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Stratigraphy and Structure of The Sunset Peak Area Near Brighton, Utah*

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ABSTRACT.—The Sunset Peak area is located 20 miles southeast of Salt Lake City near the once-prosperous mining camp of Alta. Exposed sedimentary rocks over 2,000 feet thick range in age from Cambrian to Mississippian and consist of orthoquartzite, shale, limestone, and dolomite.

The Alta Stock forms the northern border and the Clayton Peak Stock, the eastern border of the area. Paleozoic rocks surrounding the intrusive masses have been affected by varying degrees of thermal metamorphism. In metamorphic belts quartzite remains unchanged, shale becomes more micaceous and hornfelsic, and limestone and dolomite become sugary dolomitic marble.

Paleozoic rocks have undergone gentle late Cambrian to early Devonian warping followed by a long period of quiescence. Extensive folding and thrusting occurred as a result of the Sevier and, possibly, the Laramide orogenies during Late Cretaceous and Tertiary. Subsequent introduction of the Alta and Clayton Peak stocks, during the Eocene, faulted, fractured, folded, metamorphosed, and mineralized the overlying rocks.

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INTRODUCTION

The Sunset Peak area is located near Alta, a highly productive mining camp prior to 1900. It is a classical area of contact metasomatism and metamorphism with structural complexity caused by the Sevier orogeny and sub-

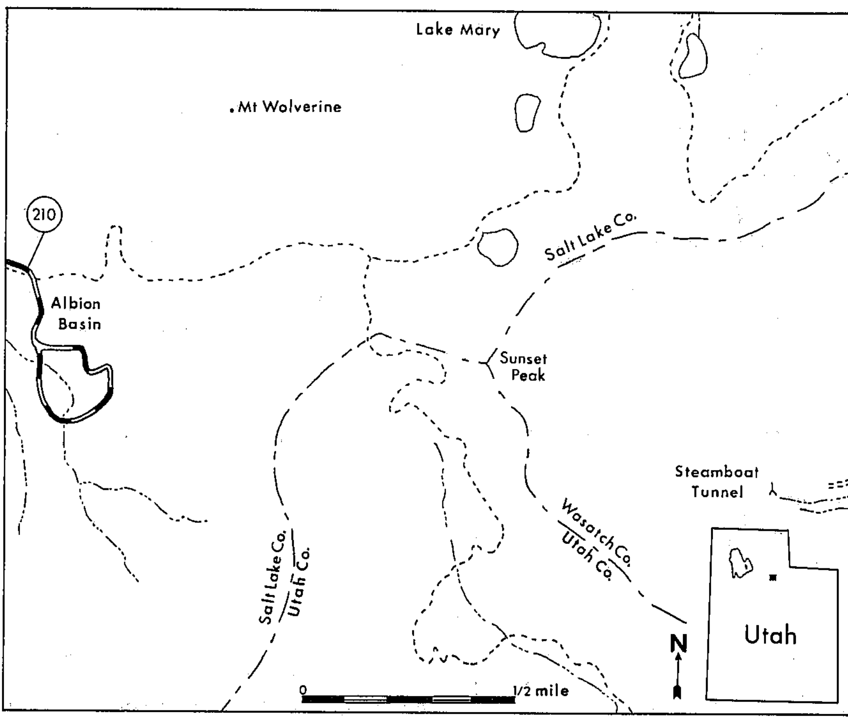
*A thesis presented to the Department of Geology of Brigham Young University in partial fulfillment of the requirements for the degree Master of Science, April 1973. Kenneth C. Bullock, thesis chairman.

sequent introduction of the Alta and Clayton Peak stocks. The purposes of this study are (1) to revise a portion of the geologic map produced by Calkins and Butler, (2) to describe the unaltered rocks, (3) to determine the degree and type of alteration present in each formation, and (4) to determine the structural features and their relationship to the metamorphism and ore mineralization.

Location and Accessibility

Sunset Peak area is located 20 miles southeast of Salt Lake City in the Wasatch Mountains, in the northwest quarter of the Brighton Quadrangle, Utah. It is bounded by 40° 36′ to 40° 33′ N. latitude and 111° 37′ to 111° 33′ W. longitude (Text-fig. 1). The area is a rugged part of the Wasatch Range, with most of the area at an elevation above 9,000 feet, ranging up to as high as 11,000 feet.

