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History, Geology, and Mining Methods of the Moscow Silver Mines in Utah

MINING LLLA 3B-6. SAN FRANCISCO DISTRICT,UTAH.

On E edge orogenic belt almost within Hurrican-Sevier fault zone bounding Colo.Plateau.

B.S.Butler: Geologyn& Ore Deposots of the San Francisco District, Utah. USGS PP.80, 1913.

13,000' Paleo plus 5000' Triassic.

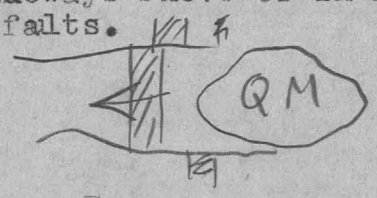
Trias.Thin-bedded shale,IB ls.....	5000'	
Carb.-Dev.-Sil. ls,some IB sh,qtzits	4500	
Sil-Ord.Moorehouse qtzits	4500	Mainly competent
Ord. Limey shale.....	300	
Ord-Camb.Grampian ls.....	4000	
	18300	

Rhyolite, dacite flows and tuffs unconformably above seds.but pre-QM.

A number of stocks occur,largest,NW part,3 mi N-S, 4 mi.plus E-W (QAL on W). Older,GDP,small stocks on E.Younger,QM,the main stocks. QM dikes extend out fromstocks. Age unknown. Tertiary?

Structure: Folding minor;intrusions broke region into blocks,tilted them. Same type of uplift out in frame as shown in Muddy Mts.,Pioche, Gold Hill. Also Bannock region.

Here is one district where stocks have domed and arched the rocks, and are largely or wholly responsible for the Pre-Basin Range structure. Cactus stock -quaquaversal dome. Sideways shove of intrusuve masses also shoved blocks away between lateral faults.



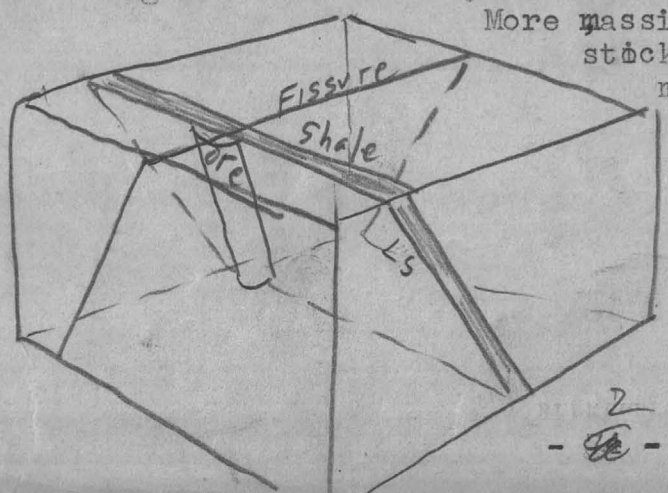
Faulting not marked;main faults N-S Basin-range,largely concealed by Al. p.73: "Faulting has probably been in progress in the area over a long period.Important faults had doubtless formed before the intrusion of the quartz monzonite,and there has certainly been faulting since the intrusion.". Movement largely completed by late Pliocene. Here again we have strong probability that basin-range trends of faulting started long before BR time.

Fissures: Ore channels.E-W,vert.or steep, Star district, SE corner. E-W.N-S,intermediate,S.F. or Cactus area.Fissures caused by stock entry. Strong CM,marble.

12/1/50

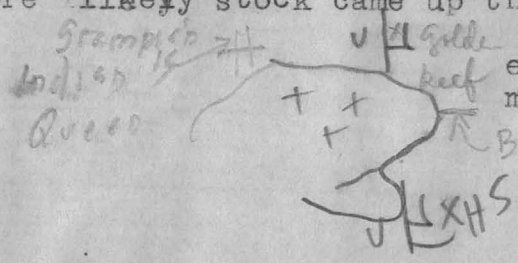
Geologic history.p.91. "Upn an old erosion surface were poured out, probably in Tertiary time,great flows of lava,enearly or quite burying the entire area. Soon after this outpouring of lava the region was broken by faulting,mainly along north-south lines,with minor breaks running east and west. At about the same time the region the region was invaded by extensive masses of intrusive material,forming the stocks of quartz monsonite.." Intrusion ~~followed by~~ accomp.by fltg.,fissuring of earlier rks. then CM,dep.of ores,both close to contact and along channel fissures. "Nearly contemporaneous with the igneous activity there was a general elevation of the region,accompanied by faulting and tilting of the fault blocks.

Ores: Au-Ag-Cu-Pb-Zn. Copper along stock contacts. Pb-Ag-Zn,replacements of bedd along fissures exactly as at Pioche. Typically beneath shale. More massive the ls ,the more the ore stocks to fissure,altho replacement type. Heterogeneous beds, selective replacement,ore extends out from fissure considerably.



Replacement fissure veins in lavas too, E flank Cactus dome. Part open-space filling. PbS, py., ZnS. Gangue qtz., calcite, barite.

Hornsilver mine along synthetic fault? N-S, along E side Cactus stock; or more likely stock came up this fault, blotting it out in center Ls on W, lavas on E. Looks like ore replaced both in brecciated stuff. Lavas brecciated more.



Pb-Zn

Beaver Carb mine in altered latite; fissure, steep, E-W. Gougy, crushed. Ore in open spaces and dissem, thru altered rock. Qtz-calcite gangue with open space ore. Pb Zn.

Golden reef mine in qtzite along same flt. Gold ore along flt. and parallel fissures.

SE or Star district, another N-S fissure fed replacements in ls beds at Cedar-Talisman mine.

