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Geology of the Star Range, Beaver County, Utah*

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ABSTRACT.—A new geologic map of the Star Range and adjacent area near Milford, Utah, shows more than 9500 feet of Devonian to Jurassic sediments exposed. Formation names used are: Devonian.—Sevy (?), Guilmette, Pilot; Mississippian.—Redwall; Pennsylvanian.—Callville, Talisman; Permian.—Kaibab; Triassic.—Moenkopi, Shinarump, Chinle; Jurassic.—Navajo. These names replace: Devonian.—Red Warrior, Mowitza; Carboniferous.—Topache, Elephant; Triassic.—Harrington, formations proposed by Butler in 1913. Tertiary extrusive and intrusive rocks are also exposed. Latite, andesite, and basalt have been intruded and mineralized by granitic to porphyritic quartz monzonite to granodiorite intrusions. Contact and thermal metamorphism has altered both sedimentary and extrusive igneous rocks.

Laramide thrust faults are exposed and cut by two sets of Late Tertiary normal faults; a northerly striking set cut by a later easterly striking set. Repeated movement has occurred along normal faults with later movements elevating the range to essentially its present position.

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TEXT

*A thesis submitted to the Faculty of the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science.

EXPLANATION OF PLATE 1
Thrust Relations in Section 12, T. 28 S., R. 12 W.

FIG. 1.—Permian Kaibab (Pk) thrust over Jurassic Navajo (Jn).

FIG. 2.—Brecciated zone of the thrust seen in figure 1.

FIG. 3.—Brecciated top of Navajo Sandstone in Section 7, T. 29 S., R. 12 W.

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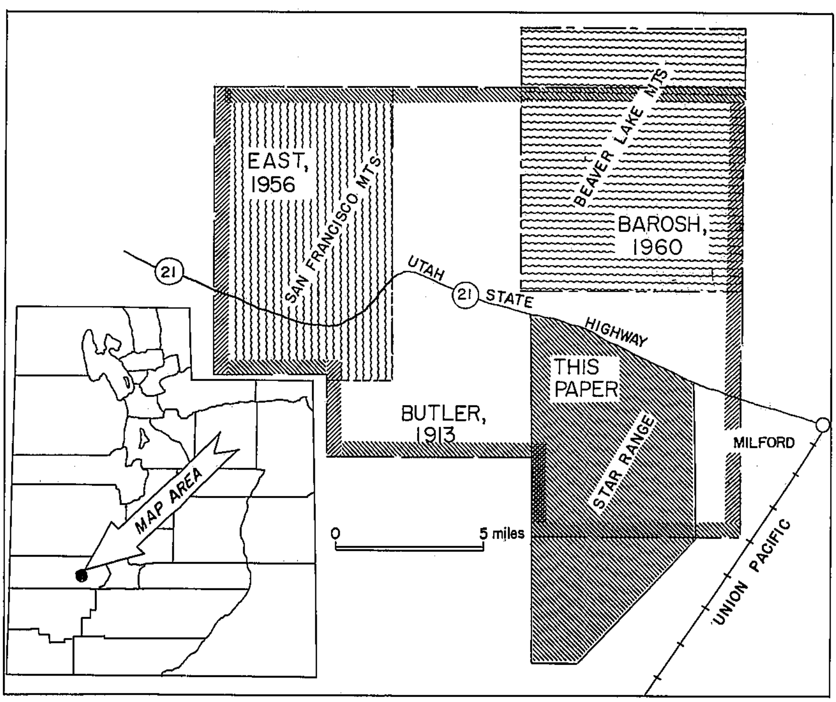
ILLUSTRATIONS

INTRODUCTION

The map area is approximately 80 square miles and is located near the east-central part of Beaver County, five miles southwest of Milford (Text-fig. 1). The Star Range is also referred to as the Picacho Mountains, but the former is the more popular name and will be used in this report.

The Star Range lies near the eastern edge of the Basin and Range Province. It consists of block faulted eastward dipping sediments, igneous and metamorphic rocks. A number of east-west canyons traverse the range, the largest being Elephant Canyon. Relief in the mapped area is almost 1900 feet with a maximum elevation of 6894 feet and a minimum of 5100 feet. Vegetation is the normal desert variety of sagebrush, cactus, and scrub oak, and flourishes better on volcanics than on other bedrock.



TEXT-FIGURE 1.—Index map showing areas mapped by Butler and others.

Field work was done during the summer months of 1961. Geologic data were plotted on air photos having an approximate scale of 1:37,400. Data were then transferred to United States Geological Survey topographic sheets on the scale of 1:24,000, which was the final base map used.

Previous work in this area was concentrated on a specific mine or section of sedimentary rocks. B. S. Butler mapped the Star District with the Frisco District for U.S. Geological Survey Professional Paper 80 (1913). Townsend (1950, 1953) worked in the Harrington-Hickory and Vicksburg Mine areas. Clark (1957) measured a section of Triassic rocks near the Harrington-Hickory mine. The Star Range is included in a current U.S. Geological Survey investigation by Dwight Lemmon, who is making a complete study of four quadrangles.

Butler (1913) was primarily interested in the mineralogy and igneous rocks of the area. The stratigraphic nomenclature he proposed has subsequently been found to need revision to bring it into line with that current in this part of the Great Basin. For this reason and because the area needed remapping for the new Utah State Geologic Map, study of the Star Range was undertaken as a thesis problem (map in back of volume).

ACKNOWLEDGMENTS

Dr. Lehi F. Hintze suggested the Star Range as a possible thesis problem and served as chairman. Dr. J. Keith Rigby served as committee member and accompanied the writer in the field and aided in some of the structural problems. Dwight Lemmon of the U.S. Geological Survey was helpful with his criticisms and advice. Mr. and Mrs. Paul King of Milford allowed the writer to stay in their home during the field investigations. Mr. Van J. Symons accompanied the writer in the field and helped measure the stratigraphic sections. My wife, Ruth, typed the manuscript and gave constant encouragement.

The writer received financial aid from the Utah State Geological Survey that defrayed some field expenses.

STRATIGRAPHY

General Statement

Rocks of the Star Range include sedimentary, intrusive and extrusive igneous, and metamorphosed sedimentary and igneous types. The sedimentary sequence is exposed in approximately 65 square miles of the 80 square miles mapped, and consists of eastward dipping Devonian to Jurassic strata. Intrusive igneous rocks occupy nearly four square miles and have metamorphosed adjacent rocks. Volcanic rocks occur in the western and southern portions of the mapped area and are part of a larger field to the west of the mapped area.

Metamorphism has altered the rocks and fossils and in many cases has made positive identification impossible. Some microfossils survived alteration and proved to be valuable in dating, particularly in the Devonian sequence. Total measured thickness of sedimentary rocks is over 9500 feet (Text-fig. 2 and 3).

The intrusive igneous rocks are mostly of intermediate quartz monzonite to granodiorite. A number of lamprophyre and aplite dikes cut the sedimentary and intrusive rocks. Volcanic rocks are latite, rhyolite, andesite and basalt.

Sedimentary and volcanic rocks have been contact and hydrothermally metamorphosed. Contact metamorphic minerals are evident along the borders of some intrusives. Greater metamorphism is displayed in the northern, eastern, and southwestern parts of the mapped area (Text-fig. 4).

Most of the formation names proposed by Butler (1913) are rejected and terms commonly used in Basin and Range stratigraphy are applied.

Devonian System

Sevy (?) Dolomite

Sevy Dolomite was named by Nolan (1935, p. 8) for certain rocks exposed in Sevy Canyon in the Deep Creek Mountains. Sevy (?) Dolomite and Guilmette Formation were mapped by Butler (1913, p. 34) as the Red Warrior Limestone, and it is recommended that the latter name for these beds be discontinued and that the former names replace it.

The Sevy (?) Dolomite is exposed in Section 26, T. 28 S., R. 12 W., where it has been intruded by granite and metamorphosed so that much alteration has occurred. Several fluorite deposits in the Sevy (?) Dolomite further give evidence of its hydrothermal mineralization.

