THE GEOLOGY AND GYPSUM DEPOSITS OF THE SOUTHERN WHETSTONE MOUNTAINS, COCHISE COUNTY, ARIZONA

by

Frederick Turner Graybeal

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SIGNED: Frederick Turner Graybeal

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This thesis has been approved on the date shown below:

W. C. Lacy
W. C. LACY
Professor of Geology

May 21, 1962
Date

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ABSTRACT

The sedimentary rocks of the southern Whetstone Mountains include the Permian-Pennsylvanian Earp formation, and the Permian Colina limestone, Epitaph dolomite, Scherrer formation, and the Concha limestone. The upper part of the Pennsylvanian Horquilla limestone, and possibly the upper Permian Rainvalley formation are also present. Extensive gypsum deposits occur within the Epitaph dolomite.

The range forms a westward-dipping homocline which has been separated from the main body of the Whetstones by a strong northwest-trending, right-lateral, strike-slip fault. Movement along this fault has amounted to about 2.5 miles. Within the range is a series of northeast-trending vertical faults, all downfaulted on the south side. The south end of the range is terminated by a west-plunging anticline.

Minor thrusting has thinned several of the formations. The structural pattern possibly formed under a left-lateral couple acting along a northeasterly direction. Later, right-lateral forces acting toward the northwest caused movement to occur along these predetermined directions.

Three small granodiorite stocks, possibly volcanic in nature, and andesite and felsite dikes comprise the dominant igneous rocks in the area. Their positions are fault controlled.

The gypsum member of the Epitaph dolomite has been broken into three separate areas, and potentially valuable gypsum is found in two. Extensive red siltstones in the third mark the margin of the depositional basin in which the gypsum formed.

Extreme plasticity of the gypsum is evidenced by the development of an intrusive sill-like body of gypsum. During intrusion, mobility was probably greatly increased by the solution of gypsum at the areas of greatest pressure and deposition at areas away from these points. The gypsum probably formed in a restricted inland lake during periods of low silt influx, and shows no evidence of being altered to anhydrite during burial.

About 19,625,700 tons of 80.2 percent gypsum is available for mining.

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1. INTRODUCTION

(1.1) General Statement:

The geology of the Whetstone Mountains of northern Cochise County, Arizona, has been studied by Tyrrell (1957); however, details of geologic relations at the south end of the range were unknown. The area consists of faulted Permian strata, cut by occasional igneous rocks. Several major faults and potentially economic gypsum beds occur there.

Previous work in the range consists of a stratigraphic section (Appendix I) measured by the Shell Oil Co. This section was examined by Bryant (1955) and correlated with the type Permian formations worked out by Gilluly, Cooper, and Williams (1954) for southern Arizona.

(1.2) Scope of Problem:

The nature and origin of basin and range structures are still unsolved problems due to the great expanse of alluvial cover between adjacent ranges. Geologic studies of the borders of these ranges often disclose structures pertinent to these problems. It was hoped from the position of the southern Whetstone Mountains that they might disclose some of the principles of separation of mountain ranges.

Within the range are some extensive gypsum beds. The origin of gypsum has generally been agreed upon, although detailed investigations are rare. Structural and mineralogic studies of the gypsum are presented herein, related both to the economic value and origin of the beds.

Geology was mapped on a scale of 1:12,000, using as a base map the Mustang Mountains quadrangle (7.5-minute series). The most extensive gypsum unit was mapped using tape and compass methods at a scale of 1 inch to 100 feet. Samples were taken and assayed for gypsum, anhydrite, and insoluble content. The results, combined with petrographic work, were used to suggest a possible origin of the gypsum.

(1.3) Geography and Physiography:

The southern Whetstone Mountains are located in northwest Cochise County, Arizona, about 50 miles southeast of Tucson (Fig. 1). A paved highway passes the southern end of the range. Unimproved dirt roads along the east and west slopes make the range moderately accessible by car.

The range forms a southeasterly trending ridge, rising to a crest of about 6,200 feet at Mescal Peak. Steep talus-covered slopes have been incised by gullies formed during the torrential summer

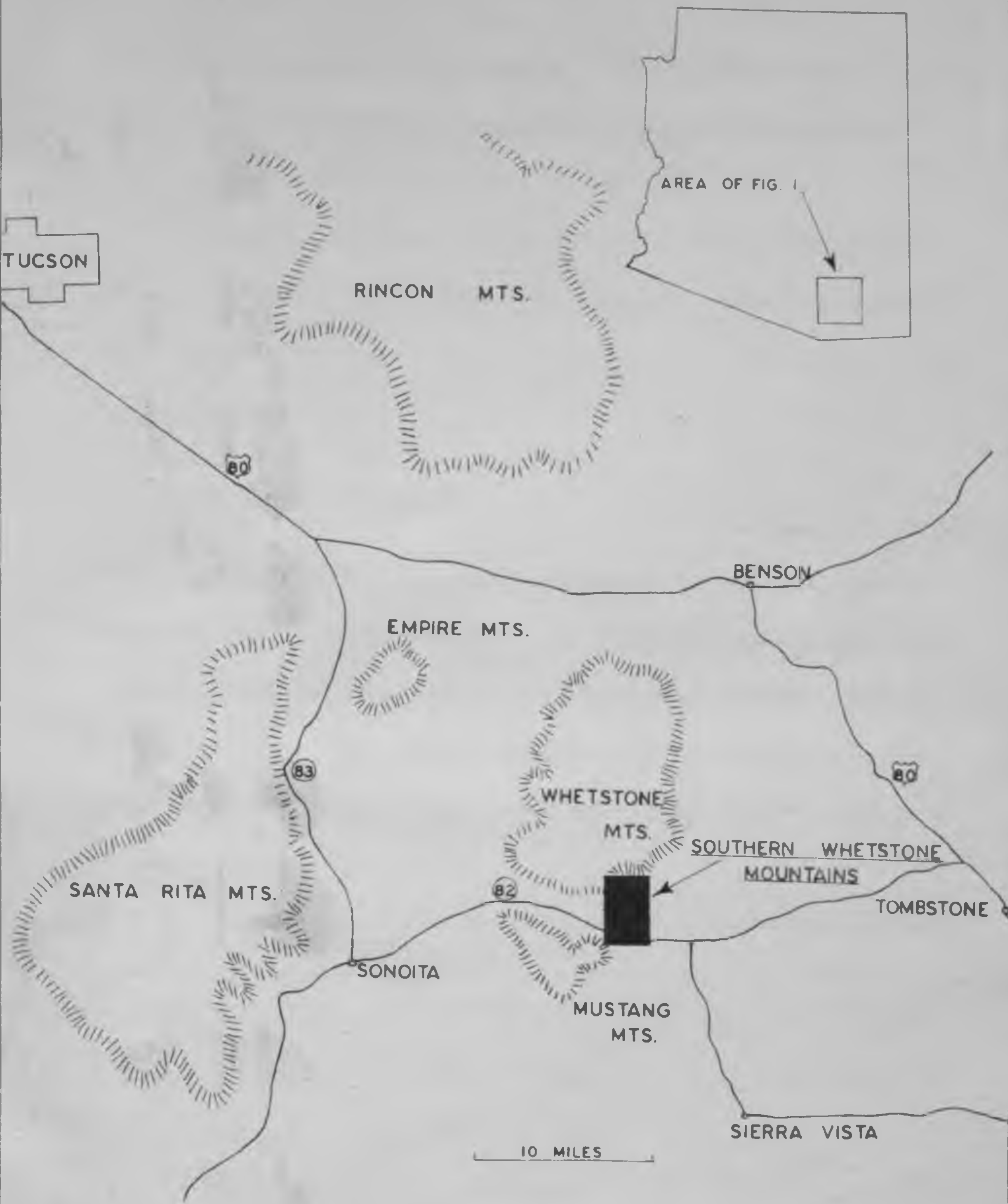

FIG. 1. INDEX MAP OF SOUTHEAST ARIZONA
SHOWING SOUTHERN WHETSTONE MTS.

rains. The east side of the mountains is cut off by an eastward-sloping bajada. Drainage is to the east into the San Pedro River, about 15 miles distant.

The climate is semiarid, typical of the Sonoran desert, with summer temperatures averaging 90°F. Rainfall seldom exceeds 12 inches a year. Scrub desert thorn and cacti abound and animal life is surprisingly abundant.

(1.4) Acknowledgments:

Turney, Irvin & Associates employed the writer during the summer of 1961 when the fieldwork was done, and assisted with later expenses. John Lacy cut and prepared most of the gypsum samples for assay. Dr. W. C. Lacy generously counseled the writer during the preparation of this manuscript and made pertinent suggestions for its improvement.

The kind assistance of these people is gratefully acknowledged by the writer.

2. STRATIGRAPHY

(2.1). General:

The rocks of the southern Whetstone Mountains offer an excellent Permian section for southeastern Arizona. The formations present include the top of the Horquilla limestone, the Earp formation, the Colina limestone, the Epitaph dolomite, the Scherrer formation, and the Concha limestone, all described by Gilluly, et al. (1954). Bits of the Rainvalley formation (Bryant, 1955) may be present, but this is not definitely established. These formations are for the most part easily distinguished in the field.

The Horquilla, Earp, Colina, and Epitaph were originally mapped by Ransome as the Naco limestone. Gilluly, et al. (1954) recognized distinct faunal assemblages and lithologies and subdivided the Naco into the above formations. The term Naco was then elevated to a group rank to include them. However, the Scherrer and Concha, not present in Tombstone where the Naco was defined, were also included in the Naco group. This extends the term Naco beyond its original sense. Bryant (1955) proposed to restrict the term Naco to the formations through the Epitaph. The overlying formations, the Scherrer, Concha, and Rainvalley, were then defined as the Snyder Hill group. This seems a more plausible solution, and does not confuse the terminology.

The stratigraphic section for the southern Whetstones was measured east of Mescal Peak by the Shell Oil Co. Thicknesses from this section are considered as typical for the area, as faulting and facies changes in other areas have thinned several of the formations. The Scherrer formation, however, has a questionable thickness, and this problem is discussed below.

(2.2) Pennsylvanian:

(2.2.1) Horquilla Limestone:

The Horquilla limestone underlies the low areas east of the main ridge, and crops out on two small knobs near Sands Ranch. It is covered in most places by a coarse gravel of unknown thickness.

The Horquilla is a massive, light-gray weathering, gray limestone with lenses of buff chert occurring irregularly throughout the upper portion. The thickness in this area is unknown; however, rough calculations between known outcrops indicate at least 2,000 feet is present. This is 400 feet thicker than any previously reported section in southern Arizona, indicating possible thickening by folding or faulting beneath the alluvium.

The upper contact with the Earp can be located within 5 to 10 feet. In the Tombstone Hills (Gilluly, et al., 1954) the boundary is gradational and is selected arbitrarily where shales dominate over limestones. In the southern Whetstones the change from limestone to interbedded sandstone and limestone is abrupt. The contact of the upper Horquilla is taken where the dark-gray limestones and sandstones of the Earp appear.

(2.3) Permian-Pennsylvanian:

(2.3.1) Earp Formation:

The Earp formation forms the base of the eastern ridge, and crops out in the northern half of the area. To the south its presence may be inferred. In general, the Earp is susceptible to erosion, forming gentle slopes with frequent covered intervals.

Two separate units are distinguished within the Earp. The lower one is 320 feet thick, and consists of thin gray limestone beds interbedded with red, gray, and buff siltstones and sandstones. About 120 feet above the base is a 2-foot limestone conglomerate bed. It consists of pebbles of black chert, buff and gray dolomite, gray limestone, and rare buff sandstone fragments. They are all held in a black limy matrix. This unit occurs between a red-brown limestone below and a possible siltstone above. A second, but thinner, conglomerate is present 40 feet below the first.

The upper unit is more sandy and redder than the lower with rare limestone beds. It consists of red, pink, and buff sandstones and siltstones which weather to hues of dark red, gray, and yellow. A limestone conglomerate unit occurs about 240 feet below the top of this unit, lying between gray siltstone beds. It is quite striking, as it contains scattered red chert pebbles. The bed, where present, is about 5 feet thick, and the chert occurs at the top of three individual units, each distinguished by graded bedding. The pebbles are elongate and parallel the bedding. The source of the chert is not known locally, and 1, 500 feet along the strike of the horizon these pebbles are absent. Instead, dolomite, sandstone, and black chert pebbles are present with no change in thickness. This unit can probably be correlated with similar conglomerates in the Tombstone Hills and Gunnison Hills (Bryant, 1959).

North of Mescal Peak a thin 2-foot bed of banded orange and black dolomite was found in the Earp formation. The bands averaged about an eighth of an inch thick, and were found near the suspected base of the Colina. A similar unit is present in the Tombstone Hills.

The Earp is 700 feet thick in the southern Whetstones. Its upper contact is taken at the point where limestone beds begin to appear. This boundary is transitional, and its location is arbitrary. Near Tombstone, 20 miles east, the Earp thins to 595 feet.

The Permian-Pennsylvanian boundary lies somewhere in the

Earp and is distinguished by fusulinids. This boundary is transitional and lies near the center of the formation. It may be significant that no prominent fusulinid zones are found above the conspicuous chert conglomerate described above. Whether this represents a significant time break or not is unknown.

The Earp records a change to a shallower marine environment than was present during Horquilla times. The lower conglomerates may be intraformational, as suggested by Gilluly, et al. (1954); however, the pebbles are quite rounded indicating a moderate period of abrasion. The upper conglomerate is thicker than the lower ones, and a shallow-water environment is indicated by the graded bedding. It also consists of pebbles not known to occur in any nearby beds (red chert), indicating a large area is involved. The similarity of this conglomerate to others in southern Arizona supports this idea. Fossil evidence indicates no large time interval existed during the formation of the conglomerate (Gilluly, et al., 1954).

(2.4) Permian:

(2.4.1) Colina Limestone:

In the north half of the area studied, the Colina limestone forms the prominent eastern ridge. To the south it crops out as small knobs set out from the main mountain mass. It is generally resistant to erosion, and weathers to a smooth, prominent surface.

The lower part of the Colina consists of thin to medium beds of dark-gray limestone, interbedded with gray and red sandstones and siltstones, and buff-weathering dolomites. The sandstones are commonly specked with limonite and erode to a smooth slope. The limestones form small ridges, and are occasionally dolomitic and coarse grained. This lower unit is about 300 feet thick.

The upper part consists of massive dark-gray limestone beds, becoming more massive and slightly dolomitic toward the top. This is a cliff former, with some beds 10 to 15 feet thick. Occasional light-gray weathering units occur lower in the section; however, the fresh surface is always dark gray. Brown chert is present throughout, and rare stylolites are found. This upper unit is 400 feet thick.

The Colina limestone totals 700 feet in thickness. The upper contact with the Epitaph dolomite is very sharp, and is marked by a medium-bedded, dark-gray, dolomitic limestone with a thin-bedded, light-gray weathering dolomite. It appears that no transition zone exists between the limestones and dolomites. The same contact in the Tombstone Hills is more transitional. There the Colina is 630 feet thick, 70 feet thinner than in the southern Whetstones.

The Colina represents a change to a deeper water environment than existed in Earp times. This is indicated by massive limestones and a total lack (in the upper part) of any clastic sediments.

(2.4.2) Epitaph Dolomite:

The Epitaph dolomite forms the broad saddle east of Mescal Peak, and forms the lower part of the ridge to the south. The lower and middle parts tend to erode easily. The upper part is rather massive and resistant to erosion.