Note similarity with Pioche: dependence on fissuring for ore channels or places in which to deposit. OBs closely associated with stocks, contacts probaby provided main ore channels. Stocks rose thru 10 or 12000' of seds. Big Basin Range flt N-S thru center of district, others on either side, all dipping west, beds tilted east. Another district where Basin Range trend started in "Laramide".

-75-

x x x x x x x x x x x x x x x x x

Note similarity with Pioche, Gold Hill: basement type of deformation in E frame of Cordilleran geanticline, here farther E of highland.

AN ANALYSIS OF THE MINING GEOLOGY OF THE SAN FRANCISCO DISTRICT , UTAH

R. S. CREELY

1950

for:

Prof. E. Wisser

Mining 111B

Spring, 1950

CONTENTS

INTRODUCTION .....

GENERAL GEOLOGY .....

DESCRIPTION OF FORMATIONS
Sedimentary Rocks
Grampian Limestone .....
Morehouse Quartzite .....
Red Warrior Limestone .....
Mowitza Shale .....
Topache Limestone .....
Talisman Quartzite .....
Elephant Limestone .....
Harrington Formation .....

Igneous Rocks
Extrusive .....
Intrusive Igneous Rocks .....

METASOMATIC ALTERATION .....

STRUCTURE 13
Tectonic Relations .....

NATURE OF THE ORE DEPOSITS .....
Ore Deposits in the Quartz Monzonite .....
Ore Deposits in the Volcanic Rocks .....
Ore Deposits in Sedimentary Rocks .....
A.) Contact Deposits .....
B.) Replacement-Fissure Deposits .....

ORE CONTROLS .....

CONCLUSIONS .....

INTRODUCTION

The San Francisco district is located in Beaver County, in southwestern Utah. It lies toward the eastern margin of the basin and range province, and close to the western edge of the Colorado Plateau. The latest and most comprehensive paper on the district is by Butler.[1]

1. Butler, B. S. "Geology and ore deposits of the San Francisco and adjacent districts, Utah." U.S.G.S. Prof. Paper 80, pp. 1-212, 1913.

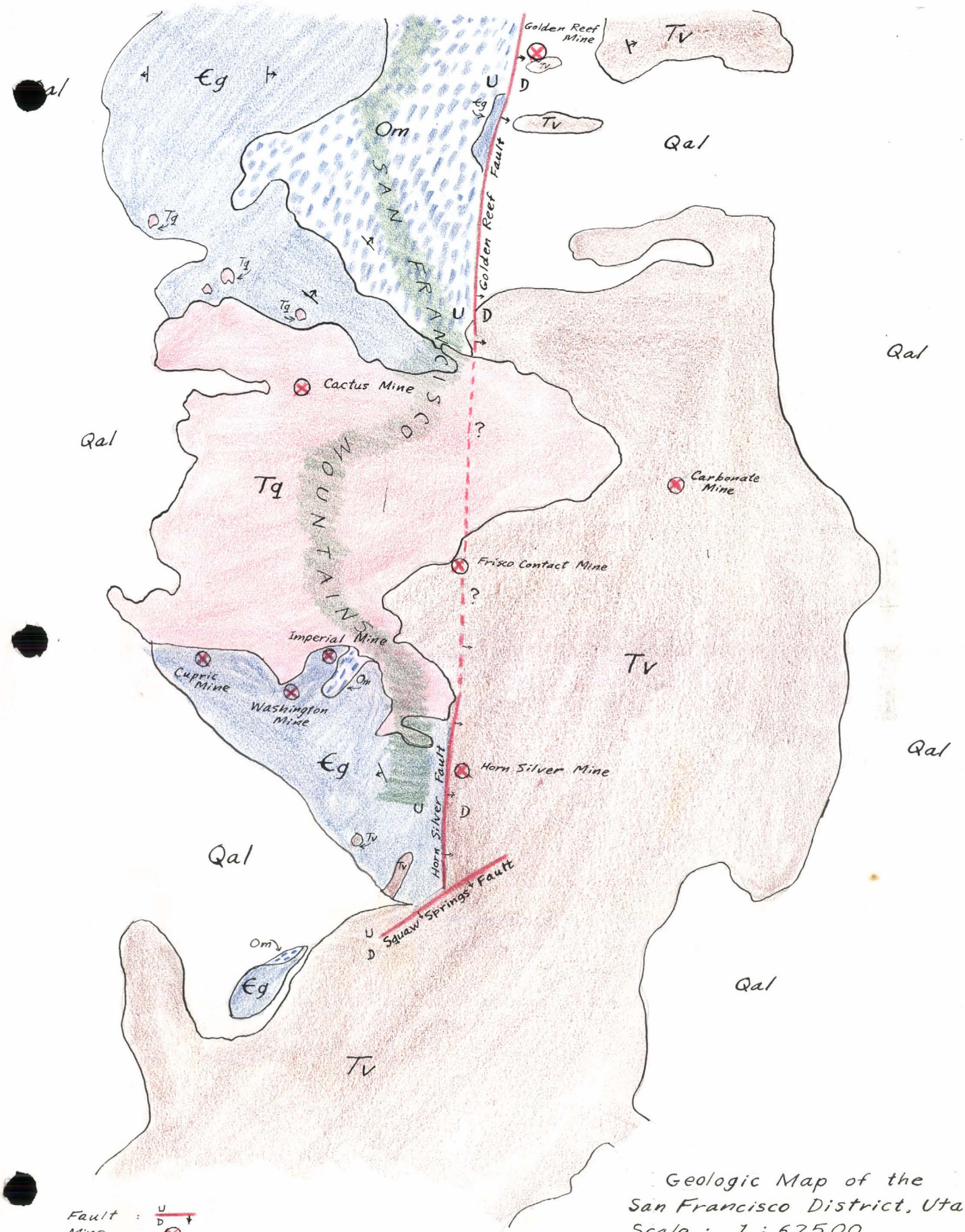
GENERAL GEOLOGY

Approximately 18000 feet of sedimentary rocks have been deposited in the district. These extend in age from Cambrian (?) to Triassic, and include essentially limestones, quartzites, and shales.