The Sevy (?) Dolomite is completely recrystallized and unfossiliferous. It lies stratigraphically below the Guilmette Formation with the contact within the zone of alteration. The Sevy (?) Dolomite and the overlying altered zone are at least 500 feet thick. The altered interval may represent parts of both the Sevy (?) Dolomite and Simonson Dolomite, but the name Sevy (?) Dolomite is applied because its lithology, even though altered, more nearly resembles the type Sevy than it does Simonson or Guilmette.

Guilmette Formation

Nolan (1935, p. 20) named the Guilmette Formation from outcrops in the Deep Creek Mountains. There the beds are chiefly massive gray dolomite with limestone and sandstone beds. The dolomites contain *Amphipora* beds and help serve to distinguish this formation.

Best exposures of the Guilmette Formation are in sections 24 and 25, T. 28 S., R. 12 W. Dark gray, sugary, medium-bedded dolomites overlie the altered Sevy (?) Dolomite. The lower contact is not well defined because of the alteration. The upper contact, apparently conformable, is with thin-bedded, light gray, calcareous shale of the Pilot Shale. Dark gray dolomite with abundant *Amphipora* makes up the major part of this formation. Occasional sandstone beds, altered to quartzite, make up the balance. The formation is everywhere altered to a degree, with fossils and sedimentary features obscured. The dark gray sugary dolomites with the "spaghetti" beds make field identification possible.

Aside from the *Amphipora* beds, fossils found in the Guilmette were not well enough preserved to be identified. Fragments of brachiopods and crinoids were found near the top of the formation. Samples of the Guilmette Formation were acidized for microfossils but the only fossils found were nondiagnostic fish teeth. Nolan (1935, p. 21) called the Guilmette Formation Medial Devonian in the type locality, and the Guilmette Formation of the Star Range is considered to be of the same age.

The Guilmette Formation is 396 feet thick in Section 24, T. 28 S., R. 12 W., just north of the head of Elephant Canyon. This does not represent the entire thickness of the Guilmette, but it is nevertheless its best exposure. The lower part of the measured section is intruded by granite.

Pilot Shale

Spencer (1917, p. 26) named the Pilot Shale from outcrops on Pilot Knob in the Ely Quadrangle, Nevada. There the formation consists of platy calcareous shale with interbedded limestones and siltstones. Butler (1913, p. 34) mapped a narrow band of calcareous shale as Mowitza Shale, named from exposures near the Mowitza Mine. Butler's Mowitza Shale is represented by 40 feet of thin-bedded to laminated calcareous shales that make up the lower portion of the Pilot Shale. An additional 210 feet of thin-bedded limestone and dolomite is included with this lower portion to make up the Pilot Shale as mapped and defined in this paper.

The Pilot Shale conformably overlies the Guilmette Formation and forms a slope just above the Guilmette ledges. Its slope-forming character and thin-bedded nature facilitate field identification in the non-metamorphosed sections. Pilot Shale is best exposed in Section 24, T. 28 S., R. 11 W., in a gully north from the Hoosier Boy Mine to the road where the formation was measured.

In the Star Range the Pilot Shale is a thin-bedded to laminated limestone in the lower 40 feet overlain by a thin-bedded, dominantly dark gray, fine-grained dolomite. Contact with the overlying Redwall Limestone is apparently conformable and is drawn where the dark gray, thin-bedded dolomite gives way to overlying thick-bedded gray limestone.

Megafossils found in the Pilot Shale were not well preserved. Microfossils found in Section 24, T. 28 S., R. 12 W., B.Y.U. Locality 12049 (Pl. 2), in the uppermost ten feet of the formation were identified by the writer as:

Polygnathus nodocostata Branson and Mehl
Palmatolepis rugosa Branson and Mehl
Ancanthodema sp.
fish teeth
crinoid stems

Polygnathus nodocostata and *Palmatolepis rugosa* are included in Zone C of Clark & Becker (1960, p. 1666) and Beach (1961, p. 43) and are medial Late Devonian. Therefore, the Pilot Shale of the Star Range is considered to be Late Devonian. Pinyon Peak Limestone and Fitchville Formation are correlative, at least in part, with the Pilot Shale.

A thickness of 250 feet of Pilot Shale was measured in Section 24, T. 28 S., R. 11 W.

Mississippian System

Redwall Limestone

The Redwall Limestone was named from exposures in the Grand Canyon by Darton (1910, p. 1958). Redwall Limestone of this paper correlates with the lower half of the Topache Limestone of Butler (1913, p. 35). Butler's Topache Limestone includes Pennsylvanian as well as Mississippian rocks and has been divided in the present study into the Redwall Limestone and Callville Limestone. These formation names are used for the rocks formerly referred to by Butler as Topache Limestone.

Rocks assigned to the Redwall Limestone are well exposed along the north side of Elephant Canyon. Here, dark gray to black thick-bedded to massive limestone and dolomite make a striking contrast with the thinner bedded lighter colored rocks of Pilot Shale below and the brown to light red-brown Callville Limestone above. Dark gray dolomite and limestone that contain bedded and nodular chert and case-hardened limestone nodules make up the greater part of the formation. Metamorphism has altered the formation in the Star Range to some extent. Adjacent to the intrusives, marbles and tactite occur, while at some distance from the intrusives the fossils have been re-crystallized and appear as white outlines against a black background. The Redwall is distinctive because it is thick-bedded (over 3 feet) to massive (over 6 feet) in much of its exposure. This factor, along with the dark color, is a key in field identification. Contact with the overlying Callville Limestone is placed at the first appearance of brown sandstone and gray thin-bedded limestone and is gradational.

The Redwall Limestone is one of the most fossiliferous formations in the area. Corals, brachiopods, bryozoans, ammonites, and crinoids were found, but due to the alteration most of them were not identifiable.

Some excellent silicified corals were collected from exposures of the Redwall Limestone in the White Mountains about nine miles southwest of the Star Range and were identified by the writer. These corals proved to be the best age indicators for the Redwall Limestone, for they compare favorably with the corals described by Easton & Gutschick (1953) from the Redwall Limestone of Arizona and those described by Davis (1956) in Central Utah. Redwall Limestone has a probable age of Kinderhookian to Osagean and correlates, at least partly, with the Joana Limestone, Madison Limestone, Rogers Spring Limestone and Gardison Formation. Following is a list of fossils found in the Redwall Limestone at the White Mountains and the Star Range:

**Triplophylites ellipticus* White
**T. compressus* Milne and Edwards
**T. subcrassus* Easton and Gutschick
**Ekvasophyllum inclinatum* Parks
**Lithostrotion whitneyi* Meek
**Syringopora aculeata* Girty
Syringopora sp.
Cravenoceras sp.
Spirifer sp.
crinoid stems

(*Specimens collected from White Mountain)

The Redwall Limestone is 1240 feet on the north side of Elephant Canyon in Section 24, T. 28 S., R. 12 W.

Pennsylvanian System

Callville Limestone

Longwell (1928, p. 47) named the Callville Limestone in the Muddy Mountains near Las Vegas, Nevada.

Good exposures of the Callville Limestone can be seen just north of the Lenora Mine in Elephant Canyon, where it is reddish-brown as contrasted with the underlying dark gray of the Redwall Limestone and the dark brown of the overlying Talisman. Lower strata of the Callville consist of gray to brown sandstones with thin lenses of gray limestone, while the upper beds are dark gray dolomites that weather light brown, brown, and brownish red. Contact between the Callville Limestone and the overlying Talisman Quartzite is covered in most places, but where exposed it is gradational with dolomite becoming more siliceous until it gives way upward to orthoquartzite.