The Epitaph occurs in three distinct units. The lowest is formed by thin-bedded light-gray and black dolomites, interbedded with buff-colored siltstones. The siltstones are often highly sheared, indicating they served as surfaces for bedding-plane slippage. Light-gray dolomite dominates in the lower part of this unit, with black-colored beds becoming more abundant toward the top. Black dolomite weathers both light gray and black, and the weathered surface of these dolomites is characteristically jagged. Calcite veinlets 3 to 4 feet long and quartz-filled geodes are often present. This unit is 480 feet thick.

The central unit consists of interbedded siltstone, dolomite, and gypsum, reaching a maximum thickness of about 450 feet. The base of this unit is normally formed by a gray and red siltstone about 120 feet thick, which is overlain by 15 feet of gray siltstone, 2 feet of yellow siltstone, and a 1- to 2-foot bed of dolomitic limestone. On top of this rests the gypsum member, which is 310 feet thick in the type area but averages about 280 feet. This consists of about 250 feet of gypsum and 30 feet of interbedded dolomites. The gypsum will be further discussed below.

The upper unit is a massive cliff-forming gray to black dolomite 310 feet thick. It is dolomitic at the base, becoming more calcareous toward the middle, then increasingly dolomitic near the top. It generally weathers to form jagged surfaces, similar to the lower unit. Rare thin silt beds are present. Abundant quartz-filled geodes occur near the contact with the Scherrer. Occasional blocks of this unit have slumped into the gypsum.

The upper contact of the Epitaph with the Scherrer formation is sharp; red siltstones rest directly on the dolomite with no evidence of channeling. The measured section of the Epitaph for this area measures 1,240 feet, while the type section of the Epitaph (Tombstone Hills) is 783 feet thick. Although the thicknesses differ by 500 feet, the general lithologic sequences for each area are similar. If the 450 feet of gypsum and siltstone were present at Tombstone, the two formations would be identical.

The upper and lower units within the Epitaph dolomite are consistently the same thickness; however, the central unit varies from 125 to 450 feet in thickness, dependent on whether or not the gypsum is present. In most instances the lack of gypsum is due to its being squeezed out during folding and faulting. The marginal facies of the gypsum is present at the south end of the range, where it is intimately interbedded with red siltstones.

The Epitaph represents deposition in shallow water, both marine and nonmarine. After the lower dolomite was deposited a basin with restricted outflow of water developed. This may have been preceded by a local uplift to near-shore conditions with higher land in surrounding areas with possible climatic changes, thus depositing the siltstone and gypsum. A return to marine conditions is marked by the somewhat fossiliferous upper unit. This probably was never a deep marine environment.

(2.4.3) Scherrer Formation:

The Scherrer formation crops out over the entire area. It erodes readily,. but forms irregular steep slopes due to the overlying resistant Concha limestone. It is distinctive from a distance as a whitish band along the upper part of the ridges.

The Scherrer may be subdivided into four parts. The lowest consists of 50 feet of red siltstone with a few dolomite layers, capped by a 20-foot dolomite bed. The siltstone becomes more silty toward the top.

The second unit is a 200-foot bed of reddish-weathering, thin- to medium-bedded, pinkish-white, crossbedded, quartzitic sandstone. Parts of this weather to a yellow and gray color. Small iron-rich spots occur throughout the bed. This unit generally weathers redder than the upper unit.

The third unit is a vuggy, thick-bedded, buff to gray dolomite, 130 feet thick, containing scattered chert nodules.

The upper unit is an 80-foot bed of crossbedded, gray-to white-weathering, pinkish-white sandstone. It erodes more easily than the lower sandstone. Concretionlike structures about 2 inches in diameter are obvious on weathered surfaces but not in the fresh rock.

The type Scherrer in the Gunnison Hills, 30 miles to the northeast, is 687 feet thick. Five miles to the southwest in the Mustang Mountains, the Scherrer is about 630 feet thick. Bryant (1955) suggests the difference may be due to unrecognized faulting in the sandstone units, as a 150-foot thinning within 5 miles would not be expected. Thinning by bedding-plane faulting was recognized in the Mustangs.

In its thickest section in the southern Whetstone Mountains the Scherrer totals 480 feet. It appears to be rather incompetent and is thinned greatly in areas of undoubted faulting. However, the individual units and the formation as a whole remain of constant thickness for 4 to 5 miles.

No direct evidence of faulting was observed in the measured section on Mescal Peak. Here the Scherrer appears to be relatively undisturbed. An interesting relation arises from a comparison of thicknesses of the individual units within the Scherrer. From the top down in the Mustang Mountains thicknesses are 152, 156, and 320 feet, respectively. In the southern Whetstones they are 80, 130, and 270 feet, respectively. Thus, from the top down, the southern Whetstone units are 72, 26, and 50 feet thinner, respectively, than their counterparts in the Mustangs. It seems improbable that these units were all consistently thinned during faulting, especially the central dolomite bed.

Thinning appears to have occurred, however, and a possible thrust (or bedding-plane) fault may exist. If so, it has thinned all units equally.

Shallow-water depositional conditions are clearly indicated for most of the Scherrer, with a short marine transgression depositing the central dolomite. The upper contact with the Concha is sharp, as is the lower contact with the Epitaph. The Scherrer remains consistent in its lithology over all of southeastern Arizona.

(2.4.4) Concha Limestone:

The Concha limestone crops out over most of the southern Whetstones capping the ridges and western slopes. It is resistant to erosion, commonly forming cliffs wherever a sufficient thickness is present.

The lower part of the Concha on Mescal Peak is a thick-bedded, very cherty, gray, dolomitic limestone about 90 feet thick. Near the base the chert is bedded, elsewhere it occurs as buff-colored nodules.

The upper part of the Concha is a thick-bedded, gray- and buff-weathering, black limestone. Chert is less abundant in this unit. A characteristic feature of this part of the Concha is red blotches of limestone which grade within an inch or so to black limestone. This unit measures 170 feet in thickness and is capped by an erosion surface. Both units are typically marine in lithology.

There is a 250-foot section of Concha limestone exposed on Mescal Peak. South of the peak more Concha is exposed, but it is faulted, under cover, and lacks a convenient marker bed, so the measuring of this portion of the section was not possible. Rough estimates in this area indicate there is probably an additional thickness of 500 feet present.

Along the base of the western ridge are several outcrops which do not conform to the lithologies of the rocks along their strike. They are distinctive and occur in separate units, consisting mostly of thin-bedded, light- to dark-gray, buff- and orange-weathering, gray limestones and one continuous limestone conglomerate bed. Near the top of this series are two beds exposing algal-like structures. Both are about 3 feet thick, and form excellent marker beds. The beds contain dark-gray, circular, concentrically banded structures ranging from 1/2 inch to 8 inches in diameter. The larger ones occur above the smaller ones, in the manner of an overturned graded bed.

The Concha section measured in the Mustang Mountains, 6 miles to the southwest, is 560 feet thick. There it is a massive limestone with a consistent gray color. Above the Concha is the Rainvalley formation, a name proposed by Bryant (1955). It is distinguished from the Concha by its thin-bedded varicolored limestones that have a distinctive faunal assemblage. The rocks at the base of the western ridge resemble this formation; however, the complex structure and scarcity of continuous outcrops prevent positive correlation. Further faunal studies might establish its true identity.

(2. 4. 5) Quaternary Alluvium:

Rocks at the base of the southern Whetstone Mountains disappear abruptly under Quaternary and Recent alluvium. This is mostly a very coarse, caliche-cemented gravel exposed in washes up to 40 feet deep. It is locally used as a source of aggregate.

3. STRUCTURE

(3.1) General:

The southern Whetstone Mountains form a narrow southern extension of the main body of the Whetstone Mountains. Their structure in general is not difficult to resolve, although its relation to the broader picture is less clear.

The range lies on the eastern edge of a basin filled with Cretaceous sediments. This basin is about 15 miles in diameter, and is mantled with recent alluvium. The general dips are inward; however, gentle dip reversals forming anticlines and synclines are common.

The southern Whetstones are separated from the main body of the Whetstones by a narrow east-west valley. Directly north of this valley, along the strike of the Permian rocks of the southern Whetstones, is a thick section of Cretaceous(?) sediments. The contact between the two lies somewhere near the stream which flows through the valley. The rocks, consisting of red, yellow, and white sandstones, with some possible basic dike rocks present, have been highly altered, bleached, sheared, and folded.

The Permian section is found about 2.5 miles to the east, at the south end of the Whetstones. Here it strikes into the central mass of the Whetstones N. 30° W. and dips 25° W.

From this relationship it is evident that a major east-west, right-lateral, strike-slip fault is present in the valley. If this fault had been normal, over a mile of vertical movement would have been necessary to place the rocks in their present position. It seems more plausible that a strike-slip fault with horizontal movement of at least 2 miles exists. This fault is probably related to the structure of the southern Whetstones, and is referred to as the Mescal fault. The structural relations between the Mustang and southern Whetstone Mountains are not known and can only be postulated. Definite thrusting has been reported in the Mustangs (Bryant, 1951). Neither direction nor magnitude of thrusting are known; however, Bryant (1951) felt directions were either from northeast to southwest, or in an easterly direction. As will be shown later, strong tectonic forces acted in a northwesterly direction, and probably the rocks of the Mustangs were thrust toward the northwest. On a geologic map they appear to be right-laterally offset from the southern Whetstones (Fig. 2), however, thrusting to the northwest could easily account for this offset. It is also possible that these thrust features resulted from outward thrusting during basining, much in the manner of formation of drag folds on the flank of a syncline. Whether the Permian section of the southern Whetstones dips undisturbed under the Mustangs or is cut off is unknown.

No large overthrusts were found in the southern Whetstones.

Minor thrusts exist, but the main mountain mass does not appear to have broken away from the underlying rocks.

(3.2) Folds:

The southern Whetstone Mountains form a homocline (Pl. 2, C-C', D-D') which dips 25° to 30° SW. This probably formed during the general basining to the west. Whether this homocline formerly arched over an anticline, or was upfaulted on its eastern front is unknown. Possibly a large vertical fault, downdropping the San Pedro valley side, accompanied downwarping to the west. Erosion has removed all clues. The homocline is broken into a series of separate fault blocks, each dipping and striking in the same general direction.

The south end of the range is formed by a west-plunging, asymmetrical anticline with the steep side on the north. The axis is slightly S-shaped, striking generally about N. 85° W. The north limb bends around very sharply into a poorly defined syncline. The more gently dipping south side of the anticline disappears under the alluvium. Within the anticline several axial plane shear zones were mapped. They consistently strike N. 70° W. to west and dip 65° to 75° S. Just south of the anticlinal axis within the upper Epitaph dolomite is an incongruous drag fold, measuring about 30 feet across. A normal drag fold would have its axial plane dipping parallel to that of the larger fold, also it would indicate movement of the upper bed toward the crest of the anticline. However, the axial plane of this fold dips 65° N., and indicates movement such that the flank of the fold was partially thrust under the crest.

Other minor flexures and folds occur throughout the area. The beds on the north slope of Mescal Peak tend to swing in a westerly direction, forming a very gentle synclinal structure. Occasional sharp drag features are common near faults.

(3.3) Faults:

(3.3.1) Strike-Slip Faults:

Two major strike-slip faults exist at the northern boundary of the southern Whetstone Mountains. Strike-slip movement may have occurred along other faults, but was minor when compared to the dip-slip component.

The first is the Mescal fault which has separated the main body of the Whetstones from the southern Whetstones. About 2.5 miles of right-lateral offset has occurred here. The absence of any igneous rocks along the approximate trace of the fault indicates that either sufficient compression was present to keep the walls of the fault together, or movement took place at a period of sparse igneous activity. Enough shearing occurred, however, to enable hydrothermal activity to extensively bleach the rocks.

A second right-lateral, strike-slip fault was mapped on the northwest side of Mescal Peak. The exact position of the fault is poorly defined, although igneous rocks crop out along its trace. Two outcrops of strongly sheared and bleached rocks along the gully following the fault indicate that this is probably a branch shear of the main fault. The fault is also indicated by the offset of the two small hills of Colina limestone.

(3.3.2) Vertical Faults:

Nearly vertical faults are common in the area. The majority trend N. 60° E. (Fig. 3), and the remainder trend N. 60° W. These faults are called vertical, as it was not possible to determine absolute movement, and they all dip approximately 90°. Areas of intense faulting and igneous activity locally break the continuity of the homocline into a series of fault blocks. Examples of this are numerous around Mescal Peak.

With one exception, all faults in the southern Whetstones indicate movement of the south side down. The depth to which these faults extend is unknown; however, those associated with igneous activity may extend down to considerable depths. The amount of movement on the faults is variable. On the major northwest-trending fault just south of Mescal Peak, the south side has moved down relatively about 700 feet. This was the largest vertical offset noted.

Several faults have been inferred, either to resolve certain structural discontinuities unexplainable any other way, or as normal projections of known faults. In the valley south of Mescal Peak a northeast-trending fault was inferred southwest of the small stock. This seemed warranted on the basis of the offset contacts of the Scherrer formation, and the semielongate shape of the stock in a northeast direction.

The northeast-trending fault in the N-1/2 sec. 10 was inferred to explain the offset contact of the Colina limestone and Epitaph dolomite. This fault may bend and continue west to the small hill in the SW-1/4 sec. 9 where erosion has exposed a slice of the Scherrer formation. At the west end of this hill, an area of brecciated limestone (Fig. 13), with boulders a foot and more in diameter, is present, indicating strong faulting.

Other inferred faults are present in the area mapped, however, they are of minor importance. Either they are small, have little structural significance, or merely represent extensions of known faults.

The north slope of Mescal Peak has been intensely faulted. The most interesting area lies about 800 feet north of the "32" in section 32. Here is a possible intersection between two faults, one striking east and the other N. 35° E. At this point a coarse pebble breccia has been exposed in a gully for about 230 feet. Its southern contact is marked by a possible zone of intrusive breccia which is in contact with a 20-foot zone of intensely sheared and bleached limestone. The northern contact was not exposed; however, in its vicinity shearing and much yellow limonite were observed in the pebble breccia. The east and west contacts were not exposed.

The rocks forming this pebble breccia ranged from small pebbles to boulders nearly a foot in diameter. Their shapes were subangular to rounded, and the rock types present included andesite, limestone, dolomite, sandstone, and chert fragments. These boulders are all intimately mixed, both according to lithology and size. No bedding or planar structure of any type was noticed.

The composition of the matrix varies greatly in different areas. Near the north contact it is limy, and resembles a fine-grained sandstone. Toward the southern contact, the matrix becomes a maroon color, and resembles an igneous rock, possibly andesite (Fig. 11). Local patches of light-colored pebble breccia are present, and the matrix is almost totally quartz. Nowhere in the pebble breccia are the rims of the boulders altered.

Microscopically, the igneous matrix of the rock showed the following mineral percentages:

Andesine (An_{45})	30 percent
Calcite	15
Quartz	15
Clay	5

Pyrite	5 percent
Chert inclusions	30

The plagioclase was strongly altered to sericite and clay. Calcite veinlets indicate late stage alteration, however, this was preweathering since all veinlets were coated with clay.

The above-mentioned intersection of two near vertical faults probably extends to considerable depths, and may have experienced some movement. Faulting, combined with probable gas action, are indicated by the extensive rounding of the boulders—which is due to attrition rather than alteration—and by the great variation in lithology. The boulders appear to have been carried to their present position by a combined upward push of magma and/or gas. The presence of a powerful vent of steam is indicated by the tightly packed sandstonelike matrix at the north end of the pipe.

