite melt, the interspaces would be filled with analcite as the melt crystallized, a process requiring only minor movements of fluid. If the residual fluid was of the concentration of a hydrothermal solution, the interspaces could also be filled, but only if there was extensive movement of fluid through them. Complete filling could result, but there would be a tendency for some interspaces to be incompletely filled. The fact that such incompletely filled interspaces are present, however, does not prove that all the interstitial analcite is hydrothermal, because the same features could be produced if an analcite melt had been drained off before crystallization was complete. One, therefore, cannot rule out the possibility that some analcite may have formed during the late magmatic stage of crystallization.

Evidence for the deposition of analcite during the hydrothermal stage, however, is positive. Its occurrence in vesicles and veinlets in association with zeolites and calcite and its occurrence as a replacement of plagioclase can only be interpreted as deposition from hydrothermal solutions. This replacement of plagioclase, which can be demonstrated because it was only partial, invites the speculation that the interstitial analcite may be complete replacements of minerals other than feldspar—minerals such as leucite or nepheline.

The temperature range within which analcite can crystallize, although in the low-temperature field, is so great that it is of little help in precisely fixing the relative time of formation of the mineral. Bradley (1929, p. 1–7) demonstrates that analcite formed syngenetically in the Green River shales at temperatures below 30° C by the interaction of the products of alteration of volcanic ash and the salts of lake water. The experiments of Doelter, Lemberg, and Straub (Morey and Ingerson, 1937, p. 654, 640–641, 664–665, 744–745) show that analcite can be formed from various mixtures in a water system at temperatures ranging from 190° to 282° C. The above experimental results put neither a maximum nor minimum limit on the temperature of formation of analcite, but they do indicate that analcite can readily form at a fairly low temperature and may form most readily during the hydrothermal stage.

ANALCITE SYENITE

Intrusive analcite syenite forms a plug at Sawmill Mountain and several small sills between Leon and Bee Mountains. The plug at Sawmill Mountain con-

[4] The term "hydrothermal stage" is used in this discussion to refer to a stage in the crystallization of the small near-surface intrusive bodies exposed in the Terlingua district. It is highly local in nature and should not be confused with the hydrothermal processes that produced the quicksilver deposits, which are of later origin and only indirectly related to the igneous rocks exposed in the district.

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sists of two concentrically arranged varieties of analcite syenite. The outer part of the plug is a white to gray, fine-grained vesicular rock with a satiny lustre, and the inner core of the plug is a grayish-brown, medium-grained porphyritic rock.

The inner phase composes the bulk of the plug and is a rock consisting of more than 80 percent feldspar, in part replaced by analcite, and lesser amounts of olivine, aegerine-augite, and magnetite. The phenocrysts are zoned plagioclase, anorthoclase, and orthoclase, arranged in clusters. The groundmass is a hypidiomorphic arrangement of orthoclase and anorthoclase with small crystals of aegerine-augite that are bordered by aegerine. Magnetite occurs in small euhedral to anhedral grains. Some feldspar phenocrysts enclose small crystals of epidote, which may be an alteration of augite. In places the ferromagnesian minerals are altered to an orange-yellow fibrous mineral. The analcite occurs only in veins and as replacements of feldspar, in particular plagioclase.

A thin section of rock from the border phase shows it to consist of a groundmass of orthoclase and rare phenocrysts of zoned plagioclase, armored by orthoclase arranged in a well-developed trachytic texture. Analcite was not seen as a replacement of feldspar but small amounts are in the abundant vesicles. Mafic minerals are minute prisms of aegerine-augite bordered by aegerine, in lesser abundance than in the center phase. Magnetite was proxied by ilmenite, which occurs as small euhedral grains altered to leucoxene. In neither phase of the rock is the plagioclase content greater than 10 percent.

ANALCITE-PLAGIOCLASE SYENITE

Sills of analcite-plagioclase syenite are numerous near Sawmill Mountain, and are exemplified by the large sills just west of the mountain (pl. 1). These sills are fairly uniform, fine-grained, dark-gray rocks cut by a few dikelets of a coarser grained, lighter rock. These rocks are similar in mineral composition to the analcite syenite, except they contain more plagioclase, commonly 10 to 30 percent.

ANALCITE-ORTHOCLASE GABBRO (ANALCITE SYENOGABBRO)

Prominent examples of analcite-orthoclase gabbro are the intrusions forming Cigar and Leon Mountains. This is a fine-grained to medium-grained, dark gray rock, commonly porphyritic with plagioclase phenocrysts. Amygdules of analcite, zeolites, and calcite are abundant in some intrusions.

Textural varieties include hypidiomorphic granular, ophitic, and intergranular. Some thin sections show two kinds of texture; for example, a thin section of rock from Cigar Mountain contained both ophitic and intergranular textures, suggesting two generations of augite.

Feldspars make up about 60 percent of the rock bulk; they are in the proportion of 2 or more parts plagioclase to 1 of alkalic feldspar. The plagioclase ranges from phenocrysts as calcic as sodic bytownite (An_{72}) to groundmass laths as sodic as calcic oligoclase (An_{25}). Most of the groundmass plagioclase, however, is either calcic andesine or labradorite. Most plagioclase phenocrysts are zoned with more calcic centers and are armored with orthoclase, as are many of the groundmass plagioclase laths. There has been a little albitization of some of the groundmass plagioclase. Alkalic feldspar is absent as phenocrysts but occurs as subhedral to anhedral grains in the groundmass and as armor on plagioclase phenocrysts.

Mafic minerals compose from 20 to 25 percent of the rock and are augite, olivine, biotite, and magnetite or ilmenite or both. The augite, faintly purple, is titaniferous and occurs as phenocrysts, small grains, and ophitic to the feldspar. The olivine is in small grains and is only about half as abundant as the augite. In places it is partly or completely altered to serpentine minerals. The biotite is a deep reddish brown variety and is mostly a reaction product of the augite, but it also occurs as rims about ilmenite and analcite. Some biotite, however, is subhedral and appears to have crystallized directly from the melt. Magnetite and ilmenite are in small euhedral to subhedral grains and are not commonly together. Ilmenite is generally altered to leucoxene. Apatite is always present but is commonly less than 1 percent of the rock volume.

Analcite is more abundant in the analcite-orthoclase gabbros than in any of the other rocks. It locally makes up as much as 30 percent of the rock volume. It is mainly as replacements of feldspar and as vesicle fillings and is only rarely interstitial to the plagioclase. One thin section of the rock from Cigar Mountain shows the space between plagioclase laths rimmed by alkali feldspar and the center filled by analcite. Analcite is both clear and clouded by inclusions. Some is faintly birefringent, but most is isotropic. That in vesicles is commonly associated with zeolites and calcite, which are always younger than it.

ANALCITE BASALT

Small pluglike bodies of analcite basalt are found at Clay Mountain and in Long Draw, as well as at several other places in the district. They are black, aphanitic, slightly porphyritic rocks with occasional phenocrysts of augite and olivine. Specimens studied under the microscope had an analcite content that ranged from about 1 to 10 percent. The analcite is almost entirely interstitial or in vesicles.

The analcite basalt is holocrystalline except near the chilled margins of the rock where there is a thin glassy selvage. The texture is intergranular and commonly there is a seriate range in grain size between the largest phenocrysts (20 mm) and the finest groundmass crystals. The groundmass consists of plagioclase laths (An_{53} to An_{62}), composing from 60 to 70 percent of the rock, and irregular grains of augite and olivine and some magnetite and analcite.

STRUCTURAL GEOLOGY

REGIONAL RELATIONS

STRUCTURAL SETTING

In most of the Big Bend region vigorous erosion by tributary streams of the Rio Grande has differentially carved the hard and soft rocks into boldly contrasting relief and effectively revealed their structure. The region (fig. 1) may be divided into three areas of contrasting topography and structure; these are, the Marathon Basin, the lava-covered plateau south and west of Alpine, and the topographically diverse mountains and intermontane areas of the southern part of the Big Bend region. The Terlingua district is part of the third area.

The Marathon Basin (King, 1937) is an erosional basin formed by the excavation of a broad structural dome more than 50 miles in diameter. The basin is floored mainly by weak rocks of Paleozoic age and rimmed by escarpments of resistant Cretaceous limestones. The northern, eastern, and southern sides of the dome are tilted gently outward. The western side, according to King, (1937, p. 138–139) "is formed by the Del Norte and Santiago Mountains, which structurally constitute a single unit * * *. The rocks of the mountains are raised into a sharp monocline or anticline, overturned toward the west and broken in most places by an eastward dipping thrust fault."

West of the Marathon Basin and south and west of the town of Alpine is the lava-covered plateau that is the second major topographic and structural division. This is a broad lava plain extending over almost the entire northern and western part of the Big Bend region. Higher mesas and isolated mountains stand above this plain; they are erosional remnants of still higher lava flows, of igneous instrusions that pierce the lava flows, and of fault-block mountains.

The main features of the third topographic and structural division, the southern part of the Big Bend region, are the Chisos Mountains, the Solitario, the Terlingua uplift, and Mesa de Anguila. The Chisos Mountains, which are the largest feature, are composed largely of volcanic and intrusive rocks piled up in the structurally lowest part of the Big Bend region. The most impressive feature is the Solitario. (See geologic map, Sellards, Adkins, and Plummer, 1933, p. 119, fig. 9; or Lonsdale, 1940, p. 1539, pl. 1.) It is a high, mountain-rimmed basin that has been carved from a dome by erosional de-roofing to expose the rocks of Paleozoic age in its center (pl. 4*A*). The Solitario is noteworthy as a nearly perfect circle. Structurally, it may be pictured as a high round dome unsymmetrically atop a low irregular dome.

This low irregular dome is the Terlingua uplift,[5] which extends south and east from the Solitario for a distance of 13 miles and forms the dominating structure of the Terlingua district.

South of the Solitario and the Terlingua uplift is the high Mesa de Anguila, the larger part of which is in Mexico. The northern boundary of Mesa de Anguila, the Santa Helena Canyon fault, is a normal fault with a displacement of thousands of feet.

AGE OF THE STRUCTURE

The earliest deformation recorded in the Big Bend region is in the rocks of Paleozoic age of the Marathon Basin and the Solitario, where strong folds and thrust faults trend northeastward (fig. 5). This early deformation is pre-Cretaceous and mainly pre-Permian. According to King (1937, p. 134), deformation during the Paleozoic in the Marathon Basin culminated at the end of the Pennsylvanian epoch.

The Cretaceous rocks, which rest on the eroded edges of the deformed rocks of Paleozoic age, were domed and faulted during a second epoch of deformation. The broad Marathon dome and the sharp fold and thrust fault along its western side formed after deposition of the Upper Cretaceous rocks on its flanks and probably in part after the volcanic eruptions in Tertiary time (King, 1937, p. 139–140). About the same time, the Solitario dome and the Terlingua uplift were formed. This deformation may have been contemporaneous with the formation of the northwest-trending anticlines of the Sierra Madre Oriental, which are well developed in Mexico east and west of the Big Bend region. The post-Cretaceous deformation was thus characterized by trends at nearly right angles to the northeast-trending pre-Cretaceous structures.

GENERAL FEATURES OF THE TERLINGUA DISTRICT

The structure of the Terlingua district, which is part of the southern Big Bend area, is dominated by large domes and grabens. On a smaller scale the rocks have also been irregularly deformed by intrusion, offset by innumerable faults, and pierced by breccia pipes. The Terlingua uplift, the largest domical structure, extends beyond the district to the north and northwest. On

[5] The Terlingua uplift has previously been called the Solitario uplift by Lonsdale and the Terlingua anticline by Ross, but to avoid confusion with the Solitario dome and to describe adequately the structure, the new name is desirable.

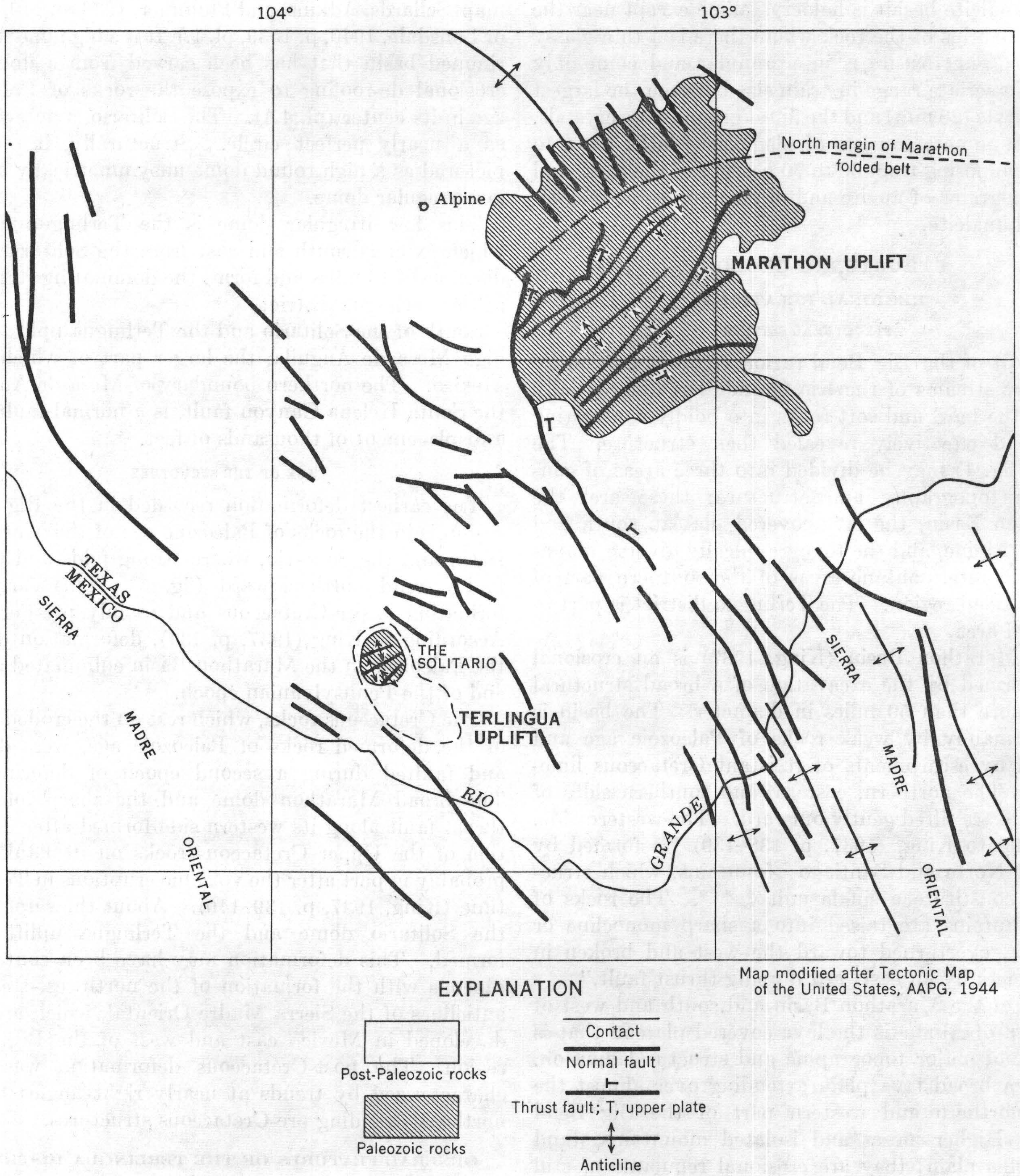


FIGURE 5.—Regional structural trends. Faults and folds trending northeastward are mainly pre-Permian, in age, but some are pre-Cretaceous; those trending northwestward are post-Cretaceous in age. The pre-Cretaceous structures, revealed only in the Marathon and Solitario uplifts, differ in type as well as in trend from the post-Cretaceous structures.

the east it is bounded by the Long Draw graben. Its southwestern and southern boundary is an abrupt flexure, the Terlingua monocline, that extends eastward beyond the uplift, across the entire district. A number of smaller domes, some of which are superimposed on the Terlingua uplift, are prominent structural features of the district. Several grabens, the longest of which is Long Draw graben, break the continuity of the Terlingua uplift. Flat-bottomed, steep-walled canyons such as the Long Draw and Well Creek Valley are topographic expressions of these grabens. The general trend of the grabens is northwest, but the Black Mesa graben zone strikes northeast. As major structures, the grabens die out along the Terlingua monocline, which thus serves as a hinge line for the graben faults. Hypabyssal intruded bodies of many different shapes have invaded the sedimentary rocks and have an important bearing on the structural geology because of the deformation that accompanied their emplacement. Sills and laccoliths made way for themselves by lifting and shouldering aside the enclosing strata; plugs and dikes also caused deformation, although in some places they may have pushed into preexisting openings. Monoclinal flexures over the margins of sills and laccolithic domes are prominent examples of deformation by intrusion (fig. 3). Small faults and fractures are numerous in most parts of the district; they are perhaps best shown by the drainage pattern on the higher parts of the Terlingua uplift, where erosion has emphasized them in the exposed limestone (pl. 4*B*). In some areas solution of the limestone has caused collapse, which is not limited to the limestone but extends upward into the overlying rocks, forming breccia pipes, one of the more unusual geological features of the district.

TERLINGUA UPLIFT

The Terlingua uplift may conveniently be defined as approximately coextensive with the area of Lower Cretaceous rocks shown in figure 6. It covers somewhat less than half of the Terlingua district. The regional relations of this elongate domical structure have been commented upon by Ross (1941; 1935a, p. 558–568), in Newhouse (1942, p. 193–195), Lonsdale (1940), and King (1937, p. 141).

Figure 6 illustrates the general outline and size of the Terlingua uplift and the Solitario dome, which together constitute a single composite unit about 18 miles long and 8 miles wide. The rocks along the northeastern border dip away at angles from less than 10° to about 20°. The rocks along the southwestern border are tilted much more steeply, forming part of the Terlingua monocline. The top of the uplift is relatively flat, with a slight eastward plunge, which steepens north and east of Long Draw. This steepened plunge and the normal faults at Long Draw, which have a net vertical displacement of 800 feet between the eastern and western sides of the draw, form the eastern end of the uplift.

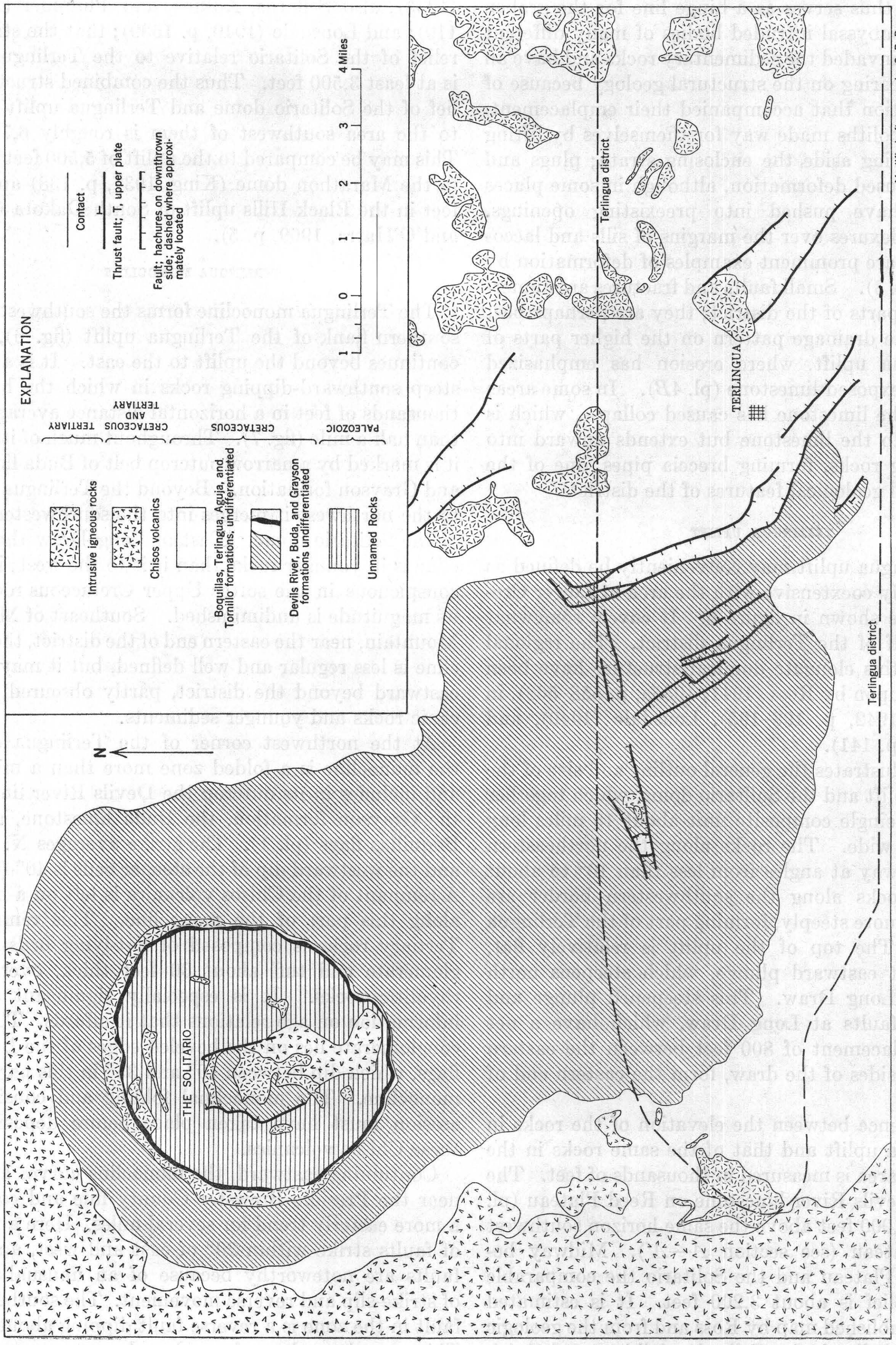
The difference between the elevation of the rocks in the Terlingua uplift and that of the same rocks in the surrounding area is measured in thousands of feet. The top of the Devils River limestone on Reed Plateau (pl. 1) is about 2,000 feet above the same horizon southwest of Reed Plateau (see section *A—A'*). Midway between Reed Plateau and the Solitario the comparable structural relief is about 3,200 feet. It is estimated from an unpublished map by Ross and from the geologic map of the Solitario by Sellards, Adkins, and Arick (1933), also Sellards, Adkins, and Plummer (1933, p. 119); and Lonsdale (1940, p. 1539); that the structural relief of the Solitario relative to the Terlingua uplift is at least 3,500 feet. Thus the combined structural relief of the Solitario dome and Terlingua uplift relative to the area southwest of them is roughly 6,700 feet. This may be compared to the uplift of 5,500 feet or more in the Marathon dome (King, 1937, p. 138) and 9,000 feet in the Black Hills uplift of South Dakota (Darton and O'Harra, 1909, p. 5).

TERLINGUA MONOCLINE

The Terlingua monocline forms the southwestern and southern flank of the Terlingua uplift (fig. 6), and it continues beyond the uplift to the east. It is a zone of steep southward-dipping rocks in which the beds rise thousands of feet in a horizontal distance averaging less than half a mile (fig. 7). Throughout much of its length it is marked by a narrow outcrop belt of Buda limestone and Grayson formation. Beyond the Terlingua district to the northwest it merges into the southwestern flank of the Solitario dome. East of Long Draw the monocline is in younger rocks than it is to the west, it is less conspicuous in the softer Upper Cretaceous rocks, but its magnitude is undiminished. Southeast of Maverick Mountain, near the eastern end of the district, the monocline is less regular and well defined, but it may extend eastward beyond the district, partly obscured by volcanic rocks and younger sediments.

At the northwest corner of the Terlingua district, the monocline is a folded zone more than a mile wide and includes in its outcrop the Devils River limestone, the Grayson formation, the Buda limestone, and the Boquillas flags (pl. 1). The strike averages N. 35° W. and the westward dip of the steeper beds is 40° (pl. 5*A*). A remnant of the Chisos volcanics is left on a high hill along this part of the monocline. This remnant of Tertiary rocks is composed of flat-lying beds of conglomerate and tuff about 30 feet thick, overlain by rhyolitic rocks. It is especially significant for the information on age relations that it affords. The basal conglomerate lies on the beveled edges of the Boquillas flags, which dip between 10° and 35° in this part of the monocline. The monoclinal folding and considerable erosion must have taken place before deposition of these Chisos volcanics.

Continuing eastward, the monocline curves abruptly near the Presidio-Brewster County line and continues a more easterly trend for several miles. Here a number of faults strike within 20° of east and west, and these faults are noteworthy because of an unusual amount of strike-slip and reverse movement. The southernmost fault in the zone is a reverse fault dipping about 50° N. This may have been formed early as a normal fault



Modified after maps by C. P. Ross and J. T. Lonsdale

FIGURE 6.—Generalized geologic map showing structure of the Terlingua uplift and the Solitario dome. Extent of Terlingua district shown by dashed line.

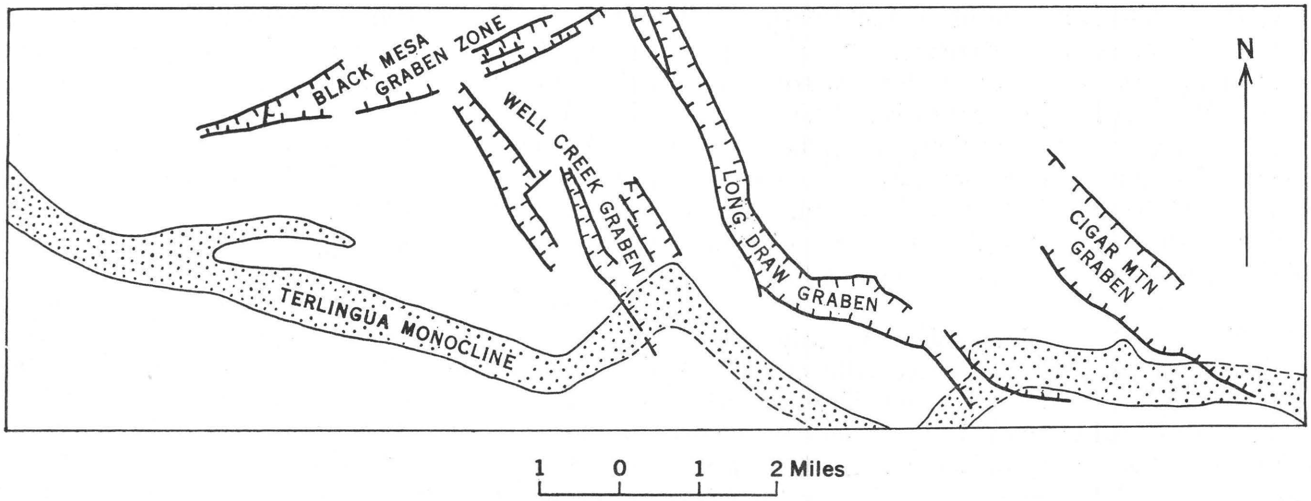


FIGURE 7.—Generalized structure map of Terlingua district, showing Terlingua monocline and principal graben. The monocline is delimited as a zone of southerly dips exceeding 15°.

and later tilted to a reverse position, along with the strata in the monocline, but more likely it was formed as a reverse fault by local squeezing where the strike of the monocline changes.

The faults on the eastward extension of this fault zone show only normal movement. The fault zone is north of and roughly parallel to the sinuous eastward course of the monocline, and along the zone are several intruded bodies and breccia pipes and a downfaulted synclinal area (on the north side of the monocline west of Maggie Sink; pl. 1). Remnants of Buda limestone and Grayson formation are preserved in the downfaulted syncline (fig. 8).

From the downfaulted syncline eastward to Tres Cuevas Mountain and beyond, the monocline is paralleled by an anticline north of it and by a syncline north of the anticline. The monocline near Tres Cuevas is a half-mile wide zone of southerly dips ranging from 20° to 70° (pl. 5*B*).

From Tres Cuevas Mountain, the monocline extends eastward for 1½ miles, with an average strike of S. 70° E. and southward dips of as much as 60°. South of the Mariposa mine, it makes a major curve to a new strike of about N. 65° E., which continues for 1½ miles and crosses the fault zone of Well Creek Draw (pl. 1 and fig. 4*B*). This northwest-trending sector of the monocline is flatter on the average, although the steepest beds dip as much as 60°. The Well Creek graben faults can be traced southward to the monocline, where their displacements are negligible compared to their displacements on the Terlingua uplift to the northwest. This is a generalization that may be extended to most of the normal faults that are so conspicuous on the Terlingua uplift, for they weaken greatly or die out where they intersect the monocline.

South of the Waldron and Little Thirty-Eight mines, the monocline again makes an abrupt change in strike from N. 65° E. to about S. 50° E., and this new trend continues southeastward along Reed Plateau (pls. 1 and 4*B*). The steepest beds just east of the change in strike dip only 25°, but 1½ miles to the southeast, along the southwestern edge of Reed Plateau, they have steepened to 75° and locally even more. Here the monocline is a zone of steeply dipping beds only a little more than half a mile wide.

At the southern end of Reed Plateau the monocline bifurcates, and its main branch extends about S. 60° E. The other branch trends N. 55° E.; in it the beds dip only about 10°. The southward limit of the main monocline is buried in alluvium, and thus the width, steepness, and amount of faulting of the fold are unknown. Three low-angle thrust faults in this area dip southwest and approximately parallel the monocline (pl. 1). In their exposed parts they displace the rocks vertically less than 100 feet. A possible explanation of these thrusts is that they are related in origin to the monocline. The rocks north and south of the monocline are carried toward each other by the folding, and this horizontal component of movement is greatest where the fold is steepest. Near the thrust faults, where the monocline bifurcates and also becomes more gentle, the horizontal component of movement on the fold is less, but the thrust faults add to the horizontal movement, making the net movement more nearly constant and thereby minimizing the disruption of the rocks north or south of the monocline.

The monocline turns northeastward south of the town of Terlingua, along the southern border of the mapped area. Across the southeastern end of the Long Draw it has a trend of about N. 35° E., and the beds dip as much as 35°. The fault zone of the Long Draw graben dies out as it crosses the monocline. The part of the Terlingua district east of Long Draw is structurally lower and is covered by younger rocks. This eastward descent is partly owing to the faults of the Long Draw graben, which have a net downthrow to the east, and partly owing to eastward dip of the strata (pl. 1, section *A—A′*); south of the monocline the eastward descent is fully as great and is almost entirely due to eastward dip.

The Terlingua monocline strikes approximately S. 80° E. from Long Draw to Cuesta Blanca (fig. 8). Cuesta Blanca is a notable hill of Boquillas flags baked gray by a concealed intruded body. The structure of the hill, doubtless due to the same body, is that of a dome, broken on the northeastern side by the Cigar Mountain graben and steepened on the southwestern side by coincidence with the monocline (fig. 8). The monocline, thus modified, swings around Cuesta Blanca as though the latter were a blunt instrument pressed southwestward. The result is a monoclinal trend of S. 55° E. on the southwestern side of Cuesta Blanca, changing to N. 70° E. on the southeastern side.

The southwest fault of the Cigar Mountain graben diminishes in magnitude southeastward and has a relatively small displacement where it crosses the monocline. It probably dies out within the zone of monoclinal folding; the other fault bounding the graben dies out north of the monocline.

The monocline continues its northeastward trend from Cuesta Blanca across the southeastern end of the Cigar Mountain graben and then swings to a trend of almost due east. South dips between 20° and 40° characterize a zone more than half a mile wide, but the total width is not known because the southern limit is outside of the area mapped. East of Cuesta Blanca the monocline is topographically less conspicuous, but the structural relief is as great as in the western part of the district. For example, the structural relief south of Maverick Mountain is more than 2,000 feet (fig. 8).

DOMES

A dome may be defined as an anticlinal uplift without a distinct trend. Several domes are described here, beginning with those at the western end of the district. They range in diameter from 1 to 3 miles, and all are probably genetically related to the process of intrusion.

WAX FACTORY LACCOLITH AND DOME

Only part of the Wax Factory laccolith (Lonsdale, 1940, p. 1554) extends into the western edge of the district (pl. 1). Because this intrusion is well dissected, it reveals the doming, crumpling, and offsetting of the intruded beds in greater detail than elsewhere in the district. The large area of igneous rock at the western extremity of the district is the thinning eastern edge of the laccolith. Remnants of the top contact are preserved in the small patches of overlying Boquillas flags, and a projection of the top and bottom contacts indicates that the eastern edge is but little eroded and is nearly at its former limit.

CONTRABANDO DOME

Immediately southeast of the Wax Factory laccolith is the broad Contrabando dome. It is more than 2 miles in diameter and has a structural relief of roughly 500 feet. The dome is crossed by several small faults of northeast and northwest trends characteristic of faults in the entire district. Rhyolite dikes and plugs are intruded discontinuously along two faults; other rhyolite plugs are scattered over the dome, and a large rhyolite sill is exposed at the eastern extremity of the dome. The Boquillas flags are baked throughout the area where most of the dikes and plugs are exposed. As dikes and plugs elsewhere in the district have not baked the surrounding rocks for such great distances laterally, the baked rock here must indicate a more widespread intruded mass below, probably a laccolith or sill. This concealed mass, indicated by the expanse of baked rock, is very likely the cause of the dome.

BLACK MESA DOME

The Black Mesa dome is 2½ miles northwest of the Mariposa mine and adjacent to Lowes Valley. This flat-topped dome is 1½ miles in diameter and has a structural relief of 600 feet (fig. 9). The northwest quarter of the dome is not discernable in the chaotic structure of Lowes Valley, which was formed at the same time or later than the dome.

The Black Mesa dome was probably formed through lifting of the sedimentary rocks by igneous intrusion; there are igneous rocks in Lowes Valley but no direct evidence of intrusion under the dome was found. The theoretical possibility of a nearly circular dome being formed by direct horizontal compression is discussed and rejected in the section on origin of the domes.

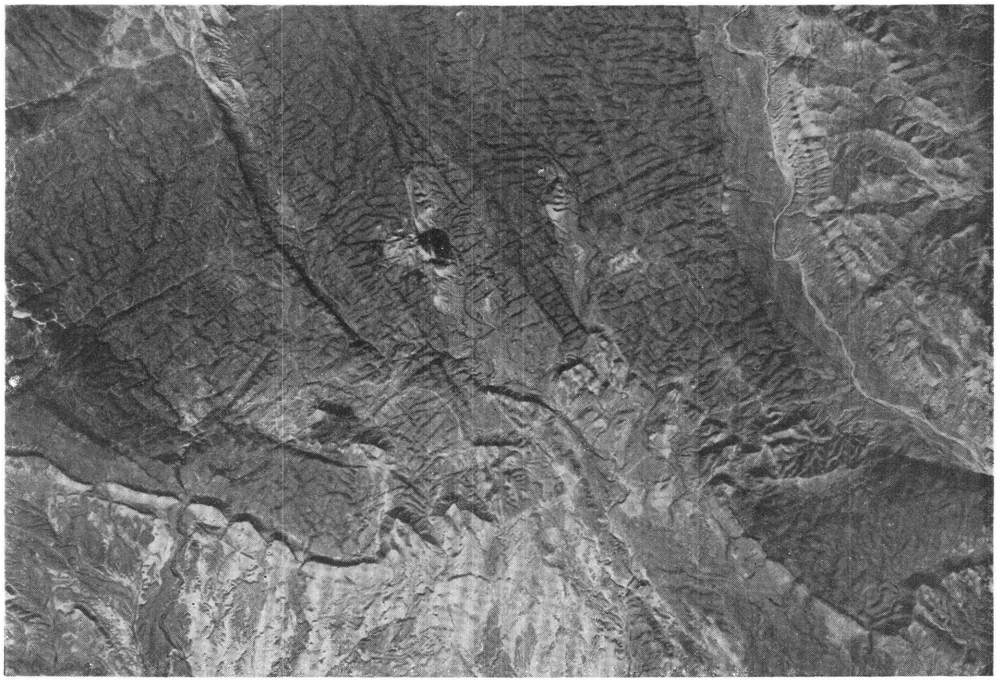
LONG DRAW DOME

At the northern end of Long Draw the southern third of a dome is indicated by a crescent-shaped belt of beds dipping 10° to 30° S. on both sides of, and within, the Long Draw graben. Its northeastern flank merges with the monoclinal northeastern border of the Terlingua uplift. The dome is 3 miles in diameter and has a structural relief of 300 or 400 feet.

FOSSIL KNOBS DOME

Directly northwest of Terlingua is a low irregular domical structure ½ mile wide by 1¼ miles long, which

A. SOUTHWESTERN FLANK OF THE SOLITARIO DOME



B. VERTICAL AERIAL PHOTOGRAPH OF PART OF THE TERLINGUA DISTRICT

North is toward the top, scale about 1:50,000. The dark rock covering most of the area is Devils River limestone, upon which erosion has strikingly accentuated the pattern of fractures and faults. The sinuous Terlingua monocline can be seen extending across the southern part of the area, and the Long Draw graben is conspicuous near the eastern edge. Photograph courtesy U.S. Army Air Force.

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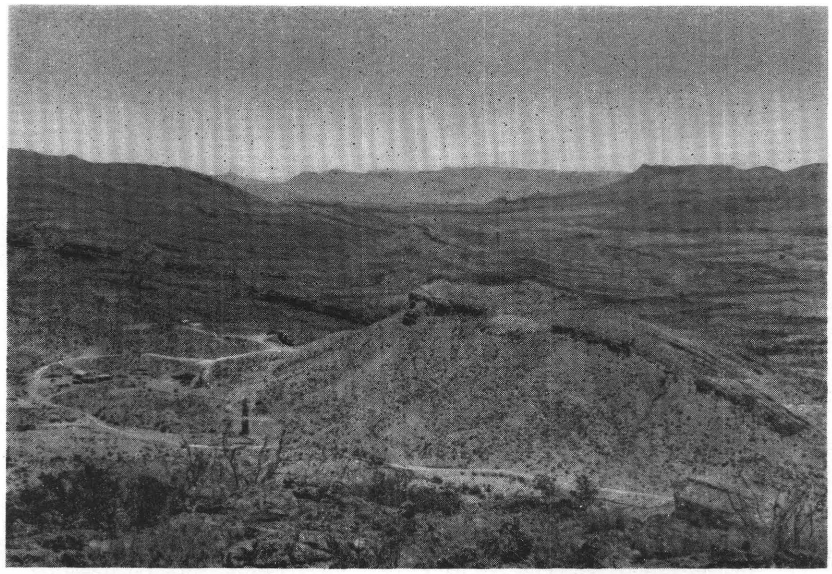
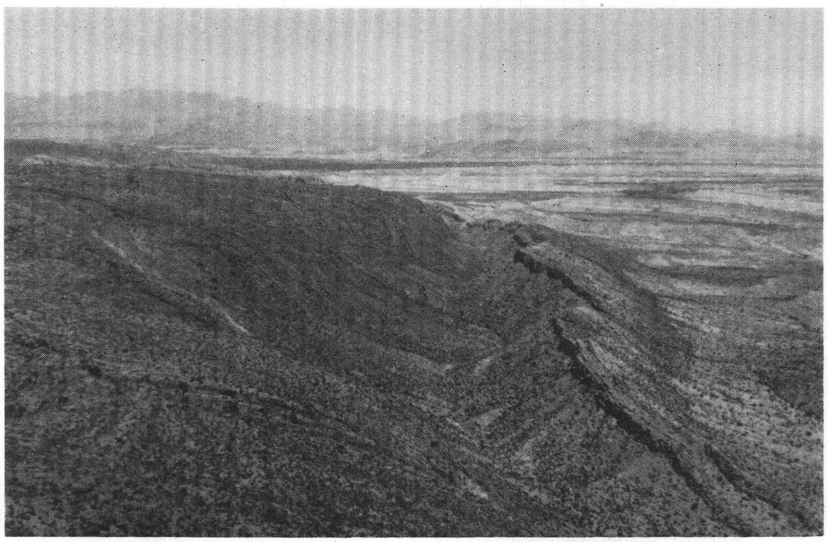
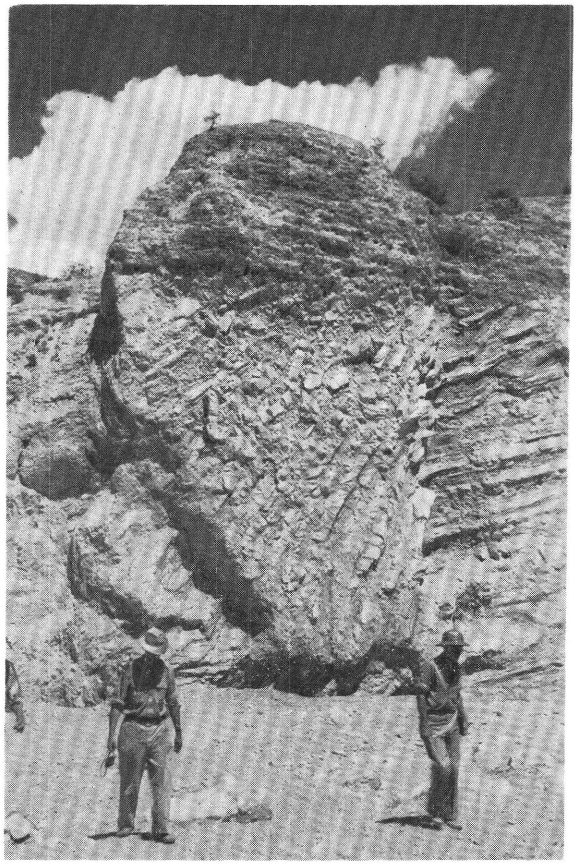


A. VIEW SOUTHEASTWARD ALONG THE TERLINGUA MONOCLINE AT THE FRESNO MINE

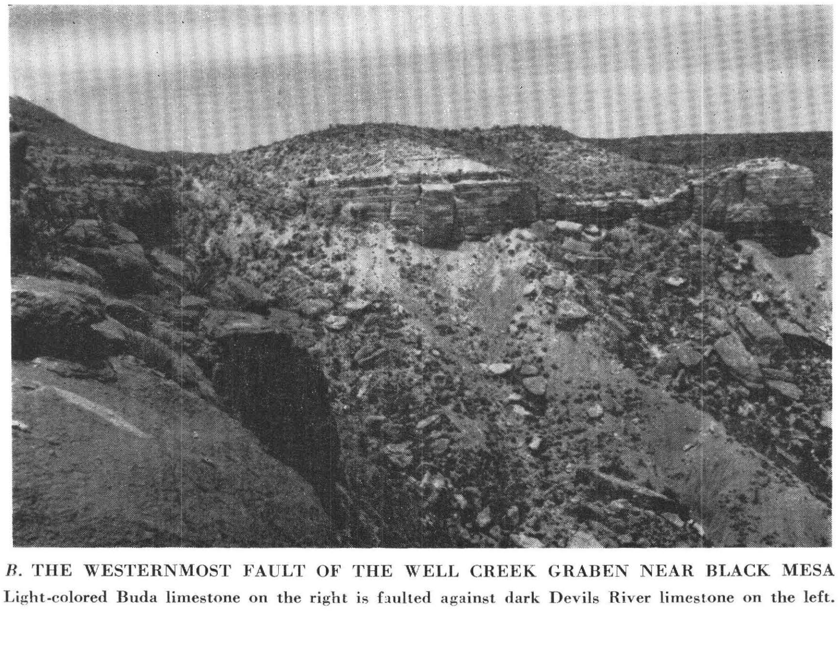


B. THE TERLINGUA MONOCLINE EAST OF TRES CUEVAS MOUNTAIN. THE CHISOS MOUNTAINS ARE IN THE BACKGROUND



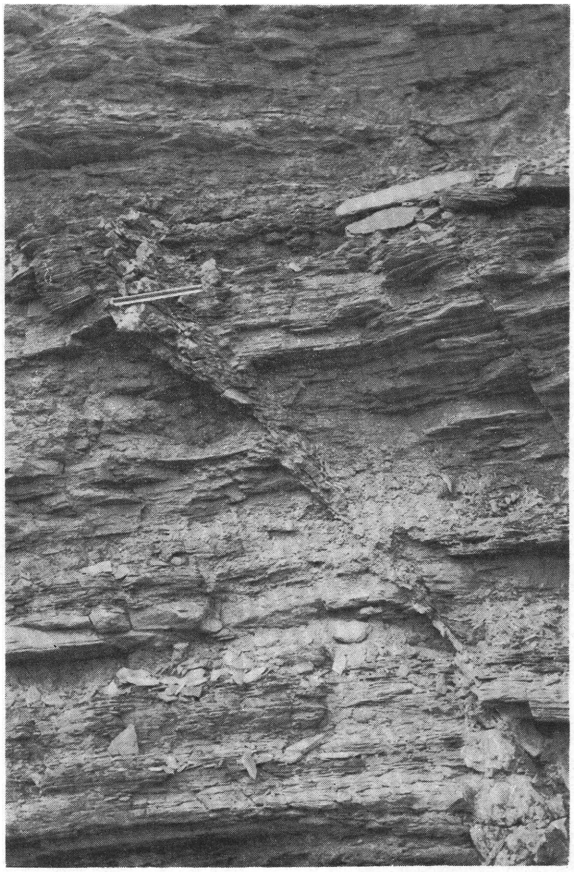
A. FAULT BRECCIA OF BOQUILLAS FLAGS ON NORTHEASTERN FAULT OF THE LONG DRAW GRABEN

The flat-lying topmost beds are alluvium cemented by caliche and are not faulted.



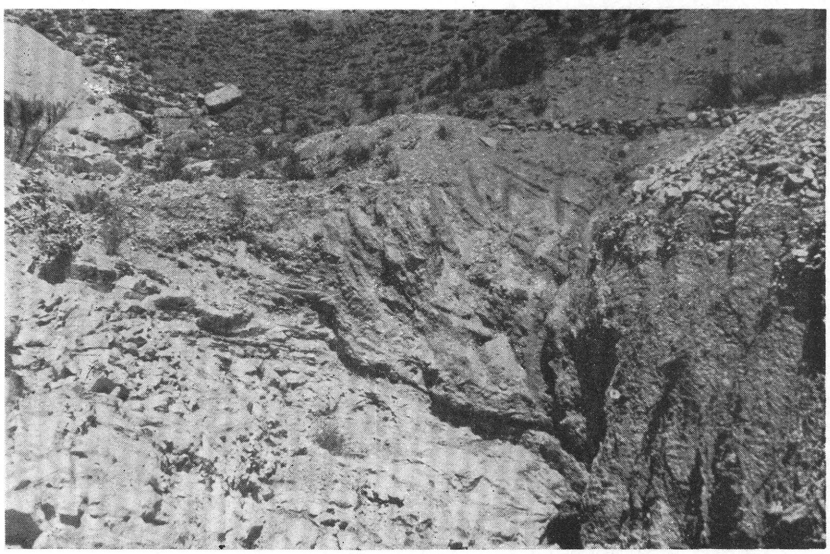
B. THE WESTERNMOST FAULT OF THE WELL CREEK GRABEN NEAR BLACK MESA

Light-colored Buda limestone on the right is faulted against dark Devils River limestone on the left.



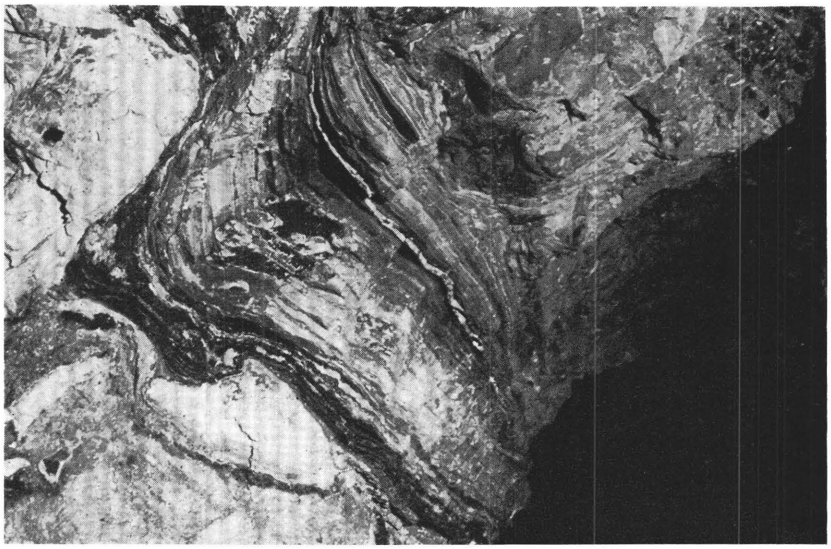
A. BULBOUS CALCITE VEIN ON A FRACTURE, SHOWING STRIKE-SLIP MOVEMENT

The vein and fracture end on a bedding plane above the 12-inch scale, the displacement being taken up by bedding-plane slippage.



