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

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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THE ANTICLINAL THEORY AS APPLIED TO SOME QUICKSILVER DEPOSITS*

J. A. UDDEN

INTRODUCTORY

From his general studies of the quicksilver deposits of the world, Becker came to the conclusion that the source of quicksilver is to be found in deep-lying crystalline rocks, such as granites. On such an hypothesis the distribution of quicksilver in the Terlingua district also would seem to have a natural explanation. Cinnabar is here found in quite diverse kinds of rocks, ranging from the Edwards limestone in the Comanchean to the sandstones of the Rattlesnake beds in the Upper Cretaceous. It also occurs in some igneous rocks which intrude these sediments. It has even been reported from Paleozoic rocks in the Solitario uplift, though the present writer has no reliable information on this occurrence. Under all circumstances it would seem that the cinnabar is not limited in its occurrence here to any particular formation. That the source is deep-seated may also be inferred from the fact that the mineral is distributed over a fairly wide area extending from the Mariscal Mountains on the east to the Lajitas Mesa on the west, and from beyond the Mexican boundary on the south to the Christmas Mountains on the north. The known east and west extension of the district is about thirty miles, and the greatest north and south extension is at least twenty miles. It is also interesting to note that all the quicksilver may be said to occur within the limits of a huge sunken block just west of the main Front Range of the Rock Mounains. The sinking of this block must have been accompanied by a rising of the isogeothermals with reference to the parts of which this block itself consists. The deep-seated heat, which may be looked upon as having been re-

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*Read before the Geological Society of America at its meeting in Baltimore, December 28, 1918.

sponsible for the upward migration of the quicksilver, is here, as in California, yet in evidence in hot springs. Such waters emerge just east of the district on the banks of the Rio Grande. The fact that the present mines, which represent the best ore so far found, are strung on a line extending from west-northwest to east-southeast, suggests the possible existence of some linear fracture at a depth sufficient to be entirely concealed by the more superficial structures in the "outer crust" of the earth.

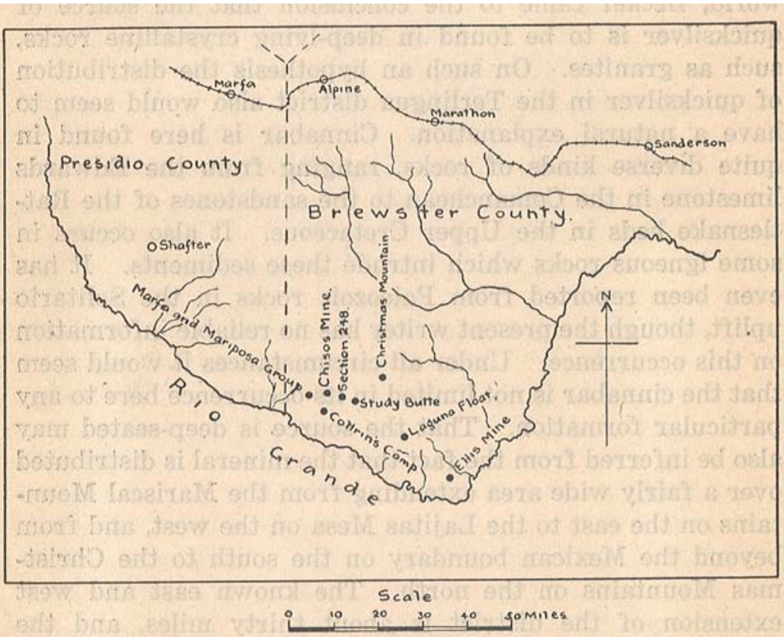

Fig. 1. Sketch map showing localities of quicksilver ore described in text.

The date of the deposition of the quicksilver is probably quite late, since the deposits have been found not only in the latest Cretaceous sediments, but also in some of the intrusives which in this region are regarded as belonging to the last half of the Tertiary period.

The present writer, who has had opportunity to see most of the quicksilver occurrences in Brewster County, believes that structural conditions clearly affect deposition in this district and have a direct practical bearing on the finding and development of the quicksilver ores. Briefly stated observations here indicate that the deposition of the quicksilver fumes rising from great depths has resulted from the capture of the fumes and from their retention, mainly in the form of sulphides, in structures practically resembling those which determine the retention of upwardly migrating liquid and volatile bitumens. The quicksilver deposits in almost every case occur in anticlines and domes or along decided belts in what are known as "structural terraces," or arrested monoclines. Invariably they occur in these structures at levels where the rising solutions have encountered strata that are less pervious than those immediately below. This appears to be true both on a large and on a small scale. The richest cinnabar deposits so far encountered have been found in the contact between the Georgetown (which is the upper fifty feet of a thick limestone usually referred to as the Edwards) and the Del Rio clay. The next richest horizon has been proved to be the contact between the Buda limestone and the overlying, less penetrable flags and shales of the Eagle Ford. In the Eagle Ford itself, which in this region measures at least some 600 feet in thickness, and which consists of beds rapidly alternating from compact limestone to black shale, the distribution of ore frequently shows a direct relation to these alternations. Even in the small details of these beds it has been found that pockets of cinnabar frequently underlie layers of shale. It may be that there is a coincidence of other circumstances affecting this arrangement in the distribution of the cinnabar. All of these shales are more or less bituminous and contain organic matter. This may have aided in the precipitation of the quicksilver fumes as sulphides. But that the structures themselves have been the most important factor is indicated by the fact that bitumens also have accumulated in the same structures. Oil has been found in the ore in the Eagle Ford in sufficient quantity to materially aid in its reduction in the furnace.