This feature probably represents combined volcanic and fault activity. The pipe may extend irregularly downward to an igneous stock, as a strong upward push or source of gas was needed to bring the varied fragments to their present positions. Similar large features such as intrusive breccias have seldom been traced to their base. Smaller features such as pebble dikes have often been noted to grade downward into igneous dikes, from whence the "push came." There is no reason why this pebble breccia could not be a larger example of this phenomenon. The presence of an andesite boulder in it complicates matters somewhat, and hints that there may either have been more than one period of faulting, or faulting extended over a considerable period of time.

The remainder of the north slope of Mescal Peak is cut by numerous faults and has been well sheared. Several small faults have been exposed in washes. Some of these fault zones are less than an inch wide, even though displacement may have exceeded 60 feet (Fig. 9).

The largest fault within the southern Whetstones occurs on the south side of Mescal Peak, striking N. 60° W. (Fig. 7). It will be referred to as the Northwest fault, and it can be traced for nearly 2 miles to the east where its continuity is disrupted by several crosscutting breaks. Although it is the major fault in the area, it is the only major fault in the range which trends northwest. Displaced contacts along the fault indicate that the south side has moved down. Assuming only vertical movement, approximately 700 feet of vertical displacement was calculated. It appears this movement may have been greater in the east, in the manner of a scissor fault.

This fault zone is generally about 2 feet wide and sharply defined. Rarely, its position is obscured by a zone of intense shearing over 10 feet wide. An occasional fragment of rock representing rocks found considerably higher in the section has been dragged into the zone. For the most part, the fault appears to have been under tension during most of its formation with resultant open cavities. In these cavities undulating layers of aragonite have been deposited (Fig. 10) as large needles oriented perpendicular to the wall of the fault. The calcium carbonate for the aragonite was possibly freed from the dolomite due to a reaction with saline solutions high in sulphate (Dana, 1955, p. 521-523). Since the only source of sulphate in the area is gypsum, and the gypsum occurs below all known aragonite deposits, it appears that the aragonite was deposited by ascending waters, probably heated by igneous activity. The presence of numerous small andesite dikes along the fault suggest this probable mode of formation of the aragonite, and further attest to the openness of the fault.

Southeast of Mescal Peak the Northwest fault forms the southern border of a large block of Concha limestone which appears to have been downdropped on all sides. The geologic relations here are obscure due to alluvial cover.

Hydrothermal activity existed along some faults not visibly associated with igneous rocks. Between sections 5 and 8, this was especially noticeable in a small prospect shaft near the top of the ridge. A small but highly brecciated fault zone about 1.5 feet wide has been replaced with iron, mostly in the form of hematite. No shearing or alteration of the surrounding limestone was noticed. The breccia fragments consisted entirely of chert, and moderate silicification accompanied the introduction of the iron. This fault crops out irregularly to the northeast and is easily distinguished due to the presence of this red iron staining.

An anomalous block of Concha limestone in the western part of section 10 has been thoroughly broken by a myraid of small faults. It appears to have been dropped into its present position, although its relations are anything but clear.

At the south end of the range a series of vertical faults, consistently with the south side down, cut the homocline and are especially numerous within the anticline. Displacement along most of these faults has been of the order of 200 feet. Many are marked on the surface by zones of jasperoid which occur so consistently with known faults that the presence of silica was taken to indicate the presence of a fault. The jasperoid is a dense red material which in many places has replaced both breccia fragments and areas of the surrounding rock. No alteration other than the jasperoid was present. Irregular pods of the jasperoid appear to occur where jointing perpendicular to the fault is especially common. Replacement appears to have been controlled only by the presence of open spaces, not rock composition. This jasperoid is believed by the writer to have been associated with hydrothermal activity.

(3.3.3) Thrust Faults:

Thrust faults have been recognized in the southern Whetstone

Mountains. They appear to have developed during folding, and represent adjustment in a plane parallel to the bedding. In any one area the direction of movement is consistently the same, representing adjustment to a particular force. They occur mostly along clastic beds.

Small bedding plane faults invariably occur along thin silty beds lying between more massive and competent dolomite beds. Where exposed the siltstones are highly sheared and iron stained. They are most common in the Earp and Epitaph. The amount of movement along these faults is assumed to be small, as they represent slipping of beds over each other.

Several thrusts were found in the mapped area and others are suspected. A major fault is present about 1,500 feet east of the 4 in section 4. It occurs in the Colina limestone, just below the Colina-Epitaph contact, and its surface trend parallels that contact. The fault is considered to dip west parallel to the rocks above it, while slightly truncating the rocks below it (Pl. 2, C-C'). This fault has considerably thinned the Colina at this point, and is actually apparent as viewed from the south (Fig. 8). Thrust movement is indicated with the upper beds moving eastward over the lower ones. This fault was not observed elsewhere at this horizon. Either its presence was too subtle to be recognized, or else it was localized within that particular area.

A second thrust fault is present in the NE-1/4 sec. 9, north of the high cliff. Here beds of the Scherrer formation have been greatly thinned, and in places completely removed. Thrusting evidently took place along the less competent Scherrer, between the more competent beds of the Epitaph dolomite and Concha limestone. Here again the fault cannot be traced over any great lateral area indicating that thrusting within the southern Whetstones may be local, representing relief to forces of restricted areal extent.

A third possible thrust, possibly continuous with the one above, may exist on Mescal Peak within the Scherrer formation. On the western slope of Mescal Peak a small fenster of Scherrer is exposed. This is about 400 feet stratigraphically higher than projected dips permit. This may represent a thrust sheet of Concha, which was thrust over and considerably thinned the Scherrer.

(3. 3. 4) Landslide Fault Blocks:

Landslide faulting has occurred in scattered areas. These are represented mostly by large blocks of Concha 100 feet or more thick, resting on gentle slopes of Scherrer and Epitaph. These represent breaking along joints and subsequent slow sliding downhill as erosion developed the present landscape.

On the north slope of Mescal Peak a large block of Concha was found on top of the Epitaph. This block may have been dropped into its present position early in the structural history of the area. As distinct from the topographic prominences formed by the smaller slide blocks, this rests within the rocks surrounding it, and its origin is uncertain.

(3.4) Origin of Structures:

Any analysis of the origin of the structures of the southern Whetstones must be approached with considerable care, especially in an area of such limited size. As is often the case, it is not possible to make positive statements; however, certain suggestions are made on the basis of the existing evidence. Using the theory of the strain ellipsoid, an attempt was made to correlate the structural framework of the mountains with general directions of force and movement which may have existed in the past. A generalized tectonic map is given on Figure 3.

Before applying the strain ellipsoid, it is necessary to distinguish tension from shear directions. The vertical faults in the range appear to have resulted from tensional and possibly vertical forces. This may be inferred from evidence that the faults had been open, and to the lack of shearing along these faults. Their consistent trends indicate they are part of a pattern formed by stress of possible regional magnitude.

The most important structure is the Mescal fault at the north end of the mountains. This fault shows undisputed right-lateral movement for a distance of about 2.5 miles. The major part of the movement must have been strike-slip to displace the moderately dipping beds

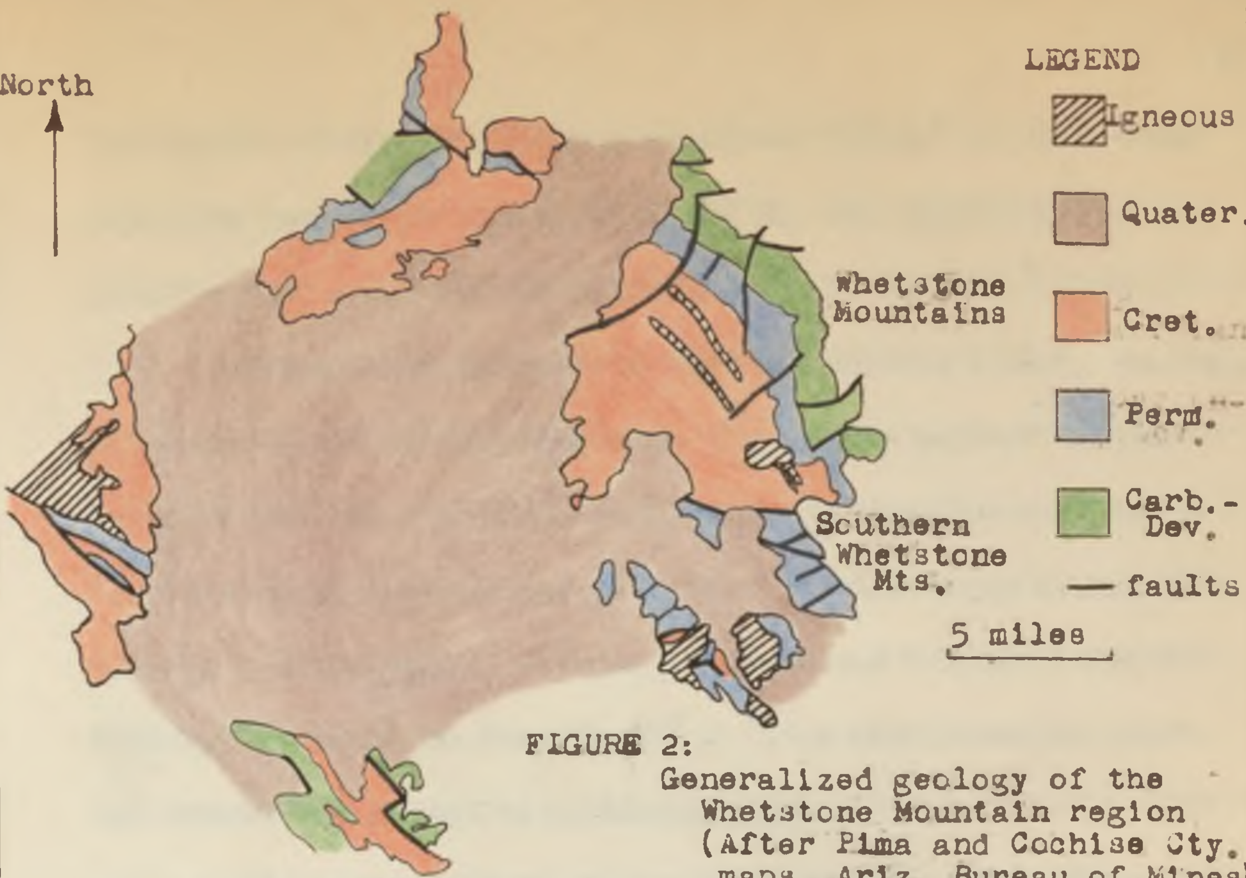

FIGURE 2:
Generalized geology of the Whetstone Mountain region (After Pima and Cochise Cty. maps, Ariz. Bureau of Mines)

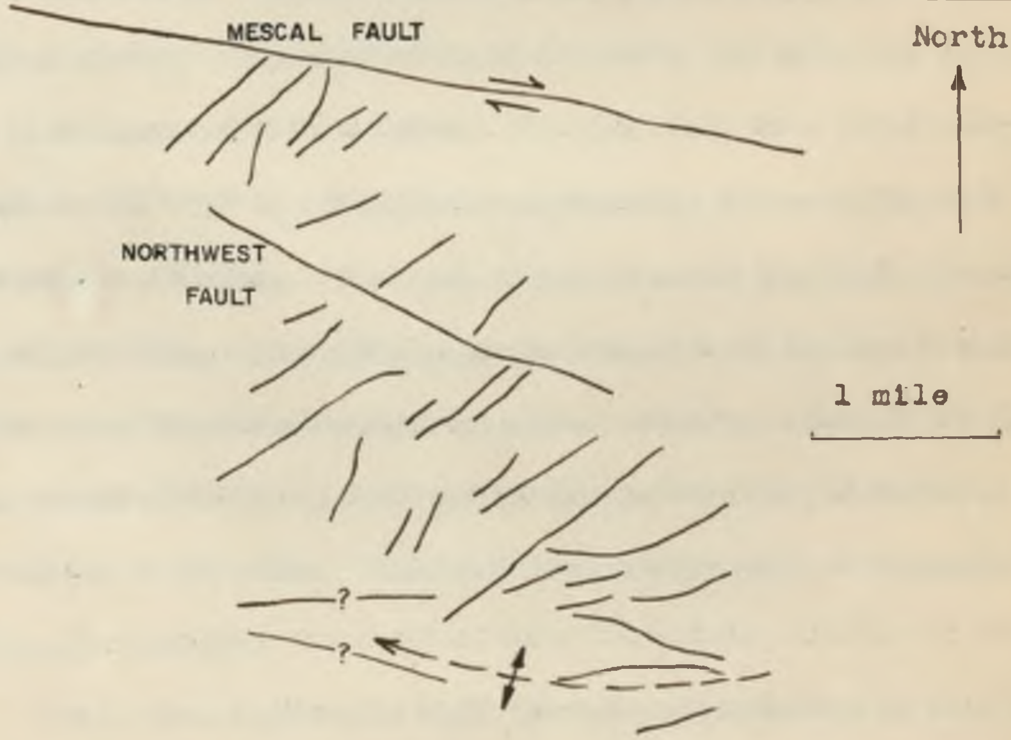

FIGURE 3 :
Generalized tectonic map of the Southern Whetstone Mountains

this amount. The fault strikes generally N. 75°-80° W. This would orient the least strain axis about N. 80° E., and would indicate compression from a direction of S. 10° E.

Although this direction of force is relatively certain, the faults of the southern Whetstone Mountains, of probable tensional origin, could not have been formed by compression in this direction. Since tension fractures parallel the direction of greatest compression, it is possible that the original direction of stress was coincident with the strike of the faults, or about N. 55° E. This would make the stress left-lateral with respect to the Mescal fault.

These observations suggest the possibility of two different periods of stress. This suggestion is debatable, but sufficient evidence exists to at least merit its mention. The first may have acted along a direction N. 50°-60° E., being later replaced by forces acting in a northwesterly direction. The first stress direction may have developed the fractures along which subsequent movement occurred due to compression along the second stress direction. Further evidence for the second stress direction is provided by the east-trending anticline at the south end of the range. This indicates compression in a general north-south direction.

This second period of right-lateral movement can be seen in other areas of southeastern Arizona. The Mustang Mountains with an identical section to that of the southern Whetstones may be right-laterally offset nearly 5 miles. The Mustangs contain a thrust plate with Permian resting on Cretaceous rocks. The right-lateral position indicates thrusting may have been toward the northwest. Right-lateral offset on a regional scale can be seen by a comparison of the Whetstone and Huachuca Mountains. Their stratigraphy is quite similar, however, they are also offset in a right-lateral direction. This may indicate that the basin and range structures in this region were formed by right-lateral wrench faulting, instead of the often suspected vertical faulting which gives rise to graben-horst structures.

A definite pattern of step faulting is seen in the range. Where dips could be determined, the larger faults were nearly vertical. The smaller faults were assumed to accord with this pattern. The larger faults of the area are downfaulted on the south side, and this has dropped the section at the south end of the range nearly 1,000 feet below that found to the north. This consistent downfaulting on the south side of each fault indicated vertical forces may have been important, and may possibly have been caused by a rising igneous mass to the north. Forces resulting from the Mescal fault may also have been important.

The timing of right-lateral forces can be most accurately dated as post-Cretaceous and probably no later than middle Tertiary. This is best indicated by the displaced Permian-Cretaceous contact. It is believed that the forces did not continue much beyond the middle Tertiary as most of the igneous rocks present are unsheared.