Fossils are uncommon in the Callville but a few silicified brachiopods were found. These were identified by the writer as *Neospirifer cameratus* Morton and *Composita subtilita* Shepard and are indicated as B.Y.U. Locality 12050. Brachiopods were found to be inconclusive as to age, and acidized samples yielded only nondescript crinoid fragments and fish teeth. Derryan fusulinids were found in the Callville (*Fusulinella* sp.) and Desmoinesian fusulinids (*Fusulina sp.*) in the overlying Talisman Quartzite (H. J. Bissell, 1961, personal communication), dating that part of the Callville as early Medial Pennsylvanian age. Lithologically the Callville Limestone is similar to the lower part of the Oquirrh Formation and correlates partially with the Ely Limestone and Bird Spring Formation.

A thickness of 1397 feet for the formation was measured just east of the Lenora Mine, Section 24, T. 28 S., R. 12 W.

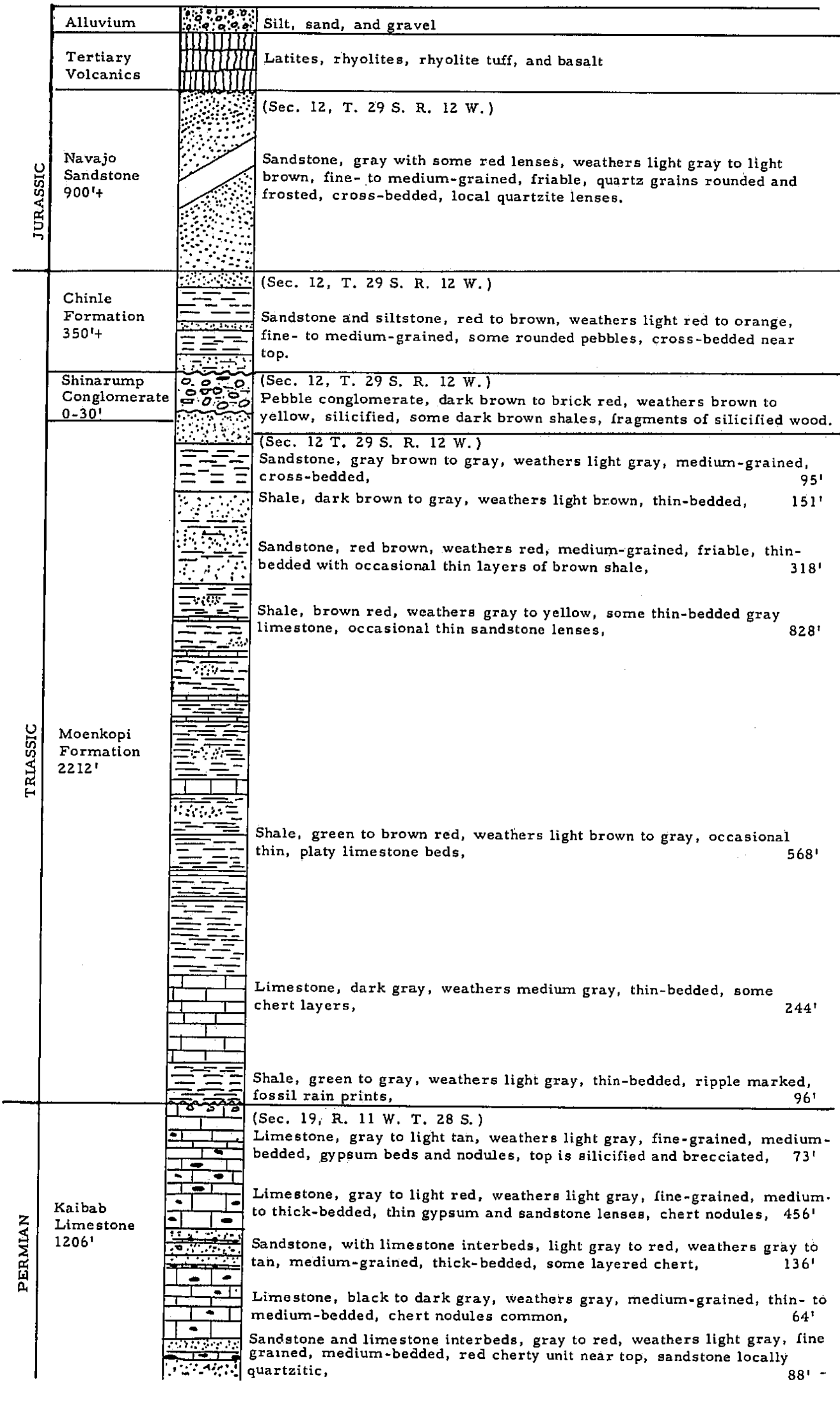
Talisman Quartzite

Talisman Quartzite was named from exposures just east of the Cedar-Talisman Mine of the Star Range by Butler (1913, p. 36). This formation is predominantly a fine-grained brown to pink orthoquartzite with some lenses of gypsum and limestone.

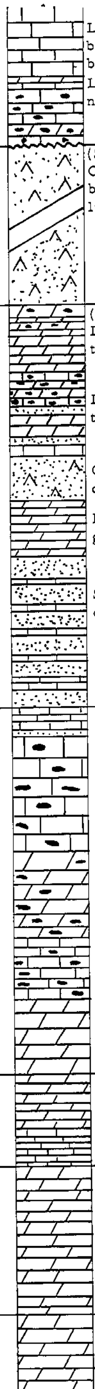
The most striking outcrops within the Star Range are those of the Talisman Quartzite. It forms a broad dark brown band of rocks that can be easily recognized on aerial photos. Weathered quartzite of the Talisman is highly fractured; broken fragments are covered with desert varnish. Talus slopes made from the Talisman Quartzite are common and have a dark chunky appearance that resembles volcanic rock. This can best be seen in Section 30, T. 28 S., R. 11 W. just south of the mouth of Elephant Canyon. Orthoquartzites are light brown to red, medium-bedded, and are weakly cross-bedded. Talus slopes are common and cover the contacts with the rocks above and below. Where exposed, the upper contact is placed where quartzite is overlain by a six-foot thick silicified brecciated zone at the base of the Kaibab Limestone.

Rocks assigned to the Talisman Quartzite were regarded as of Pennsylvanian age solely on stratigraphic position by Butler (1913, p. 36). The writer found no fossils in this formation, but Dr. H. J. Bissell has reported to the writer that he found *Fusulina* sp. in a limestone lense 187 feet above the base of the formation in Section 24, T. 28 S., R. 12 W. On the basis of this occurrence, the Talisman is considered to be Early to Medial Pennsylvanian, at least in part. The Kaibab Limestone is indicated to be Medial Permian and the intervening beds could be Late Pennsylvanian and/or Early Permian. There is a marked unconformity at the Talisman-Kaibab contact, but the time vacuity was not determined in the present study.

The Talisman presents a correlation problem with beds of similar lithology in surrounding areas. Earll (1957 *ms.*, p. 20) named beds found in the Mineral Range which are similar in lithology and evidently equivalent to the Talisman Quartzite, Coconino Sandstone, and assigned them to the Permian. McKee (1952, p. 53) recognized this problem and stated:



TEXT-FIGURE 2.—Stratigraphic section.



