

GEOLOGY OF THE
SAN FRANCISCO MOUNTAINS,
WESTERN UTAH

by

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A thesis submitted in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

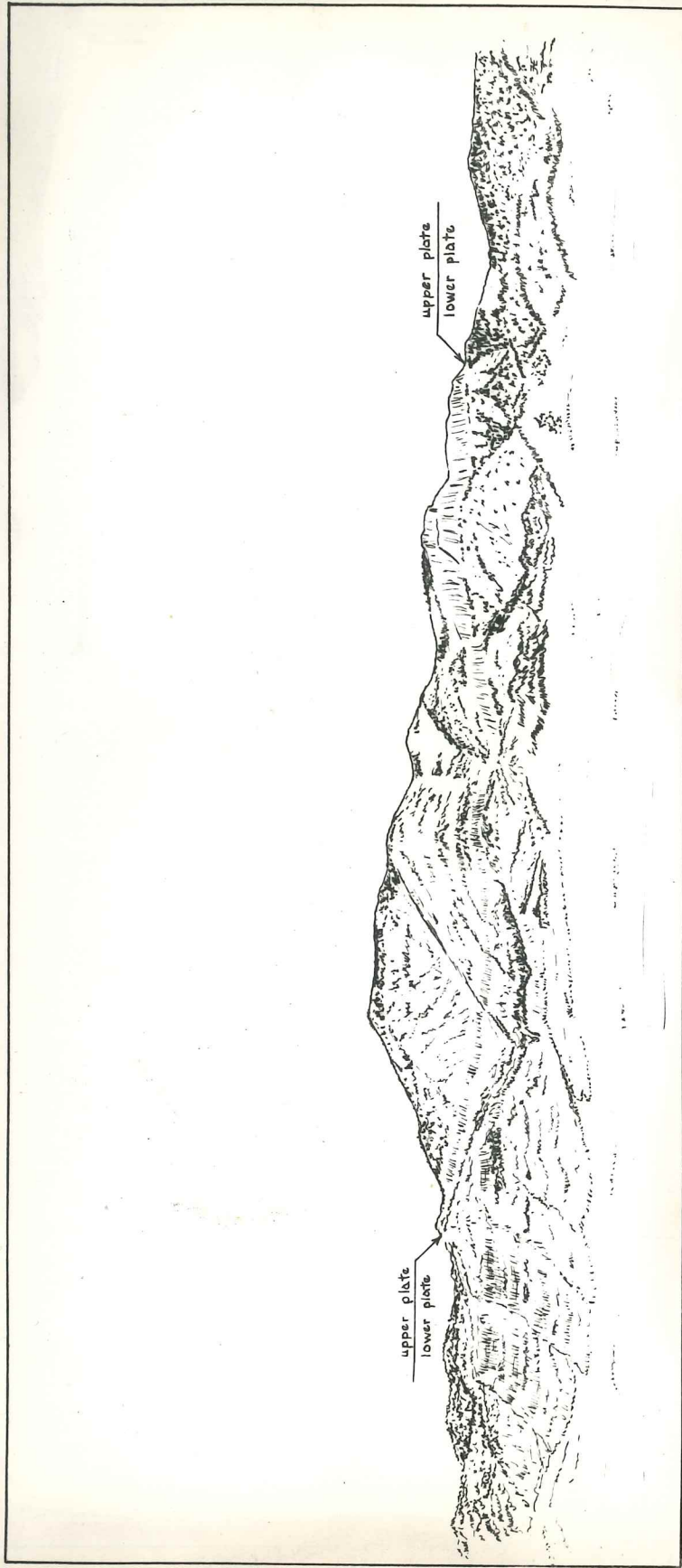
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VIEW OF FRISCO PEAK FROM WEST

Fig. 1. The upper plate is composed of Upper Pre-Cambrian and Lower Cambrian Prospect Mountain quartzite and the lower plate of Middle (?) - Upper Cambrian limestone and dolomite and Ordovician Pogonip limestone. The far right ridge is composed of a quartz monzonite intrusive stock which post-dates the thrust. The far left ridge in the background is also upper plate.

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INTRODUCTION

Geographic Setting

The San Francisco Mountains are a northeast-southwest trending range in the eastern portion of the Great Basin. The range is about 170 miles southwest of Salt Lake City slightly south of west-central Utah. The area (refer to index map, fig. 2) is in the north-central part of Beaver County in the western half of the Frisco Special Quadrangle. The geologic map (plate 1) is bounded by parallels $38^{\circ}25'$ and $38^{\circ}32'$ north and by meridians $113^{\circ}15'$ and $113^{\circ}21'$ west.

The area mapped encompasses the old San Francisco Mining District and extends about $8\frac{1}{3}$ miles in a north-south direction and 4 miles in an east-west direction covering slightly more than 33 square miles. The San Francisco Mountains rise rather abruptly on the west flank in less than 3 miles from Wah Wah Valley at an elevation of 5000 feet to Frisco Peak, (Quartzite Hill) 9648 feet above sea level. The slope is much more gentle on the east flank of the range. Near the ghost town of Frisco, the range slopes from 6500 feet to 5000 feet at Milford 15 miles to the east and farther north opposite the highest peak in the range, the slope begins at 7550 feet.

Accessibility

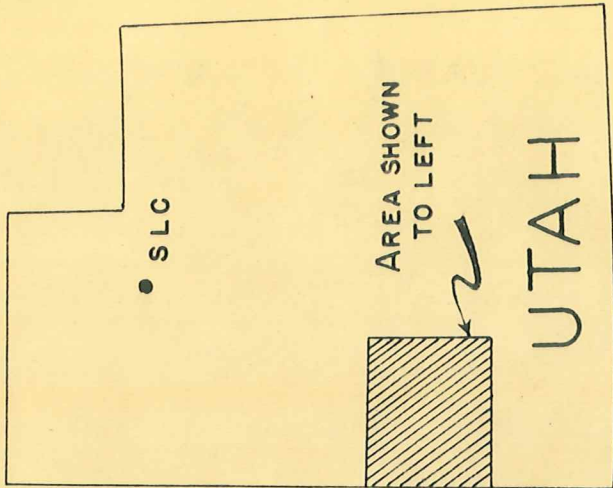
Access to the region is readily gained by Utah State Highway 21 which leads westward from Milford, Utah and skirts the southern foot of the San Francisco Mountains in Squaw Springs Pass. The highway crosses Wah Wah Valley which borders the range on the west side and then travels

in a northwest direction through the Wah Wah Mountains and into Pine Valley to Garrison, Utah located near the Nevada state line. The highway then passes through Baker, Nevada joining United States Highway 6 about 7 miles northwest of Baker.

Since the area is an old mining district, there are numerous dirt roads leading from the highway to the abandoned towns of Frisco on the east side of the range and Newhouse on the west side of the range and to the mines themselves. These roads are in various stages of repair; the more important roads are kept up by the grazing service for the use of the sheepmen. It is possible by these roads to drive high on the fans and pediments at several points on either side of the range in an ordinary sedan. Cloudbursts causing washouts however, are a constant threat to the mobility of the worker who does not have a vehicle with a 4-wheel drive as was my experience. An army trenching shovel with an adjustable head converting to a pick or shovel turned out to be an indispensable piece of field equipment for digging free a high-centered sedan.

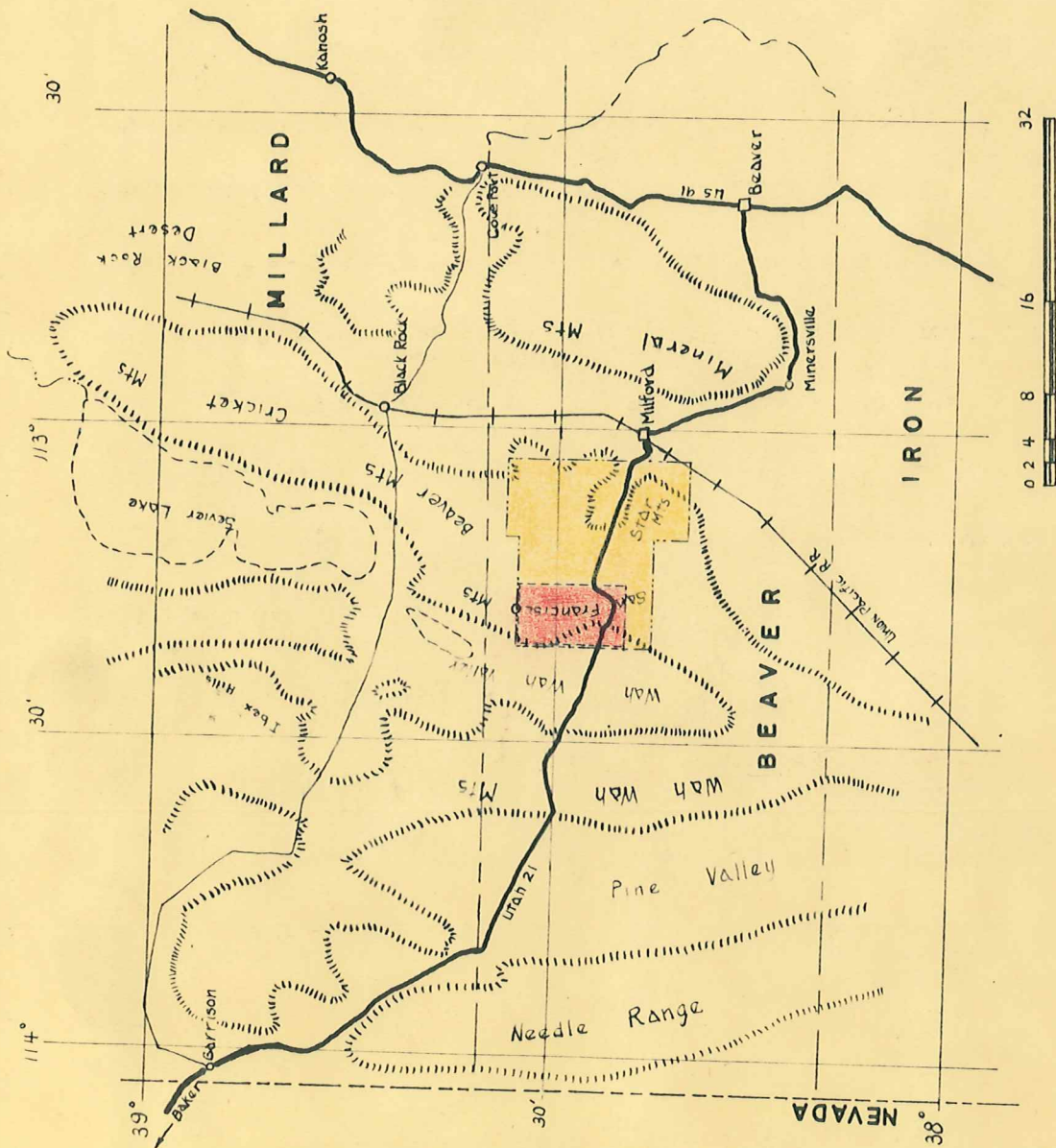
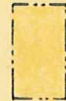
Previous Work

The areal geology of the Frisco Special Quadrangle was mapped in a reconnaissance fashion in the summer of 1908 by E. S. Butler of the Geological Survey. In the field season of 1909 he undertook the study of the ore deposits. The results of his work were published in 1913 in Professional Paper #80 of the Geological Survey. Butler has summarized quite adequately investigations previous to his study which had to do mainly with specific



AREA COVERED IN USGS
PROF PAPER 80

AREA COVERED IN THIS
PAPER



SCALE IN MILES

INDEX MAP

FIGURE 2

mines in the district and their associated ore deposits. An exception to this is a thesis presented to the University of Utah in 1908 by Joseph Jensen titled "Some Salient Features of the Geology of Newhouse, Utah and Vicinity." This thesis was not available to the author because the University of Utah was unable to locate it.

More recently S. W. Hobbs (1945) investigated the scheelite deposits in Beaver County, Utah and in his report reviewed the geology of the San Francisco District as mapped by Butler. He described in more detail however, the structure, stratigraphy, and contact metamorphism adjacent to the scheelite deposits on the Cupric Mines Company claim south of the intrusion in the vicinity of Loeber Gulch west of the Washington mine. Lehi F. Hintze (1949) has examined a fossil locality first described by Butler in Barrel Spring Canyon in connection with his study of the Ordovician stratigraphy of western Utah and eastern Nevada.

Field and Laboratory Investigation

Although a topographic base was available, actually photographs taken by Fairchild Aerial Surveys were used for field mapping because they had a larger scale and permitted far more accurate location of geological features. Each days mapping was inked at night in various colors. The topographic map was very useful in finding localities referred to in reports, for the determination of elevations and for other controls. After conclusion of the field work, the topographic map was enlarged to the scale of 1 inch to 2000 feet and the geology was transferred to this map from the photographs.

Stratigraphic thicknesses were determined graphically from scaled linear distances, known elevations, and the measured attitudes of the beds. Brunton traverses were employed to measure the thicknesses of smaller units.

In the laboratory, fossil determinations were checked and supplemented by Dr. William H. Easton of the University of Southern California. The fossil material is deposited in the Paleontology Museum, Department of Geology, University of Washington as Lot No. 26. Plate 2 (folder) is an index to the fossil localities. Collections of volcanic, igneous, and contact-metamorphosed rocks were sectioned and studied for classification. The identifications were checked by Dr. Peter Misch my thesis adviser.

I arrived in the field in mid-June of 1955 and spent 12 weeks mapping the area until the early part of September. Work was done from a mobile camp which consisted of a 7 x 9 floored and walled, lightweight tent, a folding camp table and chair, and a Coleman 2-burner stove and lantern.

During the latter part of the summer I was working in terrain unsuitable for pitching a tent so my car served as camp, the site being determined by how far my car would travel up the fans. I was able to camp near a spring for the first two weeks of the summer but thereafter my camps were dry and I had to bring water from Milford a distance of 15 miles. Springs with drinkable water are scarce in this part of Utah, and water is therefore of major importance to the geologist living in the field.

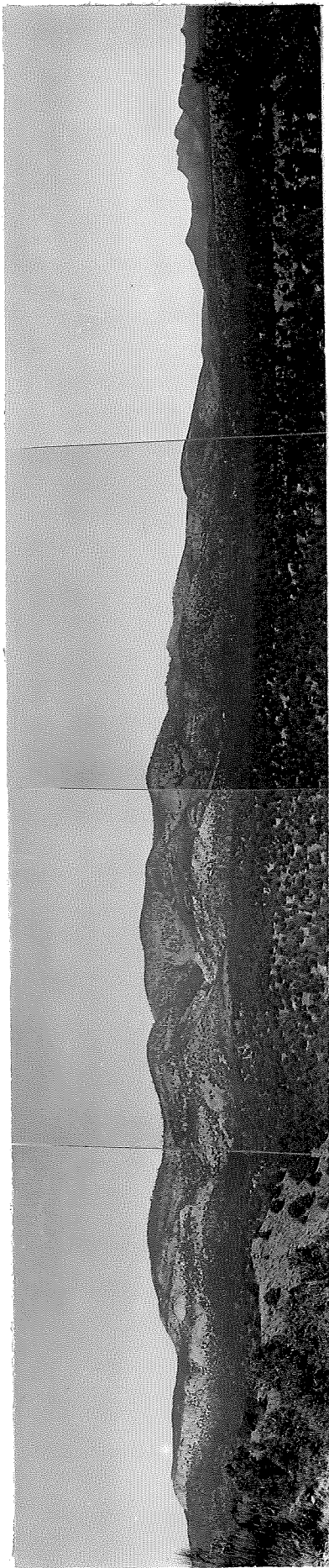


Fig. 3. View of Frisco Peak from east.

Purpose of Investigation

During the field season of 1954, while employed by the Union Oil Company of California I had an opportunity to do field reconnaissance in ranges adjacent to the area studied and to spend a day reconnoitering in the area that was later selected. The San Francisco Mountains of Utah presented an interesting structural problem and at the suggestion of Doctors Peter Misch and John C. Hazzard, the latter a representative of Union Oil Company of California, the area was selected for study.

The reason for the investigation was to examine the stratigraphy and structure of that portion of the geology of the Frisco Special Quadrangle outlined above. The original work was of a reconnaissance nature and more detailed work was deemed necessary to determine whether the stratigraphic sequence exposed in the San Francisco Mountains represents a conformable section as originally mapped by Butler or whether in reality the section is not conformable but included a large overthrust bringing older rocks over younger. Conclusive evidence was obtained that the upper portion of the range consists of a flat thrust sheet which had no root within the range and is therefore of a magnitude larger than the size of the present range.

Acknowledgements

I am most grateful to those people who spent time with me in the field not only for their new ideas and suggestions but for the mere companionship of their visits. I wish to especially thank Doctors John C. Hazzard and F. Earl Turner who took time from their busy schedules to see how I was

progressing. I wish to acknowledge the welcome visits of Dr. Clarence Allen with whom I worked the previous summer and of my brother, Gordon, who spent his vacation with me.

The study was made possible by financial assistance from the Union Oil Company of California who were also very generous in the loan of field equipment and in the procurement of air photographs. I would like to acknowledge the role played by Dr. William H. Easton of the University of Southern California who checked and supplemented the fossil determinations.

I owe very much to my professors at the University of Washington who discussed certain aspects of the thesis with me and I benefited greatly from talks with Dr. Peter Misch my thesis adviser who checked my petrographic work and who was a constant guide during the preparation of the manuscript and who critically read the thesis. Finally I cannot forget to say thanks to the kindly and generous folks of Milford who befriended me during my brief stay in Utah, and to my wife Margaret who assisted with the typing and preparation of the thesis.

COMPOSITE COLUMNAR SECTION


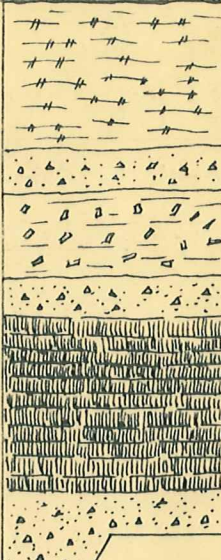
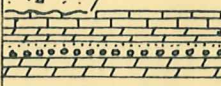
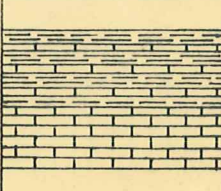
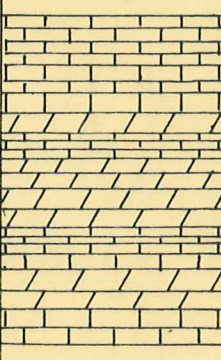

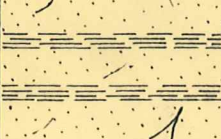
	AGE	NAME AND LITHOLOGY	DIAGRAMATIC SECTION	THICKNESS AND STRATIGRAPHIC RELATIONS
QUAT.		<u>Alluvium</u> : Pre & Post Bonneville fan and gravel deposits		
TERTIARY	Lower (Oligocene?)	<u>Tertiary Volcanics</u> : Undiff. flows and interbedded Igmmbrites; green acidic lithic tuffs, leucobasalts, red lithic and vitric rhyolitic tuffs, light gray vitric crystal rhyolitic tuffs, white vitric & lithic rhyolitic tuffs, and purple and dark gray coarsely porphyritic andesites		Exact thickness uncertain due to repetition by faulting; approx. imately... <u>4800'</u> In part overlies Ely ls. & Prospect Mt. qtz. Elsewhere base is cut out by faulting & intrusion.
	PENN.	Lower	<u>Ely Limestone</u> : Inter. mass. gray ls. & thin-to thick-bedded dol. & lenses of qtz. & chert pebble cgl.	 Top cut out in part by faulting, 670', base concealed by dol.
ORD.	Middle	<u>Pogonip Group - Kanosh shale</u> : Top buff, crinkly ls. inter. with green noncalc. shale, minor lenses of qtz., silst. & ss. Base - thin to med. bedded gray ls. locally altered to marble.		Top truncated by thrusting <u>1440'</u> Base terminated by faulting & igneous intrusion
	Lower			
CAMBRIAN	Upper	<u>Cambrian Limestone & Dolomite</u> : white & lt. tan to dark gray & black, banded, thin-to thick-bedded, platy to mass. wx., locally cherty, fine to coarsely crystalline inter. ls. & dol. Prom. lt. tan dol. mam. with dark gray band at top and bottom about midway above base of sequence.		Top of formation cut out by faulting and thrusting <u>3440'</u> Base not exposed
	Middle(?)			
CAL.	Lower	<u>Prospect Mountain Quartzite</u> : white, pink, reddish to purplish, fine to coarse grained, locally conglomeratic massive & cross-bedded quartzite. Inter. near base are green & red, micaceous, & quartzose siltstones & shales.		Top removed by erosion; thin cover of Tertiary volcanics locally preserved <u>3000'</u> Base in thrust contact with u. & m. Ord fm.
PRE-C.				

FIG. 4

STRATIGRAPHY OF BEDDED ROCKS

General Areal and Stratigraphic Relations

Sedimentary rocks of late pre-Cambrian, Cambrian, Ordovician, and Pennsylvanian age are exposed in the San Francisco Mountains and are composed of quartzites, shales, limestones, and dolomites of marine origin. The carbonate rocks have the greatest stratigraphic thickness and areal extent, the quartzites range second, and the shales are minor. Slightly more than 5 square miles of outcrop in the range is underlain by limestones and dolomites. Roughly 3 square miles is underlain by quartzites which overlie the carbonate rocks and form the crest of the range from the head of Copper Gulch to the northern boundary of the geologic map. A composite section totals 8550 feet of strata and represents mainly Cambro-Ordovician rocks. The Pennsylvanian rocks form minor hills and ridges in the southern part of the range and are under 1000 feet in thickness.

The range and consequently the sedimentary rocks are separated into a northern and southern part by an igneous intrusion. The greater portion of the sedimentary rocks are to the north of the intrusion but exposures have been preserved to the south in the vicinity of Crampian Hill and Squaw Springs Pass. The quartzite to the south is assumed to represent the same formation as the larger body of quartzite to the north, only separated by the intrusion, since both have the same type of lithology and topographic relation, occupying the summits of their respective areas. The dolomitic and calcareous Cambro-Ordovician section to the north is thought at one

time to have been continuous with similar rocks to the south before being disrupted and altered by the intrusion; however, fossil evidence to substantiate this point is lacking at Grampian Hill. On the contrary Dr. Easton is of the opinion that unidentifiable fragmentary fossil remains from this area have a Siluro-Devonian appearance.

Extrusive rocks of Tertiary age underlie about 2/3 of the area mapped. The volcanic sequence rests unconformably on the Paleozoic sedimentary rocks and consists of approximately 4800 feet of interbedded flows and pyroclastic rocks ranging from basalts to rhyolites. The volcanic rocks have been subsequently cut by the intrusive body as well as the sedimentary rocks.

Stream wash, alluvial fan deposits, and lake shore sediments mantle the lower slopes and basins bordering the San Francisco Mountains.

Stratigraphic Revision

The present work has revised the "Cambro(?) - Ordovician Grampian limestone" and the "Ordovician-Silurian(?) Morehouse quartzite" as originally mapped by B. S. Butler in the San Francisco Mountains. In this report, the Grampian limestone has been divided into 3 stratigraphic sequences of differing ages and the Morehouse quartzite has been placed at the base of the section (see fig. 5).

To familiarize the reader with the earlier work, Butler reported finding only one datable fossil zone in the San Francisco Mountains. These

COMPARISON OF SEDIMENTARY SEQUENCE IN SAN FRANCISCO MOUNTAINS

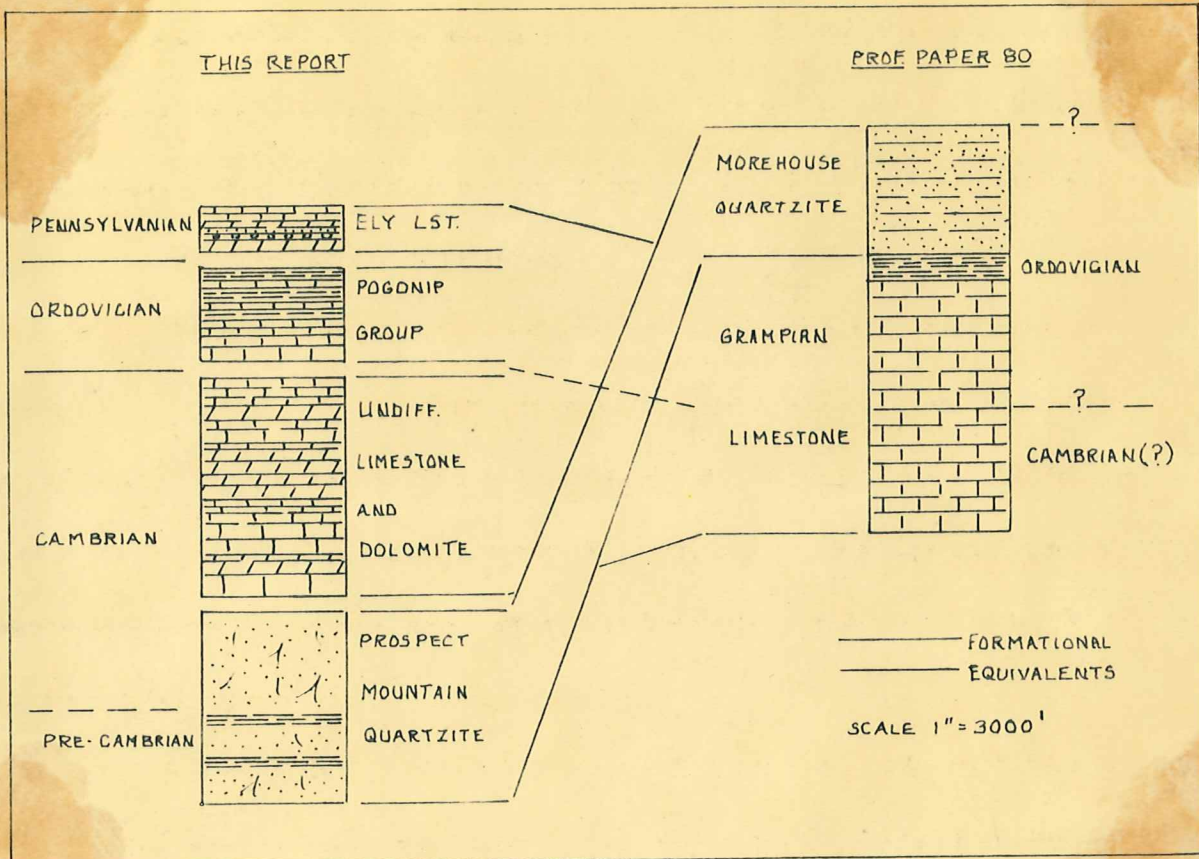


Fig. 5

fossils were collected in the Grampian limestone outcropping in Barrel Spring Canyon on the east side of the range. They were dated as Beekmantown by Girty and on the basis of this one find, Butler assigned the Grampian limestone to the Cambro(?) - Ordovician and the overlying Morehouse quartzite to the Ordovician-Silurian(?). His contention was that sedimentation must have begun in Cambrian time in order to accumulate the 4000 feet of strata which are exposed beneath the fossil bearing beds and especially since known Upper Cambrian rocks in the adjacent Wah Wah Range were similar in rock type to the strata beneath the fossil bearing beds in the San Francisco

Mountains. Butler's premise also was that the Morehouse quartzite immediately overlies the Lower Ordovician rocks in conformable succession and that it therefore is probably also Ordovician in age and might extend into the Silurian since in the nearby Star Mountains, he found a comparable quartzite to be conformably overlain by rocks of Devonian age and no break was evident between the rocks of Ordovician and Devonian age.