The timing of left-lateral forces, if they existed, is uncertain; however, they were certainly post-Permian. They may have been formed during the suspected early Triassic uplift of southern Arizona. Basining in post-Cretaceous time to the west is clearly evident (Fig. 2), and this may have exerted a strong influence on the pattern of faulting in the southern Whetstones. The relation between basining and right-lateral forces, if one exists, is unknown.

4. IGNEOUS ROCKS

(4.1) General:

Various igneous rock types are irregularly scattered throughout the southern Whetstone Mountains. They occur either in small stocks or dikes, usually in very small outcrops, so probably some of the dikes may have gone unnoticed.

(4.2) Stocks:

There are three stocks in the southern Whetstones. The best exposed is located at the southeast foot of Mescal Peak. A smaller one occurs northwest of Mescal Peak, and a large but vaguely defined stock is exposed on the north flank of the anticline at the south end of the range.

The stock south of Mescal Peak is the best exposed and will be described as a typical example. It is composed principally of maroon granodiorite which grades into a granodiorite breccia near the center of the stock. Only traces of flow structure are present.

An east-trending system of calcite dikes occurs in the central portion of the main stock. They vary from .15 to 1 inch wide and often extend 5 feet, filling probable joints in the granodiorite breccia. Slivers of the granodiorite are often present in these calcite dikes. These dikes may be the result of either late volcanic gases rising in the stock, or limestone mobilized by the heat of the intrusive. A long sliver of marbleized dolomite crops out in the vicinity of these dikes.

The stocks are all closely associated with faults. The central stock occurs at the intersection of two large faults. They appear to be volcanic necks and may have been the source of the capping volcanics found in the Mustang Mountains.

The major igneous rock in these stocks and also in the southern Whetstones is a maroon, porphyritic, moderately altered granodiorite, The minerals present, as determined microscopically, are:

Andesine (An_{34})	60 percent
Orthoclase	10
Sericite	4
Quartz	4
Calcite	2
Hornblende	3
Pyrite	2
Clay	5
Groundmass	10

The above minerals constitute about 90 percent of the rock. The remaining 10 percent is composed of a very fine grained matrix, giving the rock much of its maroon color. The rock has been moderately altered, with clay, sericite, and calcite found replacing andesine phenocrysts, and pyrite replacing the hornblende. Local rounded fragments composing the breccia range in composition from andesite to dacite.

Two types of alteration are common in the granodiorite. The first is a pervasive sericite and weaker clay flooding. The second is a spotty propylitic alteration of the plagioclase appearing to have no definite relation to any structure. With the epidote, calcite, and pyrite are found occasional patches of lime silicates, dominantly wollastonite and possibly idocrase. These minerals may represent small partially digested xenoliths of limestone. One limestone contact was exposed. Near the contact the granodiorite was sheared to a gougy material, and was separated from the limestone by a narrow silicified zone. The limestone was only slightly bleached.

Within the granodiorite are several dark-red felsite dikes. Accurate classification was not possible, as the rock was too fine grained. Quartz comprises about 40 percent of the rock, and traces of biotite were noted. Apparent hydrothermal activity has occasionally bleached the felsite to a light color.

Closely associated with the felsite are small breccia dikes. They are composed of angular fragments about .25 inches across. The fragments are dominantly chert, and rarely fine-grained volcanic rocks, set in a matrix of quartz and clay. The origin of these dikes is not clear. Although they appear to be fault breccias, one breccia was found on the north slope of Mescal Peak showing good intrusive contacts against an unbroken limestone. Adjacent to it is a highly sheared and altered rock, consisting of 60 percent sericite, 25 percent quartz, and 15 percent clay. Traces of malachite are visible here and two small shafts have been sunk in the vicinity. Traces of azurite are present on some of the dump material.

(4.3) Dikes:

Dikes of the southern Whetstones are mostly andesitic in composition, occurring exclusively along faults, and are most common adjacent to the main stocks. Rarely moderate shearing is present, indicating post-intrusive adjustment.

The andesite must have been quite fluid, as it appears to have travelled at least 3,000 feet along fault zones, in sheets often less than 5 feet wide. No inclusions are found in them.

There are three major dike rocks—felsite, andesite, and quartz latite porphyry. The felsite dikes, exclusive of the stocks, are found on the north side of Mescal Peak. Where found they are strongly sheared.

The quartz latite porphyry was found at one small outcrop on the north slope of Mescal Peak. It is grayish white with randomly oriented hornblende needles and albite phenocrysts. The minerals present, as determined microscopically, are:

Albite (An_6)	35 percent
Orthoclase	20
Hornblende	25
Quartz	8
Microcline(?)	3
Hypersthene	2
Clay	6
Sericite, opaques	tr

The albite phenocrysts have been extensively altered to clay. No flow structure is present.

The andesite crops out throughout the range, exclusive of the north slope of Mescal Peak. The minerals present, as determined microscopically, are:

Labradorite (An_{54})	58 percent
Quartz	4
Hornblende	20
Hypersthene	5
Calcite	6
Sericite	1
Clay	4
Pyrite	1
Sphene, hematite	tr

Flow structure is exhibited by plagioclase laths and hornblende needles. Quartz eyes are usually surrounded by clay. There appears to be very little alteration of the andesite itself. However, a dike intruded along the core of the anticline has strongly altered the adjacent Epitaph dolomite to a pure siderite. This selvage is about a foot thick, grading rapidly outward to pure dolomite, and is not continuous along the contact for any significant distance.

(4.4) Age:

Most post-Cretaceous tectonic activity in southern Arizona has been attributed to the Laramide orogeny. Although southern Arizona igneous activity has occurred in the Precambrian, and from the Mesozoic to the Quaternary, the igneous rocks of the southern Whetstones are post-Cretaceous and probably middle to late Tertiary. Since their distribution is closely restricted to areas of faulting, and they are generally not faulted, they probably were intruded after the main episode of movement. Middle Tertiary granodiorite and andesite are present in the Tombstone Hills.

5. GYPSUM DEPOSITS

(5.1) General:

The gypsum deposits of the southern Whetstone Mountains represent a single member within the Epitaph dolomite. However, it crops out in three separate areas which will be discussed separately, as their stratigraphy, structure, and location differ.

The northern area lies on the east slope of Mescal Peak, and is somewhat more silty than the central area. The central area, named the high-grade zone, is centrally located in the range and is the largest of the three. The southern area crops out at the south end of the range near the core of the anticline. It is quite thin and impure.

Preliminary examination indicated that the central area was the largest and highest grade of the three. This was subsequently mapped on a scale of 1 inch to 100 feet, using tape and compass methods (Pl. 3). Cross sections of the central and northern areas are shown on Plate 4.

(5.2) Mineralogy:

Gypsum is a monoclinic, hydrous calcium sulphate ($CaSO_4 \cdot 2H_2O$) having 32.5 percent CaO, 46.6 percent SO_3, and 20.9

percent H_2O. It has a hardness of about 2, and a specific gravity of 2.3. Several varieties are common, most of which are present in the southern Whetstones.

The commonest type is alabaster. This is a white to gray, compact, fine-grained variety, with abundant clay stringers. Rock gypsum is also present (Fig. 15). It is coarse grained and massive, and is commonly a dark-gray color. These two types comprise all but trace amounts of the total gypsum present.

There are two crystalline varieties found locally, Satin spar veinlets, about .25 inch thick were noted near the andesite dike. They criss-cross in all directions and were present only in the efflorescent gypsum mantle. The other variety, selenite, was found in a gully in the southern gypsum area. Plates of the individual crystals were about an inch in diameter.

Petrographic work disclosed the presence of anhydrite within the gypsum member. It occurs as irregularly shaped grains, usually veined by secondary gypsum. The gypsum occurs as medium-grained elongate tabular prisms. The remainder was much finer grained. An occasional veinlet of secondary gypsum cuts the primary gypsum also. These secondary veinlets run both parallel and perpendicular to the bedding and are characterized by a double row of gypsum crystals growing perpendicular to the walls. Locally, these veinlets often comprise 20 percent of the rock, thus representing a significant volume increase. Lack of structural evidence for increase in volume indicates the veinlets may be derived from dissolved primary gypsum, thus representing an equal volume reaction.

Other minerals noted in thin section were dolomite rhombs, rare calcite blebs, and rare quartz grains. These occurred only in trace amounts. Occasional clayey bands make up as much as 5 percent of some of the thin sections.

(5.3) Stratigraphy:

(5.3.1) General:

The gypsum of the southern Whetstone Mountains is a series of interbedded gypsum, siltstone, and dolomite beds. The gypsum section was measured on the east slope of Mescal Peak where the beds are relatively undisturbed. The gypsum member was considered as bounded by the upper and lower gypsum beds. In the measured area, the lower gypsum unit is floored by a 140-foot thick siltstone unit, which in turn is underlain by the basal dolomite member of the Epitaph dolomite. In the rest of the southern Whetstones, however, a gypsum bed is found between the siltstone and basal dolomite. This considerably thickens the gypsum member, and is best developed on the east slope of Mescal Peak.

The gypsum normally weathers to a medium-gray color. An efflorescent capping is formed where soil water is drawn to the surface and, during evaporation, deposits any gypsum which has been taken into solution below. There are two types (Fig. 14). The first consists of solid (but porous) tabular blocks of gypsum, often up to 2 feet long. The second type is a soft, powdery, unconsolidated material which is packed around the blocks, and in crevices in the solid gypsum. This efflorescent mantle is normally about 12 to 18 inches deep, and usually conceals the presence of silt beds under it, as the greater porosity of silty beds enables a greater amount of water to evaporate.

(5.3.2) Northern Gypsum Area:

The northern gypsum area has two separate portions divided by a cross fault which offsets the lower contact, then dies out to produce a sharp monoclinal flexure in the upper part of the gypsum. On the north side of this fault is the measured gypsum section, about 300 feet thick (Pl. 4, X-X'), which consists of an upper 150-foot gypsum unit separated by a 15-foot dolomite bed from a 95-foot lower unit. The upper gypsum appears to be capped by a 10-foot dolomitic limestone bed with a final overlying 25-foot gypsum bed.

The section south of the fault is identical in its upper portion; however, the 140-foot underlying siltstone member is considered as part of the gypsum member, as it is in turn underlain by a gypsum bed about 50 feet thick. This increases the thickness of this part of the northern gypsum area to 490 feet. The siltstone member is red for most of its thickness, with gray and buff colors dominating in the lower part.

In the field the northern gypsum area appears to be siltier than the high-grade zone. It weathers to a softer material and is much softer on the fresh surface. It also is a deeper gray color. In the analyses, however, no strong difference was noted in the percent of insoluble residues from either area.

(5.3.3) High-Grade Zone:

The high-grade zone was named on the basis of field evidence. This was primarily the fact that the gypsum here was whiter, harder, more massive, and freer from silty interbeds than either of the other two areas. There appears to be a slight tendency for this zone to become more silty farther to the south.

This zone is also divided by a fault, with somewhat different stratigraphic sections on each side. South of the fault the total thickness is 402 feet, while north of the fault it is 387 feet. This difference is due to changes in thickness of the three gypsum units, presumably due to both depositional and tectonic conditions. The upper gypsum unit increases from 90 feet thick north of the fault, to 140 feet on the south. The central gypsum unit is 74 feet thick north of the fault, and 105 feet thick south of it. Both sides retain the original ratio, however, of the upper bed being thicker than the lower. The gypsum unit below the siltstone unit is 108 feet thick north of the fault, and 27 feet thick south of it. It is best exposed north of the fault where it exhibits a peculiar ropy, semimassive structure, unlike the upper units. A semblance of bedding (flow structure?) remains, however. The significance of this will be discussed under the section on structure.

Two thin dolomitic limestone beds and several silty gypsum beds occur within the zone, but nowhere do they exceed 10 feet in thickness. The remaining beds above the upper gypsum unit consist of dolomite and siltstone north of the fault, and dolomite, siltstone, and gypsum south of the fault. This unit appears to thicken to the south, independently of folding and faulting. The lower siltstone bed remains constant in thickness along strike. Although the distinctive upper contact remains, the lower part of this unit is red with only traces of buff-colored silt.

About 1,200 feet south of the last outcrop of the main beds of the high-grade gypsum zone, thinning has reduced the thickness of the zone to about 130 feet. The section here is half gypsum and siltstone. The siltstone is highly contorted, and fragments of limestone can be found within both the gypsum and siltstone.

(5.3.4) Southern Gypsum Area:

The southern gypsum area crops out near the core of the anticline at the south end of the range. It is of limited length and thickness, and cannot be traced farther south than the axis of the anticline. To the north within the poorly defined syncline only the siltstone remains.

The total section here is about 230 feet thick and retains vague similarities to the other areas farther north. Two general gypsiferous units can be defined, separated by a 9-foot dolomite bed. The upper unit consists of a lower massive gypsum bed 45 feet thick and an overlying red siltstone bed with interlaminated gypsum and dolomite beds.

The lower unit consists of a basal 35-foot buff siltstone bed, followed by a 40-foot gypsum bed, then a 47-foot red sandy siltstone bed, and an upper 30-foot massive gypsum bed. The increasingly silty nature of this area indicates it was possibly a near-shore facies of the beds seen farther north.

(5.4) Structure:

(5.4.1) Northern Gypsum Area:

The plasticity of the gypsum is illustrated by the gypsum areas of the southern Whetstones. The northern gypsum area shows this most clearly where it is cut into two separate units by a fault. As seen on the geologic map (Pl. 1) this fault does not continue upward through the area; although the fault is clearly evident in its offset of the base of the gypsum, it is reflected at the top of the horizon as a sharp monoclinal flexure. Offset along the vertical fault is approximately 140 feet, with the south side downthrown.

North of this fault the gypsum is underlain by a thick siltstone unit (Pl. 4, X-X') which is considered to represent the true section, as the member here is undisturbed. South of the fault the siltstone is floored by a thin gypsum bed. A similar bed is present in the high-grade zone. This subsiltstone gypsum bed is believed to have been squeezed into its present position during the period of greatest tectonic activity, when pressures enclosing the gypsum were most intense. Thus this lower bed is in effect an intrusive sill whose mechanics of intrusion were analogous to those of an igneous sill. Since the fault sharply divides the two units of the northern gypsum area, it is believed that it preceded the intrusion of the subsiltstone gypsum.

This unit is totally absent north of the fault, even within 20 feet of the break. Possibly, a central area of greatest intensity near the Northwest fault squeezed the entire gypsum member, and, seeking an area of weakness the gypsum was intruded along the siltstone-dolomite contact. Just why this contact was chosen is not known, but it appears that a thickening of the original units away from the area of greatest pressure might have been simpler, unless the pressure applied was local in character.

The south end of the northern gypsum area is cut off by the major fault which separates it from the central high-grade zone. The contact here is obscured under alluvial cover.

(5.4.2) High-Grade Zone:

The high-grade gypsum zone has a direct structural relation to the northern area. Its north end is terminated by the Northwest fault and several smaller faults which greatly complicate the structure.

A small andesite dike cuts through the zone in this area. Its dips indicate a pinchout at depth, however, this may not be true. It may represent a fault cutting the gypsum and underlying rock, but no field evidence to prove this was found. The manner of intrusion into the gypsum is more difficult to resolve, as fractures in the gypsum are not evident. Possibly rising gases coupled with heat and pressure softened the gypsum above the dike, allowing it to flow easily to one side.

At the north end of this zone, the gypsum underlying the siltstone is believed to be quite thick (Pl. 4, C-C'). To the south this same unit becomes considerably thinner (Pl. 4, B-B', A-A'), but it appears to be continuous for the entire mapped length of this zone. Another notable feature of this particular gypsum bed is its massive, ropy appearance. It appears to have been strongly squeezed and contorted. A beddinglike appearance is retained, however, this is probably flow structure.