Igneous rocks, both extrusive, and intrusive, are important and widespread in the district. Tertiary volcanic rocks, both acid and basic, represent several periods of extrusion. Quartz-monzonite is the chief type of intrusive rock, and was intruded shortly following the outpouring of the main body of lava.

Block faulting, rather than folding is the dominant structural feature of the region. The predominant fault trend is north-south.

Hydrothermal metamorphism has been locally extensive in the region. The limestones and volcanic rocks have been especially strongly effected.



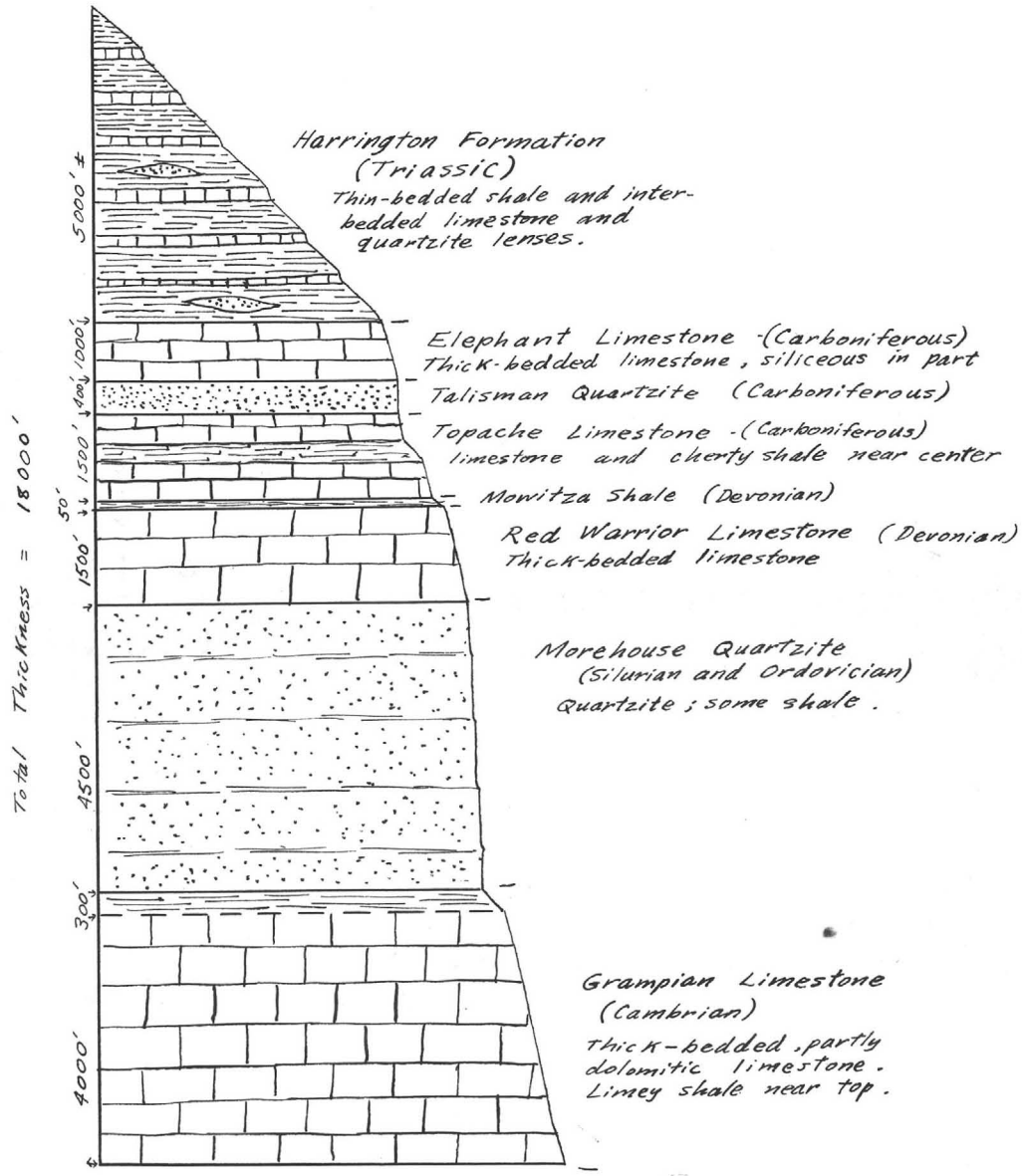
Fault : U D
Mine

Geologic Map of the
San Francisco District, Utah
Scale : 1 : 62500
Modified after Butler : USGS Prof. P. 80
R.S. Creely - 1950

Tv - volcanic rocks (Tertiary)

Approximate crest of S.F. Mountains

Qal - Quaternary alluvial + lacustrine deposits
Tq - quartz-monzonite of "Laramide" age
Om - Morehouse quartzite (Ordovician)
Eg - Grampian limestone (Cambrian)



Geologic Column of the Sedimentary Rocks of the San Francisco District, Utah.
Back-slopes indicate relative competency of rocks.

R.S.C.