However, the finding of middle(?) and late Cambrian, middle Ordovician and early Pennsylvanian fossils in the Grampian limestone necessitated a correction in the stratigraphy as mapped by Butler. The occurrence of these fossils has permitted correlation of the enclosing Ordovician rocks with the Pogonip Group and the enclosing Pennsylvanian rocks with the Ely limestone. The Middle(?) and Upper Cambrian sequence was not differentiated because of the scarcity and poor preservation of the fossils in these rocks and the dolomitized character of the rocks.

The Morehouse quartzite has been correlated with the Upper Pre-Cambrian and Lower Cambrian Prospect Mountain quartzite and designated as such in this report on the basis of its thickness, rock type, and structural discordance with the underlying rocks. Therefore, it is placed at the base of the columnar section.

Upper Pre-Cambrian and Lower CambrianProspect Mountain Quartzite

Distribution and Contacts

The Prospect Mountain quartzite of the San Francisco Mountains originally called the Morehouse quartzite by Butler, underlies the crest of the San Francisco Mountains north of the intrusion and forms the bulk of the range for a considerable distance north of the area mapped. From the east, the range resembles the prow of a ship (see fig. 3) with the whitish-colored quartzite cliffs at the base forming the hull and Frisco Peak the bridge. From the west, an impressive sight is the reddish-colored, tree-covered slopes of quartzite north of the intrusion resting on lighter, black and white banded, cliff-forming limestone and dolomite beds that rise from the valley floor. The base of the quartzite gradually plunges northward hiding the carbonate rocks from view until the quartzite alone forms the base of the range. The tilt to the north may be explained in part by doming when the intrusion was emplaced; however, regional Tertiary deformation may better explain tilting affecting the length of the range since it extends for some 60 miles.

The Prospect Mountain quartzite is in thrust contact with the underlying shales and carbonate rocks of Middle Ordovician and Middle(?) and Upper Cambrian age. The base of the quartzite is largely concealed by alluvium on the east side of the range and also by volcanic rocks which are faulted against the quartzite except in Barrel Spring Canyon and a few

thousand feet north of this canyon where the quartzite is seen to overlies the Kanosh shale of the Pogonip Group. The quartzite overlies the same formation on the west flank of the range from north of the intrusion to the high east-west trending ridge northeast of the Indian Queen mine. High angle faulting juxtaposes Cambrian strata against the Ordovician rocks so that north of this high ridge, the quartzite is thrust over Upper Cambrian dolomite and limestone. The high angle fault between the Cambrian dolomite and limestone and the Ordovician limestone apparently passes beneath the thrust plate, concealing the Ordovician strata from view north of the ridge.

Two small klippe of Prospect Mountain quartzite covering less than one-eighth of a square mile remain south of the intrusion northwest of Grampian Hill (see fig. 6). The quartzite klippe are quite inconspicuous from a few thousand feet away, resembling the underlying formation in color and weathering. In part the underlying formation is limestone which has been altered to skarn. Although the quartzite outcrops north and south of the intrusion are no longer directly connected, the areal and structural relations of the quartzites indicate a former connection. Laterally both formations end at or near the intrusive contact and both occupy the summit of their respective areas and exhibit a discordant relation with the underlying formations. Unfortunately fossils are poorly preserved in the strata underlying the quartzite south of the intrusion and direct correlation with the Pogonip Group and Middle(?) and Upper Cambrian sequence north of the intrusion cannot be made.

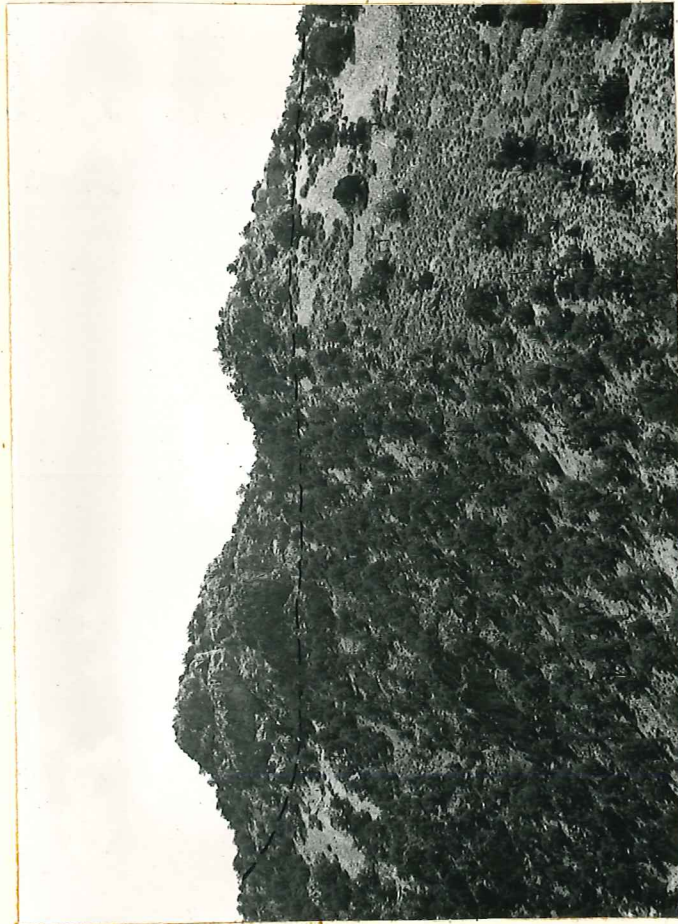


Fig. 6. View of Prospect Mountain quartzite klippe looking south from ridge northwest of Imperial mine. Dashed line indicates approximate position of thrust plane. Apparent offset of thrust plane between two klippe may be due to later warping or tilting. Underlying formation is undifferentiated Cambrian limestone altered to skarn.

Erosion has stripped away the formations normally overlying the Prospect Mountain quartzite in the San Francisco Mountains and also an undetermined thickness of the quartzite itself has been removed. However, reconnaissance north of the area mapped, in the Cricket Mountains reveals the presence of the overlying formations. Locally a much younger rhyolitic tuff-breccia overlies the Prospect Mountain quartzite. These volcanic rocks are exposed in a small area on top of the quartzite cliff immediately north of the intrusive contact. The tuff-breccia lies unconformably on a stripped bedding surface of the quartzite (see fig. 7) and near the base of this thin volcanic sequence, uniform, thin layering is exposed.



Fig. 7. View, looking south from the top of the cliff facing Copper Gulch, showing contact between Tertiary rhyolitic tuff-breccia and Prospect Mountain quartzite.

Lithology and Thickness

A cross-section of the San Francisco Mountains through Frisco Peak reveals approximately 3000 feet of Prospect Mountain quartzite. In its large areal extent, the quartzite formation displays a wide range of colors from snowy white to magenta, textures from very fine-grained to conglomeratic, and structures from thin-to thick-bedded and cross-bedded. However, the typical rock type is reddish-pink to magenta, medium-grained, thin-to thick-bedded quartzite which weathers into massive outcrops. The texture commonly varies to coarse-grained and pebbly with the included quartz grains in the granule size range (2 to 4mm). A striking quartzite pebble conglomerate has white quartz pebbles 1/16 to 1/2 inches in diameter in a reddish-purple, finer-grained, quartz matrix.

Included in the quartzite formation are finer-grained elastic rocks occurring as shale and siltstone members. Some of the shale beds are remarkable for their regular lamination caused by alternating red and white bands about a millimeter in thickness. Other siltstone and shale members are olive green and reddish-purple in color and micaceous and quartzose in composition. On the east side of the range a 60 foot shale member is exposed on top of the flat ridge south of Saw Mill Canyon above the Golden Reef Mine. The shale beds dip northwestward and can be traced in a circular outcrop pattern across the canyon. Figure 8 shows a view of this shale member in the above mentioned canyon. At least two shale members are visible on the west slope above the Kanosh-Prospect Mountain



Fig. 8. View of a shale member in Prospect Mountain quartzite taken on the north slope of Saw Mill Canyon. Note the lighter-colored blocks of quartzite talus lying on the shale.



Fig. 9. View looking north at cliff in Prospect Mountain quartzite which faces west overlooking Copper Gulch. The tree-covered slope in the right center of the photograph may conceal a shale member although the same ledge on the profile of the cliff shows no shale bedding.

contact from the ridge southeast of the Indian Queen mine. The shale members are not exposed farther south on either side of the range but they are suspected to be present in this area because of the prominent ledges in the quartzite cliffs. The shale is probably hidden by slumping of the quartzite on the inner margins of the ledge eroded in the underlying quartzite. Such a ledge is shown in figure 9.

Just north of the quartz monzonite intrusion the quartzite is fine-grained, massively bedded and snowy-white in color. The quartzite gradually changes to a pinkish hue northward along the bedding of the lower cliff on the west side of the range. The same beds maintain this white color on the east side of the range to the south slope of Barrel Spring canyon. Faulting has apparently dropped the whitish quartzite out of sight on the north slope since here, the quartzite is more pinkish in color. The quartzite also becomes more pinkish upward from the lower cliff. The explanation for this unusual whiteness of the Prospect Mountain quartzite may be a bleaching effect of the igneous intrusion since the color change occurs within individual beds.

Age and Correlation

Butler originally assigned the thick quartzite formation of the San Francisco Mountains an Ordovician-Silurian(?) age and established a new stratigraphic unit calling this formation the Morehouse quartzite. However, the writer strongly feels this quartzite formation is a correlative

of the Prospect Mountain quartzite and therefore is Upper Pre-Cambrian to Lower Cambrian in age. The age of the quartzite formation is determined by the lithologic correlation with the Prospect Mountain quartzite of the Eureka district (Hague 1883). This quartzite formation, originally considered as entirely lower Cambrian, has been assigned both to the Lower Cambrian and the highest Pre-Cambrian(?) by Wheeler (1944) in eastern Nevada and westernmost Utah. The correlation of the quartzite of the San Francisco Mountains with the Prospect Mountain quartzite is based on overall similarity in rock type and on the great thickness. Moreover, the same quartzite has been traced to the north into the Cricket Range and there it was found normally overlain by shale, quartzite and limestones (see below).

At the type locality at Eureka, Nevada, the formation consists of approximately 1500 feet of reddish-brown quartzite weathering dark brown intercalated with some thin layers of arenaceous shales. Besides the type area, the Prospect Mountain quartzite has been described from many other localities in the Great Basin. The Tintic and Brigham quartzites of north-central Utah are also stratigraphic equivalents.

Two localities where Prospect Mountain quartzite has been previously described, occur within a radius of about 60 miles of the San Francisco Mountains. Wheeler (1948) has measured some 5800 feet of Lower and Middle Cambrian strata in the adjacent Wah Wah Range, including 1200 feet of Prospect Mountain quartzite at the base of the section. The well-known Cambrian sequence in the House Range northwest of the San Francisco

Mountains first described by Gilbert (1875) and later more fully by Walcott (1908) was visited by the writer in 1954. Approximately 1000 feet of Prospect Mountain quartzite outcrops at the base of the range in the Marjum Pass area. Reconnaissance in the Beaver and Cricket Mountains which join the San Francisco Mountains to the north (see index map) shows that the quartzite outcrops continuously along the entire length of the range from the present area to the northern end of the Cricket Mountains where it disappears beneath the Black Rock Desert. North of the Black Rock-Garrison road, the formations that normally overlie the Prospect Mountain quartzite are still preserved. The formations include, in ascending order, the Pioche shale, the Busby quartzite, and undifferentiated Cambrian limestones. Even though a considerable width of outcrop is exposed in the Cricket Mountains, a series of strike faults has repeated the section several times so that no higher beds are preserved.

Since Butler's work, other writers have expressed opinions on the age and relationship of the "Morehouse quartzite" of the San Francisco Mountains, but so far as I am able to ascertain from published references, only Lehi H. Hintze visited the area and then just at one locality in the range. Kirk (1933, p. 38) states:

"Fitting the Frisco section into the general pattern of the Great Basin sediments, it is improbable that the Morehouse quartzite consists of other than Ordovician sediments. Further-it is undoubtedly the approximate equivalent of the Eureka quartzite....."

The thickness of the Eureka quartzite is everywhere very much less than that of the quartzite in the San Francisco Mountains, and also the

rock type of the Eureka is very much different. For instance, I have studied many outcrops of Eureka quartzite in the Ibex Hills area of the southern Confusion Range (see index map) and the difference in thickness between the two quartzites is quite apparent. The Eureka quartzite in the Ibex Hills area, which here appears to be at its maximum thickness in the Great Basin, is about 870 feet thick (Hintze, 1949) but it is usually around 500 feet or less in thickness. I have observed the Eureka to thin to around 50 to 100 feet in thickness at the northern end of the Fish Springs Range some 72 miles north of the Ibex Hills. Contrasted to this, the quartzite of the San Francisco Mountains is more than 3 times the maximum thickness of the Eureka quartzite. Not only in this area does the quartzite exceed in thickness the Eureka, but also wherever the Prospect Mountain quartzite is reported to occur in the Great Basin, it usually exceeds 1000 feet in thickness, as is illustrated by the two localities referred to above, and in most instances the base of the quartzite is not exposed.

The Eureka quartzite is also typically white, uniformly fine-grained, vitreous, massive-bedded, and weathers into spheroidal masses having a characteristic dark brown stain. On the contrary, the quartzite in the San Francisco Mountains is mainly reddish-pink to magenta (except where it has been apparently bleached white by the quartz monzonite intrusion), fine- to coarse-grained, locally conglomeratic, cross-bedded and contains siltstone and shale members.

Nolan (1943, p. 151) also writes that:

"...the quartzite as described by Butler differs lithologically from the Eureka at other places in the province, and there are some grounds for considering it an overthrust plate of Lower Cambrian quartzite."

Hintze (1948, p. 48) is of the same opinion as Nolan from his examination of the Kanosh shale in Barrel Spring Canyon in which he states:

"The Morehouse, a reddish to purplish quartzite, does not resemble the typical Eureka quartzite in Millard County, but is undoubtedly the equivalent of the lower Cambrian Prospect Mountain quartzite."

He goes on to say,

"The Morehouse is thrust on top of the Grampian limestone which is thought by the writer to be of Cambrian age,"

...and...

"These fossiliferous beds (referring to the Kanosh shale in Barrel Spring Canyon) were found to be isolated on all sides by faulting and are neither part of the Grampian limestone nor Morehouse quartzite."

However, as will be discussed below, the Kanosh shale is a part of the original "Grampian limestone" since it also outcrops extensively on the west flank of the range beneath the thrust sheet and therefore, the "Grampian limestone" is not entirely of Cambrian age as thought by Hintze.

In summary, there is conclusive evidence that the quartzite series of the San Francisco Mountains is not of Ordovician-Silurian(?) age or a correlative of the Eureka quartzite, but that it corresponds to the Upper Pre-Cambrian and Lower Cambrian Prospect Mountain quartzite. This evidence is: (1) the great thickness of the formation, (2) the distinctness of the rock type, and (3) the presence in the Cricket Range of conformable Cambrian formations normally overlying the quartzite in a sequence similar to that of the House Range.

Middle (?) and Upper CambrianLimestone and Dolomite

Distribution and Contacts

The Middle (?) and Upper Cambrian sequence mapped by Butler as part of the Cambro(?) - Ordovician Grampian limestone, forms the western base of the San Francisco Mountains from the northern contact of the igneous intrusion to a few thousand feet north of the area mapped where the sequence disappears as the contact with the overlying Prospect Mountain quartzite dips beneath the base of the range. The upper beds of this sequence are in part faulted against Ordovician strata and in part terminated by thrusting which brings the Prospect Mountain quartzite over the younger Cambrian beds north of the high east-west trending ridge which lies northeast of the Indian Queen mine.

This sedimentary sequence weathers to form massive, steep cliffs and in this respect contrasts with the slope-forming Ordovician rocks and even with the resistant Prospect Mountain quartzite where, although prominent quartzite cliffs are visible, much of the beds are concealed by slope wash.

Lithology and Thickness

The younger Cambrian rocks in the San Francisco Mountains are quite uniform in composition, consisting almost entirely of intercalated limestone and dolomite beds. However, these carbonate rocks vary considerably in color, texture, and structure. Good exposures of this sequence

which are readily accessible are north and northeast of the Indian Queen mine. Here massive limestone and dolomite cliffs rise from beneath the floor of Wah Wah Valley and the bedding in the cliff faces arches back into the range from an asymmetric anticline exposed at the very foot of the cliffs. Figure 10 shows a view of these beds. A typical characteristic of the formations in this sequence is their thin-to thick-layered, light and dark banded appearance.



Fig. 10. View, looking north, along the western face of the San Francisco Mountains from a point north of the Indian Queen Mine. Edm is Cambrian dolomite member; Eu is Cambrian undifferentiated. Beds in the lower left-hand corner of the photograph are bending over forming the crest of an anticline.

Limestone predominates over dolomite in the slopes and ridges above the Indian Queen mine but farther north, dolomite beds seem to be taking the place of the limestone members. Even though the limestone is more prevalent, a thick sequence of dolomite served as a stratigraphic marker in the field. It is light gray to whitish-gray, thick-bedded, cliff-forming, light tan weathering and has narrow bands of dark gray dolomite at the base and top (see fig. 10). This dolomite member proved to be continuous throughout the higher Cambrian outcrops and is shown on the geologic map as the Cambrian dolomite member. Above and below this marker bed the sediments are mainly limestone with intercalations of dolomite; however, a fairly thick series of dolomite outcrops in the vicinity of the Indian Queen mine which is stratigraphically below the marker bed.

The following is a generalized stratigraphic section comprising approximately 3440 feet of Middle (?) and Upper Cambrian sediments recorded on a traverse from the Indian Queen mine eastward to the corner of sections 28, 27, 33, and 34, T26S, R13W, and thence northward to the contact with the Prospect Mountain quartzite. Beginning at the base, the outcrops alongside of the road adjacent to the mine dump are:

1. Limestone and shale: gray and greenish banded, thin-bedded; interbeds of clay shale 1/16 to 1 inch in thickness.
2. Dolomite: gray, massive-bedded and crystalline; weathering light bluish-gray.
3. Dolomite: white, weathering in spheroidal masses, and gray, thin-bedded.

4. Limey dolomite: grayish-white, finely crystalline, thin-to medium-bedded; slabby and platy weathering.
5. Limestone: black, gray, and white banded, thin-to medium-bedded; black beds contain small gray, irregularly elongate organic (?) forms.
6. Dolomite: medium gray, thick-bedded; contains oval-shaped, bean-sized pisolites and thin layers of white calcite lying parallel to the bedding planes; approximately 20 feet thick.
7. Limestone: medium gray to dark gray, massive-bedded and cliff-forming; darker beds contain odd shaped organic (?) shadows or relics; approximately 100 feet thick.
8. Limestone: pure white, very coarsely crystalline; 10-15 feet thick.
9. Limey dolomite: grayish-white, thin-bedded and blocky weathering; about 5 feet thick.
10. Limestone: similar to unit 8; white, coarsely crystalline.
11. Limestone: medium gray, massive, cliff-forming.
12. Dolomite: (marker bed) light gray, massive-bedded; cliff-forming and light tan weathering; approximately 300-350 feet thick.
13. Limestone: gray, thin-to medium-bedded; weathers into buff-colored plates.
14. Dolomite: medium gray, massive-bedded.

15. Limestone: (outcrops which compose north-south trending ridge in vicinity of section corner) gray, thin-to medium-bedded, cliff-forming, but in part weathers to platy talus. Contains chert nodules near base and also odd-shaped algal (?) forms; elongate in outline having rounded tops and indistinct bottoms oriented at right angles to the bedding planes and having a thickness of from 1 to 1 1/2 feet. This same rock type continues to outcrop along the north-south trending ridge leading to the limestone-quartzite contact. In places this limestone weathers into small chips and also present are thin interbeds of intraformational conglomerate. On the ridge sloping from Frisco Peak where the upper plate projects farthest west, the upper limestone beds of the lower plate are tilted almost to a vertical position and the bedding surfaces of the limestone are stained purplish from their normal gray color.

Age and Correlation

The thick limestone and dolomite sequence of the San Francisco Mountains is dated as probable Middle and definite Upper Cambrian on the basis of fossil remains collected in three different localities representing 2 separate stratigraphic horizons. The fragmentary nature of the fauna prevents a more definite age determination of the sequence but enough is preserved to know it is certainly Cambrian; the absence at the base of the

section of the widespread Pioche shale also indicates that the sequence is younger than the lowest Middle Cambrian.

Dr. William H. Easton reports that fauna of loc. 33 contains Lingula sp., pelmatozoan ossicles, and trilobite fragments; loc. 34 contains Lingula sp., Sinuopea (?) sp., Bonnia-like cranidium, fucoids, and trilobite fragments; and loc. 35 contains a Crepicephalus-like pygidium and trilobite debris. The fossils of loc. 33 occur in beds beneath the dolomite marker and the fossils of locs. 34 and 35 occur in beds which represent the same formation and are exposed above the marker bed. Although the same beds which contain the fossils were examined in the traverse along the ridge east of the Indian Queen mine, the fossils were either not present, obscured or not noticed by the writer.

The locations of the fossiliferous beds are all north of the Indian Queen mine on the west side of the San Francisco Mountains (refer to pl. II). The outcrop which yielded loc. 33 is about 2700 feet north of the mine entrance on the next ridge north of the canyon which separates the strata in which the mine is located from the main body of younger Cambrian rocks (see geologic map). The fossils occur in slope-forming limestone beds just beneath the cliff-forming dolomite member. The rock containing the best preserved fossils is medium gray, thin-bedded, and weathers into plates 1/4 to 1/2 inch in thickness. Intercalated with the thin-bedded limestone are beds of limestone 4 to 5 feet in thickness. These beds form ledges on the slope and contain organic remains consisting mostly of

trilobite fragments which are packed into layers 3 to 4 inches thick. No determinable specimens could be obtained from these beds because of their massiveness and the fragmental nature of the fossil remains.

The fossils in loc. 34 were collected from limestone beds which immediately overlie dark gray dolomite (upper dark band of marker bed). The exact location of the fossil bearing beds is about 4000 feet up from the mouth of a major north-south trending canyon and about 100 feet above the bottom of this canyon on the west slope. This canyon heads on the north side of the ridge leading westward from Frisco Peak. The fossiliferous strata is medium gray, thin-to thick-bedded, reddish-tan and buff weathering limestone. The thin beds weather to form plates and slabs which have very irregular crinkly, bumpy or hummocky bedding surfaces.

The fossils in loc. 35 are found in limestone outcropping on the east slope near the mouth of the above mentioned canyon. These limestone beds immediately overlie the dolomite marker bed in which the floor of the canyon is cut. Figure 11 shows the limestone which contains loc. 35 and here on the east slope of the canyon it is a cliff-former with the thin interbeds separating the thicker beds containing the fossil fragments. The limestone beds containing locs. 34 and 35 cannot be traced but it is quite evident that they are the same beds because of the similarity in rock type and contained fossils. Furthermore, both series of beds occur in the same stratigraphic position, that is above the dolomite marker bed.



Fig. 11. View, looking northeast, of a limestone member in the younger Cambrian sequence exposed on the east slope of the prominent north-south trending canyon cut in the west flank of the range. Tribolite "hash" is abundant in the bedding surfaces of thin hummocky plates which erode from between the thicker beds of limestone. Note how the same beds have been faulted in a vertical position in the tree-covered slope in the foreground.

An interesting fossil occurrence which unfortunately is not datable is present in bluish gray, thin-to thick-bedded, cliff-forming limestone approximately 150 feet stratigraphically below the beds of loc. 33. The specimens are similar in appearance to Hyalolithes; they average about 1 inch in length and 1/4 inch in breadth at the open end and have a flattened oval cross-section.

Because the fossils from the dolomite and limestone sequence of the San Francisco Mountains are meagre and poorly preserved, direct correlation is not possible with the standard Cambrian fossil zones and formations described in the House Range. However, the probable occurrence of Crepicephalus in loc. 35 may indicate an equivalence of the beds carrying this fossil with the Weeks limestone of the House Range or the Mendha limestone of the Pioche district, Nevada, since according to Wheeler (1948) both carry the Crepicephalus zone. However, the evidence is none too conclusive, and since parts of the limestone sequence of the San Francisco Mountains have been dolomitized hampering a lithologic correlation with the formations of the House Range, the sequence is shown on the geologic map as undifferentiated Middle (?) and Upper Cambrian limestone and dolomite.