	Kaibab Limestone	Limestone, dark gray, weathers gray, fine-grained, thin- to thick-bedded, arenaceous, vugs filled with quartz crystals, some dolomite beds,	276'
		Limestone, medium gray, weathers light gray, medium-bedded, chert nodules, base is silicified and brecciated,	113'
PENNSYLVANIAN	Talisman Quartzite 1088'	(Sec. 24, T. 28 S. R. 12 W.) Orthoquartzite, gray, pink, weathers dark brown, thin- to thick-bedded, highly fractured, cross-bedded in part, some gypsum and limestone lenses.	
	Callville Limestone 1391'	(Sec. 24, T. 28 S. R. 12 W.) Dolomite, light gray, weathers gray, thin-bedded, chert nodules near top, grades into overlying orthoquartzite,	237'
		Dolomite, dark gray, weathers light gray, thin- to medium-bedded, thin sandstone and limestone beds, jasper and chert nodules common,	410'
		Orthoquartzite, gray, weathers brown, thin-bedded, highly fractured, cross-bedded,	104'
		Dolomite, gray with some red, weathers light gray to brown, fine-grained, thin-bedded,	230'
		Sandstone, with limestone interbeds, gray, weathers light gray, some cross-bedding, layered chert,	410'
MISSISSIPPIAN	Redwall Limestone 1240'	(Sec. 24,T. 28 S. R. 12 W.) Limestone, gray to red, weathers light gray, medium-grained, thin-bedded, some thin sandstone beds, some chert, highly fractured,	105'
		Limestone, black to dark gray, weathers gray, thick-bedded to massive, layered and nodular, black chert common,	410'
		Dolomite, dark gray, weathers light gray, fine-grained, thick-bedded, layered chert, hackly weathered surface,	350'
		Limestone, dark gray, weathers light gray, thin- to thick-bedded, nodular chert, calcite veinlets in fractures,	300'
		Dolomite, dark gray, weathers gray, medium-grained, thick-bedded, weathered surface hackly, calcite veinlets in fractures,	75'
DEVONIAN	Pilot Shale 250'	(Sec. 24, T. 28 S. R. 12 W.) Dolomite, dark gray, weathers light gray, fine-grained, thin-bedded, some calcite veinlets in fractures,	210'
		Limestone, gray, weathers light gray, thin-bedded to laminated, slope former,	40'
	Guilmette Formation 396' (Incomplete)	(Sec. 24, T. 28 S. R. 12 W.) Dolomite, light gray, weathers gray, medium-grained, medium-bedded, sugary texture,	128'
		Dolomite, dark gray, weathers light gray, fine-grained, thin- to medium-bedded,	268'
	Sevy (?) Dolomite 500'+	(Sec. 26, T. 28 S. R. 12 W.) Dolomite, medium gray, weathers light gray, altered to marble, lower portion intruded by granite.	

TEXT-FIGURE 2.—Stratigraphic section—continued.

Sections of the Coconino Sandstone along the Arizona-Utah and Arizona-Nevada border not only are very thin compared with those further south and east, but contain features indicating that non-aeolian processes were locally significant in developing the formation in those areas. Thus it seems likely that the original margin of deposition was in proximity to the area under discussion and that sandstones further north, some of which have been correlated with the Coconino, probably are not part of this unit despite lithologic similarities. Among deposits in this category is an unnamed, cross-stratified quartzite underlying the Toroweap Formation at Minersville, Utah.

Age determinations for the Callville Limestone and the Talisman Quartzite are based mainly on the fusulinids. The regional stratigrapher should, however, be aware that part of the Callville and all of the Talisman of the map area could possibly be Permian. Lithologies of the Callville Limestone and Talisman Quartzite as defined in this paper compare favorably with the Permian Pakoon Limestone and the Queantoweap Sandstone of southwestern Utah and eastern Nevada respectively. There is, however, the possibility the Callville and Talisman could be part of the Oquirrh Basin (Pennsylvanian-Permian) and the Pennsylvanian age determination is valid. In either instance there is need for more stratigraphic information in order to resolve this problem.

Talisman apparently represents a marine sand which compares lithologically with the sands in the upper part of the Oquirrh Formation. Butler's name Talisman Quartzite is valid for the Star Range and probably the beds in the Mineral Range referred to as Coconino by Earll (1957 *ms.*) should be called Talisman Quartzite as well.

A section of Talisman Quartzite 1088 feet thick was measured north of Elephant Canyon, Section 24, T. 28 S., R. 11 W.

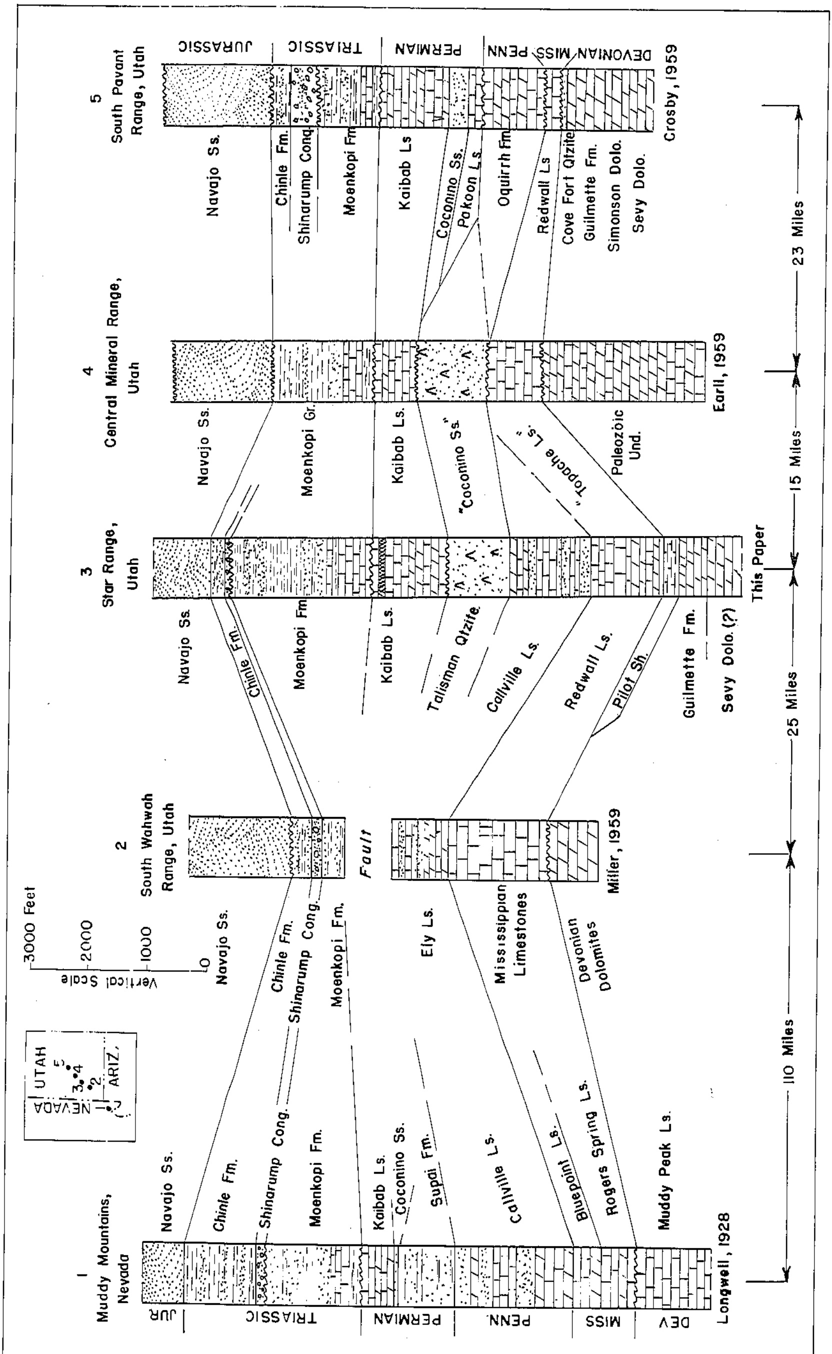
Permian System

Kaibab Limestone

Darton (1910, p. 28) proposed the name Kaibab for the top member of the Aubrey Group. Noble (1922, p. 41) designated a type locality in Kaibab Gulch eight miles southwest of the site of Paria, Utah, just six miles north of the Arizona state line. The Elephant Limestone was the name used by Butler (1913, p. 37) for the beds assigned to the Kaibab Limestone of this paper. The lower part of the Kaibab Limestone may be referred to as the Toroweap Formation, but this subdivision was not done in the map area because of the metamorphism involved.