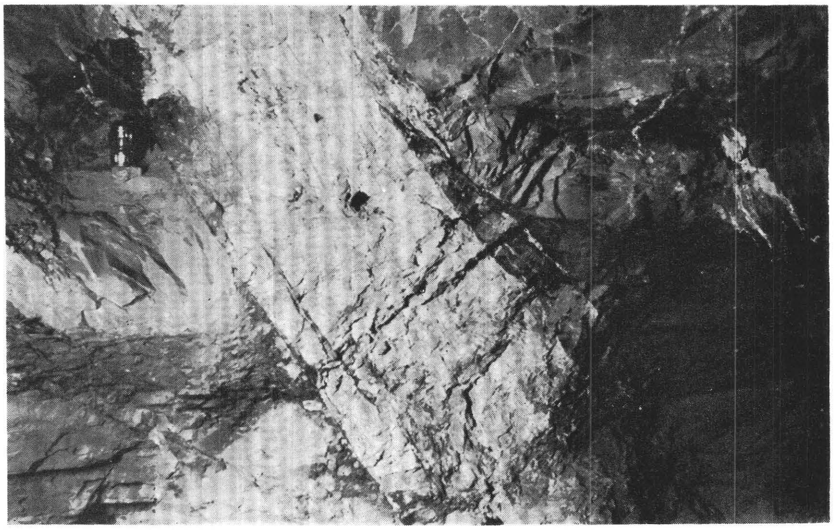
B. SLUMPED GRAYSON FORMATION AND DEVILS RIVER LIMESTONE IN A CAVE-FILL ZONE AT THE MARIPOSA MINE

The cave-fill zone developed where a vertical fracture intersected the topmost limestone beds. The white rock in the lower left of the photograph is Devils River limestone and the darker rock above is Grayson formation. The beds were horizontal before solution and slumping occurred.



A. LIMESTONE-CLAY CONTACT DEPOSIT, MAIN STOPE, FRESNO MINE

Banded rock in center is cinnabar-impregnated cave-fill clay; limestone to left. The darker bands are richer in cinnabar; the black bands contain 50 percent or more cinnabar.



B. CALCITE VEIN CONTAINING CINNABAR IN BOQUILLAS FLAGS ON 250-LEVEL, CHISOS MINE

Banded character of the vein is due to thin ribbons of gouge and country rock, as well as deposition banding of calcite.

QUICKSILVER ORE BODIES

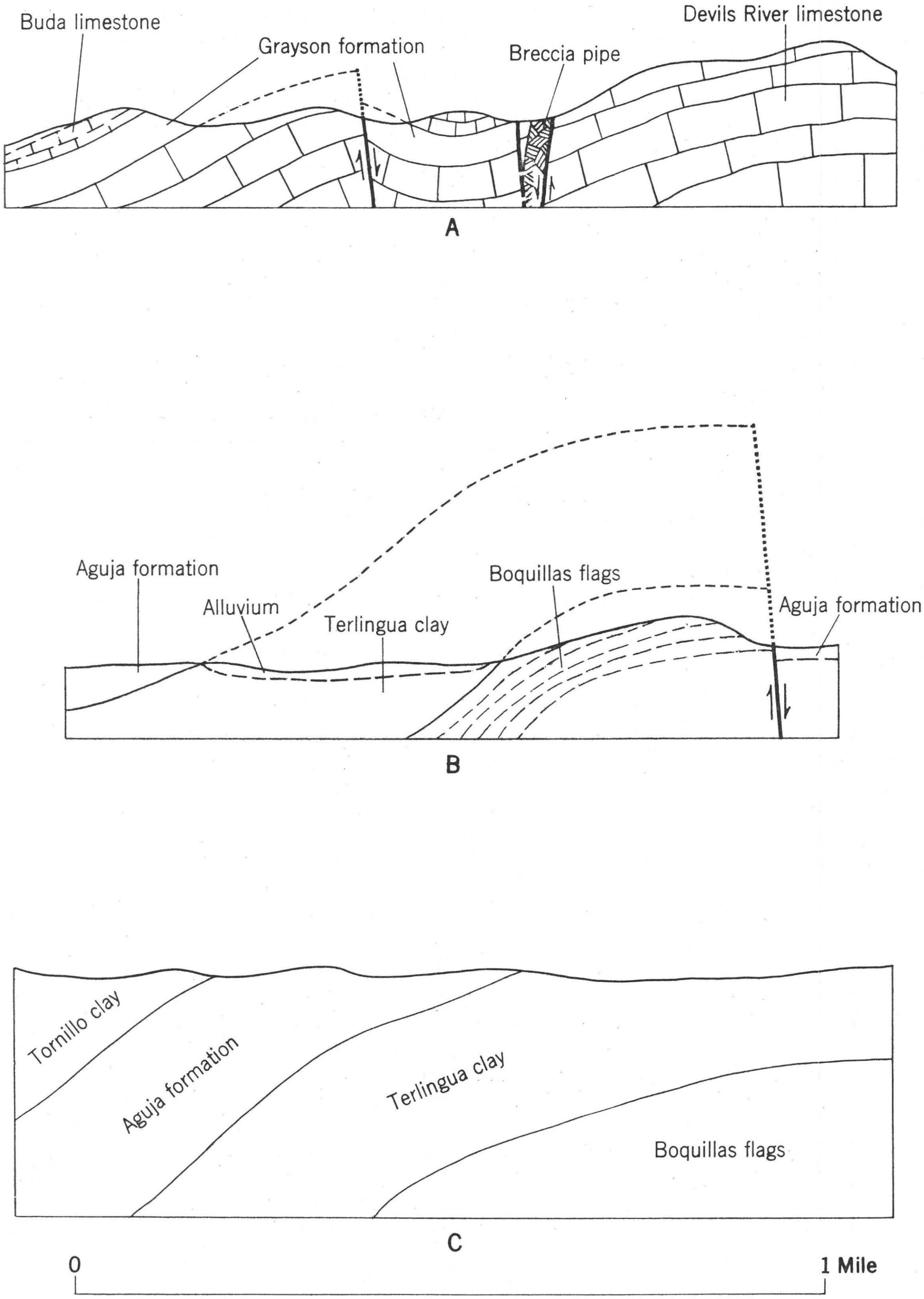


FIGURE 8.—Vertical sections across the Terlingua monocline: *A*, west of Maggie Sink; *B*, at Cuesta Blanca; *C*, south of Maverick Mountain.

is here called the Fossil Knobs dome. The origin of this structure is indicated by its coincidence with an area of baked rocks and by one large and three small outcrops of intrusive igneous rock within the area. A core drill hole near the southeast end of the baked area revealed an igneous sill, which is shown in sections *A—A′* and *B—B′*, plate 1. The northeastern border of the Terlingua dome is gentle, as though formed by a gradual thinning of the sill northeastward; dips do not exceed 15° except locally along a fault, which is probably contemporaneous with intrusion. The southwestern and northwestern flanks of the dome are abrupt and steep, with dips exceeding 35°. This steep border may be compared genetically with a better understood fold at Study Butte, where mine workings revealed the subsurface structure (fig. 3).

TWO-FORTY-EIGHT DOME

East of the Cigar Mountain graben and the Two-Forty-Eight mine is a broad low dome similar in size and shape to Contrabando dome. The upper member of the Boquillas flags is exposed over most of the domical area, which is bounded on three sides by the overlying Terlingua clay and on the fourth by the graben. The dome has a diameter of 2 to 3 miles, marginal dips as much as 15°, and a structural relief of roughly 500 feet. Uplift by a sill or broad laccolith is the inferred cause of the dome. A sill was penetrated in the Two-Forty-Eight mine at a depth of 500 feet, but it is less than 100 feet thick.

ORIGIN OF THE DOMES

Although uplift by intrusion is the indicated explanation for the Terlingua domes, some similar domes are attributed to horizontal stress. Powers (1921, p. 419) considered regional (horizontal) compressive stresses as a possible means of accounting for the Solitario dome. A consideration of the geometry of circular domes and the mechanics of "focusing" regional compressive stresses helps to distinguish between the mechanisms of vertical uplift and of horizontal compression and lends support to the theory of uplift by intrusion.

The Black Mesa dome may be taken as a specific example; it is chosen because its fairly regular shape makes it easy to analyze. Figure 9 shows a cross section of the

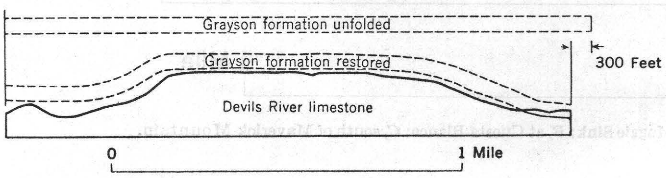


FIGURE 9.—Vertical section across Black Mesa dome. The eroded Grayson formation is restored to show the shape of the dome. Unfolding the beds increases the length of the section by 300 feet.

Black Mesa dome with the Grayson formation restored as a datum plane. As shown above the section, the Grayson formation if unfolded has a length 300 feet in excess of the length of the section; this of course is true not only of the Grayson formation but of the whole stratigraphic section. The distance of 300 feet represents the minimum shortening of any diameter of the dome that must have taken place if the dome were formed by horizontal compression. If horizontal compression is assumed, a circle just outside the dome would have its diameter and circumference reduced during doming by being pushed toward the center of the dome. The diameter would be reduced at least 300 feet and therefore the circumference reduced by about 940 feet. How was the circumferential shortening of 940 feet taken up? This shortening is sufficient to create three radiating anticlines as high as the dome and with comparable dips. To form a circular dome by horizontal compression is like pushing the sectors of a pie toward its center. It is readily seen that the part of each sector outside the presumably doming center of the pie would be thrust against neighboring sectors in such a way as to form folds or thrust faults radiating from the dome. There is good evidence against any such radial thrusts or folds at Black Mesa, for the surrounding rocks are well exposed. Nor does it answer the question to suggest that the radial thrusting might be distributed on a number of joints, for the same might as well or better be said of the doming itself, which is no greater in magnitude than the required radial folds or thrust faults.

If, however, the doming was caused by vertical lifting over an intrusive body, there are still some questions to be considered. One concerns the apparent shortening of 300 feet across the dome. Two interpretations of the apparent shortening are possible: (1) The shortening is real and is balanced by contemporaneous extension on normal faults nearby, or (2) the shortening is only apparent and it is actually a lengthening and slight thinning of the strata on the flanks of the dome. The first possibility implies a temporal relation of the dome with the adjacent Lowes Valley graben and perhaps with its associated intrusive rocks. The amount of material raised in the dome is of the same order of magnitude as the material depressed in the graben. The second possibility requires plastic deformation or distributed fracturing, which would be concentrated on the flanks of the dome rather than on its flat top. This stretching on the flanks of the dome would amount to approximately an inch per foot, but no direct evidence of it was observed in the field. Although a choice between the two possibilities is impossible to make on the basis of available evidence either at Black Mesa or at the other domes, it seems most likely that a combination of the two possibilities entered into the formation of the domes.

The intrusive body that caused the doming of Black Mesa may be at a depth of only a few hundred feet or it may be very deep, and it may be laccolithic or it may by pluglike or bysmalithic. No baked rock or other reliable evidence of the proximity of intrusion at shallow depth was found on the dome. The closest intrusive rocks are rhyolite and trachyte.

Lonsdale (1940, p. 1551) related the structural relief of the domes to the composition of the associated igneous rocks, but the present authors found no evidence for this hypothesis. In the larger area studied by Lonsdale, he lists eight thick laccoliths or bysmaliths from which the covering rocks have been stripped (p. 1555). Although these should correspond to higher domes, all but two of them are composed of soda-rich or analcite rocks, which are supposed to characterize lower domes. The viscosity, rate of crystallization, and rate of injection of the magma must have influenced the thicknesses of intrusive masses compared to their diameters. These factors, however, are not necessarily reflected in the final composition of the rock.

FAULTS AND FRACTURES

LARGE GRABENS

Many of the major faults of the Terlingua district are steeply dipping normal faults bounding depressed tracts, or grabens (fig. 7). The grabens are narrow compared to their length; for example, the Long Draw graben is more than 12 times as long as it is wide. In general the major faults trend northwest, but there is a notable exception in the Black Mesa graben zone, whose bounding faults trend northeast (pl. 1). The strikes of the individual faults vary markedly, making both sinuous curves and angular turns. In detail the faults are more complex than shown in plate 1; in many places they form irregular zones rather than single fault planes (fig. 10). The maximum vertical displacement is about half a mile, which is comparable to the structural relief across the Terlingua monocline.

Long Draw graben, with a length of 6 miles, is the longest graben in the district; it has an average width of half a mile. The vertical displacement is approximately 2,000 feet below the block southwest of the graben and 1,200 feet below the block northeast of the graben (pl. 6*A*). The graben dies out southeastward at the Terlingua monocline and northward a short distance outside the Terlingua district. Areas adjacent to the graben are in some places "sagged" toward it, and there the displacement on faults is correspondingly less. The overall trend of the bounding faults is N. 70° W. in the southern part of the graben, N. 30° W. in the central part, and N. 20° W. in the northern part.

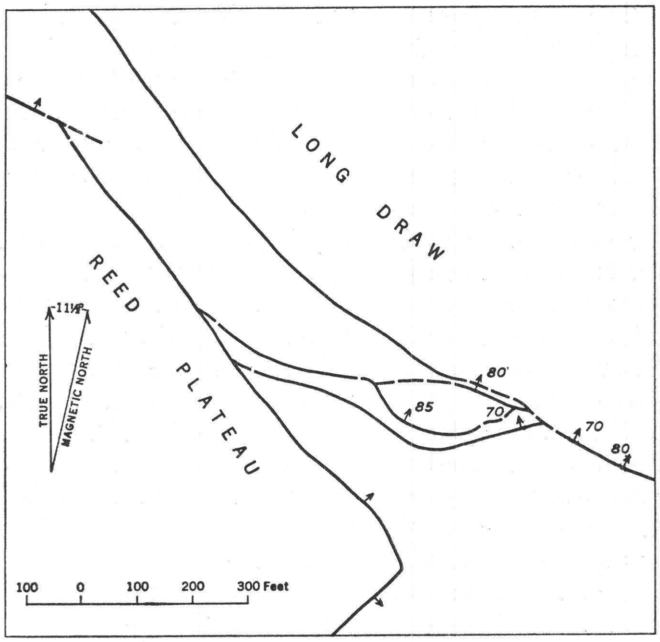


FIGURE 10.—Detailed map of normal faults bounding the southwestern side of Long Draw south of the Chisos mine. The rocks in Long Draw are displaced downward more than 2,000 feet relative to the rocks in the Reed Plateau. The displacement, divided between two faults in the northwestern part of the map, is concentrated in one fault at the eastern edge of the map; the transition occurs in the zone of connecting faults and in locally tilted beds.

There is a noticeable tendency toward parallelism of the individual, component fault planes with the regional fracture pattern. For instance, the most common directions of fracture immediately west of the northern part of the graben are N. 85° E., N. 65° E., N. 20° W., and N. 30° W. (pl. 4*B*); and the graben faults locally follow each of these trends except the first. West of the Rainbow mine the graben faults on the northern side follow a trend of N. 65° E. to N. 80° E. for half a mile. There the faults appear to be part of a throughgoing zone of faults extending from the Terlingua monocline N. 75° E. to the town of Terlingua and perhaps to Cigar Mountain.

A group of discontinuous grabens, designated as the Black Mesa graben zone, extends from west of Black Mesa almost to Long Draw, with an overall trend of N. 75° E. Although its characteristics are diverse, certain general differences from the Long Draw graben stand out. The unusual northeast trend has already been mentioned. Furthermore, the graben zone is neither so long nor so nearly continuous as the Long Draw graben; the fault displacements are generally less; and there is no marked difference between the displacements on the two sides. The northeastern part of the zone, near Long Draw, is fairly simple, whereas the Lowes Valley part, adjacent to Black Mesa, is a chaotic jumble of downfaulted blocks, lacking the relatively straight, linear boundaries of the usual grabens.

The northeastern part of the Black Mesa graben zone contains the Grayson formation and Buda limestone, which are faulted into Devils River limestone, with a maximum displacement of approximately 400 feet. The graben block is synclinal with an axial strike of N. 55° W. across the N. 65° E. strike of the graben; the graben faults die out in both directions away from the syncline. Adjacent to this part of the graben on the southeast is a square block, which is tilted southward, with faults on all four sides. Two of these faults intersect the graben faults without noticeable offset. Buda limestone is preserved in the structurally lowest part of the tilted block, along the southwestern fault, which has a displacement locally in excess of 200 feet. Between the northeastern part of the Black Mesa graben zone and Lowes Valley, the faults die out; but farther southwest, on the flank of the Black Mesa dome, the faults reappear. Here displacements along the faults are relatively insignificant, but still farther southwest, at Lowes Valley, the displacements are large.

The graben in Lowes Valley, is separated into an eastern and a western half by a ridge of Devils River limestone extending two-thirds of the way across the graben. The eastern half contains pyroclastic rocks and conglomerates correlated with those of the Chisos volcanics, rhyolite that is thought to be intrusive, Buda limestone, and a small outcrop of Boquillas flags, which is tentatively correlated on the basis of rock character with the lower member of Boquillas flags. A minimum vertical displacement of at least 800 feet is represented by the latter outcrop. The western half of Lowes Valley is floored by the Grayson formation, Buda limestone, and Boquillas flags. The displacement of the Boquillas flags is at least 1,100 feet downward relative to the surrounding area. Southwest of Lowes Valley the rocks in the graben are all Devils River limestone and are displaced vertically no more than 500 feet. This change in displacement, from 1,100 to 500 feet, is so abrupt that a cross fault, concealed beneath the alluvium in the floor of the graben, is required to explain it.

The Chisos volcanics in the eastern part of Lowes Valley are interpreted as having been faulted down along with Boquillas flags and Buda limestone, which they overlie unconformably farther west. The peculiar distribution of the volcanics, which occur in patches in the Devils River limestone, might suggest that they were deposited in hollows after the graben was completely formed, but this interpretation is untenable, because steep dips in bedded pyroclastic rocks indicate that the Chisos volcanics were deformed subsequent to their deposition. Still another possibility is that the igneous rocks lie in a volcanic vent choked with its own debris. This seems unlikely, because the volcanics contain bedded stream gravels with limestone pebbles of Paleozoic age, and these gravels are characteristic of those interbedded with the Chisos volcanics elsewhere. The questionable intrusive rock may have been faulted down along with the bedded volcanic rocks or intruded later.

Three grabens, called the Well Creek grabens for the intermittent stream that drains the area, extend southeast from Black Mesa to the Terlingua monocline. They contain Grayson formation, Buda limestone, and, locally, Boquillas flags. The pattern of overlapping, convergent, and angular faults bounding these three grabens is best grasped by reference to plate 1. The displacement on the bounding faults (pl. 6*B*) is nowhere more than 500 feet and in most places only about 250 feet. Where the faults die out, monoclinal rolls commonly take their places; these rolls become lower and lower until they too finally disappear. Some graben faults end abruptly, however, with the displacement taken up on a terminal cross fault or fold, as for example, the boxlike northwestern end of the graben adjacent to the Waldron mine. In summary, the Well Creek grabens differ from the Long Draw graben in their smaller size and lesser displacement and the fact that the blocks east and west of the grabens are not differentially displaced as at Long Draw. Otherwise, the structural affinities between the Long Draw and Well Creek grabens are close.

The Cigar Mountain graben, striking southeastward from Cigar Mountain, is one of the larger grabens of the Terlingua district. It has a length of about 3 miles, a width of 1 mile, and a vertical displacement of 1,000 to 2,000 feet. Its trend projects into the faulted, structurally low area extending northwestward from Cigar Mountain. Cigar Mountain itself is a sill or laccolith intruded during or after the faulting. The southwestern fault of the graben may have served as one of the feeding channels for the intrusion, which protrudes southeastward as a narrow dike for a short distance along the fault. Within the graben, the units are the Terlingua clay and Aguja formation. Alluvium conceals most of the area.

OTHER NORMAL FAULTS AND FRACTURES

The majority of the faults, fractures,[6] and joints in the Terlingua district belong to two sets, one trending northeast and the other trending northwest. Although each of these sets varies considerably in strike, their intersections are commonly at nearly right angles. The northwest set includes most of the major faults

[6] The term "fracture" is used for ruptures on which there is no measurable displacement but which are more persistent than joints. Some of these fractures can be traced for half a mile or more.

already discussed, the main exception being the Black Mesa graben zone which trends northeast. Among the smaller faults and the fractures, those belonging to the northeast set are in many places the most persistent and conspicuous (pl. 4*B*). The great majority of all the faults and fractures have steep dips (60° to 90°).

In the southwestern part of the Terlingua district, south of the Terlingua monocline and west of the lower end of Long Draw, are many small faults splitting and crossing in a complex pattern, in contrast to the simpler fault pattern north of the monocline. Much of the difference is attributable simply to the different rocks exposed in the two areas. Faults that are single planes in the thick-bedded Devils River limestone split into multiple faults in the less homogeneous rocks above the Devils River limestone. This significant difference tends to be magnified in mapping because small faults are harder to detect in the relatively massive limestone.

The northwest-trending faults and perhaps the minor folds south and southwest of Tres Cuevas Mountain appear to be the dying-out end of the great Santa Helena Canyon fault south of the Terlingua district. Here as elsewhere in the district, the Terlingua monocline is a relatively unfaulted strip dividing the faults north of it from those south of it.

RELATIVE AGE AND DIRECTION OF MOVEMENT

Intersections of faults and fractures show offsets of either set or both offset; they thus reveal no evidence tending to establish separate ages for the northeast and northwest sets. Many of the faults and fractures, particularly those of the northeast trend, show good evidence of oft-repeated small movements. This is shown by calcite veins, which occur in most of the faults; alternating deposition and movement have produced an interleaving of calcite with thin sheets of country rock (pl. 8*B*). Movements possibly continued longer on the northeast set, as suggested by the almost total restriction of quicksilver mineralization to this set.

The movements on the large normal faults were predominantly dip-slip, as shown by the lack of large horizontal displacements at fault intersections and by angular changes in strike. However, no way was found to detect and measure accurately small horizontal displacements. That some horizontal movement took place is indicated by horizontal or gently inclined grooves, as, for example, those on the Chisos fault in the Chisos mine and those on the graben faults near the southeastern end of Long Draw.

THRUST FAULTS

Thrust or reverse faults are not common in the Terlingua district, but they occur in at least four localities: (1) A reverse fault in the Terlingua monocline east of the boundary between Presidio and Brewster Counties has been mentioned in the discussion of the monocline. This fault strikes parallel to the monocline and dips 50° northward. (2) Three thrust faults southeast of Reed Plateau have also been mentioned. They strike almost parallel with the monocline and dip southward. (3) A small thrust fault 1½ miles west and a little south of Reed Plateau dips eastward and is offset by a normal fault. (4) A mile south of Cigar Mountain a thrust fault strikes N. 20° W. and dips 20° to 30° W.

The faults at the first two localities seem to represent minor adjustments related to the formation of the monocline. Alternatively, the faults at the first locality might have been caused by intrusive igneous rocks, for these crop our near them. The thrust at the fourth locality strikes transverse to the monocline but is conspicuously parallel to the western side of the Cuesta Blanca dome a mile to the east; it may have resulted from the pressure of igneous intrusion within the dome.

In summary, the thrust faults are local in extent, small in displacement, and diverse in trend. They are probably the result of local adjustments to larger structures or to igneous intrusions.

BRECCIA PIPES AND OTHER FEATURES CAUSED BY SOLUTION

Solution features are of three main types: limestone caverns; filled caverns, or cave-fill zones; and breccia pipes. The open caverns, with the exception of a few in the Buda limestone, are in the Devils River limestone. The cave-fill zones occur near the top of the Devils River limestone, where overlying rocks have slumped contemporaneously with solution of the limestone. The breccia pipes have their roots in the Devils River limestone but some extend more than 1,000 feet above the limestone.

In general there are two kinds of open caverns: vertical caves developed mainly along fractures, and horizontal caves developed mainly along bedding planes. Examples of vertical caves are in the Little Thirty-Eight mine and in the Contratiro workings of the Mariposa mine. Vertical caves are usually less than 10 feet wide but some are locally as much as 50 feet or more in width. The length and height reach hundreds of feet. Horizontal caves occur in many places, and good examples are in the Waldron mine and in the Contratiro workings of the Mariposa mine. Single rooms in the horizontal caves are rarely more than 100 feet in width, and though generally low, they may be 50 feet or more in height.

The antiquity of some of the caverns is established by their relation to mineralization. Coatings of cinnabar and coarsely crystalline hydrothermal calcite line the walls of many of them, as for example at the

Waldron, Little Thirty-Eight, Mariposa, and Chisos mines. Other caverns are smooth walled and bare; ordinary dripstone is rare. One such cavern is a large open sinkhole near the Waldron mine. Cave-fill zones are commonly associated with open caverns. occurring at greater depths along the same fracture, and thus the two are probably closely related in age and origin.

The cave-fill zones (pls. 7*A* and 8*A*) are generally formed at intersections of nearly vertical fractures with the top of the Devils River limestone; they are filled with slumped Grayson formation and residual blocks of limestone. They are usually hundreds of feet long and less than 50 feet wide, but in form and size are varied and complex, depending partly on the pattern of intersecting fractures. Their vertical dimension is usually less than 50 feet but in exceptional cases is several hundred feet. The fill is generally highly brecciated near the bottom and grades upward into slumped, but not brecciated, beds. Fifty feet or more above the top of the Devils River limestone, in the Grayson formation, the cave-fill zones may be expressed as small synclines, and above the Grayson they are not likely to be expressed at all except above very large cave-fill zones.

The cave-fill zones are old features; they are much older than the present erosion cycle. At the Mariposa mine, for example, cave-fill has been invaded by igneous rock of probable Tertiary age, which was later fractured and the fractures filled with cinnabar. At many other places the cave-fill is older than the ore.

Masses of breccia with a vertical pipelike or chimney-like shape are designated as breccia-filled pipes, or simply breccia pipes. They are shown on plate 1 as small oval or circular areas. Displacement of the breccia is downward, strongly indicating that the pipes formed as a result of solution in the Devils River limestone accompanied by collapse-stoping of overlying strata.

Four breccia pipes will be described in detail: Maggie Sink pipe, in Devils River limestone 1¾ miles west of Mariposa; Two-Forty-Eight pipe in Boquillas flags at the Two-Forty-Eight mine; Aguja pipe in Boquillas flags on the Chisos mine property; and Chisos pipe in the Grayson formation and Buda limestone in the Chisos mine.

MAGGIE SINK PIPE

Maggie Sink breccia pipe is in Devils River limestone about 1½ miles west of the Mariposa mine. It is in a topographic depression on the crest of an asymmetric anticline. Exploration for quicksilver ore to a depth of about 600 feet has provided considerable data about the pipe. The pipe is roughly elliptical in outcrop, having a length of 540 feet and a width of 200 feet (fig. 11*C*); the long dimension is oblique to the axial

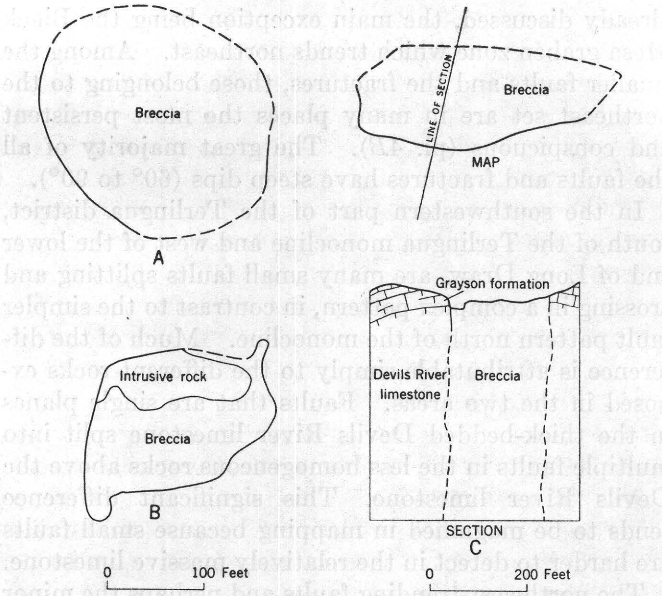


FIGURE 11.—Outline maps of breccia pipes. A, Outline map of Aguja breccia pipe, near the Chisos mine. The surrounding rocks are Boquillas flags; the breccia is broken sandstone and clay of the Aguja formation, displaced downward an estimated minimum of 1,500 feet. B, Outline map of breccia and intrusion south of the Aguja pipe. The surrounding rocks are Boquillas flags; the breccia is broken Boquillas; and the intrusive rock is basaltic. C, Outline map and vertical section of Maggie Sink breccia pipe. The surrounding rock is Devils River limestone; the breccia is broken Grayson formation, Buda limestone, Boquillas flags, and possibly some Tertiary volcanic rock. The breccia in the outcrop is displaced downward as much as 500 feet or perhaps more.

trend of the anticline. Fractures and small faults, many filled with calcite, are numerous in the surrounding Devils River limestone, as they are throughout the Terlingua district, but significant intersections or concentrations of fractures that might control the localization of the structure are absent.

The nearly vertical walls of the pipe, which are solution-pitted and coated by coarsely crystalline calcite, enclose a collapsed brecciated mass of intermixed Grayson formation, Buda limestone and Boquillas flags. Clay of the Grayson, which is soft and plastic when moist, serves as a matrix for fragments of the harder rocks. The brecciated Buda and Boquillas rocks are present as randomly oriented fragments ranging in diameter from less than an inch to several feet. Some blocks of Devils River limestone are present, especially near the borders of the pipe, and a few fragments similar to Chisos volcanics were found on the surface at the southeastern corner of the outcrop.

Between 1943 and 1946 a tunnel was extended to intersect the pipe about 150 feet below the surface, and from this tunnel a winze was sunk to explore several hundred feet deeper. The winze was not accessible at the time of the last visit to the property (1946), but the engineer in charge, Mr. Roy Hammond, reported that the wall of the pipe maintained an overall vertical attitude to the bottom of the winze, about 400 feet below the tunnel. It is reported also that no bottom to the breccia pipe was found and that the breccia contained Buda limestone to the depth explored. At the tunnel level, the breccia consisted of the same rocks as at the surface, Boquillas flags as well as the older strata having collapsed to this depth.

The results of solution are conspicuous along the walls of the pipe. Surfaces that may have been formed originally by caving of Devils River limestone during formation of the breccia pipe are now pitted, rounded, and coated with calcite, some of which contains cinnabar. The breccia near the walls and locally far within the pipe is bleached and iron-stained, the Grayson formation and Boquillas flags having been affected most, whereas the Buda limestone is unaltered.

Maggie Sink pipe, in summary, is a breccia mass of unknown depth, with nearly vertical walls extending at least 600 feet below the present surface and at least 1,100 feet below the surface at the time the pipe was formed. It is filled with collapsed breccia of rocks normally overlying the Devils River limestone. Some of the breccia has moved downward at least 500 feet and probably considerably more.

TWO-FORTY-EIGHT PIPE

The breccia pipe explored by the Two-Forty-Eight mine is on the western side of the broad, low Two-Forty-Eight dome. The upper member of the Boquillas flags in the vicinity dips gently westward at angles of less than 10° and is unbroken except for the breccia pipe and fractures of less-than-a-foot displacement trending N. 65° E. and N. 20° W. These fractures belong to the regional system of northeastward and northwestward fractures and are weak here.

This breccia pipe is more thoroughly explored for a greater vertical distance than any other in the district (pls. 21 and 22). From a mine shaft more than 600 feet deep, exploratory drifts are driven along the contact of the breccia. Near the surface, the pipe is nearly circular and has a diameter of 115 feet; on the 420 level it is elliptical and has a maximum dimension, in a northerly direction, of about 200 feet (pl. 21). The breccia consists of Boquillas flags on the upper levels and intermixed Boquillas and Buda rocks below. One block, seen on the 556 level, contains the Buda-Boquillas contact and has been displaced 25 feet downward. The breccia is much like that in a caved mine stope, consisting of blocks and fragments of all sizes, oriented randomly. The contact between breccia and enclosing country rock is sharp. Blocks are in all stages of detachment and, without exception, show downward movement. The wall rocks are not dragged or bent at the contact but are broken off cleanly. This and the intermixture of rocks suggests that the pipe formed by caving block by block. Much of the breccia has a matrix of the softer shaly parts of the Boquillas flags, but some of it has open space with no matrix. In many places, calcite, hydrocarbons, and analcite are present. Locally, hydrocarbons were abundant enough in the quicksilver ore to provide the fuel for furnacing, and in some places were so abundant that they caused the furnaces to overheat.

A post-brecciation sill surrounds the pipe on the 500-foot level, having lifted the wall rocks without lifting the breccia. It fingers into the breccia and has baked the breccia along the contact. Altered, but probably similar, igneous rock is intruded into the breccia explored by the main shaft below the 556-foot level. Calcite and cinnabar occur in veinlets in the igneous rock, thus revealing a history of fracturing and mineralization after intrusion.

Some breccia fragments are softened and bleached, and here, as at Maggie Sink, the shale is affected much more than the limestone. The igneous rock is also altered and in places is completely changed to clay. The alteration of the igneous rock is most intense along the border of the pipe. Warm water and hydrogen sulfide were present in newly opened parts of the mine but were exhausted after a few days.

The breccia in the Two-Forty-Eight pipe is similar to the breccia in the Maggie Sink pipe, and the direction of displacement is the same. Also, the overall form of two pipes is similar. The principal difference between the two pipes is the presence of the igneous intrusive body at Two-Forty-Eight. This intrusion may account for part of the alteration, and certainly it is partly responsible for the structure itself, because lifting of the surrounding beds increased the displacement of the brecciated rocks from their normal stratigraphic positions and must have extended the pipe upward if it had not already reached the surface.

In summary, the geologic history of the Two-Forty-Eight breccia pipe is: (1) formation of a collapse breccia due to removal of material at depth; (2) sill-like igneous intrusion into the surrounding strata and into the breccia itself; and (3) further minor faulting and mineralization by calcite and cinnabar.

AGUJA PIPE

On the Chisos mine property 1,500 feet east of the main, or No. 8, shaft is the Aguja breccia pipe. It is in the trough of a syncline, which has an axial trend of S. 23° W., maximum dips of 30°, and a southwestward plunge. The rocks enclosing the pipe belong to the upper member of the Boquillas flags, but the breccia within the pipe is sandstone and clay of the Aguja formation. Numerous calcite veins filling fractures and faults of the regional northwestward and northeastward systems traverse this general area, and one northeast-trending vein, explored in the shallow Susano prospect shaft, cuts the breccia.

The outcrop of the pipe covers a roughly circular area 250 feet in diameter (fig. 11*A*). The walls are almost vertical where exposed and where explored by drill holes. The filling of the pipe consists of rocks of the Aguja formation, with jumbled blocks of sandstone in a clay matrix. Some sandstone blocks are very large: as much as tens of feet in diameter. Because the Aguja formation normally overlies about 1,200 feet of Terlingua clay, which rests upon Boquillas flags, the presence of Aguja rocks in a pipe surrounded by the upper member of the Boquillas flags indicates a very large displacement. The probable displacement is estimated to be more than 1,500 feet. This figure may be too high, as it depends upon the thickness of the Terlingua clay, no section of which is exposed nearby; but the displacement must be at least 1,000 feet. The known geologic history of the Aguja breccia pipe includes: formation of the breccia by collapse, and repeated movement accompanied by calcite mineralization and ending with cinnabar mineralization on at least one fracture.

Another breccia mass crops out 800 feet south of the Aguja pipe. It is enclosed in Boquillas flags, consists of fragments of the same formation, and contains an intrusive body of basalt (fig. 11*B*). A drill hole between the two breccia bodies, but closer to the Aguja pipe, passed through a 7-foot sill of similar basalt at the lower Boquillas contact 852 feet below the surface. On this evidence, the second breccia mass appears to be similar to the Two-Forty-Eight pipe; that is, it is a breccia pipe formed by collapse and later intruded by igneous rock.

CHISOS MINE PIPE

The most famous of the Terlingua breccia pipes is the Chisos pipe in the Chisos mine (pls. 19 and 20, section *C–C'*), because from it was mined the largest and most valuable single ore body in the district. This pipe does not reach the surface but was discovered in mine workings at a depth of 550 feet and was mined and explored an additional 250 feet downward. It is tangent to the Chisos fault in an area where this fault begins to fray out into a number of calcite veins along fractures with little displacement. There appears to have been minor movement along the Chisos fault after formation of the breccia. Above the breccia pipe are flat-lying Boquillas flags, undisturbed except by the Chisos fault. Below its roughly arched roof of Boquillas flags, the pipe is surrounded by near-vertical walls of Buda limestone and below that by the Grayson formation; information regarding the walls at greater depths is lacking.

The pipe, which is roughly circular and has a diameter of about 75 feet, is filled by breccia of Boquillas flags, Buda limestone, and Grayson formation, all displaced downward. The upper part of the pipe, now mined out, is reported to have been a breccia of Boquillas flags and Buda limestone with interstices filled with calcite and cinnabar. The lower part of the pipe, also mineralized in places, is mainly a breccia of Buda limestone in a matrix of Grayson formation. Warm water was found on lower levels in this part of the mine and was pumped to the surface for domestic use.

The Chisos pipe is thus an irregular vertical cylinder filled with breccia that has moved downward to its present position. As the overlying rocks are undisturbed, material must have been removed from below. This suggests solution of Devils River limestone and contemporaneous collapse-stoping, which advanced upward until brecciation increased the volume of the rock enough to support the roof.

OTHER BRECCIA PIPES IN THE TERLINGUA DISTRICT

A total of 76 breccia pipes is shown on the map (pl. 1), and their geology is summarized in table 10. They appear in outcrop as a mixed jumble of rock fragments from different strata. Some form small conical hills or low mounds because the breccia is more resistant to erosion than are the surrounding rocks; others form depressions because they are less resistant than the surrounding rocks. They commonly have a roughly circular or roughly elliptical outcrop with a preferred northeast elongation, but some are too irregular to be thus described. The oldest rock in which the breccia pipes are found is the oldest rock exposed in the district, the Devils River limestone. The youngest rock in which they have been found is Terlingua clay, but the breccia filling includes the younger Aguja formation and Chisos volcanics. The breccia pipes thus crop out not only in Devils River limestone where they are directly associated with solution features, but also in younger rocks where only mechanical collapse—and no solution—is apparent. As the Devils River limestone is the only thick limestone, the conclusion seems warranted that the pipes cropping out in younger rocks are the upper parts of pipes that extend downward into the Devils River limestone; this conclusion has been proved in some instances by mining or drilling.

The walls bounding the breccia are generally sharp and nearly vertical. They characteristically show no drag, but locally show blocks that are partially slumped into the breccia. The breccia is composed of randomly oriented fragments ranging from a fraction of an inch to

TABLE 10.—*Breccia pipes shown on plate 1*

[Breccia pipes are listed in order from west to east. Symbols: Kdr, Devils River limestone; Kg, Grayson formation; Kbu, Buda limestone; Kbol, lower member of Boquillas flags; Kbou, upper member of Boquillas flags; Kbo, undifferentiated upper and lower members of the Boquillas flags; Ktc, Terlingua clay; Ka, Aguja sandstone; Ti, volcanic rock and conglomerate of Tertiary age]

Location	Surrounding rock at surface	Observed composition of breccia at surface	Estimated displacement of fragments of youngest rock at surface (feet)
1. West of Fresno	Kbol		
2. West of Fresno, in plunging syncline.	Kbol		
3. Northwest of Fresno	Kg, Kbu	Kbu	50
4. Fresno area	Kbu	Kbo	50
5. Northwest of Fresno	Kdr	Kg, Kbu, Kbo	300
6. Fresno area	Kbu	Kbo	100
7. Do	Kbu		
8. Do	Kdr, Kg	Kbo	300
9. Do	Kg, Kbu	Kbo	100
10. Do	Kg	Kbu, Kbo	150
11. Do	Kg	Kbu	50
12. Do	Kg	Kbu, Kbo, Ti	400
13. Do	Kg	Kbu, Kbo, Ti	400
14. Do	Kg	Kbu, Kbo	200
15. Do	Kdr	Kbu, Kbo, Ti	450
16. Do	Kg	Kbu, Kbo, Ti	300
17. Do	Kdr	Kg, Kbu, Kbo, Ti.	450
18. South of Fresno area	Kg		
19. Fresno area	Kdr	Kg, Kbu, Kbo	300
20. Do	Kg		
21. County line	Kdr		
22. Do	Kdr		
23. In structural depression.	Kdr	Kg, Kbu, Kbo.	300
24. Do	Kg	Kbo	200
25. Do	Kdr, Kg	Kbo	300
26. Do	Kdr	Kg	50
27. Monocline at intrusion.	Kdr	Kg, Kbu	200
28. North of monocline	Kdr	Kg, Kbu, Kbo.	350
29. Do	Kdr	Kg, Kbu	200
30. Monocline	Kdr, Kg		
31. Downfaulted syncline.	Kg, Kbu.	Kbo	100
32. Do	Kdr, Kg	Kbo	250
33. South of monocline	Kbol	Kbo	
34. Downfaulted syncline.	Kg, Kbu.	Kbo	100
35. North of Lowes Valley.	Kdr	Kg, Kbu	200
36. Lowes Valley	Kdr	Kg, Kbu, Kbo.	300
37. South of Lowes Valley.	Kdr	Kg, Kbo	300
38. Do	Kdr	Kbu, Kbo	300
39. Do	Kdr	Kbo	300
40. Maggie Sink, on an anticline.	Kdr	Kg, Kbu, Kbo, Ti (?).	500
41. East of Lowes Valley.	Kdr	Ti (?)	
42. Monocline	Kg		
43. Mariposa, intruded by igneous rock.	Kdr	Kbu, Kbo	300
44. East of Lowes Valley	Kg	Kbu, Kbo	100
45. Mariposa, intruded by igneous rock.	Kg	Kbu, Kbo	100
46. Do	Kg, Kbu	Kbu, Kbo	100
47. Mariposa area	Kdr, Kg.	Kbu, Kbo	300
48. Southeast of Mariposa.	Kdr	Kg	50
49. Mariposa area	Kdr, Kg.	Kbu, Kbo	300
50. Southeast of Mariposa.	Kdr	Kg, Kbu	200
51. Do	Kdr	Kg, Kbu	200
52. Do	Kdr	Kg, Kbu	200
53. Do	Kdr	Kg	50
54. Do	Kdr	Kg, Kbu	200
55. Do	Kdr	Kg, Kbu	200
56. Do	Kdr	Kg, Kbu	200
57. Do	Kdr	Kg, Kbu	200
58. Mariposa road, intruded by igneous rock.	Kdr, Kg	Kbu, Kbo	300
59. At monocline	Kbu	Kbo	50
60. Northwest of Waldron mine.	Kg, Kbu	Kbu, Kbo	100
61. West of Waldron mine.	Kbu	Kbo	50
62. Southeast of Waldron mine.	Kg	Kbu, Kbo	250
63. Southwest of Little Thirty-Eight mine.	Kg	Kbu, Kbo	100
64. Southwest of Little Thirty-Eight mine.	Kdr, Kg	Kg, Kbu, Kbo.	300
65. South of Little Thirty-Eight mine.	Kbu	Kbo	50
66. Do	Kg, Kbu.	Kg, Kbu, Kbo.	100
67. Do	Kg	Kg, Kbu, Kbo.	200
68. Southeast of Little Thirty-Eight mine.	Kdr, Kg	Kbu, Kbo	250
69. North of Reed Plateau.	Kdr	Kg, Kbu	200
70. Do	Kg	Kg, Kbu	150
71. Do	Kdr	Kg, Kbu	200
72. Long Draw, along graben fault.	Ktc	Ktc, Ka, Ti	1,000
73. Aguja pipe, Chisos mine area; in plunging syncline.	Kbou	Ka	1,500
74. Chisos mine area, intruded by igneous rock.	Kbou	Kbo	
75. Two-Forty-Eight mine, intruded by igneous rock.	Kbou	Kbo	25
76. North of Two-Forty-Eight mine.	Kbou		

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tens of feet in diameter, and these fragments are displaced below their normal stratigraphic positions in every pipe. The amount of downward displacement, which can be measured most accurately where the lithologic units are thin, reaches a maximum of many hundreds of feet.

Tertiary extrusive rocks are older than the pipes in the six places where relative ages were revealed by the presence of fragments of Chisos volcanics and conglomerates in the breccia; but Tertiary igneous rocks intrude at least five breccia pipes. This evidence of pipes intruded by igneous rocks is conclusive in the Two-Forty-Eight pipe and also in some of the Mariposa pipes. In one of the latter, for example, the intrusive igneous rock forms a matrix for a mixed jumble of blocks of the Buda and Boquillas formations on one side of the pipe. Around the intrusive rock is a halo of baked breccia and wall rock. Thus the collapse and intermixture of the Buda and Boquillas must have preceded the baking resulting from intrusion.

The distribution of the breccia pipes that have been found is not uniform (pl. 1); the majority are in the outcrop area of Devils River limestone. There are probably two reasons for this. First, some pipes like the Chisos pipe, may never have reached the surface, and the known breccia pipes are thus most numerous in the area of Devils River limestone because this is the area of deepest erosion. Second, the stratigraphic units immediately overlying Devils River limestone are thin and distinctive, and pipes in the Devils River therefore contain foreign fragments that make recognition of the pipe easy. This is not true of higher stratigraphic horizons.

ORIGIN OF SOLUTION FEATURES

Because of their general association, the caverns, cave-fill zones, and breccia pipes are thought to be contemporaneous features caused by solution of limestone. Although they may have formed over a long period of time, many are definitely older than the quicksilver ore, and several are older than igneous intrusive bodies. On the other hand, several breccia pipes contain fragments of the overlying stratified Chisos volcanics (tab. 10), indicating that these pipes formed after deposition of the Chisos, but before deposition of the cinnabar found in them. A possible explanation of the association between igneous activity and pipe formation is that many of the solution features were formed during the period of volcanism and hydrothermal activity.

Most solution features exposed at the surface or in mine workings are now above the ground-water table and are dry but caverns and cave-fill zones are found in the Chisos mine below the present ground-water table, which is about at the altitude of the Rio Grande. The Chisos pipe extends at least a hundred feet and the Two-Forty-Eight pipe, several hundred feet below the water table. Furthermore, the water table must have been higher before the streams had cut to their present depths. The solution features were therefore formed at least partly below the water table. This is in agreement with theories of origin of limestone caverns proposed for other regions (Davis, 1930, p. 548–550) and is in agreement with the fact that the flow of ground water is not restricted to a zone near the water table (Hubbert, 1940, p. 926).

The possibility remains that some of the solution features are products of thermal waters rather than of normal cold ground water. During the time when the Chisos volcanics were being deposited and the numerous intrusive rocks were being emplaced, normal ground water must locally have been heated and augmented by magmatic constituents. The ability of hydrothermal solutions to form caverns was recognized by Davis (1930, p. 487) who says, "In regions that are invaded by volcanic magmas it is believed that warm juvenile water and carbon dioxide may ascend toward the earth's surface. This rising addition to descending ground water of meteoric origin would probably give it a great increase in solvent power while the mixture is still deep underground." Walker (1928) states that some of the caves at Tintic were formed by ascending hot water. In the Terlingua district, an enormous volume of coarsely crystalline calcite is present in veins. If this calcite was extracted from limestone, the most logical source, and deposited in veins closer to the surface, caverns must surely have formed in the limestone.

ORIGIN OF THE BRECCIA PIPES

The breccia pipes are remarkable for their vertical cylindrical form, their breccia consisting of mixed fragments from various formations, and their great penetration into noncalcareous rocks. They differ from caverns and cave-fill zones in all of these characteristics and thus present a special problem of origin.

A mechanical process of breaking off and slumping was evidently essential in forming the pipes. The chemical process of solution was effective only in the Devils River limestone, for younger calcareous rocks, like the Buda limestone and calcareous layers in the Boquillas flags, are interstratified with shales of low permeability and are thus generally isolated from solvent waters. Any suggestion that the pipes were violently blasted out, a process that may seem attractive because of the large amount of breccia and its proximity to igneous activity, is clearly ruled out by the lack of any fragments moved upward and by the termination of the Chisos pipe, whose top lies 550 feet below the present surface. The pipes therefore seem to represent the slumping that would be inevitable above caverns that grew so broad that their roofs could no longer stand.