Cambrian-Ordovician (?) Undifferentiated

Limestone and Dolomite

Distribution and Contacts

The sequence of sedimentary rocks which underlie about 2 square miles of the San Francisco Mountains south of the quartz monzonite intrusion deserve separate discussion because they are not joined to the Cambrian and Ordovician rocks exposed north of the intrusion. This sequence is exposed just north of Utah State Highway 21 where it parallels the highway from the area of Squaw Springs westward for about 3 miles until it disappears beneath the alluvium. To the north, this sequence is bounded by the igneous body and is quite altered and replaced along the intrusive contact. To the east, volcanic rocks are faulted against the tilted strata composing Grampian Hill. Rocks of Pennsylvanian age are faulted against the southern slope of Grampian Hill terminating the sequence in this direction (see fig. 12). Elsewhere the base is concealed by alluvium. Locally, this sequence is discordantly overlain by 2 small klippen of Prospect Mountain quartzite which cap the ridges south of the Imperial Mine.

Lithology and Thickness

The lower part of this sequence is well-exposed in Grampian Hill. It consists of approximately 1600 feet of light and dark banded, white to gray and black, finely to coarsely crystalline, thin-to thick-bedded and locally crossbedded and cherty dolomite. Almost the entire series is

dolomite except for medium-bedded, gray limestone intercalated with the dolomite near the base of the hill on the south slope. A prominent 55 foot bed of black dolomite outcrops near the summit of Grampian Hill and can be followed westward along the cliffs rising above the alluvium. The unit is easily recognizable because it contains rounded, elongate, whitish chert nodules which lie parallel to the bedding planes. This dolomite member is well-exposed in Marble Gulch where the canyon cuts the bedding planes at right angles to the strike. Here, thin, closely spaced beds of a light gray color are intercalated with the black beds and extend upwards through 2/3 of the member. Overlying this unit is a white,

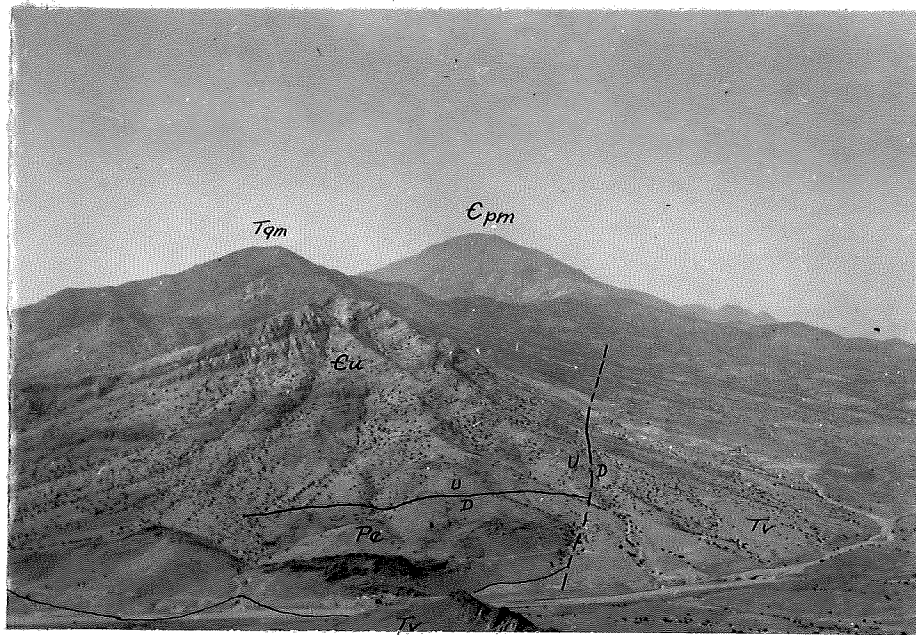


Fig. 12. View of the San Francisco Mountains from the south looking along the trend of the range. The peak in the foreground is Grampian Hill. The intermediate peak is in the quartz monzonite intrusion which underlies the crest of the range in the dark ridge beneath Frisco Peak in the background. *Pe* is Pennsylvanian Ely limestone; *Tv* is Tertiary volcanics; *Eu* is Cambrian undifferentiated; *Tqm* is Tertiary quartz monzonite; and *Epm* is Cambrian Prospect Mountain quartzite.

massively bedded dolomite which has about twice the thickness of the black member. The white dolomite is overlain by a dark gray, massively bedded dolomite which has about the same order or thickness as the white member. This unit is very conspicuous because the outcrops contain what I believe are recrystallized fossil fragments. The remains are thin and wispy, suggesting gastropods or brachiopods in outline, but the material was too badly altered for identification. Overlying the last described member is a thin unit of whitish to light gray, thin-bedded dolomite weathering into plates and containing rounded chert nodules and thin stringers of chert lying parallel to the bedding planes. This member also contains odd-shaped algal (?) forms similar to those described on the traverse above the Indian Queen mine (cf. above). Above this dolomite member, which appears to be the last unit of the dolomitic series, the topography changes to a small plateau and the next outcrops encountered at a higher elevation toward the intrusive contact consist of a grayish-white, medium-bedded limestone.

The black 55 foot dolomite member becomes lighter in color and finally loses its distinctness from the summit of Gramplan Hill northward toward the intrusive contact. All the strata in this vicinity are bleached light gray to white and recrystallized as a result of the igneous intrusion. Limestone also takes the place of dolomite along the ridge top toward the intrusive contact. The outcrops around and above the King David mine are composed of limestone and dolomitic limestone; however, the strata on strike to the south, composing Gramplan Hill proper, are

dolomite. To account for this apparent change of composition along the strike, either the dolomite has irregularly replaced the limestone across the bedding planes or faulting has brought the limestone against the dolomite series of Grampian Hill.

The beds outcropping along the length of the intrusive contact are limestones and are stratigraphically higher than the uppermost dolomite beds of Grampian Hill. The limestone series appears to be considerably thicker than the underlying dolomite series and may approach 4000 feet in thickness. However, the sum total of the dolomite and limestone series (1600 plus 4000 feet) has not been included in the thickness of the composite columnar section because it is not known how much, if any, of these rocks duplicate the measured Cambrian and Ordovician sections north of the intrusion.

Age and Correlation

This sedimentary sequence is part of the Grampian limestone as originally described by Butler. The formation received its name from Grampian Hill, and it was probably the outcrops in this vicinity that led Butler to conclude that all of the Grampian limestone was unfossiliferous except for the strata he encountered in Barrel Spring Canyon. Close scrutiny of the outcrops in this area by the writer has not revealed any identifiable fossils (cf. above). Besides the occurrence mentioned above, fossil-like structures were discovered in a medium gray, medium-bedded, finely crystalline dolomite on the southeast slope of Grampian Hill. This

series of beds is below a thick group of light-colored dolomite beds below the aforementioned black 55 foot, cherty dolomite bed exposed near the summit of the hill. These specimens were submitted to Dr. William H. Easton who reported that the age was not determinable but the specimens might be brachiopod fragments, and he felt that they had a Siluro-Devonian appearance. Also, float was picked up on Grampian Hill which contained plano-spiraled outlines suggesting gastropods but nowhere in the entire sequence was a recognizable fossil discovered.

Since the fossil evidence is not conclusive, this sequence is tentatively assigned to the Cambrian period because of its thickness and light and dark banded appearance typical of other Cambrian formations in the Great Basin. Some of the uppermost beds of this sequence may extend into the Ordovician, as is shown on the geologic map, since Ordovician rocks are associated with the Cambrian north of the intrusive body.

This is the simplest interpretation of the sequence and is strengthened by the fact that north of the intrusion the Prospect Mountain quartzite is thrust over Middle (?) and Upper Cambrian and Middle Ordovician rocks and south of the intrusion, remnants of this thrust sheet are still preserved. Therefore, it is reasonable to assume that since the upper plate is similar in rock type in both localities, the lower plate would also be similar in rock type in both localities, the intervening intrusion being only 2 miles wide.

Ordovician Pogonip Group

Distribution and Contacts

Sedimentary rocks of known Ordovician age outcrop on both flanks of the San Francisco Mountains. These rocks were originally included in the Grampian limestone by Butler. Extensive exposures on the west side of the range form the steep whitish slopes beneath the darker weathering vertical quartzite cliffs. This sequence extends from the intrusive contact in Copper Gulch northward to the high east-west ridge northeast of the Indian Queen Mine. A view of this slope and the overlying cliffs is seen in fig. 13. On the east flank of the range, exposures are limited to sparse outcrops in the mouth of Barrel Spring Canyon and northward along the base of the range to the tailings of the Golden Reef Mine.

Neither the top nor the bottom of the Pogonip Group is exposed in the range but correlation of the fauna reveals that the top is approached. The upper part of the section is terminated by a thrust plate of older rocks on either side of the range. Faulting and igneous intrusion have cut off the base of the sequence on the west side. Alluvium covers the base of the section in Barrel Spring Canyon, but a major range border fault is presumed to be present beneath the alluvium.

Lithology and Thickness

West Flank of the Range:

Erosion of the overlying quartzite formation has produced large scree slides, which cover much of the slope underlain by the Ordovician

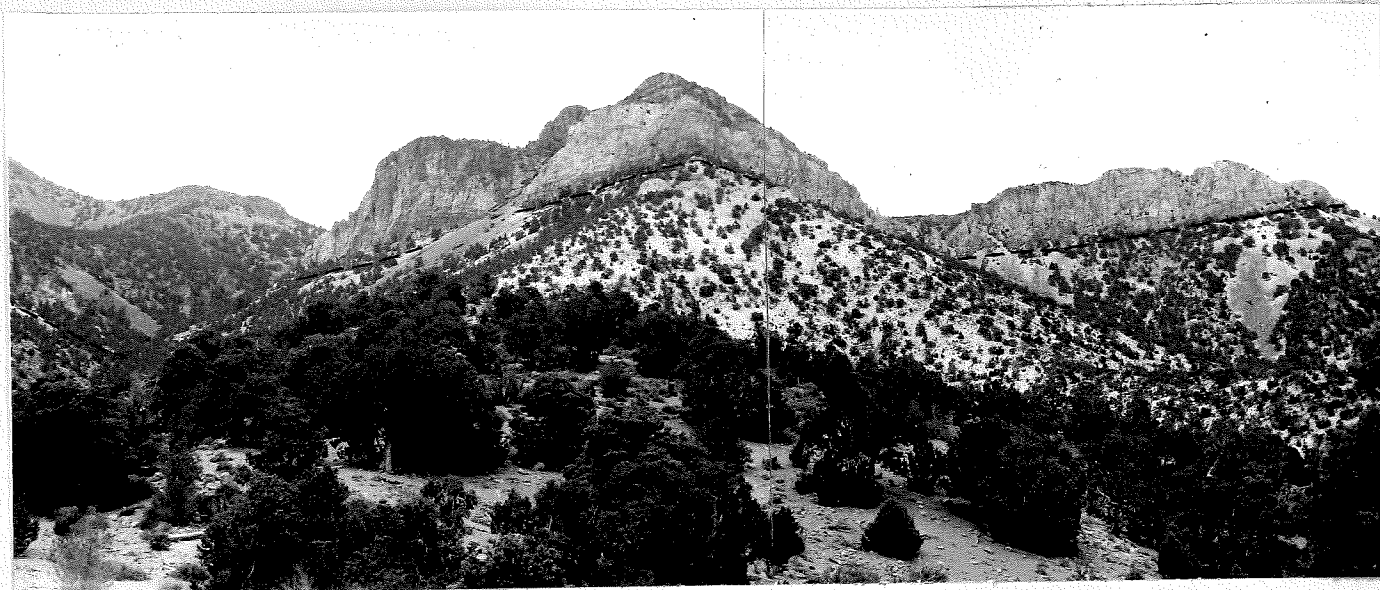


Fig. 13. View from west of Prospect Mountain thrust over the Pogonip Group. Copper Gulch is on the right. The tree-covered hill in the immediate foreground from which the photograph was taken is in the intrusive body. The dashed line marks the approximate position of the thrust plane. This thrust plane has been dropped by a normal fault in the left edge of the photograph. This view is looking up which causes some foreshortening.

sequence, nonetheless the limited lateral extent of the slides and bedrock projections through the talus establishes the continuity of the Ordovician strata. The section is primarily one of limestone which becomes more clastic in the highest part where interbedded shales and limey siltstones and also minor interbeds of quartzite and calcareous sandstones are exposed.

The maximum exposed thickness of the Ordovician sequence is 1440 feet as measured on the slope north of Copper Gulch. The igneous intrusion limits the lower portion and the massive quartzite cliff truncates the upper part of the section. At the base is grayish-white, thin-bedded, medium crystalline limestone which weathers into platy fragments.

Locally the limestone is recrystallized to a sparkling white marble but the texture decreases in coarseness away from the intrusion. For quite a distance up the slope, the rock type is quite uniform, being characterized by a "lacy" or "reticulate" bedding feature due to buff weathering, thin, undulating, less calcareous layers $1/8$ to $1/4$ inches thick which are separated by interbeds of limestone several inches thick. About halfway up the ridge the slope steepens considerably and here the limestone is fossiliferous. Most of the outcrops to this point are very smooth and slope wash is abundant. The first outcrops of any size are intercalated whitish-green, medium-bedded limestone and shale beds. The intrusion has locally altered the interbedded shales and limey siltstones to hornfelsic argillites. Overlying this is a prominent ledge which is visible from the old mine workings far below in Copper Gulch. The strata at this point are alternating white and gray beds of thin-bedded, fossiliferous limestone and hornfelsic argillite. The interbedded hornfelsic argillite above and below this outcrop is both dark brown and green in color. Above this outcrop to the Pagonip-Prospect Mountain contact, the slope is in interbedded limestone and hornfelsic argillite with slightly altered greenish, sandy limestone immediately below the overlying quartzite formation. A photomicrograph of this rock is shown in pl. 9, fig. 1.

A traverse farther north on a prominent ridge about a mile southeast of the Indian Queen Mine reveals that here the lower part of the section is faulted against Cambrian rocks. Beginning at the fault, the limestone is buff-colored, weathers into plates and displays the "lacy"

structure described above. The characteristic weathering which leaves the slightly less calcareous beds standing out perceptibly in relief is shown in fig. 14; it is interesting to note the resemblance of this outcrop to the structure of the contact-metamorphosed limestone in Loeber Gulch shown in fig. 23. The section becomes more shaly to the quartzite contact above a small knob on the ridge produced by the cliff shown in fig. 14. Gray limestone interbeds in the shale above the cliff weather into buff-colored, crinkly plates and are composed almost entirely of brachiopod valves and the ostracode Leperditia sp. The sequence also has lenses of brown, fine-grained quartzite and yellowish-brown, well-rounded and sorted, porous, calcareous quartz sandstone. Much of the slope underlain by shale is covered by platy limestone float, but in one locality, just beneath the quartzite contact, enough of the shale is exposed to show that the shale is in part highly contorted. Apparently the less competent shale beds yielded readily to the stress active during the thrusting.



Fig. 14. View of tilted cliff-forming limestone member in Kanosh shale of Pogonip Group.

East Flank of the Range:

The Ordovician sequence in Barrel Spring Canyon is not too well-exposed because brush and slope wash mask much of the bedrock. Resistant beds of limestone form ledges and are more conspicuous than the shale in which they are interbedded. The limestone is buff, weathers into crinkly plates, is thin-bedded and fossiliferous. Orthis michaelis Clark is quite abundant in some of the limestone ledges. The shale is blackish-green, noncalcareous, unfossiliferous and somewhat massive in appearance. A photograph (fig. 15) taken in Barrel Spring Canyon shows a 3-foot bed of quartzite in the shale. Deformation of the shale has also occurred in this locality as is shown by the small upright fan fold in fig. 16. The folding here is undoubtedly due to the same cause which deformed the shale in the Ordovician sequence exposed on the west flank of the range just below the thrust.

The bedding planes dip beneath the thrust plate in a northwesterly direction higher in the canyon, but toward the mouth of the canyon there is a reversal of dip toward the northeast which may be the result of drag on the normal range border fault or may be due to folding associated with earlier deformation. The thickness of the strata was not determined here although Hintze (1949) says that two or three hundred feet are exposed with the bedding planes dipping eastward with the slope.



Fig. 15. View of Kanosh shale in Barrel Spring Canyon. The hammer is lying on a shale bed and the massive block to the left has broken away from the overlying 3-foot quartzite interbed shown near the top of the photograph.



Fig. 16. View of small symmetric fan fold in the Kanosh shale exposed in Barrel Spring Canyon. The hammer is hanging on a bedding plane by the pick end for scale.

Age and Correlation

Fossils obtained from this sequence are of late middle Ordovician age. Two of the 6 fossil localities (22 and 40) contain gastropods and brachiopods that are so altered as to be unidentifiable but due to their occurrence in the same sequence they must be considered to be of the same age.

Ordovician Fauna

	Loc. 19	Loc. 26	Loc. 27	Loc. 28
Brachiopoda				
<i>Orthis michaelis</i> Clark	x	x	x	x
Gastropoda				
<i>Maclurites</i> ? sp.				x
<i>Maclurites</i> sp.			x	
<i>Raphistomina</i> ? sp.				x
Ostracoda				
<i>Leperditia</i> sp.				x
<i>Macronotella</i> ? sp.	x			
Porifera ?				
<i>Receptaculites mammillaris</i> Walcott		x	x	
Trilobita				
<i>Protopliomerops</i> ? sp.			x	

The only fossil occurrence found on the east flank of the range was in the strata exposed in Barrel Spring Canyon and the fossils therein were designated as loc. 19. The best collecting is on the north slope

near the canyon mouth. Outcrops north of the canyon to the Golden Reef Mine are very sparse due to the abundant quartzite float shed from the higher slopes.

A prominent limestone ledge outcropping on the west flank of the range high on the slope just beneath the vertical cliffs (cf. above) yielded the fauna of loc. 26. Receptaculites mammillaris Walcott was picked up as float lower on the slope below the strata containing the fossils of loc. 26; also, recrystallized organic remains occur in the bedrock below this zone. However, neither occurrence justified a locality designation.

The intrusion has greatly handicapped the recovery of material from this usually fossiliferous strata. An example of how the intrusion has affected the fossils has been mentioned in the cases of fossil localities 22 and 40 and it is also shown by a sectioned sample of slightly altered limestone collected near the contact. The hand specimen appeared unfossiliferous; however, a thin section of the rock (see pl. 10, fig. 2) revealed recrystallized brachiopod ? valves.

The fossils comprising localities 27 and 28 are found in strata on the ridge southeast of the Indian Queen Mine. The specimens of loc. 27 occur in the base of the limestone cliff shown in figure 14. The fauna of loc. 28 comes from limestone interbeds higher on the ridge in the more shaly sequence, just below the overlying massively bedded Prospect Mountain quartzite.

The shale formation of the Ordovician sequence containing interbeds of fossiliferous limestone is correlated with the Kanosh shale of the upper Pogonip Group on the basis of similarity in rock type and fauna. The Pogonip limestone has been studied in detail by Hintze (1951) in eastern Nevada and western Utah. He has measured more than 3000 feet of Pogonip in the Ibex Hills area (see Index map); he has recognized six lithologic units within the formation and has raised its status to that of a group, creating six new formations: the House limestone, the Fillmore limestone, the Wahwah limestone, the Juab limestone, the Kanosh shale, and the Lehman formation. The type section of the Kanosh shale is less than 25 miles to the northwest, on the north slope of Fossil Mountain in the Heckethorn Hills (adjacent to the Ibex Hills) which are the southernmost tip of the Confusion Range. According to Hintze (1951) the formation reaches its maximum thickness of 550 feet at the Ibex section K in the above locality and thins eastward.

The Kanosh shale is the uppermost limit of the Pogonip Group visible on either side of the San Francisco Mountains beneath the thrust sheet. Only the Kanosh shale is exposed in Barrel Spring Canyon but on the west flank of the range about 1200 feet of conformable strata is exposed beneath the lowermost beds carrying the Kanosh fauna. Due to the lack of identifiable fossils in this strata, exact correlation with the Ibex area cannot be made. It is reasonable to assume, however, that all of these strata belong in the Pogonip group because there are over 2300 feet of sediments

comprising the Pogonip Group beneath the Kanosh shale in the Ibex section, almost twice the thickness of the strata in question in the San Francisco Mountains.

In the absence of a definable lower boundary of the Kanosh shale along the western range front, the apparent restricted vertical distribution of Receptaculites mammallaris Walcott therein indicates the shale formation has been truncated. The above mentioned fossil was collected at only one horizon in two different localities in the Kanosh shale. The strata of loc. 26 containing this particular fossil are approximately 225 feet stratigraphically below the quartzite-shale contact and the strata of loc. 27 (about a mile to the northwest from loc. 26) also containing the above mentioned fossil are approximately 720 feet below the quartzite-shale contact. According to Hintze (1951), the faunal assemblage containing this fossil ranges from the base of the Kanosh shale upwards through about 300 feet of strata. Even if the fauna of the two locs. are at the extreme opposite ends of the range of the assemblage, it is still obvious that a different thickness of rock is present along the strike of the sequence from any given horizon to the shale-quartzite contact. The observed folding in the shale at the one locality is not of a degree to balance the difference in the thickness. Therefore, a southward truncation of the shale is indicated bringing lower parts of the sequence to view at the shale-quartzite contact in that direction.

Pennsylvanian Ely Limestone

Distribution and Contacts

The youngest sedimentary rocks outcrop in a northeast-southwest trending belt on both sides of Utah State Highway 21 in the vicinity of Squaw Springs. The outcrops are not continuous across the highway by reason of a low saddle covered by alluvium. Their continuity beneath the alluvium is indicated by a small inlier south of the highway midway between the larger exposures.

The exposure to the south is easily viewed from the highway and forms the low, rolling, light-colored hills the summits of which display thin beds of steeply dipping, darker-colored, more resistant strata. The exposures to the north begin only a few hundred feet from the highway and include a conspicuous dark brown hogback ridge folded in a sinuous pattern near the base of the southern slope of Grampian Hill as shown in fig. 17. The ridge is the north limb of an anticline plunging to the west with the southern limb partly removed by erosion. Fresh outcrops are seen in the abandoned railroad cuts above the dry wash adjacent to the highway.

North of the highway the top of the section is faulted against the older sedimentary rocks which compose Grampian Hill (cf. above) and younger volcanic rocks overlie the southern extremity of the exposure. South of the highway the Pennsylvanian strata dip beneath the alluvium except for a small width of volcanic rocks which overlie the strata and are continuous with the volcanic rocks forming the high hills to the east.

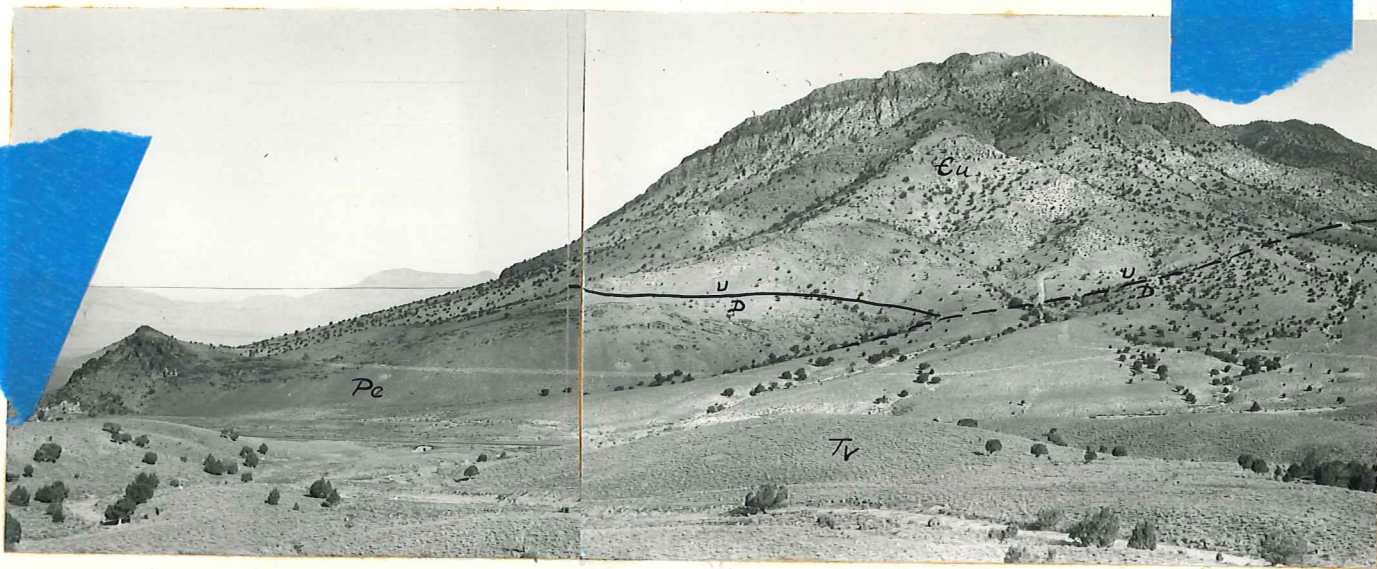


Fig. 17. View, from southeast, of Grampian Hill. The folded beds in the lower left are Pennsylvanian Ely limestone which are faulted against the Cambrian strata of Grampian Hill. The low rolling hills in the foreground are volcanic and the Wah Wah Range rises above the Ely limestone in the distant background.

The contact here appears to be depositional which has been subsequently deformed.

Lithology and Thickness

The Pennsylvanian sequence is composed primarily of carbonate rocks, including limestone and a large proportion of secondary dolomite. However, considerable quantities of clastic sedimentary rocks in the form of quartzite and chert pebble conglomerate are interbedded with the limestone and dolomite.

A good exposure of the Pennsylvanian rocks is seen in a cross-cutting gulch in the low rolling hills south of the highway. Access to the gulch is by a dirt road which leaves the highway about 3000 feet west of

Squaw Springs and then runs parallel to the hills and at the beginning of the gulch veers in a southeast direction.