In Section 19, T. 28 S., R. 11 W., excellent exposures of the Kaibab Limestone can be seen on the north side of Elephant Canyon. Dark gray, medium-bedded limestone makes up the major part of the Kaibab. The limestones are commonly fossiliferous and contain brachiopods, gastropods, bryozoans, crinoids, and sponges. Thin-bedded dolomite, dark gray to light gray, is found in the middle and upper parts of the formation. Sandstone and orthoquartzite alternate with limestone and gypsum beds in the upper part of the Kaibab. Gray chert and case-hardened limestone nodules occur in abundance in the upper parts, with layered chert near the top. Gypsum-bearing beds are from five to fifteen feet thick and occur near the top of the formation. Contact between the Kaibab Limestone and the overlying Moenkopi Formation is an unconformity with some local conglomerate and slight angular discordance.

Although the Kaibab is quite fossiliferous, the poor state of preservation makes positive fossil identification difficult. Fossils that were identified by the



TEXT-FIGURE 3.—Stratigraphic correlation sections.

writer indicate the Kaibab Limestone to be Medial Permian. Samples of Kaibab Limestone were acidized but no diagnostic microfossils were found. The following is a list of fossils found in the Kaibab Limestone from B.Y.U. Locality 12051:

Dictyoclostus bassi McKee	*Meekopora* sp.
D. ivesi McKee	gastropods
Composita sp.	crinoid stems
Spirifer pseudocameratus (Girty)	sponges
Juresania sp.	

The Kaibab Limestone is reported in the Mineral Range (Earll, 1957 *ms.*, p. 26) and the Pavant Range by Crosby (1959, p. 25). Kaibab Limestone correlates in part with the lower member of the Park City Formation in northern Utah.

The Kaibab was measured on the north side of Elephant Canyon where a thickness of 1206 feet was recorded.

Triassic System

Moenkopi Formation

The name "Moenkopi" was first used by Gregory (1917, p. 79). A type section was defined by the U.S. Geological Survey in Moenkopi Wash of the Grand Canyon in Arizona (Baker, *et al.* 1929, p. 1413). For a more complete history of the term see McKee (1959, p. 4). Butler's Harrington Formation (1913, p. 37) was poorly defined as he included in it, locally, part of his Elephant Limestone and Talisman Quartzite. The lower part of his Harrington Formation is equivalent to the Moenkopi Formation of this paper and the term Harrington Formation is not used.

The Moenkopi Formation forms the low hills just east of the range front proper. It is faulted and metamorphosed, particularly in the northern exposures. The formation on the west side of the range, just northwest of the road near the Hoosier Boy Mine, is partially covered by volcanics and alluvium. The best exposure of the Moenkopi is in Section 12, T. 29 S., R. 12 W.

The Moenkopi Formation offers the most varied lithology of any formation exposed in the Star Range. The lower portion is dark gray marine limestone and green shale which may correlate in part with the Virgin Limestone. The *Meekoceras* zone occurs about 250 feet from the base. Red, brown, and green shale with limestone interbeds makes up the next 500 feet. Limestone grades to sandstone higher in the formation until sandstone is the predominant rock. The top portion of the formation consists of dark red to brown shale with some cross-bedded, gray to red sandstone. Some of the upper sandstone is thin-bedded and displays an attractive liesgang banding that could make good facing stone. Ripple marks and fossil rainprints are common in the shales. In the metamorphosed sections the brown and red shale is changed to green hornfels and the ripple marks and rainprints preserved in some cases, and limestone is changed to grained marbles which locally show mineral segregation. The sandstone is silicified and bleached and is gray to white quartzite.

Fossils in the Moenkopi Formation occur mostly in the lower marine section and are so poorly preserved they cannot be identified with any degree of certainty. In addition to *Meekoceras,* oysters, a variety of small pelecypods and gastropods were found. The Moenkopi Formation of the Star Range is probably Early to Medial Triassic. It correlates with the Moenkopi sections of the Mineral Range (Earll, 1957 *ms.*, p. 27) and the Pavant Range (Crosby, 1959, p. 27).

Twenty-three hundred feet of Moenkopi Formation was measured in Section 12, T. 28 S., R. 12 W.

Shinarump Conglomerate

Gilbert (1928, p. 60) established a type section for the Shinarump Conglomerate in the Shinarump Cliffs, south of the Vermillion Cliffs, in the southern part of Kane County, Utah. The Shinarump Conglomerate was not recognized by Butler (1913), but was included in his Harrington Formation.

The Shinarump Conglomerate marks an erosional surface on the Moenkopi Formation. It is, therefore, very lenticular and relatively thin and absent in some places. Outcrops of the Shinarump occur just east of the Moscow Wash road, along the south slope of the foothills east of the mouth of Elephant Canyon, and in small lenses on the Triassic rocks exposed on the west side of the range.

The Shinarump Conglomerate is a pebble conglomerate that is highly silicified for the most part. The pebbles are quartzitic and are generally well rounded. Fragments of silicified fossil wood are found in some, but not all, exposures. Bedding is not distinctive in the Shinarump but seems to be a series of discontinuous lenses that probably represent an old erosion surface.

Since no fossils other than the fossil wood are found in the Shinarump Conglomerate, only a relative age can be assigned. It is younger than Early Triassic Moenkopi Formation and older than the overlying Chinle Formation. The Chinle Formation is generally considered to be Late Triassic. Therefore, the Shinarump Conglomerate is either all Medial Triassic or represents a part of Medial Triassic and the early Late Triassic. The Shinarump Conglomerate may not be one bed, but a series of beds that were deposited over an extended period of time.

Thicknesses of six inches to 30 feet were noted; in some localities no Shinarump beds were found and the Moenkopi shale is overlain by the Chinle sandstones.

Chinle Formation

Gregory (1917, p. 42) named Chinle Formation from outcrops in the Chinle Valley in northeast Arizona. Butler included these beds in his Harrington Formation.

The Chinle Formation crops out above the Shinarump Conglomerate and Moenkopi Formation. The best exposure is along the western edge of the hogback that is just east of the Moscow Wash road in Section 12, T. 29 S., R. 12 W.

The Chinle Formation presents a striking light red to orange outcrop. It consists mainly of red to brown siltstone and shale, with red to pink coarse-grained sandstone. There are some isolated rounded pebbles in cross-bedded sandstone near the top. Contact between the Chinle and the Navajo formations appears to be gradational and the contact is arbitrarily drawn where the pink to red, thin-bedded sandstone of the Chinle Formation gives way to the gray to white cross-bedded medium to thick-bedded sandstone of the Navajo Sandstone.

No fossils were found in the Chinle Formation, but in light of its stratigraphic position it appears to be Late Triassic. The Chinle Formation is recognized in the Mineral Range (Earll, 1957 *ms*, p. 31) and the Pavant Range (Crosby, 1959, p. 29) and in the Blue Mountains by Miller (1959 *ms.*, p. 98). Because the contact between the Chinle Formation and the Navajo Sandstone is gradational, the thickness of the Chinle ranges from a few tens of feet to nearly 400 feet. Measured thickness is 350 feet in Section 12, T. 29 S., R. 11 W.

Jurassic System

Navajo Sandstone

Gregory (1917, p. 57) named the Navajo Sandstone but it was redefined by Baker & Reeside (1936, p. 21). Butler (1913) did not recognize the Navajo Sandstone, but included it in the Harrington Formation. He also mapped Navajo Sandstone exposures in Section 14, T. 28 S., R. 12 W. as Morehouse Quartzite.

The Navajo Sandstone crops out above the Chinle Formation on the east side and west side of the range, and is best exposed in Section 12, T. 29 S., R. 12 W. Western outcrops are highly brecciated and silicified (Pl. 1, fig. 2). The Navajo Sandstone is largely a light gray to white sandstone with some light pink to red bands. The sandstone is friable and weathers to rounded beds with sweeping eolian cross-bedding. In some places the sandstone is silicified to form an orthoquartzite, where it may be confused with the Talisman Quartzite. Talisman is usaully darker colored and more susceptible to coating by desert varnish than the Navajo Sandstone, however, and is generally more broken and forms talus slopes not usually associated with the Navajo.