DESCRIPTION OF FORMATIONS

Sedimentary Rocks

Paleozoic

Cambrian (?) and Ordovician

Grampian Limestone

The oldest formation recognized in the area is the Grampian limestone. It consists of thick-bedded, blue dolomitic limestone, and shows a remarkable uniformity of character through a great thickness of the formation. Locally, the limestone is somewhat siliceous. The upper part of the formation becomes shaly, and the top few hundred feet consist of limy shales and minor quartzite. Apparently these upper beds are gradational into the overlying Morehouse quartzite. The Grampian limestone has a total thickness of about 4000 feet.

Ordovician and Silurian(?)

Morehouse Quartzite

The Grampian limestone is conformably overlain by the Morehouse quartzite, and the contact is apparently gradational. The Morehouse is composed largely of thick-bedded, dense, white or pink, fine-grained quartzite, and lesser amounts of red shale. Minor sandy or limy beds are also present. The Morehouse quartzite, has a known thickness of 2000 feet, but an additional 2500 feet of quartzite of supposed Morehouse age should be taken into account. The Morehouse quartzite is overlain, apparently gradationally, by the Red Warrior limestone.

Silurian (?) and Devonian (?)

Red Warrior Limestone

The Red Warrior limestone is for the most part thick-bedded, blue, dolomitic and in places siliceous. Lenses of quartzite are found in the lower part of the formation. Its thickness is roughly 1500 feet.

Devonian

Mowitza Shale

The Mowitza shale consists of limy shale beds intercalated with thin beds of limestone, both of which are dark grayish-blue. The shales are underlain and overlain by thick-bedded limestone. The thickness of the Mowitza is about 50 feet. Its relation with the overlying and underlying formations are conformable.

Carboniferous

Mississippian (?)

Topache Limestone

The lower portion of the Topache limestone consists of thick-bedded, blue, dolomitic limestone. This grades into shaly limestones, and these in turn grade into cherty and siliceous beds and intercalated limestone and shale at the top of the formation. The formation has an average thickness of 1500 feet, and is conformable with the overlying Talisman quartzite.

Pennsylvanian (?)

Talisman Quartzite

The Talisman quartzite is fine-grained and pink. It has an average thickness of about 400 feet, and is apparently conformable below the overlying Elephant limestone.

Pennsylvanian

Elephant Limestone

In the southern part of the district, the Elephant limestone is made up of thick-bedded, blue, dolomitic, and in part siliceous limestone. To the north the limestone becomes distinctly more siliceous, and siliceous shales and intercalated shale become predominant. In places the thickness of the formation exceeds 1000 feet. The contact between the Elephant limestone and the underlying Talisman quartzite is possibly gradational. The overlying Harrington formation is apparently conformable, but the contact is distinctly gradational.

Mesozoic

Triassic

Harrington Formation

5000 feet of shales with lesser amounts of limestone and quartzite make up the Harrington formation. The shale is thin-bedded, red and gray, and is either quite friable, as in the southern part of the district, or is hard and siliceous, as in the northern part. The shale is overlain by the thick-bedded limestone in the northern part, and by thin-bedded limestone and shale in the southern part of the district. At the top of the formation is a series of interbedded limestone and siliceous shale. Lenses of quartzite are found locally.

Igneous Rocks

Extrusive

A considerable portion of the district is covered by post-Triassic volcanic rocks. The series is composed of several flows and pyrodastic members. The flows have the form of lenses of varying thickness from place to place, and each flow is not present in all parts of the area. The lowest member is a coarse dacite-porphyry and andesite flow, several hundred feet thick. Rhyolite-tuff and rhyolite flows overlie these, and are in turn overlain by a succession of dacite and rhyolite flows having a total thickness of several thousand feet. The latest volcanic rock in the area is a thin sheet of basalt, and is believed to have been extruded considerably later than the underlying volcanics.

Intrusive Igneous Rocks

Granodiorite porphyry forms a small stock between the Rocky Range and the Beaver Lake Mountains. It is a dark, fine-grained porphyritic rock. The granodiorite is the earliest of the intrusive rocks of the area.

Quartz-monzonite is by far the most important intrusive igneous rock in the district. It forms a large stock in the San Francisco Range, and two large bodies in the Beaver Lake Mountains. (A somewhat smaller body is present in the Rocky Range. Several stocks are found in the Star district.) Mapped as quartz-monzonite are rocks of the granite family from granodiorite or quartz-diorite to granite. (Butler[2] devotes several pages to petrographic and chemical descriptions of these rocks throughout the area.)

Various dikes of quartz-monzonite, lamprophyre, and aplite, along with more basic types, are apparently related to the larger intrusive bodies. They represent somewhat later differentiates of the crystallizing magma. In some cases, dikes may be directly traced into the stocks of quartz-monzonite.

(The effects which these intrusive igneous rocks have had upon the older rocks of the region are discussed in other sections of this paper.) It seems highly probable that the various intrusives represent a single igneous cycle, with the early intrusion of granodiorite, closely followed by a more extensive intrusion of quartz-monzonite, and finally in the later stages of crystallization, differentiation from the magma at depth of the basic and acidic dikes.

2. Op. cit., pp. 52-59.

The exact time of the intrusion is not known, but it certainly followed the extrusion of the lavas of the district. By comparison with other sections, a Tertiary age for the igneous activity is indicated. Butler[3] suggests that the quartz-monzonite may correspond to intermediate extrusive rocks found in other parts of Utah.

3. Op. cit., pg. 70.

METASOMATIC ALTERATION

The rocks of the San Francisco district have been locally altered due to the action of heated gases and liquids which were closely related to the intrusion of the quartz-monzonite. Apparently, these mobile solutions were in part given off by the magma during the later stages of crystallization. The various effects of this hydrothermal alteration upon the different rocks of the district may be briefly summarized.