The roughly cylindrical shape of the pipes is a natural form resulting from collapse, as shown by ordinary sinkholes in limestone. Sinkholes in noncalcareous rocks several hundred feet above limestone are known on the Cumberland Plateau near Chattanooga, Tenn. (Stockdale, 1936, p. 515–522; Laurence, 1937, p. 214–215). The sides of the pipes appear nearly vertical but more precisely the sides probably converge gradually upward in the form of a very high arch; this convergence is evident in the Two-Forty-Eight pipe (pl. 22). Similarly in mining practice, the walls of block-caved stopes generally stand nearly vertical (Gardner, 1930, p. 11). The circular or oval horizontal cross section of pipes is explained by the tendency of caverns to collapse only at their broadest parts, leaving corners and narrower spans intact. Joints and other irregularities cause some modification of the ideal shape (pl. 21).

The mixing of fragments from different formations, which is a characteristic of the action of most of the pipes, can best be explained by contemporaneous slumping from two or more formations into a large opening near the top of the pipe; the mixing thus gives some indication of how the pipes developed. The process may be pictured as follows. (1) A cavern in the Devils River limestone becomes so broad that large blocks begin to peel from its roof. Because the broken material occupies more volume, the opening below the roof tends to become smaller as the roof moves upward, but contemporaneous solution of the limestone breccia may keep the opening large. (2) When the roof reaches the weak Grayson formation, the clay slumps rapidly and may temporarily fill the opening. (3) When the Buda limestone is reached, an opening may again form below this thin but strong rock, and as the arch grows upward, blocks of Buda limestone and Boquillas flags peel from the sides and top of the arch to form the characteristically mixed breccia of these rocks. (4) As the top moves farther up into the Boquillas flags, the supply of breccia may come entirely from this thick formation, as in the upper part of the Two-Forty-Eight pipe. The mixture of rocks in the breccia may alternatively be explained by slow turbulent stirring of the mass of breccia as it slides downward, without the existence of a large opening at the top, but the degree of turbulence that would be required seems unlikely.

The diameter of a breccia pipe is controlled to a large extent by the strength of the rocks. Pipes are commonly from 100 to 300 feet in diameter but some are as small as 50 feet and some are larger than 300 feet. Openings as wide as 50 to 100 feet are maintained indefinitely in large caverns and old mine stopes in the Devils River limestone. The upper size limit of permanent openings is perhaps 300 to 500 feet, as indicated by the size of the pipes themselves; openings as large as this inevitably collapse to form pipes. Caverns formed at the top of the Devils River and having a roof of clay of the Grayson formation are filled by collapse of the weak roof before the opening can grow wide; mine stopes as wide as 50 feet in dry clay of the Grayson formation are filled by blocks falling from their roofs in a period of a few years, and the process is much more rapid where the clay is wet. This weakness of the clay of the Grayson formation explains the cave-fill zones. Caverns with roofs of the clay can never become broad enough to form breccia pipes but are filled by slumping clay and residual blocks of limestone as they form; caverns with roofs of limestone may become very wide. None of the rocks younger than the Devils River limestone can maintain so broad an arch as it, and once collapse begins in this limestone, a pipe grows upward as long as space is available below.

The amount of rock dissolved to form a breccia pipe is large. Assuming the rocks expand 25 percent by brecciation, the rocks dissolved must be 25 percent of the volume of the pipe. The large pipes must therefore have formed above the floors of very large and extensive caverns or, perhaps more likely, solution of limestone continued actively during the growth of the pipes. As long as solution continued, the pipes continued to grow and penetrate farther upward.

COMPARISON WITH BRECCIA PIPES AND DIATREMES IN OTHER REGIONS

Cylindrical bodies of breccia are by no means rare, and several explanations for them have been proposed. Most explanations fall into one of two general classes: (1) subsidence owing to solution of limestone or other soluble rocks, or owing to hydrothermal alteration; (2) an explosive origin, commonly followed by subsidence. It may be difficult to determine which explains some pipes.

The filled sinks of southern and central Missouri are very numerous, and in many ways they resemble the Terlingua breccia pipes (Tarr, 1919, p. 830–841; Grawe, 1945; Bretz, 1950). They are generally regarded as products of solution by ordinary ground water, accompanied or followed by subsidence of overlying rocks. Some of the filled sinks contain pyrite, galena, and sphalerite; this association of metallic minerals with the sinks has not been satisfactorily explained.

In southeastern Missouri there are many breccia pipes similar in size and form to the filled sinks just described. Igneous rocks have intruded the breccia in some of them, and for this reason the pipes of southeastern Missouri have been ascribed to explosive volcanism. In describing them, Rust (1937, p. 61) says, "It is very common to find limestone fragments carrying Devonian fossils in a rock which also contains an abundance of granite inclusions. The granite pieces have come up several hundred feet and the Devonian fossils are at least 3,000 feet below their source beds. These two rock types, normally separated by about 4,000 feet of sediments, are found side by side at the intermediate Cambrian horizon of the area." Rust explained these conditions as being due to explosions, following which magma rose into the debris-choked explosion tubes, incorporating the debris in the tubes. In the same area, an ultrabasic intrusive body of pipelike form has been described by Singewald and Milton (1930, p. 54). The intrusion has a slightly elliptical outcrop with the longer axis measuring 200 feet; drill holes indicate that it is about vertical. The surrounding Bonneterre dolomite is brecciated and metamorphosed at the contact, and the borders contain calcite, galena, sphalerite, marcasite, chalcopyrite, pyrite, and smoky quartz. Singewald and Milton believed it analogous to a diatreme in origin.

Many mineralized breccia pipes have been reviewed by Locke (1926), who attributed them to "mineralization stoping" in both calcareous and noncalcareous rocks. The process is described as "removal of rock along trunk channels by rising solutions during an early stage of their activity, collapse and brecciation of the rock thus left unsupported, and deposition of ore and gangue minerals in the brecciated mass." In some of Locke's examples, the breccia has a measurable downward displacement. Furthermore, he cites two examples of breccia pipes in which "the actual downward terminations are visible; there is a rapid convergence of the walls forming a rude keel below which the silicified breccia descends only in irregular protuberances. No intrusive plug appears in either case and the hypothesis that such a plug has advanced and retreated is inadmissible." (Locke, 1926, p. 446–447.) Locke's postulation of hydrothermal solutions has the advantage of explaining the close association of metallic deposits with some breccia pipes.

Some of the pipes cited by Locke as products of "mineralization stoping" are listed by W. H. Emmons (1938) as examples of diatremes. Emmons has assembled comparative data on a large number of pipes, and he interprets most of them as diatremes or incipient diatremes, blown through the rock by gases. The structures included in his discussion range from vein systems believed to represent incipient diatremes to volcanic necks. The material within at least one of the pipes is below its normal stratigraphic position; in most of them the direction of displacement is not given. Limestone occurs in some of the areas containing pipes.

Volcanic necks and the South African diamond pipes attracted the attention of the great French experimenter Daubrée, who introduced the term diatreme (Daubrée, 1891). In his experiments Daubrée used a device consisting of a central chamber containing dynamite or guncotton and a subsidiary chamber at one end containing a cylinder of the rock to be tested, through which the explosion gases had to pass in order to escape. The explosives developed pressures of 1,100 to 1,700 atmospheres and temperatures of 2,500° to 3,200°C. The duration of the explosions ranged from 0.00002 second for guncotton to 0.003 second for dynamite. Each cylindrical rock had been cut in such a way that a natural crack occupied a diametral plane or else a tiny hole had been drilled along its axis. The purpose of using a crack or drilling a hole was to concentrate the explosive action and thus prevent a blowout around the outside of the rock cylinder. The holes produced by the explosion had a roughly circular or elliptical cross section. In a rock cylinder having a diametral crack the exploded hole was zig-zagged like a lightning streak within the plane of the crack. In a cylinder with a drilled guide-hole the exploded hole was fairly straight. Some of the material blown out of the holes was fused and some was clastic. It is worth emphasizing that in these experiments the holes were not punched out but eroded out: the gases began to leak along a crack or hole, which was rapidly and violently enlarged by tearing and melting away of small pieces. Daubrée concluded that the effectiveness of high-pressure, high-temperature gases in producing openings was proved, and he felt that the experimental results were directly applicable to the formation of the South African diamond pipes and to volcanic necks.

There are many excellent examples of breccia pipes associated with volcanic activity in northeastern Arizona (Hack, 1942). They occur in a dense cluster covering about 800 square miles, but some are far removed from the cluster. Their diameter generally decreases downward, and the more deeply dissected pipes range in diameter from 500 to 3,000 feet. The filling is largely of pyroclastic material and it generally shows evidence of inward and downward slumping. The pipes are thought to be due to explosive volcanism and are called diatremes.

The pit craters of Hawaii (Wentworth and Macdonald, 1953) afford an interesting example of pipes associated with volcanic activity but due entirely to subsidence, without explosion. They are circular to ellipsoidal open pits that range in size from 100 feet to more than half a mile across and from less than 50 to 800 feet deep. Their walls are almost vertical. They are thought to be formed by collapse resulting from the withdrawal downward of underlying magma.

Many other examples of pipelike structures could be given, but these are sufficient to indicate the diversity in origin of features that appear superficially similar. Subsidence is clearly an adequate process to form pipe-shaped openings or masses of breccia; an explosive origin is not indicated by the shape alone. The term "diatreme" should be modified or applied only to pipes where there is clear evidence of formation by explosion. Pipes formed originally by subsidence and later intruded by igneous rocks may contain blocks pushed up from below, or intermixed blocks from above and below, without ever having been subjected to explosion.

THEORETICAL PROBLEMS

AGE OF THE STRUCTURES

If our knowledge of the timing of structural events were complete and precise, we would derive directly a deep insight into their origin. This ideal can only be approached, because chronological evidence is fragmentary and incomplete.

The earliest major structural movement after deposition of Cretaceous rocks was the beginning of the rise of the Terlingua uplift. Evidence for this is found on the flank of the uplift near the Fresno mine, where Chisos volcanics rest with angular unconformity on the lower member of the Boquillas flags; the hiatus decreases away from the uplift. Similar evidence can be seen on the north flank of the Solitario dome (Erickson, 1953, p. 1385), where additionally the thick volcanic sequence thins and becomes conglomeratic against the flank of the dome, indicating continued uplift during deposition of the volcanics. The absence of the Aguja formation and Tornillo clay at these localities is due either to nondeposition or to erosion; the former would imply that uplift began in late Cretaceous time, as Erickson assumes, but the possibility of erosion is consistent with uplift beginning in Cenozoic time before deposition of the volcanic rocks. The volcanic rocks have been identified elsewhere by fossils in the tuff beds as being Eocene and Oligocene (King, 1937, p. 117, quoting Baker, Bowman, Berry, and Plummer). McAnulty (1955, p. 556) found vertebrate fossils that indicate a late Eocene age in the lowermost tuff, sandstone, and conglomerate beds in the Cathedral Mountain quadrangle. Erickson's finding of continued uplift of the Solitario dome during deposition of the volcanic rocks is consistent with the evidence in the Marathon area, where King (1937, p. 140) observed anticlines in which the presence of volcanic rocks lead him to conclude that a considerable part of the uplift of the Marathon dome took place after the volcanic eruptions in Tertiary time. The Terlingua uplift thus began to rise sometime between Late Cretaceous and Late Eocene times, and it continued to rise for an unknown length of Tertiary time.

The large normal faults appear to have formed contemporaneously with the Terlingua uplift. This conclusion is based on a genetic interpretation of the relations between the Terlingua uplift and the large grabens; the grabens die out at the Terlingua monocline (fig. 7), strongly suggesting a time relation as well as space relation between the faulting and the doming. In the Marathon area King (1937, p. 140) judged the normal faults to be later than the folds because the folds are cut across and displaced by the faults, but this evidence is equally consistent with contemporaneity of the faults and folds. A parallel may be drawn with the normal faults around salt domes: are the normal faults later than a salt dome because they cut across it? On the contrary, the salt dome and faults are clearly contemporaneous and interrelated. Further support for the probable contemporaneity of faults and domical uplifts in the Big Bend region has been derived from a study of air photographs of the region. These show many smaller domes that are bounded partly by monoclines and partly by faults, an arrangement that suggests the response to lifting was partly by doming and partly by simultaneous faulting.

Intrusive igneous activity, which is intimately related to the structural development, is both older and younger than individual normal faults and hence is roughly contemporaneous with normal faulting. The faults of Long Draw have served as channels for intrusive bodies (exposed in the Chisos mine), and later movements on these faults have displaced the same bodies. The southwestern fault of the Cigar Mountain graben cuts a small intrusion and is in turn intruded by the Cigar Mountain laccolith (pl. 1). Intrusions south of Sawmill Mountain also invade faults. The Cuesta Blanca dome is perhaps a good example of a laccolithic dome that formed by faulting on one side and doming on the other sides, while magma rose within it. Because many minor faults and some breccia pipes have also been intruded by igneous rock, these smaller structures also appear to belong to the period of igneous activity.

In summary, the Terlingua uplift began to develop in Late Cretaceous or early Tertiary time. It continued to rise during the extrusive volcanism in the Tertiary. About the same time, normal faulting and igneous intrusion were taking place. The duration of this structural period is not known, and it may have continued throughout a large part of the Cenozoic era.

The subsequent geologic history of the district is mainly one of erosion modifying the surface of a structurally quiescent area, which, however, may have been subjected to regional tilting and uplifting.

ANALYSIS OF MOVEMENTS

Have the rocks in the Terlingua district undergone horizontal compression during their structural evolution or alternatively have they been extended? Whence came the added volume of material beneath the domes and uplifts? An attempt to answer these questions depends upon accurate geologic data from the surrounding region, and such data are available only in part.

The added material beneath the uplifts is believed to have come from parts nearby of the Big Bend region. On the west side of the Chisos Mountains and extending northwestward to the Terlingua uplift is an area where Cretaceous strata are structurally some 3,000 to 4,000 feet below their average altitude in the Big Bend region (King, 1937, pl. 22). Yet in the Solitario dome, the same strata are roughly 3,000 feet above, and in the Marathon uplift 4,000 feet above, their average altitude. This clearly suggests that the Terlingua uplift and Solitario dome and in part the Marathon uplift are complementary to the structurally low area—that material at depth has moved from the low area to form the structurally high. Such mobility seems possible only by melting, which is reasonable in view of the widespread igneous activity in the region.

Estimates of horizontal compression or extension lead to the tentative conclusion that the Terlingua district as a whole has been neither compressed nor extended but has maintained a nearly constant area. Measurements of horizontal compression or extension have sometimes been made on geologic cross sections by unfolding and unfaulting the structure and observing the change in length. A more suitable method for the Terlingua district, where the trends of the folds and faults are diverse, is to estimate the changes in area. Thus the increase in area owing to normal faulting is the sum of the areas obtained by multiplying the length of each fault segment by the horizontal component of dip slip applicable to that segment. Similarly, the decrease in area owing to folding is the difference between the area of a deformed stratigraphic reference surface and the area of the horizontal projection of the same surface. The net increase or decrease in area (areal extension or compression) is the difference between the extension on normal faults and the compression on folds. Strike-slip movement on faults has no effect on the calculation.

The analysis was applied to the part of the Terlingua uplift that lies in the Terlingua district. The reduction in area, which is almost entirely along the Terlingua monocline, was estimated by measuring the shortening in a series of sections across the monocline, multiplying each value by the applicable length along the monocline, and then summing the areas so obtained. The reduction in area along the monocline from Long Draw to the western end of the district is about 1.4 square miles. Similarly, the extension in area along the faults of the Long Draw graben is 0.6 square mile if an average dip of 80° is assumed, or 1.2 square miles, assuming an average dip of 70°; the intermediate value, for a dip of 75°, is 0.9 square mile. The other faults on or adjacent to the Terlingua uplift, taken together, probably contribute about an equal amount to the extension. It thus appears that the extension by faulting is about equal to the reduction by folding and the net extension or compression of the Terlingua uplift is near zero.

The calculations are of course very rough but serve to indicate that a balance between extension and compression is at least a possibility. Another test may be applied in the area where the Terlingua monocline and the Long Draw graben are parallel and close to each other. The extension on the graben, measured on section *A—A′* (pl. 1), is 1,100 feet and the shortening on the fold is 800 feet. If the faults are a little steeper than the 70° shown, the two figures would correspond exactly. The extension on faults for the entire length of section *A—A′* is 1,600 feet, and the shortening on folds is 1,100 feet. Again, if the faults are a little steeper than shown, the two figures would be the same and the net extension or compression would be zero.

ORIGIN OF THE TERLINGUA UPLIFT AND TERLINGUA MONOCLINE

The Terlingua uplift and the high circular dome of the Solitario, which forms the crest of the uplift, exhibit the form of a bulge that might be raised by a mobile igneous mass. An igneous origin for the Solitario dome was inferred by several earlier observers (Lonsdale, 1940, p. 1546). Details of the suggested igneous mass are completely speculative, however, for no intrusive body of requisite size is exposed in the Solitario, where erosion has laid bare all of the rocks down to the crumpled and thrust-faulted rocks of Paleozoic age. As an example of the kind of intrusive mass that might underlie the uplift, the Pilansberg complex might be chosen. This complex of basic, soda-rich rocks is superimposed on the Bushveld complex in the western Transvaal; it has been interpreted as a laccolith (Shand, 1929, p. 149). It covers about 200 square miles and has a probable thickness of 2,000 to 3,000 feet; the Terlingua uplift covers more than 100 square miles and has a structural relief of several thousand feet.

The Terlingua monocline, which forms the abrupt southern and southwestern margin of the uplift and also extends eastward beyond the uplift, is parallel in its western part to the anticlines of the Sierra Madre Oriental farther west (fig. 5). In its eastern part, however, it corresponds in trend with neither these anticlines nor the older Paleozoic folds exposed in the Marathon uplift and the Solitario; no control for its east-west strike is obvious. The monocline evidently marks the edge, or a line of abrupt thinning, of the igneous mass postulated beneath the Terlingua uplift; it may be compared with the monoclinal fold over the southern edge of the Study Butte intrusive body (fig. 3).

ORIGIN OF THE GRABENS

The magnitude and shape of the large grabens strongly suggest that, when they formed, material much more mobile than ordinary rocks was present at a depth no greater than a few miles. The faults bounding individual grabens, if extended downward on the dips measured at the surface and in mines, converge rapidly and join at depths of only about a mile. The faults of the Long Draw graben, projected downward at 70° (sec. *A—A′*, pl. 1), join at a depth of 1 mile; projected at a dip of 80° they join at a depth of 2 miles. The graben is only half a mile wide, yet its vertical displacement reaches a magnitude of more than a quarter of a mile. These relations, particularly the convergence of the faults, may well be explained by magma beneath the grabens at the time they formed. Dilation of the crust by thick dikes below the grabens might be suggested or, alternatively, the large body of igneous rock already postulated to explain the Terlingua uplift may lie approximately at the depth where the graben faults converge.

Compared to the other large grabens, the Lowes Valley structure is distinctive because of its irregular outlines, its large displacement, the broken-up character of the rocks in it, and its possibly closer association with igneous activity. Space for the downfaulted rocks could possibly have been provided by solution of limestone or withdrawal of magma. The second possibility suggests a comparison with calderas or with cryptovolcanic structures (Williams, 1941). Grabens along rift zones on the Hawaiian shield volcanoes are described by Wentworth and Macdonald (1953, p. 11, 14). They also note that there are all gradations between pit craters and grabens. The northeast trend of Lowes Valley and the entire Black Mesa graben zone is nearly at right angles to the other major grabens but parallel to the structures formed during Paleozoic time and are now exposed in the Solitario; perhaps the trend of the younger structure was influenced by the earlier.

Many structural depressions other than grabens are evident on plate 1. These include saucer-shaped structural basins, like the one east of the Fresno mine, and irregular downfaulted blocks, like the Mariposa mine area. Some that are small and composed largely of jumbled blocks have been mapped as breccia pipes but are actually larger and more irregular than typical breccia pipes. Perhaps many of these structures, like the Lowes Valley structure, were caused by withdrawal of support in an underlying magma.

The large grabens are thus regarded as interrelated in time and space with the Terlingua uplift and with igneous activity. Their development may be pictured as similar to the development of rifts in regions of present igneous activity. In Hawaii, tumescence of the volcanoes amounting to several feet of uplift is observed preceding and during eruptions, and subsidence after eruptions (Wentworth and Macdonald, 1953, p. 14). At depth the Hawaiian rift zones are occupied by hundreds of dikes (p. 11), representing a large horizontal extension of the strata. An alternation of tumescence and lesser subsidence, repeated many times through a long period of geologic time, is clearly capable also of explaining many details such as the minor thrust faults in the Terlingua district.

A small graben in the Fresno mine area, although not comparable in size with the principal grabens of the district, is significant because of the quantitative information on origin that can be obtained from a study of it. It was caused by the deflection in dip of a single master fault (fig. 12). This fault, which bounds the graben on the north, has a dip of about 80° in the

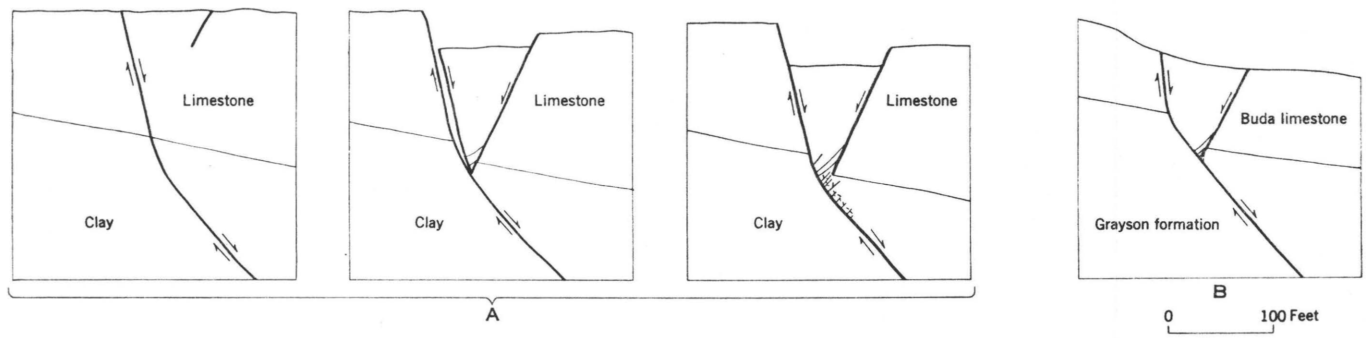


FIGURE 12.—*A*, Vertical sections showing theoretical stages in the development of a small graben caused by the flattening in dip of a normal fault. Stages 2 and 3 occur simultaneously but are separated for clarity. *B*, Vertical section of the Fresno graben.

Buda limestone and about 50° in the underlying Grayson formation. During the dip-slip movement of 20 to 50 feet on this normal fault, the part of the fault in the Buda limestone tended to open; this allowed a segment of the Buda limestone, bounded by a new fault on the south, to slide into the potential opening. Cross sections of the graben and theoretical sections showing its origin are given in figure 12. The development of the large grabens cannot be exactly similar, because, with the exception of the Long Draw graben, the displacements on the two sides are equal.

QUICKSILVER DEPOSITS

HISTORY AND PRODUCTION

This section on "History and production" except the part "World War II" is condensed from a manuscript report by Clyde P. Ross. Ross gathered his information and data from works listed in "Selected bibliography" and from local mining men, particularly W. D. Burcham, Jack Dawson, Frank Lewis, H. E. Perry, and E. A. Waldron.

EARLY ACTIVITY

Local stories relate that Indians passing through the district going to and from Mexico collected cinnabar and used it as a pigment. Pictographs at camping places have suggested such a use and have inspired the stories. Ross collected a sample of a red pigment from a pictograph at Comanche Springs, an old camp site, 3 miles northeast of Lajitas, and had the sample tested by Efe Daggett of the Chisos Mining Co. The pigment was found to contain no appreciable quicksilver.

The very early history of quicksilver discovery and mining is not well recorded. According to Phillips (1905, p. 155) reports of the presence of cinnabar in the Terlingua region began to trickle out as early as 1850. Mexican miners passing through the area in the seventies and later are thought to have known about the presence of quicksilver. It is reported that a merchant from Presidio named Klineman took up claims near California Mountain about 1884. There is definite knowledge that by 1894 there was some mining in the area, for Blake (1896) reports that early in 1894, George W. Wanless and Charles Allen, hearing of the deposits through reports of Mexicans, visited the area and began work in the vicinity of California Mountain. Thomas Golby (1924, p. 579–580) reports that he found ore in the same locality in 1896. Several other Americans including Jack Dawson, J. A. Davies, and Louis Lindheim began mining at and close to California Mountain about this time. This last named group of men set up a battery of retorts and may have been the first producers of quicksilver in the district.

About 1898 at the mining settlement that had grown about California Mountain a post office was established and named Terlingua. The exact origin and meaning of this name is unknown. It is locally supposed to be a corruption of some early Mexican name, such as Tres Lenguas, that had been applied to some local feature. By 1903 there were about 3,000 people in this settlement. As more discoveries were made, the mining center shifted further to the east and this resulted in the transfer of the post office and its name to the settlement at the Chisos mine. The retention of the name Terlingua by the post office caused the original settlement of Terlingua to lose its name and acquire a new name—Mariposa. References to "Terlingua" in early reports refer to the locality that is now known as Mariposa; in this report "Terlingua" refers to the settlement later built around the Chisos mine.

About 1900 Golby and associates erected a 10-ton Scott furnace at California Mountain and began production. By 1901 this operation was known as the Marfa and Mariposa Mining Co. and was composed of two Norman brothers, Montroyd Shayse, and Thomas Golby. This company continued mining until 1910 and although their operations were mainly about California Mountain (the Mariposa mine of this report), their property extended well beyond this area and ore was mined as far away as 2 miles to the northeast (sec. 38, Block G–12). Although no accurate records for individual mines were available, it is estimated with fair assurance that between 20,000 and 30,000 flasks of quicksilver have been produced from the workings about California Mountain.

Another early operation in this general area was in and near the southeast corner of sec. 40, Block G–12. From 1901 to 1906 this group of claims was worked by the Terlingua Mining Co. A Scott furnace with a capacity of 40 to 50 tons of ore a day was built, but judging from the dumps of "burned" ore it was not long in operation.

By 1900 cinnabar had been discovered near the present town of Terlingua. By April of 1902, the McKinney-Parker mine (McKinney-Parker workings of the Chisos mine) had yielded a considerable quantity of ore from some of which a small quantity of quicksilver had been retorted. This mine was located about one-fourth mile southwest of Terlingua. According to Hill (1902, p. 38) there were in 1902 numerous openings to the northeast of the McKinney-Parker mine showing the presence of cinnabar. This would be at the site of the present Chisos mine, which is supposed to have begun operations about this time. The Chisos mine soon became the principal producer in the district and until 1942 was in almost continuous operation. Before 1904 the ore was retorted, but that year a 20-ton Scott furnace was put into operation on the property and used almost continuously until 1942.

About the same time quicksilver was discovered near Terlingua, it was found farther east at what is now called Study Butte, in sec. 216, Block G–4 (Study Butte mine) and in sec. 248, Block G–4 (Two-Forty-Eight mine). Hill (1902, p. 13) reports these discoveries as of January 1902. In sec. 216 the Big Bend Mining Co. began operations in 1903 and the Texas-Almaden Co. began soon afterward on adjoining ground. Big Bend built a 50-ton Scott furnace, and Texas-Almaden built a 20-ton Scott furnace. These furnaces shut down after only a few hundred flasks of quicksilver had been produced. In 1905 or 1906 both companies ceased operations and the properties remained idle for about 10 years.

WORLD WAR I PERIOD

For several years before World War I the Chisos mine was the only significant mine in the district. The increase in price resulting from the war revived operations in the district, and several of the old properties returned to production. By a fortunate coincident, the Chisos mine was able to take maximum advantage of the price increase, because they had just begun to stope the largest ore body in their history. This, the Pipe stope, was mined from 1915 through 1918, and ore from it was treated in the Scott furnace. A rotary furnace was installed and operated on low-grade ore from 1918 until 1922, when it was judged unsatisfactory and its use discontinued until 1942.

Among other mines that reopened were Mariposa and Colquitt-Tigner. The Rainbow mine was opened in 1916, after a shaft was sunk to a depth of 624 feet. The Mariposa mine was reopened in 1916 and operated until 1919, during which period it produced around 8,000 flasks of quicksilver. The old Colquitt-Tigner mine was reopened and produced a little quicksilver in 1916.

In 1915 the (Texas Almaden and Big Bend) properties at Study Butte were reopened and worked as a unit until 1920. About $500,000 worth of quicksilver was produced during this time. Lower prices and a water problem on the lower levels brought an end to mining.

INTERWAR PERIOD

The postwar depression of the early twenties with its unfavorable market conditions caused the suspension of all mining activity except that at the Chisos mine. F. W. Oakes, Jr., became interested in the district about 1923 and in time acquired control of many of the properties in the western part of the district, including the old Marfa and Mariposa property. By 1927 he was producing quicksilver in retorts and the following year he built a 30-ton rotary furnace, which, upon Oakes' suspension of activities in 1930, was moved to the Study Butte mine.

In 1931 the Tarrant Mining Co. acquired control of much of the property that was operated by Oakes. They carried out some development at several places, notably in sec. 39, Block G–12, in sec. 70, Block 341, and on the Monte Cristo claim northwest of the Mariposa mine. They produced their first quicksilver in August 1933 mainly from ore from the Monte Cristo claim.

In 1928 the Waldron Quicksilver Properties, Inc., began development at the Colquitt-Tigner property on sec. 38, Block G–12. They operated a 12-ton Scott furnace from December 1926 to August 1927, when they had to shut down, partly because of law suits. This furnace was not operated again until 1936. During the intervening period the operations of the company were fairly inconsequential.

The old Rainbow mine near Terlingua was reopened by a new company in 1927. In 1934 a 10-ton rotary furnace was operating on fairly rich ore.

In 1928 the Study Butte mine was reopened under lease by the Brewster Quicksilver Consolidated, the beginning of its period of longest operation. During most of the following years the mine was in curtailed production, because the low price of quicksilver did not permit the pumping of the flooded lower level of the mine. However, W. D. Burcham, who was general manager from 1928 to 1934, estimates that about $400,000 worth of quicksilver was produced during these years. In 1936 there was a reorganization and a company known as the Southwest Mines took over control.

WORLD WAR II PERIOD

The increased demand for quicksilver during World War II stimulated renewed activity in mining and prospecting. The Study Butte mine, which was a steady producer, was deepened and extended. Mining was carried on from the Big Bend and Dallas shafts and shallow shafts north of the butte. The Big Bend shaft was sunk to the bottom of the Study Butte sill at a depth of 440 feet. The Chisos mine was active sporadically, and most of the ore came from the 250-foot level near the No. 8 shaft. Some ore was brought from the lower levels of the No. 9 shaft during the early war years. Prospecting and development work was carried on also in the No. 14 and Susano Prospect shafts on the Chisos property. A considerable amount of quicksilver was recovered from dismantling and treating the old Scott furnace at the Chisos mine. The Two-Forty-Eight mine was deepened and explored extensively. A Herschoff furnace was installed, but production remained small. The Mariposa mine was worked at intervals and the ore hauled to the Chisos and Two-Forty-Eight mines for treatment. Production came from shallow open cuts; some material from old dumps was furnaced also. During the latter war years the Chisos, Two-Forty-Eight, and Mariposa mines were operated by one company, the Esperado Mining Co.

The discovery and development of what is now the Fresno mine by Harris S. Smith and his partner, Homer Wilson, was perhaps the outstanding event of this period. The development of the Fresno mine extended the belt of productive deposits about 6 miles westward. The Fresno mine became a steady producer from an ore body less than 100 feet below the surface.

The most extensive additional exploration was carried on at Maggie Sink and Contrabando dome. At Maggie Sink an adit was extended to intersect the breccia pipe at a depth of about 150 feet, and from this level a winze was sunk several hundred feet deeper; no ore was discovered. At Contrabando dome, cinnabar showings were explored by pits and shallow shafts around several small rhyolite intrusions.

With falling quicksilver prices, all the mines had closed by 1947.

SUMMARY OF PRODUCTION DATA

Reliable information on the production of individual mines in the Terlingua district is both rare and unsatisfactory. Some production information—whatever is available—is given under the descriptions of the individual mines. Judging from the annual statements in "Mineral resources of the United States" and estimates made by H. E. Perry, W. D. Burcham, and others for the particular property in which they are interested, it appears that the total production of the Terlingua district is approximately 150,000 flasks.

Table 11 was compiled by C. P. Ross from tables given in "Mineral resources of the United States" and, for recent years, the "Mineral yearbooks." The entire production of Texas as given in these reports is to be credited to the Terlingua and Mariscal districts. At best these figures would be minimum figures for the early years when there was probably considerable unrecorded production. Since 1922 the production of Texas has been combined with certain other States, but in general the quantities produced by these other States has been small. Production from 1938 through 1944, which is not given in table 11, averaged 1,132 flasks per year.

TABLE 11.—*Quicksilver production of Texas*

[Compiled by C. P. Ross]

Year	Number of flasks	Price per flask at San Fransisco	Year	Number of flasks	Price per flask at San Francisco
1899	1,000	$47.70	1919	5,019	$90.29
1900	1,800	44.94	1920	3,436	79.66
1901	2,932	48.46	1921	3,283	47.42
1902	5,319	43.20	1922	2,970	57.78
1903	5,029	45.29	1923	[1] 2,490	65.68
1904	5,336	43.50	1924	[2] 2,119	68.69
1905	4,723	36.22	1925	[3] 1,560	82.67
1906	4,761	39.50	1926	[4] 1,224	91.60
1907	3,686	39.60	1927	[4] 2,423	117.61
1908	2,382	44.17	1928	[5] 4,316	125.34
1909	4,188	45.45	1929	[4] 3,725	124.00
1910	3,320	46.51	1930	[4] 2,822	[10] 115.01
1911	2,326	46.01	1931	[6] 3,711	[10] 87.35
1912	1,990	42.05	1932	[6] 4,046	[10] 57.925
1913	2,750	40.23	1933	[7] 4,010	[10] 59.227
1914	3,144	49.05	1934	[8] 3,059	[10] 73.87
1915	4,417	85.80	1935	[8] 4,191	[10] 71.99
1916	6,306	125.89	1936	[7] 4,010	[10] 79.92
1917	10,791	105.32	1937	[9] 3,514	90.18
1918	8,451	117.50			

Total flasks produced 146,579

[1] Plus Nevada, Oregon, and Idaho.
[2] Plus Nevada, Arizona, Oregon, and Idaho.
[3] Plus Nevada, Arizona, and Idaho.
[4] Plus Arizona and Alaska.
[5] Plus Washington and Arizona.
[6] Plus Arizona, Arkansas, and Alaska.
[7] Plus Arkansas, Washington, and Utah.
[8] Plus Arizona.
[9] Plus Arkansas, Arizona, and Washington.
[10] New York price.

FUTURE OF THE DISTRICT

The future of the Terlingua quicksilver district depends largely upon exploration. With the exception of the Study Butte mine, known ore bodies are largely exhausted. Under the stimulus of the high prices of World War II the district responded with considerable exploration, but few ore bodies were discovered. This exploration did not, however, exhaust the possibilities of finding new ore bodies. Probably all ore bodies that crop out have been found, consequently undiscovered ones will have to be located by subsurface exploration in areas where there are showings of cinnabar and geologic structures that favored deposition. Geologic structures that are associated with the known ore bodies are described in the general discussion that follows. Similar, but unexplored, structures appear on the geologic maps that accompany this report and more specific recommendations on particularly favorable areas are given in the descriptions of individual mines.

GENERAL GEOLOGIC RELATIONS

Quicksilver minerals occur at widely separated places in the Big Bend region, but the only extensively mineralized area is the long, narrow east-west belt that comprises the Terlingua district. With the exception of the Mariscal district, southeast of the Chisos Mountains, the occurrences of quicksilver minerals outside of this belt have not yet proved to be of economic importance.

Within the Terlingua district, the deposits are veins and tabular and pipelike bodies in both the Cretaceous sedimentary rocks and Tertiary igneous intrusive rocks. Cinnabar is the principal ore mineral, but there are minor quantities of native mercury, calomel, and rarer mercury minerals. Associated with these are calcite, clay, pyrite, hydrocarbons, and, less commonly, several other minerals.

As the geology of the quicksilver deposits is so closely a part of the general geology of the district, it seems best to precede the descriptions of the deposits with a brief correlation with those features, described in preceding sections, that have a direct bearing upon any interpretation of the geology of the quicksilver deposits. The ore deposits are directly or indirectly related to the Terlingua monocline, to fractures and breccia pipes, to the igneous rocks, and to the physical and chemical character of the sedimentary rocks.

Relation between the quicksilver belt and the Terlingua monocline.—The east-west trend of the Terlingua monocline is unique among the major structural trends of the Terlingua region, which range from northerly to northwesterly. The corresponding east-west trend of the quicksilver belt and the closeness of the belt to the monocline suggests that there may be a direct relation between the two features. However, the hypothesis that the monocline was a structure that directly controlled the location of the lodes can be discarded for the following reasons: (1) the quicksilver belt is not even approximately superimposed upon the monocline, but in places is as far as 2 miles to the north, and at its west end is actually crossed by the monocline; (2) the irregularities of the monocline are not repeated in the quicksilver belt; and (3) minor fractures that control the trends of individual lodes within the quicksilver belt are not restricted to the zone of monoclinal folding but are regional. Therefore, if there is a genetic relation between the monocline and quicksilver belt, the only valid hypothesis remaining is that the trends of the monocline and quicksilver belt were determined by a common factor. In a preceding section, the interpretation of structural data suggests that the Terlingua monocline was formed by an igneous intrusion, the trend of which is defined by the monocline. Accordingly, an extension of this hypothesis interprets the trend of the quicksilver belt as either a reflection of the trend of the same intrusive body—or of a deeper structure that controlled the emplacement of the intrusion, as well as the upward course of the rising solutions.

Relation between mineralized rock and minor structures.—The arrangement, form, and trend of the individual ore bodies within the mineralized belt was determined by minor structures, which existed before quicksilver mineralization. The ore bodies are along, or adjacent to, fractures and are in breccia pipes, which are all structures along which there has been almost no movement after mineralization. No relation between minor folds and ore bodies is apparent.

Almost all the ore bodies are associated with fractures that range in trend from N. 20° E. to N. 85° E., consequently the quicksilver belt is a zone of in echelon northeasterly trending veins. Fractures of northwesterly trend are as common as those of northeasterly trend but almost without exception are barren. Some fractures are joints with no visible displacement; others are faults with vertical displacements of more than 50 feet. The ore-bearing fractures range in length from less than 100 feet to more than 1 mile, with very little relation between lengths and vertical displacement. In many places the relation between ore and fractures is an indirect one; the ore occurs, not along the fracture, but in a cave-fill zone in limestone, which was indirectly controlled by the fracture.

Many breccia pipes in the district are mineralized and all may have been potential controlling structures for ore deposits. They are generally unrelated to the fractures; their distribution is throughout the district. On the other hand, all gradations exist between fracture-controlled cave-fill zones and breccia pipes, which in places are within cave-fill zones.

Relation between mineralization and igneous intrusion.—Field relations indicate that the igneous rocks were emplaced before the quicksilver deposits were formed, but they do not show any direct association between the deposits and the exposed igneous intrusive bodies, either individually or collectively. Cinnabar has been found in postintrusion structures in both analcite and analcite-free rocks; but appears to be unrelated to either. Although there are several sporadic occurrences of cinnabar in several places outside the Terlingua district, the main mineralized belt is a very much restricted area. In contrast to this, the igneous rocks are widespread and of fairly general distribution. The arrangement of outcrops of igneous rocks, both within and without the district, is unrelated to the location and trend of the mineralized rocks. The absence of close relations between the outcropping igneous rocks and the quicksilver deposits is further demonstrated by: the lack of zonal or other arrangements between veins and intrusive masses, the failure of any one rock type to occur persistently along the quicksilver belt, and the diversity of rock types that contain cinnabar. The association of cinnabar with rhyolite plugs at Contrabando dome, as well as with other igneous intrusive bodies, is structural.

As suggested in a preceding paragraph, there probably is, however, an indirect genetic relation between the exposed igneous rocks and the quicksilver deposits.

The former may well have been differentiated at depth from the same parent magma that was the source of the mercury-bearing solutions.

Relation between mineralization and sedimentary rocks.—Ore deposits are most abundant in the sedimentary rocks and have been found in the Devils River limestone, Grayson formation, Buda limestone, Boquillas flags, and Terlingua clay, with certain of these formations and certain parts of them more favorable host rocks than others. The most favorable ore horizon is the contact of the Devils River limestone with the overlying Grayson formation, where cave-fill zones commonly developed. Ore rarely extended more than 50 feet below this horizon into the Devils River limestone or 10 feet above into the Grayson formation. The Buda limestone and Boquillas flags were important host rocks only in the Chisos mine. The only ore bodies found in the Terlingua clay were in baked beds above the Study Butte intrusion. Ore deposits have not been found in rocks stratigraphically higher than the Terlingua clay, possibly because the mercury was all precipitated from the rising solutions before the higher formations were reached.

The physical characters of the sedimentary rocks and possibly their chemical and mineralogical compositions determined their qualities as host rocks. The limestones, brittle and hence more permeable when fractured, formed the best solution channels, whereas the relatively impermeable clays and breccias with clay matrices were the best ore hosts wherever they could be penetrated by the ore-bearing solutions.

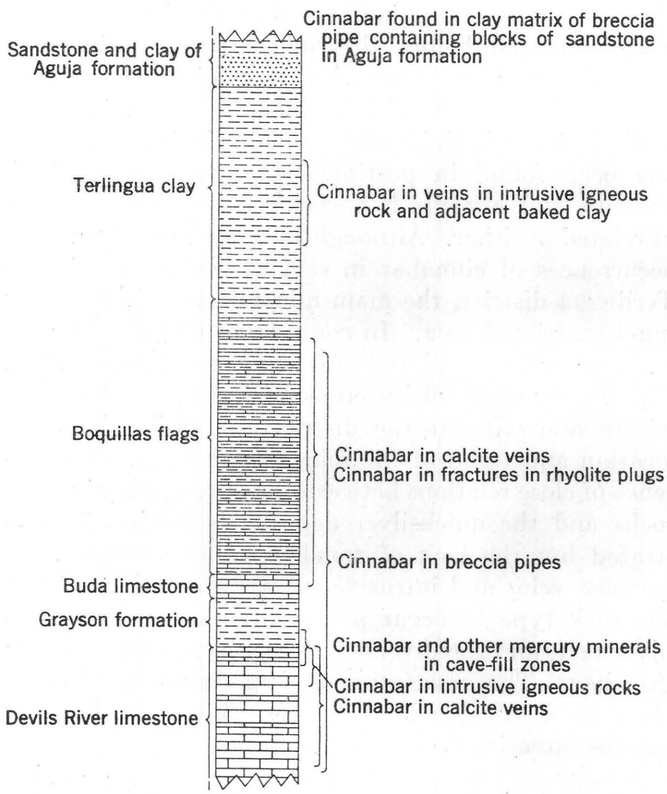


FIGURE 13.—Stratigraphic section showing vertical range of quicksilver deposits of the several types that occur in the Terlingua district.

Time of quicksilver mineralization.—Quicksilver mineralization was late in the geologic history of the area. The quicksilver deposits were formed after the folding of the monocline, after the faulting of the grabens, and after the extrusion and intrusion of igneous rocks. The lack of postore faulting indicates that structural movements had died out by the end of mineralization, although it is probable that the area has since undergone a general uplift. The present study has not yielded data that could be used to correlate quicksilver mineralization with any particular phase of the Cenozoic history of the area, but such might be possible if a comprehensive study were made of the physiography and volcanic deposits of the Big Bend region. It seems improbable—but it is not impossible—that the deposits could be as young as Pleistocene, and it seems hardly more probable that they could have formed during the early Tertiary. Most likely their age is middle or late Tertiary.

CLASSIFICATION AND GEOLOGIC FEATURES OF DEPOSITS

The Terlingua quicksilver deposits are readily classified. This is fortunate, for descriptions are simplified and comparisons and contrasts can be clearly pointed out. As all the deposits formed during the same general period of mineralization and by fundamentally identical processes, the physical distinctions that separate the several classes are the results of differences in the environments of deposition. The environments of deposition naturally overlap and intergrade; consequently some deposits have the characteristics of two or more classes. It is always possible, however, to place a particular deposit in the class to which it shows greatest affinity.

The classification here used is based upon variations in environment as determined by structural features and rock types in which the deposit formed. Because a given environment always produced a particular class of deposit, it is possible, if the geology of any given area is known, to predict the classes of deposits that might be found there. The quicksilver deposits are divided into the following classes: (1) deposits formed along the contact between the Devils River limestone and Grayson formation (hereafter called the limestone-clay contact deposits), (2) deposits in calcite veins in the Boquillas flags, (3) deposits in breccia pipes, and (4) deposits in igneous rocks. Class 4 can be subdivided into regular deposits occurring along well-defined fractures and irregular deposits occurring as irregular bodies in brecciated rock. The stratigraphic range of the various classes of deposits is shown in figure 13.

LIMESTONE-CLAY CONTACT DEPOSITS

The limestone-clay contact deposits are by far the most common and the most valuable in the district and include all those deposits—elongate in plan and relatively thin in cross section—that occur at and near the contact between the Devils River limestone and the Grayson formation. The limestone immediately beneath the clay was dissolved along fractures and bedding planes; this allowed the clay to collapse into the solution cavity thus produced and formed what is hereafter referred to as "cave-fill," an excellent host material for cinnabar (see fig. 14). Cinnabar also occurs in the undisturbed clay and limestone adjacent to the cave-fill zones. The cave-fill commonly has a root, which is a narrow, calcite-lined fracture containing small amounts of cinnabar. In some places these "fracture-roots," instead of being filled by calcite, are differentially widened through solution of their limestone walls, and the opening thus formed is filled by detritus from above and locally mineralized by solutions from below. Because these calcite- and detritus-filled fissures extend from the limestone-clay contact and are so closely related to the limestone-clay contact deposits, they are described here, instead of under a separate heading.

Ore bodies along the contact of the Devils River limestone and Grayson formation have been worked at the Chisos-Rainbow mines, Mariposa mine, and Fresno mine. The roots of similar ore bodies, now removed by erosion, have been mined and prospected at many places in the Devils River limestone in the west-central part of the district, in particular near Tres Cuevas Mountain and north and east of California Mountain.

The quicksilver deposits of the Mariposa mine are typical and well-developed examples of the limestone-clay contact deposits. Although little ore could be seen when the field work was done (1945), the extensive surface and underground development provides numerous exposures that show the deposits in all stages of development. Because the Mariposa mine so well serves as the type example for the Terlingua district of this class of deposit, the descriptions and interpretations that follow, although confined mostly to this mine, can be applied to other places in the district.

The cave-fill, which contains most of the ore, is in long, narrow, relatively shallow troughs, that have a keel-like downward projection extending to variable depths. In cross section the troughs have either a U or V shape with a pronounced upward and outward flaring of the walls. The cross-section shape may be either symmetric or asymmetric; where symmetric, the keel extends downward from the center of the trough; where asymmetric, the keel extends downward from the side of the trough. The keels of the U-shaped forms tend to pinch to narrow calcite-lined fractures in shorter distances than those of the V-shaped forms. The general shape, size, and character of the cave-fill zones is shown in figure 15.

The dimensions of the cave-fill range through wide limits. The upward flaring tops are from a few feet to more than 200 feet wide, and in places two or more cave-fill zones converge to form even wider zones. The average width, however, is probably between 40 and 50 feet. There is little relation between the width of the zone and depth to which it extends. Some of the wider zones are only 20 or 30 feet thick, whereas some of the narrow zones have keels of cave-fill several feet in width at depths of more than 100 feet. The great majority of cave-fill deposits do not extend more than 50 feet into the limestone. Commonly the cave-fill deposits are several hundred feet long, and some are longer than 2,000 feet.

