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THE STRUCTURAL GEOLOGY OF THE DRAGOON MOUNTAINS, ARIZONA.

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ABSTRACT. The Dragoon Mountains lie in Cochise County in southeastern Arizona. Cambrian quartzites and shales overlie pre-Cambrian granite and are succeeded by Devonian, Mississippian, and Permian (?) limestones and Cretaceous quartzites, shales, and limestones. These strata were intruded by granite and by rhyolite dikes during the Laramide Revolution. Low-lying areas are incompletely covered by younger alluvium.

During the Laramide Revolution the Paleozoic and Cretaceous sediments were greatly compressed. Cambrian strata rose along a low-angle overthrust fault and came to rest on upper Paleozoic and Cretaceous sediments. Overthrust blocks of resistant Cambrian quartzite cap several outstanding shaly peaks or knobs to-day.

Following the overthrust faulting, the sediments and their overthrust burden were folded. As the limit of compression by folding was reached, faulting along high-angle reverse fault planes took place. The Silver Cloud and Dragoon anticlines, the Sala anticlinorium, the Middlemarch syncline, and the Dragoon fault are the major structures that resulted from this phase of deformation.

Late normal faulting occurred on a small scale after the granite intrusion, which was concomitant with or followed the folding.

INTRODUCTION.

Location:—The Dragoon Mountains are in Cochise County southeastern Arizona and lie largely within township 23N and range 18E of the Gila and Salt River base and meridian. They extend from the mining towns of Gleeson and Courtland north-northwestward to Dragoon on the Southern Pacific Railroad, a distance of twenty-five miles. Historically famous Tombstone lies thirteen miles to the southwest and Bisbee, the important copper camp, is twenty-eight miles to the south. Pearce, an important silver producer in the years 1895 to 1929, is eight miles east of the Dragoons.

At both ends of the range granitic rock masses form outstanding peaks and rugged terrane. Cochise's Stronghold, a natural fortress once used by the Chiricahua tribesmen, lies within the northern granitic mass. Southeast of the pinnacled Stronghold country lies a strip of sedimentary rocks nine miles long. This paper deals with the expanded northwestern portion of that strip. The area considered extends from a point one

Fig. 1. Outline map of Arizona showing location of Dragoon Mountains.

mile southeast of Dragoon Camp to a point one mile northwest of Cochise Peak and is from two to three and one-half miles wide. The Middle Pass trail, which connects Tombstone with Pearce, divides the area into two equal halves.

Purpose of Investigation:—This paper presents a portion of a geological study made by the writer in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Geology of the University of Arizona. Field work was carried on during parts of the summers of 1932, 1933, 1934, and 1936.

Acknowledgements:—The writer is greatly indebted to members of the faculty of the Department of Geology of the University of Arizona for encouragement, help and advice given during the course of this work. Dr. B. S. Butler and Dr. M. N. Short visited the area several times and later checked some of the more important findings. Dr. Eldred D. Wilson and Mr. J. B. Tenney of the Arizona Bureau of Mines rendered valuable assistance in a like manner.

The writer is indebted to Mr. Adam Dodd and Mr. E. J. Kelley of Pearce and Mr. John Sala of Tombstone who provided living quarters for the writer and were otherwise helpful. Thanks are due other individuals who have also given assistance and constructive criticism.

PREVIOUS WORK IN ADJACENT AREAS.

In the Santa Rita Mountains,[1] 55 miles west of the Dragoons, "the main structural feature is a thrust fault dipping to the west." Sections show that the overthrust plane is strongly folded. In the Empire Mountains, east of the Santa Ritas, upper Paleozoic limestones have been thrust westward on Cretaceous sediments.

R. A. Wilson,[2] in a detailed study of a smaller portion of the Empire Mountains, mapped another thrust plane that dips gently to the west. He states that a period of high-angle faulting followed the overthrusting.

The structural history of the Bisbee area, 28 miles south of the Dragoon Mountains[3] may be outlined as follows:

1. Post Permian pre-Comanchean normal faulting (Dividend fault).
2. During the Laramide Revolution compressive stresses resulted in doming of the sediments around a resistant core of pre-Cambrian granite. South of the Dividend

[1] Schrader, F. C.; 1915. Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona: U. S. Geol. Survey Bull. 582, p. 93.

[2] Wilson, Roy A.: 1934, Thrust faulting in the Empire Mountains of southeastern Arizona: Jour. Geology, 88, p. 422.

[3] Ransome, F. L.: 1904. The geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21, 106-107.

Fault the massive Paleozoic beds resisted doming and folding but developed large block faults (Copper Queen Block).

3. Low-angle overthrust faulting (Queen Hill Block).
4. Intense shattering by normal faults.

The compression is said to have acted from west to east.

In the Courtland-Gleeson area,[4] 12 miles to the southeast of the area considered in this paper and at the end of the Dragoon Range, thrust faulting of possibly late Tertiary age was preceded by a post-Cretaceous period of normal faulting. At Courtland the overthrust plane is approximately flat whereas at Gleeson it dips 20° southwest. Here, as in the Empire Mountains, thrusting is judged to be much later in time than at Bisbee, since "supposedly Tertiary" rhyolite has been involved.

B. S. Butler and E. D. Wilson[5] summarize the structural history of the Tombstone area in part as follows:

1. Possible mild Mesozoic volcanism.
2. Laramide folding along a northwest-southeast axis, accompanied by faulting.
3. Dike fissures develop, trending N16°E.
4. Strong faulting in approximately an east-west direction.
5. Fissuring along a southwest-northeast axis.
6. Normal faulting of post valley-fill age.
7. Intrusion of basaltic dikes.