Exposed in this gulch is an asymmetric anticline. From the axis of the anticline to the northwest, 670 feet of dolomite and chert pebble conglomerate are seen in beds steeply tilted to the northwest at an average angle of 55 degrees. The lower part of the section is composed of gray, medium-bedded dolomite containing nodular chert. The dolomite continues for several hundred feet until interrupted by 3 rib-forming beds of chert pebble conglomerate which lie within an interval of approximately 20 to 30 feet. These beds are from 1 to 4 feet in thickness consisting of rounded chert pebbles and cobbles up to 2 inches in diameter in a coarse sandstone matrix also composed of chert fragments and form the crest of the highest of the hills in the Pennsylvanian sequence. Overlying this member is a fossiliferous, light gray, thin-to medium-bedded dolomite which weathers to dark brown. In places the bedding approaches laminated structure and contains white chert bands usually masked by staining. Above the dolomite member last described the conformity of the section is broken by a minor thrust plane which has caused local structural discordance. Evidence in the rock of a movement plane is fractured and brecciated limestone and dolomite, reddish soil, calcite veins in the rock, and an almost 90 degree change of strike in the beds across the shear zone. Beds overlying this fault zone are light gray, thick-bedded, finely crystalline, fossiliferous limestone weathering into massive outcrops and containing chert nodules.

The thickness of this upper member could not be accurately measured and is not included in the figured section but it is approximately 200 to 300 feet in thickness.

Following the Pennsylvanian outcrops northeastward along their strike, massive-bedded, dark brown, very well-indurated, quartzite overlies the fossiliferous dolomite beds described above. The quartzite must thin out to the southwest, since it is absent in the section measured in the gulch. It is well developed north of the highway where it forms the dark brown hogback ridge described above that outcrops along the base of the southern flank of Grampian Hill. Conformably overlying the quartzite is gray, medium-to thick-bedded, finely crystalline limestone, some beds of which are crowded with crinoid (?) stems. Folding brings up the quartzite beds again farther north higher on the slope near the fault contact with the formations comprising Grampian Hill proper.

Age and Correlation

Fossils found in at least 4 different stratigraphic intervals in the outcrops in the vicinity of Squaw Springs indicate the sequence is lower Pennsylvanian in age. The only exception are certain limestone beds containing the horn coral Caninophyllum cf. C. incrassatum Easton & Gutschick, 1953 of probable lower Mississippian age (loc. 24) referred to below.

Dr. William H. Easton has identified the fossils from this sequence which include 6 locs. as follows:

Pennsylvanian Fauna

	Loc. 20	Loc. 25	Loc. 29	Loc. 30	Loc. 31	Loc. 37
Brachiopoda						
Composita sp.	x					
Composita cf. <i>C. ovata</i> Mather	x					
Composita <i>ovata</i> Mather				x		
Dielasma ? sp.	x					
Dictyoclostus sp.		x				
Dictyoclostus cf. <i>D. americanus</i> Dunbar and Condra						x
Juresania ? sp.		x				
Linoproductus ? sp.		x				
Orthotetes or Derbya	x			x		
Punctospirifer cf. <i>P. campestris</i> (White)	x					
Spirifer sp.		x			x	
Spirifer cf. <i>S. opimus</i> Hall				x		
Spirifer <i>opimus</i> Hall	x					
Spirifer <i>occidentalis</i> Girty	x		x	x		x
Bryozoa						
Tabulipora cf. <i>T. carbonaria</i> (Worthen)						x
Coelenterata						
Caninia sp.					x	
Triplophyllites sp.	x				x	
Echinoderma						
crinoid ossicles	x			x		
Mollusca						
gastropod ? fragment				x		

Specimens from the above localities may be collected within minutes of leaving the highway (see pl. 2). Across the wide wash from the old frame buildings at Squaw Springs and up the slopes leading to the dark brown quartzite beds, brachiopods contributing to loc. 20 can be seen protruding from the thick beds of dolomite below the overlying quartzite. Productids of loc. 25 occur in the same vicinity in gray, medium-to thick-bedded, finely crystalline limestone overlying the quartzite in a fairly recent road cut a few dozen yards east of a mine shaft headframe.

South of the highway in the low rolling hills (cf. above), the fossil zone occupying the same stratigraphic position as loc. 20 and collected as loc. 30 is much more continuous along its strike than the former. However, the strata bearing the fossil zone is offset by two transverse faults which shift the outcrops of the fossil bearing beds from the west side of the hill to the east side of the hill in a northeast direction.

At the northwestern end of the gulch in which the stratigraphic thickness of the formation was determined, fossils representing the horizon of loc. 30 occur in two distinct layers separated by 15 to 20 feet of unfossiliferous strata. Brachiopods are fairly abundant in from 3 to 10 feet of light gray, thin-to medium-bedded, crystalline dolomite in both zones and are in a better state of preservation than those collected at the same horizon north of the highway. This occurrence is included in the same lot because of the similarity of fauna in each and the limited thickness of unfossiliferous strata between the two zones. Moreover, two separate

faunal layers were not noticed wherever the particular fauna was encountered.

Beds containing loc. 31 stratigraphically underlie the beds containing loc. 30 by 150 feet in the same gulch and the fauna includes horn corals and one fragmentary Spirifer. These occur in the chert pebble conglomerate interbedded with the dolomite. The corals are not part of the pebbles but are distinct entities and may or may not be contemporaneous with the deposition of the clastic rock. It is the writer's opinion that the corals are of the same age as the enclosing rock because abrasion vigorous enough to round a durable rock like chert would certainly reduce a calcareous structure to sand. However, since the corals are silicified, it is possible that they had previously become silicified and were then re-deposited without being broken up.

The fossils listed as loc. 37 did not come from any one single bed but from limestone which everywhere overlies the dolomite producing loc. 30. They were put in the same loc. because the containing rocks are only sparingly fossiliferous and the fossils difficult to break out. The nature of the contact between the dolomite of loc. 30 and the limestone of loc. 37 does not appear conformable and evidence indicates that it is a fault contact; however, the contained fossils of both formations are of the same age and therefore the stratigraphic throw is apparently negligible.

The occurrence of loc. 29 containing Spirifer occidentalis Girty is in an inconspicuous inlier of massive-bedded limestone and quartzite

south of the highway between the two larger exposures of Pennsylvanian strata.

The limestone beds containing the horn corals identified as probable Lower Mississippian conformably overlie the dolomite beds which contain the early Pennsylvanian fossils of loc. 20 and are separated by less than 100 feet of stratigraphic thickness from these beds. The early Mississippian age of the corals of loc. 24 would make necessary two assumptions: namely an inverted section and a large hiatus between the Lower Mississippian and the Lower Pennsylvanian beds. Field evidence does not appear to support either assumption. Furthermore, the fossils of loc. 25 which are dated as probable early Pennsylvanian occur at about the same stratigraphic horizon as the supposedly Mississippian fauna. Therefore, since the identification of the horn corals of loc. 24 as early Mississippian is only tentative, I am inclined to include these limestone beds as part of the Pennsylvanian sequence.

The Pennsylvanian strata shown on Butler's geologic map as Cambro(?) - Ordovician Grampian limestone is correlated with the Ely limestone of eastern Nevada and western Utah on the basis of its fossils but with some reservation because of certain differences in lithology. The difference in lithology of the Pennsylvanian sequence compared to the type section (cf. below) are the included quartzite and conglomerate beds. The dolomite beds appear to be secondary in origin and therefore do not constitute any real difference.

The Ely limestone was first described by Lawson (1908) in the Robinson mining district near Ely, Nevada, but subsequently redefined and extended by Spencer (1917) in the same district. At the type locality the Ely consists of 2000 to perhaps 2500 feet of gray to bluish, dense, thin- to thick-bedded, massive limestone locally containing prominent chert nodules.

To the writer's knowledge the closest outcrops of dated Ely limestone occur in the Confusion Range of western Utah, a distance of 56 miles northwest of the San Francisco Mountains. Bacon (1948) correlated the Pennsylvanian formations in the Confusion Range with the Bird Springs limestone of southeastern Nevada; however, subsequently the Stratigraphic Committee of the Eastern Nevada Geological Association superseded the Bird Spring limestone with Ely limestone.

The Bird Spring limestone according to Hewett (1931) comprises 2500 feet of gray limestone and dolomite beds separated by shale and sandstone. A conglomeratic sandstone at the base of the formation in places is made of two or three lenses of closely packed well-rounded chert pebbles, whose maximum diameter is 4 inches. The description of the chert pebble conglomerate greatly resembles that of the conglomerate member of the Pennsylvanian sequence in the San Francisco Mountains.

Strata of Pennsylvanian age named the Elephant limestone have been mapped by Butler in the Star Mountains less than 10 miles distant

to the east. The described lithology* of the Elephant limestone corresponds to that of the Ely mapped by the author, and because of the geographic proximity, both formations are probably the same.

Other well-known formations of Pennsylvanian age besides the Ely and Bird Spring limestones are the Oquirrh formation of west-and north-central Utah, and the Calville limestone of the Grand Canyon area. The Oquirrh formation (Gilluly, 1932) is a very thick series of interbedded quartzites and limestones with the clastics predominating. The Calville limestone described in the Muddy Mountains by Longwell (1928) has about the same order of thickness as the Ely and Bird Spring limestones and is primarily a limestone sequence with intervals of shale.

From the foregoing lithologic description of the Pennsylvanian sequence in the San Francisco Mountains, the formation does not exactly fit any of those described but rather is a combination of several. It appears that the San Francisco Mountains is an area where the Oquirrh and Ely are intertonguing. The chert pebble conglomerate and quartzite members are probably extensions of the Oquirrh formation from the northeast whereas the carbonate members correspond to the normal Ely extending from the northwest. Nonetheless, the exposed section has a greater proportion of nonclastics to clastics and since the formational name Ely

*Butler (1913) p. 37, "...the Elephant limestone is a heavy-bedded blue dolomitic and in part rather siliceous (quartzitic ?) limestone."

limestone has the law of priority over the Bird Spring limestone, the Pennsylvanian sequence is correlated with the Ely limestone.

Tertiary Volcanic Sequence

Introduction

Alteration, faulting and poor exposures of the volcanic rocks have made it necessary to group the sequence as one unit on the geologic map. A stratigraphic succession will be described from one good section available in the district. This succession does not appear to be the same throughout the volcanic terrane; however, certain units seem to be more widespread than others and possible correlations exist between units exposed elsewhere and the standard sequence.

Distribution

North of Squaw Springs Pass, the volcanic rocks are tilted to the east and form low rounded foothills and ridges along the eastern flank of the San Francisco Mountains. The highest relief is in the hills just southeast of Squaw Springs. South of the Pass, the elevation of the range decreases and it is entirely underlain by volcanic rocks with the exception of the exposures of Ely limestone (cf. above). The eastward tilt persists in this area and locally very steep dips occur.

In the greater part of the San Francisco District, the volcanic rocks are either faulted against the Paleozoic sedimentary rocks or are cut by the intrusion. For this reason, the base of the sequence is rarely exposed; however, it is seen at least in two places. One locality has been mentioned previously in the discussion of the Prospect Mountain quartzite (cf. above) but unfortunately only a thin series of the volcanic rock remains.

The other locality is in the area where the Ely limestone crops out in Squaw Springs Pass. Although the contact between the Ely and the volcanic sequence is not well-exposed, the irregular pattern of the volcanic outcrops straddling the folded beds of Ely limestone are obviously the erosional remnants of an unconformable volcanic cover.

Stratigraphic and Petrographic Description

Volcanic Succession in Squaw Springs Pass:

The thickness of the volcanic succession in the one good area available for a detailed stratigraphic study is approximately 4800 feet. Inasmuch as the area appears to be complexly faulted as is seen wherever a fresh road cut or a prospect pit provides good exposures, the measured thickness may be exaggerated although repetition of the units studied was not actually observed with one possible exception. A view of some of the units in this area is shown in fig. 18.

Flows of latitic, andesitic and basaltic composition make up about 3000 feet of the sequence. The more acidic flows are the highest units and the basic flows are next to the lowest exposures in the succession. Occurring at the base of the succession and between the flows are tuffs and glasses of rhyolitic or acidic composition. The tuffs are fragmental in texture and are generally poorer in phenocrysts than the flows.

The stratigraphic succession in the volcanic sequence south of Squaw Springs is as follows:

Approx. maximum
thickness in feet

9. Dark gray porphyritic andesite)	- 1100
8. Light purplish-brown porphyritic latite)	
7. White rhyolitic vitric and lithic tuff	- 220
6. Brownish-gray rhyolitic crystall tuff	- 250
5. Mottled gray blue and green rhyolitic perlite	- 250
4. Red rhyolitic vitric tuff	- 230
3. Light purplish-brown hornblende leucobasalt	- 875
2. Reddish-brown leucobasalt	- 1000
1. Grayish-green crystal tuff	- 875

The individual units are described separately in ascending order beginning with unit 1 which outcrops 2000 feet S70W of Squaw Springs. The succeeding units are exposed in a southeasterly direction from this point in a section which extends to the summit of a prominent 7308-foot knob which is underlain by unit 9.

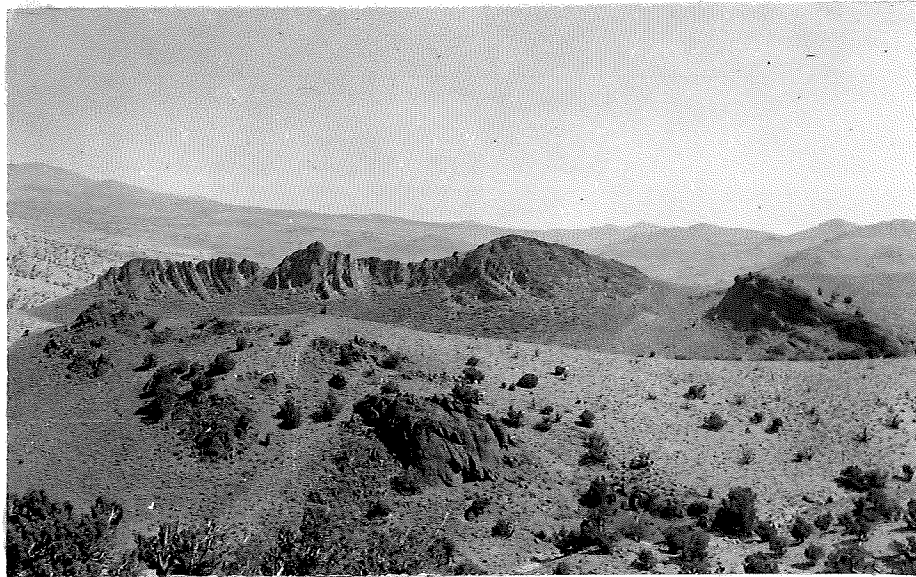


Fig. 18. View, looking northeast at a volcanic ridge exposed south of the highway in Squaw Springs Pass. The flows (unit 3) in the ridge have been steeply tilted to the southeast. The outcrop in the hill in the foreground is a red tuff (unit 4), and the outcrop seen at the far right of the figure separated from the steeply tilted flows by a small saddle, is also unit 4. The outer ring of hills in the right background are volcanic but those in the far left are in the quartz monzonite intrusion.

1. Grayish-green crystal tuff

A crystal tuff over 300 feet thick is the basal unit of the sequence and unconformably overlies the Ely limestone. Cobbles of gray limestone are embedded in the tuff and probably represent fragments of the underlying limestone. This unit weathers to a mottled reddish-purple color and shows a perceptible alignment of the grains. An irregular type of fracture pattern characterizes the outcrops. The tuff is moderately indurated, but does not ring to the blow of the hammer. It has a uniformly finely granular appearance due to the abundance of crystals and crystal fragments. The upper part of the unit displays a more uniform layering. In the area of the traverse, alluvium covers much of this green tuff; however, the contact with the overlying unit is exposed farther south.

In thin section (pl. 3, fig. 1) the tuff is seen to have a fragmental texture and is composed predominantly of angular, broken phenocrysts and euhedra of plagioclase and quartz in a greenish chloritic matrix. Biotite, hornblende and fragments of volcanic rock are also present in lesser amounts. The plagioclase includes both andesine and labradorite, the An content ranging from An_{30} to An_{64} . The plagioclase phenocrysts constitute about 55% of the rock. The quartz crystals are resorbed in part and make up 10% of the rock. Foils of biotite are partially altered to magnetite and many are bent indicating compression. The hornblende is green. Its alteration product, chlorite, has imparted a green color to the matrix of the tuff. Together, the mafics and rock fragments constitute about 10% of the unit. The

remaining 25% is matrix. This is the smallest amount of matrix observed in any of the units of the volcanic succession; generally the matrix makes up over 50% of the volume of the rocks studied.

2. Reddish-brown leucobasalt

In the field this member and the overlying unit (3) have the appearance of typical andesite flows. Unit 2 is about 1000 feet thick and is massive with no apparent flow banding, although its weathering produces fractures which suggest flow structure. The flow is finely and abundantly porphyritic, the phenocrysts being difficult to distinguish from the matrix.

The lower of the two flows (unit 2) is classified as a porphyritic tholeiitic leucobasalt because olivine is absent, because the plagioclase is labradorite, and because feldspar greatly predominates over the mafics. Under the microscope (see pl. 3, fig. 2) about 30% of the rock consists of plagioclase phenocrysts ($Ab_{43}An_{57}$). Augite phenocrysts comprise about 5% of the rock. Phenocrysts of biotite and basaltic hornblende are minor constituents. Magnetite may make up as much as 5% of the rock. The matrix is a dusty divitrified glass which exceeds 50% of the rock volume.

3. Light-purplish-brown hornblende leucobasalt

The upper flow (unit 3) is differentiated from the underlying flow by abundant hornblende phenocrysts seen in the hand specimen. It has about the same order of thickness as unit 2 but the outcrops show very even flow layers from 1 inch to several inches in thickness. The color of the

matrix changes from light purple to gray in the exposures in the hills southeast of the Ely limestone cropping out south of the highway.

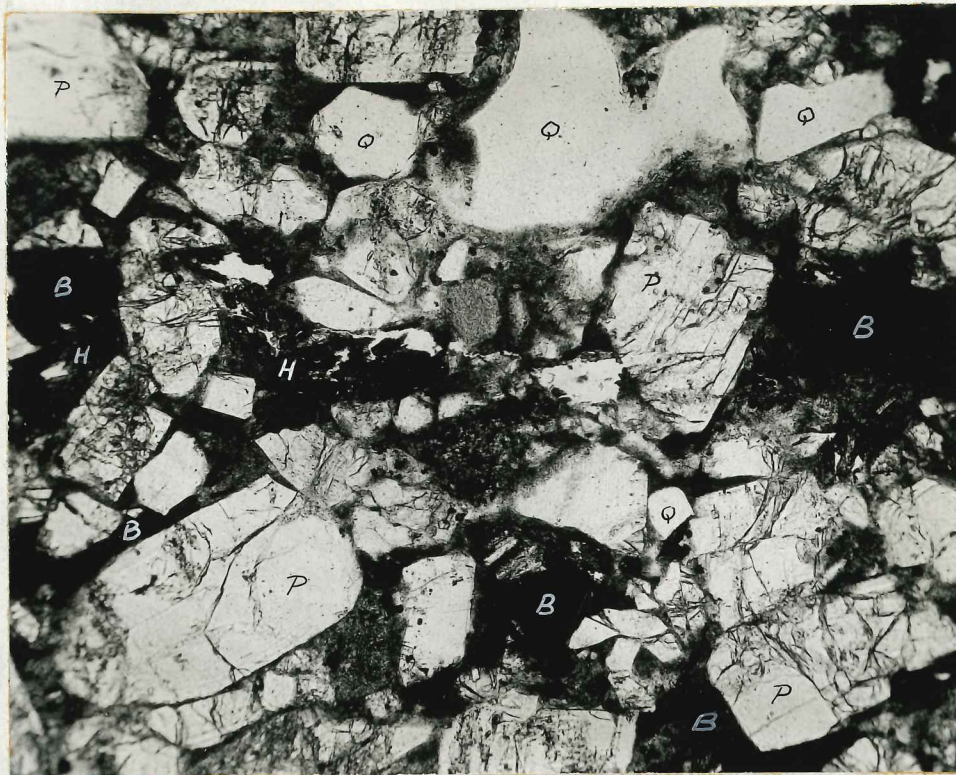
Like unit 2, this flow is also classified as a tholeiitic leucobasalt and for the same reasons. In thin section (pl. 4, fig. 1) the plagioclase phenocrysts are determined as labradorite very close in composition to that of unit 2, namely $Ab_{41}An_{59}$. The plagioclase phenocrysts make up about 25% of the volume of the flow. Basaltic hornblende is the dominant mafic phenocryst constituting about 10% of the volume of the rock. Many crystals are oriented as six-sided basal sections. The few flakes of biotite observed where altered. Augite crystals are more abundant than the biotite but still constitute less than 5% of the rock volume. Magnetite is an accessory mineral. The matrix is devitrified glass which comprises about 55% of the flow.

4. Red rhyolitic vitric tuff

This member appears to be repeated by faulting although an apparent offset of the outcrops may be due to erosion rather than faulting since the critical areas are covered which lie in the saddles between the ridges. This unit is limited in areal extent along the strike of the outcrop but may reach 200 feet at its maximum thickness. The rock is moderately indurated, miarolitic, and contains phenocrysts. The matrix is dense and dull, resembling unglazed porcelain whereas the previous two units have a finely crystalline groundmass. The unit as a whole is fairly massive but fine banding was observed, suggesting that parts of the unit flowed.

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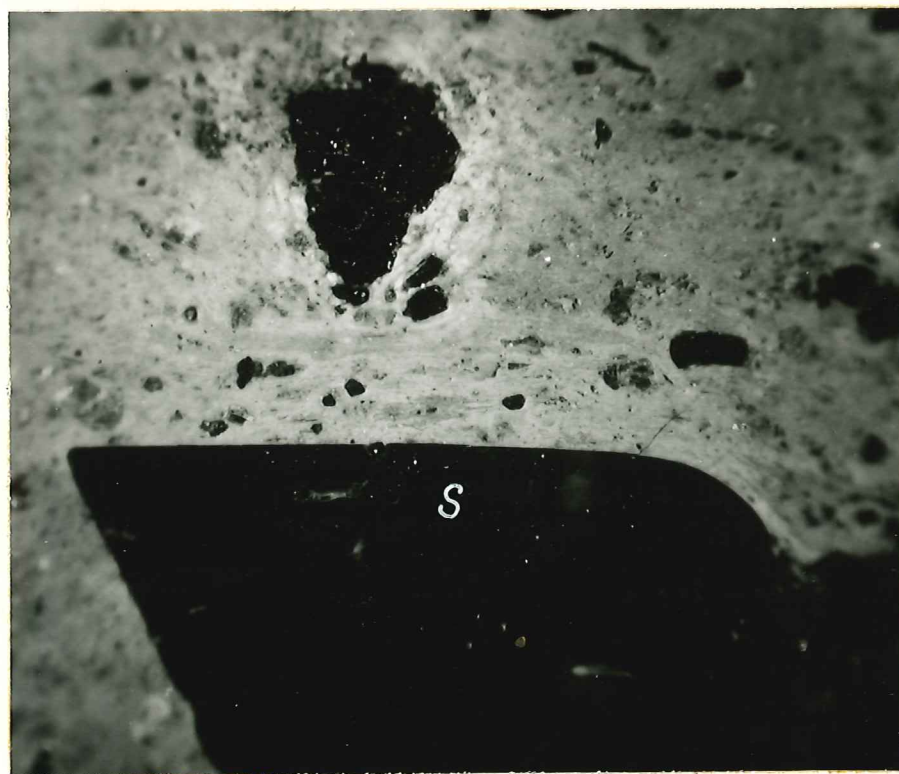
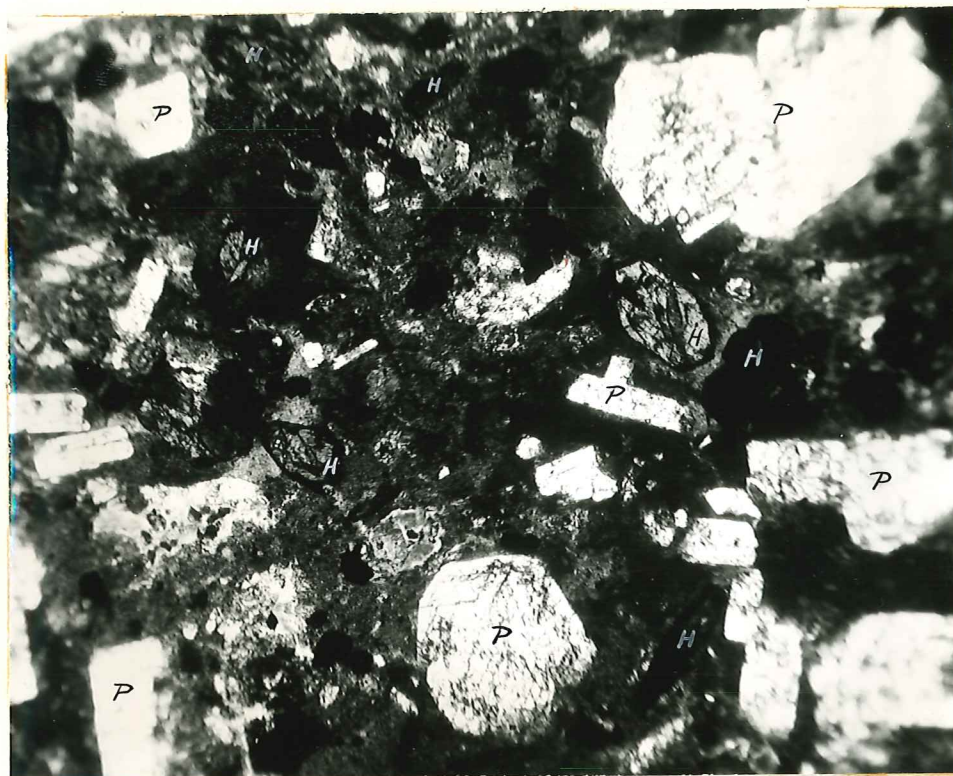
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Under the microscope (pl. 4, fig. 2) the vitroclastic structure is obscured by subsequent devitrification, but thin dark lines which represent the collapsed pores of original pumice fragments prove the pyroclastic origin of the unit. Sanidine occurs in large twinned phenocrysts. It is the most abundant mineral constituting about 15% of the rock. Quartz and magnetite each make up less than 5% of the tuff. Many rectangular cavities in the rock contain a soft, white fibrous mineral which swells in water and is lost in cutting of the rock. The swelling character of the mineral suggests montmorillonite which may have formed from plagioclase phenocrysts since the cavities, without the white mineral, resemble crystal moulds of feldspar. Certain well-defined areas, lighter in color than the rest of the rock, in part lenticular and in part blunted in outline, from a few millimeters to 3 and 4 centimeters in length, are full of vesicles or miarolitic cavities. These areas usually are orientated parallel to the surface of the unit and may range from a crude alignment to a very uniform even foliation with an increase in the number of lenticles present.