I have on a previous occasion briefly described my views

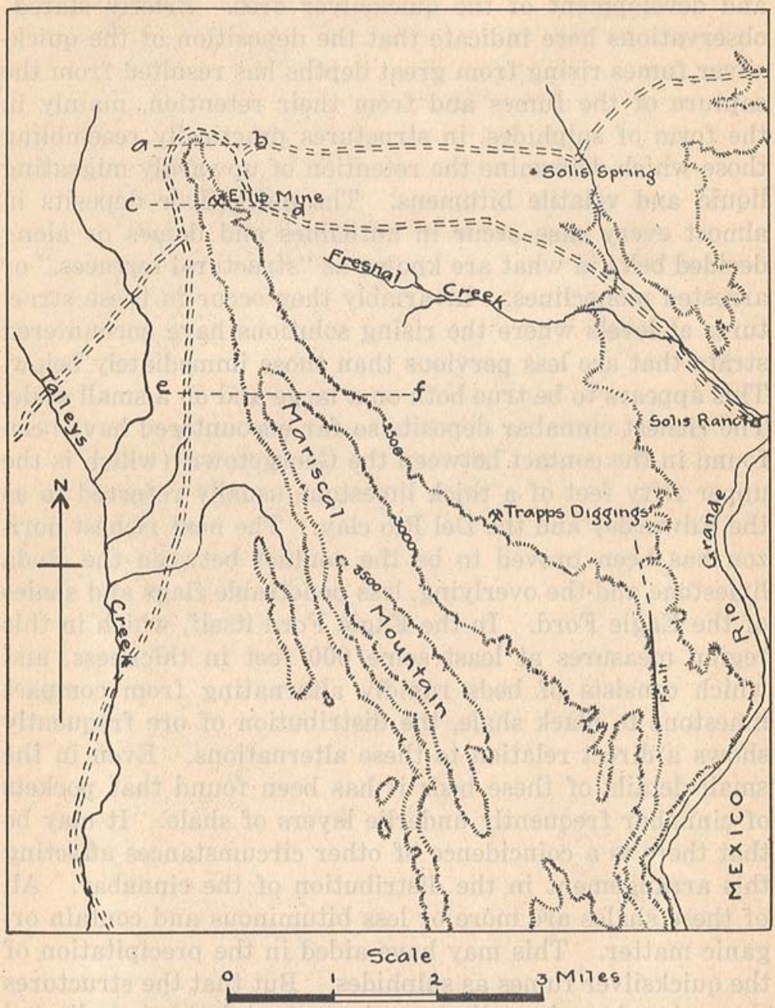

Fig. 2. Map of Mariscal Mountain showing approximate position of the three sections in Fig. 3.

on the distribution of the quicksilver in this region.* It is my purpose here to present in slightly greater detail than before the evidence which illustrates my views, some of which evidence has come to light through more recent developments of the deposits in this region. I will therefore briefly describe the natural conditions as they exist at the several points where quicksilver ores occur, and also venture to present my interpretation of the significance of the conditions noted.

The W. K. Ellis Mine

The easternmost mine in this district is the W. K. Ellis mine, located on the north end of the Mariscal Mountain. This mountain is an anticline extending from Mexico across the Rio Grande a distance of about twelve miles north-northwest into Brewster County. It is some five miles wide at the river, and tapers to a fairly sharp point at the north. The crest of the fold at the river consists of the Edwards limestone. This formation at the north dips under the Del Rio horizon which is represented by only a few feet of marly material in turn dipping under the Buda limestone. The northernmost end of the ridge is covered by the Eagle Ford, or the Boquillas flags, which has a thickness in this region of about 600 feet. These in turn go under the Austin chalk and the Taylor marls. The softness of the latter beds has caused them to be eroded away leaving the axial part of the anticline as a prominent ridge. It should be noted that two sills of acidic volcanic rock, one of which is quite glassy, have been intruded between some of the layers of the Eagle Ford beds, and lie folded with these.

The "nose," as petroleum geologists would call it, of the plunging anticline, is itself flexed downward at the north end, and this has resulted in some transverse fissuring of the ridge. In these fissures the best ore was first found, and in one of them the principal ore so far discovered is taken at the present time. Most of the work, both on the

*Structural Relations of Quicksilver Deposits. Mining World, Vol. 34, May 13, 1911.

surface and underground, has been done in the middle part of the Eagle Ford. This part of the Eagle Ford consists of calcareous shaly flags that are quite compact and frequently highly bituminous. They have been found to contain some small pockets of oil, and small "seepages" of solid bituminous material have also been noted. Some ore has

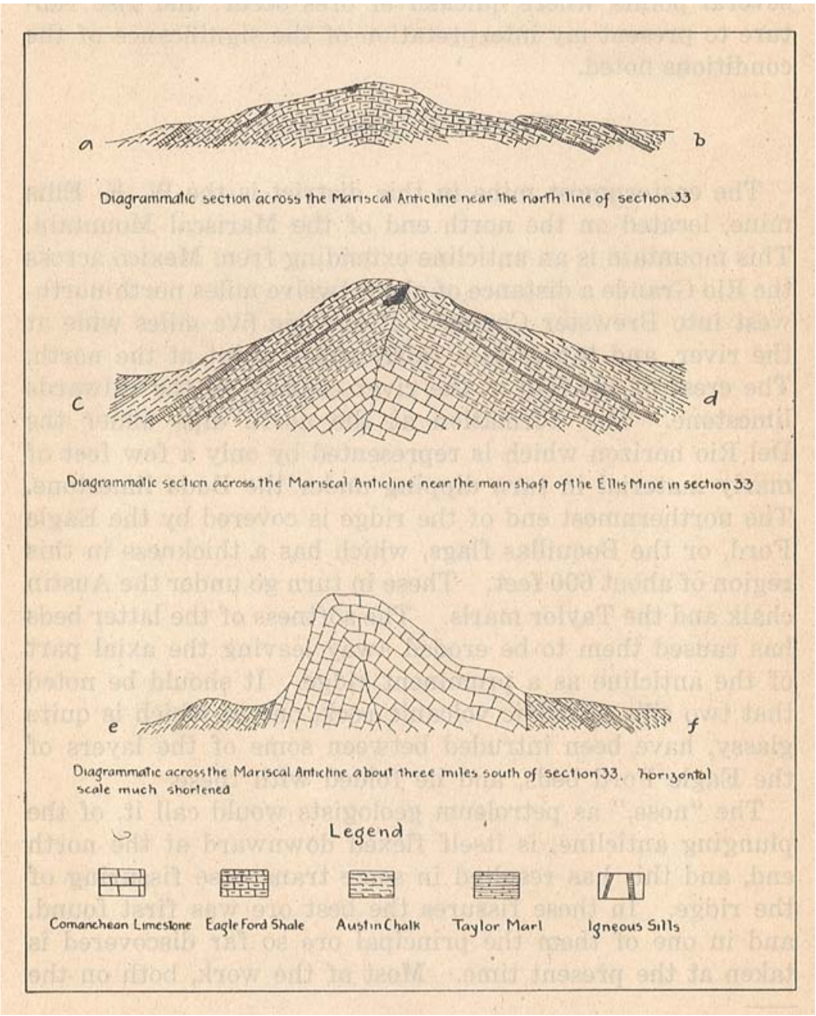

Fig. 3. Diagrammatic sections from east to west across the Mariscal Mountain. Positions of sections shown in Fig. 2.

been found in the contacts of the shales with the igneous rocks and the igneous rock itself has been found to be slightly impregnated with cinnabar, especially close to its contacts with the shale. Judging by conditions in other mines, richer deposits may be expected where fissures cut the contact of the Buda limestone with the overlying Eagle Ford and also at the depth where they may cut the Del Rio horizon. Here the underlying Georgetown or Edwards furnish a more open body of rock than either the overlying Buda or the marly sheet representing the Del Rio, which is quite thin. The workings in this mine have not yet extended down to these deeper horizons. The accompanying illustrations are intended to more clearly represent the geologic conditions at this mine.