There are four access roads to the margin of the study area. State Highway 210 to Alta provides access to the western boundary, and State Highway 150 to Brighton terminates a mile from the northeast boundary. In American Fork Canyon a Forest Service road provides access to within two miles of the southern border. A dirt road used by the Mid-Park Mining Co. joins U.S. 189 near Heber and provides access to the southeast border (Pl. 2, fig. 4). The interior of the mapped area can be reached on the ground only by foot or



TEXT-FIGURE 1.—Index map to the Sunset Peak area.

horseback. The most convenient means of access to the entire area was by the Alta Road (State Highway 210) to the Albion Basin (Pl. 1, fig. 3), from which foot trails lead northeast to Brighton and southeast to American Fork Canyon.

Previous Work

The Wasatch Range has been studied extensively for the last century because of its economic deposits of minerals and its general academic interest to the nearby University of Utah and Brigham Young University.

The earliest geologic map covering this part of Utah was published in the atlas accompanying King's Fortieth Parallel Survey Report in 1877. Rocks in this region were considered to be Precambrian, Silurian, Devonian, and Carboniferous.

J. M. Boutwell (1912) published a geological study of the Park City District, which is 20 miles east of the Alta-Brighton area. A higher stratigraphic section is exposed in the Park City area, yet the general structural features described there are pertinent to the present study.

Butler, Loughlin, and Heikes (1916) published a preliminary report of the Cottonwood—American Fork mining region. A few years later, Butler and others (1920) completed U.S. Geological Survey Professional Paper 111, which included the first complete report and map of the Cottonwood—American Fork mining region.

Gilluly (1932), while mapping in the Oquirrh Range, defined Cambrian, Devonian, Mississippian, and Pennsylvanian stratigraphic units and established type locations for the rocks also present in the south-central Wasatch Mountains.

Eardley (1933) described the rocks, prepared a reconnaissance map of the Southern Wasatch Range, and correlated stratigraphic units found in the Oquirrh Range and the north-central Wasatch Range. Eardley (1939) also published a review of the structure of the Wasatch Range just north of the study area and (1944) a comprehensive geologic report on the stratigraphy, structure, and physiography of the north-central Wasatch Mountains.

Calkins and Butler (1943) published U.S. Geological Survey Professional Paper 201 on the Cottonwood—American Fork mining region. The geologic map published earlier in Professional Paper 111 was revised, and more detail was added. Compilation of the mine workings was made, and stratigraphy and structure were more fully worked out. Their effort is by far the most comprehensive publication concerning the area to date. Their geologic map was later revised by Baker, Calkins, Crittenden, and Bromfield (1966).

Perkins (1955) published a thesis on the stratigraphy of the lower American Fork Canyon, 15 miles south of the Sunset Peak area. His lithologic descriptions, measured sections, and bibliography were helpful in the present study.

Crittenden (1959) published a paper on the Mississippian stratigraphy of the Central Wasatch and western Uinta Mountains. The formations mentioned are found in the Sunset Peak area. Also presented is a general review of the transition area between the Wasatch and Uinta Mountains. Eardley (1968) presented a summary geologic report of the Park City district and discussed regional geology.

Several reports have come out on the isotopic dating of the Clayton Peak, Alta, and Cottonwood stocks. The results of Jaffe's study (1959) are: Clayton 40-48 m.y., Alta 54 m.y., and Little Cottonwood 46 m.y. Armstrong (1963,

p. 167-68) determined ages for the stocks as: Alta 39 m.y. and Cottonwood 22 m.y. Kulp (1961, p. 463) reported a 25 m.y. date for the Cottonwood Stock.

Many unpublished mining company reports have been written on the study area. However, the only one available, written by Bullock (1970) for the Great Western Mines Company of Salt Lake, is primarily an evaluation of mining property.

A thesis on the geochemistry of the skarn zones, by John Cranor (1974), and one on the petrology of the Clayton Peak Stock, by Joel Palmer, Brigham Young University graduate students, are currently under way.