The cave-fill zones occur in areas of horizontal or gently inclined limestone, and many appear to occupy small local synclines. The synclinal structures, however, are solution features and not tectonic features, and as such do not extend below the cave-fill. They do, however, extend above the cave-fill zones, and in places where the Grayson formation has not been eroded a narrow synclinal warp may indicate an underlying cave-fill zone. These synclines were formed by the solution of limestone just below the base of the Grayson formation and a consequent settling of the overlying rocks as solution progressed. Although the beds of limestone forming the walls of the cave-fill dip inward, only rarely can it be shown that their inward dip was produced by solution. Solution features in these beds are not apparent, because solution proceeded along bedding planes in a uniform manner and gradually died out away from the cave-fill zone. The synclinal structure in the walls of the cave-fill was, therefore, produced by a thinning of the limestone beds, which gave each bed a wedge-shape. Below the cave-fill this thinning of the beds did not occur and the limestone has its normal attitude. The development of these synclinal structures is shown diagrammatically in figure 14.

Almost all the cave-fill zones occur within the upper 50 feet of the Devils River limestone. This part of the Devils River limestone, which is lighter in color, more argillaceous, and thinner-bedded than the rest of the formation, is sometimes locally called the Georgetown limestone. It weathers more rapidly than the underlying limestone, probably because it is

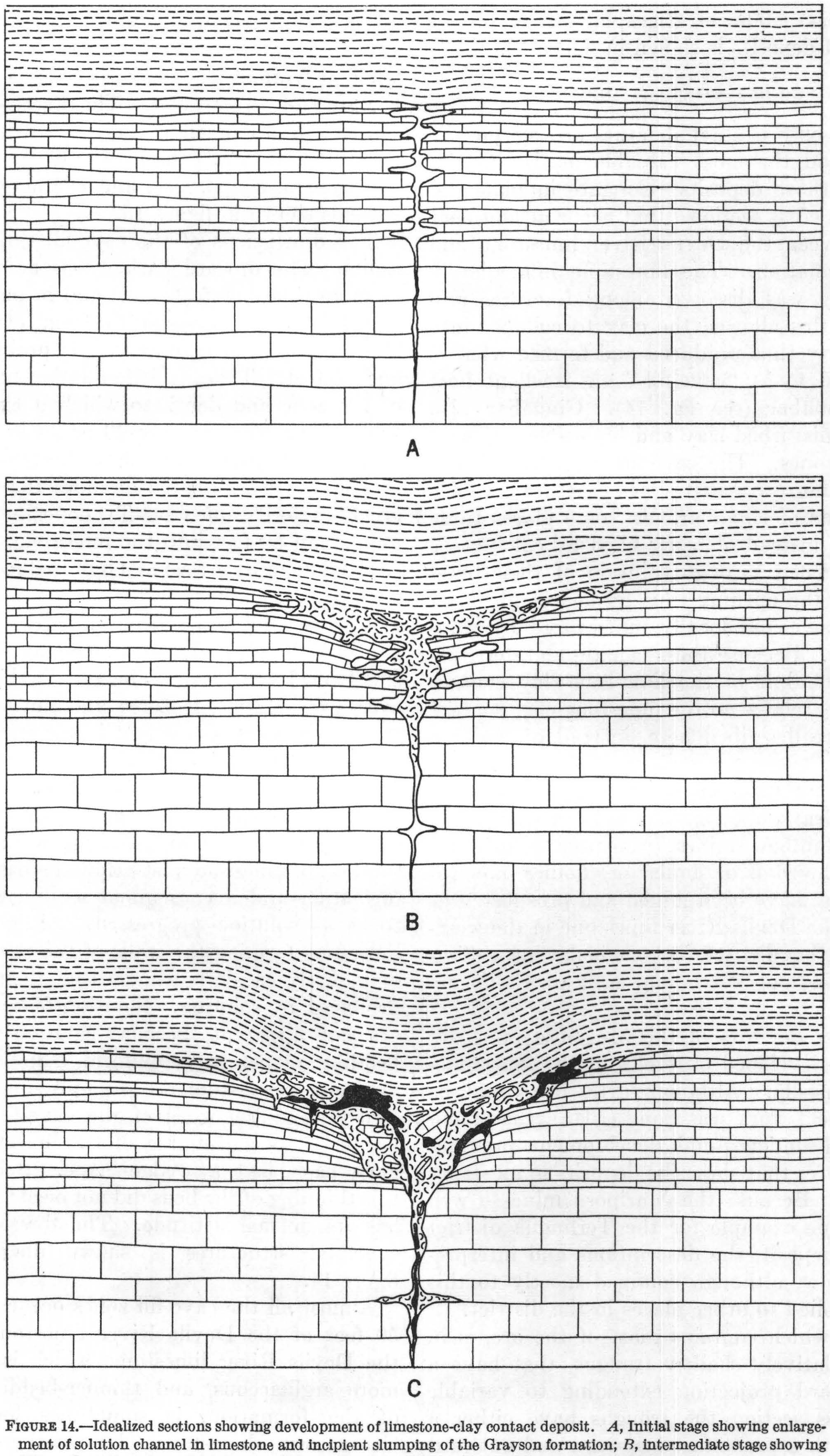


FIGURE 14.—Idealized sections showing development of limestone-clay contact deposit. *A*, Initial stage showing enlargement of solution channel in limestone and incipient slumping of the Grayson formation; *B*, intermediate stage showing filling of solution channel by increased slumping and addition of cave-debris. Actually the initial and intermediate stages are concomitant and cannot be separated. *C*, Final, or ore stage, showing cinnabar in cave-fill.

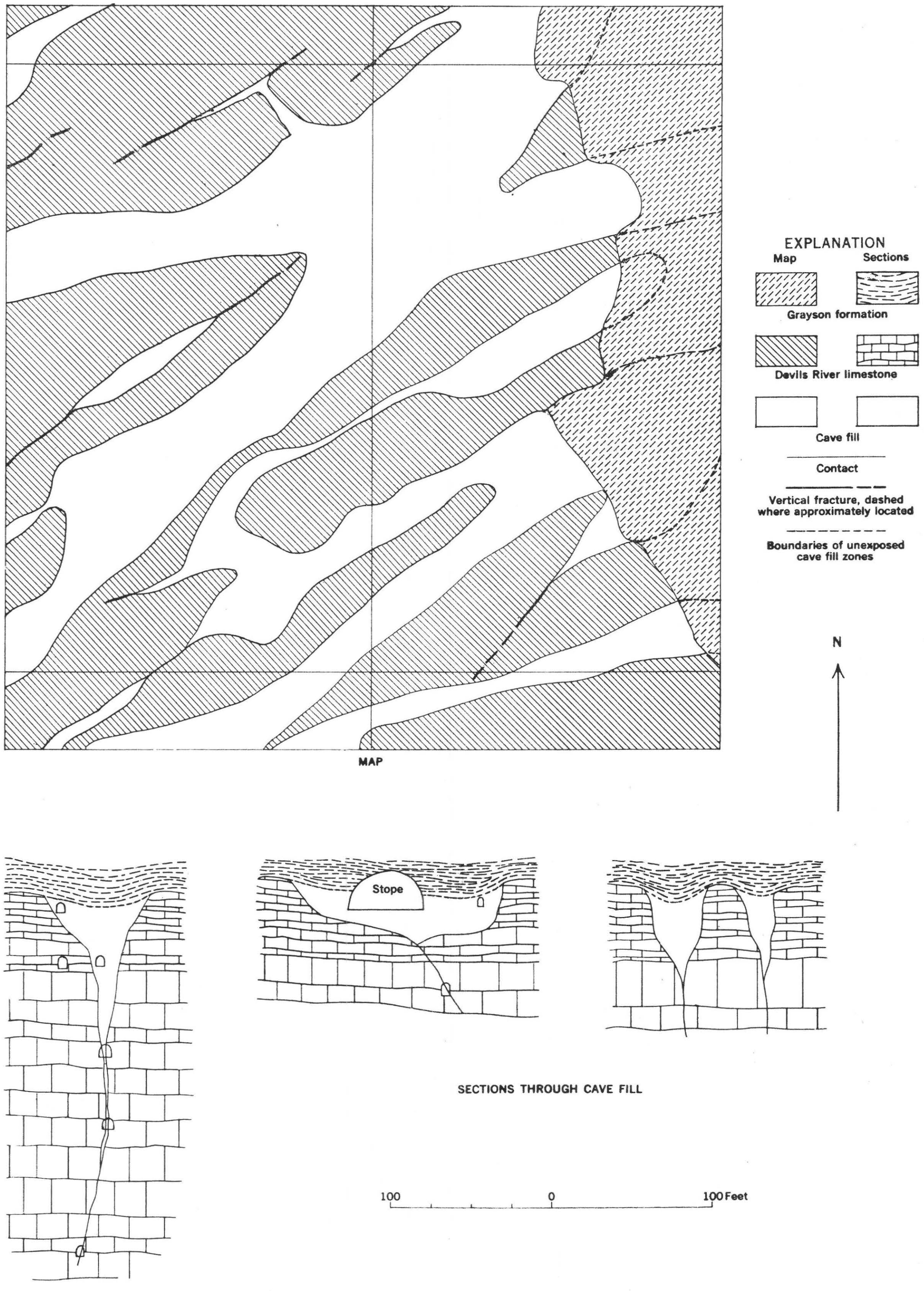


FIGURE 15.—Map and sections of cave-fill at Mariposa mine. Map of cave-fill showing distribution, trend, and controlling fractures in Devils River limestone. Limestone and cave-fill covered along east border of map by alluvium.

more closely jointed and thinner bedded and perhaps more soluble.

The limestone walls bounding the cave-fill are longitudinally fairly straight and smooth, with curved rather than angular irregularities. They are, however, locally fluted and embayed by small caverns, which are usually lined with calcite crystals. In some places the walls are also coated with calcite crystals, but more commonly they are altered to a soft porous limestone rock. Small calcite veins extend from the cave-fill out into the limestone.

The cave-fill is composed mainly of clay and rounded to subangular blocks of limestone. Some clay is clearly from the Grayson formation that slumped into the limestone caverns, other is from the Grayson formation that was disintegrated by water and redeposited in the cavern openings, and a small amount is residual from the solution of argillaceous limestone. Clays of all three origins are found within single cave-fill deposits and in some places probably form intimate mixtures. The clays range from the dark gray of the unaltered Grayson through shades of red and light brown to a light cream. Some is banded and the original bedding is preserved by the bands, and some has concentric bands of red, pink, and tans that are unrelated to bedding. Much of the clay contains considerable amounts of calcite, which occurs in layers and as very small grains. Clay that contains very little calcite and is light cream, mottled with pink and red or is dark red, is named "jaboncillo" by the Mexican miners, because of its soapy feel when wet. The color of the clay is mainly from disseminated hematite, which was derived, at least in part, from the pyrite that is fairly abundant near the base of the Grayson formation.

Some cave-fill is a breccia, with fragments of limestone and more indurated Grayson formation in a clay matrix. Locally breccias are so well developed that Turner (1905) classified the cave-fill deposits as "friction breccia lodes" and the keels of the cave-fill deposits as "calcite lodes." Friction breccia is a misnomer, as the breccia was not produced by fault movements, but by solution and collapse. The breccia is commonly cut by small calcite veins, and gypsum veinlets are common in the slumped Grayson.

Most of the cinnabar and other quicksilver minerals that formed the ore occurred in the cave-fill but a little occurred in the limestone of the walls. The ore was found in shoots that occupied only a small part of the cave-fill zone; only rarely was the ore deposited across the entire zone. In form the ore shoots were more irregular than the cave-fill. They were usually in line with the keel of the zone and some extended down into the keel, in a few places for distances greater than 100 feet. The ore shoots were not continuous along the length of the cave-fill zone; a few were several hundred feet long, but the average was probably less than 50 feet.

It is difficult to estimate the average grade of ore of the deposits of this class, because most of them were mined early in the history of the district when few records were kept. According to Phillips (1905, p. 160) the 60-ton Scott furnace of the Marfa and Mariposa mine in 1904 was treating ore that contained less than 1.5 percent mercury and not infrequently treated ore that contained as much as 2.0 to 2.5 percent mercury. The cinnabar-bearing cave-fill that was furnaced from 1942 to 1945 ranged from ore containing less than 0.2 percent mercury to ore taken from small pockets that contained almost 50 percent mercury.

Cinnabar, the most important ore mineral, occurs as cloudlike disseminations and as irregular veins in the clay and limestone and as nodules and "beds" in the clay of the cave-fill. Some cinnabar occurs as fillings in openings in the limestone, but most of it occurs as replacements of the clay (see pl. 8*A*) and to a lesser extent as replacements of the limestone. Generally the cinnabar is so intimately mixed with the clay that it megascopically appears to be amorphous, but when examined microscopically it is seen to be aggregates of small well-developed crystals. Its distribution is controlled by variations in the texture and composition of the cave-fill and by minute fractures.

The Terlingua quicksilver district is as well known to mineralogists for the rare minerals that occur there as for cinnabar, which is much more abundant. The rare mercury minerals occurring at Terlingua are almost entirely restricted to the limestone-clay contact deposits and include native mercury, calomel, terlinguaite, eglestonite, mosesite, kleinite, and montroydite, which have been described by Hillebrand and Schaller (1909) and by Canfield, Hillebrand, and Schaller (1910). These minerals occur in open spaces and only rarely is cinnabar found in close association with them.

The other minerals in the cave-fill deposits are mainly clay and calcite and minor amounts of barite, fluorite, chalcedonic quartz, and pyrite, as well as the previously mentioned hematite, limonite, jarosite, and gypsum. These minerals are described and their age relations discussed in a later section.

The ore in the calcite vein which form the keels of the limestone-clay contact deposits differs from that in the cave-fill. Except where clay has fallen or washed into the solution-enlarged fractures, the cinnabar is associated with banded calcite, where it occurs as crusts and films between the successive bands and between the calcite and the limestone walls, as well as within fractures in the calcite. The better ore occurs as irregular masses of cinnabar replacing the calcite. Although the cinnabar in these calcite veins is brilliant red, it is much less pure than that in the cave-fill because it contains inclusions of fine-grained clay and calcite. Almost all the calcite veins in the Devils River limestone contain traces of cinnabar, but few even moderately large ore shoots have been found in them. Some calcite-filled fractures contain pockets of clay that fell or was washed into the solution cavity before or during calcite deposition. All such pockets of cave-fill were potential hosts for ore bodies and ore in such pockets is almost always richer than that in the calcite veins.

In some deposits, such as those of the Little Thirty-eight and Colquitt-Tigner mines, the mechanical redistribution of some of the cinnabar since its original deposition has caused the lodes to differ considerably from those described above. Cinnabar occurs in these deposits as detrital grains and nuggets with a rubblelike accumulation of water-rounded fragments of limestone in a clay and silt matrix. The deposits occupy either vertical or horizontal solution caverns in the Devils River limestone. The cave silt and rubble in the horizontal caverns is usually stratified, and that in the vertical caverns is usually an unsorted jumble of material of all sizes.

A vertical, rubble-filled fissure at the Little Thirty-eight mine has been described by Lonsdale (1929, p. 630–631) as a placer cinnabar deposit, formed by surface waters that washed in detritus from deposits nearby at higher altitudes. The observations of the writers confirm the interpretation of C. P. Ross, who believes this deposit to be of somewhat different origin than that advanced by Lonsdale. Ross's interpretation (written communication) is as follows:

> In mines such as those on sec. 38, Block G–12, the rubble and silt partly filling the caves constitutes much of the ore. Some of the clastic material is so intimately associated with calcite that it must have come to place before or during the deposition of the calcite. Some, however, shows no direct evidence of the date of deposition. In some pockets the fill in the bottom is reported to have been relatively high in quicksilver, suggesting the influence of gravity. Bones of animals of Pliocene or Pleistocene age were found in some of the clastic fill of the Little Thirty-eight mine (Turner, 1905, p. 275; Lonsdale, 1929, p. 629). The animals presumably got into the fill at a time when the cavern was open to the surface and long after primary ore deposition had ceased.
>
> Such factors as those above cited led Lonsdale to suggest that the ore in the Little Thirty-eight mine is a mere filling of solution openings by debris transported by storm waters. * * * It is clear from such observation as could be made by the writer, from statements of men familiar with the ore, and from the data published by Turner (1905) that much ore, at least, was in bands of crystalline calcite and clay similar to those of other mines in the district, rather than in loose rubble.
>
> The most probable explanation of the loose or poorly cemented, recent rubble locally present is that it represents the residue of insoluble and incompletely attacked material resulting from solution by groundwater. * * * This residue has been transported and sorted to a greater or less extent. Where erosion has provided suitable connection with the surface, the material of this sort may well have been added to by debris transported by storm water. When the debris happened to have been derived from erosion of an outcrop of quicksilver ore, it may have added to the content of quicksilver in the cave filling sufficiently so that gravitative concentration could produce valuable pockets.

Cinnabar and mercury chlorides that occurred in the horizontally bedded cave detritus at the old Colquitt-Tigner mine had a somewhat different origin. The ore minerals here appear to have been formed after a large fairly horizontal cavern in the Devils River limestone was partly filled by cave rubble. This material that partly fills the cave is locally well bedded and some beds are sugary-grained limestone. All the cave material is highly calcareous. At the time of the writers' visit to this mine there was no ore visible, but a little cinnabar that was seen was a replacement of the cave material and consequently of later origin than the filling of the cavern. The discoverers of this cavern reportedly found heaps of almost pure cinnabar on the top of the cave-fill, which was about 20 feet below the roof of the cavern. It seems probable that this cinnabar was residual after the removal of the upper part of the fill by solution and the concentrating action of streams of underground water. There is no reason to believe that any of the ore was washed in from surface sources.

In summary, the limestone-clay contact deposits formed in filled solution caverns that occur near the top of the Devils River limestone. The caverns are along northeasterly trending fractures that served as channels for the rising ore-forming solutions. The best ore occurs in the upper parts of the cave-fill, near the base of the Grayson formation. Locally cave-fill, in places ore-bearing, extends down into the solution-widened fracture. Most fractures, however, are filled by calcite veins, which for the most part contain only very small amounts of cinnabar.

DEPOSITS IN CALCITE VEINS IN THE BOQUILLAS FLAGS

The Boquillas flags that crop out between the Rainbow and Two-Forty-Eight mines are cut by numerous calcite veins and many of these contain cinnabar, but only those at the Chisos mine have yielded commercial ore. The calcite veins range from thin stringers of calcite less than 1 inch wide to vein zones more than 10 feet wide. Almost all the cinnabar-bearing veins have northeasterly strikes and steep dips. Some occur along minor faults with vertical displacements of a few feet, but the walls of most show no visible displacement. Cinnabar, the only ore mineral, and pyrite occur in the vein calcite and in clay seams in the veins and along the walls of the veins.

The calcite veins range greatly in length and thickness; and, as with the calcite veins in the Devils River limestone, there is no relation between length and thickness. Many veins are less than 10 feet long and these have maximum widths of from a fraction of an inch to 18 inches or even more, whereas a vein several hundred feet long may have an average width of 2 inches or less. Although veins more than 1,000 feet long are not uncommon, the average length is probably between 200 feet and 500 feet. A thickness of 3 feet of solid calcite is uncommon, thicknesses of 1 foot to 2 feet

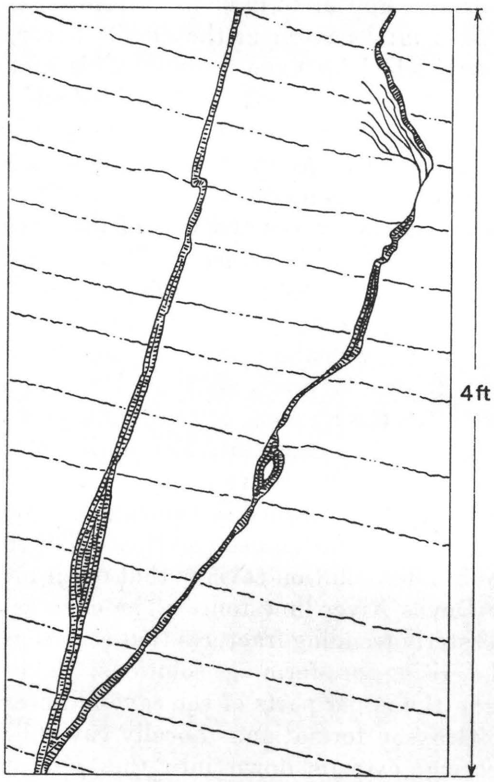


FIGURE 16.—Sketch of calcite vein in Boquillas flags in face of drift, Chisos mine. Illustrates tendency of veins to split and feather out.

of calcite are fairly common, and thicknesses of 2 inches to 8 inches are common.

In some places the veins are multiple; that is, a vein zone, from 2 feet to 50 feet wide, has been formed from numerous, small, subparallel, closely spaced veins and stringers. Vein zones are usually local features not continuous for any great distance along the strike. Commonly the veins that compose them converge to form a single vein. A few veins feather out (see fig. 16); that is, the vein frays out into small stringers. Acute angle splits, or forks, in the veins along their strikes are not very common, and where they occur the vein that splits off from the main vein is generally a short one. Vein intersections or vein crossings, however, are common. Veins of northwesterly trends, which are fairly common but very rarely cinnabar-bearing, end against northeasterly trending veins or northeasterly veins end against them. There is no consistent relation between vein trends and terminations or between vein crossings that could be used to interpret the relative ages of the two trends.

The calcite veins are commonly of uniform strike over long distances; irregularities are gentle sinuous curves rather than sharp angular bends. Variations in dip, however, are more pronounced. Dip angles are generally high, probably averaging about 70°, but dips of 45° are abundant and dips as low as 30° occur. Because of the variation in angle and direction of dip there are many vein convergences, with two veins joining to form a stronger vein. As changes in dip are more common and more abrupt than changes in strike, there is commonly a split in the vein at the place where the change occurs. Common vein patterns are illustrated in figures 17 and 18.

Although calcite is commonly present along major faults, the calcite veins that contain cinnabar are along minor faults or along fractures that have no measurable displacement. Minor faults with displacements of several feet or less are abundant and the veins along these faults are in many places associated with fault breccia and gouge. Breccia fragments and gouge occur both within the vein and along its walls. Some veins, in particular those that are cinnabar-bearing, have well-developed sheeted structure, with thin seams of gouge cutting through brecciated and rehealed calcite. Veins that have not been fractured are composed of parallel bands of calcite, but the banding is not as pronounced as that in the calcite veins in the Devils River limestone.

The calcite in the veins has the characteristics of calcite deposited in open fractures. The veins are commonly banded and contain vugs and unoriented inclusions of the country rock. The calcite ranges from finely-crystalline to coarsely-crystalline. Terminal parts of the calcite crystals are found extending into the now open parts of the veins and can be seen as phantoms in the filled parts of the veins. Modified scalenohedrons are most common, but rhombohedral forms are fairly abundant. The color is commonly light-gray or yellowish brown, but some veins contain snow-white or pale apple-green calcite. The gray is probably from inclusions of fine clay and the yellow brown from inclusions of limonite and hydrocarbon compounds. Some calcite contains sufficient hydrocarbon to exude the odor of petroleum from freshly crushed crystals. The gouge in and along the veins

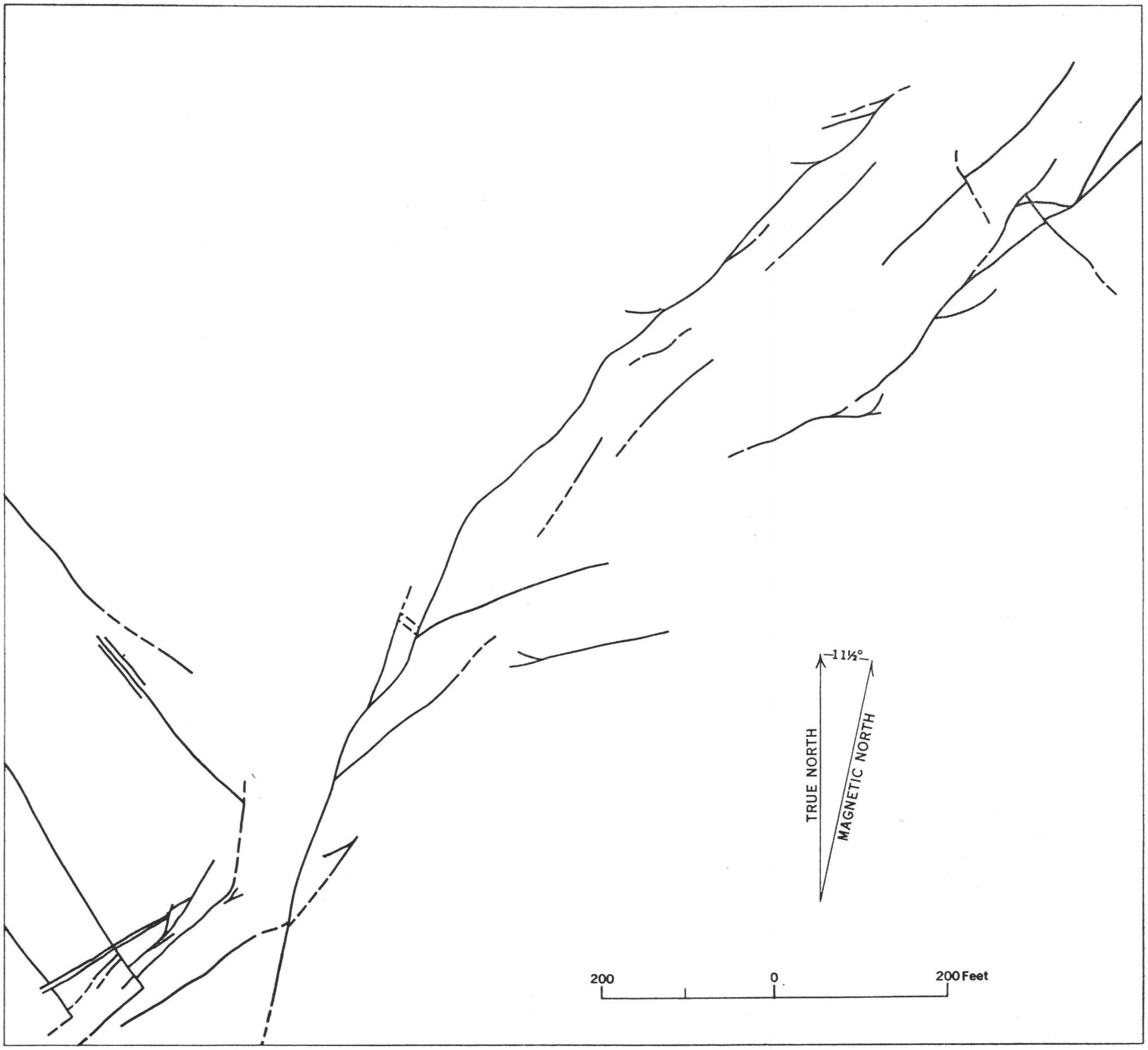


FIGURE 17.—Map showing calcite vein pattern in Boquillas flags of Brown prospect, sec. 286, Block G-4.

also contains hydrocarbon compounds, which locally are abundant enough to ignite before the flame of a miner's lamp.

The banding of the calcite, although typical of the veins, is not always conspicuous. Some veins have a pronounced banding, with striking contrasts between the color and grain size of the constituent bands, but more commonly the banding is only noticeable through close inspection. The inconspicuously banded veins have only minor variations in grain size and color of the bands. In general, the last formed bands are more coarsely crystalline. The banding is not always parallel to the walls of the vein. Some bands are lenslike and some extend through earlier formed bands at acute angles, apparently following fractures that were opened after the deposition of earlier calcite.

Cinnabar is the only mercury mineral that has been found associated with calcite veins in the Boquillas flags or the Buda limestone. It occurs in very finely crystalline aggregates replacing brecciated calcite and clay gouge in the veins and to a much lesser extent as dissemination in the flaggy limestone of the walls. It also fills small fracture openings. The veins that contain cinnabar generally have a higher development of brecciated calcite and sheeted structure than the barren veins. Hydrocarbons, as tar and oil, and pyrite

FIGURE 18.—Map showing calcite vein pattern in Boquillas flags southeast of Susano shaft, Chisos mine.

are associated with the cinnabar, but also occur in parts of the veins where cinnabar is absent.

Pyrite is abundant in the calcite veins, but is only rarely seen in outcrop. Even as far below the surface as the 200-foot level of the Chisos mine, it is partly oxidized to hydrous iron oxides. Much oxidized pyrite seen in underground workings may have been oxidized after the mine was opened, because melanterite and other hydrous sulfates coat the mine walls in many places. That the normal depth of oxidized pyrite is not so deep as the mine workings suggest, is indicated by diamond-drill cores taken from Boquillas flags just east of the Chisos mine. These cores contain abundant fresh pyrite from a few feet of the surface to the base of the Boquillas flags. The pyrite occurs as fillings in the calcite veins, as disseminated grains in the calcite, and as veinlets and disseminated grains in the wall rocks. Disseminated pyrite is more abundant in the calcareous beds than in the argillaceous.

Some calcite veins extend through the Boquillas flags and down into the Buda limestone, but very little ore has been found in calcite veins in this lower formation. Few fractures in the Buda limestone are completely filled with calcite; most are only partly filled and some have been enlarged by solution to vertical caverns several feet wide. In general, the calcite in veins in the Buda is whiter and more coarsely crystalline than that in veins in the Boquillas flags.

A related but different kind of ore body, is the rich 550 ore body of the Chisos mine, which is described in detail on page 103. This ore body was in a breccia zone at the intersection of the Buda-Boquillas contact with the Chisos fault. Although calcite was only of minor importance, this deposit is included under the calcite vein deposits because it graded upwards into calcite veins in the Boquillas flags.

Almost all the calcite veins end at the base of the Buda limestone or extend only a few feet into the underlying

Grayson formation. A few calcite veins, however, do extend into and through the Grayson formation, but they are negligible in abundance and size when compared to those in the Boquillas flags. A vein 2 inches thick is uncommon, and even these are not persistent, but pinch out in short distances. Calcite veins in the Grayson are rarely directly linked to those in the Boquillas flags and Devils River limestone. Exceptions to this are those along the larger faults.

In summary, the Devils River limestone and Boquillas flags contain numerous calcite veins that are well developed, whereas the Grayson formation contains few calcite veins and these are poorly developed.

DEPOSITS IN BRECCIA PIPES

Cinnabar has been found in many places in the Terlingua district and has been mined from pipes at the Chisos mine, the Two-Forty-Eight mine, and Bobs mine. The Chisos pipe contained the most valuable ore body ever found in the Terlingua district. Ore found in the Two-Forty-Eight pipe and Maggie Sink pipe (Bobs mine) has been in small, but fairly rich, pockets.

The distribution, character, and origin of the breccia pipes are given in a preceding section (p. 44–47). Details of individual pipes are given under the mine descriptions in the final part of this report.

Ore that has been found within the breccia pipes either fills the pipe locally, as in the Chisos pipe, or is in small shoots along or near the borders of the pipe, as in the Two-Forty-Eight and Maggie Sink pipes. Intermediate types may exist, but none has yet been found.

The Chisos pipe, beyond containing the largest and richest ore body, is unique in the Terlingua district. It is the only pipe that does not extend to the surface, and it is the only pipe that contained an ore body extending from wall to wall. Its uniqueness as a pipe that did not extend to the surface is perhaps more apparent than real; such pipes could be discovered only by subsurface exploration, which has been done in an area that is trivial in contrast to the total area of the district. The ore body in the Chisos pipe is much greater than those found in the other pipes.

Although the shape, size, and structural relations of the Chisos pipe can be determined from the mine workings, the character of the breccia and ore can not be directly observed. The ore body was mined during the first World War period, and was so thoroughly removed that in 1942 the writers could find only traces of cinnabar in the stope walls. The former Chisos Mining Co. had a long established policy of secrecy, which has resulted in a great dearth of published information on the mine and its ore. In spite of this, a fair concept of the character of the ore and breccia can be pieced together from information received from those who saw the pipe during its exploitation, from observations along the stope walls, and from comparisons with other breccia pipes. The following summary description is based upon such information. For a more detailed description the reader is referred to pages 42 and 103.

The ore body, roughly circular in plan, had a maximum diameter of about 70 feet in its upper part and extended vertically for about 200 feet, pinching to a diameter of less than 10 feet. It thus had the general shape of a stubby carrot. It filled almost the entire upper part of the enclosing breccia pipe and in places the ore extended out into brecciated wall rock that had not collapsed. The lower part of the ore body was entirely within the breccia pipe and occupied only about 10 percent of the volume of this part of the pipe. Although the ore body appears to end 200 feet below its top, it may have a discontinuous "tap root" extension to greater depths, because cinnabar has been found below the bottom of the stope.

The part of the pipe containing the ore body is enclosed in Buda limestone and Grayson formation. The breccia host of the upper part of the ore body consisted of blocks and fragments of Buda limestone and Boquillas flags partly mortared with clay from the Boquillas flags; that of the lower part consisted of fragments and blocks of Buda limestone in a matrix of the Grayson formation. The breccia was most open near the top of the pipe. The ore consisted of cinnabar and minor quantities of calcite, iron oxides, and pyrite. The cinnabar was mainly a replacement of the clay matrix.

Ore found in the Two-Forty-Eight and Maggie Sink pipes was in parts of those pipes enclosed in rocks stratigraphically higher and lower, respectively, than the rocks that enclose the Chisos pipe. Both the Two-Forty-Eight and Maggie Sink pipes crop out at the surface and formerly extended into rocks now removed by erosion. It is problematical whether their upward growth was arrested before they reached a former surface, as that of the Chisos pipe. If their growth ended under a rock cover, they may have had ore bodies at their apices similar to that of the Chisos pipe.

The breccia in these pipes, although not entirely derived from the same rocks, is similar to that in the Chisos pipe: rock blocks and fragments in a clay matrix. The breccia in the Two-Forty-Eight pipe is in the upper part of the pipe, is open and porous, and contains considerable tar. The cinnabar was mainly in the clay matrix.

The greatest differences between the ore bodies in the Two-Forty-Eight and Maggie Sink pipes and the ore body in the Chisos pipe are in size and structural setting. Only pockets of ore have been found in the Maggie Sink and Two-Forty-Eight pipes. The Chisos ore body occupied a central location in the pipe, whereas the ore found in the other pipes occupied marginal locations. Ore was found in the Two-Forty-Eight pipe either along the border of the breccia or along blocks partly detached from the walls of the pipe; that in the Maggie Sink pipe has been found either at the contact of the breccia with the walls or a short distance within the pipe. In both pipes the ore bodies are irregular in shape and probably vertically elongate, although they have not been explored thoroughly enough to prove this. It may be that small irregular ore shoots such as the above are also present in the deeper, unexplored parts of the Chisos pipe. If this is so, it could be interpreted to mean that the most favorable place for ore in a pipe is near its upward termination. However, if a pipe is in rocks of Grayson or younger age and contains even a small quantity of cinnabar, it seems possible that the pipe may be connected at depth with a limestone-clay contact deposit.

DEPOSITS IN IGNEOUS ROCK

Cinnabar has been found in igneous rock in several places in the Terlingua district but, with the outstanding exception of the Study Butte mine, the occurrences have been commercially unimportant. No one kind of igneous rock is a more favorable host than any other, because cinnabar has been found in quartz soda syenite at Study Butte, in analcite syenogabbro at the Two-Forty-Eight mine, in soda latite at the Mariposa mine, and in rhyolite at Contrabando dome. At these places and in these igneous rocks cinnabar fills open spaces and replaces brecciated rock. The cinnabar deposits in igneous rock are associated with only small amounts of introduced calcite and accordingly contrast with the deposits in calcite veins in the Boquillas flags. Their structural settings are in sharp contrast to those of the limestone-clay contact deposits.

In all places where cinnabar has been found in igneous rock it has been associated with fractures. The fractures were formed both contemporaneously with and after the cooling of the igneous rock. The postcooling fractures were far more important to ore deposition. Fractures formed in the igneous rocks after the rocks cooled are of the same northeasterly trends as the ore-bearing structures in the sedimentary rocks, whereas those formed during the cooling of the igneous rocks are unrelated to any regional trends. Intrusive rocks in which cinnabar has been found at both Contrabando dome and the Mariposa mine were themselves emplaced along preexisting fractures, also of northeasterly trends. Renewed movements on these fractures after intrusion produced the cinnabar-bearing structures. At the Mariposa mine the contact between igneous rock and limestone was a controlling structure, but this is also a preintrusion structure.

Postintrusion fractures at Study Butte had greater influence on the localization of ore than fractures contemporaneous with the cooling. Here again, as at Contrabando dome, these postintrusion fractures may have resulted from renewed movements along fractures of preintrusion age. The postintrusion fractures extend for long distances through the igneous rock and are unrelated to the contacts, whereas contemporaneous fractures are not persistent and are directly related to the contacts. The ore-bearing fractures of Study Butte are described on p. 107–108.

As in the limestone-clay contact deposits and calcite vein deposits, cinnabar is the principal ore mineral and fills open spaces and replaces wall rock. Open-space filling was quantitatively more important than replacement. The open spaces that have been filled range from openings the thickness of a knife edge to those about 1 inch wide. In most places the cinnabar incompletely fills the opening as a crust on both walls, with the center of the opening unfilled. Cinnabar formed by replacement is rarely found farther than 1 inch from filled or partly filled fractures. It was seen as replacements of both felsic and mafic minerals, but far more commonly is a replacement of clay formed from the alteration of feldspar. Feldspars are commonly altered to clay minerals along the mineralized fractures, but this is not universal and only rarely does the alteration extend more than a few inches from the fracture.

Introduced minerals associated with the cinnabar are pyrite, calcite, and hydrocarbon compounds, all minerals common in the other classes of deposits. With the exception of hydrocarbons, the relative abundance of these minerals, however, is different. Pyrite is more abundant than calcite, a ratio strongly in contrast with the relative abundance of these two minerals in the other classes of deposits. The ratio of pyrite to cinnabar, however, is possibly no greater; thus the principal difference between the mineral composition of these deposits and that of the others is that they are relatively deficient in introduced calcite. As the limestone-clay contact deposits and calcite vein deposits are in calcareous rocks, the above relations indicate that the composition of the wall rocks influences the composition of the gangue minerals.

MINERALS AND MINERALIZATION HISTORY

The quicksilver deposits were formed late in the geologic history of the Terlingua district. Mineralization—a term here used to include the closely related processes that introduced the ore and gangue minerals and altered the wall rocks—took place after the major structural movements, after the volcanic activity, and after the emplacement of the intrusive igneous rocks. Geologic activity after the end of mineralization has been principally erosion and oxidation of the rocks by superficial agencies; fault movements were negligible and can be measured in inches. Although the time relations between mineralization, structural movements, and igneous activity have been set forth in preceding sections, they are summarized below, in order to establish freshly in the reader's mind the sequence of geologic events that determined the environment for mineralization.

The establishing of the environment for quicksilver mineralization begins properly with the deposition of the Cretaceous sedimentary rocks, which were to become the principal hosts to the quicksilver minerals. Towards the close of the Cretaceous, the stable conditions that produced the uniform marine limestones and clays ended, and the late Cretaceous deposits are crossbedded sandstone, coal beds, and red and black clays that contain abundant fossil wood and the bones of land animals. This change from marine to continental conditions was accompanied by volcanic activity, which became intense during the deposition of the Tornillo clay formation and reached its crest with the deposition of the Chisos volcanics. Before the close of volcanism there had been enough structural deformation to produce the Terlingua uplift and its attendant south flank, the Terlingua monocline. The graben faults and the system of northeasterly fractures were at least outlined during this period of deformation. The great development of the major faults, however, was after volcanism and before the intrusion of the exposed igneous rocks. Likewise the host structures of the ore deposits, the cave-fill zones and breccia pipes, were formed after volcanism and before igneous intrusion. After the beginning of igneous intrusion there were but few major movements on the graben faults. On the other hand the movements that had produced the northeasterly fractures persisted, old fractures reopened and new ones formed. These movements continued throughout mineralization but were in effect over by its final stages as there is almost no postcinnabar movement.

MINERAL DESCRIPTIONS

Mineralization did not introduce a great variety of minerals, but it did introduce a few rare minerals, as well as several that are common to all the deposits. Of the less than 30 epigenetic minerals (tab. 12) that have been found in the quicksilver deposits, at least 5 are supergene and only 6 are abundant and common to all deposits. The rest includes rare mercury minerals and several minerals that are not necessarily related to the quicksilver mineralization. The analcite in the Two-Forty-Eight mine, and possibly the natrolite in the Fresno mine, although of hydrothermal origin, were formed probably independently of the quicksilver miner-

TABLE 12.—*Minerals of the quicksilver deposits*

Class and mineral		*Composition*	*Distribution*	*Abundance*	*Remarks*
Native elements	mercury	Hg	restricted	minor	Found mainly in the limestone-contact deposits associated with chloride minerals.
Sulfides	cinnabar	HgS	widespread	abundant	
	pyrite	FeS_2	do.	do.	
	marcasite	FeS_2	restricted?	minor	Not easily recognized.
Haloids	calomel	$HgCl$	restricted	do.	Restricted to limestone-clay contact deposits.
	kleinite	Hg, NH_3 chloride [1]	do.	rare	
	mosesite	Hg, NH_3, Cl, SO_3, HO[1]	do.	do.	
	fluorite	CaF_2	do.	minor	
	eglestonite	Hg_4Cl_2O	do.	rare	
	terlinguaite	Hg_2ClO	do.	do.	
Oxides	quartz and chalcedony	SiO_2	do.	minor	
	hematite	Fe_2O_3	widespread	abundant	
	limonite	$Fe_2O_3+H_2O$	do.	do.	Oxidation by surficial agencies.
	montroydite	HgO	restricted	rare	Restricted to limestone-clay contact deposits.
Carbonates	calcite	$CaCO_3$	widespread	abundant	
	aragonite	$CaCO_3$	restricted	minor	
Silicates	natrolite	$Na_2Al_2Si_3O_{10}.H_2O$	do.	rare	Only at Fresno mine.
	analcite	$NaAlSi_2O_6.H_2O$	do.	do.	Only at Two-Forty-Eight mine.
	kaolinite	$Al_2(Si_2O_5)(OH)_4$	widespread	abundant	
Sulfates	barite	$BaSO_4$	restricted	minor	
	anhydrite	$CaSO_4$	do.	rare	
	gypsum	$CaSO_4 \cdot 2H_2O$	widespread	abundant	
	melanterite	$FeSO_4 \cdot 7H_2O$	restricted	minor	
	epsomite	$MgSO_4 \cdot 7H_2O$	do.	rare	
	alunite	$K_2Al_6(OH)_{12}(SO_4)_4$	do.	do.	
	jarosite	$K_2Fe_6(OH)_{12}(SO_4)_4$	widespread	minor	
Hydrocarbons	tars and oils		do.	do.	

[1] Composition uncertain.

alization. The barite and fluorite of the limestone-clay contact deposits may or may not be closely related to the quicksilver mineralization. On the other hand, the almost constant association of cinnabar, pyrite, calcite, kaolinite, and hydrocarbons clearly indicates that these minerals share a common origin and are a direct result of the processes of the quicksilver mineralization.

The following mineral descriptions emphasize features that illustrate the mode and time of emplacement of the various minerals and are not detailed descriptions of mineral appearances and properties—or even summaries of their characteristics. For such descriptions the interested reader is referred to the standard text books on mineralogy and also to papers by Hillebrand and Schaller (1909), Canfield (Canfield, Hillebrand and Schaller, 1910), and Moses (1903), who have so excellently described the rare quicksilver minerals.

CALCITE

Not only is calcite the most common mineral in the Terlingua district, but it is present in the greatest variety of forms. It is in all the deposits; it replaces all kinds of rock and fills solution and fracture openings and is found as amygdules in the volcanic and intrusive igneous rocks. It is in almost countless modifications of its two basic crystal forms, the rhombohedron and scalenohedron. It has many color variations, resulting from impurities of iron, manganese, and hydrocarbons.

The grain size of the calcite ranges from microcrystalline aggregates in the Grayson formation to scalenohedrons more than 12 inches long that line solution openings in the Devils River limestone. In general, the calcite that formed in open spaces is more coarsely crystalline than the calcite that replaces other minerals. The calcite in limestone along vein boundaries and that in hydrothermally altered Grayson formation commonly is recrystallized and in larger grains. This recrystallized calcite is strikingly evident microscopically in thin sections of the Grayson formation, which contain rhombs of calcite consisting of a slightly murky calcite core surrounded by an outer zone of clear calcite, separated from the core by a zone of iron oxide.

The calcite crystals in the filled veins have very well developed terminal faces, representing both rhombohedral and scalenohedral forms and numerous varieties of these. Both rhombohedral and the somewhat more abundant scalenohedral forms occur in the same veins. Variations in the crystal forms suggest repeated changes in the physical and chemical conditions of precipitation of the calcite.

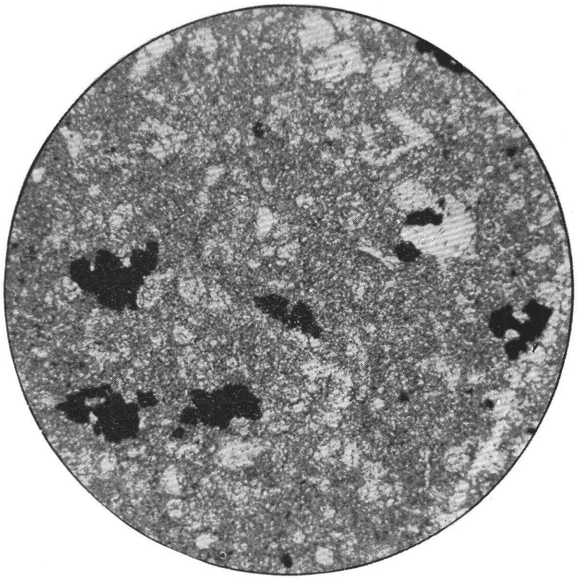
Most calcite ranges from white to gray, but a considerable quantity is light tan to yellow-brown and a much smaller quantity is black, red, pink, and pale green. The colored varieties, in particular the tans and yellow-browns, are more commonly associated with cinnabar than the white varieties. Most yellow and brown varieties receive their color from inclusions of hydrocarbons, which are so abundant in some dark-brown calcite that crushed crystals exude a strong petroleum odor. The red varieties are dusted with fine hematite. The black varieties are colored by manganese oxide, and the pink and pale green varieties are probably also colored by manganese compounds. Ross found that all the calcite seen in the quicksilver deposits is slightly manganiferous and is in contrast to the rare stalactitic calcite of the caverns, which contain neither manganese nor hydrocarbon.

Calcite was deposited throughout mineralization, but the great bulk of it was deposited before the ore minerals. A little, however, is forming today as stalactites in caves, and some formed before the beginning of quicksilver mineralization as a post-magmatic mineral in the igneous rocks. All the other minerals replace it and many are replaced by it. Although calcite crystals have been found that contain cinnabar, the common relations are cinnabar replacing calcite, cinnabar veinlets cutting calcite, and cinnabar crystals crusting calcite. Because calcite was deposited throughout mineralization it is not a good index for the determination of age relations between minerals. It is, however, a mineral that excellently demonstrates the recurrence of structural movements along solution channels during mineralization. It has been repeatedly sheared and brecciated, healed, resheared and rebrecciated, and rehealed.

CLAY MINERALS

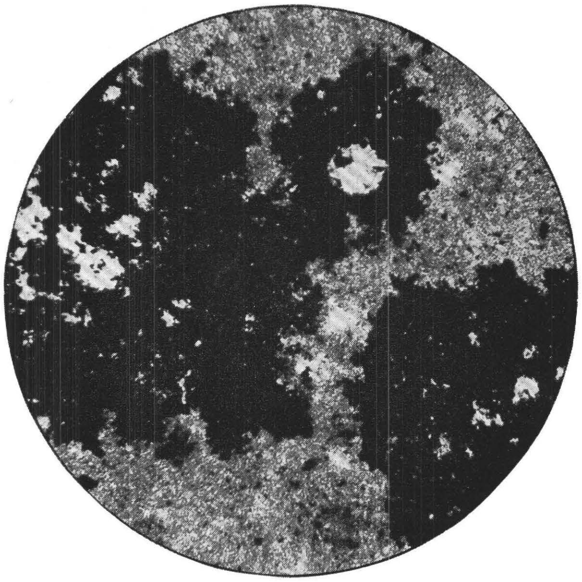
Clay minerals are the most abundant gangue material in the limestone-clay contact deposits and are in lesser amounts in the other classes of deposits. Although clay minerals are indigenous to the limestone-clay contact deposits, the clays that are intimately associated with the ore minerals are believed to be reconstitutions of these original sedimentary clays. Determinations by C. S. Ross of the clay minerals in a few samples indicate that the clays in the unaltered rocks belong to the beidellite group and those in the altered rocks to the kaolinite group. No precise mineralogic or chemical study of the clay minerals was made, consequently conclusions about their occurrence must be very general. These kaolinite clays are the principal constituent of the jaboncillo, which has been described megascopically in a preceding section, and are believed to be not introduced, but reconstituted from the original sedimentary clays.