5. Mottled gray blue and green rhyolitic perlite

The perlite and the next two units have been mapped as separate members because they are distinctive in the field, but they are believed to represent three varieties within a single depositional unit which have been modified after deposition. Together the three subdivisions (units 5, 6, 7) have a combined thickness approaching 700 feet. This unit (5) is quite brittle and crumbly due to its perlitic fracture. Layers similar in rock



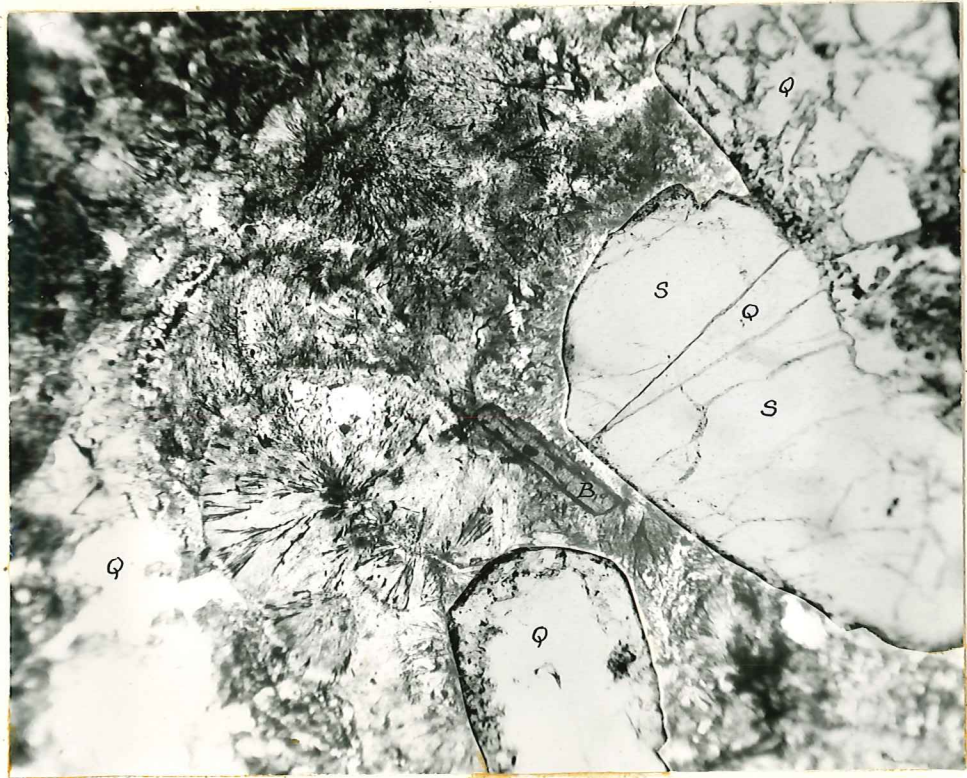
type to the overlying unit are present near the top of the perlite member. Locally the perlite grades into creamy-pink, dense, hard glass. This rock is quite similar to the perlite except for the difference in color and it does not have a perlitic fracture.

In thin section the perlite shows a few scattered phenocrysts embedded in a glassy matrix (see pl. 5, fig. 1). The rock is judged to be rhyolitic in composition, assuming that if the matrix had been able to crystallize, it would have formed crystals similar to the phenocrysts present. The phenocrysts observed are sodic plagioclase, sanidine, quartz and biotite. The plagioclase has a composition near the boundary of oligoclase and andesine, namely about $Ab_{70}An_{30}$. Biotite and plagioclase euhedra are present as discrete crystals. Brecciated plagioclase, quartz and sanidine crystals are segregated in veinlike aggregates in the matrix.

6. Brownish-gray rhyolitic crystal tuff

This member is quite resistant, massive in outcrop, and tends to form a cliff. The rock is also very siliceous in appearance. Hand specimens are obtained only with some difficulty from the outcrops. This unit is characterized by rounded concretion-like structures a few inches to several feet in diameter which weather from the outcrops. In some instances lithophysae are present in the exposures. Closely spaced foliation was observed which may represent actual flowage.

Although this tuff consists of about 85% of devitrified glass, it is assumed to have a rhyolitic composition, on the same grounds used in



case of unit 5. The hardness and strong cohesion of the rock suggests that the unit is a welded tuff, although devitrification has destroyed any evidence of vitroclastic texture. Spherulites have grown in the matrix (see pl. 5, fig. 2) and fine crystallites radiating from their centers may be intergrowths of potash feldspar and quartz. Large phenocrysts of sanidine compose about 10% of the rock and minor amounts of quartz, biotite and magnetite are also present.

7. White rhyolitic vitric and lithic tuff

This unit is uniformly massively bedded and weakly resistant to erosion. The tuff is light in specific weight, porous, somewhat friable, and contains numerous fragments of darker-colored volcanic rocks as much as 10 and 15 mm in diameter.

Broken euhedra of quartz, plagioclase, sanidine and biotite crystals (see pl. 6, fig. 1) are embedded in a glassy ash matrix which is in part devitrified. The plagioclase is probably oligoclase-andesine since those few phenocrysts favorably oriented for determination have low (10°) extinction angles measured from the trace of the 010 plane and since the optic sign is negative. The plagioclase is the dominant kind of phenocryst, constituting 7 to 10% of the rock. The quartz, sanidine and biotite crystals are about equal in amount, and together form about 20% of the rock. Hornblende is rare. Rock fragments are more abundant than any one mineral, constituting an estimated 15% of the tuff.

To summarize, the last three units are varieties of a single unit; (a) the perlite represents a basal glass phase, (b) the crystal tuff is a middle welded phase, and (c) the lithic tuff is an upper poorly consolidated phase.

8. Light purplish-brown porphyritic latite

Above the white tuff exposures the slope steepens considerably to the summit of the 7308-foot nob which is the highest point in the volcanic sequence. Two prominent cliffs occur on the steepened slope. Units 8 and 9 form the cliffs and the intervening slopes and have a combined thickness of over 1000 feet. These two units are similar in texture but differ in matrix color. Unit 8 is a massive flow with little evidence of flow banding. It has a conspicuous coarsely porphyritic texture and approaches a porphyry in character. Large phenocrysts of feldspar up to 10 mm in length are responsible for this texture.

In thin section the plagioclase phenocrysts of the specimen are determined to be oligoclase ($Ab_{75}An_{25}$) and are joined together in clusters giving the rock a glomeroporphyritic texture. Several of the plagioclase crystals are intergrown with sanidine (see pl. 6, fig. 2). Sanidine accounts for 15% of the rock. The mafic minerals present are biotite, hornblende, and augite; their phenocrysts are less than 1/10 the size of the plagioclase crystals. The biotite and hornblende are altered, leaving clusters of magnetite. Very large numbers of tiny crystallites and microlites are also present, embedded in a glassy matrix which composes about 50% of the rock.

PLATE IV

Fig. 1. Photomicrograph of white fly, the white fly (Trialeurodes vaporariorum)
(ant. 1). The figure represents the right eye (Fig. 1) containing 8
and black (Fig. 1) and the white fly (Trialeurodes vaporariorum). The black
crystal appears as a dark spot in the center of the
retina. Note the structure of the eye, which is
shown in the lower part of the figure.

Fig. 2. Photomicrograph of the right eye of the white fly (Trialeurodes vaporariorum)
(ant. 1). The figure shows the right eye (Fig. 2) which has
a rim of pigmentation (1) and contains a crystalline substance
in the center of the eye, the structure of which is shown
in the lower part of the figure. (A) and (B) are also present on the
side of the eye. (Fig. 2) (A) and (B) are also present on the side.



9. Dark gray porphyritic andesite

The upper of the two cliffs mentioned above is composed of a coarsely porphyritic, massive flow which is much darker-colored than the underlying unit (8). This member continues to underlie the hill to its summit.

Like the underlying flow, this unit has a glomeroporphyritic texture. Zoned plagioclase laths of andesine composition (average $Ab_{58}An_{42}$) are joined in clusters and compose 25% of the flow. Some of these phenocrysts also have inclusions, partly concentrated in dusty rims (see pl. 7, fig. 1) of the euhedra, and partly scattered throughout the crystals. Augite forms 5% of the rock. Hornblende, biotite and magnetite each make up less than 5% of the volume. The matrix is glass which is crowded with microlites of feldspar that almost appear to give the rock a holocrystalline texture.

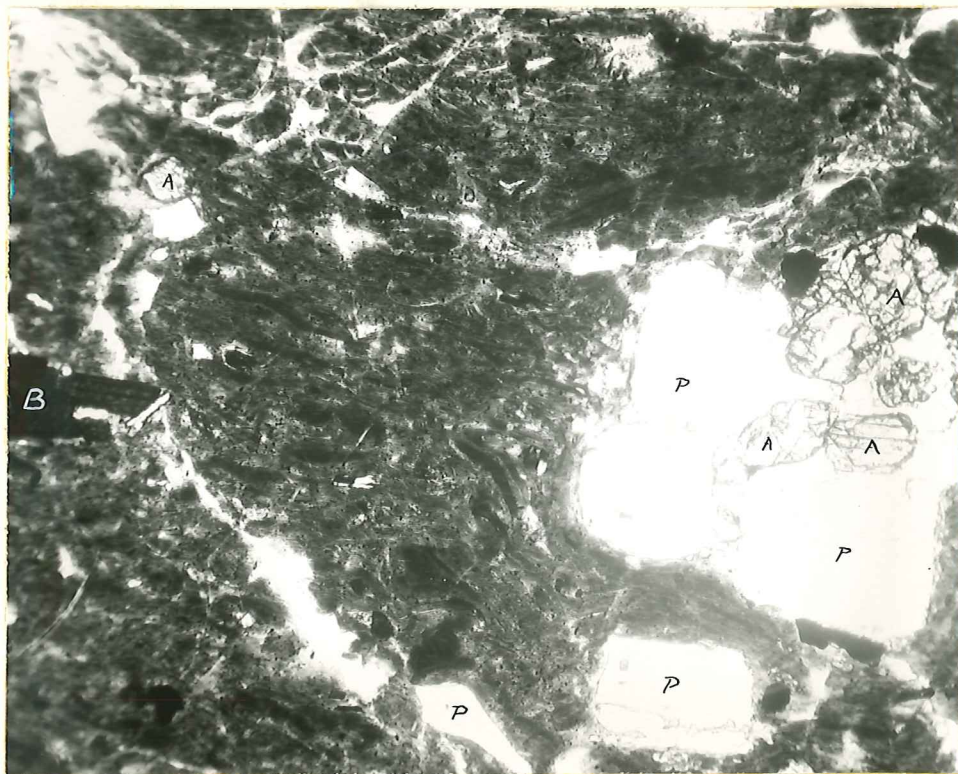
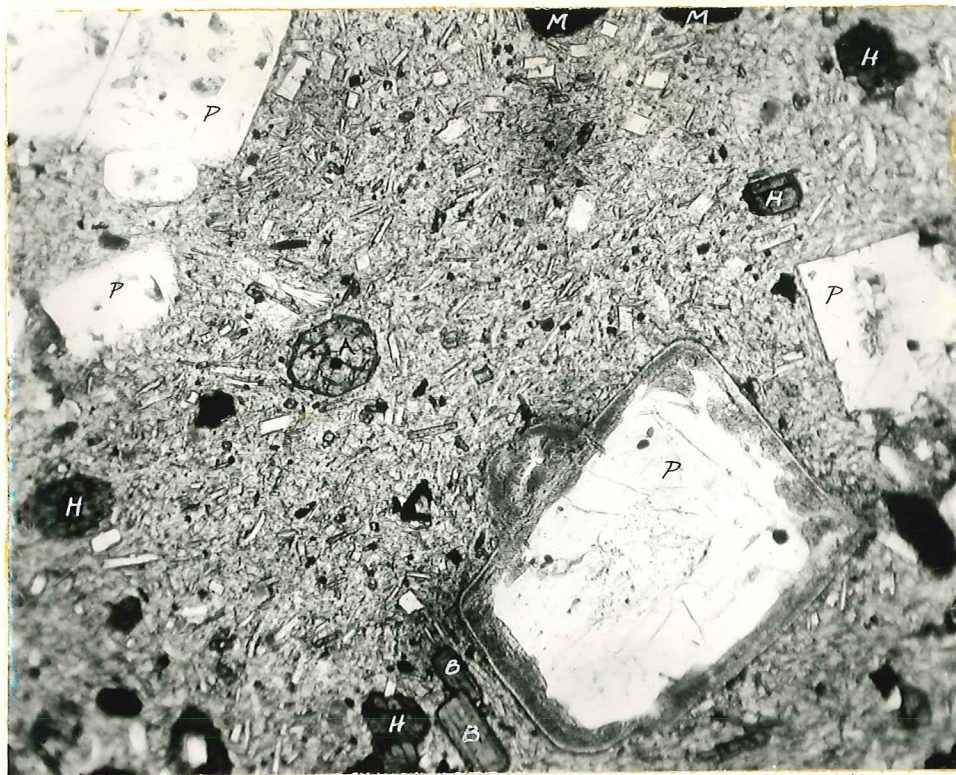
Sequence South of Frisco:

In the low hills which lie southeast of the turnoff to the Horn Silver Mine, a few hundred feet east of the highway, the following types of volcanic rocks were encountered (in ascending order): (1) a red tuff; (2) a basal glass of the overlying tuff (3); (3) a reddish-brown tuff; and (4) a basalt flow which caps the hill. This sequence is repeated by faulting west of the highway where it forms the outcrops south of the Frisco cemetery. Here the red tuff is more extensive and the intermediate glass was not observed. This red tuff is identical in hand specimen and in thin

section to the rock of unit 4 of the type section. The reddish-brown tuff differs only in having a brownish tinge.

Petrographically, the lower red tuff (1) and the upper reddish-brown tuff (3) do not differ at all. Therefore, only the rock of the latter unit (3) is described below. The glassy layer (2) is described separately, as is the basalt (4). Photomicrographs of the glass and the overlying reddish-brown tuff (pl. 7, fig. 2 and pl. 8, fig. 1) are shown because they display vitroclastic texture better than does unit 4 of the type section of which they are thought to be correlative. In contrast, the capping basalt flow has a holocrystalline texture (pl. 8, fig. 2).

The black vitrophyric obsidian (2) is only several feet thick and is not always visible beneath the reddish-brown tuff (3). It is considered to be the lower chilled member of the reddish-brown tuff (3). Light-colored pea-sized volcanic fragments are embedded in the glass together with crystal fragments and euhedra of plagioclase, augite, biotite, sanidine and quartz. The matrix accounts for 85 to 90% of the rock and only minor amounts of the above mentioned minerals are present. The glass does appear to be more basic than the overlying tuff member (3) because of the presence of augite which is not seen in the tuff. The plagioclase also appears to be more calcic (andesine, $Ab_{53}An_{47}$) than the plagioclase in the tuff. As far as may be judged from the character of these phenocrysts, the composition of the glass may range from dacitic to andesitic.



The reddish-brown rhyolitic vitric tuff (3) is about 10 feet thick where it outcrops east of the highway. Here it forms a prominent ledge which parallels the highway for some distance. West of the highway this unit thickens and overlies the red tuff (unit 1). Small vesicular lenticles oriented parallel to the surface of the unit are quite abundant in the tuff. These lenticles are also present in the underlying red tuff (1) and are discussed more fully in the description of the red tuff which makes up unit 4 of the standard section.

Sanidine composes approximately 15% of the rock, quartz and sodic plagioclase each form approximately 5%, and biotite is rare. Fragments of volcanic rocks which contain quartz, plagioclase and biotite crystals in a glassy matrix, are included in the rock and make up about 10% of the volume. The phenocrysts and fragments are embedded in a glassy matrix.

The dark greenish-gray augite basalt flow (unit 4) overlies the above described tuff and is also repeated west of the highway. The flow is limited in extent since it neither appears in the volcanic type section described south of this area, nor was it observed farther north in the vicinity of Frisco. The flow is very uniformly fine-grained and weathers into brown slabby fragments. It is estimated to be less than 100 feet in thickness.

The basalt has a trachitic and holocrystalline texture and is composed of about 75% labradorite, about 20% augite and 5% magnetite. In this section the basalt is seen to have a microporphyrritic texture.

Fig. 7. A photograph of a thin section of the mineral
(a) showing a characteristic texture. The mineral
is embedded in a matrix. The mineral is
fragments and is distributed in the matrix.
See, also, Plate I, Fig. 1.

Fig. 8. A photograph of a thin section of the mineral
showing characteristic texture. Clusters of
among the mineral grains. The mineral
and magnetic grains. See, also, Plate I, Fig. 2.



Volcanic Rocks East and North of Frisco:

Specimens of andesite were collected at various localities in (1) the hills northwest of Frisco in the vicinity of a small intrusive body, (2) the eastern slope of Indian Grave Peak, and (3) the high hills which lie just north of the road leading to Morehouse Canyon and which run parallel to this road. Generally, these andesites are purplish to grayish-purple, porphyritic and either massive or flow-banded in character. They are considered to be of flow origin for the most part; however, the tilted extrusives underlying the long ridge at locality (3) may be of pyroclastic origin.

Andesine is the dominant mineral. Quartz, biotite, hornblende, and magnetite are present in all specimens collected at these localities. The biotite and hornblende crystals are usually altered to magnetite and in some instances their original identity is hard to determine. Euhedra of augite are present in specimens from two localities. Sanidine is present in specimens from one locality. These extrusive rocks are determined to be andesites because the quartz is minor and the potash feldspar rare. However, since usually 65 to 75% of the volume of each specimen is glass, the rocks may actually be more acidic than andesite falling in the dacite or quartz latite category. This is especially true of specimens studied from locality (3) where glass layers in the matrix have devitrified to albite.

Correlation within the Area:

The pyroclastic rocks appear to be more widespread and more consistent than any one flow. Red vitric tuffs and white lithic tuffs observed

in parts of the area are similar in appearance to those described from the type section (units 4 and 7, respectively); however, there is some doubt as to the equivalence of the white tuffs (unit 7).

White rhyolitic tuffs of similar character and composition to unit 7 outcrop in the old town site of Frisco, along the highway near the turnoff to the Quad Metals Mine (old Carbonate Mine) and in Carbonate Gulch southeast of the mine. In the latter vicinity, the tuff consists almost entirely of pumice fragments. Whether all these tuff beds occupy the same stratigraphic position as unit 7 is doubtful, since the overlying and underlying volcanic units, where exposed, do not seem to correlate with those in the Squaw Springs Pass area. If the red tuffs are everywhere stratigraphically equivalent (cf. above), then the white tuff named unit 7 in the type section occupies a higher stratigraphic position than the white pumaceous tuffs outcropping farther north, since to the north, these white tuffs underlie the red tuffs, whereas in the type section the white tuff (unit 7) is stratigraphically higher than the red tuff and is separated from it by two other units.

Red tuffs similar in rock type to unit 4 of the type section outcrop south of the road to the Horn Silver Mine and east of the highway near the turnoff to the mine, and also cap the hills east of Frisco on both sides of the highway. These scattered occurrences probably represent the same formation as unit 4 of the type section, indicating that a series of red tuffs occur at a definite horizon in the volcanic sequence.

Origin of the Pyroclastic Rocks

An investigation of the origin of the tuffs is outside the scope of this paper; however, field and petrographic study indicates that they can be classified as pyroclastic ignimbrites or welded tuffs of nuee ardente origin. Gilbert (1938, p. 1852) has described the mode of origin of such rocks in his paper on the Bishop Tuff:

"The nuees are flows of intensely hot, discrete fragments of viscous magma, in which each fragment rapidly and continuously emits its gases. The fragments are thus enveloped and cushioned by extremely dense, hot gas, and the whole has the appearance of a dense, rapidly expanding 'cloud.' Such a 'cloud' rolls rapidly over even a gentle slope, driven on largely by gravity, its advance made possible by its extreme mobility due to lack of friction between gas enveloped particles."

That these tuffs are ignimbrites is shown by the textural gradation from glassy to pyroclastic which are seen within these units in the field, and by the vitroclastic textures seen under the microscope.

Age and Correlation

The volcanic sequence is probably late Oligocene in age on the basis of a correlation with volcanic rocks of that age in the Iron Springs District of southwestern Utah less than 50 miles due south of the San Francisco District. In the Iron Springs District Howard W. Jaffe has, on the basis of zircon dating, determined the average age of the extrusive rocks to be 22 plus or minus 5 million years old.

The volcanic sequence in the Iron Springs District was not visited by the author but it is believed that some of the welded tuffs of both areas

could be the same units since they are similar in appearance and sequence of deposition (personal communication, J. Hoover Mackin). It is not improbable that a single unit could extend over a distance of 50 miles, because volcanic rocks of nuee ardente origin are known to cover wide areas during a single outburst.

Regional geologic history also supports this correlation. The volcanic sequence in the Iron Springs District overlies the Eocene Claron formation (Leith & Harder, 1908) which is a series of continental sediments including conglomerates composed of Paleozoic dolomite, limestone and quartzite cobbles and boulders interbedded with reddish sandstones and fresh water algal limestones. The San Francisco volcanic sequence is likewise underlain by conglomerates similar to those found in the Iron Springs District. Although these conglomerates are not exposed in the immediate area treated by this report because the base of the volcanic sequence here is usually concealed and where it is exposed, the conglomerate beds are absent probably because of nondeposition, yet these conglomerates were found immediately north of the present area. They are well exposed in hills north of the margin of the map accompanying this report, in the eastern foothills of the northern portion of the San Francisco Mountains. According to Mackin (1954), the volcanic rocks of the Iron Springs District were spread out over essentially flat lying sediments of the Claron formation which in turn was resting on truncated structures of the older sedimentary sequence. Although the contacts are not too well-exposed in the

northern San Francisco Mountains, the same conformable relationship seems to exist between the underlying conglomerate formation and the volcanic sequence with both unconformably resting on older rocks.

Quaternary Alluvium

Introduction

The Quaternary alluvium in the area consists of extensive fan deposits, stream and interfluvial wash, lake shore embankments, and playa lake sediments. An arm of ancient Lake Bonneville extended into Wah Wah Valley (Gilbert, 1890) and most of the alluvium in the valley is clearly pre-Lake Bonneville in age. Only in recent times have the shore lines been dissected by the intermittent streams issuing from the range.

Distribution and Type of Deposits

The Quaternary alluvium is present in the lowlands bordering the San Francisco Mountains and in the gulches and canyons leading into the range.

Alluvial Fans and Stream Wash:

Stream and interfluvial wash is locally present along the eastern flank of the range, and here it merely veneers a volcanic pediment surface; whereas along the western range front, alluvial fans are spread onto the basin floor and the entire basin is filled by sediments probably to a considerable depth. Cemented gravel deposits on the west side of the range have been uncovered by recent cutting in Copper Gulch (see fig. 19). These conglomerates, composed of cobbles eroded from the rocks underlying the range (limestone, quartzite, and quartz monzonite) overlie a truncated surface of the intrusive body. Since they rest directly on the intrusive body,

they are the oldest alluvium exposed in the area. Undoubtedly older deposits exist beneath the lake sediments in Wah Wah Valley.



Fig. 19. View taken from road to Cactus Mine in Copper Gulch showing cemented gravel deposits resting on a truncated surface of the quartz monzonite stock. Note that the cemented gravel is more resistant than the igneous rock causing an overhang.

Lake Shore Gravel Embankments:

Current action and the oscillatory stages of ancient Lake Bonneville have left many well preserved shore-line features in Wah Wah Valley. Successive shore lines transect the fans built along the west flank of the San Francisco Mountains. A large bay bar, spanning the lower level of the basin, lies northwest of the abandoned town of Newhouse just off the northern boundary of the geologic map. Another bar, less well-developed, and representing a higher lake stage, lies south of Utah highway 21. A series of V-bar or triangular embankments are spaced along the west flank

of the Northern San Francisco Mountains just beyond the northern boundary of the geologic map. These V-bar embankments have been mapped in detail by G. K. Gilbert (1890) as a part of his study of Lake Bonneville and are shown in plates 16, 17, and 18 in United States Geological Survey Monograph I.

Playa Lake Sediments:

A playa lake bed lies in the central portion of Wah Wah Valley and in wetter seasons has a shallow stand of water. The whitish alkali beds of the lake floor have been rivuleted by erosive action of sheet floods.

INTRUSIVE IGNEOUS ROCK

Introduction

An igneous body of quartz monzonitic composition has intruded the Paleozoic sedimentary rocks (see fig. 20) as well as the early Tertiary volcanic rocks. It has caused extensive alteration along its contacts. The intrusive is probably responsible for the ore bearing solutions which made the San Francisco District a prosperous mining camp in the late 19th and early 20th centuries. The ore deposits of the District have been fully treated in United States Geological Survey Professional Paper 80.