Darton[6] has written briefly on the Dragoon Mountains. His cross-sections B and C correspond most closely with sections C–C′ and H–H′ in this paper. Darton recognized the structure here designated as the Sala anticline and the general southwest dip of the sediments making up both walls of Middlemarch Canyon. In his section C the easterly-dipping Paleozoics rock lying upon "Pinal schist," are shown to make up the high ridge in the southerly part of the area covered by this paper. Their relation to the folded Mesozoic sediments on the east is not clearly brought out. Porphyry dikes are shown, as is the gen-

[4] Wilson, Eldred D.: 1927, Geology and ore deposits of the Courtland-Gleeson region, Arizona: Ariz. Bureau of Mines Bull. 123, Geol. Series 5.

[5] Butler, B. S., Wilson, E. D., Rasor, C. A.: 1938, Geology and ore deposits of the Tombstone district: Univ. of Ariz., Bull. 143, IX, No. 1.

[6] Darton, N. H.: 1925, A résumé of Arizona geology: Ariz. Bur. Mines Bull. 119, 292-294.

eral relationship of the Stronghold granite to the sedimentary rocks. No suggestion of overthrust faulting is indicated and the map and sections are somewhat generalized.

GEOMORPHOLOGY.

Larger Physiographic Forms.

The portion of the Dragoon Mountains discussed in this paper consists of a belt of sedimentary rocks trending northwest-southeast which is dominated by a granite mass at its northerly end.

The southerly belt of sedimentary rocks, formed by the east limb of an anticline, makes a single high ridge which presents a steep face to the east where massive limestone overlies shaly beds. The ordinarily low, shaly terrane on the east is dominated by the resistant Black Diamond quartzitic thrust mass.

In that part of the area north of Santa Anna Gulch the belt of sediments splits into three prongs pointing toward the Cochise Stronghold granitic mass. All the sediments here are metamorphosed to some degree and are very resistant.

The longitudinal valleys are cut mainly in granitic rock and appear to have been controlled by extensive fissuring and faulting along the igneous-sedimentary boundaries. Unbroken granitic masses form outstanding blocks such as Cochise Peak, Sheepshead, and many unnamed lesser monoliths in the Stronghold to the north.

Major transverse canyons are almost lacking on the eastern side of the range due to the prevalence there of uniformly nonresistant shaly beds on the western side of the range. Santa Anna Gulch makes a deep canyon which heads into Middle Pass.

It seems probable that the Sorens Canyon originally drained southwestward across the wind gaps east of Silver Cloud Peak and above Middlemarch mine. A stream south of Silver Cloud Peak worked headward, pirated the main drainage line and thus reinforced, rapidly entrenched itself. The existence of such a major stream in this gulch is necessary to explain the deep dissection of this valley across the strike of massive limestone beds. However, the Santa Anna stream soon added the Sorens Canyon stream to its length, held it for a somewhat longer period of time than its predecessor, and finally gave it up to a tributary of the Middlemarch Canyon drainage system, as a result of which Middle Pass remains as a wind gap.

LESSER FEATURES.

The most conspicuous of the smaller topographic features are the porphyry dikes. Many stand out as ridges from a few feet to tens of feet in height and as much as a mile in length. A very prominent dike crosses Santa Anna Gulch; others are conspicuous on the floor and on either wall of Middlemarch Canyon. On the slopes and pediment below the Black Diamond camp the otherwise featureless topography of the shales is relieved by elongate, porphyry dike ridges.

DESCRIPTION AND DISTRIBUTION OF THE ROCKS.

The consolidated sedimentary rocks making up the Dragoon Mountains range in age from Cambrian through Mesozoic. Igneous rocks include a small exposure of pre-Cambrian granite, the widely distributed Stronghold granite which is intrusive into Mesozoic sediments, and porphyry dikes which intersect both the Stronghold granite and the Mesozoic sediments. The consolidated rocks are overlapped by unconsolidated late Tertiary or Pleistocene gravels.

PRE-CAMBRIAN.

The pre-Cambrian Apache group[7] of sedimentary rocks has been found as far south as the Little Dragoon Mountains,[8] 10 miles to the north, but appear to be absent in this area. A small mass of pre-Cambrian granite crops out in an arroyo in the extreme southerly part of the area and is unconformably overlain by Cambrian quartzite. It is a dark-greenish-black porphyritic rock carrying many small foreign schist fragments. Most of the phenocrysts make up more than half of the rock.

PALEOZOIC.

The Paleozoic rocks are those typical of the southern Arizona Basin as distinct from those deposited north of the Mazatzal

[7] Ransome, F. L.: 1914, Some Paleozoic sections in Arizona and their correlation, U. S. Geol. Survey Prof. Paper 98K, p. 131-141.

[8] Stoyanow, A. A.: 1936, Correlation of Arizona Paleozoic formations, Bull. Geol. Soc. Amer., 47, p. 474.

Cook, Frederic Stearns: 1938, "The geology of the Seven Dash area, Cochise County, Arizona," Master's Thesis, Univ. of Arizona.

Enlows, Harold Eugene: 1939, "Geology and ore deposits of the Little Dragoon Mountains," Doctor's Thesis, Univ. of Arizona.

Land[9] barrier which extended from southwestern to central Arizona in Paleozoic times. The sedimentary rocks are the Bolsa quartzite, the Cochise sandstones and shales, and Abrigo cherty limestones, all of the Cambrian age, the Devonian Martin limestone, the Mississippian Escabrosa limestone, and Permian (?) limestones.

Bolsa Quartzite:—The Bolsa quartzite, of Middle Cambrian age, lies unconformably upon pre-Cambrian granite in the extreme southerly part of the area. There it is about 325 feet thick, but elsewhere it is thinner.

Small masses are present southwest of Sala Peak, but the quartzite attains its greatest areal development as thrust masses capping Black Diamond Peak, the Sentinel, and Grant's Hill.

The quartzite is a vitreous fine-grained rock, more blocky than slabby, white when fresh but yellow to pink on weathered surfaces. On Black Diamond Peak the quartzite is underlain by a basal conglomerate and thin conglomeratic layers are present in the middle part of the section.