Jaboncillo, when seen in thin section, is a very fine



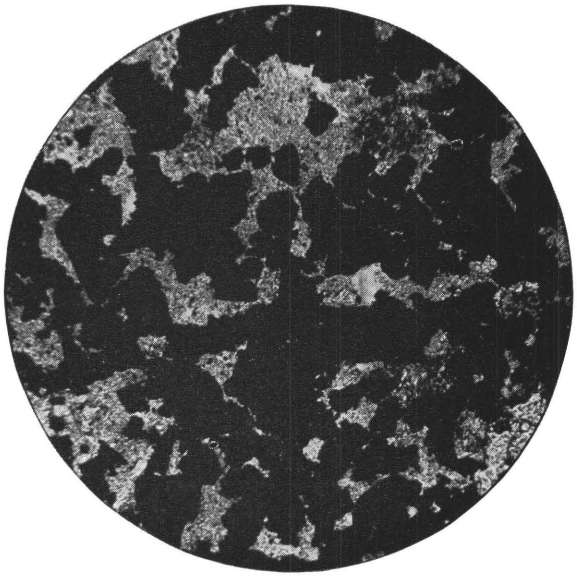
A. DEVILS RIVER LIMESTONE WITH CINNABAR REPLACING CALCITE (GRAY)

Plain light, × 30.



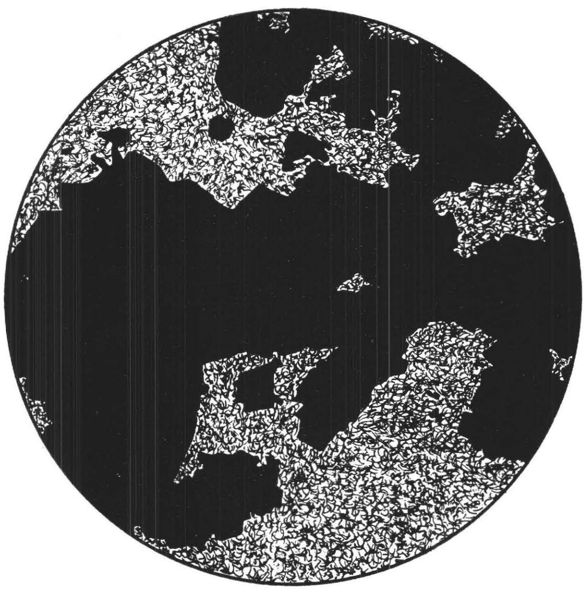
B. CINNABAR REPLACING CALCAREOUS CLAY MATRIX OF TWO-FORTY-EIGHT BRECCIA PIPE

Plain light, × 30.



C. CINNABAR REPLACING CLAY, MARIPOSA MINE

Clay (gray) contains minute scales of calcite. Plain light, × 130.



D. CINNABAR REPLACING CLAY

Specimen from dump of Little Thirty-Eight mine. Sketch, × 270.

PHOTOMICROGRAPHS AND SKETCH FROM PHOTOMICROGRAPH OF THIN SECTIONS OF CINNABAR ORE

grained rock composed mainly of tiny flakes of clay crystals, numerous small grains of quartz, and minute specks of hematite, and, if metallized, clusters of small cinnabar crystals. In the unaltered Grayson the clay is opaque under polarized light; that in the jaboncillo is sufficiently crystallized to have a "salt and pepper" appearance. The indices of refraction of the clay mineral are greater than that of canada balsam (1.54), as are those of the kaolinite group. The foregoing description is of jaboncillo formed from the Grayson formation from which the carbonate has been completely removed, and accordingly represents the maximum of alteration. Commonly alteration is not so nearly complete; partly altered Grayson formation may contain 20 percent or more of soluble carbonate. In order to evaluate the chemical changes involved in the formation of jaboncillo, C. P. Ross selected samples of this material and of the rock from which it appeared to have been derived and had them analyzed. These analyses, along with those samples collected by the writers are shown in table 13.

The analyses bring out differences in composition, both between and among the altered and unaltered clay of the Grayson formation, that require interpretation. A comparison of the analyses of samples 1, 3, and 5 demonstrates that there is considerable variation from place to place in the composition of the unaltered clay. Therefore, it cannot be assumed that sample 2 was derived from a clay chemically equivalent to sample 1, because the locations of the two sample localities are stratigraphically unrelated. Yet, it can be assumed with some assurance that sample 4 was derived from a clay chemically similar to sample 3, because these samples were collected from the same bed within a horizontal distance of 20 feet. All three unaltered clays are calcareous; but sample 1 contains 35 percent by weight of carbonates, sample 3, 50 percent, and sample 5, 27 percent. The remainders are largely clay and quartz, representing the alumina and silica of the analyses.

TABLE 13.—*Analyses of altered and unaltered clay from the Grayson formation*

	(1) Unaltered	(2) Altered	(3) Unaltered	(4) Altered	(5) Unaltered
SiO_2	39.76	63.10	27.38	20.60	45.03
Al_2O_3	14.29	20.84	9.51	7.02	16.23
Fe_2O_3	1.79	6.30	4.13	4.89	3.04
FeO	1.73	.14	------	------	------
TiO_2	.60	.63	1.78	1.60	1.12
MnO	------	------	.07	.14	------
CaO	17.49	.02	22.40	27.03	13.00
MgO	1.30	.02	4.75	5.94	2.15
Na_2O	.42	.36	------	------	------
K_2O	1.32	1.00	------	------	2.10
H_2O	5.46	7.87	[1] 4.54	[1] 4.66	6.25
S	------	------	[2] 1.66	[2] .08	------
CO_2	15.85	none	22.77	27.96	11.94
Hg	none	.08	none	[3] <.001	------
Cl	.05	.17	------	------	------
	100.06	100.53	98.99	99.89	100.86
			[4] −.62		
			98.37		

[1] Water by Penfield method, uncertain because hydrocarbons known to be present.
[2] Total sulfur reported as S. Acid soluble sulfates present in traces only.
[3] Fluorescent screen test for mercury by J. J. Fahey.
[4] Less O=S.

(1) Unaltered Grayson formation collected by C. P. Ross from the 50-foot level of the Mariposa mine. Analyzed by J. J. Fahey.
(2) Altered Grayson formation (jaboncillo) collected by C. P. Ross from the portal of the No. 5 tunnel of the Mariposa mine. Analyzed by J. J. Fahey.
(3) Unaltered Grayson formation clay collected by R. G. Yates and G. A. Thompson from a bed (same bed as sample 4) 3 feet above the base of the formation on the 50-foot level of the Mariposa mine at coordinates 100 S. and 500 E. Analyzed by Marie L. Lindberg.
(4) Altered Grayson formation collected by R. G. Yates and G. A. Thompson from the same bed as sample 3 and 20 feet closer to a cave-fill zone. Analyzed by Marie L. Lindberg.
(5) Unaltered Grayson formation collected by C. P. Ross from the road to the Mariposa mine in sec. 39, block G-12. Analyzed by Charles Milton.

Despite the great differences between the quantities of alumina and silica in the rocks, the ratios of alumina to silica are fairly constant throughout both altered and unaltered rocks, as can be seen from the following tabulation.

Sample	Al_2O_3 : SiO_2	*Average*
1	14.29:39.76 or 1:2.57	1:2.73 (Unaltered rock)
3	9.51:27.38 or 1:2.86	
5	16.23:45.03 or 1:2.76	
2	20.84:63.10 or 1:3.02	1:2.98 (Altered rock)
4	7.02:20.60 or 1:2.93	

The tabulation also shows that there is an average increase of about 9 percent in the quantity of silica relative to alumina in the altered rock over that of the unaltered rock. As all the alumina and only part of the silica are combined as clay minerals, in the ratio of 1 alumina to 1.18 silica in kaolinite in the altered rock and 1 alumina to 1.77 silica in beidellite in the unaltered rock, there is a far greater amount of free silica, as quartz, in the altered rock. Although the change from beidellite to kaolinite produces a decrease in the combined silica, making more silica available for quartz, it does not change the alumina:silica ratio of the rock unless there is an addition or subtraction of silica or alumina from the system.

It is obvious from a comparison of the analyses of samples 2 and 4 that these altered rocks are very unlike and therefore may have been produced by different processes. Sample 2 is a highly altered rock and sample 4 a mildly altered rock. Furthermore, the changes of alteration are different; carbonate was completely extracted from sample 2 and carbonate was added to sample 4; 20 percent over that in its unaltered equivalent. This may mean that carbonate gained by sample 4 is carbonate lost during the production of a rock similar to sample 2. That is, sample 4 is not a progressive step towards jaboncillo, but is an "aureole rock" enriched in carbonate given off from centers of more intense alteration.

The above interpretation is favored both by the analyses of samples 3 and 4 and by what can be seen in thin sections of sample 4. A thin section of sample 4 shows that carbonate replaced the clay. If the replacement process involved either the extraction of the total clay molecule or only alumina from the clay mineral, there would be a considerable change in the alumina:silica ratio of the rock, because about 40 percent of the total silica in the unaltered rock is in the form of quartz. However, if the replacement process involved the nonpreferential extraction of the total clay molecule and the quartz, which is intimately mixed with the clay as grains for the most part too fine to be resolved by the microscope, there would be no change in the alumina:silica ratio. This, apparently, is what happened; because the difference between the alumina:silica ratios of samples 3 and 4 is less than 2 percent—a difference that could well be a prealteration difference in the compositions of the two samples.

Because there is no appreciable difference in the alumina: silica ratios of samples 3 and 4, it is not possible to tell by the analyses whether the clay in sample 4 is mineralogically different from sample 3. If there has been either a complete or partial change from beidellite to kaolinite, the silica that was lost from the beidellite did not migrate from the rock, but is present as quartz, with a consequent increase in the free silica present.

SILICA MINERALS

Epigenetic silica, as quartz and chalcedonic quartz, is present in small quantities in the limestone-clay contact deposits, but it is not present in the calcite vein deposits in the Boquillas flags nor in the deposits in igneous rocks, with the exception of the occurrences of cinnabar in silicified rhyolite in Lowes Valley and Contrabando dome.

Irregular, elongate masses of jaspery silica occur as replacements of Devils River limestone at several places between the Mariposa mine and Black Mesa. They are small, being rarely more than 5 feet wide and 30 feet long. They are oriented along fractures in the limestone and are not to be confused with the chert nodules that are locally abundant in the same limestone. They consist of fine-grained quartz and hematite dust. No cinnabar has been found in association with these jaspery masses.

Locally the cave-fill is partly silicified to a moderately hard, coherent rock. The silica is in the form of microcrystalline quartz erratically distributed through the rock. No quartz veinlets or vugs were observed.

Silica minerals are more abundant on the west side of Lowes Valley than elsewhere in the district. Here both rhyolite and Devils River limestone are completely silicified, in some places so thoroughly that it is difficult to determine the original rock. The silica mineral is quartz, which ranges from cryptocrystalline to moderately coarse grained. Crosscutting veinlets of quartz of several generations are common. Cinnabar occurs along fractures in the quartz.

IRON MINERALS

The iron sulfides pyrite and marcasite and the iron oxides hematite and limonite are widely distributed in the Terlingua district. The oxides are most abundant in the limestone-clay contact deposits and the sulfides in the other deposits. Although marcasite was recognized at only a few places it may be fairly common, but at best it is much less abundant than pyrite. Most iron oxide is hydrous, but some has the crystal form and streak of hematite.

Pyrite, of both hydrothermal and authigenic sedimentary origin, is common. Hydrothermal pyrite is particularly abundant in the veins in igneous rock at Study Butte. Because it oxidizes rapidly, pyrite is not particularly evident on the surface or on the walls of old mine workings, but unweathered rock of diamond-drill cores taken from both the Boquillas flags and Grayson formation contains abundant pyrite. Its former abundance is attested to in many places by pseudomorphs of iron oxide after pyrite.

It is difficult to tell how much pyrite is authigenic sedimentary and how much was introduced hydrothermally during mineralization. The pyrite that is almost everywhere near the base of the Grayson formation is unquestionably in part authigenic, especially that which is in nodular and concretionary masses. Conversely, that which is in veins in igneous rock and the Boquillas flags is just as unquestionably hydrothermal. But some pyrite, as for example, disseminated cubic crystals in Devils River limestone and Boquillas flags, can be interpreted as having formed either hydrothermally or diagenetically with the enclosing sediments. In general, pyrite is most abundant in places where there is evidence of hydrothermal mineralization.

Pyrite is older than cinnabar in almost all cases where the two minerals were observed in determinable paragenetic relations. The one exception noted is an incrustation of pyrite on cinnabar that lined a fracture in igneous rock at the Study Butte mine. Elsewhere, cinnabar was seen as crusts on pyrite and as veinlets that cut through pyrite. Cinnabar was not observed, however, as a replacement of pyrite.

Marcasite was recognized, by its crystal form, at only the Chisos and Study Butte mines and not in sufficient abundance to determine its precise relations to the other minerals. Its association with hydrothermal minerals suggests that it is also such a mineral and may have been introduced about the same time as the pyrite.

Hematite and hydrous iron oxides are particularly abundant in the jaboncillo of the limestone-clay contact deposits and are common minerals in the other deposits. Small concretionary masses may have as much as 50 percent iron oxide, but most jaboncillo contains less than 10 percent. Most iron oxides, both hydrous and anhydrous, that were seen by the writers had no crystal form of their own but in many cases had assumed the crystal forms of pyrite or jarosite, which they pseudomorphed. However, some hematite seen by C. P. Ross (written communication) in the cave silt of the Little Thirty-Eight and Colquitt-Tigner mines is in distinct crystal plates, the form of crystalline hematite. In addition, the writers observed in a few thin sections of cave-fill from the Mariposa and Fresno mines, a few crystals of hydrated hematite in cubelike rhombohedrons and hexagonal plates typical of direct crystallization of hematite.

The red of the cave-fill results from fine particles of iron oxide that locally cloud the rock. Clouds of these particles are in many places arranged in bands that follow the bedding. The red of the cave-fill zones contrasts with the yellow-brown of the oxidized pyritic zone near the base of the Grayson in areas where no hydrothermal alteration has occurred. This suggests that the iron oxide of the quicksilver deposits was formed in part by the fluids that formed the ore minerals.

CINNABAR

Cinnabar is the most abundant ore mineral in all classes of deposits, although in a few ore shoots at the Mariposa mine it was exceeded by calomel and oxychlorides of mercury. It occurs as massive cinnabar in veins, as small grains and groups of grains disseminated through the gangue rock, as rare encrustations of crystals on rock surfaces, and most commonly as irregular replacements of the gangue rock. Megascopically, much of it appears massive, without crystal form, but microscopically, much of the massive cinnabar is seen to be aggregates of small, fairly well-formed crystals (see pl. 9).

Cinnabar is both a filling in previously existing openings and a replacement of rock and gangue minerals. Commonly only openings less than 0.5 mm. wide are completely filled with cinnabar, larger openings are only partly filled, and the very large openings rarely have encrustations of cinnabar on their walls.

The introduction of cinnabar by replacement processes was common in the Terlingua district. Most rich ore bodies, in particular those that contained large masses of high-grade ore, were formed in this way. In many places it is difficult to separate cinnabar formed only by replacement processes from that formed by processes of both replacement and filling. However, disseminated grains of euhedral cinnabar in limestone and clay are as clearly of replacement origin as partly filled fractures are of origin by filling. Aggregates of grains, with the angular outlines of bounding crystal faces, also suggest a replacement origin (see pl. 9*A–D*), as does the branching irregular form of much of the cinnabar. Cinnabar formed through replacement is commonly controlled by small fractures, from which the cinnabar extends outward. Disseminated cinnabar is never found far from cinnabar-filled fractures.

Cinnabar apparently replaced certain minerals more readily than others. Pyrite, iron oxides, and jarosite were not seen replaced by cinnabar, although it is possible that in places they are. Some cinnabar in thin section appears to have a cubic form suggesting pseudomorphism after pyrite. It seems more probable that these apparent cubes are square sections cut through nearly cubic rhombhedrons, a form not uncommon to cinnabar. Likewise, the hexagonal outlines of some cinnabar crystals found sparsely in the same thin sections with jarosite do not necessarily indicate that the cinnabar is pseudomorphic after jarosite; instead the section may be cut across a rhombohedron to produce a six-sided surface. Minerals most readily replaced by cinnabar are calcite and kaolinite, kaolinite being the more readily replaced. Cinnabar was not found in contact with fluorite; therefore the relative ages of the two could not be directly determined. Cinnabar found in the barite gangue at the McQuirk workings, south of the Mariposa mine, both veined and replaced the barite.

Cinnabar formed late in the mineralization of the deposits. It was preceded by kaolinite, by barite, by almost all the calcite and pyrite, and it was followed as well as preceded by hydrocarbons. Its relation to the other mercury minerals is not clear. The writers had the opportunity to examine only one specimen in which cinnabar occurred with the chloride or oxychlorides of mercury. In this specimen the apparent resting of a crystal of cinnabar on a corroded surface of calomel suggests that cinnabar is later than calomel.

MERCURY MINERALS OTHER THAN CINNABAR

A greater variety of mercury minerals have been found at the Mariposa mine than anywhere else in the world. Of the 15 mercury minerals listed by Dana, 8 are found here and these, exclusive of cinnabar, are: native mercury, calomel, eglestonite and terlinguaite, montroydite, and kleinite and mosesite. They represent the native element, the chloride (calomel), 2 oxychlorides (eglestonite and terlinguaite), the oxide (montroydite), and 2 complex ammonium chlorides (kleinite and mosesite). In addition to those 8 minerals, metacinnabar has been reported by Hill (1902

p. 28–29), but this mineral was not seen by the writers nor by C. P. Ross (written communication).

Although larger quantities of most of the foregoing minerals have been found in the Terlingua district than elsewhere, they were never abundant even here, and, with the exception of native mercury, determinable specimens have been found only in the limestone-clay contact deposits. They were most abundant at the Mariposa mine, but calomel and the oxychlorides, as well as native mercury, were found in lesser amounts in neighboring mines and prospects. During recent years it has become increasingly difficult to find even specimen samples in the mine workings or on the dumps. The writers, however, were fortunate in obtaining some good specimens from a pocket in the Perry pit (see pl. 13) during the winter of 1945. These specimens did not contain any cinnabar, although cinnabar was the principal ore mineral taken from this pit.

These rare mercury minerals are commonly regarded as formed by supergene processes, but it is very probable that most of them were formed by hypogene processes. Important evidence for this belief is presented by C. P. Ross who says (written communication) of these minerals:

Most chloride minerals in deposits of metallic ores are of supergene origin and it might therefore be assumed that this group of seven rare quicksilver minerals [mentioned above], which are closely related to each other, have such an origin. In this instance, however, chlorine and ammonium compounds might equally well have been present in the ground water with which the ascending quicksilver solutions are believed to have mingled. As such materials are common constituents of hot-spring waters it is also entirely possible that the ascending solutions themselves contained sufficient Cl and NH_3 to account for the formation of the minerals containing them. The kleinite and mosesite, according to the descriptions above cited [see footnote 7], furnish direct evidence that they were formed at temperatures well above those to be expected during weathering. Optically a basal section of kleinite, which is hexagonal, shows double refraction, but on heating to about 130°C it becomes singly refracting, being uniaxial, positive. This indicates dimorphism and a temperature of formation above 130°C. Similarly mosesite has the form of an isometric mineral but at ordinary temperatures shows double refraction. On heating to 186°C the crystals become isotropic in accord with their form. That is, mosesite crystallized at an elevated temperature in isometric crystals (which are optically isotropic) and changed to the dimorphous, doubly refracting condition at temperatures below 186°C. It seems obvious therefore that weathering would not take place at temperatures well above the boiling point of water and hence that kleinite and mosesite must be hypogene minerals and are not products of weathering.

[7] Descriptions cited refer to work of Canfield, Hillebrand, and Schaller (1910, p. 206-208) on mosesite and Hillebrand and Schaller (1910, p. 46). It was found that mosesite had an isometric form and was anisotropic but became isotropic on heating to 186°C and that kleinite, a hexagonal mineral, was doubly refracting in basal section but became singly refracting on heating to 130°C. The preparation of artificial mosesite by Switzer and others (1953) at 25°C casts some doubt on the validity of the conclusion that these inversions represented minimum temperatures of deposition.

Ross points out that chlorides of mercury are commonly present in small amounts in many cinnabar ores, although this fact is not well known.

J. J. Fahey tested 20 samples of ore and altered rock associated with ore from 9 mines in the Terlingua region. Of these, 11 contained no detectable quicksilver. All but one of those containing the metal had part of it as mercurous chloride, although only one of the samples tested show visible amounts of any of the chloride minerals. Samples 2 to 7 inclusive [table 14 of this report] have much of their quicksilver as cinnabar. The others do not have detectable amounts of this mineral. Specimens of cinnabar ore in the U. S. National Museum from Alaska, Arizona, Arkansas, California, and Nevada were also found by Fahey to contain quicksilver as chloride (Ross, 1935b). * * * In order to make these determinations Fahey (1937) devised special methods of distillation. The distinction between sulfide and chloride would not be made by ordinary assay methods. The methods employed are such that all the chlorine present as a compound of quicksilver minerals was determined. Such chloride sublimates in the form of mercurous chloride and the results are reported in terms of this substance. Any chloride present as sodium chloride and similar substances would be nonvolatile at the temperatures employed and would not affect the results reported.

Ross's table follows:

TABLE 14.—*Mercury chloride content, in percent, of samples from the Terlingua region*

[Determined by J. J. Fahey]

	Total quicksilver (Hg)	*Mercurous chloride (Hg_2Cl_2)*
1. Altered rock from portal of No. 5 tunnel, Mariposa mine	0. 08	0. 07
2. Study Butte mine	20. 90	. 06
3. Chisos mine	7. 48	. 05
4. Ore, 600-ft level, Rainbow mine	4. 12	. 22
5. High-grade ore from lowest stope in Rainbow mine	36. 20	none
6. Ore, Mariposa mine near Cruz shaft	74. 04	1. 20
7. Upper level, Mariscal mine	28. 16	. 22
8. Cave-fill in lower stope, Little Thirty-Eight mine	. 60	. 05
9. Chloride ore from prospect south of California Mountain	1. 13	. 28

Ross's conclusion that the rare mercury minerals in the Terlingua district were not formed by supergene waters is supported by the complete lack of etching, pitting, or any other solution features on any cinnabar crystals that were examined by the writers. The observed cinnabar has crystal faces that are sharp, smooth planes that show no effects of resolution. If cinnabar had been the only hypogene ore mineral and all the others had been derived from it by supergene processes, it is indeed remarkable that none of the crystals examined showed the effects of solution by the postulated supergene waters. Also, it is difficult to understand how descending waters, which would have been high in ferrous sulfate and sulfuric acid derived from the decomposition of iron sulfide, could have dissolved the cinnabar, a mineral that is considered almost insoluble in such waters.

The rare mercury minerals were deposted dominantly in open spaces and apparently did not replace any previously formed material. In this they differ from cinnabar. Calomel, kleinite, mosesite, eglestonite, and terlinguaite all occur in well-developed crystals. Calomel forms veinlets and crystal encrustations on solution and fracture surfaces in limestone and cave-fill material. The other minerals were not observed in veinlets, but otherwise occur similar to the calomel. Montroydite occurs as hairs and growths and as needlelike crystals along the cleavage planes of calcite. Minerals commonly associated with them are kaolinite, calcite, gypsum, and iron oxides, which are the same minerals associated with cinnabar. Native mercury is commonly associated with montroydite, but the reverse is not true.

Age relations within this group of minerals are not too well established. Calomel appears to be the oldest and native mercury and montroydite the youngest, although at least some montroydite is older than terlinguaite. Mosesite, kleinite, terlinguaite, and eglestonite occupy an intermediate position and at least locally form in this order.

Age relations between this group and cinnabar are less well known. From evidence cited in a preceding paragraph it is believed that cinnabar is younger than all except the native mercury and montroydite. Other reasons for believing this are discussed under the origin of the deposits.

HYDROCARBON COMPOUNDS

Bituminous matter (or hydrocarbon compounds) is in minor quantities in all the quicksilver deposits and is particularly abundant in the Two-Forty-Eight mine. It occurs as a yellow to brown pigmenting material in vein calcite, as a glossy black, brittle to plastic substance in small veinlets, and as a dull black material that impregnates rock fragments and fault gouge. Its distribution is closely associated with that of the quicksilver deposits.

C. P. Ross collected three kinds of bituminous material from the Two-forty-Eight mine and a sample of bituminous calcite from the Study Butte mine and had them examined in the Geological Survey. The results of the examinations (table 15) and the interpretation of the results given by Ross (written communication) follow:

E. T. Erickson, who did the work, states that the proportion and character of the saturated hydrocarbons is similar to that given by asphaltic bitumens that have been derived from petroleum and that there is sufficient resemblance in the four samples to suggest that the petroleums from which they originated were similar in nature. As some paraffin is present in the samples, the originating petroleums may have had a tendency towards a mixed base (asphaltic paraffin) composition. The percentage of saturated hydrocarbons in all the samples is critically higher than that of gilsonite and grahamite (Richardson, 1916, p. 493). The distillate from specimen BC 68, according to Erickson, is sufficiently different from the others recorded in the table to indicate that it has suffered less modification than they have. It contains asphaltic oil and some paraffin and hence is apparently not fundamentally different from the other bituminous materials tested.

TABLE 15.—*Analyses of bituminous material from the Terlingua district*

[Analyst, E. T. Erickson, Geological Survey, February 27, 1935]

Sample	Weight of sample (grams)	Asphalt bitumen extracted by heating with chloroform (percent of sample)	Fractions resulting from treatment of asphalt bitumen with an excess of light petroleum ether (boiling point 30°–60° C)						
			Insoluble fraction [1]				Soluble fraction		
			Percent	Softens at—(° C)	Flows at—(° C)	Sulfur (percent of fraction)	Saturated hydrocarbons (percent) [2]	Qualitative indication of paraffin [3]	Chiefly unsaturated hydrocarbons (percent)
TT 66	1.002	75.5	28.7	165	175	1.25	22.2	Fairly positive	49.1
TT 22	5	21.7	44.7	160	170	1.50	16.2	Smaller than TT 66	39.1
TT 23	42.06	1.88	46.3	180	190	1.61	19.9	Smaller than TT 66	33.8
TT 52	19.21	4.77	30.8	160	170	1.32	26.8	Fairly positive; similar to TT 66.	42.4
BC 68	75	.07	----	----	----	----	----	----	----

[1] Generally black and highly viscous.
[2] Viscous amber-colored oil.
[3] About one-tenth gram of the saturated hydrocarbon material in a test tube was dissolved with 2 cc of ether, an equal volume of absolute alcohol was added, and the test tube was then placed in an ice-salt freezing mixture. In the "fairly positive" test light-colored flocculent material distinctly appeared (in about 15 minutes) in the solution. In TT 22 and TT 23 the quantity of the precipitated material was less. The fractionation of the extracted bitumen with light petroleum ether and the determination of saturated hydrocarbons are by methods described by Clifford Richardson in chapter 28 of the "Modern asphalt pavement" 2d ed., 1908, John Wiley & Sons, New York.

TT 66. Plastic asphalt from the Two-Forty-Eight mine.
TT 22. Dull massive asphalt impregnating sedimentary rock from the Two-Forty-Eight mine.
TT 23. Calcite impregnated with bituminous material. From the Two-Forty-Eight mine.
TT 52. Asphalt in rock from the Study Butte mine.
BC 68. Carbonaceous shale from near the base of the Boquillas flags in the northeastern part of sec. 300, Block G-4.

In order to determine whether the bituminous material could be of local origin, Ross collected samples of Boquillas flags and Terlingua clay and had these samples analyzed for possible hydrocarbon content. Only one, BC–68 of the preceding table, a carbonaceous shale from the lower part of the measured section of Boquillas flags in the northwestern part of sec. 300, Block G–4, yielded an appreciable amount of bitumen. Of the hydrocarbon in this specimen Ross says (written communication):

> A portion of specimen BC–68 weighing 75 grams was treated by Erickson with redistilled chloroform and yielded 0.07 percent of amber brown, viscous material upon evaporation of the chloroform solvent. When this was heated with an excess of light petroleum ether, 9.7 percent of an insoluble dark solid bitumen was obtained. The filtrate from this treatment after prolonged heating and retreating with light petroleum ether yielded an additional 14.3 percent of the dark insoluble substance. The filtrate from this treatment was found to contain a small amount of paraffin. These tests show that the bituminous material in the carbonaceous shale is in general similar to that in the four specimens listed in [table 15] except that in the shale there has been less alteration as evidenced by the smaller quantity of material insoluble in light petroleum ether.

The only sample of unmineralized rock that yielded measurable amounts of bitumen was taken from rocks that are stratigraphically and structurally above many of the quicksilver deposits that contain the most bitumen. There are, however, limestones and shales of Cretaceous and Paleozoic ages that lie beneath the lowest known quicksilver deposits and that were not sampled and tested for possible bitumen. King (1937, p. 143) states that the pre-Carboniferous rocks of the Marathon Basin contain abundant bituminous material.

Regardless of the ultimate source of the bituminous material, much of it was deposited definitely later than the cinnabar, as tar is found coating the surface of cinnabar in vugs. On the other hand, it is very possible that some bitumen was deposited earlier than the cinnabar. This conclusion is indicated by the bitumen that is dispersed through calcite that is itself earlier than cinnabar. It seems possible, however, that bitumen may have impregnated the calcite along submicroscopic cracks and cleavage planes at some time after it was formed, and the bitumen is therefore not necessarily contemporaneous with the calcite. Another possibility that must be considered is that bitumen may have been introduced into the deposits during an early phase in their formation and was redistributed throughout mineralization.

FLUORITE AND BARITE

Many of the quicksilver deposits in the west-central part of the district contain small amounts of fluorite and barite. These two minerals, which are more commonly found apart than together, were seen only in deposits in the Devils River limestone and not in deposits in any higher stratigraphic units. Their relative ages were not determined. Barite is most abundant at the McGuirk workings, south of the Mariposa mine, and fluorite at the surface workings of the Little Thirty-Eight mine.

The fluorite forms single, euhedral cubic crystals and clusters of crystals commonly enclosed in a matrix of clay and calcite or studded on fracture and solution faces of limestone. It ranges from colorless to pale yellow-brown and generally is very transparent. A specimen of cave-fill collected from the dumps of the Little Thirty-Eight mine contains pseudomorphs of calcite after fluorite. A thin section of this specimen shows the partial replacement of the fluorite by the calcite. This is the only evidence obtained that indicates that at least some calcite was later than the fluorite. Age relations between fluorite and other minerals was not obtained.

Barite forms nodular masses (in the cave-fill) and euhedral crystals, which range from white to pale yellow-tan. The best formed crystals are in vugs in the limestone. The white, massively crystalline barite appears to be somewhat earlier than the pale yellow-tan. In places calcite replaces and veins barite; the reverse relation was not noted. The barite in the nodular masses is white to gray and cryptocrystalline. Contraction cracks in the nodules suggest that this barite may have a colloidal origin.

One specimen, presented to the writers by Frank Duncan, excellently demonstrates the relation between barite and cinnabar. Megascopically this specimen is mainly fine-grained, grayish-white barite through which are disseminated irregular aggregates of cinnabar. One surface of the specimen is covered by a druse of yellow-tan barite crystals, which is separated from the grayish-white barite by a black layer. The black layer is barite colored by inclusions of hydrocarbon. The skeletal arrangement of the hydrocarbon inclusions indicates that they were deposited during the growth of the barite crystals. A few tiny veinlets of white to yellow-tan barite extend from the drusy barite through the grayish-white barite. Cinnabar is not in these barite veinlets nor is it in the drusy barite above the black layer of hydrocarbon inclusions.

The foregoing facts, derived from a study of the hand specimen, lead one to interpret the paragenesis as a continuous deposition of barite, accompanied in its early stages by deposition of cinnabar, a deposition which ended when hydrocarbons were deposited with the later yellow-tan barite. Microscopic examination of a thin section of the specimen confirms the above facts, but rejects the above interpretation. Megascopic examination did not show that the grayish-white barite is a replacement of kaolinite and that it is locally crowded with kaolinite inclusions, whereas the drusy barite and barite veinlets were deposited in open spaces and are accordingly free of kaolinite inclusions. The microscopic examination shows that the distribution of cinnabar is controlled by the distribution of unreplaced kaolinite, which it replaces. The cinnabar not only replaces the kaolinite but also replaces, to a much lesser extent, the barite, as is indicated by replacement veinlets of cinnabar that extend from cinnabar-replaced kaolinite along fractures into the barite. These additional facts support the correct interpretation that the cinnabar was deposited after the barite.

NATROLITE AND ANALCITE

Two members of the zeolite group of minerals, natrolite and analcite, were found—but not together—in two quicksilver deposits in widely separated areas. Natrolite was found in cinnabar ore from the main stope of the Fresno mine in the extreme western part of the district, and analcite was found in collapse breccia that contains cinnabar in the Two-Forty-Eight mine in the eastern part of the district. Both minerals are common in the intrusive igneous rocks, with which they are genetically related as late magmatic minerals. Their presence in the quicksilver deposits is believed to be fortuitous and unrelated to the quicksilver mineralization. This belief is corroborated by their great abundance in the igneous rocks and their great rarity in the quicksilver deposits. Both minerals are earlier than the cinnabar of the deposits in which they occur.

Natrolite is associated with the quartz that has been described in the Fresno mine. The natrolite and associated quartz is in a breccia composed of angular fragments of limestone and calcite in a clay matrix. The natrolite, seen only in thin section, is in typical radiating crystals in what appears to have beer an open space. It is fractured, and a little cinnabar replaces the natrolite along the fractures.

Analcite is very abundant in the upper levels of the Two-Forty-Eight mine, where it is in a hydrocarbon-impregnated breccia of limestone and clay. It was not observed in the lower levels of the mine, except in the analcite syenogabbro that intrudes the breccia. The analcite in the collapse breccia is in euhedral crystals, as much as 5 millimeters in diameter, but that in the syenogabbro has no crystal form, being present mainly as replacement of feldspar. The analcite crystals commonly are fractured. Most are fairly clear, but some are stained light brown by hydrocarbon and others contain inclusions of titanite in haphazard arrangement. Most crystals when examined microscopically show a faint birefringence.

Although cinnabar was not seen in contact with the analcite, indirect evidence indicates that the analcite formed before the cinnabar and probably has no relation to it. Both the analcite and the cinnabar are younger than the breccia pipe. The analcite replaces the clay matrix and breccia fragments and the cinnabar is controlled by fractures formed during and after the filling of the pipe. The igneous rock is later than the breccia pipe, which it intrudes, and as the cinnabar is in the igneous rock, as well as the breccia, it is therefore later than both. Analcite is contemporaneous with the analcite syenogabbro, as it is a late magmatic mineral in that rock. Accordingly, it seems logical to interpret the analcite in the breccia as derived from the analcite syenogabbro during its final cooling. This proposed correlation between the analcite in the intrusive igneous rock and the analcite in the breccia is supported by the titanite inclusions in the analcite of the breccia. Pseudomorphs of leucoxene after ilmenite are abundant in the igneous rock, and this alteration of the ilmenite appears to be contemporaneous with the analcite. This indicates that the titanium of the ilmenite was reorganizing into leucoxene (for the most part to be identified with titanite) at the same time that analcite was forming in the igneous rock. Because similar relations existed between the analcite and titanite in the breccia, it is reasonable to assume that the analcite of the igneous rock is contemporaneous with the analcite of the breccia. The most unlikely possibility that the analcite of the breccia pipe was derived from the analcite of the igneous rock by being dissolved by the mineralizing solutions and redeposited by them, however, cannot be precluded from the evidence at hand.

SULFATES

With the exception of barite, which has been described above, the sulfate minerals that were identified in the quicksilver deposits are anhydrite, gypsum, melanterite, epsomite, alunite, and jarosite. Gypsum, melanterite, and epsomite are hydrous sulfates formed by the weathering of the deposits, and as the latter two are unrelated to the mineralization they will not be mentioned again. The anhydrite, alunite, and jarosite may also have been formed by weathering processes, but it is possible that they were formed in part by hydrothermal processes.

Gypsum is a very common mineral and is particularly abundant in the limestone-clay contact deposits. It forms veins in clay, limestone, and cave-fill, coatings on rock surfaces, and impregnations in porous rock. In some limestone caverns a snow of fine, powdery gypsum covers the walls and floors of the caverns; in others, beautiful, curved, stalactitelike "crystals" as long as 1 foot hang suspended from the roofs.

Some gypsum is forming at the present day through the reaction of sulfate ground water, produced by the oxidation of pyrite, with the limestone. Probably most, if not all, the gypsum was formed in a similar way and is postcinnabar in age. The possibility remains, however, that some gypsum was formed contemporaneously with the cave-fill and breccia pipes, which are definitely preintrusion and precinnabar, but this possibility seems remote.

The presence of anhydrite, found in small veinlets in limestone at the Mariposa mine, suggests that some gypsum may have formed by the hydration of this mineral.

C. P. Ross collected "a bright yellow more or less pulverulent material from the surface close to the west end of the Study Butte mine, which was found by W. T. Schaller to be a mixture of jarosite and alunite with a little lead." Hillebrand and Schaller (1909, p. 17) report jarosite in a brown brecciated mass sent to them by W. B. Phillips, who reported its being collected from sec. 100 in Block G–12. As there is no sec. 100 in Block G–12, the specimen probably came from sec. 100, Block G–5, on the northwest side of Lowes Valley, a locality from which the writers collected similar specimens. The writers also found jarosite in altered limestone and clays from the Fresno, Mariposa, and Chisos mines. When judged by the material examined microscopically, jarosite appears to be a mineral widely distributed in the altered rocks of the Terlingua quicksilver district.

The jarosite in Lowes Valley is in crystals (as much as 0.5 millimeters in diameter) in a brecciated and altered rhyolite. The jarosite crystals line and fill vugs and form boxwork septi that join the breccia fragments. The crystals range from a light yellow-brown to a dark resin brown.

The jarosite in the altered limestones and clays throughout the district occurs in minute grains that can only be recognized with the aid of the microscope. Many grains have been altered to limonite but still retain the characteristic hexagonal basal section of jarosite.

Some alunite and jarosite in the Terlingua district is an oxidation product of pyrite, but the writers were unable to tell whether this oxidation occurred early in mineralization or during the present weathering cycle.

SUMMARY AND CONCLUSIONS

Although the preceding mineral descriptions are meager in data that directly show the age relations among the various minerals, they contain enough direct evidence to give, when supplemented with indirect evidence, a fairly complete history of the quicksilver mineralization. However, gaps in this history do appear, gaps that cannot be closed by the combined direct and indirect factual data. In such cases, the writers have bridged the gaps with inferences, which are clearly labeled as such.

The history of mineralization is divided into two general periods, the first characterized by the deposition of nonmetallic minerals and the second characterized by the deposition of metallic minerals. How closely related these two periods are can only be inferred, for there are no minerals whose deposition was restricted to a period transitional between the period of nonmetallic minerals into the period of metallic minerals. The deposition of hydrocarbons during both periods, however, does suggest—but does not prove—that there is a close genetic relation between the two periods, even though the acmes of mineral deposition in each may be widely separated in time. Minerals that were formed during the period of nonmetallic minerals are: kaolinite, iron oxides, silica minerals, fluorite, barite, and possibly alunite, jarosite, and anhydrite. Minerals that were formed during the period of deposition of metallic minerals are: calomel, mosesite, kleinite, pyrite, cinnabar, and possibly the oxychlorides and oxide of mercury. Minerals that formed during both periods are calcite and hydrocarbons.

The period of nonmetallic minerals begins with the formation of kaolinite, iron oxides, and silica minerals, and ends with the deposition of fluorite and barite. The kaolinite, iron oxides, and silica minerals were probably formed almost contemporaneously. The iron oxides could have formed from the authigenic sedimentary pyrite in the Grayson formation. The silica in the cave-fill may have been formed at least in part from the breakdown of beidellite into kaolinite, but it is not possible to tell whether the jaspery silica in the Devils River limestone was deposited at this time. Nor is it possible to tell whether the deposition of barite and fluorite were in part contemporaneous with kaolinite or were entirely later. Both minerals replace kaolinite, but this does not mean that kaolinization was complete before their introduction. Another gap is the age relation between barite and fluorite. From possible temperatures of formation of these minerals it is inferred that fluorite was deposited first. This, of course, is based upon the assumption that the period of nonmetallic minerals was a period of falling temperatures. The position of alunite, jarosite, and anhydrite is doubtful.

The period of metallic minerals includes the deposition of calcite in varying intensity throughout its entire duration. The deposition and recrystallization of calcite occurred, however, during the period of nonmetallic minerals and probably reached its acme during the closing stages of this period. It is doubtful that calcite deposition continued uninterrupted into the period of metallic minerals. Most calcite was certainly deposited before the pyrite and cinnabar. The relations between pyrite and cinnabar are clear; cinnabar was not deposited until pyrite deposition had almost ceased. The age of the hydrocarbons, unfortunately, is not so clear; some hydrocarbon is as old as the barite and some is younger than the cinnabar. These relations suggest that the hydrocarbons may have been deposited during most of the mineralization, and that found in the calcite may be contemporaneous with it and not introduced at a later date.

Age relations within the chloride group of minerals are fairly well demonstrated in the specimens examined, but the relations between this group and cinnabar are not positively determined from the study of the specimens. The probable sequence within the chloride group is calomel (oldest), mosesite, kleinite, terlinguaite, and eglestonite (youngest). Montroydite and native mercury in some specimens are younger than terlinguaite. Mercury is enclosed as globules in all the calomel, a fact which suggests that deposition of this mineral may have been early as well as late, if not continuous. Cinnabar appears to be younger than calomel in the one specimen that showed these minerals in contact.

Some minerals found in the deposits are truly supergene. Among these are gypsum, some of the hydrous iron oxides, aragonite, and probably some montroydite and some native guicksilver. Some alunite and jarosite may also be of supergene origin.

ORIGIN

The writers believe that the quicksilver deposits were formed by hydrothermal solutions and associated gaseous phases. The heat and part of the water are believed to have come from a magma of unknown depth and unknown composition. The source of the quicksilver is problematical; it may have come from a magma or it may have been distilled by magmatic heat from overlying sedimentary rocks. The postulated "ore-bearing" fluids migrated towards the surface along interconnected openings of rock fractures that they enlarged. Parts of these channels in suitable environments became host structures for the deposits. Potential host structures were probably no deeper than 2,000 feet below the surface and were where openings were smaller than average. The writers believe that the ore minerals were deposited at temperatures below 300°C and pressures locally at least as high as 30 atmospheres and that the mercury was probably transported at least partly in a gas phase and was deposited as both chlorides and sulfide. The common gangue mineral, calcite, was probably deposited by carbonic acid waters that dissolved calcite from limestones, transported it as the bicarbonate, and deposited it as calcite under conditions of reduced pressure.

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STRUCTURAL CONTROL

The term "structural control" as ordinarily used refers to the structures that directly controlled the deposition of the ore elements; as used in this report it is broader in scope and refers to structures that gave access to and determined the routes of the fluids that transported the ore and gangue elements from their source to their place of deposition. With this broad definition it is possible to discuss structural control under three headings: regional control, district control, and local control.

REGIONAL CONTROL

The Terlingua district, the Mariscal district, and occurrences of cinnabar at Christmas Mountains, Mesa de Anguila, and across the border in Mexico, constitute a metallogenic province. The province requires some explanation, or at least invites some speculation.

Regional controls for metallogenic provinces must necessarily be highly theoretical and can only be proposed after the geologic features of a large number of similar provinces are compared and interpretations are made from those features that are common to all or to nearly all. The quicksilver deposits of the United States and the rest of the world have, with few exceptions, the common characteristic of being in regions where there were earth movements and volcanic activity at no great geologic time before quicksilver mineralization.

The Big Bend region, like most other quicksilver provinces, is a region where structural movements, igneous activity, and quicksilver mineralization are interrelated in time and space. As stated in preceding sections of this report, structural movements and igneous activity are closely related; igneous activity has produced not only local but district structures. Because the exposed igneous rocks are not the direct source of the mercury minerals, it may be postulated that both igneous rocks and mercury minerals were derived by processes of differentiation at depth from a common magma. An alternate hypothesis is that the magma was not the source of the quicksilver but was only the source of heat that distilled quicksilver from deep-seated sedimentary rocks. The magma must have underlain much of the Big Bend region because related igneous rocks are widespread. The quicksilver deposits, however, are restricted to a small area and therefore the mere presence of the underlying magma was not all that was essential for their formation.

The factors that determined the location of the quicksilver province within a particular part of the

Big Bend region can only be speculated upon. If the quicksilver had a magmatic source, there may have been a certain local differentiation of the magma that permitted a localized migration of the mercury; there may have been certain structural conditions that permitted the mercury to be concentrated as mercury minerals in restricted channels and not diffused into the rocks or lost in the ground water; or there may have been a certain critical thickness of rocks overlying the magma that permitted the mercury to be concentrated and preserved. All these possibilities, as well as others that might be suggested, are difficult to weigh. If the quicksilver was caused to migrate from a nonmagmatic source by magmatic heat, any of these factors but the first might account for the location of the province.

DISTRICT CONTROL

The district control is more tangible than the regional control. The district is closely related in space to the west-striking Terlingua monocline but not closely enough for the relation to be direct. Reasons for this have been pointed out on page 53. The writers believe that the quicksilver district and the monocline were both controlled by the same underlying structure, which was either an intrusive body or a structure that controlled an intrusive body. The Terlingua monocline is, nevertheless, the exposed expression of this postulated structure and therefore indirectly controls the location of the quicksilver belt.

There is only a general and not a close space relationship between the quicksilver belt and the monocline. Although both have general east-west trends and are roughly parallel for much of their lengths, the monocline swings northwestward at its west end and is crossed by the quicksilver belt, which maintains its straighter course. The quicksilver deposits are not on the monocline but, with a few exceptions, are updip from it. However, the northeasterly fractures that control the location of individual ore bodies, although not restricted to the belt, are more abundant there and their distribution and trends appear to be related to the monocline. South of the monocline these northeasterly fractures are subordinate in number to northwesterly fractures; immediately north of the monocline and within the quicksilver belt the situation is reversed, the northwesterly fractures, although individually stronger, are subordinate in number to the northeasterly fractures. North of the quicksilver belt the number and strength of northeasterly and northwesterly fractures is about equal.

These relations between the monocline, fractures, and quicksilver belt are best developed in the west-central part of the district, where the Devils River limestone is the exposed rock. Although comparisons are being made between areas where the different fracture patterns are in rocks of different physical properties, this should not seriously affect the validity of the comparison, because the relative abundance of the trends should remain constant regardless of the different strengths of the rocks.

The uneven distribution, or "bunching," of the deposits within the belt cannot be correlated with particular variations in steepness or local trends of the monocline nor with the grabens that breach the monocline. However, the belt may have been more evenly mineralized than the mine locations indicate, because some deposits doubtless have been eroded away and others probably have not been discovered.

From the foregoing it is obvious that the belt does not coincide with a major structural high, and it is equally obvious that the more intensely mineralized parts of the belt (pl. 1) do not correspond with local highs. On the contrary, some of the more productive mines, notably the Mariposa and Fresno, are in areas that are structurally depressed, and others, such as the Chisos-Rainbow, are on the borders of depressed areas. These facts do not support the views of Udden (1918), who has applied the anticlinal theory of petroleum accumulation to the Terlingua quicksilver deposits.

The almost constant association between rock fractures and the quicksilver deposits indicates that fracture openings were the best available channels for the ascending ore-forming fluids. The quicksilver deposits occur in association with the system of northeasterly fractures, probably because these fractures were, at the time of mineralization, the most open connections between deeper channels of the fluids and either the surface or the circulating ground water.