Methods of Study

Field work began June 8, 1972. Snow conditions prevented an earlier start. The first objective was to determine the geologic formations and members present and the varying degrees of alteration caused by the igneous intrusions.

The next major objective was to reinterpret the formation contacts and plot them accordingly on aerial photographs. At the same time, the structural features were noted, and strikes and dips were taken at strategic localities and recorded on the same aerial photographs. In camp this information was replotted onto a 24" x 24" enlarged aerial photo of the Sunset Peak area (ELK-4-232) with a scale of 1 inch equal to 650 feet.

Few exposures of unaltered sediments are present in the area. However, sections at Devils Castle (Pl. 2, fig. 3) and in Albion Basin (near sample localities 107 to 620) are fairly complete, and contacts and beds are distinguishable. These outcrops were used to obtain two measured sections.

Samples were collected from the various units. Sample locations were plotted on the aerial photographs and later were transferred to an enlarged topographic map. Samples were collected at regular intervals away from the intrusions, and their relations to stratigraphic units were established (Text-fig. 3).

In the laboratory the samples were coded and filed. Thin sections were made of each sample for petrographic study.

Acknowledgments

The writer is grateful for the assistance provided by Dr. Kenneth C. Bullock, who served as chairman of the thesis committee and was responsible for the conception of the project. He also provided continual advice and encouragement. Dr. Morris Peterson provided information on the stratigraphy and assistance with field correlations. Dr. James Baer provided advice on the structure of the area.

Field expenses were defrayed by a grant from the Great Western Mines, which has land holdings in the area. Appreciation is also extended to the writer's parents, who provided considerable financial aid during the entire graduate program.

STRATIGRAPHY

Sedimentary rocks of Cambrian through Mississippian age are exposed in the area, the oldest being the Tintic Quartzite and the youngest, the Humbug Formation. Total thickness of the sedimentary rocks is in excess of 2,000 feet.

Overlying Quaternary deposits are extensive as a result of glacial and water action.

Exposures of the various formations and Quaternary deposits are represented on the geologic map (Pl. 3); their thicknesses, by the columnar sections (Text-fig. 2).

Most of the sedimentary rocks have been altered by thermal metamorphism, except those in the immediate vicinity of Devils Castle (Pl. 2, fig. 3). These unaltered rocks were used for descriptions of the various formations.

Cambrian System

Tintic Quartzite.—The upper portion of the Tintic Quartzite is exposed on the southwest side of the area in Albion Basin. Approximately 80 feet of Tintic Quartzite are exposed here, the remaining 700 feet being covered by landslide and glacial debris. For this reason only the upper part will be discussed. More extensive exposures occur immediately west of Albion Basin.

The formation is a fairly homogeneous quartzite with a 10-foot gradational interval into the overlying lower member of the Ophir Shale. The main rock type in main Tintic Quartzite exposures is a cross-bedded arenaceous orthoquartzite that is very light gray to flesh tinted on fresh surfaces. It has a medium- to coarse-grained texture with subangular to rounded grains and consists primarily of quartz, with mainly silica cement. Some minor iron-oxide cement is present, which, upon weathering, gives these rocks a characteristic brown color. Part of this brown stain was also attributed, by Calkins and Butler (1943), to weathering of secondary iron carbonates that formed in the fracture system and bedding planes of the formation.

No fossils have been found in this formation in the Cottonwood—American Fork area and none were observed in the sections exposed in Albion Basin. Its age is assumed to be Cambrian because it overlies the Precambrian Mineral Fork Tillite and gradationally underlies the middle Cambrian Ophir Shale.