Abrigo Formation:—In the extreme southerly part of the area, 435 feet of gray, slabby, thin-bedded limestones separated by closely spaced bands of chert are assigned to the Abrigo formation of Upper Cambrian age. The fifty feet of poorly exposed shales beneath the typical Abrigo rocks may represent the Cochise formation.[10]

The limestone is also well developed in the Paleozoic section west of Sala Peak and overlies the Bolsa on the Grant's Hill and Sentinel thrust masses.

Martin Limestone:—The Martin limestone[11] of upper Devonian age is about 350 feet thick in the southwestern part of the area. Here it is a moderately massive-bedded limestone in which are intercalated four thin sandstone or quartzite beds. The limestones are black, gray, brown, pink and buff, the darker hues predominating. A reef of silicified corals, characteristic of the Martin in southern Arizona, is present near the top of the section. Southwest of Sala Peak the Martin includes five strata, apparently thoroughly silicified limestones, from 4 to 20 feet

[9] Stoyanow, A. A.: op. cit., p. 461.
[10] Stoyanow, A. A.: op. cit., p. 466.
[11] Ransome, F. L.: 1904, Geology and ore deposits of the Bisbee Quadrangle: U. S. Geol. Survey Prof. Paper 21, 33-35.

thick. These light-colored beds stand out in sharp contrast to the drab background.

Escabrosa limestone:—The Escabrosa limestone of Lower Mississippian age[12] is a cliff-forming, massive bedded white to gray granular limestone, in places made up largely of crinoid stems. It is about 300 feet thick in the southern part of the area; smaller exposures are present south of Sala Peak and on the pediment east of Middlemarch Canyon. It is possible that some of the recrystallized limestone mapped as Permian (?) limestone in the northerly part of the area is really Escabrosa.

Permian (?) Limestone:—The Permian (?) limestone[13] is thinner bedded than the underlying Escabrosa limestone and the texture is finer grained. Some beds have a pinkish hue. Chert is common and occurs in irregular bunches and nodules and in thin layers. Lying above the cliff-forming Escabrosa, these strata make up the crest of the range from Silver Cloud Peak southeastward.[14] Similar strata are also found on Sala Peak and south of there along Santa Anna Gulch.

The recrystallized strata making up part of both walls of Middlemarch Canyon and extending into the head of Stronghold Canyon are most probably Permian (?) limestones as are other smaller areas in the northwest which are mapped as Permian (?).

MESOZOIC.

The Mesozoic rocks underlie a relatively large portion of the area; to the south they occupy much of the area east of the crest of the range; to the north they make up the ridge on which Aerie Peak is located. Smaller areas are found southwest of Aerie Peak and south of China Peak.

Along the Dragoon fault, east of the Sentinel and at the lower end of Middlemarch Canyon, the base of the Mesozoic is marked by a limestone conglomerate containing cobbles up to six inches in diameter in a limy matrix. This conglomerate lies unconformably upon the Paleozoic limestone. Its thickness is variable, but east of the Sentinel it is up to 100 feet thick. It is absent in other parts of the area. The limestone

[12] Ransome, F. L.: op. cit., pp. 42-54.

[13] Stoyanow, A. A.: 1936, Correlation of Arizona Paleozoic formations, Bull. Geol. Soc. Amer., 47,—. 522.

[14] According to Dr. A. A. Stoyanow, poorly preserved fossils collected from these beds by the writer have a Permian aspect; hence the Naco formation (now restricted to Pennsylvanian beds alone) appears to be absent.

conglomerate is suggestive of the Glance conglomerate of Bisbee,[15] but no definite correlation is proposed other than that these rocks and the overlying shaly series are correlated with the Bisbee group (Lower Cretaceous) as a whole.

Above the limestone conglomerate, or directly upon the Permian (?) limestone where the conglomerate is absent, lies a series of sandstones and shales whose maximum thickness is unknown. The full thickness may be nearly 3000 feet, but, since the section may have been repeated by faulting, the total thickness may be only about 1000 feet.

The lower 100 feet of material above the limestone conglomerate is predominately quartzitic. Higher in the section the rock is shale with subordinate intercalated sandstones; individual shaly members may be as much as 100 feet thick, whereas the sandstone members are rarely more than 20 feet thick. Red and red-brown colors predominate.

The southwest wall of Sorens Canyon between Santa Anna Gulch and Aerie Peak is made up of a series of epidotized, garnetized, and highly silicified rocks in which wide streaks of black hornfelsic material is intercalated. These overlie about 200 feet of quartzitic and shaly material which in turn rests upon the Paleozoic limestones.

On weathered surfaces the strata have a brown nondescript appearance and are pitted where garnet and epidote have weathered out. B. S. Butler has stated[16] that these rocks are similar to the series of rocks lying above the typical lower shales and sandstones of Mesozoic age in the Tombstone area. The description of the "Novaculite" from that area[17] seems applicable in large part to these rocks.

The variously metamorphosed rocks making up the southwest wall of Sorens Canyon have a minimum thickness of 400 feet, but northwestward they increase to more than 1000 feet.

PRE-CRETACEOUS DEFORMATION.

The Mesozoic rocks everywhere rest upon Permian (?) strata. No suggestion of angular unconformity was noted. Hence the

[15] Ransome, F. L.: op. cit., p. 56.

[16] Oral communication, Aug. 17, 1934.

[17] Butler, B. S., Wilson, E. D., Rasor, C. A.: 1938, Geology and ore deposits of the Tombstone district: Univ. of Ariz., Bull. 143, IX, No. 1, 19-20.

post-Paleozoic pre-Cretaceous deformation of the Bisbee area has no counterpart in this portion of the Dragoon Mountains.

THE STRONGHOLD GRANITE.

Relation to the Sedimentary Rocks:—The coarse-grained granite making up the Cochise Stronghold mass extends southward as narrow bands into the area and the borders of the mass itself fall within the northern and western limits of the map.