The first mining in the Terlingua district was done on Sections 40, 41, 58, and 59, in Block G-12, in Brewster County. This group of mines lies farthest to the west in the district. It is at the upper fold of a monocline. dipping south, at a point where the Georgetown, immediately below the Del Rio clay, has been laid bare by the removal of this clay and other overlying beds. The Del Rio still underlies California Hill, which is capped by a smaller remnant of the Buda limestone. It goes down under this limestone, which caps the series of hills to the south, called the Tres Cuevas Mountain and the Sierra del Cal. The country north of this line of hills is traversed by several small faults and a larger one which runs from west-northwest to east-southeast. This fault has a downthrow to the north, of from a few to perhaps eighty feet. Following the north side of this fault, a remnant of the Del Rio clay still is seen. The block of rock south of this fault dips to the south and in about a half mile from the fault, the general dip to the south rapidly brings down the succession of Cretaceous beds standing at angles of from twenty to sixty degrees. The strike of this strong dip is shown in the Sierra del Cal. The south dip is continued by a much gentler dip in the same direction for a distance of three miles. To me it is a significant feature that the monocline of the Sierra del Cal forms an arc of a circle, or a periphery of a dome, as it were, and that the ground under the Del Rio clay in the subtended segment of this dome has been very generally mineralized. Here is a tract toward which an inverted funnel-like attitude of the impervious Del Rio clay would naturally drive any ascending currents of mineralizing solutions, gathered from a large collecting area to the south,

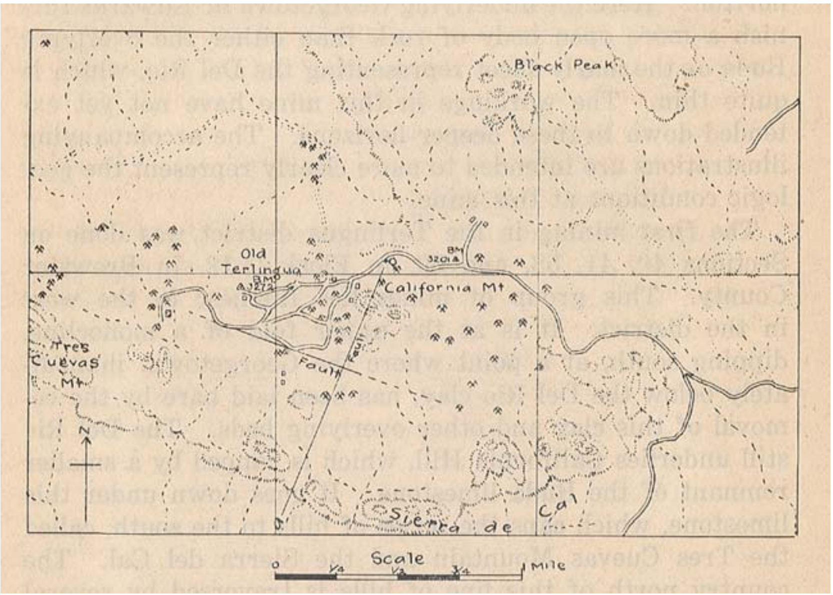

Fig. 4. Sketch map of the vicinity of the Marfa and Mariposa and the Old Terlingua Mines showing the position of section given in Fig. 5.

The ore in the Marfa and Mariposa mine, and also in the old Terlingua mine, has been deposited mostly in joints, fissures, and cavernous openings that extend down in the upper surface of the Georgetown limestone. The material filling these fissures is locally known as *jaboncillo.* It is a material of mixed nature, consisting in places largely of clay and in other places of material quite like caliche. It is evident that it has been formed in these fissures partly by precipitation from solutions which have followed the lower surface of the Del Rio clay, and partly also by the Del Rio clay itself which has settled perhaps gradually into solution caverns, pari passu with their enlargement by solution. The jaboncillo frequently contains fragments of the limestone itself and is in places not unlike a fault breccia, cemented with calcareous material. At the surface, this jaboncillo in places changes into caliche, clearly formed at a recent date. Even this caliche contains fragments of cinnabar, which apparently have been entombed quite recently in the formation of superficial caliche. The fissures extend to varying depths and no doubt in some place, or places, join "pipes," most probably along fault lines, through which the quicksilver has ascended. The great number of these ore bodies gives out in less than twenty feet below the upper surface of the Georgetown limestone and the mining on most of the hills in the sections mentioned has been done in shallow pits which stud the land at the present time. In places, ore occurs at greater depths and some fissures have been found with open vugs set with calcite and gypsum crystals.

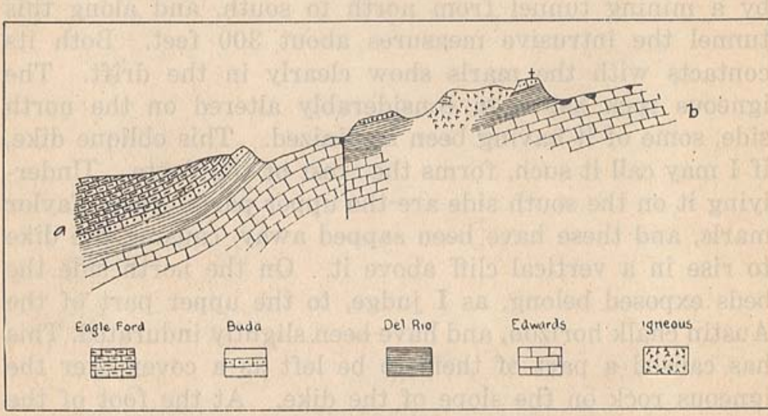

Fig. 5. Diagrammatic section extending from south-southwest to north-northeast along the line indicated in Fig. 4. Known occurrences of ore-bearing rock are approximately indicated by solid black

It would seem altogether likely that further prospecting may result in the finding of deeper pipes and it would seem quite probable that these should, as already stated, be found in some of the faulted fissures known to exist.