The Navajo Sandstone is devoid of fossils and its age is in question. It is generally considered to be Jurassic, but recent studies (Lewis, *et al.* 1961, p. 1437) of the Navajo Sandstone in the Colorado Plateau have dated the lower part of it as Late Triassic (?). It is considered to be Lower Jurassic in this paper. Correlation of the Navajo Sandstone exposed in the Star Range with sections in the Mineral Range (Earll, 1957 *ms.*, p. 34) and Pavant Range (Crosby, 1959, p. 30) seem fairly certain. It is correlated with the Nugget Sandstone of northern Utah and the Aztec Sandstone of Nevada.

Incomplete thickness of the formation is 900 feet with the upper contact covered. It is probably much thicker as thicknesses of 2000 feet or more have been recorded in nearby areas.

Tertiary System

Igneous Rocks

Both extrusive and intrusive igneous rocks are found in the map area. Intrusive stocks are generally intermediate quartz monzonite to granodiorite and volcanics are mostly rhyolite, andesite, latite, and basalt. The volcanics are older, for the intrusions cut them and have introduced mineralization in a number of areas. Acidic and basic dikes also occur. Study of the igneous rocks is generalized and only seemingly representative samples were examined and classified according to the Johannsen system.

Extrusive Igneous Rocks.—Volcanic rocks are found in the southern and western part of the map area, and were mapped as a unit rather than as individual flows or types. Andesite, latite, rhyolite tuff, and basalt occur within the area. The flows have been highly altered and mineralized in certain areas, particularly near the intrusions. Two samples of the more abundant rock types were thin-sectioned, one from Section 12, T. 28 S., R. 12 W. and the other from

Section 26, T. 28 S., R. 12 W. Both were similar mineralogically and petrographically. Following is an averaged analysis:

Andesine	80%
Biotite (altering to chlorite)	8%
Augite	2%
Opaques	8%
Epidote, apatite, glass	2%

These rocks are andesite and have a Johannsen number of 2212E.

Intrusive Rocks.—Representative samples from each of the major intrusions were collected. Stocks are differentiated on the map on the basis of field and laboratory identification. All the intrusions except the dikes are either granitic of porphyritic with a granitic ground mass. Intrusions in Section 21, T. 28 S., R. 11 W. are granodiorites with the following analysis:

Quartz	10%
Andesine (altering to clay and sericite)	55%
Orthoclase and perthite	10%
Biotite	10%
Hornblende	3%
Augite	8%
Opaques	3%
Zircon, apatite, sphene	1%

Johannsen number is 227P and the rock is termed a granodiorite.

The large intrusive occurring in Section 35, T. 28 S., R. 12 W. was sampled, analyzed, and was classified as an alaskite; however, the more common term granite is used on the map for these rocks. Following is the analysis:

Quartz	35%
Perthite and orthoclase	50%
Albite	10%
Biotite	3%
Apatite, sphene, zircon	2%

Johannsen number is 116P.

A series of small instrusive bodies occur near the Wild Bill Mine in Section 13, T. 28 S., R. 12 W. Rocks from these plutons are porphyritic with phenocrysts of perthite and orthoclase as large as 8 mm. Under the Johannsen system the rocks are termed adamellite, but the more general term quartz monzonite porphyry is used on the map. Analysis of this rock is as follows:

Quartz	15%
Perthite and orthoclase (large phenocrysts)	40%
Andesine (commonly zoned)	35%
Biotite	5%
Hornblende	3%
Opaques	1%
Zircon, apatite, sphene	1%

Johannsen number is 226'P.

The intrusion on the northern extremity of the range in Section 4, T. 27 S., R. 11 W., is called a quartz monzonite. Thin-section examination revealed this analysis as follows:

Quartz	25%
Orthoclase and perthite (altering to sericite)	35%
Andesine (zoned)	30%
Biotite (altering to epidote and chlorite)	7%
Opaques	2%
Zircon, apatite, spene	1%

Johannsen number is 226'P.

Dikes of the area are of two general types: ferro-magnesium rich are termed lamprophyre and those of more acidic nature are termed aplite, with lamprophyric and aplitic textures respectively. Analysis of an aplite dike found cutting the intrusion in Section 21, T. 28 S., R. 11 W. is as follows:

Quartz	30%
Orthoclase and perthite	50%
Andesine (zoned)	15%
Biotite (altering to chlorite and epidote)	3%
Opaques	1%
Zircon, apatite	1%

This rock is a granite aplite with a Johannsen number of 226D.

Lamprophyre dikes are part of the latest igneous activity, for they cut the sedimentary rocks and intrusions alike. These dikes are commonly dark green and highly altered, and range in thickness from one inch to ten feet. Analysis of a sample from one of the larger dikes in Section 24, T. 28 S., R. 12 W., is as follows:

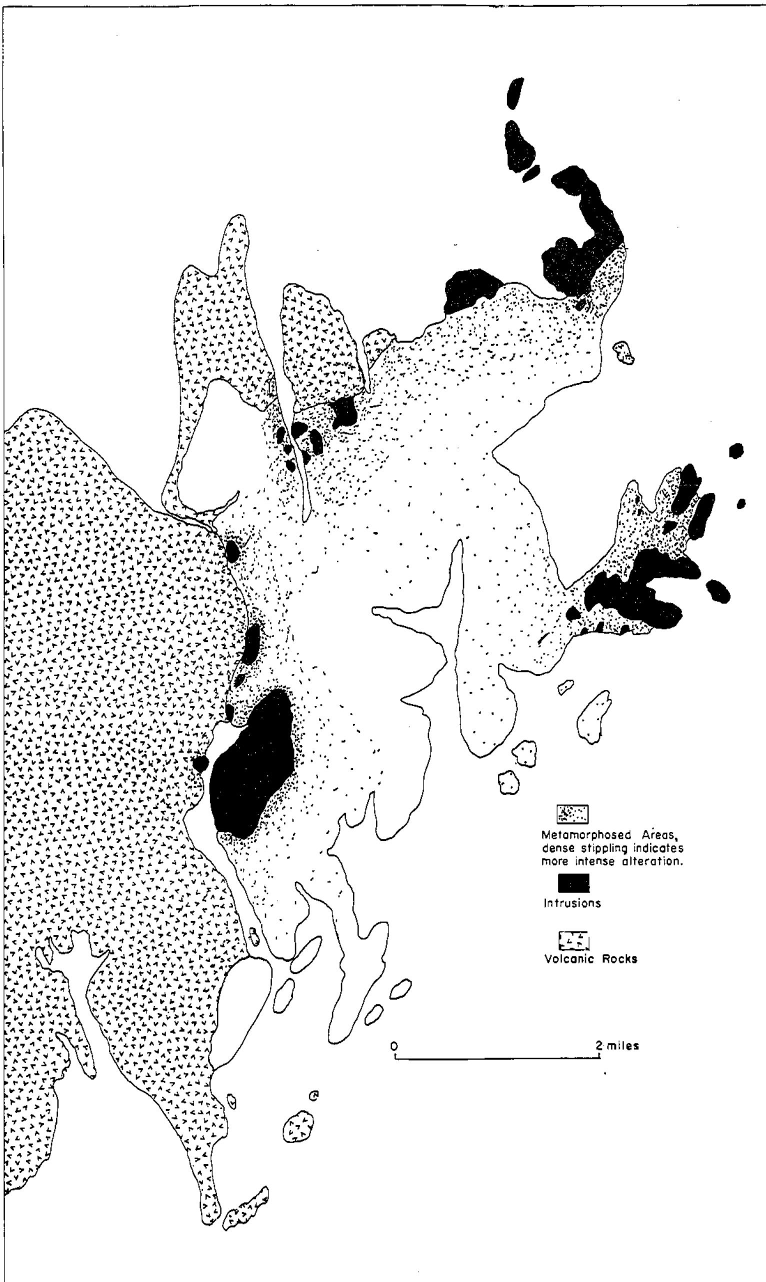
Quartz	3%
Oligoclase	57%
Pyroxene (altering to hornblende)	20%
Biotite (altering to chlorite and epidote)	15%
Amphibole	3%
Opaques	2%

This rock is spessartite, with a Johannsen number of 2212D.