Distribution

The quartz monzonite body lies in the center of the map area forming an irregular triangular outcrop, the apex of which projects eastward into the volcanic rocks and the base of which parallels the alluvial basin to the west. This triangle is interrupted by a projection southward into the sedimentary rocks. Small inliers of intrusive rock, which are considered to be offshoots of the main body, outcrop outside the main intrusive body in the volcanic and sedimentary rocks. A small body has intruded the volcanic rocks near the abandoned town of Frisco in some low hills northwest behind a conspicuous group of beehive kilns.

Several smaller offshoots or dikes outcrop in the carbonate rocks in the vicinity of Grampian Hill. Another body was mapped in the Cambrian limestone north of the Blackbird Mine.

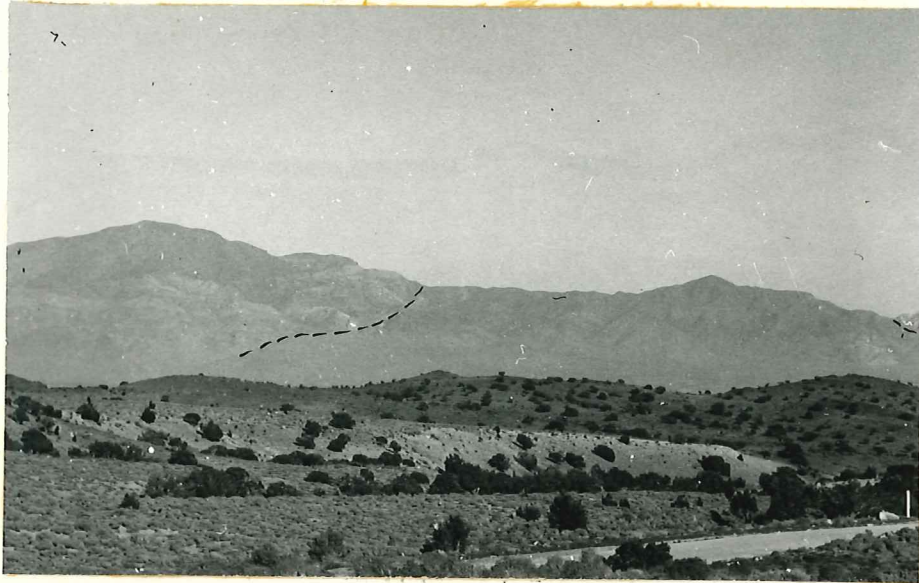


Fig. 20. View of Quartz Monzonite stock from west. Darker area is igneous rock intruded into lighter-colored bedded strata. Note slight doming of the beds north of the intrusive body.

Field Relations and Petrographic Description

Field Appearance

The texture of the quartz monzonite varies from fine-grained and porphyritic to medium-grained and even-granular. The porphyritic rock, representing a contact facies, is present along the eastern margin of the body where the stock has intruded the volcanic rocks. This texture grades to a uniformly even-granular, medium-grained texture in Copper Gulch. Along the southern border of the intrusion, the texture is also similarly non-porphyritic and granular. The two facies of the quartz monzonite weather quite differently. The medium-grained rock is more easily broken down, usually forming rounded outcrops and boulders, whereas the

fine-grained porphyritic rock is more resistant, and jointing shapes the outcrops producing sharp angular blocks.

Petrographic Description

A sample of the porphyritic contact facies of the quartz monzonite was collected near the eastern end of the stock where a pipeline, running from Morehouse Spring to the Horn Silver Mine, crosses the southern contact. The hand specimen has an overall grayish-brown color and is porphyritic, with medium-grained phenocrysts and a fine-grained pale pinkish groundmass. Euhedra of feldspar, hornblende and biotite are readily visible. Some of the feldspar laths reach 5 mm in length and the biotite euhedra 2 mm in diameter. With a hand lens, striations are noted on the feldspar laths. The hornblende is dark green, and the combination of the green and pink appears to give the rock the overall brownish color.

In thin section (pl. 9, fig. 1) the specimen is seen to have large phenocrysts of plagioclase, biotite, uraltic hornblende and augite embedded in a finely crystalline allotriomorphic matrix of quartz and potash feldspar. The plagioclase is andesine ($Ab_{60}An_{40}$) and is quite cloudy and partly replaced by sericite. The uraltic hornblende is pale green, and some of its crystals are entirely replaced by magnetite. The biotite is less abundant than the hornblende, is dark brown, and is altering to magnetite and a chloritic mineral. The potash feldspar of the matrix was identified by staining with cobalt nitrate; it is estimated to be slightly more abundant

than the plagioclase phenocrysts. Together, the feldspars constitute about 60% of the rock. Quartz is the next most abundant mineral (25%) and the mafic minerals make up about 15% of the rock. The mineral ratios of the sample fall into the field of quartz monzonite, but are close to the granitic side.

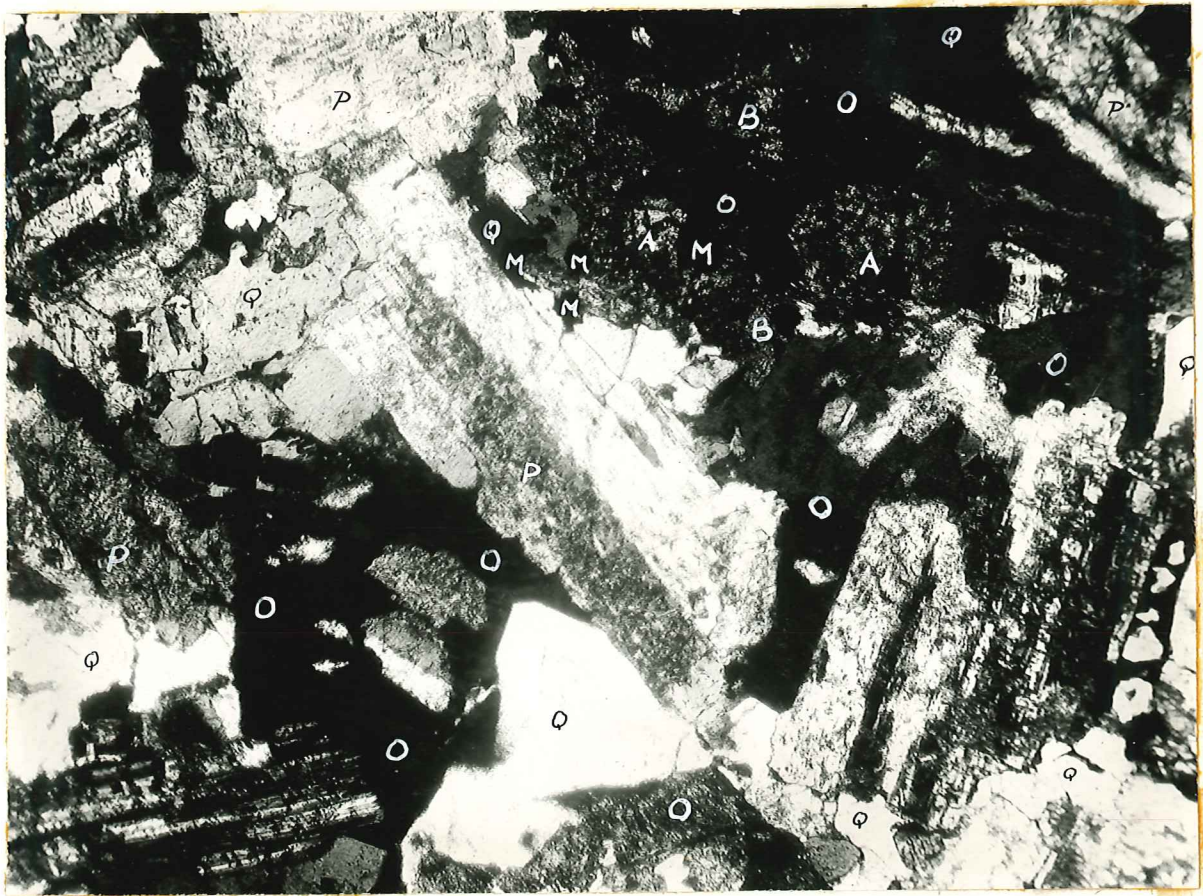
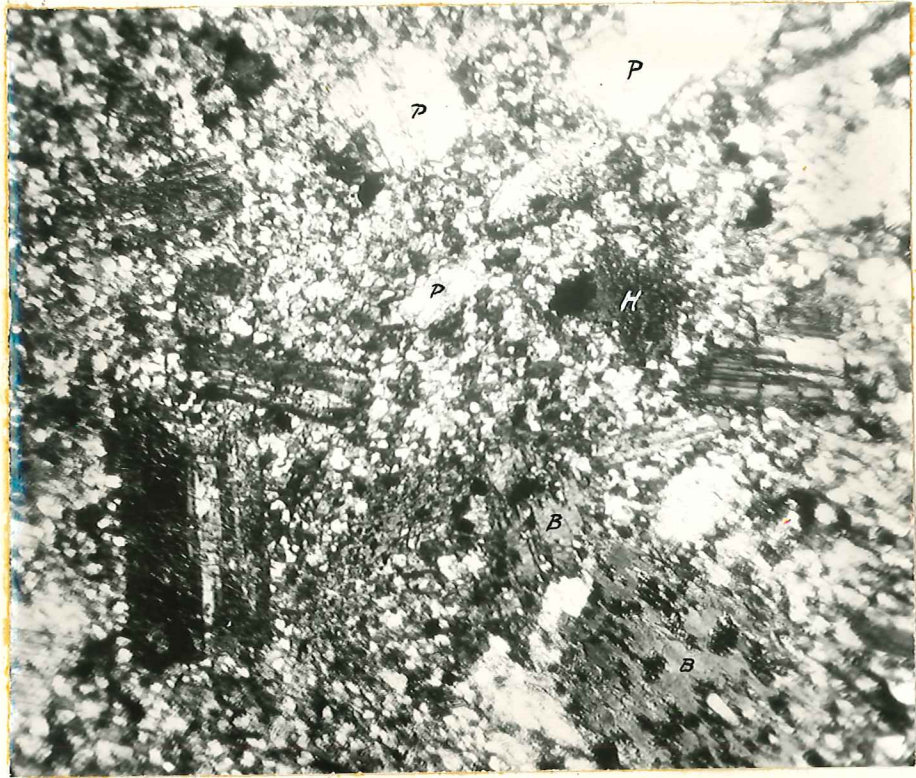
A typical specimen of the even-granular quartz monzonite was collected near the contact north of the new shaft of the Horn Silver Mine (old King David Mine). The rock is uniformly medium-grained and light gray with uniformly scattered black specks. Under the hand lens, striated, whitish-gray plagioclase is observed, and interlocking pink grains which are judged to be orthoclase. The dark minerals visible are black euhedral biotite flakes and dark green pyroxene or amphibole crystals. Quartz is not readily identified.

In thin section (pl. 9, fig. 2) the rock is seen to have a hypidiomorphic texture. The plagioclase and the mafic minerals are euhedral; the orthoclase crystals are subhedral and the quartz grains are anhedral. The mineral percentages are estimated to be: plagioclase, 35%; orthoclase, 30%; quartz, 15%; biotite, uraltic hornblende, and augite, 15%; and accessory magnetite and apatite less than 5%. The plagioclase is andesine of a composition of $Ab_{63}An_{37}$ very close to that of the porphyritic facies. Its grains are clouded with alteration products. The orthoclase is also quite cloudy with alteration minerals occurring along cleavage traces. The quartz is interstitial. The hornblende is uraltic; it is

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pleochroic with Z equals light green and Y equals light olive green. The augite is colorless, has a positive 2V of about 60 degrees, an extinction of C to Z equals 48° , and a birefringence of .025. The biotite is brown and occurs in plates.

Contact Relations

The igneous body is shown in the geologic cross-sections with steep cross-cutting contacts. Wherever the contact is exposed, this appears to be the relationship as is attested by figs. 21 and 22. The contact with the limestone beds is quite distinctive and sharp, whereas the contact is less well-defined where the quartz monzonite has intruded the volcanic rocks. The contact between the quartz monzonite and the volcanic flows is, in part, dashed on the geologic map because it is difficult to locate because of hydrothermal alteration, poor exposures and a similarity in texture of the porphyritic facies of the intrusive rock and of the extrusive rocks. Along the contact from Indian Grave Peak to the easternmost part of the intrusive body, hydrothermal alteration has greatly affected both rocks. Here the outcrops are bleached white and in some exposures faint outlines of phenocrysts are all that has remained visible to even suggest an igneous rock. The contact was mapped in this area by arbitrarily plotting a line along the white zones of altered rock. Along the northern contact of the eastward projection of the intrusive body, the porphyritic variety of the quartz monzonite continues, and the intruded volcanic rocks have the same texture. Hydrothermal alteration has not been so active in



Fig. 21. View, looking west toward the intrusive contact from the tailings of the Cupric mine. The adits are in the contact zone. Note how the limestone beds have been turned up by the intrusion. The limestone has only been recrystallized along this segment of the contact.



Fig. 22. View, looking west toward the intrusive contact near the Imperial Mine. The dashed line indicates the approximate position of the contact. The limestone has been altered to skarn and note the difference in outcrop appearance between the skarn exposed below the contact and the granitic rock exposed above. In the lower left hand corner of the fig., vertical banding can be seen in the skarn.

this area but the similarity of texture coupled with poor exposures accounts for the indefinite boundary shown on the geologic map.

Inclusions and Dikes within the Intrusive

Recrystallized limestone inclusions and later igneous dikes were noted in the intrusive body, but the latter were not differentiated on the geologic map. The limestone inclusions are shown on the map as Cambrian although their age is not quite certain. The larger of the two limestone bodies shown on the map is in the eastern portion of the intrusive body, and the other at the eastern contact of its southern projection.

Mode of Emplacement

Contact metamorphism, sharp contacts, the presence of a porphyritic border facies, the textures of the intrusive rock, and deformation of the wall rocks, all clearly indicate that the quartz monzonite is an igneous intrusion. The forceful intrusive contact relationship is best displayed along the southern border of the intrusion where the sedimentary rocks have been broken and turned up parallel to the contact from their regional northeast trend (see fig. 21). Moreover, near vertical banding in the skarn, which probably represents original bedding planes, trends parallel to the contact in the same general area. The sedimentary strata in Copper Gulch also dip away from the intrusion, and the dip angle lessens with increasing distance from the contact, suggesting doming by the intrusion. However, the emplacement of the stock has not affected the trends

south of the igneous body any great distance from the contact. Figure 21 shows that the beds are only deflected adjacent to the contact, and the regional strike in this area is discordant to the intrusion. It is true that the volcanic rocks dip away from the axial portions of the range but this could be the result of regional tilting not associated with the intrusion. These facts indicate that shouldering aside of the wall rocks has only played a minor part in the emplacement of the intrusive body. Stoping is not believed to have been the main mechanism of emplacement either, because there is little evidence for it. Nor is the target-like pattern of doming present in some other areas, markedly displayed in this region, although part of the evidence may have been obliterated by erosion of the sedimentary cover which might have conformed more closely to the shape of the intrusive body. Probably, an upward displacement of the rocks previously occupying the space now filled by the stock must be considered as the main mechanism of intrusion. Such piston-like action certainly seems to be suggested by the sharp but local upturning of the wall rocks at the contact.

Age of Intrusion

The quartz monzonite stock was probably emplaced in middle Tertiary times. The stock is clearly intrusive into the sedimentary sequence. Although the contact with the volcanic rocks is not well-exposed and none too well-defined, it is without any doubt also intrusive into the volcanic rocks, as is indicated by structural relations, mineralization and

hydrothermal alteration. The oldest sediments resting on the quartz monzonite are caliche cemented gravel deposits which are exposed near the mouth of Copper Gulch. These deposits can be traced basinward where Lake Bonneville shore lines have been built on them. According to Gilbert (1890), Lake Bonneville was late Pleistocene. Therefore, since the volcanic rocks are the youngest rocks which are cut by the intrusion and the pre-Lake Bonneville gravels are the oldest rocks which overlie the intrusion, it can only be dated as late to post-Oligocene and as pre-late Pleistocene. An age later than middle Tertiary, however, is considered improbable.

CONTACT METAMORPHISM

Introduction

A contact aureole has been produced by the intrusion of the quartz monzonite stock, noticeably altering the sedimentary rocks to a distance of 2000 feet from the contact. The dominant intruded rock is limestone, but dolomites, shales, and limey and dolomitic sandstones and siltstones are interbedded. Generally the sedimentary rocks have been isochemically recrystallized, but replacement has been dominant in the alteration of certain areas.

Distribution of the Altered Rock

The sedimentary rocks bound the intrusive stock along parts of its northern and southern borders. Elsewhere, volcanic rocks and alluvium border the intrusive body. The recrystallization of the sedimentary rocks has been mainly isochemical along the northern border of the stock with the formation of finely crystalline limestones to granular marbles, dense hornfelsic argillites, and quartzitic sandstones. Although silicate minerals have been formed in the carbonate rocks, they are subordinate in amount and have not greatly affected the original mineral assemblages. Extensive replacement has occurred along the southern border of the quartz monzonite body. In the vicinity of the Prospect Mountain quartzite klippe, the limestone has been replaced by a dark brownish, garnet-rich skarn. The best exposures of this rock are in Loeber Gulch

on the slopes above the Imperial and Washington Mines (see fig. 22). Here the limestone has been almost completely replaced by silicate minerals. Westward along the southern intrusive contact, in the area of the Cupric Mine, the skarn abruptly ends and the limestone is merely isochemically recrystallized.

Field and Petrographic Description

Specimens of both the isochemically recrystallized and the replaced wall rock outcropping along the northern and southern contacts were collected for study. Minerals identified in these specimens are garnet (grossularite), tremolite, diopside, epidote, phlogopite, calcite, and quartz.

A specimen of the skarn rock, classified as a garnet-rich lime silicate hornfels, was obtained in Loeber Gulch near the Washington Mine. The bedrock is very characteristic (fig. 23); it is banded, and weathers into massive, rounded outcrops. The bands appear to be steeply inclined and generally trend parallel to the intrusive contact. They probably represent relict bedding planes of the original limestone.

Under the microscope the lime-silicate hornfels specimen is seen to have an idiomorphic texture caused by the growth of the grossularite. Under crossed nicols, anomalous birefringence shows well-developed zoning in the garnet (see pl. 10, fig. 1). The garnet is the dominant mineral, composing 80% of the rock. Diopside is the next most abundant mineral forming about 15% of the rock. Calcite and quartz are usually associated,

filling together irregular spaces between the garnet. Calcite is more abundant than quartz, but both are minor, making up the remaining 5% of the rock.



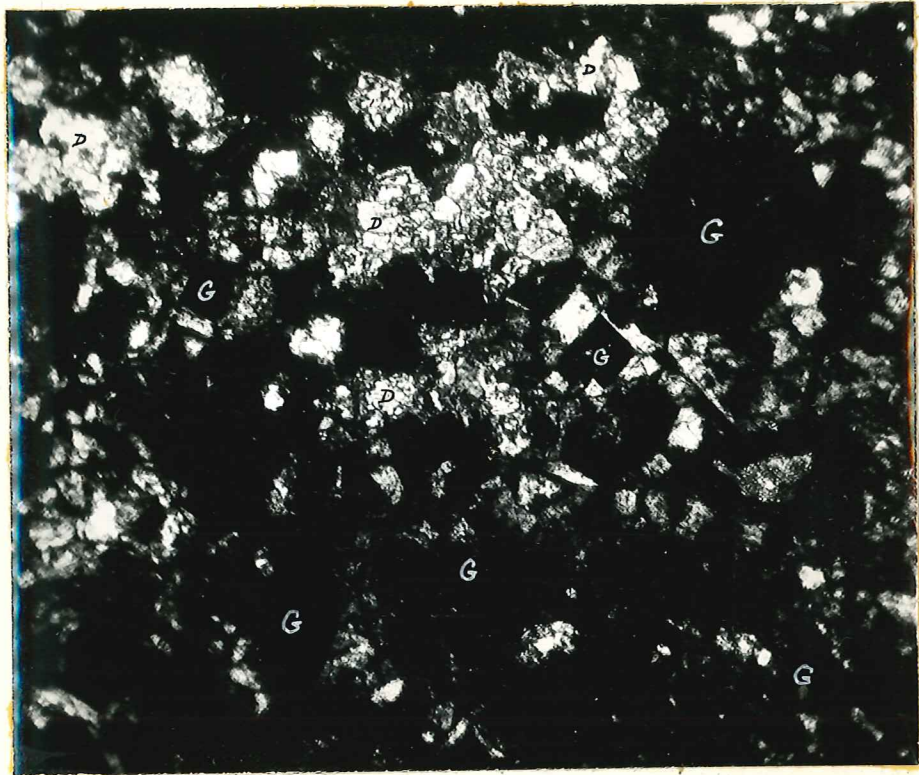
Fig. 23. View of dark brown, banded lime silicate hornfels exposed in Loeber Gulch. The scale is indicated by hammer lying on outcrop.

A sample of a very fine-grained, lime silicate bearing quartzitic sandstone was obtained from beds intercalated with altered siltstones, shales, and limestones of the Pogonip Group. The specimen was collected from a prominent outcrop high on the south slope of Copper Gulch just below the foot of the cliffs of Prospect Mountain quartzite. The fresh hand specimen is yellowish-green and fractures reveal tiny vitreous quartz grains. The weathered surface is brownish gray-green, dull and dense appearing.

Under the microscope (pl. 10, fig. 2) the clastic texture of the specimen is apparent. The sandy nature of the rock is not readily seen on a weathered surface (cf. above). Rounded quartz grains make up most of the rock (80-90%) and have recrystallized into a mosaic pattern where they are closely packed. Newly formed minerals are minor, but epidote, diopside, garnet, and calcite are present. Epidote is the most abundant, occurring between the quartz grains. It is largely responsible for the yellowish-green color of the specimen. Replaced outlines of microorganisms can be seen in the thin section.

A slightly altered greenish, sandy limestone was collected from a sandy member in the Kanosh shale outcropping north of Copper Gulch immediately below the Prospect Mountain quartzite. Rounded quartz grains are easily visible and are embedded in a light, gray-green irregularly banded fine-grained matrix.

In thin section (pl. 11, fig. 1) the matrix of the specimen is seen to consist of matted, directionless aggregates of fibrous tremolite crystals. The quartz grains make up about 25% of the rock, the remainder being tremolite. The quartz grains are rudely segregated into bands which may represent original bedding. Tremolite has completely replaced some of the quartz grains but the rounded outline of the original quartz grains is visible in plain light. Although most of the grains are partially replaced, some are unaltered. The formation of the tremolite indicates that the original rock was probably a sandy dolomitic limestone.



A slightly altered limestone was collected from Pogonip outcrops along the northern border of the quartz monzonite intrusive within several hundred feet of the contact just below the crest of the range. The limestone outcrops at this locality are characterized by thin (several millimeters) closely spaced shear planes which parallel the bedding planes. Only in the closely spaced shear planes is the limestone crystalline. The shear planes may indirectly indicate the nearness of the thrust contact between the Prospect Mountain quartzite and the Pogonip limestone although, by reason of the intrusion and erosion, the quartzite formation has been removed above the limestone at this locality.

In thin section (pl. 11, fig. 2) phlogopite flakes have formed in shear planes seen in the hand specimen. The remainder of the rock is calcite. Evidently argillaceous impurities have been responsible for the formation of the phlogopite.

Origin of Skarn

Lime silicate formation in contact metamorphosed carbonate rocks is known to occur either as a result of metasomatic addition of material from the emplacing magma or without addition, if the invaded carbonate rocks contain impurities, such as silica and clay minerals.

In the present area the contact metamorphosed rocks, although generally recrystallized, are metasomatically replaced only in few areas along the intrusive contact. An example of isochemical lime-silicate formation is the slightly altered silty and shaly limestones and dolomites of the

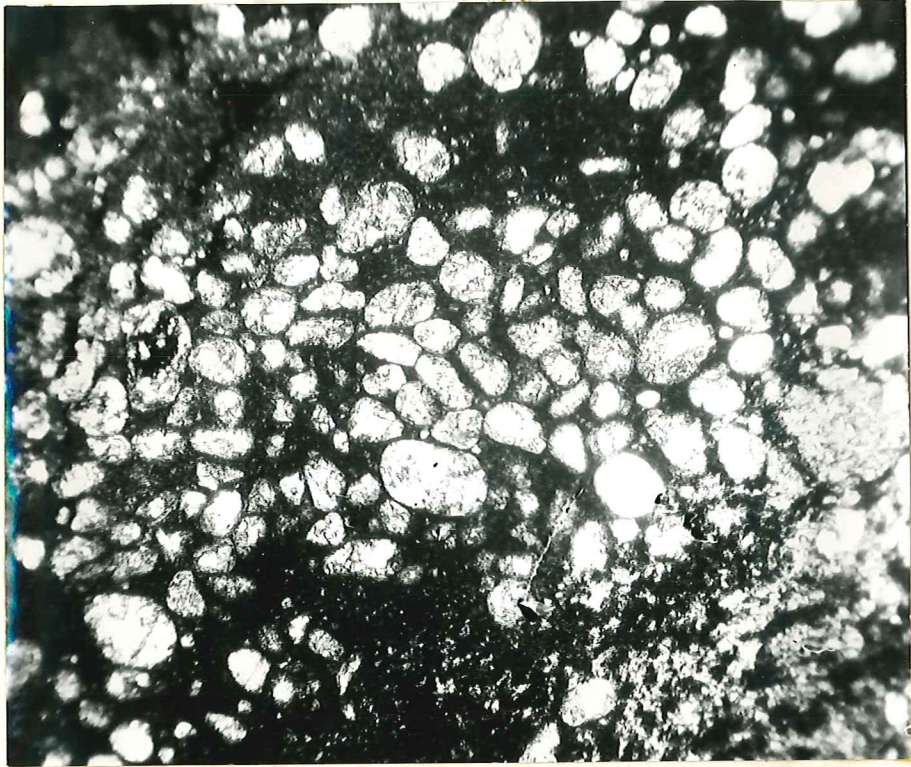
Pogonip Group in the area of Copper Gulch. Where skarn type replacement occurs, it shows a highly irregular pattern which rules out the possibility of impurities alone accounting for the alteration. However, the reason for the localization of the metasomatic contact replacement is not clear. Butler (1913, p. 90) concludes:

"...the intrusion of the quartz monzonite caused a recrystallization of the limestone through the whole extent of the contact and doubtless some material was given off from the magma and added to the limestone all along the contact. The great extent of mineralization at certain points, however, suggests that the solutions given off by the crystallizing magma were collected into channels and entered the limestone at these points rather than uniformly along the entire contact zone.