A strong fault cuts this zone into two separate units. Relations to this fault again illustrate the peculiar nature of gypsum during tectonic activity. At the base of the gypsum, the south side of the fault is clearly downfaulted, as are most of the faults in the range. This movement is especially evident in the sediments below the gypsum. However, the upper dolomite unit of the Epitaph on the north side of the fault has slumped downward into the gypsum. The result is a marked thinning of the gypsum just north of the fault. Several small faults are present in the gypsum; however, their displacement has been slight. Since this fault cuts the subsiltstone gypsum bed it is believed to be post-squeezing.

The source of the gypsum for the bed below the siltstone unit must have been from somewhere within the gypsum member, and was probably near the area of greatest pressure. This area may have been near the Northwest fault. Two factors indicate this. First, in the northern area this subsiltstone gypsum bed appears to have been squeezed into its present position toward the north where it buttressed against a fault. Second, in the high-grade zone the bed is thickest near the north end where the gypsum member is cut by the Northwest fault and thins considerably toward the south. The pressure needed to mobilize the gypsum may have been provided either by movement on the Northwest fault, or by the small plug which is present along the fault.

In any intrusion inclusions of surrounding wall rock may be expected; although no angular blocks are found in the gypsum sill, there are several discontinuous red siltstone bands. They may be present but are obscured by the efflorescent mantle and gravel. However, the gypsum may have been emplaced gently, only slightly disturbing the surrounding rocks. In this case few inclusions would be expected. Also, the overlying red siltstone is quite incompetent and would be expected to accommodate itself to the advancing sill by bending, rather than breaking.

Griggs (1940) performed some interesting experiments on flow in rocks, with special emphasis on gypsum. Over short time intervals he found that simple pressure will produce an elastic deformation with slight creep before fracturing. Over a long period of time, purely elastic flow occurred. He also found temperature to be a relatively unimportant factor.

However, the effect of the presence of solutions was striking (Fig. 4). When surrounded by a small amount of water the creep rate was greatly accelerated, and it was proven that the increased creep rate was not due to the action of water as a lubricant between grains. Griggs suspected that creep, or flow, might occur by solution at points of greatest stress, and deposition at points of least pressure. More rapid flow in an HCl solution (more powerful solvent than water) was observed, illustrating this point.

This experiment appears to shed some light on the mechanics of flow of the lower gypsum bed in the southern Whetstones. Pressure must have been present, both to initiate solution and redeposition, and to control the direction of flow. There was probably a minimum of 1,200 feet of overlying rock which would have exerted an approximate pressure of 1,320 pounds per square inch—more than enough to initiate creep phenomena. The other necessary factor is the presence of a solvent.

Griggs experiments were made on gypsum, but the often assumed form of gypsum at depth is as anhydrite. However, the source of water presents a problem. Experiments show that simple alteration of gypsum to anhydrite with resulting freeing of water does not occur under pressure—in fact, gypsum is the stable phase. This is because the total volume of anhydrite plus water is 9 percent greater than an equivalent weight of gypsum. Avenues for escape of the water in a compact matrix of gypsum do not exist. Therefore, unless gypsum is altered during deposition to anhydrite at the surface by a heat increase, the gypsum remains buried in a metastable state.

It should be noted that gypsum is significantly more soluble than anhydrite. Since a great amount of flow is exhibited by the gypsum, it is logical to expect an easily soluble material was present. The metastable nature of the gypsum may have contributed to an increased solubility. The water for solution of the gypsum during flow may have been present originally as trapped interstitial water during the deposition of the gypsum. Anhydrite may have been less susceptible to flow due to its greater stability, greater insolubility, and small amount of water available for its solution.

Undoubtedly there was anhydrite present in the gypsum during flow. However, the intrusive gypsum sill was believed to have been emplaced primarily as gypsum. Further evidence for the presence of gypsum at depth will be given below.

(5.4.3) Southern Gypsum Area:

The southern gypsum area lies along the flank of an anticline. It is only exposed over a short distance and shows nothing of any structural interest. To the north it pinches out in the trough of a poorly defined syncline.

(5.5) Origin of Gypsum:

The origin of gypsum deposits has never been the subject of a concentrated study, but many controversies exist with regard to it. Some ideas (Withington and Jaster, 1960) favor deposition of primary gypsum, then alteration under pressure to anhydrite, then hydration back to gypsum. Other deposits seem to indicate that anhydrite was the primary mineral, later being hydrated to gypsum. Varied structural and petrographic criteria are used to illustrate these points. It is generally agreed that the deposits are a result of high evaporation in restricted basins. This causes an inflow of water and a concentration of salts.

It appears in the southern Whetstones that there was very little alteration of gypsum to anhydrite. Most of the buried gypsum appears to have remained as gypsum until again exposed at the surface by erosion. Four factors considered important in determining the origin are stratigraphic, structural, chemical, and petrographic.

An analysis of the stratigraphy of the gypsum member shows that mildly unstable, transitional-continental environments may have existed. The series of red siltstones and dolomite beds within the gypsum indicate that the environment was semicontinental with possible minor restricted marine invasions. It is difficult to rationalize the interbedded dolomites in the gypsum as being due to periodic destruction of off-shore bars and the subsequent deposition of a fresher water sediment. If the environment was forceful enough to have developed and destroyed off-shore bars, then dolomite—a quiet-water rock—would never have been deposited. Probably the dolomites are of an evaporite type. The southern gypsum area, with the high percentage of siltstone, probably remained as a near-shore facies of the evaporite lagoon throughout deposition of the gypsum. Krumbein (1951) has emphasized that no climatic restrictions are necessary for the formation of evaporites, as they grade laterally into normal marine sections. The tectonic setting is believed to be the most important. He notes that the

Permian was the first period when shelf-type evaporites occurred with red beds.

Structural features of the gypsum member have already been discussed. One structural feature common to many gypsum deposits is conspicuously absent—that is the contortion and the intra-member buckling which indicate that swelling has occurred. This is usually believed to represent a volume expansion due to hydration of anhydrite to gypsum. The only contorted bed in the southern Whetstones is the subsiltstone intrusive sill. It is significant to note that the sill was probably intruded as gypsum for reasons discussed above. It does not represent contortion due to the anhydrite-gypsum transition. Drilling in the gypsum of the Empire Mountains, about 30 miles northwest, to depths of 500 feet has shown that gypsum persists below that depth. No evidence is present there to indicate volume expansion (Lacy, 1962, personal communication).

The chemical factors are varied and difficult to correlate with field observations. Posnjak (1940) discussed the deposition of gypsum from sea water at $30^{\circ}C$. He found that gypsum is the stable phase up to a concentration of 4.8 times the normal amount of sea salts. Above this concentration anhydrite is the stable phase. Figure 5 illustrates these relationships; the dashed line represents the increase of concentration of $CaSO_4$ as evaporation of sea water occurs, and intersects the gypsum solubility curve at 3.35 times the normal salinity of sea

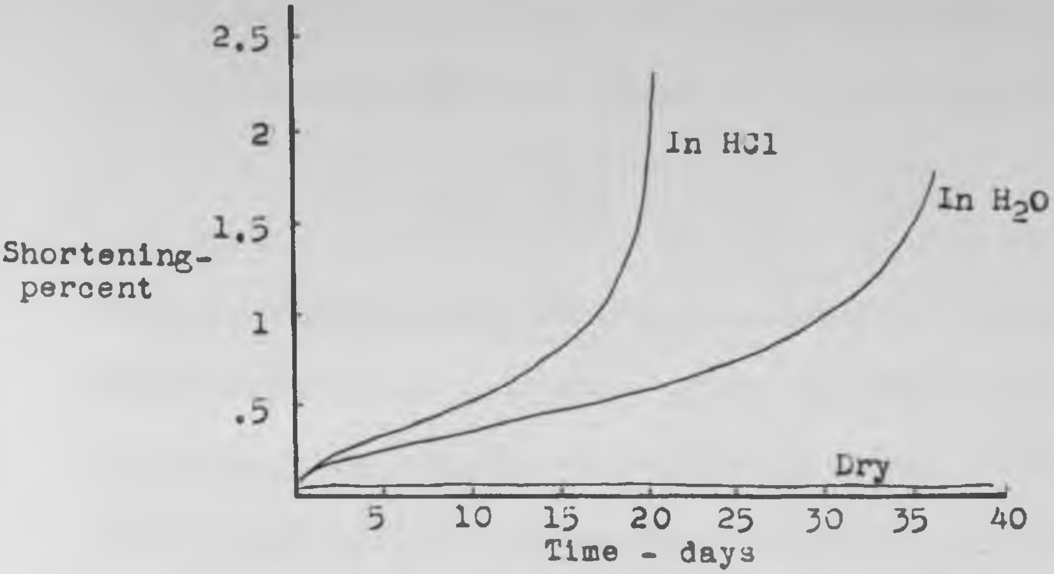

FIGURE 4:
Creep of alabaster in different chemical environments (After Griggs, 1940)

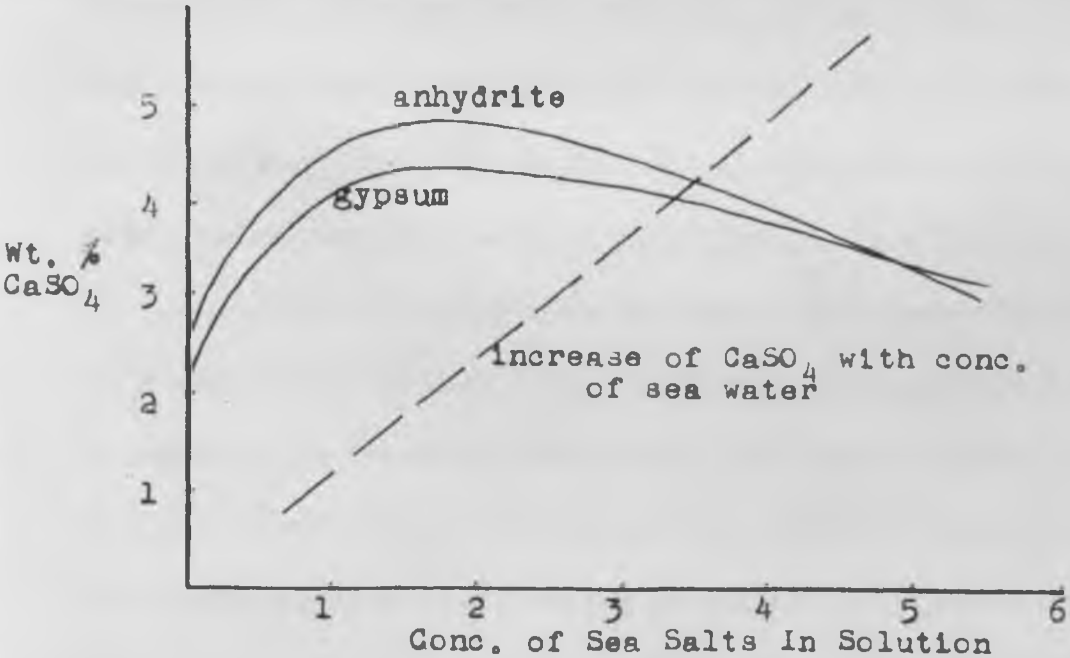

FIGURE 5:
Solubility curves for gypsum and anhydrite in sea water (After Posnjak, 1940)

water. This is the point at which gypsum precipitates.

Posnjak (1938) showed that the transition point of gypsum to anhydrite is about $42^{o}C$. The transition is shown by the reaction:

$$CaSO_4 \cdot 2H_2O = CaSO_4 + 2H_2O$$

Thus above 42^{o} anhydrite will be deposited at a concentration of 3.35 times normal salinity. However, gypsum is, when in contact with a saturated calcium sulphate solution between 42^{o} and $97.5^{o}C$, a metastable system, and, if anhydrite nuclei are not present, may persist indefinitely.

Douglas and Goodman (1957) pointed out that the bottoms of very saline lagoons are warmer than the surfaces. This is due to the sun's radiant heat passing through the clear water at the surface and heating up the more saline bottom layers which have a lower specific heat. Actual examples of the temperature gradient are given. It was not unusual for the waters at the bottoms of the lagoons to reach temperatures as great as $70^{o}C$. In these environments anhydrite would be deposited as the stable calcium sulphate phase. They noted also that an influx of silty water would absorb the radiant energy of the sun, and prevent a heating up of the bottom layers. It would cool the bottom layers, and if present over a long time, would permit a conversion of anhydrite to gypsum.

It has already been noted that there is a certain amount of silt in the gypsum. It is both disseminated and in silty beds about a foot thick. Considerable quantities of coarser silt were evidently present along the margin of the lagoon. According to Douglas and Goodman (1957), an increase in gypsum content should be reflected by an increase in silt content. However, the reverse was found to be true in the gypsum member of the Epitaph dolomite. That is, as the gypsum content increases the silt (or insoluble) content decreases. Figure 6 illustrates this relationship.

This relationship may be due to inflow within the depositional basin. An increase in silt content probably indicates a heavy influx of fresh water. As this fresh water entered the basin, it would have reduced the concentration of calcium sulphate and less gypsum would have precipitated.

The good correlation of points in Figure 6 emphasizes another point. This indicates that most of the gypsum is of primary origin. Alteration of gypsum from anhydrite would have made the curve much more irregular, as anhydrite shows no relation to silt content (Fig. 6).

Thus it appears that the influence of silt as an insulating blanket was nonexistent. Whether this is true for other deposits is not known. The idea of silt acting as an insulator was proposed by Douglas and Goodman (1957) to explain certain observed sequences. This hypothesis does not apply to the gypsum of the southern Whetstones and may indicate low salinity.