Study Butte

The Study Butte is one of the places where extensive explorations have been made. It is the site of two quicksilver mines which are both in operation at the present time: the Big Bend mine and the Texas Almaden mine. These are adjoining properties, the Texas Almaden lying on the north of the Butte, with the Big Bend on the south. They are at present operated jointly. Study Butte rises from an area of the Taylor marl which is exposed over most of Section 216, east of the center of which the Butte is located. The Butte is clearly the result of differential erosion. It rises from a low "flat," where erosion has for some time been in active progress on the soft marls overlying the Austin chalk. The Butte itself consists of a dike-like body of andesite, locally known as rhyolite, which has cut the marls, now mostly eroded, at an angle of about 45 degrees, hading to the north. The dike itself has been penetrated by a mining tunnel from north to south, and along this tunnel the intrusive measures about 300 feet. Both its contacts with the marls show clearly in the drift. The igneous rock has been considerably altered on the north side, some of it having been kaolinized. This oblique dike, if I may call it such, forms the crest of the Butte. Underlying it on the south side are the upper parts of the Taylor marls, and these have been sapped away, causing the dike to rise in a vertical cliff above it. On the north side the beds exposed belong, as I judge, to the upper part of the Austin chalk horizon, and have been slightly indurated. This has caused a part of them to be left as a cover over the igneous rock on the slope of the dike. At the foot of the hill on the north side, the intruded sediments are about 100 feet deep. Explorations which have been made by the diamond drill show that at this point the intrusive measures 400 feet in thickness and is underlaid by a dark clay. This part of the intrusion is of the nature of a laccolith. At a depth of 500 feet it rests on a black marl or clay, possibly corresponding to the Austin chalk. The remaining overlying beds on the north side lie nearly flat or show even a slight dip to the south. On the south side of the intrusive the Taylor marls seem to lie perfectly horizontal.

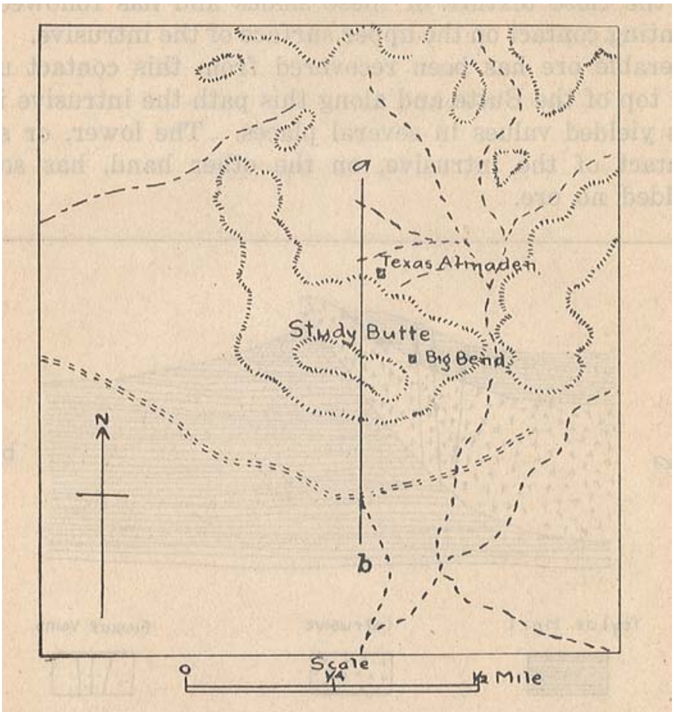

Fig. 6. Sketch map of Study Butte showing the position of the section in Fig. 7.

This mine is known for its quantity of low grade ore which has been found on the north side of the dike. Some high grade ore has been found in the contact between the overlying marls and the dike, and also in some fissure veins that cut the andesite. These stand almost vertically, apparently through the entire depth of the intrusive, on the Texas Almaden property. While the geological conditions in this mine thus differ radically in some respects from those in the other mines of the district, one can readily see the similarity of the conditions in both. The quicksilver has evidently followed the fissures in the intrusive up to its upper contact with the overlying shales. From here it has partly followed continuations of the same fissures upward in the shale, while much of it has also been diverted by the close texture of these shales and has followed the slanting contact on the upper surface of the intrusive. Considerable ore has been recovered from this contact up to the top of the Butte and along this path the intrusive itself has yielded values in several places. The lower, or south contact of the intrusive, on the other hand, has so far yielded no ore.

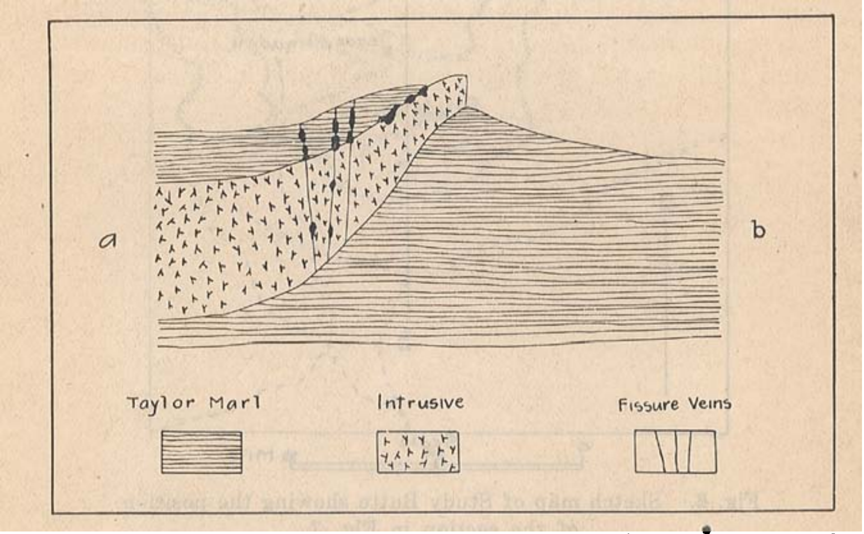

Fig. 7. Section of Study Butte extending from north to south along the line indicated in Fig. 6. Known occurrences of cinnabar-bearing rock roughly indicated by solid black.

The Christmas Mountain Prospects

One of the most interesting occurrences of quicksilver in this region, from a theoretical, not to say didactic, stand point, is to be found in the Christmas Mountain. This mountain forms one of the most perfect dome structures in the region. It is located about twelve miles northwest of the Chisos Mountains. The dome has a length from north-northwest to south-southeast of about five miles and a width of about four miles. The greatest vertical displacement at the center of this dome is at the least 4000 feet. The mountain itself rises above the surrounding country to a height of 2000 feet. It consists of the Edwards limestone which evidently has been lifted up by a laccolitic intrusion. At the foot of the mountain we find the Upper Cretaceous dipping outward in all directions away from the uplift at high angles. It is evident that the Upper Cretaceous covered the entire uplift at one time, and has been removed by erosion from its central area. The uplift is somewhat unsymmetrical. The slope to the east and northeast is more gentle than that to the west and southwest. In fact, the west side of the mountain is at some points much sheared and faulted. At the south end the limestones are fissured and the fissures are filled with calcite.