The pre-intrusive structures of the country rock may be associated with the local invasion by replacing solutions, since the banding in the skarn parallels the contact for some distance from the border of the stock, whereas the isochemically recrystallized rocks strike into the intrusive body, except for local upturning at the contact.

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STRUCTURE

General Statement

The San Francisco Mountains are part of a fault block range which has been uplifted relative to the bordering intermontane basins. Moreover, the San Francisco Mountains have undergone strong orogeny prior to the tectonism resulting in their present relief. These episodes of diastrophism, characterized by bedrock structures and physiography respectively, can be separated into those structures developed during pre-Tertiary orogeny, and those structures that are clearly younger, cutting across the earlier structures. The structural features produced during Cenozoic tectonism can be further subdivided into early-middle Tertiary structures and late Tertiary-early Quaternary basin and range structures.

A review of Great Basin structure follows, emphasizing the role of the earlier, geosynclinal-type deformation exposed within basin-ranges several hundred miles from the San Francisco Mountains.

Regional Structure

Generally two major periods of tectonism, characterized by the below described orogenic structures, are widely recognized in the Great Basin. One period is commonly referred to as the Laramide, unrestricted, although much of it is probably pre-Laramide Mesozoic orogeny. The other period of tectonism is referred to as the time of basin

and range deformation which is generally considered to have begun in Oligocene time and which has been more or less continuous to the present (Nolan, 1943).

The Province is characterized by intensely folded and thrust faulted structures which at a later date have been cut and displaced by high angle faulting and warped by gentle folding. Prior to the orogenic disturbances, broad epeirogenic uplifts, interrupting Paleozoic and Mesozoic geosynclinal sedimentation, have resulted in regional unconformities and have been an important process in the structural history of the Province (Nolan, 1943). Of course, every part of the Province has not been subjected to equally intense orogeny nor has the orogeny been simultaneous everywhere.

In the western Great Basin, pre-Mesozoic orogeny has also been important. One example is the Roberts Mountains in north-central Nevada where intense folding and overthrusting of a large magnitude were first discovered by Anderson and Merriam (1942) and are now known to have begun about latest Mississippian times (personal communication P. Misch). This area was again subjected to intense Mesozoic orogeny.

Complexly folded and overthrust structures have been reported from numerous basin-ranges within a radius of several hundred miles of the San Francisco Mountains. Some of these ranges lie along the eastern border of the Great Basin and include: the southern Wasatch Mountains near Provo (Baker et al, 1949), Mt. Nebo near Nephi (Eardly, 1934, authors ref.,

Eardley, 1951), the Canyon Range northwest of Scipio (Christiansen, 1952), and the Pavant Range east of Fillmore (Maxey, 1946). Other localities in which such structures have been reported are the Confusion (Utah Guide Book, 1951) and the Deep Creek Ranges (Nolan, 1935) located in western Utah, and the Snake Range (Hazzard and Misch, et al, 1953) and Schell Creek Mountains (Misch and Easton, 1954) both located in easternmost Nevada. Most of these ranges are characterized by large scale overthrusting of pre-Tertiary age. Only the Confusion Range is devoid of major thrusting; however, the strata underlying the range are folded and in part overturned. Within this wide deformed belt lies the tilted fault block of the House Range, which shows surprisingly little internal disturbance. It lies just east of the Confusion Range across an alluvial basin called either White or Toole Valley. The exposed portions of the House Range suggest that this is a unit that escaped earlier intense orogeny typified by folding and overthrusting.

Pre-Tertiary Structure

Introduction

During Laramide or pre-Laramide orogeny, the geosynclinal strata underlying the San Francisco Mountains were faulted and folded prior to large scale overthrusting. The basal sedimentary rocks of the known geologic column, apparently sheared off from the crystalline basement, were thrust over deformed younger Paleozoic rocks.

Butler in United States Geological Survey Professional Paper 80 discussed only the Tertiary structures present in the San Francisco Mountains. He failed to recognize a large scale pre-Tertiary overthrust in the range, but mapped the whole as a conformable sequence. However, it is easy to understand how such a structure would go unnoticed because according to Nolan (1953, p. 174), it was not until 1900 that thrusting was recognized in the Great Basin and it remained until 1910 before the structural importance of thrusting was realized in the province, several years after Butler had completed his field work.

Folds and Faults

The beds of the Ely limestone are anticlinally and synclinally folded and faulted against older Paleozoic rocks (refer back to fig. 17). Since the Tertiary volcanic sequence rests unconformably on these folds, the age of the folding is earlier than the deposition of the volcanic rocks. This in itself does not prove that the folding is older than the thrusting; however, folding is not present in the upper thrust plate nor has the thrust plane been folded, which one would expect had the period of folding been later than the thrusting. Therefore, indications are that the Ely limestone was folded before overthrusting.

Two transverse faults cut the folded Ely limestone beds which are exposed south of the highway. A low angle reverse fault of minor displacement, referred to previously, was also discovered in this area. Displacement of the rock on either side of the transverse fault planes has no

reflection in the present topography of the hills. These two faults are shown as strike slip faults although evidence for a dominant horizontal component was not very conclusive. At one locality along the more northerly of the two faults, fragments of a chert pebble conglomerate bed were sheared out between the displaced ends of a single bed indicating horizontal displacement. The faults do not pass into the volcanic rocks and therefore are older than the volcanic rocks but younger than the folding of the Ely limestone. The reverse fault appears to be older than the transverse faults and may be slightly later than the folding of the Ely limestone.

The fault separating the Ely limestone from the Cambrian dolomites and limestones underlying Grampian Hill proper trends north of east for several thousand feet in the bedrock. To the southwest, alluvium covers the bedrock concealing the fault and to the northeast, the fault is terminated by a younger north-south trending fault. Several prospect pits have been excavated in the brecciated fault zone. There is no direct evidence that the Ely beds were faulted against the Cambrian beds underlying Grampian Hill prior to the time of thrusting. All that can be said is that the faulting took place before the range border faulting which has dropped volcanic rocks across this fault. However, if the faulting is post-thrusting, it would mean that the Ely beds had been displaced from a position in the upper thrust plate. Therefore, the displacement along this fault would be approximately 40,000 feet, which is quite unlikely. A more reasonable solution is that folding and faulting preceded the overthrusting; it would then be unnecessary to assume a displacement of such magnitude along the fault.

Other evidence confirms that a period of faulting preceded the overthrusting. This is a high angle fault which apparently passes beneath the upper plate where the rocks of the upper plate underlie the ridge leading from Frisco Peak. This fault can be easily followed in the bedrock of the lower plate where it has dropped Ordovician rocks against Cambrian rocks which occur on the west and continue to the range front north of the intrusion. Beds of Pogonip limestone are turned up sharply along the fault and a breccia zone three to five feet wide has been formed. In one locality, the beds adjacent to the breccia zone have eroded leaving the breccia standing like a wall. The strike of the fault trends a few degrees west of north for some distance, then it apparently veers in a more westerly direction beyond the ridge southeast of the Indian Queen Mine. The dip of the fault where it can be determined is near vertical. The breccia zone can be followed southward until it butts into the quartz monzonite intrusive body. On the north slope of the ridge southeast of the Indian Queen Mine, numerous prospect pits have been dug in the fault zone. However, the fault is obscured from a point in the bottom of the canyon below this ridge up to the base of the thrust sheet of Prospect Mountain quartzite (see fig. 24). The only bedrock evidence that the fault continues is that in one part of the slope beneath the thrust contact the dip of the beds locally increase from an average of 25 degrees to 65 degrees. North of the high ridge shown in fig. 24, the rocks exposed on the west side below the overthrust plate are Cambrian. Therefore, if the fault continues, it is concealed by the thrust sheet of Prospect Mountain quartzite.



Fig. 24. View, looking north, from ridge southeast of Indian Queen Mine. Dashed, near horizontal, line is approximate emergence of thrust plane. Dashed vertical line is approximate fault contact between Ordovician Pogonip and Middle (?) and Upper Cambrian limestones. The fault apparently passes beneath the upper thrust plate.

On the map, this fault is shown to diverge beneath the thrust plate and one branch to emerge on the north and to continue along the bottom of a deep north-south trending canyon. It is shown to split again and pass through a divide into a parallel canyon east of the one just mentioned. There is an apparent displacement of the same beds outcropping on either side of the east canyon, the east side being up and west side being down, although, because of talus cover, the beds cannot be directly traced where they cross the canyon. The actual fault plane is not visible either, being concealed beneath the canyon floor. However, the canyon is aligned with the fault south of the high ridge leading from Frisco Peak, and the canyon is probably the result of erosion along a shear zone. Evidence of the

western branch fault are breccia zones in the dolomite and limestone outcropping on the slopes beneath the upper thrust plate and in the saddle separating the western canyon from the eastern one. However, again the fault is not visible, being concealed beneath the floor of the western canyon.

San Francisco Mountain Thrust

The large overthrust in the area will be called the San Francisco Mountain thrust. The upper plate is pre-Cambrian and Lower Cambrian Prospect Mountain quartzite which has been thrust over a carbonate section of Cambrian, Ordovician and Pennsylvanian age. North of the quartz monzonite intrusion, the upper plate underlies the crest of the range and here forms the bulk of the San Francisco Mountains (see frontispiece). Two small klippe lie south of the intrusion as isolated erosive remnants of the thrust sheet. Projected attitudes measured on either side of the range indicate that the thrust plane has been slightly warped in a very gentle syncline. The places where the thrust plane emerges at the flanks of the range, have been described above when the contacts of the Prospect Mountain quartzite were discussed (see p. 14). To reiterate then, the thrust plane is best exposed where it emerges along the west flank of the range. The actual plane of thrusting is not often exposed but it can be placed with certainty within very narrow limits because of the difference in lithologies between the quartzite of the upper plate and the limestone and shales of the lower plate. In many localities along the thrust contact, a topographic break

occurs on the slope because of a difference in resistance to erosion of the rocks of both plates. This is well-illustrated in the view from Copper Gulch shown in fig. 13.

Along the southern emergence of the thrust plane above Copper Gulch there is no apparent deformation of the rocks in the overlying and underlying plates. Breccia, gouge, or mylonite zones are lacking in this area, but truncation of the strata in the lower plate attests to the presence of the thrust. Fig. 25 shows a view of the structural discordance in the angle of dip between the beds in the upper plate and those in the lower plate. Moreover truncation of the underlying beds was observed on a

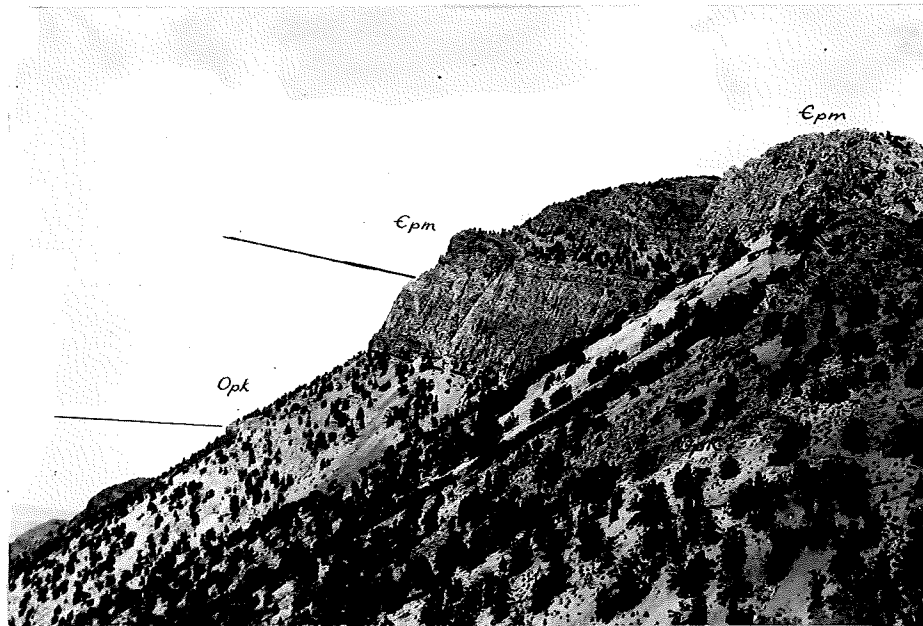


Fig. 25. View, looking north, along the west slope of the San Francisco Mountains showing emergence of thrust plane. Note the difference in angle of dip between the beds of the Prospect Mountain quartzite of the upper plate and the beds of the Pogonip-Kanosh shale of the lower plate. The apparent displacement of the quartzite cliff in the foreground is due to foreshortening and a slight tilting of the beds. The dark cliff in center of right margin of the fig. is in Tertiary volcanic rocks faulted against the Prospect Mountain quartzite.

smaller scale in the same area. This slight truncation was seen in a distance of about 20 feet in a direction parallel to the cliff face. The net result is that successively older beds come up against the thrust plane in a southward direction.



Fig. 26. View of actual thrust plane, uncovered by prospect pit, showing gouge zone (hammer) between Prospect Mountain quartzite of the upper plate and limestone members of the Pogonip-Kanosh shale of the lower plate.

Several thousand feet north of the area shown in fig. 25, a prospect pit has been excavated in the shear zone. The workings have uncovered a gouge zone several feet thick between the Prospect Mountain quartzite and the limestone beds of the Kanosh shale. The shear zone strikes N60W and

dips 25 degrees to the NE. The dip of the shear zone is greater than the dip of the underlying limestone beds. This shear zone is shown in fig. 26. A few dozen yards from this pit, slightly higher on the slope, the quartzite of the upper plate shows signs of internal movement. The massively bedded quartzite has been granulated and sheared out along definite movement planes. A view of this rock is shown in fig. 27.



Fig. 27. View of granulated Prospect Mountain quartzite. The rock to the butt of the hammer is merely fractured but above this is a zone of granulated quartzite over a foot in thickness.

From the above mentioned outcrop northward, the quartzite immediately above the thrust zone is highly fractured and in part brecciated but it still retains some of its bedding (see figs. 28 and 29). Figure 30 shows a distant view of the west flank of the range and the emergence of the thrust plane. This view also pinpoints the location of the outcrops shown in the last two figs. as immediately above the thrust plane.



Fig. 28. View of highly fractured and in part brecciated Prospect Mountain quartzite exposed just above thrust plane which emerges along west flank of the San Francisco Mountains. Pine tree in right margin of fig. is about 20 feet high.



Fig. 29. This view taken several dozen yards from outcrop shown in fig. 28. Here the original bedding planes are seen although fractures across the bedding planes have separated parts of the same bed into segments.

The thrusting in the San Francisco Mountains can locally be dated no more accurately than as post-Pennsylvanian and pre-Oligocene in age since the Ely limestone is the youngest formation participating in the thrusting and the volcanic rocks are the oldest units lying unconformably on the Paleozoic sequence. Just north of the immediate area, conglomerates are the oldest rocks unconformably overlying the pre-Tertiary structures. However, they are probably not much older than the overlying volcanic rocks. The time of thrusting can be narrowed considerably if evidence from adjacent ranges is used, assuming, of course, that the thrusting occurred more or less at the same time in this, the eastern part



Fig. 30. This view locates the outcrops shown in the previous two figs. (28 and 29). Note their position (circle) immediately above approximate emergence of thrust plane. View looking north.

of the Great Basin. Christiansen (1952) has postulated that thrusting in the Canyon Range began in late Jurassic (?) time and culminated in early Cretaceous time. Here, Upper pre-Cambrian (?) rocks have been thrust over Lower Paleozoic rocks. The upper plate consists of a thick series (7955 feet) of alternating red to light olive-green shales and massive red to pale purplish quartzites and conglomerates. Light gray limestone beds occur in the lower part of the thrust sheet. Formations in the lower plate are the Lower Cambrian Tintic quartzite (1500 feet), the Middle Cambrian Ophir formation (975 feet), and Upper Cambrian and Ordovician (?) undifferentiated limestones and dolomites (4750 feet). The thrust plane has been subsequently folded into a syncline and it emerges at a high angle of dip on both the east and west sides of the range which makes the thrust sheet a huge synclinal klippe with no root in the range. Christiansen's description shows that the structure and stratigraphy exposed in the Canyon Range is very similar to that of the San Francisco Mountains. The only difference is that Lower Cambrian rocks are exposed in the lower plate in the Canyon Range. The Tintic quartzite is a correlative of the Prospect Mountain quartzite and the Upper pre-Cambrian rocks in the Canyon Range agree in rock type with those identified as Upper pre-Cambrian and Lower Cambrian Prospect Mountain quartzite in the San Francisco Mountains. In short, even though Christiansen distinguishes between the quartzites exposed in the upper and lower plates, they are probably, in part, the same formation repeated by overthrusting. The over-thrust sheet has merely exposed

lower members of the Tintic or Prospect Mountain quartzite. It is not improbable then that the thrust sheets in both areas are the same since the formations involved are most certainly the same, and since neither thrust has a root within the range. Christiansen also finds evidence of a second, namely Laramide episode of movement likewise involving thrusting which occurred in post-Indianola time (latest Cretaceous to early Paleocene) which Eardley (1951) would correlate with the thrusting in the southern Wasatch Mountains and at Mt. Nebo. In the Pavant Range, Maxey (1946) has dated the thrusting as post Jurassic and pre-Wasatch (Eocene-?, author's note). There is no way of telling if Laramide orogeny has affected the San Francisco Mountains; however, it is believed that the main movement is late Mesozoic and pre-Laramide in age, being correlative with the earlier thrusting in the Canyon Range. The thrusting is certainly post-Triassic since marine sediments of that age which are exposed in the nearby Star Mountains have participated in the pre-Tertiary strong orogeny.

The direction in which the upper plate moved and its amount of displacement are questions which cannot be answered from the study of the San Francisco Mountains alone. The thrust sheets have moved to the east in the Schell Creek Mountains (Misch and Easton, 1954) and the Snake Range (Hazard and Misch, et al, 1953) northwest of the present area; as well as in Mt. Nebo (Eardley, 1934, author's ref., Eardley, 1951) and the southern Wasatch Mountains (Baker et al, 1949) northeast of the present area. Therefore, the direction of movement is probably the same in this

area. Its displacement is greater than the width of the range and is most likely of great magnitude since no sign of a root for the San Francisco Mountain thrust is known to be present in the Wah Wah Mountains or the House Range. If the thrust sheets are the same in both this area and the Canyon Range, then the displacement has been at least 40 miles.

Since the thrusting in the range is the most important contribution in this thesis, I would like to summarize the stratigraphic and structural evidence for the San Francisco Mountain thrust.

Stratigraphic evidence:

- (1) Conclusive evidence that the quartzite formation is Prospect Mountain quartzite and therefore older than the underlying formations.
 - (a) Only in the late pre-Cambrian and early Cambrian of the Great Basin is such a thick sequence of quartzite known.
 - (b) To the north, in the Cricket Mountains, the same quartzite is normally overlain by Cambrian shale and limestone formations.
- (2) The lower plate is composed of dated younger rocks.
- (3) Fossil evidence indicates a truncation of the Ordovician of the lower plate.

Structural evidence:

- (1) Visible truncation of the Ordovician strata.
- (2) Exposed gouge zone between the quartzite and limestone formations.

- (3) Folding of the shale beds immediately below the quartzite formation.
- (4) Fractured, sheared, and brecciated condition of the quartzite formation immediately above the thrust plane.

Cenozoic Structure

Introduction

Cenozoic deformation has been superposed on the earlier folded, faulted, and overthrust structures and is reflected in the present topography of the San Francisco Mountains. The strata underlying the area underwent at least two periods of post-Laramide tectonism.

In early to middle Tertiary times after volcanic rocks had been extruded onto a surface underlain by deformed and eroded Paleozoic rocks, the region was broken along a major north-south trending fault which extends from south of Squaw Springs to a point beyond the northern border of the map. The western block has been raised relative to the eastern block. Intrusion of a quartz monzonite stock into the Paleozoic carbonate rocks and the Tertiary volcanic rocks closely followed the faulting, causing local displacement and doming. Erosion was active until late Tertiary or early Quaternary times when renewed tectonism uplifted the range relative to the westward bordering intermontane basins along a major fault paralleling and lying west of the earlier fault. Monoclinial folding and minor transverse faulting accompanied this major vertical fault displacement.

Early-Middle Tertiary Deformation

Eastern Range Border Fault:

A major north-south trending fault bounds the east flank of the range and has dropped volcanic rocks against the old sedimentary rocks of the San Francisco Mountains proper. Field relations indicate that the eastern border fault has been cut by the quartz monzonite intrusion. There is no bedrock evidence that the stock has been affected by this fault; there are no displaced contacts, topographic breaks, or breccia zones. In short, there is little question that the fault is pre-intrusive in age.

This fault can be traced from south of Squaw Springs Pass, where it apparently dies out or is lost in minor faulting, to north of the Horn Silver Mine where it is difficult to trace in the monotonous volcanic rocks. The actual fault plane is visible above the caved workings of the Horn Silver Mine where it also has been traced vertically underground to a depth of 1600 feet (Butler, 1913, p. 166). Here the west wall is in Cambrian limestone. Investigation of the volcanic terrane in line with the projected fault plane north of the mine revealed numerous silicified and brecciated zones in the volcanic rocks, but in view of the proximity of the intrusive body, they are not too conclusive. However, a water seep was discovered in volcanic gouge which was aligned with the projected fault plane and on this basis the fault is dashed in on the geologic map.

The continuation of the fault is traced by a straight-line scarp in the Prospect Mountain quartzite (see fig. 31) which determines the base

of the range north of the intrusion. Sporadic breccia zones and slickensided surfaces in the quartzite parallel the scarp in the vicinity of Morehouse and Barrel Spring Canyons, but along most of this front the actual fault plane is covered by quartzite talus. However, the fault is visible in the workings of the Golden Reef Mine located in Sawmill Canyon near the extreme northern end of the area mapped. A shaft has been sunk parallel to the fault, and an adit, faced in volcanic rocks, passes through the fault zone which is marked by extreme alteration and shearing of the volcanic rocks and considerable brecciation in the quartzite.

The scarp in the Prospect Mountain quartzite along the projected fault plane is not a fault scarp but a fault line scarp. Renewed movement along the fault can hardly have occurred since there is no visible displacement of the intrusive body along the projected line of the eastern range border fault.



Fig. 31. View, looking south at the pediment surface developed on Tertiary volcanics underlying the lower slopes east of the San Francisco Mountains. Note the fault-line scarp along the eastern border of the range separating the resistant Prospect Mountain quartzite from the weakly resistant Tertiary volcanics.

Intrusive Structure:

The deformation of the country rock adjacent to the quartz monzonite body has been discussed in an earlier chapter. The intrusion has apparently caused a slight doming of the Paleozoic strata along the northern contact of the stock. Here the beds have a general northeasterly dip, but farther from the stock, in the vicinity of the Indian Queen Mine, the strata bend around until the dip is toward the southeast. The deflection of those beds least affected by the intrusion of the quartz monzonite probably occurred when the range was uplifted and tilted to the east by movement along the western border fault.

Late Tertiary-Early Quaternary Deformation

Western Range Border Fault:

Evidence for the western border fault is physiographic. The truncated range spurs which extend into Wah Wah Valley are aligned and consist of Tertiary pyroclastic and extrusive rocks, Paleozoic limestone and dolomite, and intrusive quartz monzonite. If the relief along this side of the range had resulted from differential erosion, the relatively weaker rocks would not have maintained their position at the range front. The only logical conclusion is that the relief is due to differential uplift. This postulated fault is not drawn on the geologic map, but it probably would not lie far beyond the outer range spurs.

Relative uplift of the range block would necessitate a tilt unless the movement were simultaneous along both border faults and the vertical

movement were equally distributed. Since evidence shows that the western border fault is younger than the eastern border fault, it follows that the range was tilted to the east when the western border fault formed. This is borne out by the overall asymmetry of the range; however, the trend of the lower Paleozoic rocks exposed south of the intrusive body seems anomalous. Here, the asymmetry of the range is reversed, with the dip slope facing northwest. It appears that the eastward tilt has had little effect on these beds; however, in such a region of prior deformation, the present attitudes may mean little with regard to the direction of the latest tilt. The attitudes of the beds do conform to the direction of tilt along the western range front north of the intrusion. In all probability the attitudes of the beds here are the result of the tilting of the range block.

Asymmetric and Monoclinial Folds:

An asymmetric fold with a curved axis is a prominent structural feature along the western front of the range just north of the Indian Queen Mine. This flexure apparently plunges to the south as the fold was not observed in the ridge in which the Indian Queen Mine is located. The western limb has been eroded except where exposed near the base of the range where the strata dip beneath the basin alluvium. A view of the western face of the range shown in fig. 10, referred to previously, shows this asymmetric fold, and fig. 32 shows the full arching much better. Locally, the steep monocline which forms the western limb of this fold, is divided into two separate flexures. A view of these flexures is shown in fig. 33.



Fig. 32. View of the asymmetric anticline exposed along part of the western flank of the range. The west limb is seen at the base of the range where it dips into Wah Wah Valley.



Fig. 33. View of monoclinial folds in asymmetric anticline along the west flank of the range. Note the overturning in the west limb of the higher fold. The upper part of the fold has been beveled by erosion.