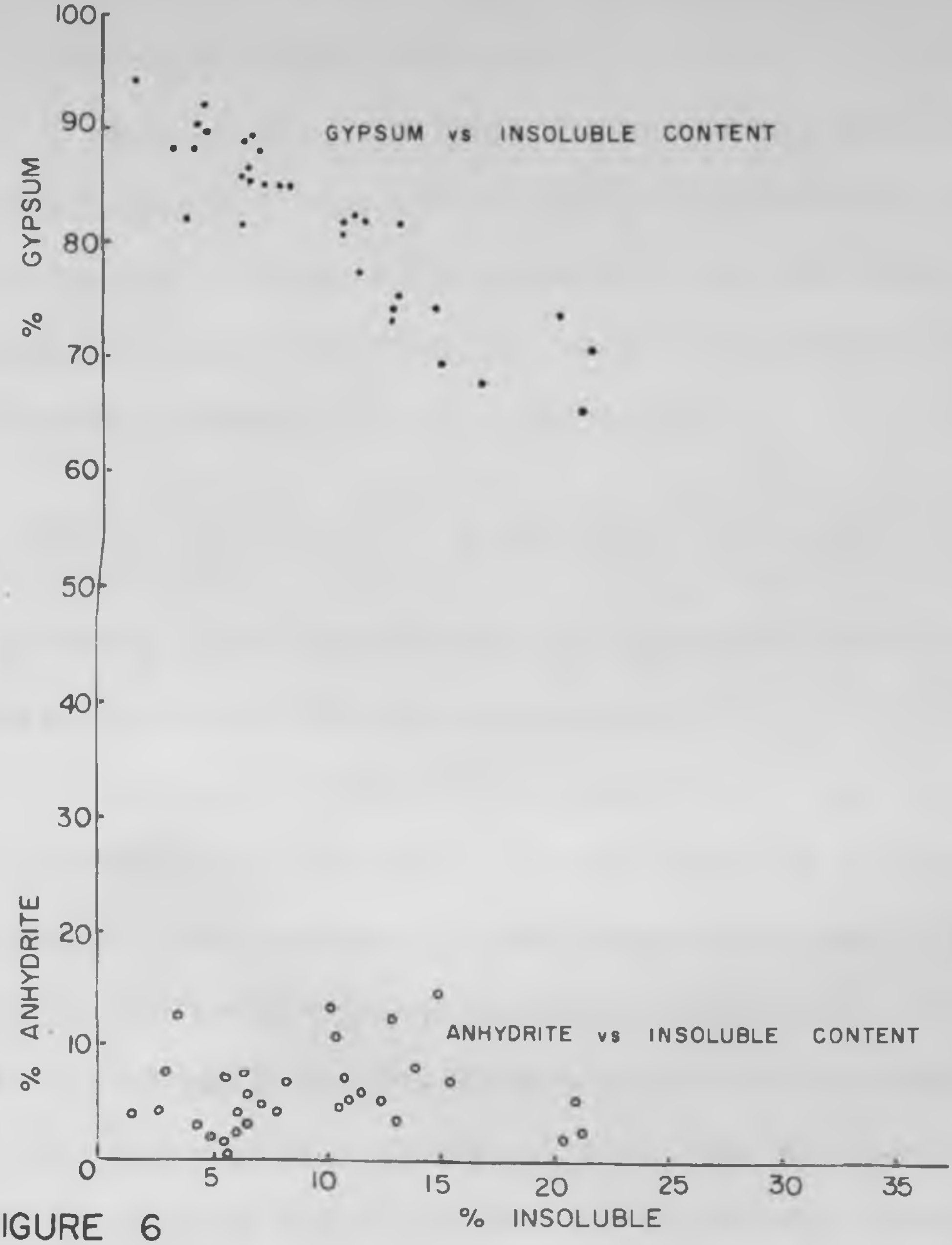

FIGURE 6

GRAPH SHOWING THE RELATION OF GYPSUM AND ANHYDRITE TO INSOLUBLE CONTENT IN THE NORTH GYPSUM AREA AND HIGH GRADE ZONE

The percentages of gypsum and anhydrite show a weak but general correlation, in that an increase in gypsum is usually reflected by a decrease in the anhydrite content.

Although there is no relation between anhydrite and silt, the anhydrite content is invariably high near the interbedded dolomitic limestone beds. It has been suspected that the action of magnesium sulphate solutions on limestone may result in the formation of calcium sulphate and dolomite according to the reaction:

$$MgSO_4 + 2CaCO_3 \xrightarrow[CO_2]{H_2O} Ca\,Mg(CO_3)_2 + CaSO_4 \text{ (anhydrite)}$$

Bundy (1956) showed thermodynamically that at 25°C and 1 atmosphere, the reaction goes in the indicated direction.

The source of magnesium could easily have been from the water of the depositional basin just prior to deposition of the dolomite. At this time the magnesium, although highly concentrated, would still be in solution and able to enter into the above reaction.

Petrographic studies disclosed several interesting facts. Both primary gypsum and anhydrite are present. They are easily distinguished from the secondary minerals by their high percentage of detrital inclusions. The secondary products are consistently nearly 100 percent pure.

Where juxtaposed, the gypsum clearly replaces the anhydrite. This indicates that anhydrite may have been originally formed but was

TABLE 1
GYPSUM ANALYSES

Sample No.	Channel length (feet)	Percent insoluble	Percent gypsum	Percent Ca remaining (as $CaSO_4$)	Percent loss at 1,000°C	Total Ca percent (as $CaSO_4$)	Total insol., gypsum, and remaining Ca (as $CaSO_4$)
1	3	10.71	77.39	11.09	4.95	72.28	99.2
2	3	11.11	81.78	5.33	2.56	69.99	98.2
3	3	1.33	93.96	4.59	1.50	78.88	99.9
4	3	10.82	82.40	3.87	2.11	69.02	97.1
5	3	5.92	88.76	3.50	1.85	73.68	98.2
6	3	4.82	89.95	4.33	0.84	75.45	99.1
7	3	4.51	90.19	2.64	1.87	73.95	97.3
8	3	4.35	87.85	5.90	3.04	75.36	98.1
9	3	7.71	85.36	7.58	2.33	75.07	100.6
10	20	10.31	82.59	11.99	2.83	77.29	104.9
11	25	6.14	85.27	8.71	3.69	76.13	100.1
12	20	3.65	82.64	13.71	6.15	79.05	100.0
13	20	14.75	74.14	9.27	4.18	67.89	98.2
14	20	21.60	65.83	5.82	4.88	57.87	93.2
15	20	20.38	72.18	2.11	2.52	59.18	94.7
16	23	13.12	81.06	3.53	2.01	67.62	97.7
17	21	5.98	86.70	6.56	2.93	75.11	99.2
18	11	4.77	92.15	3.26	1.83	76.12	100.2
19	24	6.3	89.3	3.7	2.1	74.2	99.2
20	21	6.6	88.2	3.4	2.4	73.2	98.2
21	23	7.8	85.2	4.2	2.5	71.5	97.1
22	23	13.1	75.6	7.9	4.0	67.7	96.6
23	7	21.7	70.3	3.6	3.5	59.2	95.6
24	20	12.8	74.0	6.0	5.7	64.5	92.8
25	21	14.9	69.2	16.0	7.11	70.7	100.1
26	11	7.4	85.1	4.9	2.6	72.2	97.4
27	20	5.8	82.6	7.5	4.2	72.8	95.9
28	20	6.0	86.0	0.89	3.3	68.9	92.9
29	20	3.4	87.9	8.0	3.4	77.5	99.3
30	20	13.0	73.6	11.5	6.0	69.7	98.1
31	16	10.5	81.7	5.8	3.5	70.4	98.0
32	16	15.8	67.3	8.4	7.3	61.6	91.4

later replaced by gypsum, perhaps due to greater stability of gypsum. This probably occurred before much burial, as both minerals have considerable amounts of detrital inclusions. Inclusions of anhydrite in clear gypsum grains indicate that late secondary hydration of anhydrite has occurred. Conley and Bundy (1958) state that activating cations in saline ground-water solutions speed up this very slow reaction. Alkali sulphates are believed to be the most active. This probably has not taken place in large proportions.

The absence of sodium chloride was reasonably definitely established by thin-section study. As salt is often deposited with gypsum in a sea environment, it may be inferred that the gypsum may have been deposited in an inland lake.

The secondary gypsum present occurs both as cross-cutting veinlets and long tabular crystals. These features cut all other structures present, and are invariably free from any inclusions. The grains which they replace are randomly oriented for the most part, indicating burial may never have been extreme.

The geologic history of the gypsum member is believed to be as follows:

(1) A restricted inland-lake environment was developed and salts were concentrated by evaporation in a transitional continental environment.

(2) Gypsum was precipitated during periods of low silt influx.

Concurrent with concentration of magnesium, some anhydrite was formed.

(3) The flat-lying sedimentary sequence was buried under increasing loads, with resulting temperature and pressure rises. The gypsum was at this point in a metastable state.

(4) A strong focus of pressure caused intrusion of the gypsum sill by the mechanism of solution redeposition.

(5) Tilting and erosion permitted water of hydration to escape, forming slight amounts of anhydrite at shallow to moderate depths. The anhydrite was then hydrated at the surface to form gypsum.

The writer admits the evidence is not irrevocable for the above stated conditions. The number of variables in the seemingly simple gypsum-anhydrite transition are many. Much further research must be carried out before the many problems may be satisfactorily understood.

(5. 6) Economic Geology:

The gypsum deposits of the southern Whetstones are currently held by the Sunrise Mining Co. The high-grade zone is most easily reached by pickup truck from the east side of the range near Sands

Ranch, while the northern gypsum area is more accessible from the west side.

The economic deposits are confined to the northern gypsum area and the high-grade zone. The southern gypsum area has too much silt to be of much value, however, it would be quite suitable as a local source of agricultural gypsum.

The tonnage for each gypsum area was calculated by measuring blocks and calculating the tonnage of each individual block. Tonnage was also calculated as to whether it was positive, probable, or possible ore. Table 2 has the tonnage and grade calculations listed. The minable gypsum was considered to extend to a depth of 200 feet. On the basis of several specific gravity determinations, an average specific gravity for the gypsum deposits of 2.20 was calculated. Analyses of the gypsum are given in Table 1.

Sampling was carried out on the gypsum over a period of a month. Sample channels were prepared by first excavating, then sweeping away all efflorescent gypsum present. Sample channels were then cut using a hammer and moil. Samples 1-9 were taken from a channel about 6 inches wide and 2.5 inches deep. This was done to detect any rapid vertical changes in grade. Samples 10-32 were taken from a channel an inch wide and an inch deep. The samples were then weighted according to their length and averaged together to get a composite grade for the entire gypsum member. The grade of the gypsum varies only

TABLE 2
TONNAGE-GRADE CALCULATIONS FOR THE NORTHERN GYPSUM AREA AND HIGH-GRADE GYPSUM ZONE

High-grade zone	Tons	Gypsum (percent)	Anhydrite (percent)	Insoluble (percent)
Upper unit	4,846,000	79.3	4.4	10.5
Central unit	3,468,000	76.5	7.8	12.7
Lower unit	2,546,500	84.5	3.8	9.8
Average grade of zone		80.2	5.3	11.0
Total tonnage	10,860,500			

Tons of:

Positive ore* = 7,210,600
Probable ore** = 2,030,000
Possible ore*** = 1,619,900

Northern gypsum area	Tons	Gypsum (percent)	Anhydrite (percent)	Insoluble (percent)
Average grade		80.2	7.0	8.8
Total tonnage	8,765,200			

*Positive - presence of gypsum established beyond doubt, sampled.

**Probable - reasonable geologic projection indicates presence of gypsum.

***Possible - in areas of complex structure, no outcrops, tonnage based on assumed geologic continuity.

normal to the bedding; depth and lateral variations within a single channel were not considered important, and these factors were neglected in calculating the grade of any one sample. A study of the analyses, however, shows a much higher grade average for the first nine samples, where a greater surface area relative to the depth of the sample was collected. This may or may not be a coincidence. Lateral variations in grade were determined by comparison of different channels and were not significant. No drilling has been done, however, the grade has been projected to a reasonable depth of 200 feet.

In the high-grade zone, about 10,860,500 tons of 80.2 percent gypsum is present. The average grades for each of the three gypsum units are given in Table 2. It can be seen that the upper unit has the highest tonnage, while the intrusive sill has the highest grade. Approximately 8,765,200 tons of 80.2 percent gypsum is present in the northern gypsum area. No breakdown by units was made there. Although the insoluble content does not show it, the gypsum here is more silty and clayey than that in the high-grade zone.

Before mining of the gypsum could commence, all overburden would have to be stripped. This is mostly a gravel cover, although considerable efflorescent gypsum may be present. If it could be mined separately from the gravel cover, a moderate tonnage of relatively pure gypsum could be obtained. This would require very selective and careful mining methods. The gravel mantle locally may be as deep as

20 feet.

Locally the slopes have 65-70 percent grades, making stripping operations difficult. However, after the slope had been cleaned the gypsum could be mined by open-pit methods. The overlying upper Epitaph dolomite member is fairly competent, and could hold a reasonably steep slope without slumping. When the upper gypsum unit has been mined to a depth of 200 feet downdip, this back would average about 250 feet high. Jointed and faulted areas would have to be constantly watched as potential slide areas.

Presently the location of the deposit with respect to main rail haulage routes and calcining plants is unfavorable. However, if a direct route to Benson, Ariz., is constructed, a plant might be built there to treat the gypsum. As the average grade of the deposit is presently too low to be used in the manufacture of wallboard, selective mining in certain areas might be necessary to produce a marketable product. The grade of the gypsum is more than sufficient to be used as a retarder in cement. If the insoluble content could be removed, then the average grade would be raised about 9 percent—near that of wallboard quality.

6. GEOLOGIC HISTORY

The geologic environment in the southern Whetstone region during upper Pennsylvanian and Permian times may have approximated that of a shallow, semistable marine shelf area. During this period, frequent oscillations of Permian seas alternately deposited siltstones, sandstones, and limestones. The Scherrer formation probably represented a nearly complete withdrawal to a coastal or continental environment, as is evidenced by the strong crossbedding. The gypsum deposits within the Epitaph indicate more restricted geographic and geologic conditions, but were probably formed in a lacustrine environment.

Following the Permian, uplift in Triassic and/or Jurassic times occurred, possibly setting up certain stress patterns in the rocks, along which later breaking was to occur. During Cretaceous time, mostly clastic sediments were deposited over a wide area. These may be marine, however, proof of this has yet to be shown. Following this Cretaceous deposition, and probably overlapping it, the Laramide orogeny began developing. This was accompanied by strong folding, faulting, and intrusive activity. During this time the Whetstone region was tilted to the west, and the southern Whetstone Mountains were separated from the main Whetstone mass. During and after this separation, the area of the Mustang Mountains were thrust westward. The flat-lying nature of the rocks in the Mustangs indicates this thrust may have developed before much tilting occurred.

It appears that vertical and strike-slip movement were simultaneous, although the latter may have continued over a longer interval. This is evidenced by the presence of sheared igneous rocks in the vicinity of the major fault at the north end of the range, and massive unbroken dikes elsewhere. After the main period of faulting, these areas of weakness were utilized for the intrusion of a number of small volcanic plugs and dikes. Late-stage hydrothermal activity locally altered both igneous and surrounding rocks. The volcanic plugs present in the southern Whetstones may have been the source of the extensive volcanics of the Mustang Mountains.

Dating of the faulting and intrusive activity is difficult. Possibly, faulting may have ended by middle Tertiary times. The intrusive rocks, being mostly post-faulting, would then be middle to late Tertiary in age.

Following intrusive activity, erosion developed the present landscape. Coarse gravels were deposited, and later eroded on the slopes of the range. Gullying exhibits moderate structural control.

FIGURE 7

East front of the southern Whetstone Mountains, looking west. Mescal Peak in right background.

FIGURE 8

East slope of Mescal Peak. Northwest fault seen on south slope. Northern gypsum area forms white beds at base of slope. Reddish beds are Scherrer formation. Monoclinal flexure in upper Epitaph dolomite visible just below Mescal Peak.

FIGURE 9

Thrust fault within the Colina limestone shown by discordance in dips in center of picture. More massive beds above thrust mark top of Colina.

FIGURE 10

Typical minor fault, showing upper sandstone member of Scherrer formation dropped down against the central dolomite member.

FIGURE 11

Fault zone above the gypsum member. Brown bands are aragonite crystals, forming a somewhat colloform texture. Aragonite crystals approximately parallel the hammer handle.

FIGURE 12

Portion of the pebble breccia on the north slope of Mescal Peak. Picture shows suspected intrusive part of feature.

FIGURE 13

Limestone conglomerate unit within the Earp formation. Surface forms bedding plane.

FIGURE 14

Probable fault breccia found in southwestern part of range, on west slope of Hill 4963. Boulders probably Concha limestone.

FIGURE 15

Efflorescent slope mantling high-grade gypsum zone.

FIGURE 16

Massive rock gypsum within the high-grade zone. Brownish-gray band at bottom of picture is silty bed.

7. APPENDIX I

Section of Scherrer and lower part of Concha formations of Snyder Hill group and Earp, Colina, and Epitaph formations of Naco group west of Sands Ranch in the southern Whetstone Mountains. Section measured by Jones and Bacheller of the Shell Oil Co. Base of section on eastern slope of ridge in the SW-1/4 sec. 33 and top of section on top of peak in the SE-1/4 sec. 32, T. 19 S., R. 19 E. (Mustang Mountains Quadrangle.) Taken from Bryant, 1955.