Alteration of the Quartz-Monzonite

The quartz-monzonite in general has been slightly altered. The highest degree of alteration occurs along fissures; the product is a nearly white, dull chalky, fine-grained rock. Underground, this rock is pale green, and possesses a silky luster due to the presence of abundant sericite. Microscopically, biotite and hornblende have yielded chlorite and carbonate. Feldspar has altered to masses of felt-like sericite. Quartz shows only slight alteration. No evidence was observed to indicate that any appreciable volume change occurred. Silica content has decreased slightly, and alumina content has remained fairly constant. An important inference to be drawn here is that the solutions contained considerable silica.

Alteration of the Lavas

The volcanic rocks have undergone extensive hydrothermal alteration. Locally, the lava has been silicified and thus forms a rather weather-resistant rock. The feldspars have been sericitized and quartzized. Andalusite has formed in some quantity, thus

indicating that high heat and pressure prevailed at the time of alteration.

Alteration of the Sedimentary Rocks

The greatest changes due to metasomatic alteration have been in the limestone, especially along the intrusive contacts, and along fissures at some distance from the stock. The composition of the limestone seems to have been an important factor in determining the minerals formed. Garnet, tremolite, diopside, epidote are some of the more prominent minerals in the altered zones. It is significant that the earlier contact minerals have locally undergone slight crushing and the fissures have been filled by later contact minerals. As in the alteration of the other rocks, there is no indication of any change of volume attending the alteration. Butler[4] proposes that .... "the great extent of mineralization along the contact at certain points suggests that solutions given off by the crystallizing magma were collected into channels and entered the limestone at these points."...."It seems not improbable that after molten magma had entered the sedimentary rocks and the outer margin solidified, channels were formed that directed the course of solutions coming from the interior of the crystallizing mass and concentrated their action at certain points."

4 Op. cit., pg. 90.

STRUCTURE

The structure of the district is essentially one of block-faulting. There is only one major fold; this is a broad, plunging anticline in the Grampian limestone of the San Francisco Mountains. Some doming, apparently due to the intrusion of the quartz-monzonite mass, is noted in the Cactus area.

The most important structural features of the district are the result of faulting. The San Francisco Mountains are believed to be of the typical basin and range type, being a tilted block bounded on the west, and in part on the east, by faults. The main faults of the district are the Golden Reef and Horn Silver faults, which lie along the eastern base of the range. The writer believes that the two were almost certainly continuous at the time they were first formed, and they will be treated in this paper as one fault. This fault dips steeply east and has let the volcanics down against the earlier sedimentary rocks on the west. It is possible that this fault is of the synthetic type, having aided the effects of some uplift to the west. The fault was apparently present at the time of the intrusion of the quartz-monzonite, and there has been later movement along the fault since the intrusion. There are several parallel faults on the west of the main fault. The chief displacement, however, has been the main fault line and was at least 1600 feet of vertical movement.

There are numerous east-west faults in the district showing comparitively slight throw. They were apparently formed at the time the block was uplifted, and are thus in part contemporaneous with the movement on the Golden Reef-Horn Silver fault. In the

Star district, a fault block has apparently been crowded to the west by the intrusion of the quartz-monzonite of that area. Similar action near the Cactus stock may be present, but has not been recognized.

Fissuring has been important in the district. The fissures of the San Francisco district can not be said to have any predominant direction, although those in the adjoining Star district are essentially east-west. The fissures in the limestone and lava of the San Francisco district are attributed to stresses caused by the intrusion of the quartz-monzonite. Fissures in the monzonite itself, and in the contact altered rock, probably are due to cooling-shrinkage effects.

Tectonic Relations

The San Francisco district lies within Eardley's[5] Upper Cretaceous orogenic belt on the east side of the Cordilleran geanticline. It also is located within the eastern margin of the region of mid-Cretaceous folding as defined by Spieker.[6]

The region had apparently been uplifted previous to the igneous activity, allowing the surface to undergo erosion. This uplift took place at some time following the Triassic. Probably in the late Mesozoic or early Tertiary ("Laramide" time), the region was subjected to tensional stresses accompanied by the outpouring of extensive amounts of lava. North-south normal faults were formed at this time, possibly aiding an uplift somewhere to the west. Minor east-west breaks also occured at this time. Slightly later than, but closely related to this activity, the crust was invaded by large masses of plutonic igneous rocks. These were accompanied by further faulting and fissuring. The fissures were utilized as channels for the passage of aqueous and gaseous solutions which effected the extensive alteration of the earlier rocks, and the deposition of ores in favorable loci. With cooling and crystallization of the igneous mass, and readjustment of the stresses which had been set up in the rocks, further fissuring occured, and these openings allowed the injection of basic and acidic dikes as differentiation products of the magma at depth. Solutions exuded at this time from the deeper crystallizing magma

5. A. J. Eardley, Bull. A.A.P.G. 33 (1949) pp. 655-682.

6. E. M. Spieker, U.S.G.S., Prof. Paper 205-D (1946) pp. 117-161.

escaped through the fissures and hydrothermally altered and mineralized parts of the already crystallized igneous mass. Nearly contemporaneous with, or closely following, this igneous activity was the general elevation of the region, and the faulting and tilting of the fault blocks. Subsequent erosion has reduced the surface to its present level.

NATURE OF THE ORE DEPOSITS

The ore deposits of the San Francisco district fall into the epithermal group of the classification of ore deposits in present use. The deposits check reasonably well with this classification structurally, texturally, and mineralogically. For an excellent paper on epithermal deposits, the reader is referred to Schmitt.[7]

The ore deposits are believed to be contemporaneous with each other, and their formation apparently closely followed the emplacement of the quartz-monzonite intrusive masses.