With one minor exception the granite-sedimentary contacts, where well exposed, show that some movement has occurred along the contact. The granite is not frozen to the walls but is everywhere separated from the sedimentary rock along a sharp plane. Apophyses or stringers nowhere extend into the sedimentary rocks. Breccia is present in the sedimentary rock at the contacts at the head of Middlemarch Canyon. The Cobraloma adit passes through to the contact and along it for about thirty feet exposing a face of slickensided granite on the contact. Gouge is present in many other places and shear zones along the contact are general. These data seem to indicate that the granite has been faulted against the sedimentary rocks.

However, when the pattern made by the granite within the area of sedimentary rocks is considered it appears most likely that the granite is intrusive. The granite occurs within the sedimentary rock area in the following structural forms: a long dike (extending southeastward along Sorens Canyon), a shorter tapering dike (Middlemarch Canyon), a small wedge (south-southwest of China Peak), and a plug (on the east wall of Middlemarch Canyon). These forms are considered to indicate that the rock is intrusive.

When the metamorphism of the sedimentary rocks in the northerly area is compared with the lack of metamorphism in the southerly area, a compelling argument is advanced for the intrusive nature of the granite; near the head of Sorens Canyon the rocks are now largely hornfels, schistose rock has been developed southwest of China Peak, and the Paleozoic limestone rocks have been recrystallized, bleached, silicified and mineralized.

Description:—The Stronghold Granite in most places is white where fresh and light yellow where weathered; it has a medium to coarse-grained texture and may be described as porphyritic, although the porphyritic character is not everywhere readily apparent in the hand specimen. The phenocrysts are stubby euhedral orthoclase feldspar grains.

The Stronghold granite is intrusive into Mesozoic rocks and is considered to have been implaced during the Laramide Revolution, following the folding of the range.

MINOR INTRUSIVES.

Aplite:—In several places a late aplitic granite is present as small dikes generally less than a foot wide. These intrude both the sedimentary rocks and the Stronghold granite.

Rhyolite sanidine porphyry:—Near Salas ranch house are two small dikes of pink rhyolite porphyry which are intrusive into Paleozoic rocks. The rock contains phenocrysts of euhedral quartz and sanidine feldspar.

Rhyolite albite porphyry:—The topographically impressive system of rhyolite porphyry dikes have already been mentioned. This porphyry is brown to lavender on fresh or weathered surfaces. It contains phenocrysts of quartz, albite feldspar, and subordinate pyrite.

The dikes are vertical or almost vertical in attitude and nearly all of them trend northwest-southeast. Since these dikes are intrusive into the Stronghold granite, they are regarded as a late differentiation product of the same parent magma.

Diabase Dikes:—Short narrow diabase dikes have been found in a number of places. These intersect both the sedimentary rocks and the Stronghold granite. The diabase is characteristically black or greenish-gray aspect where weathered.

STRUCTURAL DEFORMATION.

Except for the recent unconsolidated detritus skirting the range and partly filling the deep canyons, no sedimentary rocks in the central Dragoon Mountains remain in their original undisturbed position. Great stresses, acting from the southwest or northeast, have crumpled and broken the strata into many units. Other deformation of lesser magnitude has also been active.

A summary of the structural events is as follows:

1. Sedimentation in the Paleozoic and Mesozoic eras.
2. Low-angle overthrust faulting, probably acting from the southwest.
3. Folding of the sediments into broad open folds. Reverse

faulting took place where competent strata were unable to fully adjust themselves to the compressive forces by folding.

4. Intrusion of the Stronghold granite and associated dike rocks. Minor normal faulting followed volcanism.

THE FOLDS.

Folds dominate the structure of the portion of the Dragoon Mountains discussed in this paper. Later faulting has destroyed the unity of these folds and granite has obliterated parts of them.

In the southerly part of the area two parallel anticlines, axes of which fall on either side of the range, trend northwest and southeast. They are in contact along a reverse fault.

Silver Cloud anticline:—The Silver Cloud anticline, on the southwestern side of the range, makes up the two spurs extending west and southwestward from Silver Cloud Peak. On the southwest spur the Abrigo, Martin, Escabrosa, and part of the Permian (?) formations are well displayed (section F–F′, Fig. 3). Due to a gentle northwest pitch of the fold, however, the more northerly spur does not reveal the Abrigo limestone at the surface. The massive limestones dominate the structure and they crop out with a broad bold sweep. Thin-bedded Abrigo limestones exposed in the arroyo southwest of Silver Cloud Peak have responded differently to compression. Here a complex system of tight, contorted, and overturned drag folds strongly contrast with the broad arch of the overlying massive limestones. In the most southerly portion of the map area, the Paleozoic formations of the northeast limb are well exposed; the southwest limb, of which only a small portion crops out, has been faulted against the pre-Cambrian core of the fold and the upper part of the Devonian limestone lies upon it (section G–G′).

The northeastern limb of the Silver Cloud anticline is brought against the Mesozoic shales along the Dragoon fault. The fault is a warped plane dipping steeply southwest, and where the Paleozoic rocks make a reentrant into the Mesozoic rocks a synclinal structure is developed. Two such synclinal embayments are present; one at the southeast end of the range and one just east of Silver Cloud Peak (section H–H′ and F–F′, Fig. 3).

Section G–G′ is taken where the Dragoon fault trends westward and the synclinal development of the northeast limb of the

Silver Cloud anticline is lacking; unlike section H–H′, therefore it does not show all the elements of the original structure. Section G–G′ shows the basal Mesozoic conglomerate lying upon the Paleozoic rocks in sedimentary contact and establishes the fact that the full (local) thickness of Paleozoic rock is present there.

To the northwest the Silver Cloud anticline is limited by a cross fault of small displacement.

Black Diamond anticline:—The axis of the Black Diamond anticline lies on the northeasterly slope of the range; the entire fold lies within the Mesozoic sediments (sections F–F′, G–G′, and H–H′, Fig. 3). The northeastern limb is well exposed on the slopes below Black Diamond Camp and the southwestern limb higher on the slopes beneath the cliff-forming Glance. This anticline, unlike the broad arch of the Silver Cloud anticline, appears to be a sharp crease separating two series of isoclinal sediments.