Erosion surface:
Permian and Permian-Pennsylvanian—(total thickness 3,380 feet):
Synder Hill group:
Concha limestone:

Unit No.	Description	Thickness in feet
15	Limestone, gray, mottled light and dark, weathers mottled buff and red; thick-bedded; forms cliff. Fossiliferous; brachiopods and echinoid spines.	170
14	Limestone, dolomitic: gray; thick-bedded. Fossiliferous; brachiopods, mostly productids.	90
	Total thickness Concha limestone	260
	Scherrer formation:	
13	Sandstone, quartzitic: buff and red, medium- to fine-grained.	80
12	Dolomite: light-gray, thick-bedded; locally vuggy. Fossiliferous; brachiopods, bryozoans, and <u>Permocidaris</u> spines.	130
11	Orthoquartzite and quartzite sandstone: rusty to light-orange-brown, coarse-grained.	200

Unit No.	Description	Thickness in feet
10	Dolomite, silty: gray; medium- to thick-bedded.	20
9	Sandstone, silty, and siltstone, sandy: red; thin- to medium-bedded. Few dolomite beds.	50
	Total thickness Scherrer formation	480
	Total thickness Snyder Hill group	740
	Naco group:	
	Epitaph dolomite:	
8	Dolomite and limestone: gray, more dolomitic toward top. Vuggy with large vugs, especially near middle and at top. Fossiliferous; echinoid spines and eucomphalids lower part.	310
7	Gypsum with siltstone and limestone interbeds: gypsum, pure and white to silty and gray; siltstone, gypsiferous and gray to sandy and buff; limestone, gray and partly dolomitic; thin- to medium-bedded.	310
6	Siltstone: gray and buff in lower part, red and reddish-brown in upper part; thin- to medium-bedded, with few thin brown sandstone interbeds.	140
5	Dolomite and covered intervals: light-gray to nearly black; argillaceous, especially in upper part; thin- to medium-bedded. Covered intervals mostly varicolored siltstones. Forms wide saddle east of high peak.	480
	Total thickness Epitaph dolomite	1,240
	Colina limestone:	
4	Limestone: medium- to dark-gray, partly dolomitic and silty; mostly thick-bedded to massive; variably cherty, forms high cliff of eastern ridge. Stylolites in upper part.	420

Unit No.	Description	Thickness in feet
3	Limestone, dolomitic: medium- to dark-gray, medium-bedded, interbedded with gray and red siltstone and sandstone, especially in upper part. Fossiliferous lower part; gastropods and brachiopods.	280
	Total thickness Colina limestone	700
	Earp formation:	
2	Siltstone and sandstone: red and brown. Limestone conglomerate. One hundred and forty feet above base.	380
1	Partly concealed: red and gray siltstone and sandstone interbedded with thin to medium beds of gray limestone. Limestone conglomerate. One hundred and twenty feet above base. Fusulinids of Virgil age 160, 230, and 315 feet above base.	320
	Total thickness Earp formation	700
	Total thickness Naco group	2,640

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PLATE I

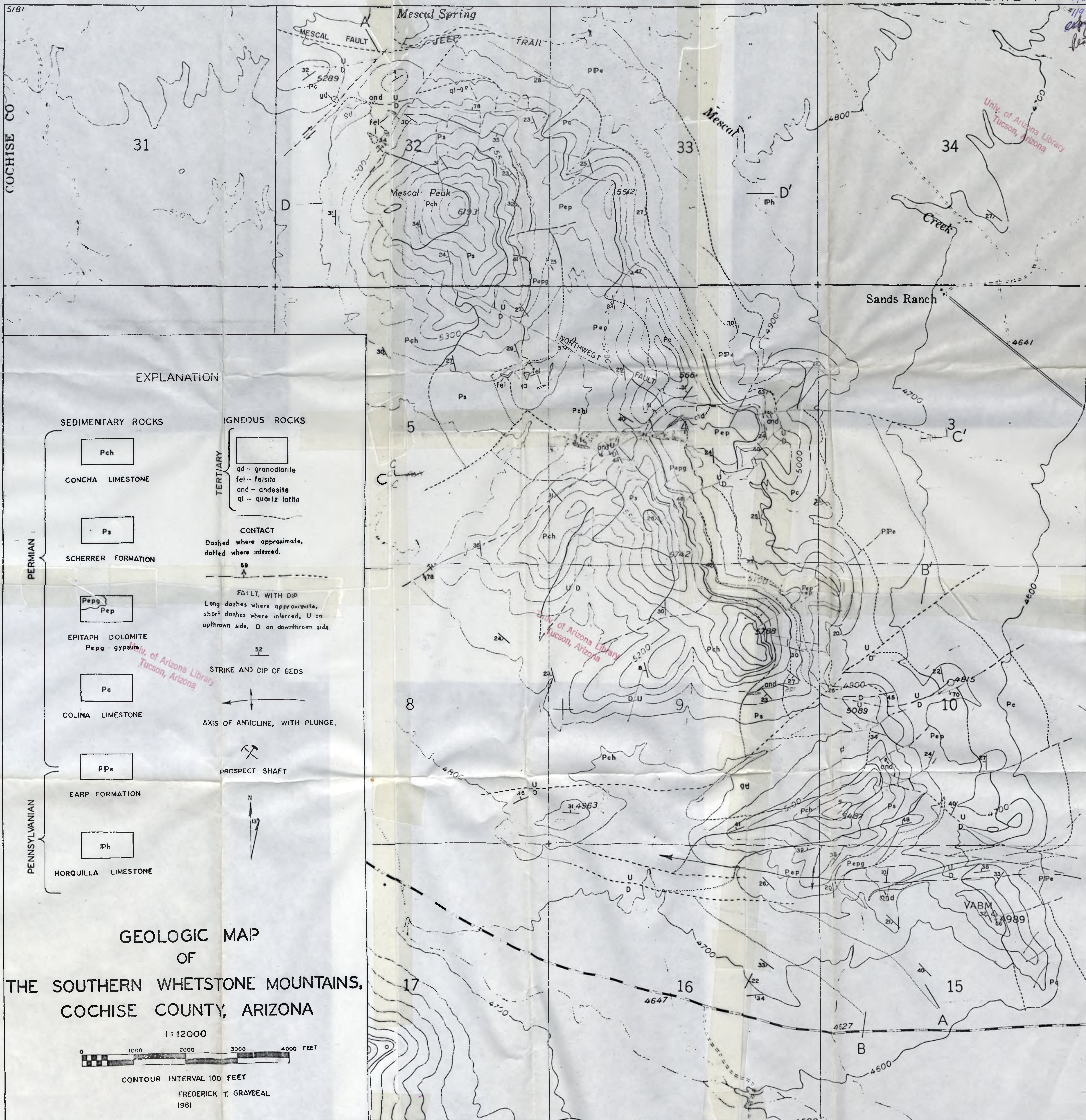
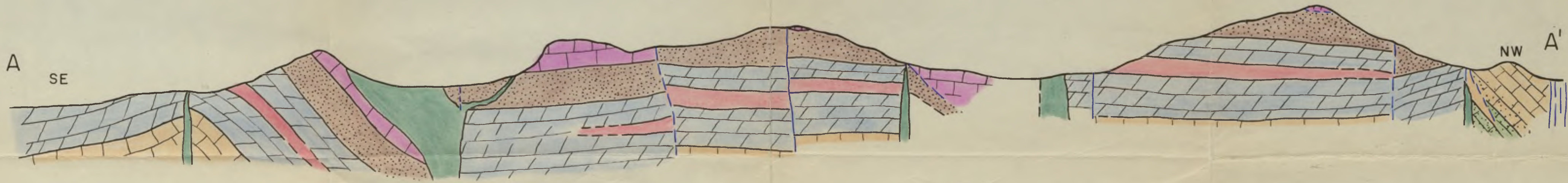
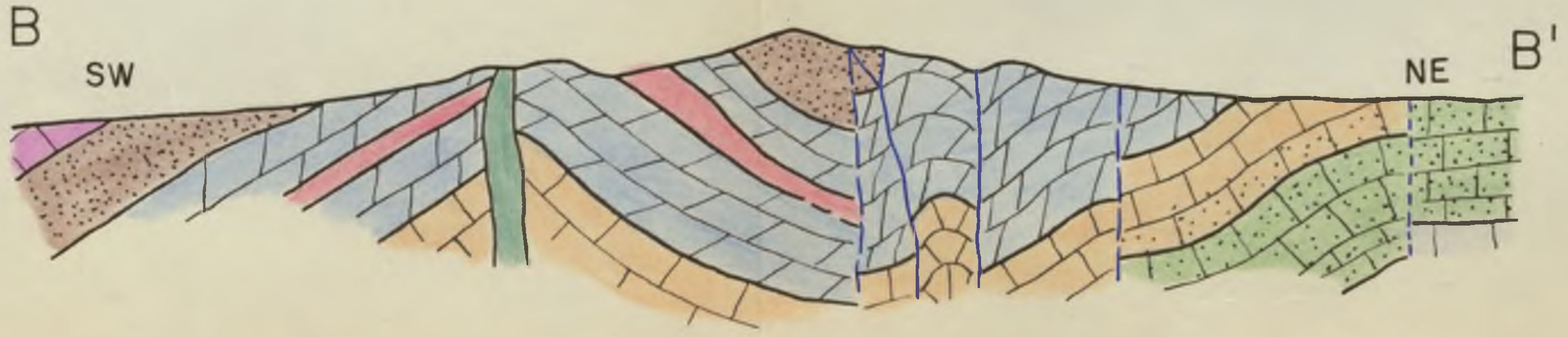
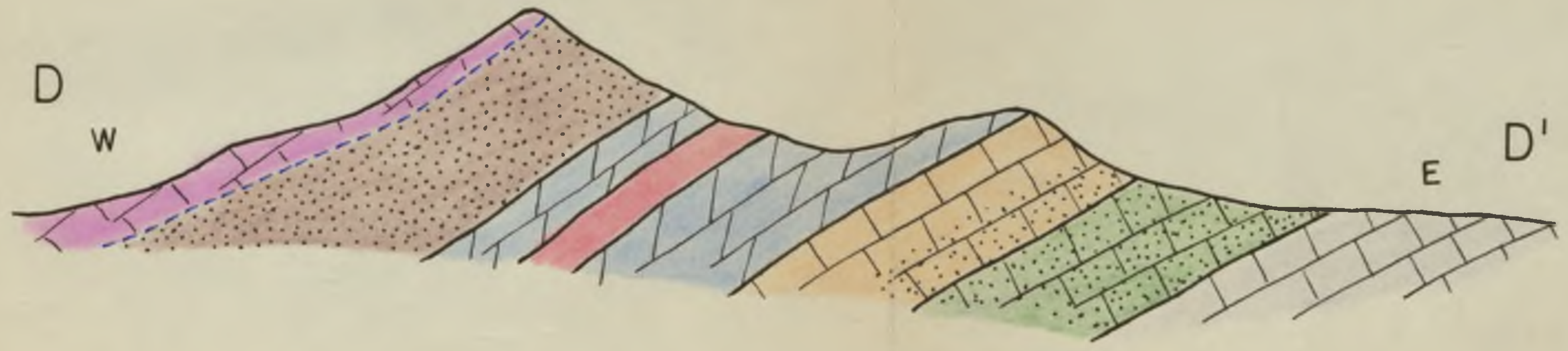
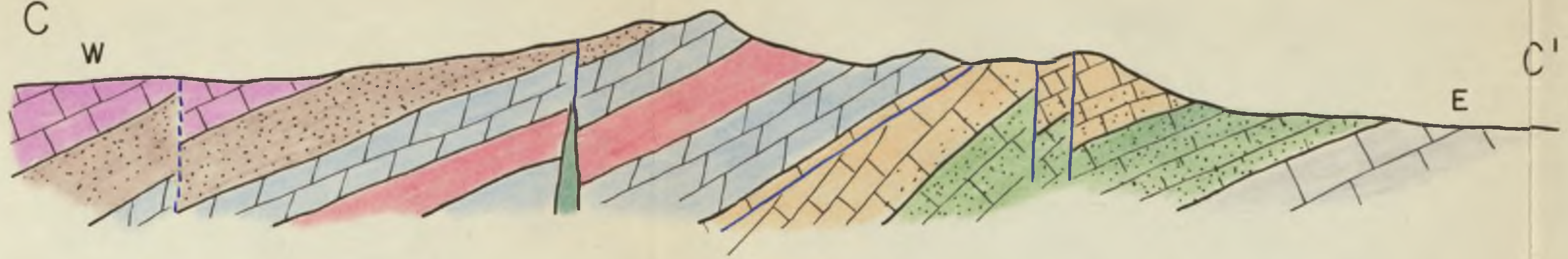

Mescal Spring
MESCAL FAULT
JEEP TRAIL
COCHISE CO
Mescal Peak
6193
5512
Mescal
Creek
Sands Ranch
NORTHWEST FAULT
5742
5788
5089
4815
4963
5487
VABM
4989
4647
4627
4641
31
32
33
34
5
4
3
8
9
10
17
16
15
A
D
D'
C
C'
B'
B
EXPLANATION
SEDIMENTARY ROCKS
PERMIAN
Pch
CONCHA LIMESTONE
Ps
SCHERRER FORMATION
Pepg
Pep
EPITAPH DOLOMITE
Pepg - gypsum
Pc
COLINA LIMESTONE
PIPe
EARP FORMATION
PENNSYLVANIAN
IPh
HORQUILLA LIMESTONE
IGNEOUS ROCKS
TERTIARY
gd – granodiorite
fel – felsite
and – andesite
ql – quartz latite
CONTACT
Dashed where approximate, dotted where inferred.
FAULT, WITH DIP
Long dashes where approximate, short dashes where inferred. U on upthrown side, D on downthrown side.
STRIKE AND DIP OF BEDS
AXIS OF ANTICLINE, WITH PLUNGE.
PROSPECT SHAFT
N
GEOLOGIC MAP
OF
THE SOUTHERN WHETSTONE MOUNTAINS,
COCHISE COUNTY, ARIZONA
1:12000
0
1000
2000
3000
4000 FEET
CONTOUR INTERVAL 100 FEET
FREDERICK T. GRAYBEAL
1961

PLATE 2









GEOLOGIC CROSS SECTIONS

OF

THE SOUTHERN WHETSTONE MOUNTAINS

(SEE PLATE 1)