The differences in the character of the various deposits are due primarily to the following:

(1) Character of the rock in which the ore occurs.

(2) Distance from the intrusive mass (thus affecting the pressure and temperature conditions.)

(3) Time of deposition of the ore in relation to the mineralization period as a whole.

Of these, (1) seems to be the most important factor.

Ore Deposits in the Quartz Monzonite

The ore deposits in the quartz-monzonite are characteristically copper with some gold and silver. Quartz and sericite are the common gangue minerals.

The Cactus ore zone is an example of the deposits in the quartz-monzonite. Pyrite, chalcopyrite, and hematite, and other sulfides are the important metallics. The gangue is largely sericite, quartz, carbonate, tourmaline, anhydrite, gypsum, and barite. These minerals

7. Schmitt, H., Origin of the "Epithermal" Mineral Deposits. Economic Geology, Vol. 45, No. 3, pp. 191-199, May, 1950.

fill open spaces in breccia and replace monzonite. Open spaces and well formed crystals are abundant in this deposit. The mineralization sequence, as determined by Butler,[8] was as follows. First period: hot aqueous solutions from monzonite magma deposited sericite, quartz, sulfides and minor amounts of iron oxide and carbonate. Second period: quartz and sulfides, plus tourmaline and hematite continued to be deposited. We have here an indication of changing physical conditions and changing composition of the solutions. The mineralization of the second phase showed a lessening of power of penetration, and more of a dependence upon fissures. It is possible that the change in composition was due to a differentiation in the magma, and the physical change was due to a decrease in temperature and / or pressure. Third period: siderite, barite, and anhydrite were precipitated, along with continuing pyrite and chalcopyrite.

The Cactus ore zone is in the shape of an irregular stockwork. The rock has been highly brecciated, apparently by slight movements, as no considerable faults can be traced from the ore-zone. At depth the breccia fragments become smaller and replacement of the monzonite is more important. Butler[9] states that .... "it is believed that .... slight movements were taking place in the zone during the process of mineralization, and that the gouges formed as a result of these movements have from time to time deflected the mineralizing solutions from certain areas." The brecciation and fissuring may have been caused by the readjustment of stresses with the cooling of the intrusive.

8. Op. cit., pg. 122.
9. Op. cit., pg. 125.

There are blocks of barren monzonite within the ore body, and these appear to be bounded by faults. Slight movement along these faults at the time of mineralization may account for the barreness of the blocks.

Ore Deposits in the Volcanic Rocks

There are two commercially important deposits in the lava on the east flank of the San Francisco Mountains. These are the Horn Silver and the Beaver Carbonate mines. Both are essentially replacement-fissure veins, in which ore in part fills open fissures and in part replaces the rock adjacent to the fissures.

12/4/50

The Horn Silver deposit is adjacent to the Horn Silver-Golden Reef fault. The minerals include pyrite, galena, sphalerite, some chalcopyrite, cerargyrite and other silver sulfantimonides and sulpharsenides. The gangue is predominantly quartz, barite, and altered country rock.

The throw of the main fault here is at least 1600 feet. It dips east 60 degrees. Lava on the east has been thrown down against the Grampian limestone. There has been some east-west faulting subsequent to the formation of the main fault. These are well shown in the workings of the Horn Silver mine. Butler[10] hypothesizes that slipping occured along the bedding planes when the beds were tilted and movement was effected along pre-existing fissures. There is no notable displacement along these fissures-turned-fault. There has been some downthrow to the south on these faults, similar to the movement on the Squaw Springs fault.

Observations in the underground workings of the Horn Silver mine have cast significant light upon movements which have occurred.

10. Op. cit., pg. 167.

The most extensive movement occurred during the uplift of the San Francisco Range, which is believed to have taken place contemporaneously with, or immediately following the intrusion of the quartz-monzonite. Movement along the cross-faults seems to have been important in producing brecciation in rocks at these points. Ore was deposited after the first faulting and subsequent movement has brecciated the ore and slickensided it. There are several faults in the limestone parallel to the Horn Silver-Golden Reef fault.

The ore occurs in a highly silicified zone in the lava, apparently physical character is the prime factor in the localization of the ore here, although considerable replacement of the country rock has occurred. The massive, competent limestone resisted the stresses tending to brecciate it, and thus did not favor the free circulation of solutions. But the lavas were inherently porous and weak. They were rendered brittle by the silicification, a function of the hydrothermal alteration, and were thus easily brecciated. Little resistance was offered to the mineralizing solutions by this material, and a high degree of mineralization was effected.

The Beaver Carbonate Mine is located on an east-west fault of unknown displacement. The alteration is not as intense as in the Horn Silver deposit, and breccia filling seems to predominate even further. Carbonate is the principal gangue here. Argentiferous galena is the only ore mineral of any note.