Metamorphic Rocks

Both igneous and sedimentary rocks have been hydrothermally altered forming a variety of metamorphic types. Metamorphic rocks were not studied in detail.

Contact minerals were observed, particularly where plutons intruded carbonate rocks. There tactite and marble were common with bleaching also evident; shale was altered to hard silicious hornfels with many of the original sedimentary features such as ripple marks preserved; sandstone was altered to



TEXT-FIGURE 4.—Map showing igneous and metamorphic rock.

hard quartzite throughout most of the map area; alteration in the volcanic rocks is also quite extensive.

Quaternary System

Alluvium

The valley and surrounding pediment of the range is covered by aluvium. Waterwells a few miles east of the range are over 500 feet deep and still in alluvium. A series of alluvial fans extend from the mouths of the canyons. Detailed study of the Quaternary deposits was not done.

STRUCTURE

General Features

The main structural features of the Star Range are those related to igneous intrusions and faulting. Intrusions have been forcefully injected into the sedimentary rocks, in general tilting and breaking up the country rocks. Faulting has also played a major role in forming the structural picture. At least two sets of normal faults were recognized: a northerly striking set cut by a later easterly striking set. Thrust faults noted in the eastern and western part of the range were pre-block faulting. Folds, other than regional dip, are of minor significance and small. Most are attributed to fault drag.

Faults

Normal Faults

The Star Range has been cut by at least two sets of normal faults; an early north-south set displaced by a younger east-west set. Fault planes and traces are not well exposed and slickensides were found associated with only the smaller faults. It is, therefore, difficult to ascertain attitude and direction of movement of faults.

The north-south striking faults are best developed along the eastern front of the range and in a small graben just south of the head of Elephant Canyon. Within this graben Talisman Quartzite and Kaibab Limestone are repeated by three north-south trending faults. These faults appear to be nearly vertical, with the west side downthrown and a stratigraphic throw of less than 50 feet. Major frontal faults along the eastern side also trend north-south. These latter faults are very close to vertical with the eastern block upthrown. Stratigraphic displacement along these faults ranges from 200 feet to nearly 2000 feet.

The east-west striking faults cut the eastward dipping beds nearly perpendicularly and are termed transverse faults. Nearly all the major canyons have formed along the trace of these faults. Faults are thus not well exposed. Relative displacement of beds along these faults is obvious. Dips of 60 degrees south and 55 degrees south were recorded for two of these faults, but they appear to be almost vertical. Townsend (1950, p. 4) reports a dip of 50 degrees north to vertical for a fault near the Vicksburg Mine.

Movement along major faults could not be discerned, but movement along the minor faults was principally vertical. Butler (1913, p. 73) concluded horizontal movement along the north-south faults in Elephant Canyon set a wedge-shaped block to the west but that extensive movement along the faults was not demonstrated. Although there may have been some lateral movement, it is believed that the major component was vertical.

Only relative movements and ages of faults can be deciphered. The earliest faulting is post-Navajo Sandstone and presumably pre-intrusion (Butler, 1913, p. 73). Faults of this age are the northerly striking set as seen in Section 24, T. 28 S., R. 12 W. This set was displaced by a later easterly striking set. A later movement along the northerly striking set is post-Tertiary volcanics and it is probably this movement that elevated the range.

Thrust Faults

Two thrust faults were mapped in the area. One is exposed on the eastern side, Section 12, T. 28 S., R. 12 W. and Section 7, T. 29 S., R. 11 W. (Pl. 1, fig. 1), where the Kaibab Limestone overlies Navajo Sandstone on three small hills. The contact is well exposed and shows a ten-foot brecciated and silicified zone at the fault (Pl. 1, fig. 2). Navajo Sandstone dips up to 68 degrees eastward and the Kaibab Limestone dips to 38 degrees southeast. Another thrust fault is inferred on the west side of the range, Section 13, T. 28 S., R. 12 W. The relationship here is not so obvious. Navajo Sandstone and Triassic formations dip gently west and lie just west of the eastward dipping lower Paleozoic strata. Although the contact is concealed by alluvium and intruded by quartz monzonite porphyry, there is some evidence to support a thrust relationship. The Navajo Sandstone is brecciated in uppermost exposure (Pl. 1, fig. 3) similar to the brecciated zone found at the fault on the east side of the range. This brecciation may be due to something other than thrusting, but the writer feels that in light of the localized nature and similarity to that found on the east side it is a thrust breccia. The Navajo Sandstone and the Triassic formations on the west are, therefore, interpreted to be part of the sole of a thrust with the Paleozoic rocks of the Star Range on the upper plate or allochthon.

The relationship of the thrusts is not readily apparent, but is probably one of an imbricate nature. The thrust fault exposed on the west side of the range represents a primary movement with the thrust found on the eastern side representing part of a second movement. Unlike the thrusts found in the Wah Wah Mountains, whose movement is generally from west to east, a northwesterly to westerly direction of movement is proposed for the thrusts found in the Star Range. Determination of direction of these faults is based on the geometry of the thrust relation (Text-fig. 5) and the local overturning found along the western edge of the range. Both these factors indicate that a northwest to west movement for the thrusts is much more probable than an easterly one. Although there is no apparent physical evidence as to magnitude of movement, the writer believes that the movement measures from one to five miles. Lateral movement along the east-west faults as described by Butler (1913, p. 73) may well be explained by shearing or tearing along the thrust plate as it moved.

Thrusting in the Star Range is part of the thrust belt occurring in eastern Nevada and western Utah described in detail by Miller (1959 *ms.*, p. 154) and Misch (1960, p. 17). Miller (1959 *ms.*, p. 156) in his investigation of the southern portion of the Wah Wah Mountains uncovered complex thrust relations and in his study of the regional geology made this statement:

> . . . the possibility that the Blue Mountain or a related Laramide thrust may exist in the subsurface of the southern part of the San Francisco Mountains and may reach the surface in the Star Range west of Milford cannot be overlooked.

The full relationship of the thrust exposed in the Star Range with the Blue Mountain thrust is yet to be worked out. But it is readily apparent that the thrusting found in the Wah Wah Mountains, Blue Mountains, San Francisco Mountains, Beaver Lake Mountains, Mineral Range, Pavant Range, and the Star Range, as well as many other exposures, are all related and that further investigation of this problem will add greatly to the understanding of regional geology.

Folds

The Star Range is unique in absence of major folds. Many of the mountain ranges in the Basin and Range have experienced some folding, but this is not apparently true in the Star Range. Only small folds were mapped and these usually less than five feet in their amplitude. Most of these folds were formed by drag along faults. The most prominent fold found was in the Moenkopi Formation, Section 20, T. 28 S., R. 11 W. where drag along the fault makes a small chevron fold that plunges gently northeast.