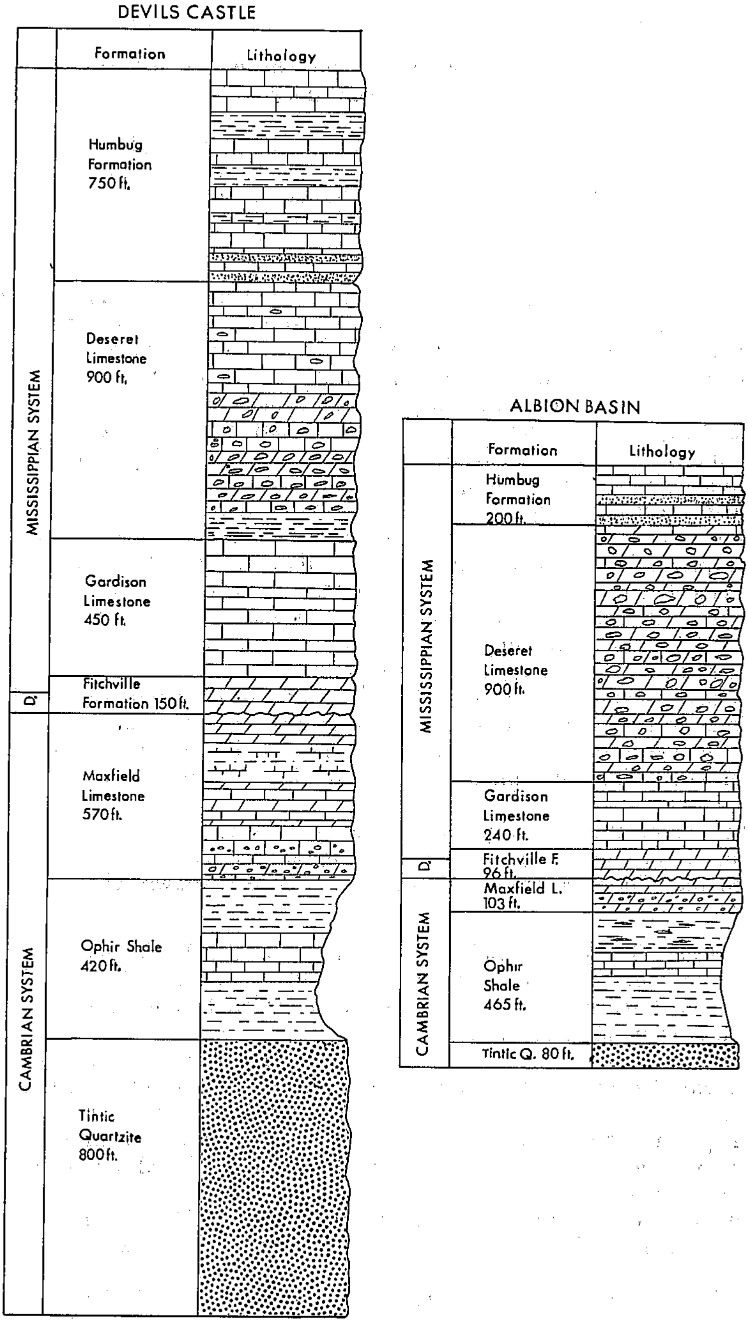
The top of the formation is marked by thin (3-5 cm) shale beds that are dark brown and that contain some micaceous material. The boundary between the Tintic Quartzite and the Ophir Shale is drawn where shale predominates.

Ophir Shale.—The Ophir Shale lies directly above the Tintic Quartzite and is exposed on the southwest boundary of the area in Albion Basin. It is subdivided into three members, a lower shale, a medial limestone, and an upper shale. It is about 308 feet thick.

The lower part of the lower member of the Ophir Shale contains bands of quartzite that give way 5 feet above the base to fissile shale. Partings are covered with bits of shiny sericite that decrease in abundance upward. The shale is greenish black but is stained on weathered surfaces by limonite. What appear to be worm trails are found in the member. Total thickness of the lower member is about 88 feet.

Exposures of the middle member are found in Albion Basin, but the limestone has been altered there and will be described in the section on altered rocks.

Unaltered exposures of the member are found above Albion Basin near Devils Castle. Here the middle member is a well-defined unit of siliceous light blue gray nonmagnesium limestone about 80 feet thick. Bedding is character-



TEXT-FIGURE 2.—Stratigraphic sections exposed in the Sunset Peak area.

istically marked by thin, wavy siliceous laminae. The limestone is medium grained, with larger grains scattered throughout a finer matrix. It is a biosparite (Folk, 1959, p. 1-38). Large numbers of allochem ghosts, apparently caused by alteration of fossils and formation of sparite, are found.