Ore Deposits in Sedimentary Rocks

A.) Contact deposits:

Ore has been formed by replacement in limestone on fissures near the quartz-monzonite. In such deposits, the ore body is irregular, but follows the contact rather closely. Chalcopyrite is the

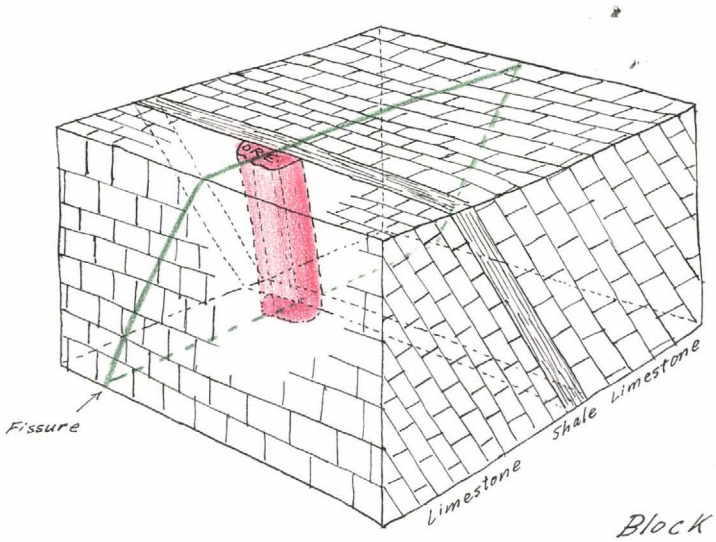
important ore mineral. Pyrite, magnetite, hematitite, garnet, and diopside are also common. The Imperial, Washington, and Cupric mines are examples of this type of deposit. Apparently the fissuring has resulted from the intrusion of the quartz-monzonite.

B.) Replacement-fissure deposits:

The replacement-fissure deposits have formed along fissures. Where the limestone bed is massive, the replacement may occur rather uniformly in different beds, and a roughly tabular ore body is locally produced parallel to the fissure. Where sediments of varying physical and chemical character are interbedded, the ore deposit has extended out from the fissure in certain beds for considerable distances, though adjacent beds have suffered little, if any, replacement by the ore. Thus physical and chemical controls have operated to localize the ore. (The tabular development is best shown in the Mammoth mine. Here, the deposit is in the Topache limestone. There has been some swelling of the ore-body in certain beds.)

(Selective replacement along certain beds is shown in the Harrington-Hickory mine and in mines underlying the Mowitza shale.) Replacement has occurred along certain beds to form "chimneys" of ore following the intersection of the fissure and the replaced bed. The fissures obviously must have been tight when passing through the shale beds. No breccia was produced in the shale as it was in the limestone. Furthermore, the shale must have presented a barrier to the rising ore-solutions in the fissure. Chemical composition is a controlling factor in deposits where thin beds of quartzite, shale, and limestone are interbedded, and the replacement has selectively been only in the limestone.

Lead and silver are the chief ores in this type of deposit.



Block diagram showing ore-shoot localized beneath shale along fissure.
Modified after Butler

Varying amounts of zinc and copper are also present. Secondary alteration has been extensive, so that present developments have disclosed little primary ore. The chief gangue is quartz and calcite. The wall rocks typically show silification.

ORE CONTROLS

The ore deposits of the San Francisco district have been controlled by three major factors which may be summarized as follows:

(1) Proximity to intrusive igneous masses of intermediate size and composition.

(2) Deformation of the rocks of the district, especially tensional stresses.

(3) Physical and / or chemical favorability of the rocks in which ore has been deposited.

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(1) A glance at the map will show that all of the mines of the district are closely associated either with surface exposures of the quartz-monzonite stocks, or are in such positions that they are probably underlain closely by the intrusive masses. It is strongly believed that the metallic constituents, and probably the aqueous solvents themselves, were derived directly from the crystallizing igneous mass at some depth, probably as end products of the differentiation cycle. The strongest piece of direct evidence for this is the fact that certain dikes, known to be genetically related to the quartz-monzonite, actually contain metallic constituents inter-crystallized with the other minerals of the rock.

It is highly probable that the igneous contacts at depth acted as channels for the passage of the ore-bearing solutions, (the heterogeniety of the rock being the main factor in this case.)

(2) Without exception, all of the deposits of the district show a marked dependence upon fissuring. It was these fissures which provided the main channels for the passage of the ore bearing

solutions, as well as the solutions which hydrothermally altered the rocks so extensively. Not only was tensional deformation going on before the introduction of the solutions, but evidence indicates that movements were going on at the time of mineralization. The channels were kept open by recurrent movements, thus allowing the free passage of the mineralizing solutions. The brecciation of the rocks, discussed under the next heading, was a direct function of the tensional deformation which affected the region.

(3) In all cases, the ore-bodies have been localized by certain physical and / or chemical characteristics of the rock in which they were deposited.

Brecciation of the rock seems to be one of the major controlling factors in the emplacement of the ore-bodies. The spaces between the breccia fragments acted not only as channels for the passage of ore-bearing solutions, but also as loci of ore deposition. While brecciation and fissure filling may predominate in the upper levels of a deposit, the breccia fragments and their intersticies often diminish in size with depth and replacement becomes the dominant mode of deposition. It must be emphasized that brecciation depended upon tensional deformation and fissuring. The faults producing considerable breccia were subjected to only slight movements. Where large movement took place, or where the deformation was locally compressional, the production of gouge resulted. The gouge was extremely impermeable and inert, and actually deflected the mobile ore-bearing solutions.

The extensive hydrothermal alteration has in some cases conditioned the rocks. For example, in the Horn Silver deposit, the

lavas and tuffs on the east side of the main fault were silicified and thus rendered brittle. They were subsequently brecciated to a high degree, and the ore is noted to be limited to this zone of silicification and brecciation.

Heterogeniety of the rock is extremely important in many of the deposits. This is especially well shown in the limestone fissure-replacement deposits of the Star district. Here, several ore bodies have been localized along fissures directly below the Mowitza shale. The fissures have produced brecciation in the more brittle, thin-bedded limestone, but due to the incompetent nature of the shale, the fissures become tight when they pass through the latter. Thus, the shale formed an impervious "dam" to the rising ore-solutions, and caused them to spread out along the favorable bed beneath this barrier. Where the deposits are in rock of a homogeneous, massive nature, the ore is more or less restricted to the fissure zones.