Northwestward the axis of the Black Diamond anticline is replaced by granite, but the northeast limb is seen on the prominent ridge just east of the Sentinel (section E–E′, Fig. 3). The limb is made up of Mesozoic massive limestone conglomerate and overlying shales, underlain by limestone bearing abundant brachiopods, considered to be Paleozoic in age. Southeast plunge of the anticline is thus indicated. It may be surmised that the basal Mesozoic conglomerate which crops out near the Sentinel lies only a short distance below the anticlinal axis south of Black Diamond Peak.

The Silver Cloud and Black Diamond folds are considered to have been part of the same structure. This structure was broken by a fault along which the Silver Cloud anticline rose a minimum of 500 feet (section G–G′), bringing Paleozoic rocks on the west side of the range to a level comparable to the Mesozoic rocks on the east.

The northern portion of the area considered in this paper differs markedly from the southern portion discussed above. Taken as a whole, the northern area may be said to consist of an anticlinorium on the southwestern side of the range, the northeastern limb of which develops into a syncline (section D–D′), the axis of which lies in Sorens Canyon. The northeastern limb of the syncline forms both walls of Middlemarch Canyon. Northward increasingly greater portions of the structure give way to the Cochise Stronghold granite mass.

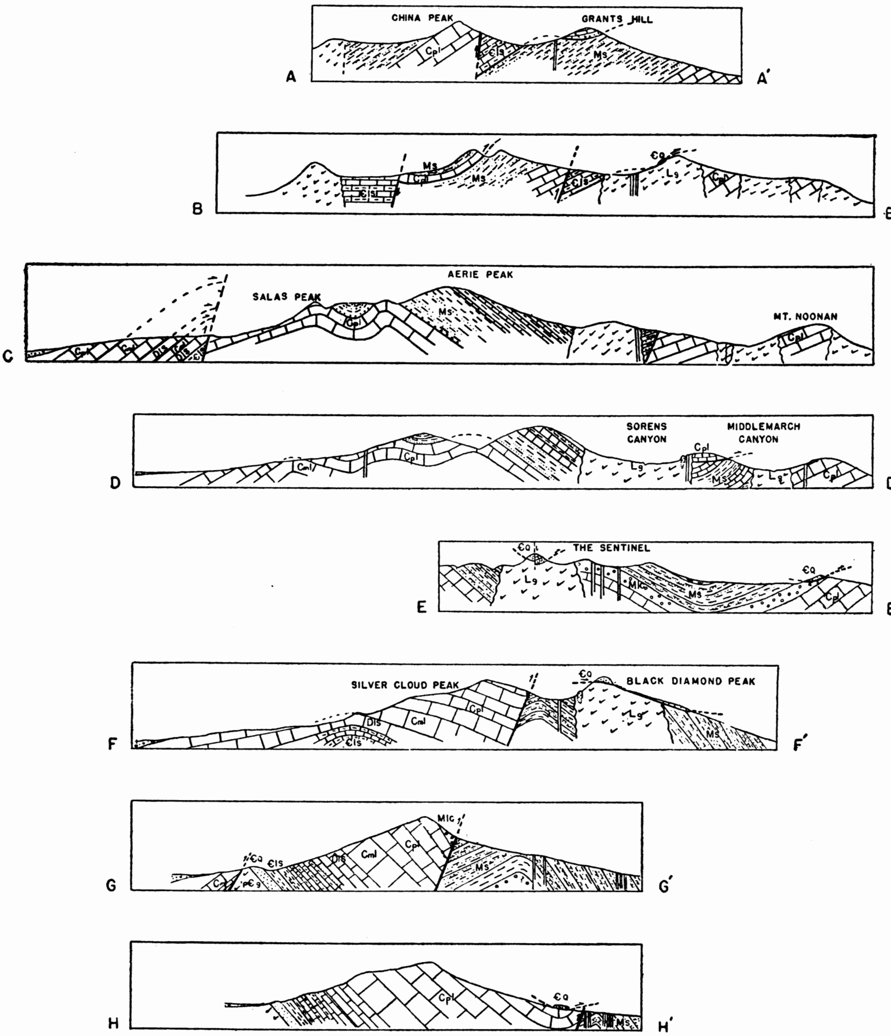

FIG. 2, GEOLOGIC CROSS SECTIONS

OF THE DRAGOON MOUNTAINS, ARIZ.

Middlemarch syncline: The northeast limb of the Black Diamond anticline has been traced northward to a point directly west of the Sentinel where the Mesozoic conglomerate forms a ridge. Northeast of the Sentinel, across the mouth of Middlemarch Canyon, the conglomerate again crops out. There it is underlain by Paleozoic limestones which have a southwest dip; a syncline, here called the Middlemarch syncline, is evident (section E–E′, Fig. 2).

The rocks making up both walls of Middlemarch Canyon dip to the southwest (sections D–D′ and C–C′, Fig. 2) and both are therefore considered to be part of the northeast limb of the Middlemarch syncline. The axis of the syncline trends west-northwest, but flexes westward at the mouth of Sorens Canyon and passes northwestward. A corresponding flexure along the strike has been observed in the massive Paleozoic limestones on the ridge southeast of Noonan Peak (Fig. 2).

The southwest dipping strata making both walls of Middlemarch Canyon may be traced northwestward to Stronghold Canyon with moderate continuity. Thus an unbroken series of folds (the Middlemarch syncline and Black Diamond anticline) appear to extend from the southeasternmost part of the area to Cochise Peak. This contrasts with the dissimilar folds on either side of Santa Anna Gulch on the western side of the range and it is believed therefore, that the transverse fault mapped in Santa Anna Gulch which separates them dies out northeastward except for the flexures mentioned.