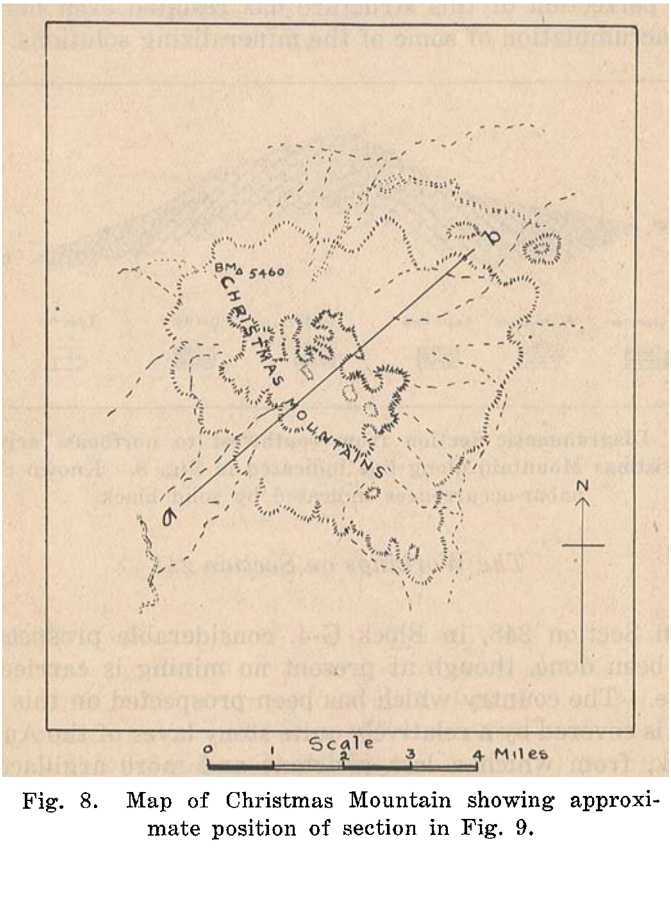

Fig. 8. Map of Christmas Mountain showing approximate position of section in Fig. 9.

On the highest point of this mountain there is a small cinnabar prospect. The ore occurs in what appears to be cavernous places in the Edwards limestone. This evidently is part of the mineralization which once existed under the Del Rio clay, that immediately overlay the limestone before it was removed by erosion. Other small prospects have been reported from fissures on the west side of the mountain. At the foot of the mountain where the Buda and the Del Rio clay set in, cinnabar has been found in fissures and cavernous places at several points. Float has been reported also from the east slope of the mountain. It should be recalled that the Christmas Mountain lies in the periphery of the quicksilver district, but it seems that the size and perfection of this structure has resulted even here in the accumulation of some of the mineralizing solutions.

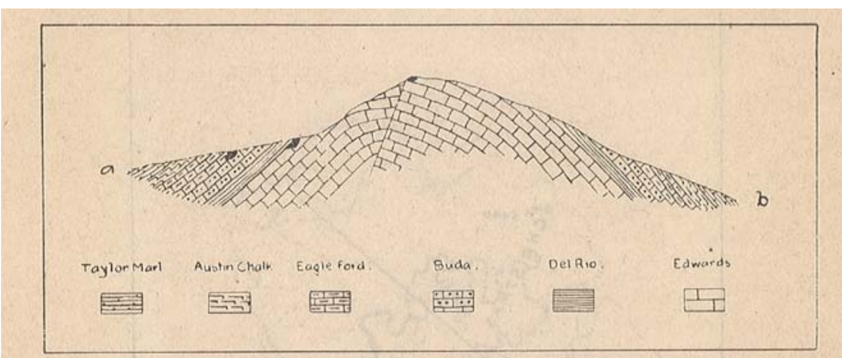

Fig. 8. Diagrammatic section from southwest to northeast across the Christmas Mountain along line indicated in Fig. 8. Known cinnabar-occurrences indicated by solid black.

The Workings on Section 248

On Section 248, in Block G-4, considerable prospecting has been done, though at present no mining is carried on there. The country which has been prospected on this section is covered by a relatively quite stony layer of the Austin chalk, from which a less resistant and more argillaceous part of this formation has recently been eroded away. We have therefore here the same conditions as have been noted

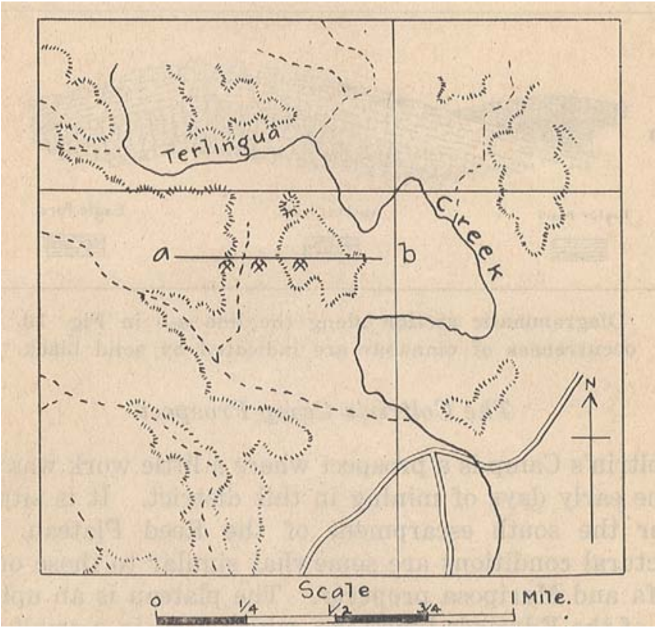

Fig. 10. Map of Section 248, and parts of sections 247, 230, and 299, Block G-4, west of the Chisos Mountains, Brewster County, showing location of section a-b, in Fig. 11.

at other places. The mercurial solutions in passing upward have been deflected on the upper contact of the at present exposed, more open layer, with the less pervious and more clayey layer that overlay it at the time the ore was deposited. The prospecting has been done on the west limb of a low anticline, which runs a course from north to south and whose axis is not far from the east line of the section The east limb of this anticline has a higher dip than the west limb. The ore has been found along some fissures that run vertically to this axis and it has been followed downward for apparently half a hundred feet or more. At several places in one of the worked joints, the country rock has been found to be highly charged with black bitumen

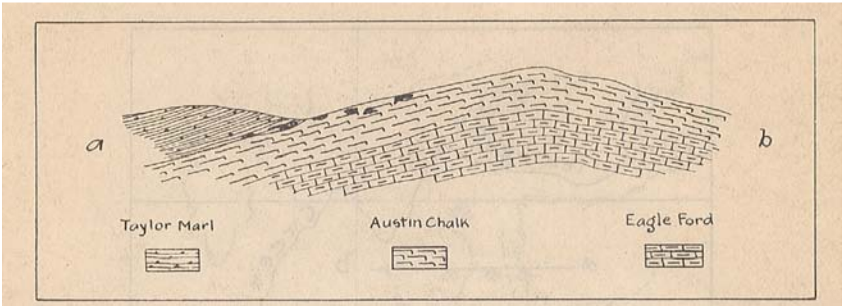

Fig. 11. Diagrammatic section along the line a-b in Fig. 10. Known occurrences of cinnabar are indicated by solid black.