It might be argued from the evidence presented above that the relief on the west flank of the range is due to folding. However, this folding is limited in extent and there is no evidence that the whole flank of the range has arched into the basin to the west. More significant, the rocks of the upper plate do not come down either. Moreover, in the northwest part of the San Francisco Mountains, just beyond the northern boundary of the map, a large block which has been faulted down from the main western face of the range protrudes from the alluvium beyond the range front. This block consists of Prospect Mountain quartzite unconformably overlain by Tertiary conglomerates and volcanic rocks which have dropped as a unit from the upper plate. This confirms that faulting has been active in the shaping of the western flank of the range. Part of this dropped block is shown in the background of fig. 10.

Transverse Faults:

Numerous transverse faults of minor displacement are present within the bedrock of the range, but only those are shown on the geologic map which appreciably offset contacts or repeat the strata within a formational unit. This faulting is believed to be Tertiary.

One set of faults, cutting diagonally through the range, is worthy of mention because between them a wedge-shaped block has been dropped down which consists of strata of both the upper and lower plates. The two faults apparently merge to the northwest and movement along the single fault is probably responsible for exposing the strata of the lower plate in

Barrel Spring Canyon. The throw on the southern border fault of this wedge-shaped block is about 400 feet; that of the northern fault is less, approximately 200 feet. The latter fault is shown in fig. 34. A partial view of the dropped block and of the position of the southern fault is shown in fig. 13. The southern fault is apparently a scissors fault with the movement of the block south of the dropped wedge being up on the southwest and down on the northeast, whereas the movement of the adjacent block is just the opposite.



Fig. 34. View, looking north, showing vertical displacement of the thrust plates. Dashed lines are approximate position of offset thrust plane. Solid line represents northern bounding fault of dropped block. View taken from position in Cambrian Prospect Mountain composing upper plate of dropped block.

Physiography

Any analysis and conclusions arrived at regarding basin and range structures necessitates investigation of the physiographic development

of the area because, in most cases, as it is with the San Francisco Mountains, the physiographic evidence is the key to the structural interpretation.

The principle physiographic problem is why the San Francisco Mountains stand high above the intermontane basins to the east and west. The possibilities are that the relief of the range is due to (1) erosion, (2) differential uplift, or (3) a combination of both.

Under hypothesis (1), it is possible that the range and the adjoining lowlands were etched out by differential erosion of a highland formed by geologic events of which there is a record in the rocks of the area - that is, intrusion of the quartz monzonite and the tectonic activity in early and middle Tertiary times. Alternative (2), which makes the relief due wholly to differential uplift, implies that all the early relief features were baseleveled by erosion prior to range front faulting. Actually there is no evidence in the way of a well-defined peneplain that this was the case, and there are no Upper Tertiary rocks to provide structural evidence of late Tertiary tilting of the range block. A combination of these hypotheses (3), is that the range owes a part of its height relative to the basins to uplift along late Tertiary or Quaternary border faults of a surface of moderate relief. This would imply that part of the relief seen today is inherited from earlier tectonism and erosion. The latter hypothesis is probably the most reasonable explanation of the relief of the range but it must be stressed that without knowledge of the thickness of the alluvium beneath the basin floor to the west, it is at best only a hypothesis.

Most of the relief features along the east side of the range can be readily accounted for in terms of differential erosion and the eastern lowland is itself erosional in origin (see fig. 31). Its average height at the eastern base of the range is 7000 feet and it is graded to a distant baselevel of about 5000 feet in Beaver Valley. Some well-defined scarps correspond closely in position with faults, but all of the evidence indicates that these are fault line scarps produced by differential erosion of rocks brought together during early Tertiary orogeny.

The west side of the range is entirely different in character and requires a different explanation for the physiographic features. Here, the relief of the range is much stronger, rising 4000 feet in a linear distance of 2 miles. Three different rock types form the range spurs, which are rudely aligned, and, more important, the lowland is upbuilding, the alluvial fans being graded to a playa lake slightly below 5000 feet in elevation. These features suggest relative uplift of the range along a range border fault. However, there is no reason for believing that the present relief of the west side of the range represents the throw along the fault because there is no way of telling how much relief was present prior to uplift.

The deep dissection along the western side of the range is believed to be due to greater altitude due to uplift and the shorter distance to base level of the westward flowing streams. This is well-displayed by the embayment eroded in the relative weak volcanic rocks forming Squaw

Springs Pass. The baselevel advantage of the westward flowing streams is so great that the divide between east and west drainage has migrated through the pass to the east side of the range, and now lies near Frisco. The recession of the normally resistant Prospect Mountain quartzite from the western border fault is explained chiefly by the above two reasons, namely greater relief and shorter distance to baselevel, but another factor is probably involved in the recession. Differential uplift along the postulated west border fault has brought to the surface weak shales and limestones of the lower thrust plate. Erosion of the weak lower plate rocks has allowed a vigorous sapping of the overlying Prospect Mountain quartzite, producing the cliffs seen today. The quartzite still forms a protective cap above the weaker formations along most of the eastern flank of the range and therefore has maintained its position since early middle Tertiary faulting although the relief has been reduced by erosion.

In conclusion, the relief of the range, from the physiographic evidence, is the result of more than one geologic process. Much of the relief on the western side is probably the result of differential uplift along a range border fault, subsequently modified by erosion, whereas most of the relief on the eastern side is the result of differential erosion. This view, in part, is in accord with Butler's conclusions because although he implies from a block diagram (fig. 8, p. 72) that erosion has modified displacement along an eastern border fault, he does not stress this point in the text.

Age of Range Border Faults

Field relations supported by physiographic evidence establish the relative ages of the two range border faults. The quartz monzonite body cuts across the eastern border fault and in turn is apparently cut by the western border fault. The eastern fault is pre-intrusive, and the western post-intrusive in age. Although the field relations indicate relative ages, they do not reveal how much time elapsed between the first period of faulting and the intrusion of the stock, or between this intrusion and the second period of faulting. However, from physiographic evidence, it is obvious that the western border fault is much younger than the eastern border fault. As had been pointed out previously, the relief at the eastern flank of the range is no longer due to uplift but to erosion, whereas the relief at the western range flank is the direct result of uplift by faulting. This indicates that erosion has been reducing the eastern flank of the range for a longer period of time, even though displacement on the western border fault is probably greater than that on the eastern border fault. Therefore, it is concluded that the western range border fault is quite young, probably late Pliocene or early Pleistocene in age, whereas the eastern border fault, being pre-intrusive and post-volcanic, is probably early to middle Tertiary in age.

SUMMARY OF GEOLOGIC HISTORY

The sedimentary record is incomplete in the San Francisco Mountains, and therefore part of the reconstruction of the geologic history will rely on adjacent areas where the record is more complete. Even though pre-Tertiary rocks of only pre-Cambrian, Cambrian, Ordovician, and Pennsylvanian age are present in the area, regional studies show that the Great Basin was part of a subsiding geosynclinal trough and underwent sedimentation from late pre-Cambrian to early Mesozoic times.

Although the oldest rocks in the area are allochthonous, they indicate that geosynclinal sedimentation began with the deposition of quartz sandstones, at least in parts of the Province, in the late pre-Cambrian. The record is missing in the district above these clastic rocks but by tracing these rocks into the mountains north of the mapped area, they were found to be conformably succeeded by finer grained siltstones and shales of late early Cambrian age. The deposition of these rocks in turn gave way to carbonate sedimentation in middle and late Cambrian times. This series completes the classic cycle of deposition in a transgressing sea. The rocks of the later part of this series are preserved in the present area (Middle (?) and Upper Cambrian limestones and dolomites). The Ordovician and Pennsylvanian rocks exposed in the present area represent only a small part of the sedimentation which is known to have taken place throughout the Paleozoic in the eastern Great Basin.

As has been pointed out previously, broad epeirogenic uplifts occurred during the period of overall subsidence of the geosyncline causing some interruption of deposition. After early Mesozoic times, the marine record ends in many areas of the Province indicating a closing of geosynclinal sedimentation. The youngest rocks of the geosynclinal series in the eastern part of the Great Basin are Lower Triassic sediments some of which are exposed in both the Star and Confusion Mountains. Widespread and intense orogeny was active in middle and late Mesozoic times, extending into the earliest Tertiary at some places. It was during this period of tectonism, that large scale overthrusting took place in the San Francisco Mountains. The oldest sedimentary rocks, apparently sheared off from the crystalline basement, were thrust eastward over younger rocks of the Paleozoic sequence. Evidence for this type of shearing off from the basement complex is reported from the Snake Range of easternmost Nevada (Hazzard and Misch et al, 1953). The fact that so much of the section is missing in the rocks of the lower plate, together with the evidence of folding and faulting within the lower plate, shows that some deformation preceded the overthrusting; this first deformation probably belongs in the same general period of orogeny that produced the overthrust.

Volcanic flows and pyroclastic rocks were laid down in considerable amounts in early Tertiary times and may have reached a mile in thickness covering a surface of moderate relief (approximately 1500 feet) cut in the deformed Paleozoic rocks. The volcanic rocks were then broken along a major north-south fault and relative movement raised a western

block. This faulting was followed closely by intrusion of a quartz monzonite stock which undoubtedly resulted in local uplift of the sedimentary and/or volcanic cover. The faulting and intrusion probably occurred in late early to mid-Tertiary times. An interval of erosion followed during which the stock was probably deroofed and a pediment surface formed in the volcanic rocks underlying the lowlands east of the range. Not until late Tertiary or early Quaternary times did the area undergo renewed basin and range faulting which elevated the range to its present height relative to the intermontane basins to the west. Erosion since the earlier Tertiary uplift has continued to strip the weaker volcanic rocks from their elevated positions in the range, until today only one small area of volcanic rocks remains in the higher part of the San Francisco Mountains.

After the latest relative uplift along the western border fault, material eroded from the range has been carried to the bordering intermontane basins. The depositional basin on the eastern side is far outside of the mapped area but the basin on the western side is immediately adjacent to the range. Here, alluvial debris spread out on the lowland to the west and built large fan deposits which have deeply buried the bedrock of the dropped block. Subsequently, during the late Pleistocene, Lake Bonneville was formed which flooded the alluvial basin and reworked the fan deposits along the lake shore forming embankments and shore lines. Recession of the water has left an ephemeral playa lake in the basin. Recent cutting has dissected the shore features in Wah Wah Valley and incised deep washes in the buried volcanic terrane east of the range.

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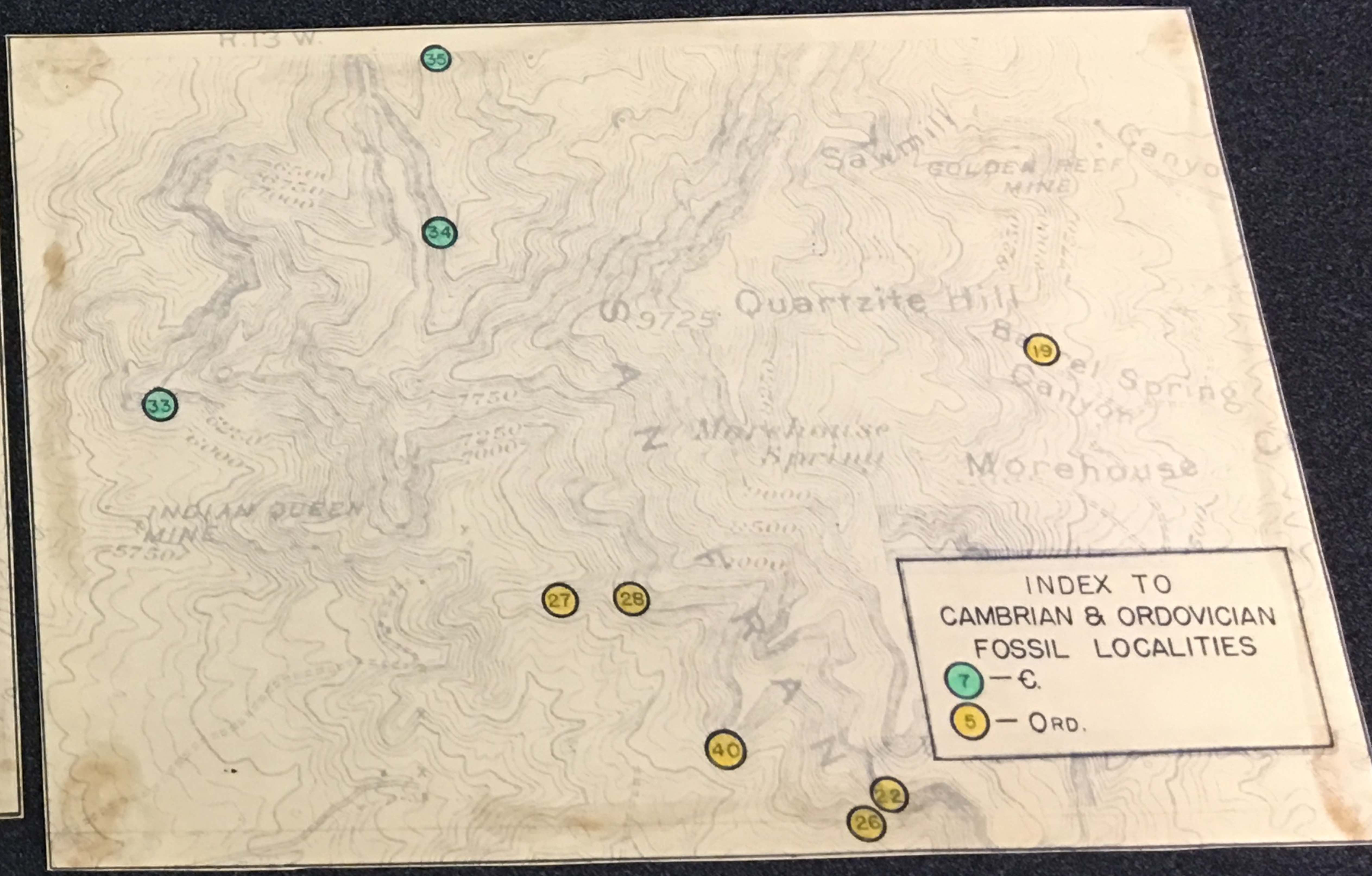
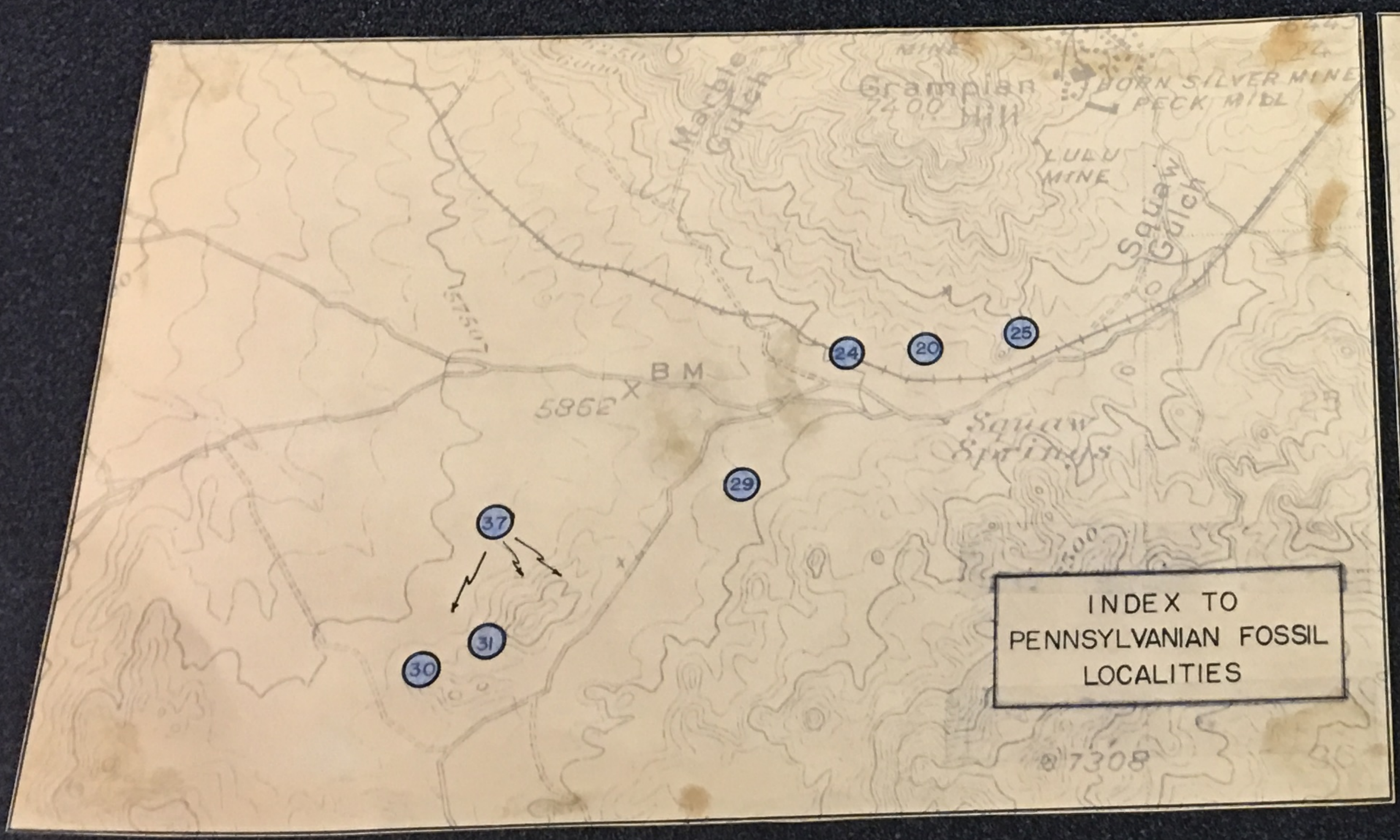
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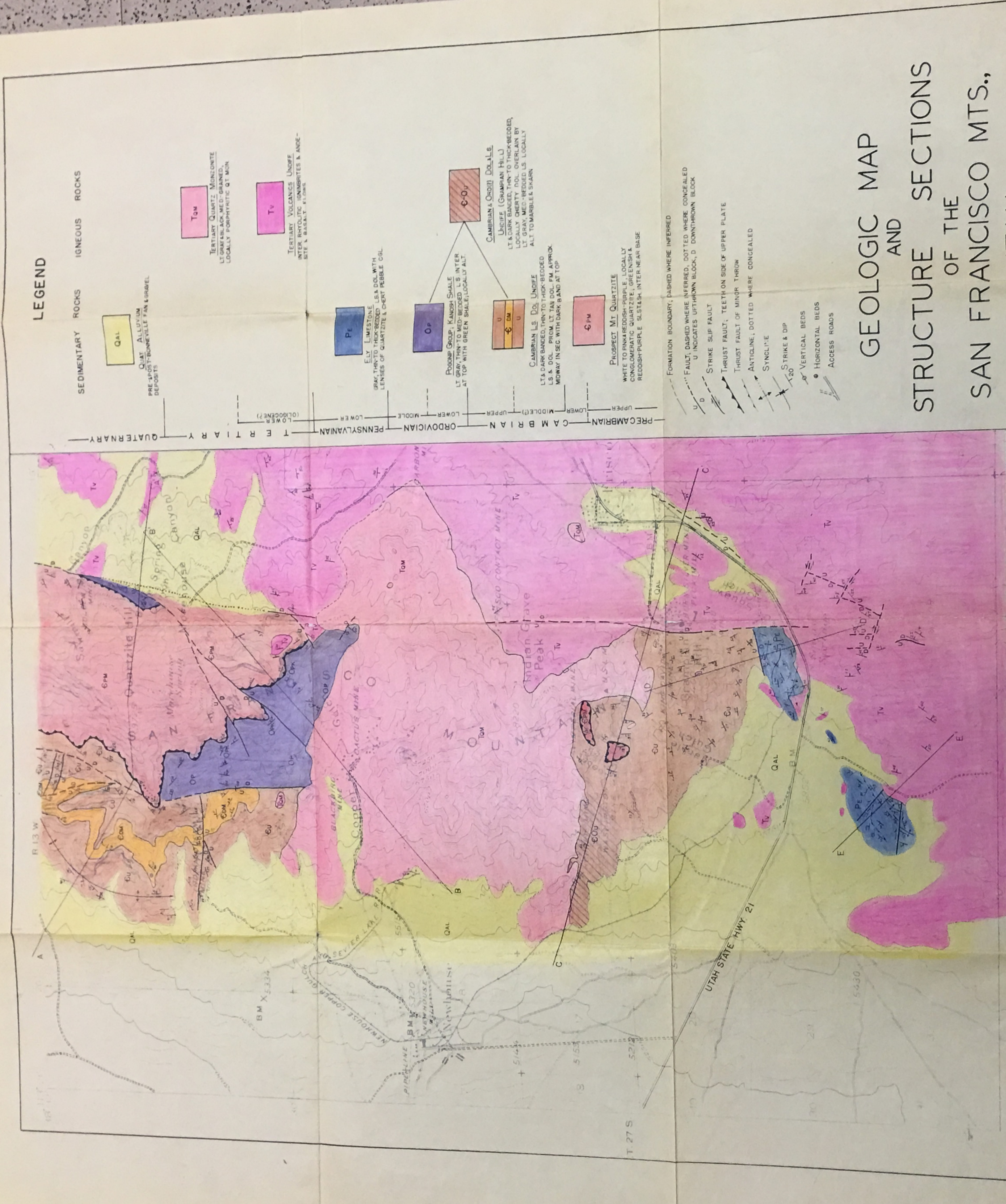
Swingline Heavy Duty Staples

HD Staple Size	Sheet Capacity*
1/4"	2-25
3/8"	25-60
1/2"	40-90
5/8"	75-120
3/4"	90-160
15/16"	160-210

* Capacity based on 20LB paper weight.
Do NOT use 1/4" standard staples. They will jam this stapler.

Swingline



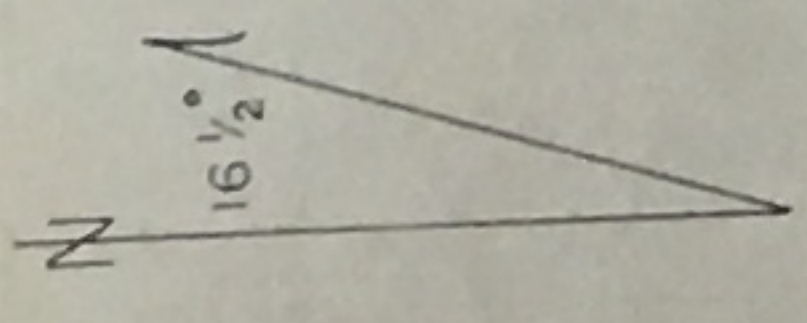


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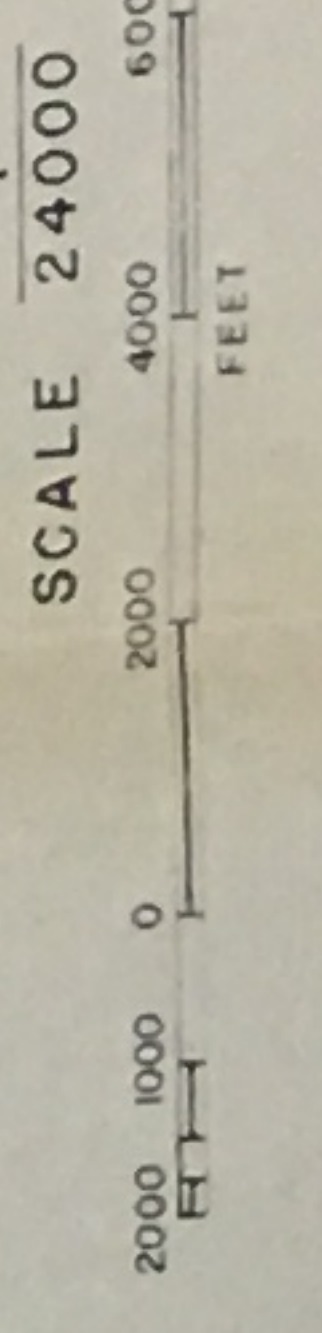
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| SEDIMENTARY ROCKS | IGNEOUS ROCKS | ROCKS |
| QAL ALLUVIUM
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DEPOSITS | Tm
TERTIARY QUARTZ MONZONITE
LIGHT-BROWN MED-GRAINED,
LOCALLY PORPHYRYC QT MIN | |
| | Tv
TERTIARY VOLCANICS UNDEF
INTER-INTRUSIVE GRANITITES & ANDE-
SITE & BASALT FLOW | |
| | | C-Op
ROOSEV. GR. SANDSHALE
INTER-INTRUSIVE
AT TOP WITH GREEN SHALE, LOCALLY ALT. |
| | | C-Ou
CAMBRIAN & ORDOV. DOLOMITE
UNDEF. (GRAMPHAN HILL)
LT & DK Banded, THIN-TO THICK-BEDDED,
LOCALLY MED-GRAINED, LOCALY
ALT TO MARBLE & SHARN |
| | | C-PM
PROSPECT MOUNTAIN QUARTZITE
WHITE TO BROWNISH-PURPLE, LOCALLY
CONGLOMERATIC QUARTZITE; GREENISH &
REDDISH-PURPLE SLATES, INTER NEAR BASE |

- FORMATION BOUNDARY, DASHED WHERE INFERRED
- FAULT, DASHED WHERE INFERRED, DOTTED WHERE CONCEALED
U INDICATES UPTHROW BLOCK, D DOWNTHROW BLOCK
- STRIKE SLIP FAULT
- THRUST FAULT, TEETH ON SIDE OF UPPER PLATE
- THRUST FAULT OF MINOR THROW
- ANTICLINE, DOTTED WHERE CONCEALED
- SYNCLINE
- STRIKE & DIP
- VERTICAL BEDS
- HORIZONTAL BEDS
- ACCESS ROADS

**GEOLOGIC MAP
AND
STRUCTURE SECTIONS
OF THE
SAN FRANCISCO MTS.,
UTAH**



CONTOUR INTERVAL 50'



GEOLOGY BY EDWIN H. EAST
1956



PLATE I