Sala anticlinorium: In the area south of the Aerie it is seen that the Sala anticlinorium consists of three distinct anticlines with intervening synclines (section D–D′). The three anticlines occur within about the same distance across the strike as that required by the Silver Cloud anticline, but the Sala anticlinorium and the Silver Cloud anticline are not considered to be parts of one structure. It is thought that the strata north of Santa Anna Gulch, although possibly continuous with the strata to the southeast in the early stages of folding, acted as an independent unit and were shortened a relatively greater amount and are now separated from the Silver Cloud anticline by a cross fault of small displacement as noted above. The offset at the head of Santa Anna Gulch is cited as evidence for this interpretation.

The folds south of Aerie Peak strike about N45°W and plunge less than 5° to the southeast. The two higher anticlines are traced to the spur connecting Salas Peak with the Aerie. The projection one-half mile northwest of this point is hypothetical in part because metamorphism of the strata has largely obliterated the bedding planes and salient characteristics. Directly west of Salas Peak the simple folded structure is destroyed. Bolsa quartzite of the Cambrian is brought up to a high level and a mashing of the structure by some force acting obliquely to the strike is suggested.

The lowest of the three anticlines shown in section D–D′ is traced west-northwestward where it breaks into a series of imbricate reverse faults. They are considered below.

The folds in the Gordons claims area are not continuous with those of the Sala anticlinorium but are separated from the latter structure by a cross fault. Here, within a basin-like depression (section B–B′), a slightly warped lower Paleozoic section has been brought against Mesozoic shales by a reverse fault. The Mesozoic shales themselves bear a thrust mass of folded Pennsylvanian limestones directly upon them. Presumably the Mesozoic strata beneath the thrust mass are folded as well. The strata may have been continuous with the rising Sala anticlinorium but greater relief was gained by faulting and a markedly different structure was created.

FAULTS ASSOCIATED WITH FOLDING.

In several places the strata were unable to obtain full relief by folding during periods of mountain building and further relief was gained by reverse faulting. In addition, important cross-faulting occurred at this time.

Dragoon fault: The Dragoon fault, the trace of which extends northward for a distance of almost three miles from the southern limit of the area, is a high-angle reverse fault. Where it crosses the deep gulch southwest of Black Diamond Peak the fault plane dips about 75° to the southwest. One-half mile north of Silver Cloud peak the Dragoon fault is lost in the granite; however, there seems to be no necessity to postulate its northward continuation into the area east and southeast of Aerie Peak.

At the head of Middlemarch Canyon Mesozoic sediments rest on Paleozoic rocks along a fault dipping steeply to the southwest. This is considered to be a reverse fault, related in time to the Dragoon fault, and possibly an offset continuation of the Dragoon fault.

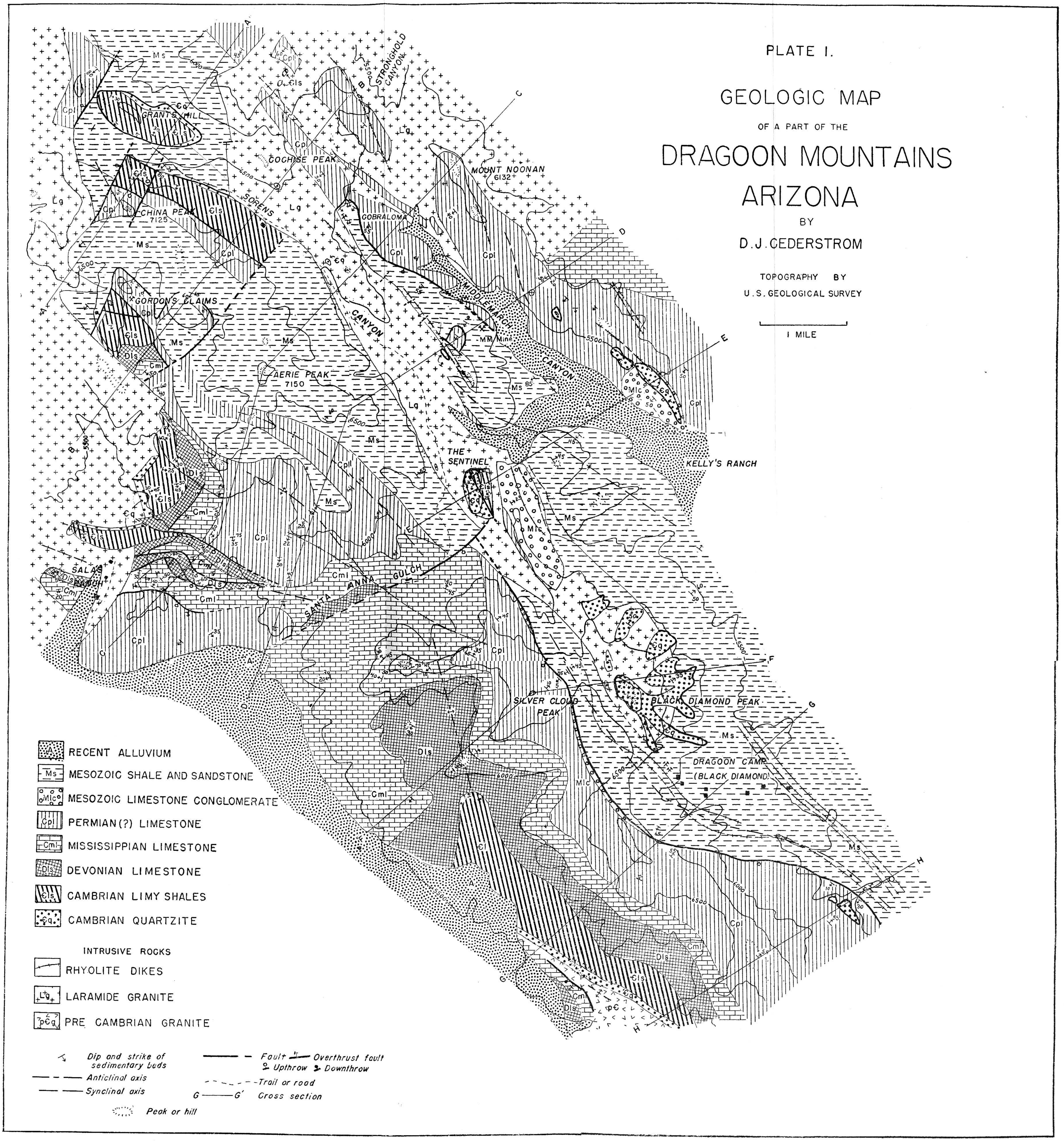
PLATE I.
GEOLOGIC MAP
OF A PART OF THE
DRAGOON MOUNTAINS
ARIZONA
BY
D.J. CEDERSTROM
TOPOGRAPHY BY
U.S. GEOLOGICAL SURVEY
1 MILE
RECENT ALLUVIUM
MESOZOIC SHALE AND SANDSTONE
MESOZOIC LIMESTONE CONGLOMERATE
PERMIAN(?) LIMESTONE
MISSISSIPPIAN LIMESTONE
DEVONIAN LIMESTONE
CAMBRIAN LIMY SHALES
CAMBRIAN QUARTZITE
INTRUSIVE ROCKS
RHYOLITE DIKES
LARAMIDE GRANITE
PRE CAMBRIAN GRANITE
Dip and strike of sedimentary beds
Anticlinal axis
Synclinal axis
Peak or hill
Fault
Overthrust fault
Upthrow
Downthrow
Trail or road
G——G′ Cross section
STRONGHOLD CANYON
GRANT'S HILL
COCHISE PEAK
MOUNT NOONAN 6132
CHINA PEAK 7125
SORENS
GOBRALOMA
MIDDLEMARCH
CANYON
GORDON'S CLAIMS
MM Mine
AERIE PEAK 7150
THE SENTINEL
KELLY'S RANCH
SALAS RANCH
SANTA ANNA GULCH
SILVER CLOUD PEAK
BLACK DIAMOND PEAK
DRAGOON CAMP (BLACK DIAMOND)