LOCAL CONTROLS

Local controls are the structures with which the ore bodies are directly associated. They are the structures of those parts of the channels where the mercury minerals were deposited. Unfortunately, the term, "local control," connotes that wherever similar structures are, ore bodies should also be. This is misleading because other factors besides structure controlled the deposition of the ore minerals.

Structures that had a local controlling influence on the location, shape, and size of the ore bodies are rock fractures, cave-fill zones, and breccia pipes. Obviously many potential ore structures were not available to the mineralizing fluids and are consequently barren. Likewise, the mineralizing fluids probably circulated through many favorable structures that were not mineralized because not all the conditions essential for deposition were present.

The controlling fractures are faults and joints, which are either single, multiple or complex. The single fractures are joints or faults of small displacements. The multiple fractures are sheeted zones of closely spaced shears and faults that have multiple planes of movement. The complex fractures are intimately sheared fault zones and breccia zones along faults. Single fractures indirectly controlled the location of many of the ore bodies by providing access channels to other structures, notably the limestone-clay contact deposits, but only at a few places were ore bodies formed within a single fracture opening. Multiple fractures are fairly abundant, especially where refracturing of calcite veins produced multiple fractures for the deposition of the cinnabar. Complex fractures are the least abundant of the controlling fractures; a few ore bodies occur in fault breccia zones, but they are not common.

Fractures with little or no movement along their walls are more favorable ore structures than are faults with considerable displacement. No ore bodies, except a few small ones at the Chisos mine, have been found along any of the major faults. It is true that many ore bodies in calcite veins in the Boquillas flags formed along faults, but few, if any, of these faults have displacements greater than 20 feet. This apparent favoritism for minor instead of major fractures is usually explained on the basis of the relative permeabilities of the two structures. Presumably the greater the movement along the fracture the greater the tendency for the original irregularities to be planed off and the open spaces filled with tight gouge and breccia. This generalization might account for the preferences seen in the Terlingua district.

Many fractures in the limestones have been enlarged by solution along their walls, but the large, open fractures so produced were not favorable for the deposition of mercury minerals. Such enlarged fracture openings, and associated large caverns, are best developed in the Devils River and Buda limestones. Many of these were filled with calcite or clay, but a good many are still open and cavernous. The rare cinnabar that is found on calcite lining these openings indicates that they were open during quicksilver mineralization and hence available to the ore fluids. None of them, however, were filled with mercury minerals. This lack of deposition of cinnabar in large openings has been noted by Beyschlag, Vogt, and Krusch (1914, p. 459–460) who, in speaking of quicksilver deposits in general, say: "With the cinnabar deposits on the other hand the filling of the fissure up which the quicksilver solutions ascended usually plays but a small part, impregnation of the country rock being the principal form of the occurrence." In speaking of "impregnations of the country rock" these writers refer to the filling of pore spaces in sandstone and the openings in fractured limestone—all relatively small openings. This preference for small openings is particularly true in the Terlingua district, because it is rare for an opening more than 1 inch wide to contain cinnabar.

The mode of formation of the calcite veins produced openings of a size favorable to quicksilver mineralization because the volume of open space never became very large. Filling of these fractures by calcite was accompanied by intermittent movements along the fracture walls and through the calcite previously deposited. The calcite vein not only prevented the walls of the fracture from closing, but the surfaces of rupture developed through it acted as gliding planes for movements parallel to the walls of the fracture. Where the planes of rupture were irregular surfaces, movements along them tended locally to dilate the walls of the vein and produce open spaces between planes of rupture. These open spaces became filled or partly filled with calcite, and as the process was repeated the walls of the original fracture became farther and farther apart. By such a mechanism the walls of the original fracture were dilated with no appreciable increase in the volume of open space. A sheeted structure of multiple fractures resulted, and the open space was distributed along numerous shear planes. This kind of broken rock appears to be favorable for the deposition of cinnabar.

The relative volume of the channel apparently was not nearly so important in determining the place of deposition as the ratio between total volume of open space and total surface area of channel walls. The rarity of cinnabar in single fracture openings wider than half an inch and its common presence in zones of multiple fractures and breccia-clogged fractures attests to this. Lovering (*in* Newhouse, 1942, p. 6) made an even broader generalization by stating that replacement deposits in general are commonly associated with tight fissures rather than with open fractures. This applies to the limestone-clay contact deposits, even though most but not all the ore is of replacement origin. A restatement of the above is that any channel with a large surface area and relatively small open space is a more favorable environment for the deposition of cinnabar than a channel with a relatively small surface area and a large open space. There is, of course, a lower limit to the size of openings to which this generalization can be applied.

These two factors, surface area and contrasts in channel cross section, have their greatest influence over the stability of circulating fluids where the openings are of capillary or near capillary size, which is the size of openings that largely controlled the replacement ore. The influence of these factors has been pointed out by Bain (1936, p. 526), who states that the Bernoulli effect influences mineral precipitation under both the Van't Hoff and Le Chatelier laws. Bain states that in capillary openings the adsorption phenomena, as studied by Langmuir, control or influence metasomatism and the types of metasomatic minerals. Subsequently, however, Verhoogen (1948, p. 213) showed that surface tension is theoretically of much greater importance than the Bernoulli effect.

The above factors might, at least in part, account for the deposition of ore minerals in cave-fill and not in the underlying open fractures. The cave-fill zones are exceptionally favorable ore structures, but it is not certain whether their controlling influence is entirely physical or is in part chemical. The replacement of the clays by cinnabar is certainly a chemical phenomenon, but it may be largely dependent upon the physical or structural character of the clay.

It is the clay and not the limestone fragments in the cave-fill that directly and indirectly controlled the deposition of the ore minerals. This conclusion is strongly supported by the common selective replacement of clay by cinnabar and the common association between cinnabar and clay in the keels of the limestone-clay contact deposits. The selective replacement by cinnabar of certain layers of cave-fill that differ in grain size and clay content from neighboring unreplaced layers suggests that the controlling influence of the clay may have depended largely upon the type of channel the clay provided the circulating fluids.

The cave-fill and Grayson formation immediately above cave-fill were not impermeable barriers that completely prevented passage of the ascending fluids; instead they were channels in marked contrast to those in the underlying Devils River limestone. They were not impermeable because undisturbed Grayson formation more than 10 feet above cave-fill is cinnabar-bearing, and calcite veins, with and without cinnabar, are common in the structurally higher Boquillas flags. As channels in rocks of low permeability, they contrasted with those in the limestone by being composed of innumerable, minute, interconnected openings instead of one relatively large one. These places where the fluids could readily pass through the Grayson were the more open parts of faults, breccia pipes, and fractures in intrusive rocks that crosscut the Grayson.

The preceding discussion of the probable physical environment in the cave-fill is highly simplified and does not take into consideration all factors that may influence the environment. It does not mention, for example, that channels through the cave-fill were extremely complex, with innumerable constrictions and enlargements where pressures would locally change. Nor does it consider the constant changes that would be made in channels by solution, filling, and abrasion. The discussion is of necessity incomplete; but the writers believe that it includes a consideration of the structural factors that would most disturb the equilibrium of the ascending mineralizing fluids.

Much of the preceding discussion of local structural controls probably also applies to the ore bodies in the breccia pipes, but the application is difficult because of the limited opportunity to study these structures and their ore bodies. Fractures were important in localizing ore shoots in the Two-Forty-Eight mine, and Grayson formation was the host for cinnabar in the Chisos pipe, but aside from this the distribution of the discovered ore shoots appears to be decidedly erratic.

The occurrence of ore bodies in breccia pipes, however, does demonstrate that the collapse breccia was a better channel than the flat-lying, well-jointed surrounding rocks and that breccia pipes either extend to considerable depths or are connected with structures that do. It also suggests that there may be a genetic relation between cave-fill zones and breccia pipes.

The breccia pipes are not so tight and impermeable as they locally appear, and they were excellent channels for the mineralizing fluids. The breccia in the upper part of the Two-Forty-Eight pipe is open and very porous, and apparently that in the upper part of the Chisos pipe was similar. The breccia in the lower part of the Two-Forty-Eight pipe and in parts of the Maggie Sink pipe contains abundant clay and appears to be a tight structure; but its tightness is more apparent than real, for even the tight parts show extensive alteration and also permit the inflow of ground water in mine workings. Some parts of the pipes are obviously more permeable than others. In general the most permeable parts are along the borders of the pipes.

TRANSPORTATION AND DEPOSITION OF THE ORE ELEMENTS

The state and composition of the transporting medium can not be determined by direct observation but must be inferred from the products of mineralization and from comparisons of these products with those of observable geologic processes and laboratory experiments. The known direct products of quicksilver mineralization in the Terlingua district include a maximum of 20 minerals, representing combinations of 11 elements. Some of these 11 elements are indigenous to the wall rocks and accordingly, may not have been introduced from an outside source, but the mercury, barium, chlorine and fluorine were brought in. On the other hand, the transporting medium may have carried elements that, although materially affecting its character, did not enter into combinations now preserved. Many of these mineral products have been reproduced in the laboratory, but, for the most part, under environments that did not approximate those most likely to be found in nature. The laboratory experiments, therefore, are most useful in showing the chemical and physical possibilities of an inferred geologic process. As processes of ore deposition are suggested by mineral products that can be observed accumulating at the present time, the assumption of a magmatic origin of quicksilver deposits directs attention towards a comparison with volcanic fumaroles and hot springs.

Fumaroles and hot springs selectively transfer material from a magma to the surface. As they are surface phenomena within the zone of possible oxidation, their products are not soley those of the magma, but also contain components from atmospheric gases, ground water, and from the rocks through which they traveled. In contrast most ore deposits are believed to have formed below the zone of atmospheric oxidation, and consequently the primary products were not influenced by atmospheric oxidation. Because the Terlingua quicksilver deposits are associated with pre-ore caverns, the deposits most likely formed in or above rocks that were saturated with ground water; therefore, at some stage of mineralization the transporting medium was probably diluted with ground water. However, as fumaroles ultimately die out and many become hot springs, a comparison of the Terlingua quicksilver deposits with fumaroles cannot be neglected.

The composition and changes in composition of gases from volcanoes and fumaroles would be important factors to consider in interpreting the formation of the quicksilver deposits if the transporting medium was in a gaseous state. Common gases associated with volcanism are steam, carbon dioxide, hydrogen chloride, sulfur dioxide, hydrogen sulfide, hydrogen, carbon monoxide, methane, vapors of metallic chlorides, sulfur vapor, and gaseous compounds of fluorine and ammonia. Some of these gases, such as methane and ammonia, may not be volcanic in origin but freed from sedimentary rocks by volcanic heat. All these gases are never discharged simultaneously from any one fumarole or volcanic vent, but some of them may appear in a certain regular order as the temperature of the discharge decreases. This was pointed out by Deville and Leblanc as early as 1858, and has been restated by later investigators. Clarke (1924, p. 292), and, more recently, Sapper (1927, p. 82–83) have summarized these data. According to Sapper, gases at temperatures from 200°C to 1000°C include SO_2, HCl, CO_2, H_2O, NH_4Cl, and $FeCl_3$, and those below 200°C include H_2O, H_2S, and CO_2. Changes are primarily from decreasing temperature, which permits interaction between gases and between gases and wall rocks. These of course are generalizations based in part on data of doubtful reliability.

Mineral products of the fumaroles are mainly sublimates of sulfur, ammonium chloride, and metallic chlorides. Sulfides and oxides of some metals have been found but are not common. Most sublimates are readily soluble in water and are therefore unlikely to be preserved in an ore deposit. Moreover, the relatively insoluble ore minerals that can be readily transported in gases, in particular the metallic chlorides, are commonly considered supergene. However, at least two chloride minerals found at Terlingua are not supergene and are minerals capable of gas transport.

Quicksilver deposits, hot springs, and volcanic rock are so commonly associated that a genetic relation has long been postulated. The association was pointed out as early as 1888 by Becker (1888), who believed that quicksilver deposits were formed at shallow depths by hot waters similar to those of hot springs now flowing in areas mineralized by quicksilver. Becker reported that at the time of his visit to Steamboat Springs, Nev., and Sulphur Bank, Calif., cinnabar was being deposited from hot spring water. Although there is some doubt that cinnabar was deposited by the spring waters by the process described by Becker, there is little doubt that the quicksilver deposits so closely associated with the hot springs formed in an environment similar to that of the springs. The Terlingua quicksilver deposits were certainly not deposited at the surface but they may have formed in a system 500 to 1,000 feet below discharging hot springs.

To list, describe, and document the many places where quicksilver deposits are associated with hot springs or hot spring sinters is beyond the scope of this report (see White, D. E., 1955), but associations are numerous enough to permit the summarization of what seem to be valid generalizations, which are: (1) hot springs are common in many mercury districts mineralized in late Tertiary and Recent age, (2) quicksilver minerals are rarely found in superficial hot spring sinters, but commonly were deposited below the surface, and (3) the associated hot spring waters have a range in composition and are now very low in their content of mercury.

The mineral products of hot springs are more like those of quicksilver deposits than are products deposited directly by volcanic gases. Spring deposits contain silica and calcium carbonate, two combinations common to quicksilver deposits and foreign to most fumarolic deposits. Sulfides of the metals, notably those of iron, antimony, and arsenic, are commonly found in small amounts. Although it is chemically possible for almost all the mineral combinations found in quicksilver deposits to be transported and deposited by gases, only a few of these combinations are typical of fumarolic deposits, whereas almost all the minerals associated with quicksilver are common to hot spring deposits.

The comparisons between quicksilver deposits and the deposits of hot springs or fumaroles indicate that the environment in which the quicksilver minerals were deposited was most similar to that of hot springs. The comparisons, however, do not preclude the possibility that some of the ore elements were transported by a gas from the source to near the place of deposition. Nevertheless, to reach the place of deposition any postulated gas would most likely have to pass into a zone where rock openings were filled with ground water

The temperature and pressure range through which the ore minerals were deposited, although well within that of epithermal deposits, cannot be stated definitely, but the evidence suggests that the deposits were formed at temperatures below 300°C and at pressures that were locally at least as high as 30 atmospheres. Evidence for the temperature of deposition is mainly based upon the anomalous optics and conversion temperature of kleinite (see p. 70), which appears to have formed at temperatures over 130°C. As the paragenetic relations of this mineral indicate that it formed at an intermediate age, the other minerals were formed at both higher and lower temperatures. The melting points of kleinite (260°C) and calomel (302°C), the oldest ore mineral, suggest that the maximum temperature was below 300°C. The dissociation of mercuric sulfide into its elements at temperatures of 250°C (Krauskopf, 1951, p. 522) or less is in agreement with this maximum.

The pressures at which deposition occurred depends largely upon the thickness of rock cover and consequently upon the weight of the column of fluid above the point of deposition. Maximum pressures cannot be estimated with any accuracy because we do not know how far mineralized rock extended above the outcrops of ore, and because we do not know whether the water table was at or above the upper limit of mineralization. Minimum pressures can be postulated with more assurance, assuming that the flow was slow enough to approximate hydrostatic conditions. Since ore deposition, erosion has lowered the surface, perhaps 1,000 feet, perhaps considerably more. If the water table at the Chisos mine was 1,000 feet higher than the present surface at the time of mineralization, the hydrostatic pressure at the bottom of the mine (900 feet below the present surface) would be on the order of 60 atmospheres. If the present topographic surface at the Chisos mine was the water table that existed during mineralization, pressures at the bottom of the mine would have been about 30 atmospheres—this is the minimum.

Under these relatively low temperatures and pressures, fluids containing sulfur, iron, chlorine, hydrogen, oxygen, nitrogen, and mercury deposited these elements in various combinations to form the ore minerals. Calcium and carbon were likewise present and combined to form the gangue calcite; as the gangue minerals were replaced by cinnabar these elements again entered the fluid. Undoubtedly other elements, which did not enter into mineral combinations, were present. The elements were most likely in the waters as simple ions, complexions, un-ionized molecules, and colloid particles. Some elements were in molecular combinations, dissolved in the water and possibly free as gas bubbles. Conditions favoring separation of the ore elements from their transporting medium probably did not exist before the entry of the solutions into those parts of the channels where the ore minerals occur. Here conditions were such that the solutions were no longer stable and deposition resulted.

Because no samples of these waters are available, the state of the ore elements in the solutions is uncertain. The problem of determining how the ore elements were present is not to be solved by reversing ore deposition and redissolving the mineral products—the solutions would not be the same. Consequently from here on, reliance must be placed upon the compositions of known volcanic gases and hot springs, fortified by laboratory-verified chemistry, and filled in by assumptions of varying degrees of validity.

The above was the approach used by George F. Becker (1888) in postulating the alkaline sulfide theory of quicksilver deposits, a theory that has been widely accepted and extended to include deposits of other metals. Because cinnabar is the least soluble metallic sulfide and can only be dissolved readily in solutions of sodium or other alkaline sulfides, Becker proposed that such were the solutions from which cinnabar was deposited. Becker believed that mercury was present in complex ions of sodium sulfide in the waters of Steamboat Springs, Nev., which upon cooling precipitated cinnabar.

The alkaline sulfide theory as stated by Becker is not completely acceptable, primarily because it is not supported by the composition of hot spring waters most closely associated with cinnabar or other sulfide minerals. D. E. White (1955, p. 146) in speaking of the compositions of hot springs most closely related to quicksilver deposits says,

> The thermal waters that appear to be most closely related to quicksilver deposits are near-neutral; present springs provide no support for the theory that quicksilver is transported in alkaline sulfide solutions. In general, the highest dissolved

solids and total sulfide content are found in near neutral waters. Although thermal waters are known with pH's as high as 10.0, the most alkaline waters are relatively dilute, and none is known to contain more than a few parts per million of sulfide.

Other objections of almost equal weight are that the alkaline sulfide theory to be effective requires waters of a fairly high alkalinity; temperature decreases prevent rather than aid the precipitation of cinnabar; and cinnabar does not replace pyrite as it should to follow Schürmann's series. This last objection is overcome if excess hydrogen sulfide is present; its presence would prevent the re-solution of the pyrite.

J. P. Pollock (1943) has since shown that it is not possible to precipitate cinnabar from such a solution by either cooling or evaporation of the solution; precipitation can only be accomplished by dilution, acidification, or addition of precipitants. Accordingly, Pollock (1944) has amended Becker's theory by proposing that the mercury found in the spring waters analyzed by Becker was colloidal cinnabar that had been formed by the rapid dilution or neutralization of alkaline sulfide solutions bearing mercury coming into contact with deep ground water, or from colloidal solution near the source and subsequent flow to the point of deposition.

Recently Krauskopf (1951) has substantiated the theoretical possibility that the transportation of mercury in hydrothermal solutions can be in the form of the complex sulfide ion. This conclusion was reached after he made an analysis of the chemical data on mercury and a consequent quantitative delimitation of the physicochemical conditions of quicksilver deposition. Krauskopf, however, comes to the conclusion that this is not the only way that mercury can be transported for he says (p. 521),

Three possible mechanisms for the transportation of mercury in vein solutions stand up under detailed scrutiny: transportation as a complex ion in slightly alkaline sulfide solutions, as the volatile chloride, and as mercury vapor. For two other mechanisms, supersaturation and colloidal disperson, no definite statement can be made about their probable importance or lack of it.

Thompson (1954) in applying Krauskopf's concepts to the quicksilver deposits at Terlingua proposed the disequilibrium conditions of supersaturation to account for the concentration of ore in restricted pockets—a feature typical of quicksilver deposits. Thompson's proposal has much in common with Pollock's postulated transportation of cinnabar by colloidal solutions and has some of the same difficulties, mainly that both supersaturated solutions and colloidal solutions are not particularly stable under conditions of high temperature and turbulent flow.

Neither Pollock's nor Thompson's revision of Becker's theory is a complete explanation of the origin of the Terlingua quicksilver deposits. The presence of calomel as a primary mineral suggests that it is desirable to modify the theory still further by proposing that the ore-forming system contained a gas phase from which calomel was directly deposited.

Such a proposal would not be necessary if the calomel could be considered a supergene mineral that was derived through the leaching of cinnabar by ground waters of high hydrogen chloride content. Although such a mechanism might theoretically produce calomel, evidence that it operated at Terlingua is completely lacking, as the following discussion indicates. Broderick (1916) has experimentally demonstrated that cinnabar can be dissolved by hydrochloric acid solutions, but because his results are not quantitative it is not possible to evaluate the efficacy of such a solvent in the calcite environment that exists at the Mariposa mine. In contradiction to the supergene origin of the calomel is the complete lack of leaching of any cinnabar that was studied. The most valid objection to this concept, however, is the distribution of calomel and cinnabar which occur in the same general area and at the same depth, but almost never in close association. Pockets of calomel and other associated mercury minerals are found within a few feet of masses of cinnabar, but the pockets themselves are characteristically free of cinnabar. These relations do not suggest a supergene origin for the calomel.

Although calomel and cinnabar are both primary minerals, their striking differences in form and manner of occurrence suggest that they were formed by different processes. Cinnabar commonly replaced the gangue minerals; calomel and the other mercury minerals apparently did not. Cinnabar rarely lines open cavities as crystal druses; the mercury chloride minerals almost always occur as crystal linings in cavities. The replacement character of the cinnabar indicates that it was formed by hydrothermal processes. The "open space" character of the calomel and associated minerals would allow deposition from either water or vapor. Because the mercury chloride minerals show many features typical of sublimates, such as chains of perched crystals, long fragile acicular crystals, and fine powdery coatings, deposition from a vapor phase is the favored process.

Whether all the kleinite, mosesite, terlinguaite, eglestonite, montroydite, and native mercury is of primary origin from a gaseous phase is not known. Native mercury is so closely associated with calomel, being commonly found as tiny droplets on freshly broken cleavage planes, that some of it must be primary. If this "included" mercury is considered as having been held by the calomel in solid solution, the calomel can be interpreted as forming from vapors containing both mercury and mercury chloride. It is possible that the other rare mercury minerals may have formed in part by reactions between supergene solutions and calomel. The reaction proposed by Switzer and others (1953) for the synthesis of mosesite at 25°C,

$$4NH_4OH + 2Hg_2Cl_2 \rightarrow 2Hg + Hg_2NCl \cdot H_2O + 3H_2O + 3NH_4Cl,$$

could be typical of calomel attacked by supergene waters—providing the waters contain the proper solvents. The suggestion that kleinite, terlinguaite, eglestonite, and montroydite could also be produced by supergene waters, does not preclude the possibility that these minerals can be produced at higher temperatures by gases. Regardless of whether these minerals can be formed by gases, their distribution at Terlingua clearly indicates that they were not formed by supergene alteration of cinnabar.

Having concluded that the most feasible mechanism for the formation of the mercury minerals in the Terlingua district involves a system having both gaseous and liquid phases, it is desirable to expand this conclusion into a more complete interpretation of their origin. The mechanism proposed is essentially a system dominated by the vapor phase in the early part of its history but gradually becoming dominated by liquid-phase relations.

The basic assumption stated at the beginning of this section is that the ore elements were either derived from a magma that differentiated to produce the great variety of igneous rocks now exposed in the district or were distilled from deeply buried sedimentary rocks by heat from a magma. Relations between igneous rocks and cinnabar indicate that cinnabar is younger than the rocks and accordingly could not have formed until differentiation of a parent magma was well along or completed. If the differentiation of the parent magma resulted from or accompanied crystallization, mercury did not escape from the magma in any appreciable quantities until late in crystallization. Whether gases carrying metallic elements can and do escape from a magma at such a time is a controversy too theoretical and too involved to repeat here; nevertheless it should be pointed out that the arguments used against gas transfer do not necessarily apply to mercury, which, because of its common lack of association with most other metals, must have an almost unique cycle. If mercury was distilled from sedimentary rocks it probably would have migrated under conditions of moderately low temperatures in company with gaseous organic compounds.

The composition of the vapor phase can be set within only broad limits. Mercury, chlorine, sulfur, and doubtless large quantities of hydrogen and oxygen as steam were present. If the common fumarole and volcanic gases are a clue to the probable composition, one can safely infer the presence of sodium, potassium, and carbon. Doubtless there were other elements that were never fixed in the quicksilver deposits. The above elements could occur in many combinations; consequently the vapor phase could be exceedingly complex, but it would remain a vapor as long as temperatures remained above that at which steam could condense into water.

Metallic mercury in this vapor phase should be relatively stable as long as temperatures remain above 400°C, because, above this temperature, mercury does not precipitate with other elements. Cinnabar would not form as long as temperatures remained above 250°C, for Krauskopf (1951, p. 522) has shown that cinnabar "*cannot even exist* in any [probable] system that includes moving vapors above a temperature of around 250°C." A vapor phase such as this could not persist indefinitely; a liquid phase would logically develop as ground water entered the system and the steam condensed. A liquid phase was probably present while temperatures were still too high for cinnabar to be deposited. Mercury would be transported in this two-phase system in both the gas and liquid phases. In the gas phase it could be present as both mercury vapor and mercurous chloride; in the liquid phase it could be present as the sol, the complex sulfide ion, or perhaps some other form.

With progression up the channel and cooling by meteoric water, mercury is condensed to the liquid phase. If the quantity of mercury in the gaseous phase is greater than that which can be dissolved in equilibrium in the water, mercury either precipitates or is transported in the liquid by other than equilibrium solutions. If the mercury had been deposited from equilibrium solutions, it would be expected that deposition would be progressive and that the grade of the ore bodies would decrease downward. This, however, is not the case; there is no systematic decrease in the grade of ore with depth; ore bodies tend to terminate within short distances. It therefore appears likely that mercury was not deposited immediately once equilibrium was attained, but that it was transported further by other than equilibrium solutions.

Transportation in the liquid phase with greater concentrations than the equilibrium amounts could be accomplished by either supersaturated solutions (Thompson, 1954) or colloidal solutions (Pollock, 1943) or both. Although the feasibility of mercury existing in the supersaturated or colloid states in a temperature range between 100°C and 250°C has not been experimentally verified, it seems necessary to postulate such transport to provide a mechanism that will prevent a gradual "dribbling out" of cinnabar before structures favorable to ore deposition are reached.

At temperatures below 250°C this sulfur-bearing system, as proposed, would contain mercury in its vapor phase as well as in its water phase. The concentration of mercury ions need never have been high, because whenever mercury ions were lost by precipitation they could be replaced from the supply of colloidal cinnabar. In the advancement of such a mechanism for colloidal transport of sulfide, R. M. Garrels (1944, p. 482) has pointed out that "A highly dispersed solid phase is in equilibrium with its saturated solution and so has all the advantages of a saturated solution, plus a reservoir of material in solid form." Garrels suggests that the precipitation of galena might proceed in the following manner, "If the solution were moving in a trunk fissure, its saturated solution would penetrate the wall rock, cool and precipitate galena. This would establish a precipitation gradient, with the solution in the trunk fissure continuously dissolving and migrating outward to form the replacement deposit in the wall rocks. The final product would give no clue to the colloidal state of its origin." A precipitation gradient for the deposition of cinnabar could not be established by a simple cooling of the solution as is postulated for galena, because solubility of cinnabar is increased instead of decreased with falling temperatures. However, this change in the physical characteristics of the channel might be adequate in itself to create a precipitation gradient. The change in channel is also an enormous change in the ratio of surface area to volume; consequently it is accompanied by a corresponding increase in the influence of surface tension and adsorption phenomena. Concentrations of solutions within these small openings certainly would not be the same as those in the trunk channel. Circulations of fluids in the small openings would be negligible in contrast to movements in the trunk channel; accordingly ionic diffusion would be the main means of moving material necessary to form replacement cinnabar. The nature of the openings and of the ore indicate that a precipitation gradient did exist, regardless of what factors were important in producing this gradient.

As suggested earlier in this section, the physical properties of the clays may have had a considerable influence on the deposition of the ore minerals. The influence of the clays on the stability of the fluids may depend upon the surface tension of the clays; this may be able to change the concentration of the gases and the solubilities of solutions entering the pores of the clays. Verhoogen (1948, p. 210–217), in writing on the geological significance of surface tension, has pointed out these factors. In speaking of the gas phase of a magma he says (p. 214), "the composition of a gas phase permeating the pores of the wall rock will be different from that in equilibrium with the magma through a plane interface." If we substitute clay for "wall rock," ore fluids for "magma" (which is also a solution with a gaseous phase), and walls of the open channels for "plane interface," we have a statement that is applicable to the deposition of ore minerals. Verhoogen says (p. 213) that when a saturated solution of a number of constituents is introduced at constant temperature into small pores, the solution will become oversaturated with respect to some constituents and undersaturated with respect to others. Although the magnitude of these effects—which depend upon numerous and varied factors—is unknown, it may be that they supply the trigger action that would explain the close association between clay and cinnabar.

The preceding discussion has dealt largely with a theoretical ore-forming system that would permit the deposition of calomel and later deposition of cinnabar, but the seemingly anomalous distribution of these two minerals has not been fully interpreted. It can be explained, if it is assumed that sulfide was deficient during the vapor stage when calomel was deposited in the later liquid stage, even a little sulfide present in the liquid would react with the calomel to produce cinnabar.

In the presence of either a neutral or an alkaline solution, cinnabar, with a solubility product constant of 10^{-54}, is more stable than calomel, with a solubility product constant of 10^{-18}; consequently calomel would dissolve and cinnabar would deposit. If the system were deficient in sulfur, the dissolved mercurous chloride might be dispersed in the ground water; if the system contained a surplus of sulfur, the mercury of the dissolved calomel could be redeposited as cinnabar. If excess sulfur were present as hydrogen sulfide, the reaction might be as follows:

$$Hg_2Cl_2 + H_2S \rightleftharpoons HgS + 2HCl + Hg$$

The hydrochloric acid formed would react with calcite and thus keep the reaction going in the direction of cinnabar. If the conditions of ore genesis are as proposed, it can be assumed that the calomel that remains is calomel that was never accessible to the liquid phase of the system when cinnabar was being deposited.

TRANSPORTATION AND DEPOSITION OF THE GANGUE ELEMENTS

The gangue minerals may have been deposited during an early stage of the activity that culminated in the deposition of the ore minerals or it may have been an early event unrelated to ore deposition. No evidence to prove either hypothesis was found. The deposition of calcite and hydrocarbons through the period of ore

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minerals suggests a close association between ore and gangue, but as both hydrocarbons and calcite can migrate readily, the association means little. The traces of cinnabar in many calcite veins suggests an even closer affinity between ore and gangue, but the even more numerous barren calcite veins may indicate that the ore elements merely migrated along channels used at some preceding time by the gangue elements. It is extremely unlikely that all ore and gangue elements were from the same source; but it is very likely that their migrations were the result of processes related to the same heat source.

The barium and fluorine of the barite and fluorite may be of magmatic origin, but the great bulk of the introduced gangue, which is calcite, was derived from the limestones through which the solutions flowed. The open channels below the cave-fill deposits attest to the solution of limestone, as the calcite veins attest to the deposition of calcite. The migration of gangue elements from wall rock to deposits is common in the quicksilver deposits, as is shown by the close similarity between wall rock and gangue compositions in quicksilver deposits in Nevada (Bailey and Phoenix, 1944, p. 15), where deposits in siliceous rocks have a silica gangue and those in carbonate rocks have a carbonate gangue.

DESCRIPTIONS OF MINES AND PROSPECTS

Descriptions of both mines and prospects are included in the following pages. As it is not possible to make any sharp division between mines and prospects on the basis of ore produced—the only logical distinction—these two terms are used very loosely. Consequently, some properties are listed as mines, although their workings consist of only a few shallow open pits or trenches and their productions are not more than one or two flasks of quicksilver. On the other hand, some properties listed as prospects, although having small productions, are not developed enough to be considered as mines. The application of the term "mine" to a property, however, does not necessarily imply that the property has been, or ever will be, a profitable enterprise. Nor do the lengths of the individual descriptions have any bearing on the relative merits of the properties. Descriptions of some properties are longer than those of others that are just as important economically, purely because they are the products of relatively detailed examinations made for various Federal wartime agencies. Unfortunately, time was not available for similar detailed examinations of all properties.

The mining properties are arranged geographically, proceeding from west to east. They are located by section and block numbers, as well as by geographic features and neighboring properties. The public land lines of Texas run north and east and in general subdivide the land into mile-square sections, groups of which are designated as blocks. However, the sections are not always 1 mile square and the blocks have no uniform number of sections within them. Nor is there uniform numbering of blocks or sections within blocks.

CONTRABANDO DOME PROSPECTS

The prospects on Contrabando dome are at the western end of the district, 17 miles by road west of Terlingua. They are in secs. 104, 105, 108, and 109, Block 341. These prospects and the Fresno mine 2 miles to the north represent cinnabar discoveries made chiefly by Harris S. Smith and Homer M. Wilson in the 1930's, discoveries which extended the known belt of quicksilver mineralization about 8 miles westward.

Total production of the prospects on Contrabando dome is probably not more than 10 flasks. Two flasks were produced from one of the prospects in sec. 104.

In April 1943, B. L. Shoemaker was working two of the prospects under lease, but shortly afterward abandoned them. One of these prospects was examined in some detail. The workings consisted of a 60-foot shaft with two short crosscuts at depths of 35 and 60 feet.

Exploratory workings at other prospects on Contrabando dome are similarly shallow and small in extent. A few core drill holes have been put down to greater depth, and scattered core may still be seen at some of these, but logs of the holes were not available. None of the prospects is equipped with furnaces or retorts.

The country rock of the area is Boquillas flags. The lower member of the Boquillas flags is exposed in the central part of the dome, and the upper member covers the flanks (pl. 1). Small dikes and plugs of rhyolite have intruded the flags, particularly along faults trending northeasterly. Cinnabar has been found in several of the rhyolite bodies and in calcite veins filling the faults.

The shaft of the Shoemaker prospect in sec. 104 was sunk on cinnabar showings along the north contact of a plug. A 20-foot drift was driven southwest at a depth of 35 feet to the rhyolite-flags contact, where a small pocket of ore was mined. Shoemaker reported that this pocket assayed 10 to 12 pounds of quicksilver per ton. Most of the two flasks of quicksilver produced from the prospect came from this pocket. A drift was driven southward from the 60-foot level to intersect the mineralized zone mined above, but work stopped before either the projection of the zone or the contact was reached.

The association of cinnabar with rhyolite is probably entirely structural. Both are associated with faults, and many of the fractures within the rhyolite belong to the regional system of northeasterly-trending fractures. The rhyolite is more competent than the flags and presumably is continuous vertically through a considerable thickness of relatively impermeable shales and flags. Autobrecciation, flow banding, and dragging of the contacts help to make the rhyolite bodies and their borders relatively good hosts.

Development of mineable ore will probably depend upon deeper exploration, although shallow ore bodies are a distinct possibility that should be looked for. The areal extent of baked rock indicates more widespread intrusion at depth. This might be a sill and carry ore similar to that in the Study Butte sill. The base of the Grayson formation, if it is not too deep because of a section thickened by intrusive rocks, is also a possible locus of ore.

FRESNO MINE

The Fresno mine, at the western end of the district, is 17 miles by road west of Terlingua. It is near the north edge of sec. 106, Block 341. Cinnabar was discovered and exploration begun in the 1930's by Harris S. Smith. Mining was begun in 1940 by Smith and Homer M. Wilson. The proving of ore at Fresno justifies some optimism about chances for future discoveries in the western part of the district, because little or no prospecting has previously been done in this area. However, practically all prospecting and exploration in the Terlingua district stopped soon after World War II because of the low price of mercury.

The mine, which is shallow and dry, is reached by 2 shafts, each less than 100 feet deep (pl. 10). The main stope is nearly flat, 300 feet long, and averages about 60 feet wide (pl. 11). Crosscuts total about 500 feet and are mainly below the stope level. In addition to the main workings there are several shallow shafts and many pits. Ore was mined from the large pit east of the No. 1 shaft and also from veins on the top of the hill 1,000 feet west of the No. 2 shaft. Ore was treated in a rotary furnace 30 feet long by 2 feet inside diameter, using butane gas for fuel. The rated capacity is 35 tons per day. Production to April 1943 is estimated to be slightly more than 2,000 flasks, from ore averaging about 20 pounds of quicksilver to the ton.

The rocks of the Fresno mine area are, from oldest to youngest, Devils River limestone, Grayson formation, Buda limestone, Boquillas flags, and Chisos volcanics. Erosion has removed little of the Devils River limestone; the mine area is probably underlain by 1,000 to 2,000 feet of this formation. The Grayson formation is about 120 feet thick but varies from place to place. The thickness of the Buda limestone is 130 feet. Only the lower part of the Boquillas flags is uneroded and it has a thickness as much as 400 feet. The Chisos volcanics, consisting of undifferentiated lava flows, tuffs, and stream-laid sediments, lies unconformably on the upturned Boquillas flags.

The Fresno mine area is in a structural embayment on the monoclinal, south flank of the Terlingua uplift (pl. 1). The area is cut by numerous faults most of which trend northeasterly to easterly (pl. 10). Oval or circular outcrops of breccia pipes occur at several places. These breccia pipes are 50 to 200 feet in diameter and consist of fragments of stratigraphically higher rocks. Some of the fragments are displaced downward at least 300 feet. Calcite is present in some of the breccia pipes, both as a breccia filling and as small veins, from some of which cinnabar can be panned.

The contact of the Devils River limestone with the overlying Grayson formation is the key to an understanding of the geologic structure in the mine. This contact is highly irregular, although the limestone beds are nearly flat, dipping no more than 10°. Pockets of clay commonly extend 50 feet or more down into the limestone, and in places broken limestone and clay appear as if stirred together. The No. 2 shaft was sunk through 62 feet of clay before reaching limestone, although limestone crops out within 10 feet of the collar. Pockets of clay mixed with limestone fragments were found in the open pits and the main stope. However, the limestone is solid and relatively undisturbed in the crosscut only a few feet below the main stope. These features originated by solution of limestone and collapse of the overlying clay. Thus they are similar in origin to the cave-fill zones of the Mariposa mine. The cave-fill zones at Fresno are more irregular, however, and also less well exposed.

Most of the ore mined at Fresno came from an irregular cave-fill zone which was localized in part by fractures trending northeasterly to easterly. Much of the cinnabar was closely associated with clay, had a laminated structure similar to the unmineralized clay, and a finely crystalline to powdery texture. It is interpreted to be the result of deposition in and replacement of the clay. Associated minerals in order of relative abundance are gypsum, calcite, fluorite, quartz or chalcedony, and iron oxides. A small amount of ore was mined from a calcite vein in Buda limestone but the ore was of lower grade.

LOWE PROSPECT

The Lowe prospect is on the northwest side of Lowes Valley (pl. 1) outside the mapped area, in sec. 100, Block G-5. It consists of pits, trenches, and short adits that were opened early in the history of the district by a man named Lowe. The workings are in altered and silicified Devils River limestone near small, irregular intrusive bodies of rhyolite. For the most part, they follow fractures that range in trend from N. 15° E. to N. 30° W. The limestone along and near the fractures is silicified, brecciated, and stained brown by iron oxides. Associated with the silicified limestone is abundant iron oxide, pyrite, calcite, jarosite, and manganese oxide, and very small quantities of cinnabar. The cinnabar was the last mineral to form as it fills small fracture openings that cross all the other minerals. This area is the only place in the Terlingua district where there is abundant silica associated with the cinnabar.

PROSPECTS IN SEC. 98

In sec. 98, Block G–5 there are a few shallow cuts and trenches along narrow cave-fill zones in the Devils River limestone. The zones trend N. 20° W. and N. 70° E. No cinnabar was seen here. The cave-fill zones may represent the roots or keels of more extensive deposits that have been eroded away.

SAMPLE GROUP

Much of sec. 44, Block G–12, is included in the old Sample group of 15 claims held by Frank Duncan and associates, but in 1944 Duncan's interests were mainly in the three adjoining claims, which lay east and west through the center of the section. The topography, geology, and mine development of these three claims is shown in plate 12. The property is connected by road with Terlingua.

Development work consists of about 100 feet of adit, a 25-foot shaft (said to have been 85 feet deep before caving), and at least 1,000 feet of relatively shallow trenches. A retort capable of burning a charge of more than 600 pounds of ore is on the property. No reliable information about the production is available, but rumors have production as 1,000 flasks of quicksilver during World War I when it was worked by Colquitt and Fletcher Tigner. Judging from the extent of the workings, it seems doubtful that a fifth of the rumored quantity was produced.

Most of the rock in the area is massive, fine-grained, and somewhat cavernous Devils River limestone, containing irregular nodules of chert concentrated at certain horizons. A little Grayson formation in elongate masses about 200 feet long and as much as 50 feet wide is enclosed in the limestone east of the retort and at the largest workings east of the claims (pl. 12). Some of this clay retains stratification, whereas much is structureless and in some places contains fragments of Devils River limestone. It is the same material that is regarded as cave-fill at the Mariposa and other mines and got in its present position by collapse and washing into open solution-caverns in the limestone.

The major structure is a broad northwesterly trending anticline; the flat crest and the gently dipping upper part of the southwestern flank cross the claims diagonally. Fracturing was strong enough to brecciate some of the limestone and make channels for mineralizing solutions. Some fractures were enlarged by solution of the limestone to cavernous passages, which were subsequently lined with calcite or filled to various degrees with clay and rubble. Most of the breccia is of this kind.

Two poorly defined zones of mineralized rock trend northeasterly across the claim; one zone trends from southwest of the retort on the Lindbergh claim up the ravine to the central part of the north boundary of the Spirit of St. Louis claims; and the other trends from near the southeast corner of the Spirit of St. Louis claim through the northwest corner of the Curtis claim. Within these zones few single veins of calcite are more than 100 feet long though they are as much as 5 or 6 feet thick. Most veins, especially those of gentle dip, are associated with irregular sheets of jaboncillo. The broad zone of calcite and jaboncillo about 200 feet north of the retort (pl. 12) seems locally to be nearly parallel to the surface and perhaps 4 feet thick, although in some places, as revealed by the longest trench, coarse calcite extends downward for more than 15 feet. The longest continuous vein was traced more than 250 feet southwesterly from the road in the eastern part of the Lindbergh claim. It has been prospected by a pit 10 feet deep, which exposes 3 feet of calcite and jaboncillo to the bottom. No cinnabar was seen.

Traces of cinnabar were seen in the western group of workings that extend from the shallow pit 250 feet southwest of the retort to the trench in the gully bottom 450 feet northeast of the retort, as well as within a 100-foot strip in the eastern group of workings. Cinnabar localities are shown on the accompanying map (Pl. 12). The best showings are in a zone 6 inches wide that extends for about 20 feet in the 3-foot calcite vein exposed in the adit near the retort, and in a remnant, 6 inches by 3 feet by 2 feet, of the ore body removed from the long trench 150 feet farther east. Much poorer showings are in the calcite at the eastern end of the trench. The calcite and jaboncillo are 4 feet thick for most of the 100 feet where the gently dipping vein goes into the wall. Other showings of cinnabar are in calcite and jaboncillo exposed in the trenches on the hillside 250 feet north of the retort, in a zone of mineralized rock that dips about 20° south, approximately parallel to the surface and rather close to the dip of the beds. In the east group of workings, an excellent showing of cinnabar in a zone 2 feet wide and 6 feet long was seen in the coarse calcite of the trench 350 feet east of the road, and poorer showings at the head of the trench 250 feet east of the road.

The only visible ore is in the retort adit described above and in the two trenches described in the eastern group, which if continuous between the trenches, is a cinnabar body 80 feet long, dispersed through not more than 2 feet of the 6-foot thickness of coarse calcite.

BOBS MINE

Bobs mine, in sec. 44, Block G–12, is in the Mitchell-Gillette group of claims and lies between the claims of Frank Duncan to the northwest and those of Natural Resources, Inc., to the southeast. The most recent mining activity has been in a breccia pipe in the Maggie claim (fig. 19). However, there was considerable interest in this general area during and before World War I, when numberous trenches, pits, and shallow shafts were dug along the ridge of Tres Cuevas Mountain, which extends southward towards the Natural Resources, Inc., holdings. In 1947 the property was held by Robert Pulliam of Alpine, Tex. From 1940 through 1942 it was held by the Continental Mining Co., which did considerable development work.

The breccia pipe in which most of the recent development work was done is in the topographic feature known as Maggie Sink, which is an elliptical depression, 535 feet long by 210 feet wide. The south part of the sink has been excavated by power shovel to a maximum depth of about 30 feet and a shaft has been sunk from the bottom of the excavation. An adit has been driven from the hillside west of the sink for 540 feet to end within the breccia pipe about 135 feet below the bottom of the shaft. A winze was sunk from the end of this adit.

The Maggie Sink breccia pipe, enclosed in Devils River limestone, consists of blocks and fragments of Buda limestone, Boquillas flags, and Chisos volcanics set in a matrix of Grayson formation.

The breccia pipe is on the crest of the northwesterly trending asymetric anticline that forms the ridge of Tres Cuevas Mountain. The northeast flank of the anticline dips from 10° to 15° and the southwest flank as much as 70°. Fractures and small faults extend both across and parallel to the anticlinal axis. These are in two principal sets, one with a northeasterly trend and the other with a westerly to northwesterly trend.

The breccia pipe of Maggie Sink is described on pages 40–41. A little high-grade ore has been taken from it, but until 1946 no commercial ore bodies had been discovered. In the surface workings in the west part of the pipe, cinnabar was found in jaboncillo and calcite that coats the limestone walls of the pipe and also in brecciated material within the pipe. In the brecciated material the cinnabar is found as disseminations within jaboncillo (altered Grayson), as coatings on fracture planes, and as nodules of nearly pure cinnabar. It is reported by Mr. R. B. Davis that one nodule taken from the bottom of the shaft weighed 26 pounds and was estimated to contain 65 percent cinnabar. A small pocket containing several tons of high-grade ore was discovered in 1944 in the deeper workings below the adit level.

Southeast of Maggie Sink the Devils River limestone of Tres Cuevas Ridge is cut by numerous northeasterly trending and some northwesterly trending fractures. Most northeast-trending and some northwest-trending fractures are filled with calcite veins, the most persistent of which are shown on fig. 19. The calcite veins range from less than 1 inch wide to several feet wide, and from 1 foot to several hundred feet long. They characteristically pinch and swell both along their strikes and dips. Cinnabar is sparse in these veins and its occurrence is similar to that in veins in the Sample group of claims. There has been considerable exploration and mining on these veins, and they yielded an unknown quantity of ore during early operations in the district. For the most part the trenches are shallow and short, but a few are more than 100 feet long and two shafts have been sunk more than 40 feet. No workings, however, are more than 50 feet below the surface.

NATURAL RESOURCES, INC., CLAIMS IN SEC. 58

Natural Resources, Inc., holds claims in the northwest corner of sec. 58, Block G–12, as well as in the southern part of the same section. The claims in the northwest part are those of the old Tres Cuevas Quicksilver Co., which is reported to have mined quicksilver from them during World War I. Natural Resources, Inc., explored some of the ground in the northwest part of the section from 1941 to 1943 and extracted a small amount of ore from them. This area is shown in figure 20. Ore reduction facilities include a small retort near the principal workings and a Cottrell rotary furnace several miles away in sec. 40.

Development and exploration during World War II included extensive trenching of the cinnabar showings, sinking several shafts less than 40 feet, tunneling about 150 feet from the shafts, and drilling shallow holes. An estimated 200 tons of ore was mined. The only known ore left in place is in the opencut on the west side of No. 1 shaft (see fig. 20); even this is very limited in lateral extent and depth, for at the bottom of the shaft there are only a few streaks of powdery cinnabar. According to Mr. A. Gard about 100 tons of ore was treated in the rotary furnace in December, 1942, and only 4 pounds of quicksilver per ton were recovered. He believes the low recovery was in part caused by faulty furnace operation.