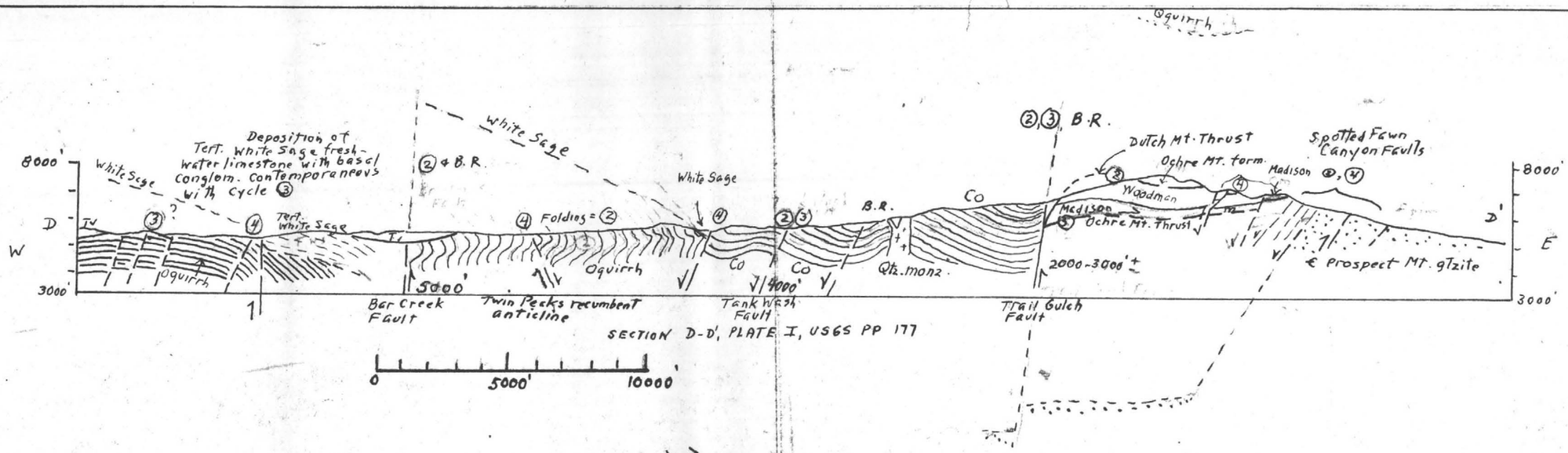
No doubt, some of the rocks in which ore was deposited was more favorable due to certain chemical and mineralogic differences, either in the original or altered state. It seems, however, that this is a local feature of the individual deposit, and not a regional control. The writer feels that where open cavity filling was possible, it was utilized by the ore-solutions, and that only when such openings were lacking did the process of replacement become important.

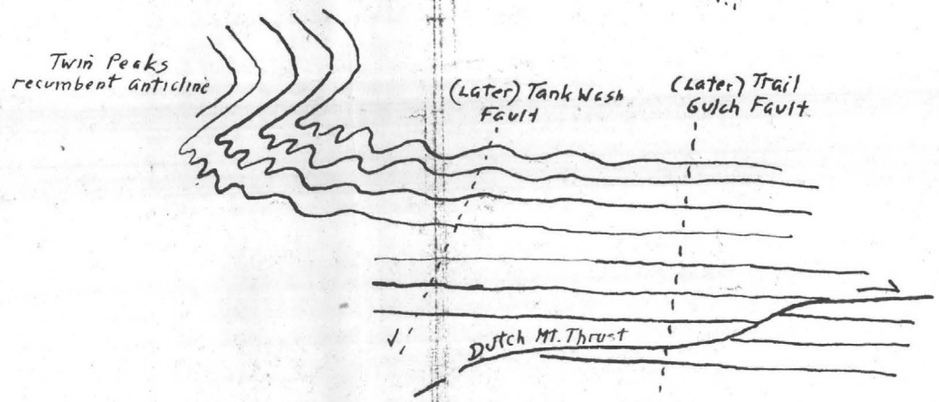
CONCLUSIONS

There is a strong similarity between the San Francisco district and the Pioche district lying 75 miles to the southwest. Structurally, the two districts show the same type of basin and range deformation, with the emphasis on block faulting and practically no folding. The section at Pioche is between 17,000 and 18,000 feet thick. The section in the San Francisco district is 18,000 feet. At Pioche, the predominance of block faulting and general lack of folding is accounted for by the general competency of the lower part of the section. A similar condition exists in the San Francisco district. The section here is quite competent in the lower half, and somewhat less competent in the upper half. As in the San Francisco district, there is a strong dependency upon fissures at Pioche, both as solution channels and as loci of deposition.

With respect to future exploration in the San Francisco district, it seems probable that a fault lies along the western base of the mountains beneath the alluvium. If such is the case, it is reasonable that new undisclosed ore deposits would lie in that zone in association with the fault and its related fissures. In addition, the area in the volcanics south of the Squaw Springs fault appears to be in a favorable position, since it would lie on an extension of the Horn Silver-Golden Reef fault zone.

As a possible guide to ore, more attention should be given the hydrothermal alteration of this district. If possible, an alteration pattern should be worked out. Similarly, a detailed map of the fissure and fault pattern might provide a sound foundation for an exploration campaign.





Restored Relations of Dutch Mt. Thrust and Twin Peaks recumbent anticline.
FIG. 11, USGS PP 177

GOLD HILL, UTAH. After T. B. Nolan, USGS PP 177, 1935

Numbers ① etc. correspond to Nolan's orogenic cycles.
B.R. = Basin Range epoch of faulting

E. Wisser 12/49