1: 12000

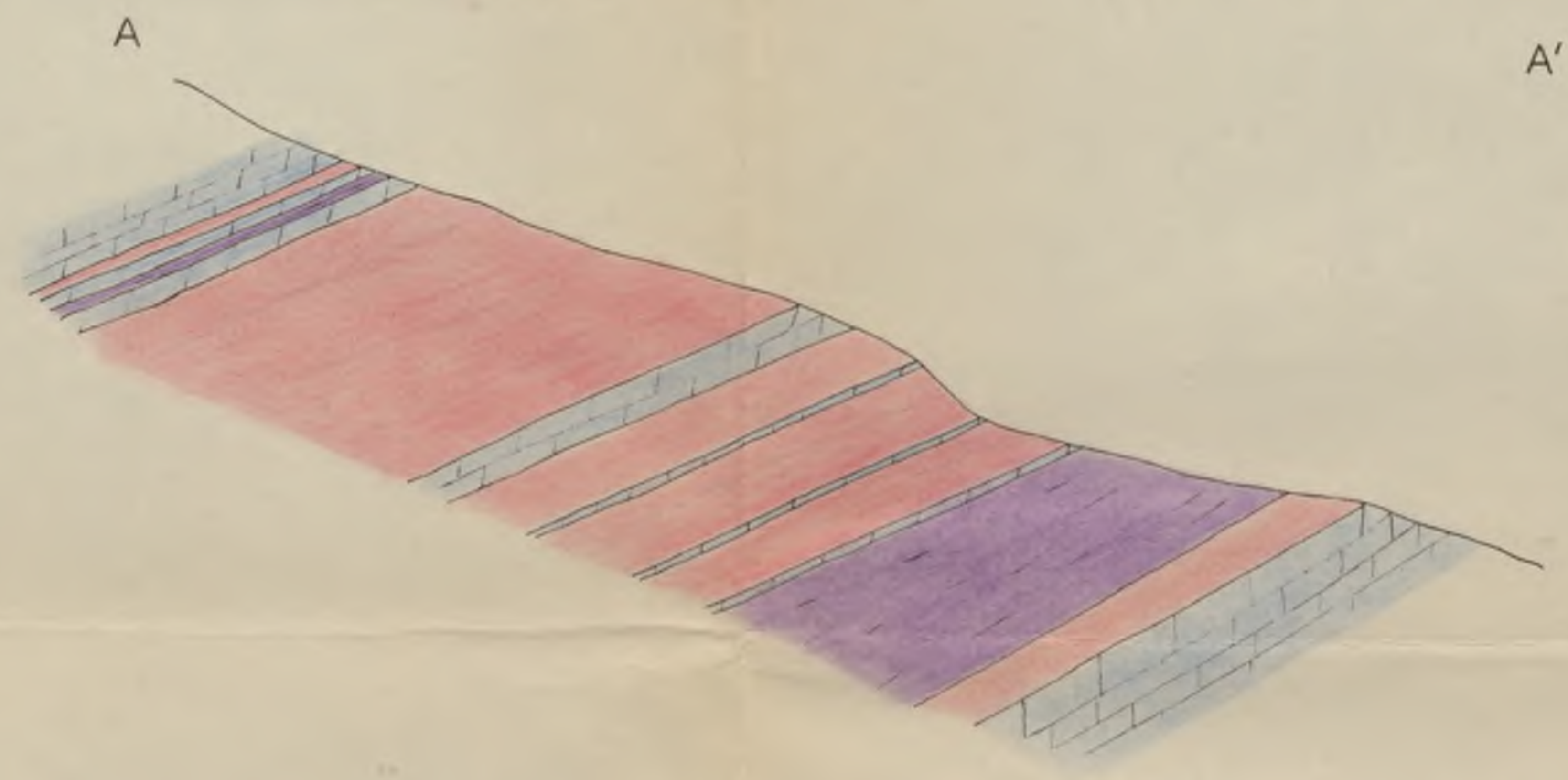
0 1000 2000 3000 4000 FEET

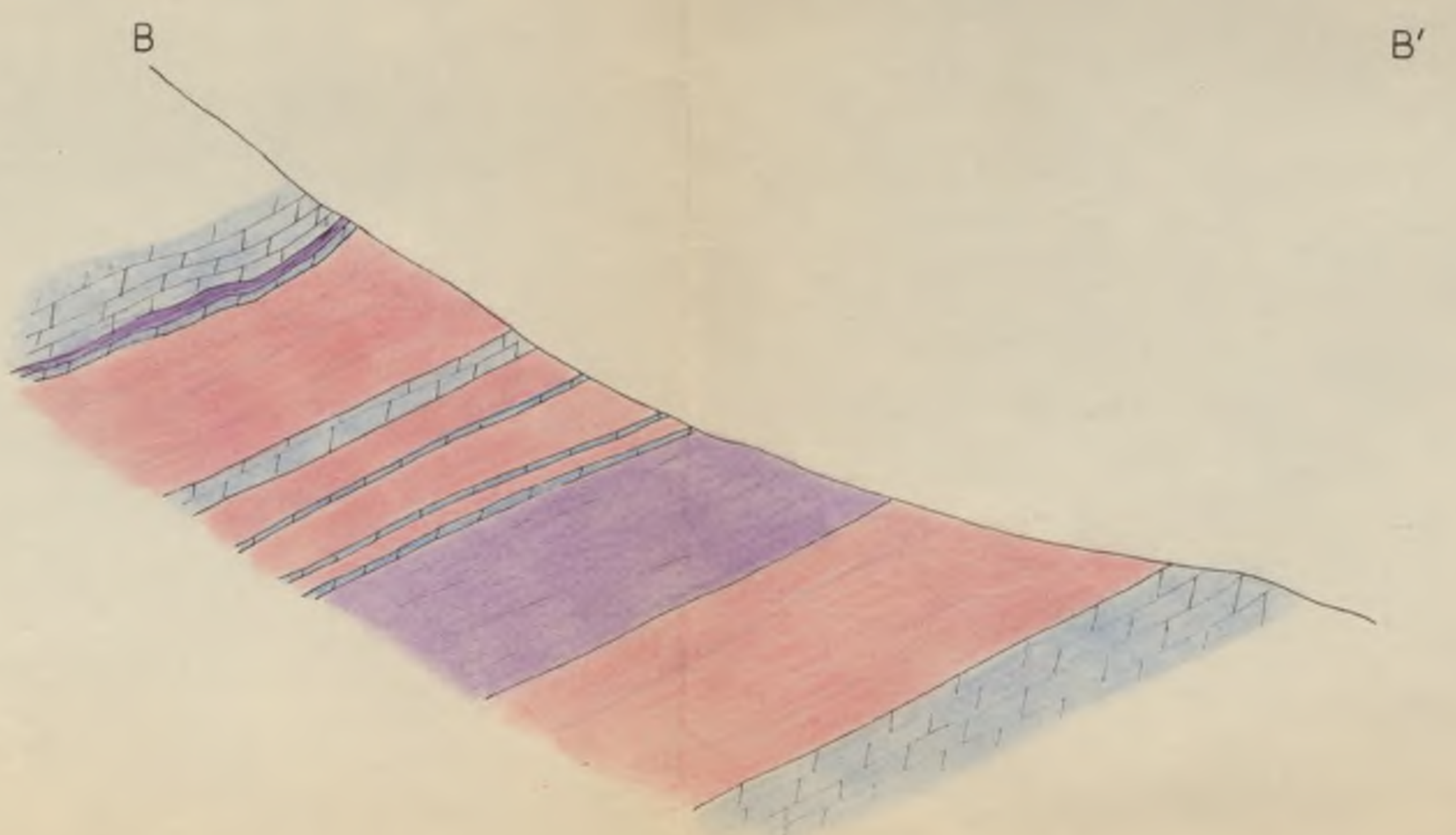
FREDERICK T. GRAYBEAL
1961

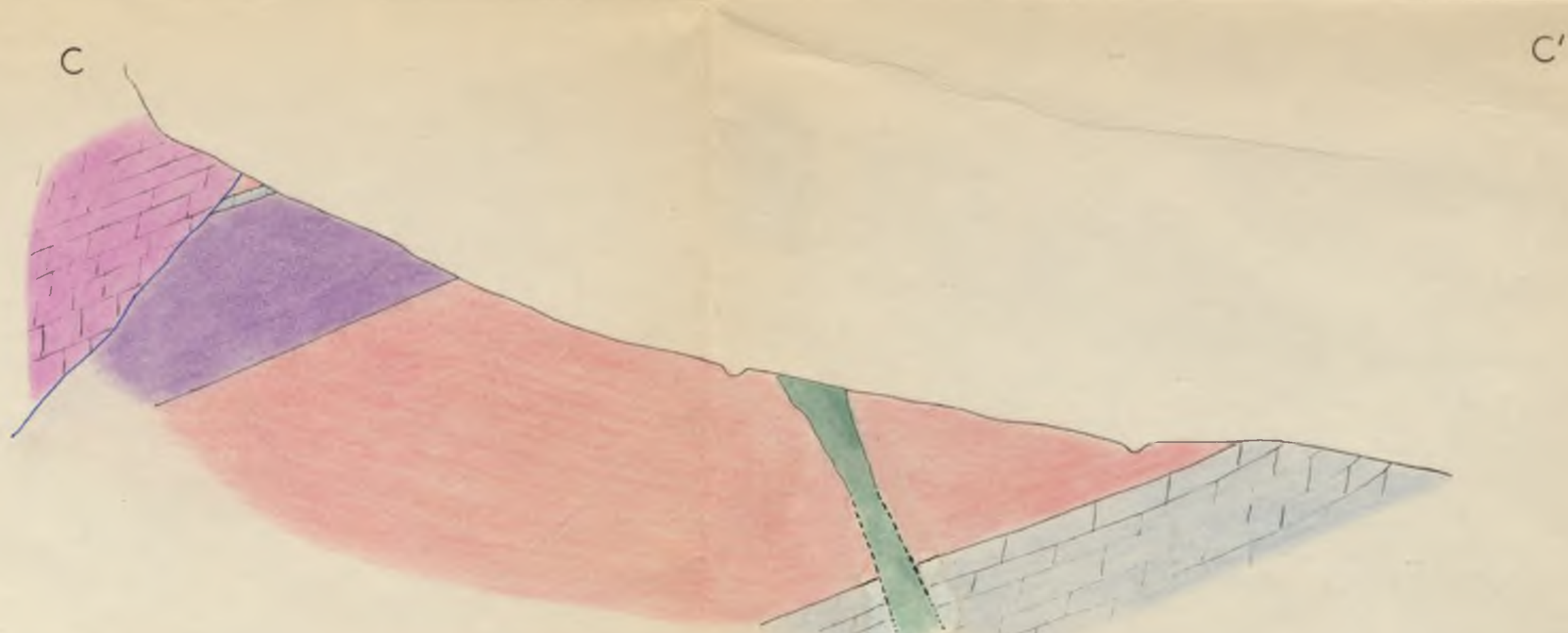
E9791
1962
119

PLATE 3

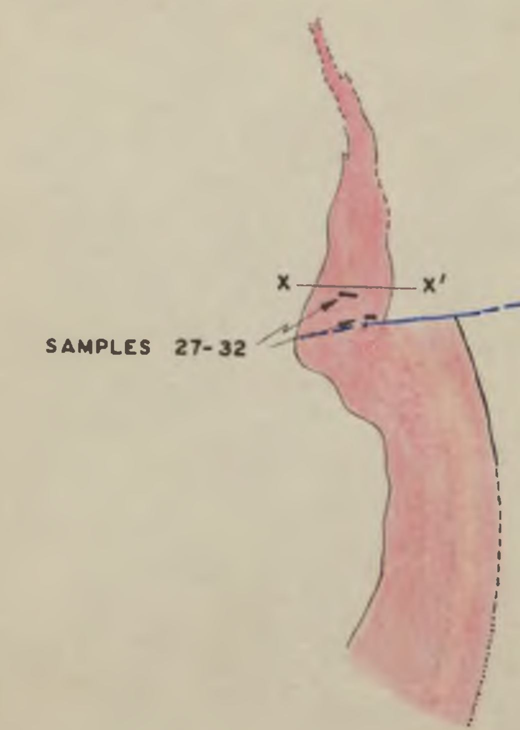
SECTIONS A-A', B-B', C-C' IN HIGH GRADE GYPSUM ZONE (SEE PLATE 3).

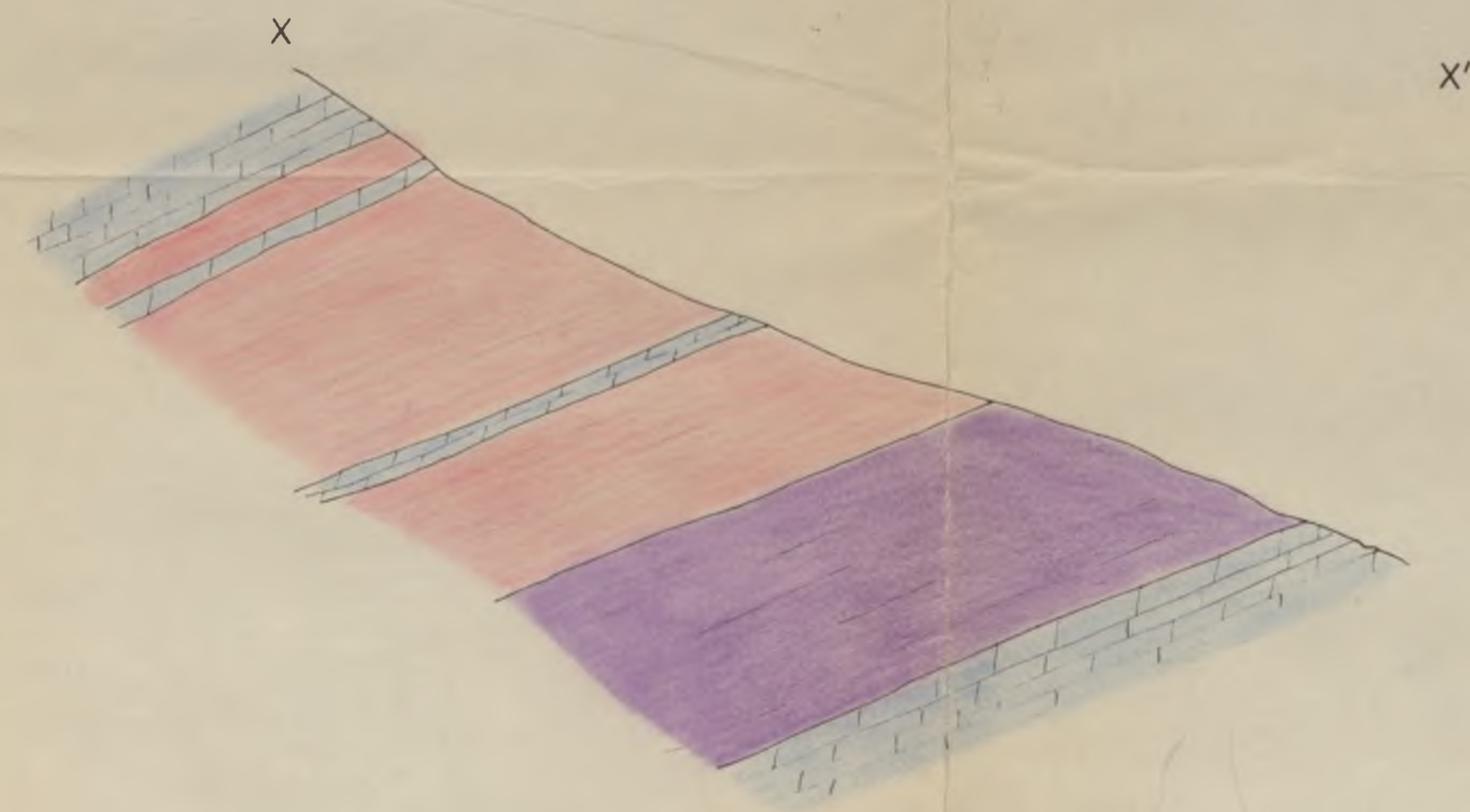






SECTION X-X' IN GYPSUM AREA EAST OF MESCAL PEAK (SEE PLATE 1 AND FIGURE AT RIGHT.)





NOTE:
All sections looking north

GEOLOGIC CROSS SECTIONS OF THE ECONOMIC GYPSUM AREAS

(SEE PLATES 1 AND 3)

1" = 100'

0 100 200 300 400 FEET

FREDERICK T. GRAYBEAL.
1961