Thick bedded to massive Devils River limestone is

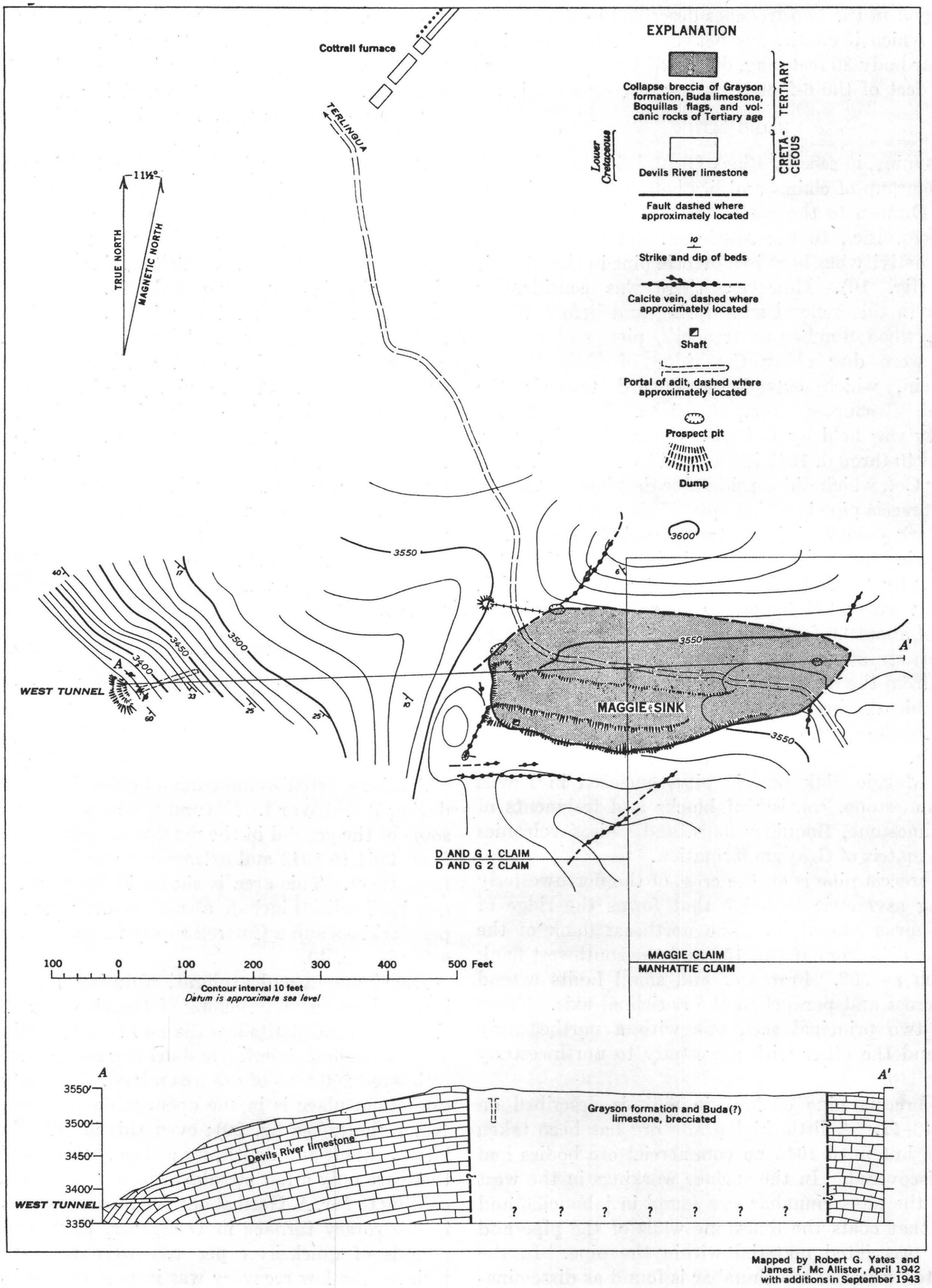


FIGURE 19.—Geologic map and section of Bobs mine, sec. 44, Block G-12.

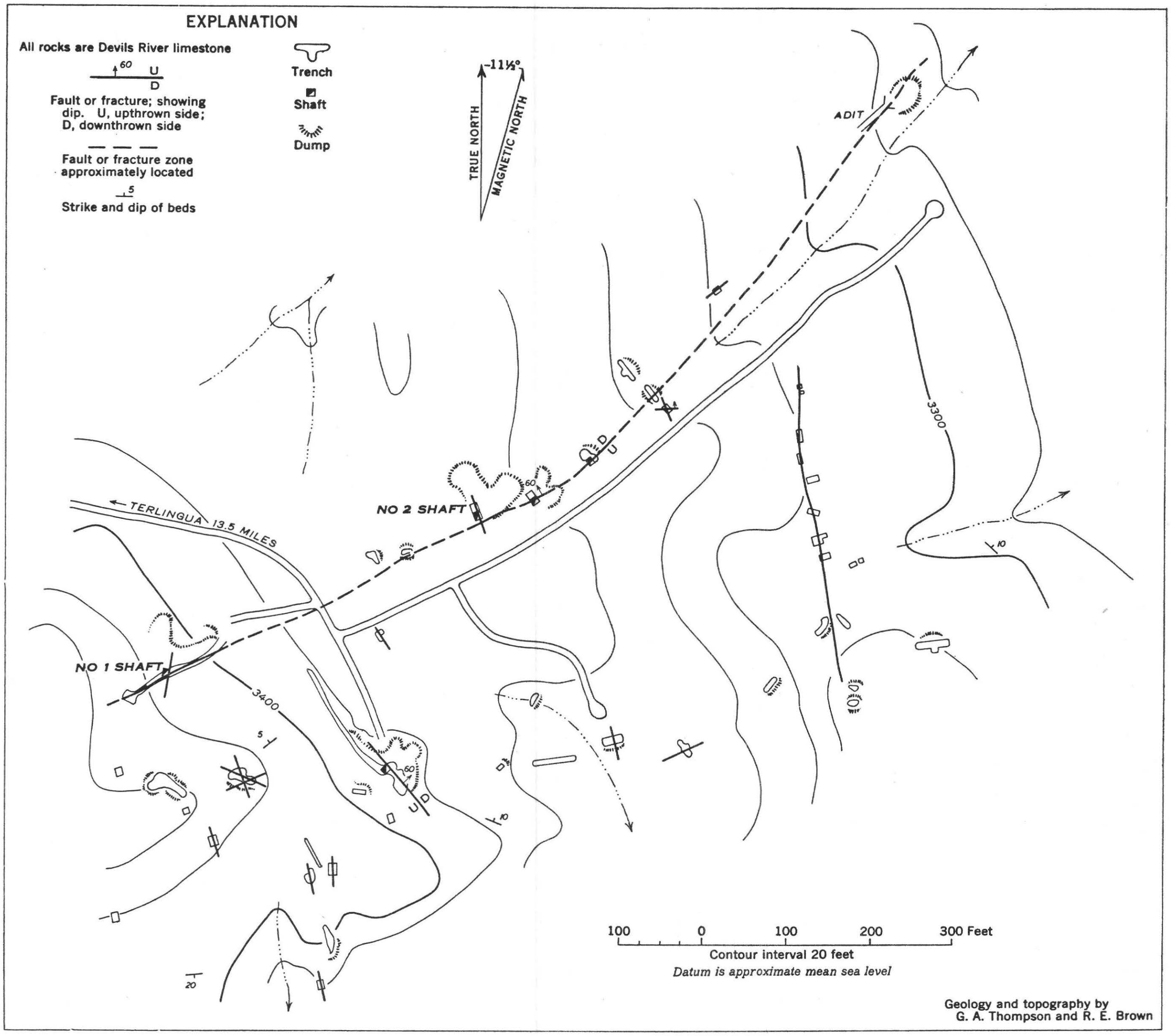


FIGURE 20.—Geologic and topographic map of part of Natural Resources, Inc., claims in sec. 58, Block G–12.

the only rock exposed at the workings. It ranges from fine to medium grain and some beds are composed almost entirely of fossil shells. The beds are flat to gently dipping, except immediately adjacent to faults, but south of the workings they are folded abruptly downward to form the Terlingua monocline. In the developed area (fig. 20) the rocks are broken by three main fracture systems: (1) vertical fractures with an average strike of N. 15° W., (2) steeply dipping fractures with an average strike of N. 40° W., and (3) steeply dipping fractures with an average strike of N. 60° E. The N. 15° W. fractures are the most numerous and persistent laterally but are the least mineralized. They commonly end against bedding planes and show slickensides that are horizontal or dip with the bedding. Vertical displacements on these fractures appear to be negligible or measured in inches. The N. 40° W. fractures locally have vertical displacements in excess of 3 feet. The N. 60° E. fractures, the best mineralized, have displacements locally of at least 4 feet but are extremely discontinuous and irregular.

The fractures along which the best cinnabar showings are localized belong to the N. 60° E. system and extend in a poorly defined zone through No. 1 shaft, No. 2 shaft, and the adit (see fig. 20). In many places the fractures are tight, nearly invisible cracks in one limestone bed and coarse breccia and clay zones in a bed immediately above or below. This has been caused by solution widening of the fractures and subsequent filling with debris. Cinnabar occurs in fractures of all three systems, but most of it is localized in the more brecciated places along the main N. 60° E. fracture zone. Associated with the cinnabar are calcite, clay, and iron oxides. Cinnabar is present as fillings in breccia, paint along cracks, and disseminations in clay.

MONTE CRISTO AND CROESUS CLAIMS

Part of the work done in the early 1930's by the Tarrant Mining Co. was on a group of four claims in the northeast corner of sec. 58, Block G–12, mainly in the claim called the Monte Cristo. These claims were not examined by the writers and the description that follows is that of C. P. Ross. Workings on the Monte Cristo claim comprise two small stopes extending from the surface down about 40 feet and a shaft begun in March 1934 to prospect ground southwest of the stoped area. The principal work done on the Croesus claim was the removal of about 500 tons of ore from a small stope in the southeastern corner of the claim. During the World War II no work was done on this claim or the adjoining Croesus claim.

The older and the higher of the two stopes on the Monte Cristo claim is an irregular opening in Devils River limestone from which were mined a number of pockets of cinnabar ore, in part along fracture planes trending N. 40° W., and in part along nearly horizontal bedding planes. Fractures of N. 60° E. trend are also present but in this stope appear to have had little effect on the ore deposition. Although individual ore bodies here were small, they are reported to have been of satisfactory tenor.

In the second stope, which adjoins and is connected with that described above, the ore was along a well-defined zone of fractures that trend N. 55° E. and dip 70° or more to the southeast. The fracture zone has been partly filled by the Grayson formation, colored dark green by disseminated pyrite. Cinnabar was found within the clay. This stope, much the larger of the two, is more than 100 feet long.

The principal stope in the Croesus claim is on the lode trending N. 50° E. shown in the extreme northwest corner of figure 21. This stope, reached by adits in the canyon wall, is a broken zone containing much of the Grayson formation, dropped or washed down from above.

DUNCAN GROUP IN SEC. 58

The Frank Duncan group of claims in sec. 58, Block G–12, is in the northeast part of the section just south of the Monte Cristo group. The group consists of eight patented claims, but as the better cinnabar showings and the principal development are in the two most northeasterly claims, the Pilkington and Hoover, the description is confined to them. Cinnabar showings are widespread and numerous, although in 1943 no ore in minable quantities was exposed. A few tons of ore have been treated in a 6-pipe retort. Development work consists of about 150 feet of tunnels, 900 feet of trenches, and several shafts less than 20 feet deep. The geology, topography, and development is shown in figure 21.

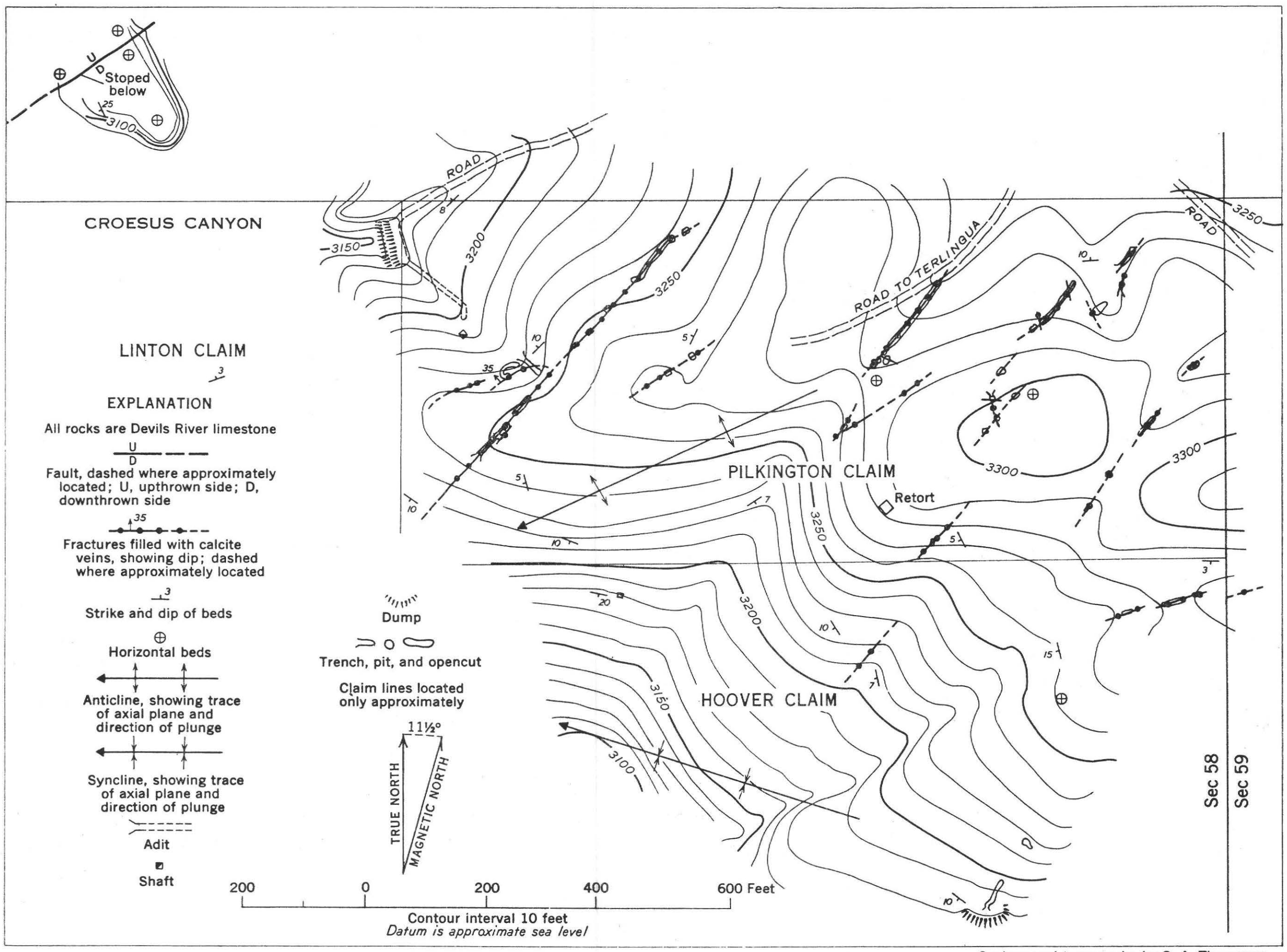
Devils River limestone is the only rock exposed; it is thick bedded to massive over most of the area but thin bedded where the uppermost beds are preserved. The beds are folded into gentle anticlines and synclines, and south of the Hoover claim they are flexed abruptly downward into the Terlingua monocline. The area is broken by steeply dipping to vertical fractures, some of which are filled by calcite. Most fractures strike northeasterly, in particular N. 40° E., and many of the fractures are arranged in echelon. Slickensides and mullions are common on fault surfaces; they are usually nearly horizontal and none were seen that plunge at an angle greater than 20° from the horizontal. Strike-slip movements on the faults were accompanied by bedding-plane slips, which resulted in lenticular breccia zones and the "capped veins" of the local miners.

Most northeasterly fractures are mineralized; cinnabar in small quantities accompanied by iron oxides and calcite is to be seen in a large proportion of the trenches. Commonly the cinnabar is thin films or irregular stringers only a few inches long and a fraction of an inch thick. Small pockets of ore have apparently been mined from the largest workings; but the largest pocket probably contained no more than 100 tons.

Local structures largely controlled the deposition of these pockets of ore, most of which are in the overlap area of two in echelon vertical fractures or in the zone of intersection of vertical fractures with bedding-plane slips. Such places are centers of brecciation and multiple fracturing, which has been intensified by solution and slump. One larger ore shoot was along a strong fracture and appears to have formed along a more open part of the fracture, as is shown by a filling of Del Rio clay that slumped or washed in from above. More ore may be found in this area by exploring the more strongly mineralized fractures.

MARGARET D LODE

The Margaret D lode (sometimes called Maggie D lode), located mainly in secs. 41 and 40, Block G–12, and extending for a short distance into sec. 58, Block G–12, is the longest, most continuous, cinnabar lode in the Terlingua district. It extends from the southwestern bounding fault of the Well Creek graben in a S. 70° W. direction for almost 7,000 feet. Its north-



Geology and topography by G. A. Thompson and R. E. Brown

FIGURE 21.—Geologic map of the Hoover and Pilkington prospects, sec. 58, Block G-12

east end is abrupt against the graben fault, which is older, but its southwest end is a gradual pinching out in the massive beds of the Devil River limestone. It lies mainly in holdings of the Texas Chisos Mining Co. and Waldron Quicksilver Properties.

This lode was worked mainly during the early history of the district before 1905. It has been described by H. W. Turner (1905, p. 274). Development consists of many trenches and pits, several shafts, and a few small underground stopes. The trenches range from a few feet to several hundred feet long, from 5 to 10 feet wide, and from 4 to 30 feet deep. The shafts are from 30 feet deep to an estimated 100 feet deep. The underground stopes are small but comparable in size with others in this part of the district. The production from the lode is unknown, but it is probably something between a few hundred and a few thousand flasks of quicksilver.

The lode is along a continuous fracture that has been differentially enlarged by solution on its limestone walls and subsequently filled by either calcite or cave-fill. The only discernible movement along the fracture was in a horizontal direction and was probably less than 10 feet. The central part of the lode appears to have been the most productive, because it contains the greatest number of workings and the most extensive development. Cinnabar and other mercury minerals were found sporadically throughout its length in both the calcite and cave-fill. The productive parts of the lode are separated by unproductive parts, which are more extensive.

Cinnabar was the principal ore mineral, but native mercury and the oxychlorides were also found. Abundant calcite, clay, and iron oxides were associated with the cinnabar, and minor quantities of fluorite and barite were also found. Much of the calcite was bituminous. The ore and its occurrence are typical of that described as keels of the limestone-clay contact deposits on pages 58 and 59.

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CANYON GROUP

In the northeast corner of sec. 42, Block G–12, is a group of five claims known as the Canyon group. Work here began in 1929 and continued intermittently through 1934. No work was done during the World War II period. The description that follows is largely that taken from the manuscript of C. P. Ross. In the graben valley which underlies much of the group a shaft, 80 feet deep, has been sunk through the Grayson formation and into the Devils River limestone a few feet. A winding drift more than 400 feet long extends N. 60° W. from the shaft. It follows a fault zone along which there has been some movement and alteration of the limestone close to the undulating base of the Grayson. The zone contains some iron oxide and calcite, but the only cinnabar reported to have been found was at the bottom of the shaft. Small solution openings are present at several places along the mineralized zone.

LAFARELLE AND PROSPECTS NEARBY

Near the center of sec. 32, Block G–12, there are some old workings mainly made under the direction of Lafarelle, one of those active in the early development of the district. Nothing appears to have been done here for a long time. The description that follows is after the manuscript report of C. P. Ross. A prospect pit about 30 feet deep and other cuts expose a mineralized zone along a fracture or joint in Devils River limestone. The fracture trends N. 80° W., and is vertical. Its limestone walls are brecciated and iron stained and are coated with calcite and oxidized pyrite. No cinnabar was seen.

Another pit about 1,500 feet to the northwest shows a similar zone of brecciation and alteration which trends N. 70° E. and is vertical. Near here the walls of the fault on the southwest side of the small graben block shown in plate 1 are slightly iron stained and enclose veinlets of calcite.

RIO GRANDE QUICKSILVER CO. CLAIMS

The Rio Grande Quicksilver Co. operated in the Terlingua region only during 1932 and 1933 and produced little quicksilver. Its principal development was in the western part of sec. 40, Block G–12, where it held some patented claims and a mining lease. No work was done on these claims during World War II. The description that follows is after that in the manuscript report of C. P. Ross. The Rio Grande Quicksilver Company had a rotary furnace and retorts near the base of a cliff. This furnace was operated for a short time during 1942 by Natural Resources, Inc., which treated ore taken from claims in sec. 58, Block G–12. The company also had a mineral prospect permit on part of sec. 36, Block G–12, and mineral leases on parts of sec. 44, Block G–12, and sec. 70, Block 341.

A shaft, northwest of the furnace and on the plateau at the top of the cliff, is reported to be 100 feet deep, but in March 1934 the lower 50 feet were inaccessible. At the 50-foot level 150 feet of workings cut 3 calcite-lined fractures in the Devils River limestone. Short drifts on the 25-foot level are connected with the surface through stopes along a 4-foot zone of brecciated limestone containing calcite, clay, and a little cinnabar. The zone trends N. 65° E. and is nearly vertical. It has been followed from the shaft for about 60 feet to the northeast and 150 feet to the southwest. In the cliff face below and northeast of these workings and close to the furnace, a short tunnel cuts several minor calcite and breccia seams of northwest trend.

WALDRON WORKINGS IN SEC. 40

Waldron Quicksilver Properties holds claims covering much of sec. 40, Block G–12. The principal development consists of a set of very irregular drifts and stopes totalling a few hundred feet of work that is located directly across the draw from the Rio Grande furnace. The workings extend to a depth of about 80 feet. When visited by C. P. Ross in August, 1934, no work had been done for about 20 years. Good ore is reported to have been mined, and the mine faces showed a little ore. Work was resumed here later in 1934, but continued for only a short time and the property was idle during World War II.

According to C. P. Ross (written communication) the principal workings follow a steep zone of brecciated and altered Devils River limestone which trends N. 60°–65° E. Calcite in small crystals coats some of the breccia and coarser calcite bands line and in part fill vugs in the limestone. In the upper workings exploratory drifts disclose calcite, lining and partly filling openings on joints of N. 60° E. and N. 40° W. trends.

MARIPOSA MINE

The Mariposa mine ranks second in production of quicksilver in the Terlingua district. It is in sec. 59, Block G–12, and is about 7 miles by road west of the Terlingua post office (see pl. 1). The property is controlled by the Esperado Mining Co. of Houston, Tex.

Since 1895 the Mariposa mine has produced between 20,000 and 30,000 flasks of quicksilver. Most was produced before 1911, but some during World War I and a little between 1933 and 1945. In the spring of 1945 the Esperado Mining Co. was reworking some of the old dumps and mining some ore from the Perry pit.

The productive ground, a rectangular area roughly 3,500 feet long and 1,000 feet wide, centers about California Hill (pl. 13). The principal subsurface workings (pl. 14), about 3 miles of drifts, stopes, and crosscuts, are under California Hill, but much of the ore was removed from pits, trenches, and shafts northeast and west of the hill. Of the 121 shafts deeper than 20 feet, 6 are more than 100 feet deep and 2 of these, the No. 5 (Cruz) shaft and the White shaft, are 300 feet or more deep. The Contratiro winze (pl. 14) extends 200 feet below the 100 level of the mine. Several thousand feet of drifts and crosscuts extending from this winze from the deeper shafts explore the mineralized ground through a vertical range of about 300 feet, but almost all the ore was removed from the uppermost workings.

The Buda limestone, Grayson formation, and Devils River limestone are the sedimentary rocks in the Mariposa area. An erosional remnant of Buda limestone caps California Hill and protects the underlying Grayson formation from rapid erosion. The Grayson forms the flanks of California Hill and covers the Devils River limestone in the southwest part of the area (pl. 13). Devils River limestone, stripped of the Grayson formation, crops out in the eastern and western ends of the area (pl. 13). The sedimentary rocks have a general northwest strike and an average dip of about 5° SW.

Soda latite dikes and sills intrude the Devils River limestone and Grayson formation in the southwest part of the area. In general the dikes occur in the limestone and the sills in the clay. The large sill that forms the southern part of California Hill connects with a dike that is explored by workings in the vicinity of No. 11 shaft. Another soda latite dike crops out 170 feet northeast of Goldby shaft.

Faults along the northwest, southwest, and southeast borders of the mapped area (pl. 13) bound a depressed block of Devils River limestone. Vertical displacements on the faults at no place exceed 100 feet. The planes of fault movement are largely obliterated by later solution of the limestone walls.

Most fractures in the depressed block trend northeast, but a few trend northwest. The northeasterly fractures range in trend from N. 40° E. to N. 85° E., but most trends are either N. 60° E. or N. 75° E. Only a few fractures have vertical displacements; however, horizontal grooves indicate that most movement was probably in a horizontal direction. East and west of California Hill, the fracture pattern is expressed in elongate outcrops of Devils River limestone that are separated by narrower zones of cave-fill. The cave-fill occupies solution caverns that developed in the upper beds of Devils River limestone adjacent to the northeasterly fractures. The cave-fill as mapped (pls. 13 and 14) includes many blocks and small pillars of limestone and some small areas of highly altered limestone or extremely cavernous limestone partly filled with calcite. The cave-fill zones extend under California Hill where they are explored by the mine workings.

The cave-fill zones at the Mariposa mine are type examples of the limestone-clay contact deposits in the Terlingua district and are described on pages 55–59. The ore bodies were distributed within and along the borders of the cave-fill zones as veinlike bodies and as irregular tabular bodies and pockets. Their general form in some places roughly corresponded to that of the cave-fill which enclosed them; however, in only a few places did they extend from wall to wall of the cave-fill. As all known ore bodies have been mined out, little can be said of their detailed character and exact dimensions. According to old reports, some ore was mined from calcite veins and a little from the limestone, but doubtless most ore came from altered clay in the cave-fill zones.

No record of the average grade of ore from the Mariposa mine is available. In the early years of the mine only the better grade ore was treated and the lower grade ore was put on the dumps, most of which have since been reworked. According to Hill (1902), in 1901 ore that was being treated in retorts averaged from 8 to 25 percent quicksilver, and ore that was being treated in the furnaces about 3 percent. During this early period many rich pockets were mined; one contained more than 20 tons of ore that averaged over 50 percent quicksilver. Figures given by Phillips (1905) for ore that was being treated in the Marfa and Mariposa Scott furnace in 1904 differ somewhat from those of Hill. According to Phillips, the furnace was treating ore that averaged less than 1.5 percent quicksilver, but not infrequently treated ore that contained as much as 2.5 percent quicksilver. Material that was mined from 1942 to 1945 ranged from ore that contained less than 0.2 percent quicksilver to ore taken from small pockets that contained almost 50 percent quicksilver.

The principal ore mineral is cinnabar, but important quantities of native mercury and other rare mercury minerals were mined. The cinnabar occurs as disseminations and as solid masses in the clay matrix of the cave-fill and to a much lesser extent as veinlets and disseminations in the limestone.

In March 1945, the Mariposa mine had no appreciable ore reserves. At that time a small body of ore was being mined from the Perry pit and a very small amount of dump material was being screened by hand and trucked to the Chisos mine for furnacing. The total production of the mine, a maximum of 30,000 flasks of quicksilver since 1895, came principally from the cave-fill zones. The geologic map (pl. 13) shows that about

75 percent of the cave-fill area has been mined or intensively explored. Less than 50 percent of the remaining cave-fill area is unexplored or inadequately prospected by widely spaced trenches and pits. A large number of the prospect pits and trenches shown on plate 13, represent exploration done since 1935. Even though the ground with the best indications of cinnabar was explored during this period, few ore bodies were found. The unexplored ground that remains shows less mineralization than did the explored places; therefore, it is not likely to be so productive.

Small ore pockets probably remain in the area shown by the geologic map (pl. 13), but because of their probable small size and scattered occurrence, the cost of exploration may not be justified. These pockets can most economically be searched for by sinking pits on the better showings of cinnabar, as determined by panning the surface clay of the cave-fill. The ground that is covered by alluvium east of the Perry pit and that in the west end of the mapped area (pl. 13) deserve special attention in any exploratory program.

Small quantities of cinnabar can be panned from much of the cave-fill clay, but this material is of too low grade to be worked, even at the high prices of the World War II period by existing mining practices. Future price conditions and new technology may make possible the mining of much of this material.

It does not seem advisable to explore the Devils River limestone at depths more than 50 feet below the base of the Grayson formation. In the mapped area (pl. 13) more than 25 percent (about 1 mile) of the total underground workings are below this depth and, judged from the number and size of the stopes on these lower levels, the ore mined probably did not compensate for the cost of its discovery and extraction.

TARRANT PROPERTY IN SEC. 39

The main camp, a 10-ton rotary furnace, and retorts of the Tarrant Mining Co., of Forth Worth, Tex., were in sec. 39, Block G–12. Mine workings are scattered over the southwestern part of the section, mainly in the grabenlike depression occupied by upper Well Creek. The Tarrant Mining Co. mined and treated ore in the district during 1933 and 1934 but did not operate during World War II. In addition to the property in sec. 39, this company had holdings in secs. 58, 38, and 60 of Block G–12, and secs. 69 and 70 of Block 341.

The more extensive underground workings (according to C. P. Ross's manuscript) in sec. 39 include those of the No. 1 shaft located at the base of the cliff near the southwest corner of the section (fig. 22). The shaft is 130 feet deep. More than 2,400 feet of exploratory drifts have been opened on the 84-foot level, largely in unaltered Devils River limestone just below the undulating base of the Grayson formation. A drift southwest of the shaft follows a fracture of northwest trend. This appears to correspond to a narrow vein of bituminous calcite on the level below. More than 100 feet north of the shaft, drifts and small stopes extend for more than 300 feet along a zone of brecciated and altered limestone of which the Grayson formation locally forms the southeast wall. The average trend is N. 55° E. At one place there is a 2-foot band of kaolinized material, possibly a much altered dike, which makes an acute angle with the fracture zone.

The parts of the drifts near the shaft explore a zone of altered Devils River limestone and partly altered the overlying Grayson formation. The trend of the zone, as developed, averages about N. 50° E., but on the 84-foot level, especially west of the shaft, there is little fractured rock along the zone. Northeast of the shaft the Grayson formation within the altered zone is flexed downward toward the southeast. Between this point and the 130 level there are small stopes. Evidently the ore mined here lay in part along the lower contact of the shale and in part formed irregular masses in the altered limestone. On the 130 level below the stopes there are fractures in the limestone, of which the principal one trends about N. 45° E. and dips steeply northwest. A little work has been done below the 130 level, presumably on a continuation of this fracture, but this part of the mine was inaccessible in 1934 as well as in 1940. Most of the 25 feet of drifts on the 130 level are in fresh Devils River limestone.

About half a mile north of the workings about the No. 1 shaft, the No. 3 shaft, which starts on top of a hillock, goes down nearly 250 feet and has more than 1,100 feet of drifts at the bottom, as shown in figure 23. The shaft and drifts are in unaltered Devils River limestone. The drifts explore a system of joints, which locally show thin calcite veins and solution vugs. At one place a little iron oxide is visible.

Numerous shallow workings are scattered over the southwestern part of sec. 39. Trenches on the high ground west of the No. 1 shaft mark a continuation of the mineralized fracture system so conspicuous near California Mountain. Others along Well Creek and its branches between Clay Mountain and the No. 2 shaft (pl. 12) and along Well Creek east of this shaft, explore seams of both the N. 40° W. and N. 60° E. systems, and locally mineralized bedding planes in the nearly flat Devils River limestone. At the workings at the No. 2 shaft, work was in progress in March 1934. Stoping here extended nearly 20 feet below the surface on a zone of calcite seams with cinnabar in Devils River limestone. The zone trends N. 10°–30° W. and dips 60° SW., flattening below. Some calcite seams

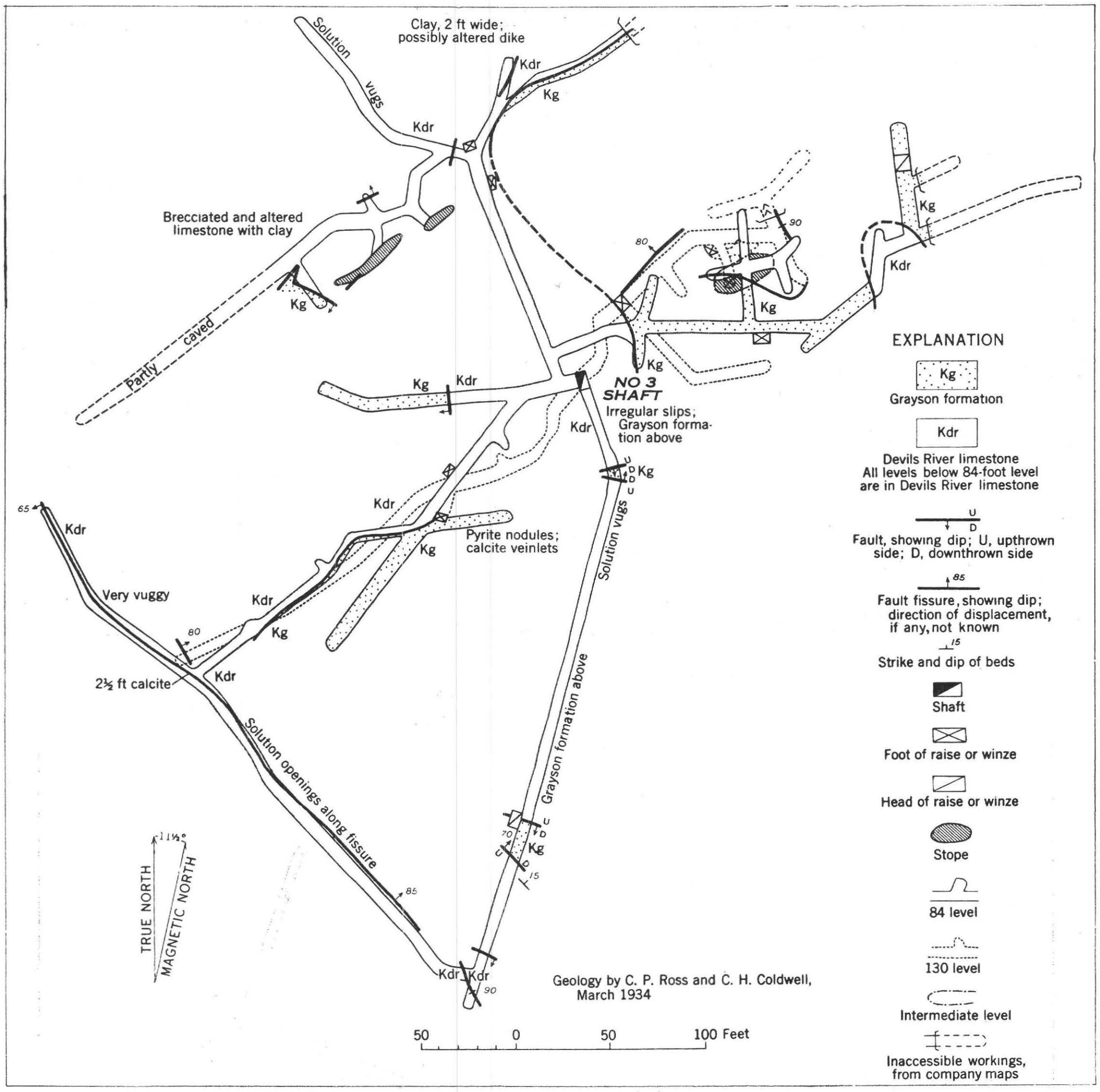

FIGURE 22.—Sketch map of the workings off the No. 1 shaft, Tarrant Mining Co. property.

are vertical and others follow the nearly flat bedding of the limestone. The maximum width of the zone in the stope was about 3 feet.

LITTLE THIRTY-EIGHT MINE [8]

The Tarrant Mining Co. controls the Little Thirty-Eight Mine in the southern part of sec. 38, Block G–12, but did very little work there. This lode has been known since early in the history of the district and yielded considerable ore during the World War I period. The workings are shown in figure 24 and include a vertical shaft 250 feet deep, with levels off it every 50 feet. Stopes and natural openings connect the levels, especially in the northeast part of the mine. Below the shaft, irregular skidways, with some drifting and stoping off them, follow the lode down to an additional depth of more than 160 feet. The lode trends N. 65° E. and dips 80° SE. Crosscuts on the 200 and 250 levels explore the hanging wall. The drifts and crosscuts total about 2,000 feet. In addition, open spaces, in part artificial, extend more than 100 feet to the northeast beyond those drifts that lie between the surface and the 200 level as a minimum depth.

The lode consists of an opening along one of the series of northeasterly joint fissures in the Devils River limestone, enlarged by solution and lined and partly filled by calcite. Locally the distance between limestone walls is more than 15 feet, but the average is only a few feet and in places it narrows to a few inches or even closes entirely. The greatest widths between walls are in the eastern part of the mine, especially on the upper levels. In some places the larger openings are scores of feet long. Elsewhere there are roughly circular solution pipes, 6 feet and less in diameter. Some of these

[8] After written communication by Clyde P. Ross.

extend out into the wall rocks. The open places left after calcite deposition, probably somewhat enlarged by renewed solution, have been in part filled by rubble. Within the workings most of the clastic fill and some of the calcite have been removed in mining. In some of the calcite-lined openings in the northwest part of the mine which may never have been filled, the calcite is corroded and small stalactites formed. In most places the calcite bands and combs are roughly parallel to the walls of the main fissure, but locally bands lie horizontal with a tendency to curve upward at their edges. Exceptionally, as in the northeast part of the 50 level, bands of calcite crystals blanket masses of poorly cemented rubble, having crystallized after filling of the opening by rubble had begun.

Most of the material filling the openings along the fissure is rubble, cemented to varying firmness by a material resembling caliche. The rubble consists of angular to slightly rounded fragments of limestone, calcite, and shale, in part held together rather loosely, in part so firmly cemented as to require blasting to mine. Many fragments are altered and many are jaboncillo. In addition it is reported that the material mined locally contained bands of jaboncillo roughly parallel to the walls. Much of the cinnabar was in such bands. The fragments commonly range from a fraction of an inch to a few inches in maximum dimension, with fine-grained material in the interstices. According to report, much of this rubble-fill contained enough cinnabar to be high-grade ore and most of it yields some cinnabar on panning. Apparently most of the cinnabar is in grains in the finest part of the interstitial material rather than in the larger fragments or in the calcite. In the northeast part of the 50 level, calcite bands and clastic material are so intermingled as to show that the two modes of filling alternated.

At the surface the northeast part of the lode is masked by caliche-cemented conglomerate fully 10 feet thick. Low, irregular rooms have been excavated along the contact between the conglomerate and the limestone

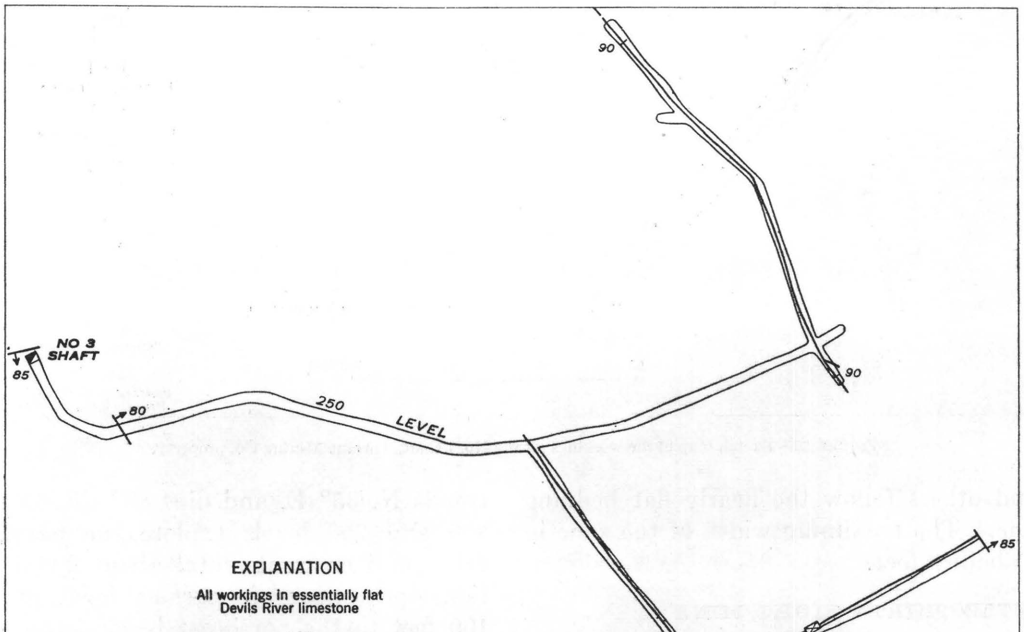

FIGURE 23.—Sketch map of the workings off No. 3 shaft Tarrant Mining Co.

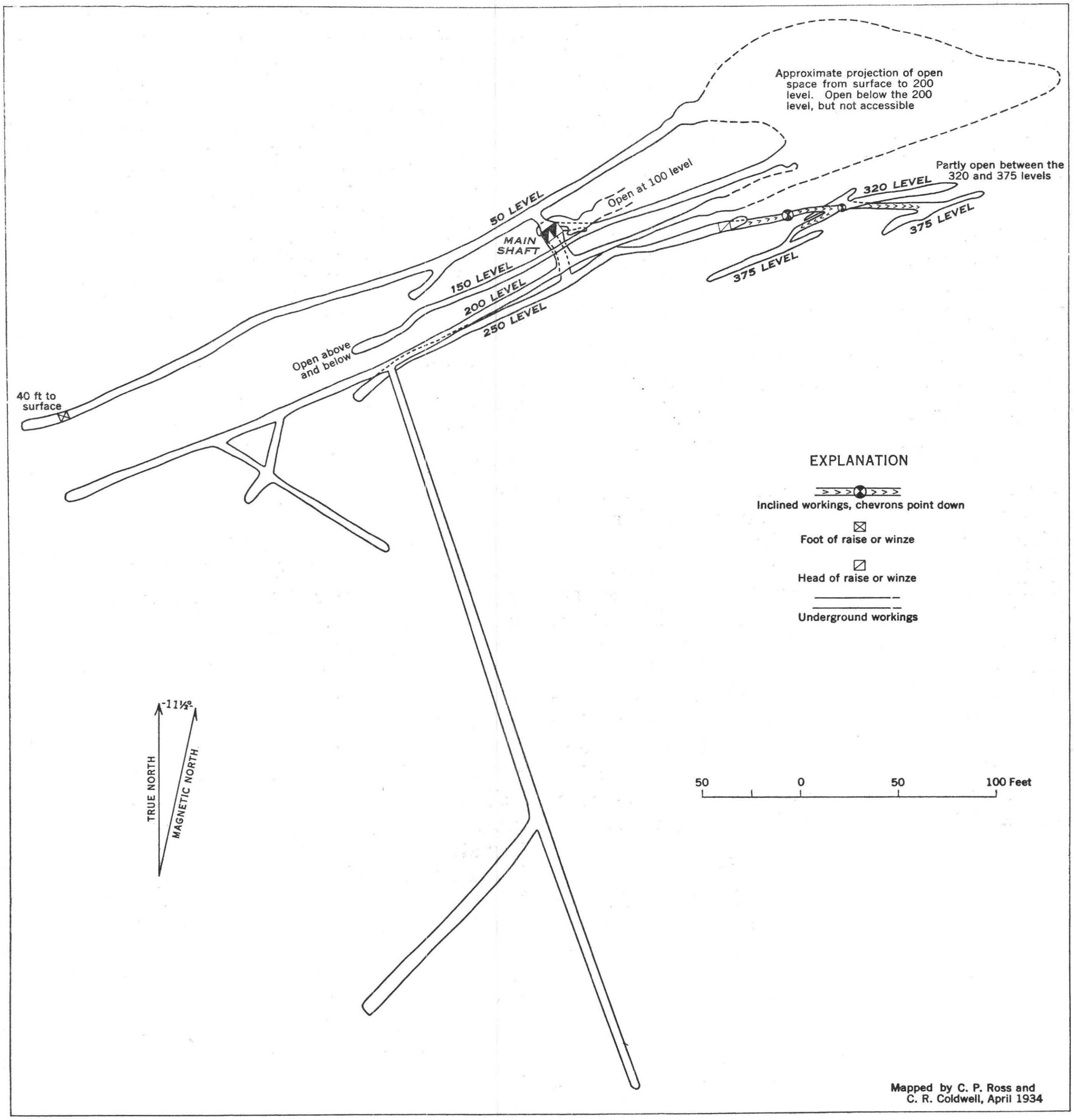

FIGURE 24.—Sketch map of the Little Thirty-Eight Mine.

on which it rests. About 250 feet southeast of the shaft (fig. 24) a series of trenches follows a lode in the limestone for about 600 feet. A little cinnabar and fairly abundant fluorite and barite were seen along this lode. This may be the same mineralized joint fissure that is explored in a drift off the long crosscut on the 200 level, although at that level it shows nothing but a little calcite.

STAR MINE AND NEIGHBORING WORKINGS

The northern part of sec. 70, Block 341, contains many trenches. The principal recent development is on the Star claim in the northeast part of the section. Here the Tarrant Mining Co. penetrated a block of Grayson formation with a shaft 80 feet deep and explored the Devils River limestone below with about 250 feet of drifts. According to C. P. Ross (written communication) one of the drifts follows for 60 feet to the northeast, a zone of rusty, brecciated limestone with calcite seams. The same company also did a little work close to the road northeast of the shaft. A few hundred feet farther west and just north of the main road trenches expose a mineralized fracture zone in Devils River limestone almost continuously for about 900 feet. The zone trends N. 70° E. and stands vertical or dips chiefly south, having well-marked nearly horizontal striae on the outermost fractures, which are several feet apart. At its southwest end this fracture zone ends against a zone 20 feet wide of closely spaced fracture planes lined with calcite that is in part bituminous. The fracture planes strike N. 45° W. and stand vertical or dip about 75° SW. There is little suggestion of displacement along either the northeasterly or northwesterly fractures.

RIO GRANDE PROSPECT IN SEC. 70, BLOCK 341

The Rio Grande Quicksilver Co. did some development near the center of sec. 70, Block 341. According to C. P. Ross (written communication), at this place a fault in the Devils River limestone strikes N. 75° E. and dips 85° N. Grooves on the fault plane are inclined 20° E. There are some brecciated limestone, calcite, iron staining, and evidence of solution along the fault. Some of the solution cavities have been enlarged artificially at a point where there is a calcite-lined cross seam that strikes N. 30° W. and dips 80° to 90° E. In the depression on the downthrown side of the fault there is a shaft that appears to be fully 75 feet deep. In 1942 this property was held by A. E. Owens, but no work had been done on it for many years.

COLQUITT-TIGNER (WALDRON) MINE

The main camp, Scott furnace, and retorts of Waldron Quicksilver Properties, Inc., are at the old Colquitt-Tigner mine in the northwestern part of sec. 38, Block G–12. This company is one of the largest property owners in the district. It has claims in secs. 38, 40, 60, and 70, Block 12, and secs. 248 and 298, Block G–4, and holds the whole of secs. 35 and 37, Block G–12, and part of sec. 70, Block 341. The company did some mining between 1925 to 1927 and again for a short time beginning in 1934. The latter work was mainly in sec. 248, Block G–4, and sec. 40, Block G–12 (see Waldron workings in sec. 40, p. 92). The ore was trucked to the plant at the Colquitt-Tigner mine. The workings in sec. 248 were actively developed during World War II and became known as the Two-Forty-Eight mine (pp. 106–107). The Waldron camp is unique among the mining camps in the central part of the district in that it has its own domestic water supply, a covered concrete tank, in a stream nearby. The description that follows is from C. P. Ross's written communication:

The Colquitt-Tigner mine contains about 900 feet of drifts on the main level, which is entered by an adit in the hillside close to the furnace and is connected with the surface on the crest of the hill by shafts and cuts (fig. 25). Several winzes, inaccessible at the time of visit, connect with lower workings. Stopings have been done at intervals along the adit and also in the caves in the northwestern part of the main level. The workings explore a set of complementary joint planes in the Devils River limestone. Most joints of northeasterly trend are accompanied by a little iron staining and other alteration in the limestone and by calcite. It is evident that there was marked local enlargement of these joint openings by solution, in part, at least before the deposition of the calcite. The interconnected caves in the northwestern part of the workings are some of the larger solution cavities in the district. They have a combined length of about 340 feet, a maximum width of about 60 feet, and are known to extend to a depth of about 200 feet. Most of this cavity was originally filled with a fine-grained, fairly distinctly banded sediment containing sulfide and chloride of quicksilver in such quantity that it could be mined as ore. The upper 20 feet or so was unfilled.

LE ROI PROSPECT

The Le Roi prospect, which consists of 8 claims in sec. 70, Block G–12, is about 1½ miles from Terlingua by road and less than 1 mile southwest of the Chisos and Rainbow mines. Superficial prospecting has been done by about a dozen shallow trenches, a shaft about 50 feet deep, and an adit 35 feet long. No ore has been found and only traces of cinnabar can be panned from the prospects.