The Coltrin's Camp Prospect

Coltrin's Camp is a prospect where a little work was done in the early days of mining in this district. It is situated under the south escarpment of the Reed Plateau. The structural conditions are somewhat similar to those on the Marfa and Mariposa property. The plateau is an uplifted part of the Edwards limestone, which rises in a small table land less than one mile wide and not quite four miles in length. On the south side of this plateau the Cretaceous series are abruptly turned down, and the softer formations lying above the Edwards are mostly eroded away. The cinnabar here occurs in some veins vertical to the longer axis of the plateau, which cut the Eagle Ford formation. Here as elsewhere, therefore, it would seem that precipitation of ore has taken place at a point where the mineralized solutions, following fissures, encountered relatively impervious materials after traversing the more easily penetrable limestones of Comanchean age, which in this region measure more than 1500 feet in thickness. (See Figures 14 and 16.)

The Laguna Float

Cinnabar has also been reported from the top of the Chisos Mountains. The Eagle Ford underlies the country surrounding the central part of the Chisos Mountains at a depth not far from sea level. In the region west of a point

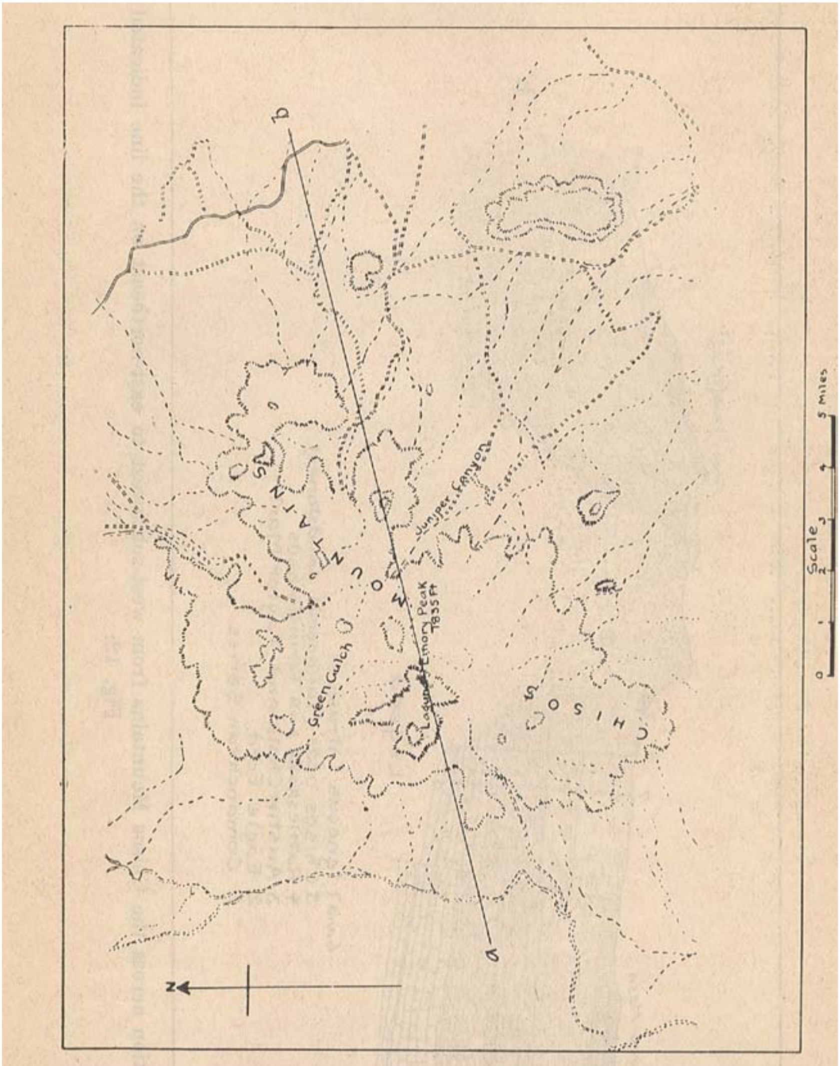

Fig. 12. Sketch map of the Chisos Mountains showing position of the section in Fig. 13.

known as Laguna, on top of the Chisos Mountains, this formation lies at an elevation of 7000 feet above sea level, dipping with a high angle to the northeast. It is not known to the writer where the float reported was found, or in association with what rocks in the upper part of the moun tains it occurred. The Chisos Mountain structure may