On the westerly side of the range, a well-defined, high-angle reverse fault which dips 80° to the southwest (section C–C′) crosses the saddle on the spur extending south-southwest of Salas Peak. Immediately to the southeast Cambrian, Devonian, and Mississippian strata have locally been brought to the surface along lower-angle reverse faults which probably originated as bedding faults. All these faults tend to merge and pass into a fold a short distance to the southeast; hence they are genetically related to the early period of folding.

Miscellaneous strike faults: In the extreme southern part of the area Martin limestone of the pediment lies against pre-Cambrian granite along a fault plane which dips 45° to the southwest. Here normal faulting accompanied the rise of the massive granite and quartzite along the pitch of the Silver Cloud fold.

In the basin-like area south of China Peak a fault is postulated between the warped, low-angle reverse fault block and the lower Paleozoics immediately to the southwest. On the hill above Middlemarch mine a wedge-shaped block of Mississippian limestone rests upon Mesozoic limestones. This small overthrust is classed with the faulting movements developed concomitantly with the folding, because it has affected younger strata than those of the large overthrust sheet, remnants of which entirely surround this area.

Cross faults:—The cross fault mapped in Santa Anna Gulch separates the Silver Cloud anticline (which pitches to the northwest) from the Sala anticlinorium (which pitches to the southeast). An offset along this fault is seen at the head of Santa Anna Gulch. Since the Middlemarch syncline continues unbroken across the eastward projection of this fault, the fault is considered to pass into a cross fold at the mouth of Sorens Canyon.

A second cross fault that extends from a point south of Gordon's Claims northeastward across the backbone of the range and across the southwest wall of Middlemarch Canyon.

One half mile south of Gordon's Claims prominent Paleozoic limestones are abruptly terminated in a deep gulch. The northeastward continuation of the fault postulated here separates the infaulted Cambrian of the early overthrust sheet on the southwest wall of Sorens Canyon (section A–A′) from the

Mesozoics farther on down the canyon. The cross fault on the wall of Middlemarch Canyon just above the Cobraloma prospect may be a further continuation of this fault.

Cross faults of smaller magnitude mapped in the northwesterly portion of the area are lost upon entering the Mesozoic shales.

Direction of force: Good determinations of the inclination of axes of the folds have not been made. However, the inclination of the planes of high- and low-angle faults associated with the folding indicate conclusively that the force creating the folds and faults came from the southwest.

THE OVERTHRUST.

Preceding the post-Cretaceous folding, the initial compressive forces caused a flat-lying sheet of lower Paleozoic rocks to override Mesozoic and Upper Paleozoic strata. The thrust sheet was involved in the later folding and faulting, was partly assimilated or stoped by granitic intrusion and has suffered greatly from erosion. Portions of the thrust mass do remain, however, and crown the Black Diamond and less majestic peaks.

Grant's Hill:—On Grant's Hill, at the head of Sorens Canyon, the overthrust is composed mainly of thin-bedded Abrigo limestone, but on the northeast and southeast sides of the hill the underlying Bolsa quartzite crops out (section A–A′). These Cambrian strata rest on steeply dipping Mesozoic shales which pass entirely beneath the hill and appear again on the other side. This thrust mass, projected, forms the southwest wall of Sorens Canyon (section A–A′). The steep southwest dip indicates a later folding of the thrust plane.

On the prominent spur extending northward from Cochise Peak are two small "islands" of thin bedded Abrigo limestone (Fig. 2), each of which is entirely isolated and rests on granite. They are remnants of the larger thrust sheet which covered this area. The lower portion of these blocks has been stoped out or replaced by granite. It seems then that the Grant's Hill mass forms the crest of an arch over this part of the range.

A small remnant of Bolsa quartzite lies on the south slope of Cochise Peak. Half a mile down the canyon from Cochise Peak and west of the Sentinel are two other quartzite masses of similar character.

The Sentinel:—An outstanding hill known as the Sentinel is capped by a mass of Bolsa quartzite dipping to the southwest.

The northeast portion of the mass has been dropped slightly by late normal faults; 50 feet of typical Abrigo limestone lie above the quartzite in the down-dropped northeastern block.