Most of the claims are along or near the base of the cliff of Devils River limestone that forms the south wall of the Long Draw graben. North of the cliff and graben fault are badly faulted and crumpled Grayson formation, Buda limestone, Boquillas flags, and Terlingua clay (see pl. 15). Vertical displacement on the Long Draw graben fault is roughly 1,500 feet. Much of this displacement is on one fault, but at the eastern end of the Speed Wagon claim it is distributed over a complex of faults. This complex of faults converge in the northeast corner of the Speed Wagon claim to form a single fault trending southeastward. At the point of convergence a northwesterly fault splits from the graben fault to bound a block of Boquillas flags between the graben fault and the Terlingua clay that floors Long Draw. The beds of Boquillas flags composing this fault block are warped into northward-plunging folds.

Some of the major faults and most of the minor fractures are associated with calcite veins. Calcite is the only abundant mineral in the veins; iron oxides in the vein zone, however, suggest that pyrite or other iron sulfides were introduced locally. Gypsum is common locally, especially in the Grayson formation. The

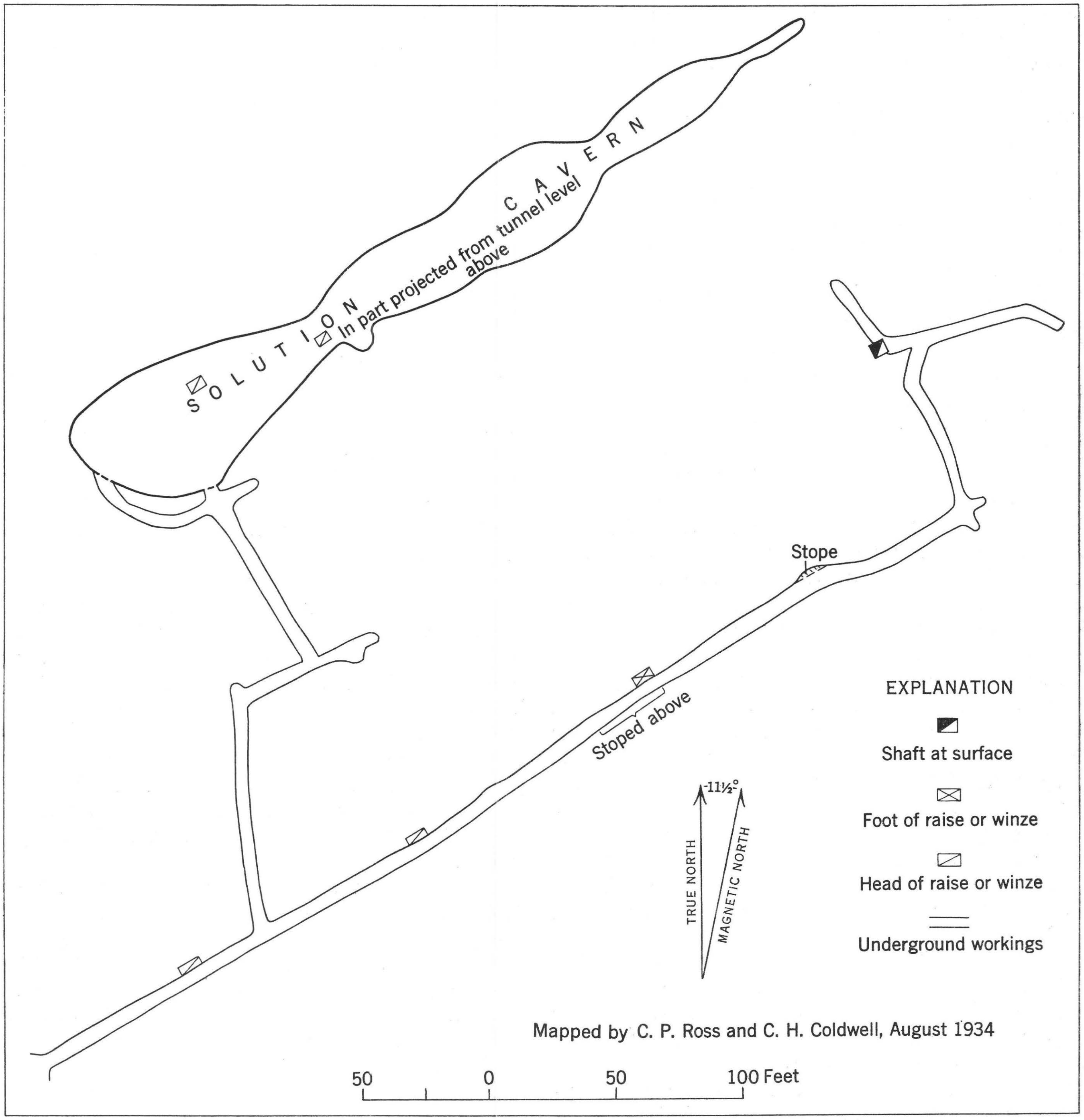

FIGURE 25.—Sketch map of the adit level, Colquitt-Tigner mine.

calcite is coarsely crystalline and some is notably bituminous. No cinnabar was seen in the veins, but traces were panned from the longest trench in the eastern part of the Speed Wagon claim and, according to Mr. Frank Duncan, it can be panned from most of the other prospects, a fact which indicates that although the mineralization was sparse it was widespread. The zone most heavily mineralized with calcite veins is at the eastern end of the Speed Wagon claim, where irregular areas of calcite in Devils River limestone are well exposed across the gully bottom for a distance of about 150 feet. An offshoot of this calcite zone is in the slot-shaped part of the gully for at least 50 feet further upstream. The calcite lode that crosses the gully extends more than 200 feet up the southwestern bank and continues beyond the Le Roi property. In some places the vein zones that compose these lodes are as much as 10 feet wide, within a lode-width of about 50 feet. Calcite is more abundant on the northwest bank of the gully and is covered by rubble on the shoulder above it; the erratically mineralized lode widens at the shoulder to about 150 feet.

The next major zone of calcite veins is at the mouth of the gulch southwest of the shaft, and it is entirely in Devils River limestone. Although erratic lodes and more widely spaced networks of veins crop out over most of the gulch for 200 feet across the mouth and back 150 feet, they tend to be alined in two directions, approximately north and approximately east. Single calcite veins are as much as 3 feet thick for short distances. Jaboncillo is commonly associated with them.

The veins in the Boquillas flags at the western end of the mapped area (pl. 15) are more persistent than those in the eastern zones; nevertheless they are commonly less than 3 inches thick, although for short distances they are as much as 15 inches thick. The eastern group of two groups of veins extends intermittently from the trench at the fault between Boquillas flags and Terlingua clay near the north boundary of the Oakland claim, under terrace alluvium to the bed of the Long Draw, where they are exposed in the southeast cliff, and then beyond intermittently for a distance of 350 feet, or a total distance of 850 feet. Alined with this zone are two veins, 1 foot and 2 feet thick, respectively, that go diagonally S. 25° E. up the steep slope. The larger one is prominent for 150 feet, but much less distinct on the other side of the ridge. At the steep bank of the creek in Long Draw the veins follow fractures of 1- or 2-foot displacement that tend to converge downward and towards the northwest. The western group of veins does not cross the creek.

Although these prospects are near the Chisos and Rainbow mines, they are on structures and veins that are entirely independent of those of these mines. Both the Le Roi property and the Chisos-Rainbow properties are associated with bounding faults of the Long Draw graben, but there the resemblance ends.

The Chisos-Rainbow productive area lies on the upthrown side of the northeast bounding-fault, whereas that area of the Le Roi property that is mineralized by calcite veins and sparse cinnabar lies mainly on the downthrown side of the southwest bounding-fault. There was no ore found on the downthrown side of the Chisos-Rainbow fault. Further structural differences are the absence of faults in the rocks on the upthrown side of the southwest bounding-fault; faults were conspicuously absent at the Chisos mine. This difference may mean, however, that the best places for finding commercial ore bodies on the Le Roi property are below the calcite mineralized area on the downthrown side of the fault. In this area the most favorable potential ore horizon would be the Devils River-Grayson contact.

CHISOS MINE

The Chisos mine, which is at the town of Terlingua, is the outstanding all-time producer in the Terlingua district, having yielded two-thirds of the quicksilver produced. Most of the mine workings are in sec. 295, Block G–4, but they also extend for a short distance into sec. 70, Block G–12, where they connect with the workings of the adjoining Rainbow mine. The mine was in almost continuous operation from the time of its discovery, about 1902, to 1943, and during that time produced about 100,000 flasks of quicksilver.

The mine, consisting of about 23 miles of workings, is accessible by three main shafts (3, 8, and 9; plate 16), but No. 8 shaft is the only one that has been used in recent years. Besides these shafts, there are several others that connect only with the upper levels and the Susano, No. 14, and No. 16 shafts that have no connection with the workings of the Chisos mine proper. The lateral extent of the workings is 3,000 feet east and west and 2,500 feet north and south; the vertical extent is 840 feet in the eastern part of the mine and 800 feet in the western part of the mine. There are 17 levels, roughly at 50 foot intervals, and many sublevels. The workings below the 800 level in the eastern part of the mine and below the 725 level in the western part of the mine are small in extent and were flooded in 1942 when the writers mapped the property. Practically all the remaining workings were accessible at that time. Maps of a few typical levels are shown as plates 17, 18, and 19.

Furnace facilities at the Chisos mine were a 20-ton Scott furnace, built in 1903 and razed in 1943, and a rotary furnace, which had a rated capacity of 100 tons of ore per day. The rotary furnace, installed in 1918, was partly destroyed by fire on July 24, 1942, but was repaired the following year. Although it is rated as a 100-ton furnace, it has never been operated at even one-half this rated capacity.

The earliest discovery of cinnabar in the area of the Chisos mine was about 1897 near the present No. 9 shaft. Workings that developed from this discovery were known as the McKinney-Parker mine, which has since become a part of the Chisos property. Discoveries were made east of here about 1902 near the present Lafarelle shaft, and these discoveries led to the development of the Chisos mine proper.

Early mining at the Chisos was done from surface workings and later from the South Lafarelle shaft, which connects with the 87 level in what is now the northeastern part of the mine. Later the No. 1, No. 3, No. 8, and No. 9 shafts were sunk. By 1912 the No. 9 shaft was down to the 500 level, the No. 3 to the 350 level, the No. 8 to the 250 level, and the No. 1 to the 150 level. In 1911 and 1912 production came mainly from the No. 3 shaft and in 1913 and 1914 from the No. 3 and No. 1. Between 1915 and 1919 rich ore from the 550 level and Pipe stope made the best production record in the history of the mine; the peak was reached in 1917 when 7,200 flasks of quicksilver were produced. In 1917 the No. 9 shaft was sunk to the 750 level, and production from the early 1920's came partly from lower levels off this shaft. As the Chisos 600 level was gradually extended northward from the No. 9 shaft, ore was followed into the Rainbow property.

In 1937 the Chisos production declined sharply, and since that time production came mainly from dumps. When the mine closed in August, 1942, the Chisos furnaces were being supplied partly from low-grade ore trucked from the Mariposa mine, partly from a very small ore body on the 250 level of the Chisos mine, and partly from old dumps.

The Chisos mine was operated until 1942 by the Chisos Mining Co., which was owned by Howard E. Perry of Portland, Me. The estate of Mr. Perry (legally separate from the Chisos Mining Co.) owns sec. 296, Block G-4, sec. 69, Block G-12, and part of sec. 70, Block G-12, all of which are adjacent to sec. 295. In November 1942 the Chisos Mining Co. was in litigation and was finally purchased by the Esperado Mining Co. of Houston, Tex.

The rocks, structures, and quicksilver deposits are more varied in the Chisos mine than in any other mine in the district. Both sedimentary and igneous rocks are present. The sedimentary strata include Devils River limestone, Grayson formation, Buda limestone, Boquillas flags, Terlingua clay, and sandstone and clay of the Aguja formation, as well as cemented and uncemented Recent alluvium. Only the Boquillas flags, Aguja formation, Terlingua clay, and alluvium are exposed at the surface. The igneous rock is intrusive and is probably a soda latite, although its altered character prevents an exact determination. The sedimentary rocks are gently folded and in places strongly faulted. Cinnabar was mined from limestone-clay contact deposits, calcite veins in the Boquillas flags and Buda limestone, and from a breccia pipe.

The Devils River limestone, Grayson formation, and Buda limestone can be seen only in the mine workings. The Devils River limestone is below the lowest workings in the eastern half of the mine, but is penetrated by workings in the western half of the mine as well as in the adjacent Rainbow mine. The Grayson formation is best exposed in the western part of the mine, but it has also been penetrated by workings near the No. 8 shaft. It ranges from 145 to 185 feet thick; probably most of this variation is the result of flowage adjustment to structural stresses rather than to depositional differences. Because this clay disintegrates upon contact with water it is a major mine hazard. The Buda limestone is penetrated by mine workings and drill holes in both the eastern and western parts of the mine. It is about 90 feet thick. The Boquillas flags is exposed both on the surface and in mine workings. On the Chisos property it is more than 900 feet thick, but an exact section could not be measured because of numerous faults. The Boquillas flags are extensively weathered as far down as the 200 level; below this, weathering is confined to the immediate wall rock of the veins, where ground water could most easily move. The Terlingua clay is well exposed in Long Draw south of the Chisos mine. In the mine it can be seen only on the west side of the McKinney-Parker fault. Its occurrence down to and below the 350 level indicates that in this area it has a minimum thickness of at least 400 feet.

The only igneous rock that crops out is south of the Susano shaft (pl. 16); however, in the underground workings sills and discordant dikelike masses of igneous rock can be observed in many places. They are most common in the western part of the mine, but are also found northeast of the No. 8 shaft and in drill holes in the Susano area. A drill hole 750 feet northwest of No. 16 shaft goes through igneous rock from 370 feet to 459 feet below the surface. Specimens of igneous rock that were collected for microscopic examination, although appearing fresh in the hand specimen, were found to be greatly changed from their original composition by deuteric alteration. They were questionably determined to be a soda latite. The fresh-appearing rock is greenish black, aphanitic, and locally porphyritic, having phenocrysts of pyroxene. Underground it is in most places altered near its borders to a soft, white rock that has lost most of its igneous characteristics.

The Chisos mine is on the northeast side of the Long Draw graben and its ore bodies are structurally related to this feature (see pl. 1). The fault that determines the northeast limit of the graben also determines the southwest limit of the mineralized ground. This fault is not a simple structure but is composed of several parts. The rocks northeast of the graben fault are folded into gentle synclines and anticlines that are broken by numerous minor faults, some of which are splits from the graben fault. All the faults in the area are pre-ore structures.

The graben fault extends across the southern edge of the mapped area (pl. 16) in a general northwesterly direction. Its course is characterized by abrupt angular bends where occur splits from the main fault. The graben fault also determines the southwestern limit of the ore bodies of the Rainbow mine, and that part of it which goes through the Rainbow property is called the Rainbow fault. Just northwest of the No. 9 shaft the Rainbow fault splits to form the Chisos fault, which extends southeasterly past the No. 9 shaft towards the No. 3 shaft, and the McKinney-Parker fault, which extends southerly towards the McKinney-Parker workings. At the McKinney-Parker workings, the McKinney-Parker segment of the Chisos fault again splits and the branch that extends to the southeast, the Cliff fault, finally passes off the south border of the area shown in plate 16.

Because of mine dump and alluvial cover the Rainbow fault is poorly exposed; wherever it can be seen it is marked by a well-developed breccia zone and forms the boundary between the Boquillas flags and Terlingua clay. Displacement is between 800 and 1,000 feet. Section D—D′ of plate 20 shows that it has an average dip of about 65°, with the downthrown block to the south. A calcite vein and fault that extend N. 75° E. through the northwest Rainbow surface workings are probably an adjustment expression of the angular bend in the Rainbow fault west of the Rainbow shaft. Likewise the wide breccia and calcite zone at the east end of the Rainbow fault is probably an adjustment expression of the junction of the Rainbow, McKinney-Parker, and Chisos faults.

The McKinney-Parker segment of the graben fault dips 65° to the west and the west side of the fault has been displaced downward at least 600 feet. (See section C—C′, pl. 20.)

The Cliff fault segment has less displacement than either the Rainbow or McKinney-Parker faults; at its west end the displacement is between 200 and 400 feet and where it leaves the mapped area (pl. 16) its displacement is only a few feet.

The Chisos fault cannot be seen on the surface, but on the 50 level it passes just east of the No. 9 shaft and splits into a number of smaller faults before it reaches the No. 3 shaft. However, on the 650 level it extends as far east as the No. 8 shaft. On the upper levels of the mine between the No. 3 and No. 8 shafts the Chisos fault is expressed by a number of small nonpersistent faults and calcite veins. The vertical component of displacement along the Chisos fault is variable; east of No. 3 shaft it is only a few feet, immediately west of No. 3 shaft and to within 150 feet of No. 9 shaft it is 85 feet, and at the west end of the fault, 100 feet north of No. 9 shaft, it is about 250 feet. The abrupt change in displacement at the No. 3 shaft is the result of cross faults that divide the south block into two parts; the change near the west end of the fault is the result of drag produced by movement on the McKinney-Parker fault. Horizontal and low-angle flutes and grooves indicate some horizontal movement along the fault.

A series of faults with an average trend of N. 30° E. are north of the No. 8 shaft, and they may be the northeast expression of the Chisos fault. Calcite veins have formed along almost all these faults, which form the northeast vein system of the Chisos mine. Displacement on these faults is in general small, probably not more than a few feet on most, although one, the 250 Vein fault has a displacement greater than 30 feet. Dips of the fault planes range from 40° to vertical. The faults die out to the northeast and tend to converge with the Chisos fault to the southwest. They tend also to converge at depth.

There are numerous other minor faults in the area southeast and east of the exploited part of the Chisos property. The most persistent of these have strikes ranging from N. 60° E. to N. 75° E. and dips ranging from 25° to 80°. Probably none have displacements greater than 40 feet.

In the area about the Chisos and Rainbow mines folds are definitely subordinate to faults. All the folds are open structures with dips of the limbs rarely exceeding 30°. The two most prominent folds in the area covered by plate 16 are synclines. The axis of one roughly corresponds to the course of the valley at the head of Grace Canyon and plunges in a southeasterly direction. The axis of the other trends N. 20° E. and passes through the Aguja breccia pipe. In general, folds in the western part of the area trend northwesterly and folds in the eastern part of the area trend northeasterly. Of particular interest is a zone of sharp monoclinal flexure that passes through the northcentral part of the area, about 300 feet south of the No. 16 shaft. This zone trends N. 60° W. and is locally more than 100 feet wide. It may mark the blunt termination of a small underlying sill.

None of these folds appear to have any direct relation to the ore bodies that have been discovered. The minor faults, however, had a marked influence on the localization of the ore bodies; they served as channels for ore-forming fluids that formed two of the following three classes of deposits that were found in the mine. The three structural classes are: (1) deposits in calcite veins in the Boquillas flags and the Buda limestone; (2) deposits along and near the contact of the Devils River limestone with the Grayson formation; and (3) breccia pipe deposits. The dividing lines between classes of deposits are not everywhere clear-cut and hence some overlapping exists: for example, breccia in varying amounts is associated with all three types of deposits.

The Chisos mine is the only place in the Terlingua district where economic deposit of cinnabar have been mined from calcite veins in the Boquillas flags. For that reason it is the type example for this class of deposit and the general description in a preceding section is essentially that of the veins in the Chisos mine. Most cinnabar-bearing calcite veins at the Chisos mine are arranged in a system of northeasterly trending veins that lie north of the No. 8 shaft and tend to converge southwestward with the eastern end of the Chisos fault, as previously described. A few other cinnabar-bearing calcite veins have been worked in the Chisos mine, notably those along and near the Chisos fault. The size, shape, and relations of the calcite veins can be seen in the mine maps and sections, and detailed descriptions of them are unnecessary. General descriptions are given on pp. 59–63.

The 550 ore body, although classified with the calcite veins, differs enough from them to warrant separate description. This ore body was mined mainly from the 550 level, from which it receives its name. On this level it is divided by a zone of barren rock into two parts. The western part of the ore body, in the vicinity of No. 3 shaft, was 550 feet long, and the eastern part of the ore body, in the vicinity of No. 8 shaft, was 500 feet long. The ore body averaged about 30 feet wide and 40 feet high. The separate parts of the ore body plunge towards each other beneath the barren zone to converge on the 600 level and form a single ore body with a length of 200 feet and an average width of 30 feet. Below the 600 level the walls of the ore body steepen to form an ore body described below as the Pipe ore body.

The 550 ore body was in a breccia zone of the Chisos fault. On the 550 level the western part of the ore body was in a breccia zone between Boquillas flags on the south side of the fault and Buda limestone on the north side of the fault. The eastern part of the ore body, where the fault displacement is less than 10 feet, was in a breccia zone entirely within the Boquillas flags just above the contact with the Buda limestone. Narrow calcite vein deposits extended upward into the Boquillas flags at the east end of the 550 ore body and in the vicinity of No. 3 shaft.

Cinnabar was in the breccia as a filling in interstices, as a replacement of the clay matrix of the breccia, and as stockworks of veinlets extending into fractured wall rocks. Veinlets of cinnabar extending into fractured wall rock that bordered the breccia locally increased the minable width of the ore body to more than 40 feet. Associated with the cinnabar were minor quantities of calcite and iron oxide.

The Pipe ore body was the downward extension of the 550 ore body, but structures of these two ore bodies are very different. The Pipe ore body had a vertical, cylindrical form, whereas both parts of the 550 ore bodies, although somewhat cylindrical in form, were inclined at low angles. The origins of the breccias in the two ore bodies are likewise different; that in the 550 ore body was dominantly a fault-friction breccia, perhaps modified by solution and slump, and that in the Pipe ore body was entirely a collapse breccia, produced by the solution of underlying limestone.

The Pipe ore body was a body of remarkably high-grade ore that extended vertically downward from the 600 level to the 800 level. The breccia pipe that contains the ore body extends deeper than the 800 level, but little ore has yet been found below this level. However, cinnabar has been found as deep as the 850 level according to Charles Worthington (oral communication) who says that the Esperado Mining Co. in 1946 found a 6-inch streak of high-grade ore in core drilled from the bottom of an old winze on the 850 level.

The Pipe ore body had an irregular, roughly circular shape, with a diameter of 70 feet on the 650 level, which decreased to about 30 feet on the 800 level. However, on the 800 level the ore body was only a small part of the breccia pipe. The Grayson formation surrounds the breccia pipe on most levels, but near its top Buda limestone is the enclosing rock. Although the Chisos fault is at the north edge of the pipe, displacement on the fault at this place is less than 10 feet. The breccia in the pipe includes Buda limestone blocks and fragments throughout, some of which have moved downward more than 150 feet. In the lower part of the pipe the blocks and fragments of limestone are in a matrix of clay from the Grayson formation; but in the upper part of the pipe blocks and fragments of both Buda limestone and Boquillas flags form either an open breccia or a breccia with a matrix of clay derived from the clayey layers of the Boquillas. The cinnabar was largely a replacement of the clay, but in the upper part of the pipe it was an interstitial filling in breccia openings, an occurrence similar to much of the ore in the 550 ore body.

Ore bodies mined from the lower levels in the western part of the mine are in marked contrast to those described above. These ore bodies belong to the limestone-clay contact class of deposit. They were flat-lying shoots along the contact between Devils River limestone and Grayson formation. In general, they are in a zone less than 50 feet thick on both sides of the contact. The zones of mineralization, ore shoots, and the ore itself are similar to those described at the Mariposa mine. Although the ore bodies were pockety, they were, in the aggregate, large and rich.

There were several limestone-clay contact deposits in the Chisos mine; the largest and most profitable was the North ore body, which extended northeasterly on the 600 level from the point on the Chisos fault where it changes trend from west to northwest. This ore body was mined for a total distance of 1,600 feet on levels that ranged from the 580 to the 700. Part of this change in elevation of the ore body is due to the dip of the favorable ore horizon, the limestone-clay contact, and part of it is due to two northwesterly pre-ore faults that drop the contact progressively towards the northeast. These two faults divide the ore body into three parts. The southwest part extended northeasterly from the Chisos fault, as stated above, for 400 feet, gradually working upward to the 580 level where it continued northeasterly for another 400 feet. At this point it is joined by an east-west ore body that extends eastward from the Rainbow mine. Also at this point the contact is dropped down to the 630 level by one of the northwesterly faults. The ore followed the contact, and on the 630 level the ore body continues in a northeasterly direction for another 400 feet, where another east-west Rainbow ore body joins it. Here the contact, followed by the ore, gradually works down to the 650 level, where it continues for 300 feet and is again stepped down, on the other northwesterly fault, to the 700 level. According to maps of the Chisos Mining Co., the ore was explored and mined on the 700 level for 100 feet. This level was inaccessible in 1942.

Another limestone-clay contact deposit lies between the 650 and 750 levels a little east of the No. 9 shaft. It extends northeasterly from the Chisos fault. It is small in comparison with the North ore body.

When the writers examined the Chisos mine in the summer and fall of 1942, there was very little ore that could be seen. It is reported by Mr. F. H. Fovargue, a former mine superintendent, that some ore remains in places that were inaccessible at the time of the examination. Notable among these places is the ground around the ore body described in the preceding paragraph; however, it is doubtful that any large tonnage of ore remains in this part of the mine, as little favorable unexplored ground remains.

Within the mine proper no large, unexplored areas where geologic conditions appear favorable for the discovery of new ore bodies remain unexplored. However, away from the mine proper, there are several places where geologic conditions and surface mineralization appear favorable for the presence of underlying ore bodies. The most favorable place is the area between the Susano and No. 14 shafts, east of the main workings.

Although this area was partly and unsuccessfully explored by a joint drilling program of the U. S. Geological Survey and U. S. Bureau of Mines during the summer of 1943, its possibilities were by no means exhausted. Mineralization is evidenced by calcite veins and by showings of cinnabar in the following places: on dumps from the No. 14 shaft, in the adit 350 feet northeast of No. 14 shaft and on dumps therefrom, in the shaft of the Susano prospect and on dumps from it, and from the small adit 200 feet southwest of this last shaft. These showings of cinnabar are in a zone of calcite-mineralized faults, trending N. 60° E., which extend from the Aguja breccia pipe southwestward to and beyond the No. 14 shaft.

A particularly favorable structure in this area is the Aguja breccia pipe, which consists of blocks of sandstone of the Aquja formation in a clay matrix. The Susano prospect shaft is at the southeast edge of this breccia pipe. Cinnabar was seen in a calcite vein in the drift from this shaft and, according to Mr. Fovargue (oral communication), a few tons of ore were mined from the vein. Two drill holes that intersect the eastern border of the pipe at depths of 115 and 185 feet found traces of cinnabar (but no ore) both in the Boquillas flags and breccia of the pipe.

In 1943 a single hole was drilled to the Devils River-Grayson contact in this area, and the core contained neither ore nor altered rocks at this horizon. This single drill hole does not disprove the existence of ore bodies at this horizon, as any comparison of the size of the favorable structures with the average size of ore bodies at Terlingua will show. Core from this drill hole showed that the Devils River-Grayson contact is about 1,140 feet below the floor of Grace Canyon; this would be about the maximum depth of the horizon in this general area because the collar of the hole was near the axis of the synclinal structure of the area. Because the most favorable ore horizon is at such a depth, exploration and possible mining would be expensive. Probably the most practical method of finding an ore body at deeper horizons in this area would be to sink on the traces of cinnabar in the Aguja breccia pipe.

RAINBOW MINE[9]

The Rainbow mine is one of the deepest and most productive mines in the Terlingua district. Cinnabar was discovered on the Rainbow ground about 1900, and it is reported that $10,000 worth of quicksilver was obtained from shallow cuts and tunnels at that time. During World War I a shaft (Rainbow) was sunk more than 600 feet but without finding ore. During the early thirties drifting from near the bottom of the shaft resulted in the discovery of several rich ore bodies, and the ore from these was treated in a 10-ton furnace. The mine was closed for lack of ore in 1942.

The early near-surface workings follow calcite veins of different trends in the Boquillas flags. These are

[9] After Clyde P. Ross's written communication.

similar to those of the adjacent Chisos mine and their distribution can be seen on plate 16.

The Rainbow shaft has a reported depth of 670 feet. Drifts extend off it at intervals of 50 feet and less, throughout a depth of about 635 feet, but most of the development and all stopes are on and below the so-called 600 level and above the 635 level. On the 550 level there is a long crosscut through barren ground, but all drifts on the levels above are short. None except those on the 50 level, which totals more than 300 feet, total as much as 100 feet.

The shaft for much of its depth follows a fault zone, which trends about N. 60° E., with local departures from this trend. On the 635 level the fault zone is a little more than 100 feet south of the shaft. The vertical displacement on the fault zone is probably more than 100 feet. The faults in the Rainbow shaft are probably subsidiary faults to the Rainbow fault, which lies a little to the south, where it has a vertical displacement of 800 to 1,000 feet.

On the 600 and 635 levels the contact between the Grayson formation and the Devils River limestone has been explored and at least three ore zones of the limestone-clay contact variety of deposit have been found.

The most northerly of these trends on the average about N. 80° E. and has a length of more than 700 feet. It follows a rolling lower contact of the Grayson formation along or in the vicinity of steeply inclined fractures. Many of these fractures have little or no displacement along them; one in the northwestern part of the mine, however, has a probable displacement of nearly 50 feet.

The second ore zone is about 250 feet south of the first and roughly parallel to it. This zone lies along a sharp monoclinal flexure, accompanied by fractures along which the beds bordering the Grayson-Devils River contact are bent downward towards the south at angles of 25° to 50° and locally more. In the eastern part of this ore zone the contact flattens and then slopes gently downward, both to the northeast and southwest of the main drift. Northeast of the drift some good ore was stoped along a group of poorly defined fractures trending about N. 65° E.

The third ore zone is in the extreme southeast part of the mine. The ore here had been found and stoping in it had begun from the east by the Chisos Mining Co. before it was also found by a drift from the Rainbow shaft and before the boundary between the properties of the two companies had been fixed. This ore zone is in an area of extensive fracturing at and somewhat below the base of the Grayson. The principal fractures trend about N. 35° E. and most of them are nearly vertical. Some steep fractures trending N. 60°–70° E. are also present. The ore mined was altered limestone and clay, with cinnabar along fractures and in irregular replacements. Much of it was of exceptionally high grade.

BROWN PROSPECTS IN SEC. 286

A group of eight full claims and six fractional claims in the southwest part of sec. 286, Block G-4 are held by Guy E. Brown of Houston, Tex. This property is about 1 mile northeast of the Chisos mine. A shaft, about 100 feet deep, and several short trenches and shallow pits represent the only prospecting on the claims. No ore has been mined from the property and only traces of cinnabar have been found.

The only exposed rocks belong to the upper part of the Boquillas flags. In general the rocks are gently flexed with dips rarely exceeding 10°; but in some places, notably in disturbed zones along minor faults, the dips are as much as 50°. Joints and minor faults are numerous and most of them are filled by calcite (see fig. 17). The common thickness of the calcite-filled fractures, or veins, ranges from 1 inch to 12 inches, but in places the veins are as much as 3 feet thick. The calcite veins are very similar to those at the Chisos mine, but they are not extensions of the ore-bearing structures of this mine.

In the southwestern part of the property the veins are arranged in two systems; one trends northeasterly and the other northwesterly. Vein intersections are locally offset, but more commonly, intersections are places where the persistency of the vein breaks down and the distribution of calcite is very irregular. Practically no prospecting has been done in this part of the property.

In the northeastern part of the property the most prominent veins trend northeasterly. On the most prominent of these, a shaft has been sunk to an approximate depth of 100 feet, but it was not accessible when the writers were in the district (1942–45). A sample taken from the vein at the collar of the shaft contained only traces of cinnabar. To the northeast the veins of this area are covered by alluvium.

In the northwestern part of the property three well-developed veins have trends of N. 70° E., N. 35° E., and N. 85° E. The N. 70° E. vein has been prospected by a pit about 12 feet deep, but neither of the other veins has been prospected. Near the western border of the property the N. 35° E. and N. 85° E. veins converge. Near the point of convergence the N. 85° E. vein splits, but the lack of continuous exposures prevents a clear understanding of this splitting.

The showings of cinnabar in the calcite veins exposed at the surface may indicate that limestone-clay contact deposits exist at depth, but the search for such bodies would be expensive. The Devils River-Grayson contact is between 800 and 1,000 feet below the surface. Another unfavorable aspect of the property is the lack of outstanding geologic structure where exploration could be concentrated.

TWO-FORTY-EIGHT MINE

The Two-Forty-Eight mine is in sec. 248, Block G–4, 2 miles east of the town of Terlingua. It is owned by E. A. Waldron of Alpine, Tex., and was last worked (1946) by the Esperado Mining Co. of Houston, Tex., which had the property under lease. Cinnabar was discovered here before 1902, but by 1934 only 700 feet of subsurface workings had been driven. Since 1940 the Esperado Mining Co. has extended the mine workings to more than 7,000 feet and has erected a Herreschoff furnace capable of treating 40 tons of ore per day.

The mine workings consist of 13 levels, which extend from the main shaft at irregular intervals. The deepest mine level is at 804 feet below the collar of the main shaft. A second shaft is 50 feet deep. Maps of levels are shown in plate 21.

The workings are in and close to a vertical breccia pipe enclosed in flat-lying, slightly fractured Boquillas flags and underlying rocks. Near the surface the pipe is 100 feet in diameter and roughly circular in plan, but as it extends downward it gradually enlarges and becomes elongate in plan.

The breccia pipe is enclosed in Boquillas flags from the surface to a depth of 465 feet where the flags are intruded, 8 feet above their base, by a sill of fine-grained analcite syenogabbro. This sill, 60 feet thick, is younger than the pipe, with which it has intrusive relations. The pipe on the 556 level of the mine is enclosed in Buda limestone, 90 feet thick, which is conformably overlain by Boquillas flags and conformably underlain by Grayson formation. The lowest level of the mine, the 804 level, is in the Grayson formation but the Devils River limestone is probably only a short distance below this level. Below the 556 level tongues of altered analcite syenogabbro irregularly intrude the pipe. In the northwest and southeast crosscuts on the 556 level soft clay separates the breccia pipe from the enclosing Buda limestone. This clay appears to be an altered dikelike body of analcite syenogabbro. Similar altered igneous rock was found in the shaft below the 556 level.

Above the 420 level the breccia filling consists of blocks of Boquillas flags, below the 500 level it consists of blocks of both Boquillas flags and Buda limestone and continues so to a depth of about 650 feet where blocks of these rocks are enclosed in a matrix of Grayson formation. In the upper levels of the mine much of the breccia has a soft clay matrix of comminuted and altered shale of the Boquillas flags, but in some places the breccia blocks have no matrix. Tar, some of which is brittle but much of which is fluid, and calcite fill or line many of the open spaces between the blocks. Some of the calcite contains tar. Analcite is common in the breccia in the upper part of the pipe.

It is evident from an inspection of the geologic map of the surface of the property (pl. 22) that the location of the breccia pipe is not controlled by intersecting faults. All the more persistent fractures in the immediate vicinity of the mine are shown on this map, and none of these fractures have vertical displacements of more than 1 foot. Minor fractures, however, locally controlled the shape of the breccia pipe, as can be seen on the maps of the various mine levels (pl. 21). Locally such fractures, or joints, have outlined large blocks of wall rock that have slumped into the pipe. Such blocks can be seen along the periphery of the pipe in all stages of detachment and slump; in particular along the west side of the pipe as shown in section *A–A′*, plate 22. The detachment and slumping of these blocks produced excellent structures for the deposition of cinnabar.

The quicksilver deposits of the Two-Forty-Eight mine are readily divided into two groups. The more important group includes deposits in marginal fissures of the breccia pipe and within the breccia. The other group comprises fillings along fractures outside of and away from the breccia pipe. In both groups the only important quicksilver mineral is cinnabar.

The deposits in fractures outside the pipe are small and low in grade; they consist of fillings by cinnabar and calcite, with small quantities of pyrite and iron oxides. Most mineralized fractures trend N. 65° E, but some trend about N. 15° W. In places the fracture walls are coated by thin films of cinnabar, which locally widen to veinlets a quarter of an inch or more wide. The widest veinlets are where the fractures cross limestone beds in the Boquillas flags, which are rarely more than 2 feet thick. Cinnabar is found in some places in shaly partings along bedding planes on both sides of fractures. The igneous sill contains cinnabar in small fractures and irregular disseminations.

Deposits in marginal fissures and within the breccia are best developed between the 270-foot and 360-foot levels. An ore body on the 320-foot level is typical of this class of deposit. On this level the smooth curve of the western border of the pipe is broken by a large block of wall rock that juts into the pipe. This block is detached and slightly slumped towards the pipe. The fissure thus developed at the back of the block is filled with small breccia fragments and is mineralized with cinnabar. The ore is limited to the length of the block. Pockets of ore fill marginal fissures along other large blocks. Where ore is found within the pipe, the associated breccia commonly contains many large blocks, as on the northern side of the pipe on the 360 level. The interior of the pipe has been explored by both mine workings and diamond-drill holes, but no ore has yet been found far from the pipe walls.

At the writer's last visit to the mine, in February 1945, the most favorable ore horizon in the district, the Devils River limestone-Grayson formation contact, had not been reached. As the breccia pipe was doubtless caused by solution in the Devils River limestone and subsequent collapse of the overlying rocks, it is probable that solution also produced at the top of the Devils River limestone deposits of cave-fill, which were very excellent hosts for cinnabar at the Mariposa, Rainbow, and Chisos mines. The possible presence of such cave-fill zones depends in large part on the existence of northeasterly fractures cutting the limestone where it borders the breccia pipe.

Although the Two-Forty-Eight mine is in one of the most geologically favorable ore structures in the district, exploration and mining is not without its hazards. Some of these hazards, none of which are insurmountable, are the unfortunate location of the main shaft within the breccia pipe, heavy ground in much of the breccia, the pockety character of the ore that has been found, and the presence of hydrogen sulfide gas, considerable water, and high temperatures. The location of the main shaft within the breccia make difficult the mining of any ore bodies that might be found near it, as for example, that on the 320-foot level. Heavy ground around the shaft and in the drifts and crosscuts requires considerable timbering, an expensive operation in the Terlingua district. The pipe has been sufficiently explored by drill holes and mine workings to indicate that it contains, at least above the 500-foot level, no large ore body similar to that in the Chisos pipe. The ore that has been found in the pipe, and probably the ore that may be found in the pipe, is in small disconnected ore bodies. The vertical extent of these has not been proven and it is possible that they may be sinuous chimneys of ore along the borders of the pipe.

In places there was hydrogen sulfide gas which was at times a hazard to mining. The gas, however, appears to be entrapped in open pockets in the breccia and is dissipitated a short time after these pockets are tapped by mine workings. High temperatures in the lower workings make mining difficult, but forced ventilation will lower these temperatures. The mine water will decrease with continuous pumping, but a greater water problem can be expected in the Devils River limestone.

STUDY BUTTE MINE

The Study Butte mine, in sec. 216, Block G–4, is the third largest producer of quicksilver in the Terlingua district. It is 5 miles east of Terlingua and marks essentially the eastern end of the district. Cinnabar was discovered early in 1902 and was being actively mined as early as 1905. Substantial production did not begin, however, until World War I, when from 1915 to 1920 quicksilver valued at $500,000 was produced. The Study Butte mine consists of two adjacent properties, the Big Bend and the Texas Almaden, which have been worked both individually and as a unit. During World War II both properties were worked under lease by the Texas Mercury Co. of San Antonio, Tex.

Before the mine closed in 1944 ore was being treated in 2 medium-sized furnaces. The mine workings include 4 principal shafts—only 3 of which had been used in recent years—many minor shafts, and more than 3 miles of horizontal workings on the 4 main and numerous sublevels. The deepest shaft is the Big Bend, which early in 1944 was slightly more than 440 feet. The other 3 main shafts are the Dallas, Fortuna, and No. 10, which reach to the 300-foot level, 250-foot level, and 200-foot level, respectively. All are vertical, except the Fortuna, which is inclined at an angle of 80°. The horizontal workings are mainly on the 150-foot, 200-foot, 250-foot, and 300-foot levels, which are named from their approximate depths below the collar of the Big Bend shaft.

The workings of the Study Butte mine are almost entirely in the Study Butte intrusion of quartz soda syenite, which forms the hill that gives the mine its name. This body, described on pages 20 and 25, is dikelike in its southern outcropping part and a sill in its northern part; the dikelike part dips steeply to the north to converge at depth with the sill part, which is horizontal. The intrusion is in Terlingua clay that is almost horizontal, except where sharply flexed to form a monoclinal fold above the intrusion. Terlingua clay adjoining the intrusive is highly baked except along the steep southern contact. The intrusion is cut by numerous joints and fairly persistent fractures, some of which were filled with cinnabar, pyrite, and calcite, and small quantities of hydrocarbons. In general, the mine workings follow these ore-bearing fractures, which are in both the concordant and discordant parts of the intrustion.

Fractures are of both northeasterly and northwesterly trends, but the northwesterly fractures are not only less persistent but for the most part are barren of cinnabar. Fractures of east-west trend, which parallel the elongation of the discordant part of the intrusive, are common locally, in particular along the upper, inclined contact of the intrusive, where shallow ore bodies have formed along them. Vertical displacements along these fractures are in no place more than a few feet. In places the contact between the intrusion and Terlingua clay is offset slightly along fractures, in other places fractures end at the contact or cross it without offset.

The main ore-bearing structures are groups of closely spaced parallel fractures that are continuous both vertically and horizontally for several hundred feet. They range in dip from 60° to vertical, with dips of 80° the most common. Each group of mineralized fractures is locally referred to as a "vein," terminology that is retained in this description. Individual fractures that constitute each vein are overlapping and discontinuous. The width of individual fractures before mineralization ranged from a knife-edge opening to about 1 inch. The width of a mineralized zone, or vein, ranges from a fraction of an inch where the vein has narrowed to a single fracture, to several feet where the vein includes several widely spaced fractures.

Compared with other vein deposits in the Terlingua district these veins are remarkable for continuity of quicksilver mineralization, although by no means are all the fractures mineralized or do any of them contain ore throughout their entire horizontal and vertical extents. Shoots of high-grade ore are most common near contacts between igneous and sedimentary rock or where fractures are numerous and closely spaced.

Mineralized fractures are not restricted to the igneous rock; they are also in the baked Terlingua clay that overlies the intrusive body. Mineralized fractures in the Terlingua clay are generally continuations of those in underlying igneous rock. In early mining operations, this fractured baked clay just above the contact with the igneous body yielded bodies of high-grade ore, both at the surface and on the 150 level. All the raises on the 150 level were to explore this contact and many of them connect with stopes above the contact. The ore was in no sense in tabular blanket deposits below or along the contact, but instead was localized in ore shoots that commonly were higher than wide and entirely within the shale above the contact. Most of them were found by following thin veins up through the igneous rock and into the shale, where the veins commonly widened into high-grade ore bodies in zones of multiple fractures in the baked clay. These ore bodies extended from 10 to 40 feet above the contact of the clay and the igneous rock.

The mine workings are in three almost unconnected blocks of mineralized ground, which are located as follows: (1) south of the Big Bend shaft, (2) north of the Big Bend shaft, between the Dallas and No. 10 shafts, and (3) west of the Big Bend shaft.

The block south of the No. 10 shaft includes a smaller area than the other two blocks, but extends through a greater vertical range. Its greatest development by mine workings is on the 300 level, where the workings have a maximum extent of about 300 feet north and south and 300 feet east and west. It has been worked on the 100, 150, 200, 250, and 300 levels and several sublevels. The ground between the levels and between the 100 level and the surface is connected by raises and by stopes. Connections with the surface above the 100 level are inaccessible.

Ore shoots in this block are along a series of closely spaced veins, which in general strike from N. 5° E. to N. 20° E. Above the 200 level, individual veins are not well defined, and some cinnabar-bearing fractures trend northwestward. Below the 200 level the veins are well defined and have been identified by the following names: Shafter, Brown, Big Fracture, Caballo, and Nuevo, given in order of increasing distances south from the Big Bend shaft. Between the 300 and 200 levels these veins abut to the southwest against Terlingua clay at the southern limit of the intrusive body. Through this distance ore has been stoped up to the clay contact. Above the 200 level this contact has not been explored and the exploited ore shoots are to the north, entirely within igneous rock. The zone of exploited ore shoots extends from the 200 level vertically upwards to the upper contact of the sill, which in this area is a local flat-lying "terrace." The ore shoots probably continued into the overlying Terlingua clay, but because of the inaccessibility of the uppermost workings this could not be definitely determined.

The exploited ground north of the Big Bend shaft is an elongate block, about 1,500 feet long, that extends in a general N. 60° E. direction between the No. 10 and Dallas shafts. It also extends about 300 feet northeast of the Dallas shaft and about 300 feet southwest of the No. 10 shaft. This ground has been worked at the surface, and on the 150, 200, 250, and 300 levels, but a large part of it is unexplored. Workings are most extensive on the 150 and 200 levels and least extensive on the 250 and 300 levels. All levels are connected with the Dallas shaft and all except the 150 are connected with the Big Bend shaft. Ground that is explored and exploited by the 150 level extends from the Dallas shaft to, and 200 feet beyond, the No. 10 shaft. This level is mainly in igneous rock in the sill part of the instrusion, a few feet below the upper contact of the sill. A small part of it, southwest of the Tank and Dallas shafts that was inaccessible in 1944 appears to be in Terlingua clay. The common trend of the veins on this level, as on the other levels is about N. 60° E. Many small stopes are above the 150 level and some of them extend to the surface and into the overlying Terlingua clay. The 200 level is entirely in igneous rock and the workings are mainly between the Dallas and Fortuna shafts. Work on the 250 level is mainly along two veins; one near the Dallas shaft and the other near the Fortuna shaft. That on the 300 level is almost entirely on the vein near the Dallas shaft.

The center of the third block of mineralized ground is about 400 feet southwest of No. 10 shaft. The workings here, almost entirely surface pits and cuts, are in a narrow east-west zone about 500 feet long. The workings follow a system of east-west to N. 75° E. fractures and are entirely within the intrusion, although the now eroded contact of the intrusive with the overlying Terlingua clay was formerly only a few feet above the surface in this area. A few inaccessible winzes of unknown depth lead from these workings, but it is doubtful that any of them are deeper than 50 feet. Workings from other parts of the mine do not connect with those in this area, nor do they extend below them to explore ground that might possibly contain downward continuations of the exploited ore bodies.

Although no specific estimates of ore reserves can be given for the Study Butte mine, it is reasonably certain that the possibility of developing reserves of low-grade ore is very favorable. This is indicated by ore on numerous faces in different parts of the mine, by company drill-hole records of ore below the present workings, and by the presence of much unexplored ground that is geologically favorable for ore.

The most favorable unexplored ground lies below the 300 level. Practically no exploration by mine workings has been done below this level. In the southern part of the mine in the vicinity of the Big Bend shaft it is about 130 feet to the locally flat, terracelike, contact of the intrusive rock with the underlying Terlingua clay. Two hundred feet north of the Big Bend shaft, on the 300 level, this contact is about 300 feet below the 300 level. This contact on the "terraces," was geologically favorable for the formation of ore bodies. Places particularly favorable are these where the contact is locally irregular.

The possibilities of finding ore at horizons that were productive in other parts of the district appear remote. The most favorable horizon, the contact of the Devils River limestone with the Grayson formation, is at least 1,800 feet below the collar of the Big Bend shaft; if there are more sills below the Study Butte intrusion, this contact could be much deeper.

Operators of the Study Butte mine have always had a water problem. Constant pumping is necessary to hold the water out of the deeper levels of the mine. It is reported that when the water is not pumped it rises until it seeps into the bed of the creek nearby. Mining at deeper levels will probably have more water to contend with. The intrusion acts as a local aquifer, the joint and fracture openings allowing free circulation. Although the unfractured parts of the intrusion are dry, these parts are unmineralized; consequently, mining must be in its open and wet parts.

PROSPECTS EAST OF STUDY BUTTE

East of Study Butte along the north foot of Maverick Mountain are a number of abandoned prospects. For the most part they consist of adits driven into the intrusive soda syenite of Maverick Mountain near its northern contact. No cinnabar was seen on the dumps from these adits. It is reported, however, that some ore was mined from this area during the early history of the district.

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