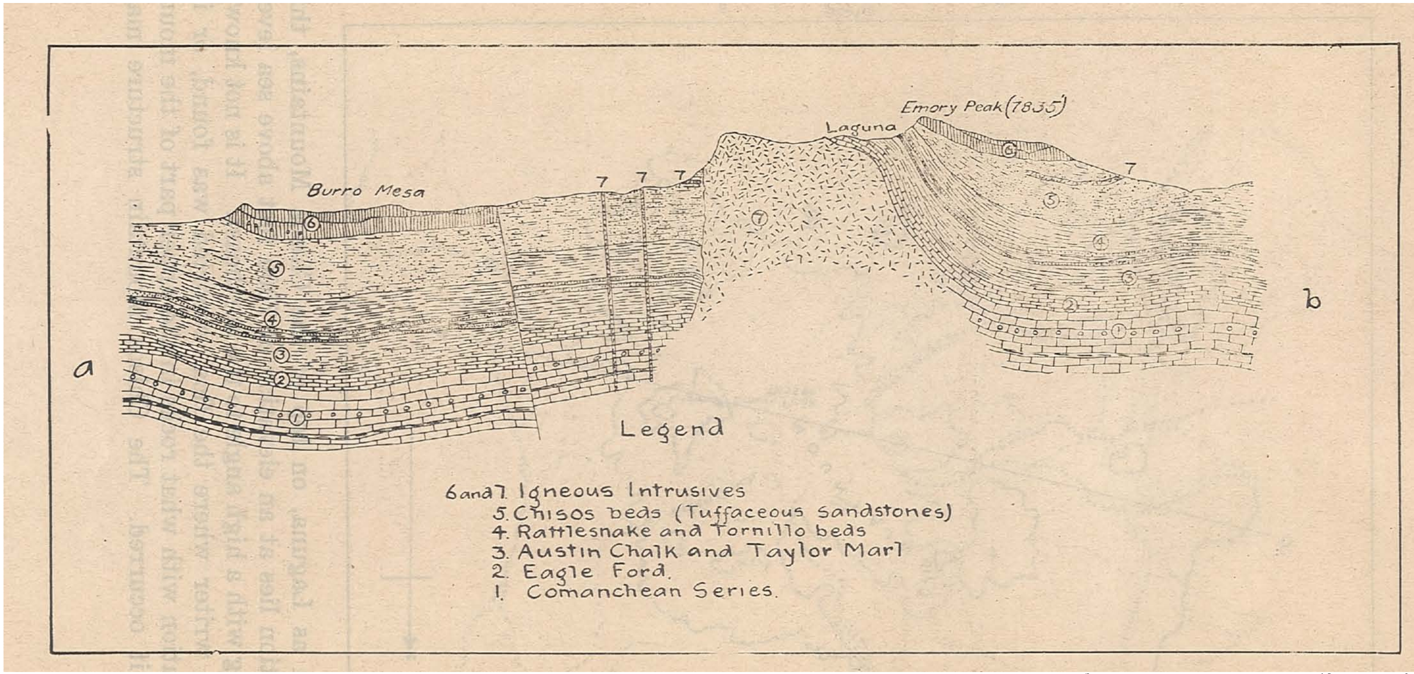

Fig. 13. Diagrammatic section across the Chisos Mountains from west-southwest to east-northeast on the line indicated in Fig. 12.

perhaps be called a greatly faulted anticline. This anticline is not very extensive laterally, but it is unusually high. No doubt it is partly filled with intrusives which, where exposed, appear to be of fine compact texture. Presumably the mineralizing currents depositing cinnabar near Laguna have here followed some more open contact.

The Chisos Mine

The Chisos Mining Company property illustrates, it seems to me, the general conditions of the deposition of the quicksilver ore in this region perhaps better than any other mine in the district. It so happens that the present writer has had his best opportunities for observation on this property. This is located on the north side of a long and narrow rift valley known as the Long Draw. This valley has a width of from one to two miles and a length of nearly nine miles The structure which has caused this valley is continuous for this distance. The valley is caused by the sinking of a narrow strip of the Cretaceous formations of the dimensions indicated, and runs a curving course following roughly the periphery of a circle some nine miles in diameter, with its center from the mine northeast. The vertical displacement of this sunken slice of the formations amounts to from 1500 to 2000 feet with reference to the adjacent block on the south. With reference to the adjacent block on the north, the displacement ranges from 500 to 1000 feet. At the Chisos Mining Company's Mine, two parallel anticlines follow the sunken elongated block of the valley, running from west-northwest to east-southeast. Both of these anticlines plunge to the southeast. The mine is located at a point where this plunging is steepest and where it has caused a transverse fracturing of the south anticline. The plunging here brings the Eagle Ford below the surface. The south side of this anticline coincides more or less with the fissures separating the sunken block of the valley from the block to the north, which is folded into the two anticlines referred to.

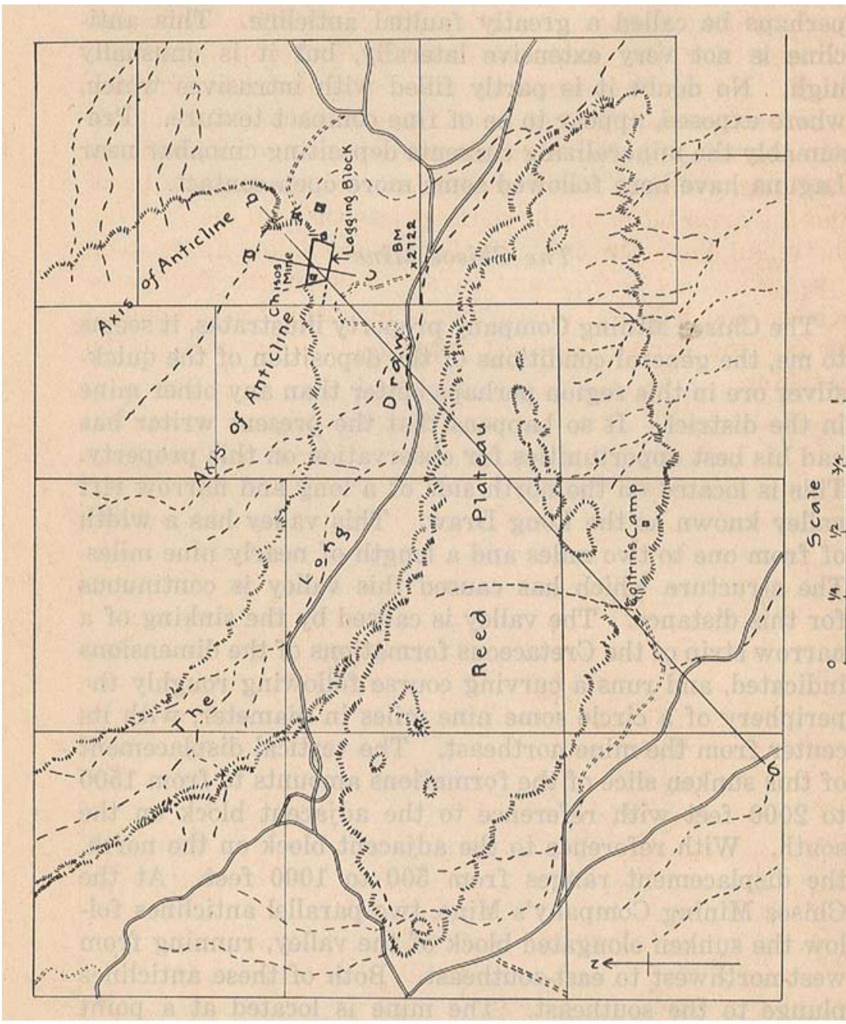

Fig. 14. Map of the region around the Chisos Mining Company property showing the Coltrin's camp and the course of the section a-b given in Fig. 15 and of section c-d in Fig. 16.

On both sides of the Long Draw can be seen lagging blocks such as usually appear along faults of considerable movement. The faults which separate the long curving sunken block from the ground on either side are thus both compound faults. These lagging blocks nearly always dip in the direction of the drag. In the ground where most of the quicksilver has been taken in this mine, occurs one of these lagging blocks. It is cut off to the west by an oblique fault, which crosses the north fault of the rift valley and extends from the north-northwest to the south-southeast Most of the movement in the compound fault has taken place between the south side of the lagging block and the sunken rift block. The displacement here amounts to probably 1000 feet while the displacement between the lagging block and the main block on the north is less than 40 feet. Ever this small movement is evidently in places taken up by steep dips. Ore has been found in all three of the faults described and it has also been found in fissures accompanied by faulting across the most rapidly plunging part of the anticline.