The upper shale member is a yellowish brown on weathered outcrops. Calkins and Butler (1943) believe that this coloration is caused by decomposition of an iron-bearing carbonate. The member breaks down into slabs but, unlike the lower member, is not fissile. Transverse jointing is present. Calkins and Butler (1943) report that the color of the unweathered rock is a greenish gray; however, it is rarely seen, owing to extensive weathering. Although the term *shale* has been used to describe the member, the rock type is actually a fine-grained calcareous quartz arenite. Medium grains of angular to subangular quartz and some orthoclase comprise from 50 to 60 percent of the rock. The remainder is composed of calcite and a very small amount of mica. Total thickness of the member is 140 feet.

Maxfield Limestone.—The Maxfield Limestone is well exposed in Albion Basin and in the thrust sheet above Albion Basin and Steamboat Tunnel and consists of three members. Owing to the unconformity, thickness also varies.

The lower member is exposed in Albion Basin and in the thrust sheet above Albion Basin, and the middle member is seen only in the thrust sheet northwest of Steamboat Tunnel (Pl. 2, fig. 4). Because an unconformity separates the Maxfield Limestone and the overlying Fitchville Formation, the third member has been eroded and is not seen in the Cottonwod—American Fork area (Text-fig. 2).

An oolitic limestone found at the bottom of the lower member helps to establish the contact between the Maxfield Limestone and the underlying Ophir Shale. Oolites are dark gray and spherical, are usually less than 1 mm in diameter, and occur in a lighter gray matrix. The limestone is about 50 feet thick and is an important marker horizon. Interpenetration of lighter and darker material has produced a mosaic of light and dark patches, especially conspicuous on weathered surfaces.

Certain beds contain what appear to be organic remains. Round "wormlike" bodies 5-10 mm in diameter and 2-5 cm in length intertwine like branches of a tree and appear to be similar to features found in the Ophir Shale. They are lighter than the surrounding matrix and have been attributed to burrowing organisms by Calkins and Butler (1943). They may also be a result of some physical phenomenon, such as that suggested by Bissell and others (1967). They believe that the markings form from an incomplete or partial dolomitization. The "wormlike" bodies, being more highly dolomitized, will therefore appear somewhat lighter than the matrix and will stand out in relief upon weathering.

Another feature characteristic of the formation is referred to as "guinea hen structure" by Calkins and Butler (1943). Small voids randomly scattered through the rock have subsequently been filled by calcite that appears light against the dark gray of the dolomitic matrix. The voids were probably formed by groundwater action and later filled by calcite.

Fossils are rare in this formation. However, a few poorly preserved trilobites were found.

At Devils Castle the lower member is, in general, a very fine grained crystalline dolomite with large dolorhombs in a very fine crystalline matrix.

One to three percent opaque material is found and it occurs in stringers or layers in some horizons. In addition the lower 100 feet contain 35 to 40 percent quartz, randomly scattered throughout the rock. Some beds contain fractures that have been filled by large dolorhombs in a very fine dolomitic matrix. The lower member is approximately 200 feet thick.

The following description is given by Calkins and Butler (1943) for the unaltered middle member in the Cottonwood—American Fork area. Alternating beds of shale and limestone are found intergrading into one another. The limestones, mottled magnesium limestones, grade into strongly nonmagnesium limestones towards the top of the middle member. The interbedded shales are olive green and fissile. Total thickness of the member is about 310 feet, but the lower 140 feet of limestone are not seen northwest of Steamboat Tunnel.

Devonian-Mississippian Systems

Fitchville Formation.—The Fitchville Formation lies unconformably on the Maxfield Limestone. It is 150 feet thick. Characteristic mottling of the Maxfield Limestone is not present in Fitchville beds, providing a useful guide for distinguishing the two.

The formation has several small lithologic units but a light to medium dark gray, thick-bedded, finely crystalline dolomite comprises most of the formation. Its most distinguishing characteristic is small vugs an inch or two in diameter that are lined with calcite or quartz. These occur throughout the Fitchville Formation, although with varying frequency. Vugs tend to be elongated parallel to bedding planes.

A dolomite bed that is a very light bluish gray on weathered surfaces and a light gray on fresh surfaces forms the top unit. It is very finely crystalline. It has a fine fracture system and is about 10 feet thick. It provides a useful marker horizon for mapping the Fitchville-Gardison contact (Pl. 1, fig. 3).