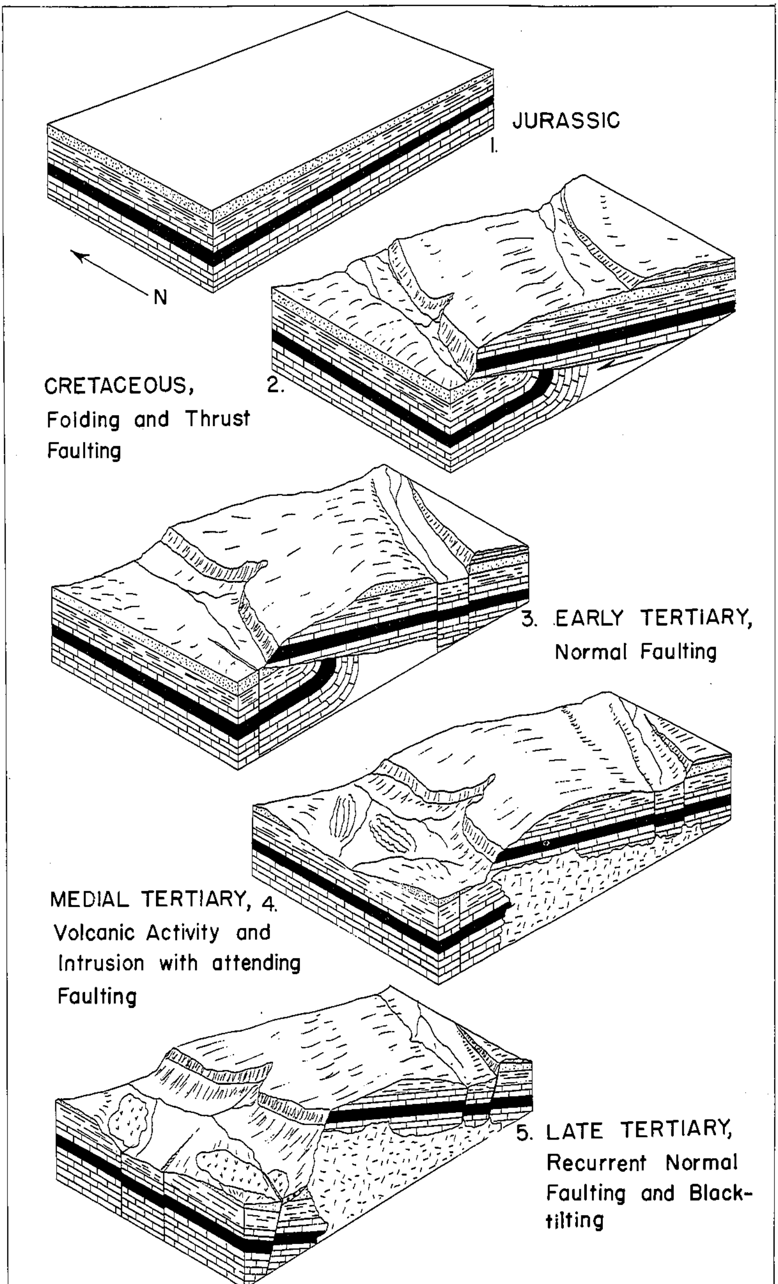
Structure Resulting from Intrusion

Intrusions have in part forcefully injected themselves into the overlying country rock and may have contributed, along with the block faulting, to the regional dip. The range proper consists of eastward tilted strata, with dips ranging from 25 to 75 degrees. Steepest dips occur near the intrusions and become progressively less toward the east. Contact with overlying country rock indicates in places active pushing aside and upward movement of the beds, while in other areas emplacement is by stoping. What caused intrusions to push aside in one area and stope in another is not clear, but must be some relation between magma and intruded sedimentary rock.

GEOLOGIC HISTORY

Deposition of Devonian dolomites and limestones of the Sevy (?), Guilmette, and Pilot formations in a marine environment was the earliest event which can be interpreted in the area. This was followed by deposition of the Mississippian Redwall Limestone, in apparent conformity, and in turn by limestone and sandstone of the Callville Limestone. The area was covered by a shallow sea when Talisman sands were deposited and may have been locally mildly positive for a time. Next, the seas allowed deposition of the Kaibab Limestone. Following this, the area was positive for a brief period as the Kaibab Limestone was partially eroded, then submerged as deposition of Early Triassic Moenkopi began. The Moenkopi Formation was probably deposited on a shallow marine shelf that gradually became more and more terrestial as shown by the marine shale and limestone grading upward to sandstone. A deltaic environment is postulated for the upper Moenkopi Formation and this was finally emergent before the deposition of the Shinarump Conglomerate. The lower part of the Chinle Formation marks the last recorded submergence of the area. Terrestial conditions were dominant in Late Chinle time and are present throughout the remaining stratigraphic record. Sand dunes that formed the Navajo Sandstone encroached on the tidal flat and eventually blanketed the region.

Sometime after the deposition of the Navajo, the area experienced mild



TEXT-FIGURE 5.—Structural evolution of the Star Range.

up-warping and attending thrust faulting from the southwest (Text-fig. 5). This thrusting can be dated locally as post-Navajo and pre-normal faulting, but regionally this thrusting is probably part of the eastern thrust belt that Eardley (1951, p. 485) dates as Laramide. Normal faulting, perhaps resulting from the relaxing of compressional forces, began in Late Cretaceous or Early Tertiary.

Volcanics spread over the area during the Tertiary and were intruded somewhat later by Tertiary granite and quartz monzonite. The intrusives appear to have used pre-existing faults, at least in part, as avenues of entry. Ore deposits of the area associated with mesothermal solutions formed as the intrusions cooled. Attendant with the cooling, normal faulting, probably the northerly striking set, developed. These faults were then cut by later easterly striking faults. Faulting was evidently before and after intrusion (Butler, 1913, p. 73) and Townsend (1950, p. 6) recorded both pre- and post-mineralization faulting in the Vicksburg area. Dikes were post intrusive but the writer was unable to discern if they were pre-faulting or not. Elevation of the range into nearly its present position probably came with block faulting, or recurrent movement along the northerly striking set boundary faults in Late Tertiary time. Canyons began to form, mostly along fault traces, and alluvial fans began to build a bajada. Lake Bonneville covered part of the map area to the west during the Pleistocene. After its retreat, the range was left with essentially its present topography.

ECONOMIC GEOLOGY

Metals

Lead, silver, copper, zinc, and minor amounts of gold are the principal metals mined from the mesothermal deposits of the Star Range. The Star Mining District history is long, but sporadic, and not too productive. The prosperous years were 1872 to 1875 (Butler, 1913, p. 14) with only occasional commercial mining since that date.

Present-day activity is confined to the Harrington-Hickory Mine and the Dotson Mine. The Harrington-Hickory Mine is operated by the New Majestic Mining Company and is worked occasionally for its lead-silver and lead-zinc ores. The Dotson Mine has produced meager amounts of lead and copper ore. Kennecott Copper Corporation has recently renewed exploration in the Rocky Range, three miles north of the Star Range. A diamond drilling program has been planned and was underway in September, 1961. Future development of the Star Range may well depend upon the results of this investigation.

Possibilities for continued development of lead, silver, and zinc metals, at best, appear unfavorable. The history of the area shows that the mines are small, short-lived operations that have generally high operating costs. The area has a meager source of water which hinders development. However, the writer proposes two recommendations regarding the possible location of undiscovered ore bodies. First, the thrust plate on the west side of the range, with the Moenkopi Formation acting as a barrier of ore-bearing solutions, is an area of possible fruitful exploration. Second, geochemical and petrographic study of the volcanics, particularly Section 12, T. 28 S., R. 12 W., and sections 34 and 35, T. 29 S., R. 12 W., may reveal significant alteration enough to warrant further investigation.

Non-Metals

Gravel deposits are present but are not high quality. Huge quantities of gravel in alluvial fans could be used if they were near large industrial or urban areas.

The economic product with a possible bright future is the thin-bedded, Liesgang-banded sandstone found in the upper part of the Moenkopi Formation and parts of the Navajo Sandstone. This sandstone makes an attractive facing stone suitable for both interior and exterior decoration. The sandstone is gray to light brown with dark red to dark brown concentric bands. The best exposure of this stone is in Section 29, T. 28 S., R. 11 W.

An extensive supply of nearly pure quartzite is found in the Talisman Quartzite, which could be used as building stone or road metal. Adverse features of the rock are its rather unattractive weathered surface and fractured character.

Oil and Gas Possibilities

Petroleum possibilities in the map area proper are poor due largely to the intrusive igneous activity involved in the geologic history of the Star Range. Accumulation is possible where the fossiliferous Redwall Limestone and the Talisman Quartzite are in a favorable structural-stratigraphic position. The Redwall Limestone could serve as source beds and the Talisman Quartzite, in areas where it is not too silicified, could be the reservoir. Oil traps could arise from faulting or wedging out of the intervening beds of the Callville Limestone, or by doming of the strata.

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