A small quartzite mass on the southeast wall of Middlemarch Canyon (northeast of the Sentinel) rests upon Mesozoic limestone conglomerate. Immediately to the northwest of this mass another rests upon Paleozoic limestone and half a mile to the northwest a third very small isolated quartzite mass also rests upon Paleozoic limestone. These are all considered to be Bolsa quartzite and part of the folded overthrust sheet of which a portion forms the Sentinel.

Black Diamond area:—Black Diamond Peak is a large quartzite mass resting on granite and Mesozoic shales which dip northeastward. The northwest-southeast alignment of the quartzite cappings from Grant's Hill to the Black Diamond, the structural similarity of Black Diamond quartzite to the rocks capping the Sentinel and Grant's Hill, and the fact that the quartzites forming Black Diamond Peak extend to a lower elevation and rest with angular unconformity of Mesozoic shale and the appearance of the rocks themselves are considered as reasonable proof that these rocks are the Bolsa quartzite.

On the north and northeast slopes, lower than the peak by two to five hundred feet, large detached quartzite blocks immediately suggest slump masses derived from the peak or segments lowered by block faulting. Directly east from the peak on one less deeply cut spur the quartzite forming the peak descends 1000 feet and the mass as a whole is seen to be folded and corresponding roughly in structure to the Black Diamond anticline.

A mile and a half southeastward of Black Diamond Peak a massive quartzite block rests on upper Paleozoic limestones. This mass, lying within a syncline of upper Paleozoic rocks, is considered to be a thrust block of Bolsa quartzite similar in character and history to the Black Diamond, Sentinel, and Grant's Hill thrust masses.

In summary, then, five well-defined thrust masses of Cambrian strata are found in the area mapped. Two of the blocks rest entirely or in part upon Mesozoic shales, one rests on the basal Mesozoic limestone conglomerate, and one upon Upper Paleozoic limestone. The sole upon which the Sentinel mass rests has been replaced by later granite.

Age of Overthrusting:—The time of overthrusting cannot be proved conclusively, but the evidence that can be cited indicates the overthrusting preceded the folding. The reasons for considering the overthrust early in time are briefly summarized as follows: first, there is a reasonable similarity between such folds as the Middlemarch syncline and the Black Diamond anticline and the warped overthrust masses; second, the thrust masses are almost conformable with the underlying sole rocks—lack of conformity in places is ascribed to the rumpling of shales by the overriding mass; third, several blocks are in protected positions (on the assumption that the thrust came from the southwest) and their later emplacement would necessitate an extremely warped thrust plane; fourth, the thrust plane intersects only uppermost Paleozoic and lower Mesozoic sediments; fifth, at the head of Sorens Canyon the thrust block has been involved in a reverse fault similar in character to and possibly a continuation of the Dragoon fault and hence almost certainly present before folding.

LATE NORMAL FAULTING.

In a few places high-angle normal faulting took place at a definitely late stage. On Grant's Hill, the Sentinel, and perhaps Black Diamond Peak, the quartzite thrust masses drop off in successive little steps in an eastward direction. These faults trend with the range and regional structure. They are regarded as resulting from settling movements that took place after compression had ceased. However, since small offsets are present from place to place in the granite-sedimentary contacts, they are more likely to be related to forces exerted following the intrusion of the Stronghold granite, the last major event recorded in the geologic history of the area studied.

RÉSUMÉ OF GEOLOGIC HISTORY.

The geologic history of the area may be summarized as follows: In pre-Cambrian times igneous intrusion of older, probably schistose, rock took place. By the end of pre-Cambrian time the region had been eroded to low relief. The Paleozoic sediments deposited are typical of those laid down in the southern and south central Arizona Paleozoic basin.[18]

In shallow seas of late Middle Cambrian time the Bolsa quartzite and Cochise shales were unconformably deposited upon the pre-Cambrian rocks. These quartzites were followed by shales

[18] **Stoyanow, A. A.: 1942, Paleozoic Paleography of Arizona: Bull. Geol. Soc. Amer., 53, 1261-1269.**

and thin-bedded limestones of the Abrigo formation of early Upper Cambrian age.

No trace of Ordovician or Silurian strata has been recognized. Martin limestones of Devonian age were laid down upon the Cambrian shaly limestones. Deepening of the Upper Devonian trough in Mississippian times led to the deposition of massive limestones upon the upper Devonian strata. Although Pennsylvanian and Permian times ushered in a new transgression of the sea, the Permian (?) limestones of the Dragoon Mountains rest upon the Escabrosa limestones without conspicuous break.

A period of erosion followed and in Mesozoic times the encroaching seas trapped coarse local material brought out of the higher land areas to form a basal conglomerate. Shallow seas persisted through much of the remainder of Mesozoic age and a great thickness of shaly sediments was deposited. The depositional basin was for the most part unstable, for quartzites, arkoses, shales, and limestones were deposited alternately and no single rock type appears to attain any great unbroken thickness. Tuffs, characteristic of the Mesozoic in other parts of southern Arizona, were not recognized.

Toward the end of Mesozoic time Paleozoic sediments were thrust northeastward (?) over the area and in places Cambrian strata came to rest upon Mesozoic shaly rocks. This movement was followed by crumpling of the sediments (and their overthrust burden) into moderately close folds. Massive and brittle strata broke when stressed too greatly and sought upward relief along both high and low angle faults.

Following the period of folding, a great mass of molten rock forced its way upward, stoping out large segments of rock in its path, pushing aside others and metamorphosing the adjacent sediments. Late, high-angle faults of small throw record a gentle settling at the termination of the compressive and igneous activity.

Further folding, faulting or igneous activity is not recorded in this portion of the Dragoons and orogenic forces appear to have been spent. The intense compression had raised these rocks to higher elevations. Erosion followed and in part stripped the pile to its core and buried the lower lying bases in a heavy mantle of alluvium. At a late date a slight uplift gave new vigor to the streams.

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