Fossils are found in the formation. Dominant types are rugose and tabulate corals, spirifers, and gastropods. However, alteration makes species identification difficult.

Mississippian System

Gardison Limestone.—An unaltered section of the Gardison Limestone is exposed near Devils Castle, above Albion Basin. It has a thickness of 500 feet and is by far the most homogeneous carbonate unit in the area. It is prevailingly blue-gray, and is well bedded in units mostly less than a foot thick.

Contact with the underlying Fitchville Formation is marked by an abrupt change from the massive light gray dolomite, nearly devoid of fossils and capped

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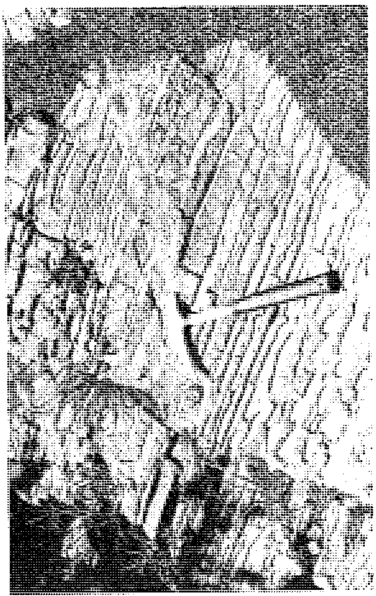
EXPLANATION OF PLATE 1
OUTCROPS AND SEDIMENTARY FEATURES

FIG. 1.—Sills in the Ophir Shale near the Alta Stock.
FIG. 2.—Upper Maxfield silicic hornfels near the Alta Stock.
FIG. 3.—Albion Basin, looking southward towards outcrops of the Fitchville Formation (arrow points to the top white dolomitic bed), Gardison Limestone, and Deseret Limestone below Devils Castle.
FIG. 4.—Silicified corals in the Gardison Limestone near sample locality 524.

PLATE 1



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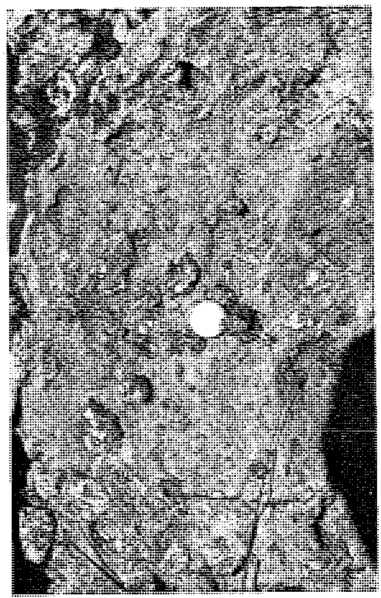

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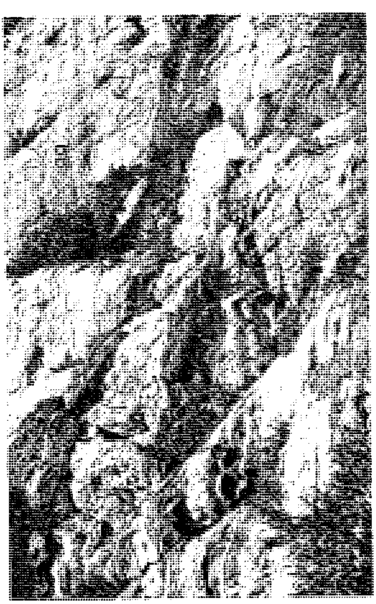

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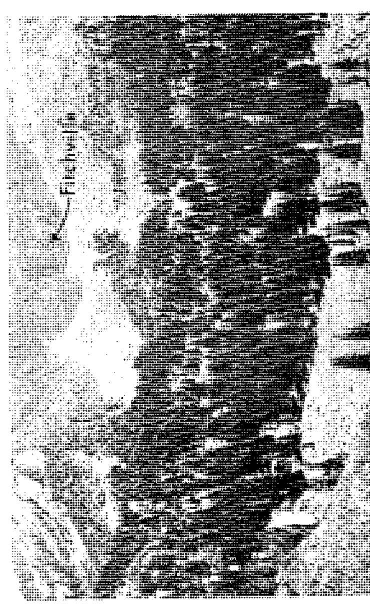

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by a white dolomitic layer, to a dark gray to black thinly bedded limestone with prolific fossil debris. Although the formation is called a limestone, dolomite and high-magnesium calcite predominate.