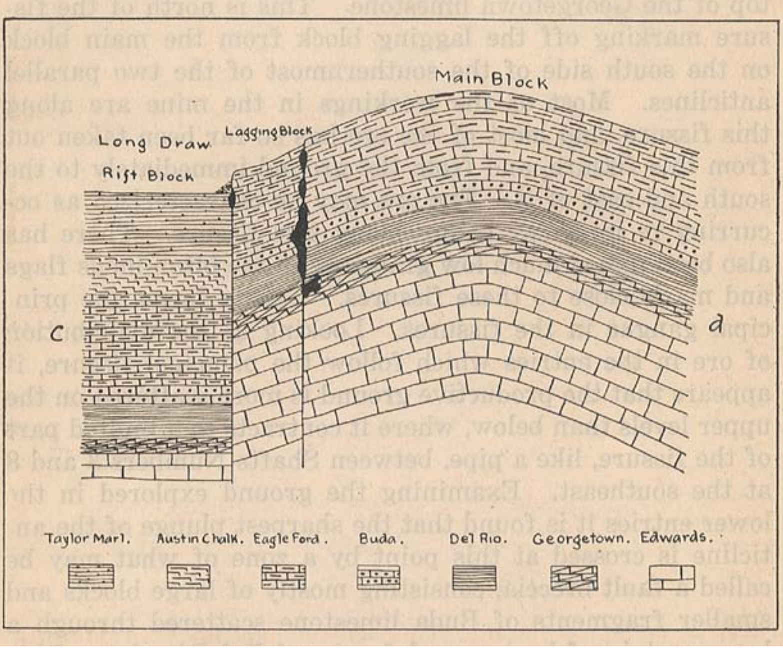

Fig. 15. Diagrammatic section running approximately from north to south along the line a-b indicated in Fig. 14. Known localities of ore-bearing rock indicated by solid black.

Some early work on this property was done at the southwest corner of the lagging block in the fissure separatin; the rift block from the southwest corner of the lagging block referred to. This deposit did not last long. It was on what was formerly known as the McKinney-Parker property. The first work in the Chisos mine proper was done in the Grace Canyon, in fissures that cut the plunging anticline tranversely to its axis where its plunge is steepest. At this point the Eagle Ford shales measure some 540 feet in thickness. For the first years mining here did not go below this depth. The ore showed variations according to the nature of the beds in which the veins occur, but it was not until the contact between the Eagle Ford with the underlying Buda limestone was reached, that the ore began to improve. Within the last two years some entries have gone below the Del Rio clay and some fine ore has been worked in the top of the Georgetown limestone. This is north of the fissure marking off the lagging block from the main block on the south side of the southernmost of the two parallel anticlines. Most of the workings in the mine are along this fissure, and most of the ore has so far been taken out from this fissure, and from the ground immediately to the south and east of it. The ore may be characterized as occurring in irregular bodies along this fissure. There has also been mined much low grade ore in the bituminous flags and marls close to these fissures. Calcite forms the principal gangue in the fissures. Looking at the distribution of ore in the entries which follow the principal fissure, it appears that the productive ground is more scattered on the upper levels than below, where it contracts to a limited part of the fissure, like a pipe, between Shafts Numbers 3 and 8 at the southeast. Examining the ground explored in the lower entries it is found that the sharpest plunge of the anticline is crossed at this point by a zone of what may be called a fault breccia, consisting mostly of large blocks and smaller fragments of Buda limestone scattered through a large matrix of broken and fractured Del Rio clay. This pipe has perhaps been one of the principal points where the mineralizing solutions ascended to the upper levels. It would seem natural that they should scatter on reaching the thin bedded flags of the Eagle Ford. From this circumstance it would be natural to expect that some solutions traversed the ground to the north under the Del Rio clay, away from the same fissures and their principal zone of deposition can be expected here, as at other places, at the Del Rio-Georgetown contact, owing to the impervious nature of the Del Rio clay.

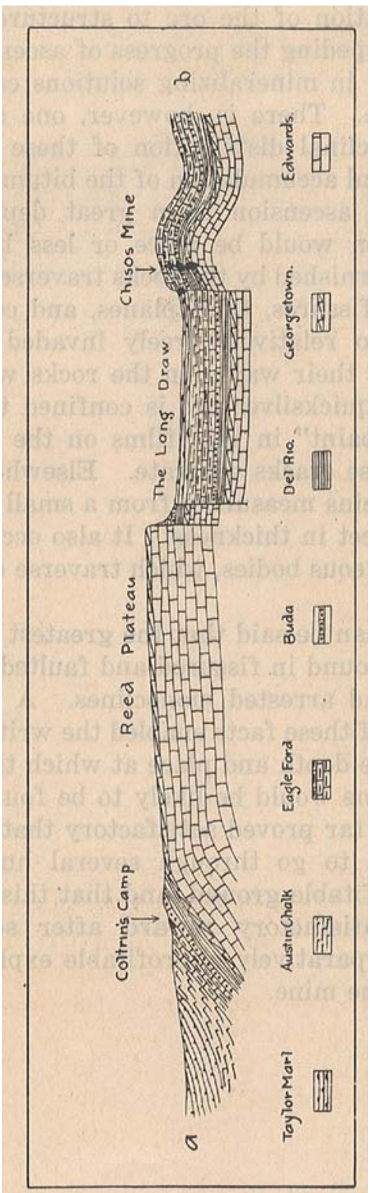

Fig. 16. Generalized section along the line c-d in Fig. 14.

CONCLUSIONS

From the foregoing accounts of practically all the im portant occurrences in the Terlingua district, it appears to me that the relation of the ore to structures suitable for collecting and impeding the progress of ascending vaporous or other solvents in mineralizing solutions can hardly be a mere coincidence. There is, however, one decided difference in the anticlinal distribution of these cinnabar ores from the anticlinal accumulation of the bitumens. It is evident that in its ascension from great depths, mercurial fumes in solution would be more or less limited to pervious conduits furnished by the rocks traversed. They have followed joints, fissures, fault planes, and contacts. They have clearly also relatively freely invaded any pervious strata coming in their way. In the rocks which are most impervious, the quicksilver ore is confined to joint cracks and occurs as "paint" in thin films on the outside of the blocks which these cracks separate. Elsewhere the ore occurs in fissure veins measuring from a small fraction of an inch to several feet in thickness. It also occurs along contact planes of igneous bodies, which traverse compact shales and marls.

In general, it can be said that the greatest amount of ore has so far been found in fissured and faulted parts of anticlines, domes, and arrested monoclines. A recognition of the significance of these facts enabled the writer many years ago to predict the depth and place at which the richest ores in the Chisos mine would be likely to be found. This prediction has in so far proved satisfactory that it encouraged the management to go through several hundred feet of somewhat unprofitable ground, and that this work enabled it to reap a satisfactory reward after some years of more or less comparatively unprofitable exploration of the upper levels in the mine.