Small nodules of black chert are found here and there in the Gardison Limestone, but the minor amount present is the main criterion for separating it from the overlying Deseret Limestone.

The Gardison Limestone consists of three definable rock types, not necessarily mutually exclusive: (1) a finely crystalline, high-magnesium limestone (crystals 1 to 2 mm), (2) a dolomitized high-magnesium intrasparite containing fossil ghosts, (3) a dolomitized skeletal limestone. All three rock types are quite porous and have a permeability much higher than that found in the underlying Fitchville and Maxfield limestones. Interclasts appear to be diagenetically altered material of previous carbonate rocks or mud. Some medium to very fine grained quartz is scattered through rock type 2, but is not in excess of 5 percent.

Deseret Limestone.—The contact between the Deseret and Gardison limestones is marked by a black phosphatic shale bed in most other areas of northern Utah, but this bed is not found in the study area. The contact was chosen, however, on three criteria: (1) a marked change in fossil content and preservation, (2) a marked increase upward in abundance of chert nodules and bands, and (3) a slightly different rock type.

A diagnostic feature of the Deseret Limestone is an abundance of chert occurring partly in nodules that may be spherical and several inches in diameter. However, all gradations from these spherical types to more lenticular ones to bedded chert are found higher in the formation. This provides a means of subdividing it into a lower chert nodule section, 400 feet thick, and an upper chert band section, 500 feet thick.

The chert breaks with a conchoidal fracture and has a lustrous appearance on fresh surfaces. Like the dolomite, it is black. Weathered surfaces are dull in appearance. Higher, there occur beds of chert several inches thick that are resistant to weathering (Pl. 2, fig. 1). The upper bedded chert is essentially identical to that found lower in the Deseret Limestone.

Chert is common in Mississippian carbonate rocks. The chert nodules appear to have had an epigenetic origin, as indicated by the rock features, which agree with Van Tuyl's (1918) conclusions for such an evolution, conclusions based upon (1) occurrence of chert along fissures in the limestone, (2) very irregular shape of some chert nodules, (3) presence of irregular patches of limestone within some nodules, (4) association of silicified fossils and chert, (5) presence of replaced fossils in the chert, (6) preservation of

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EXPLANATION OF PLATE 2

SEDIMENTARY AND STRUCTURAL FEATURES

FIG. 1.—Chert bands in the Deseret Limestone.

FIG. 2.—Weathered-out chert nodule in the Gardison-Deseret Limestone on Pioneer Peak with a lining of tremolite.

FIG. 3.—Thrust sheet of Maxfield and Fitchville limestones above Albion Basin, looking westward.

FIG. 4.—Thrust sheet of Deseret Limestone (lower) and thrust sheet of Maxfield Limestone above Steamboat Tunnel, looking northwestward.

PLATE 2

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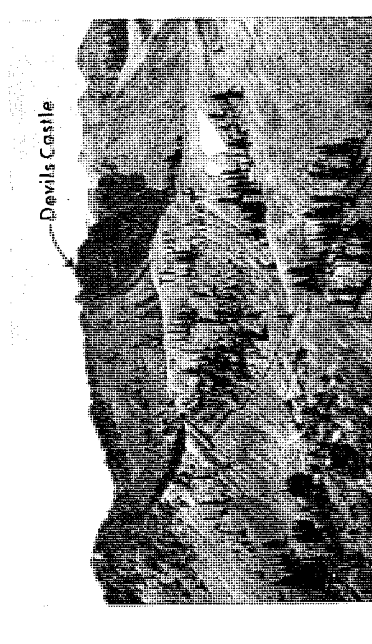

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textures and structures in the chert, and (7) failure of some chert to follow definite zones in the formation.

The bedded chert is probably a result of direct precipitation of a silica gel. This would supply underlying sediments with silica needed for the chert nodules. A replacement origin for the chert bands seems unlikely because of their abundance and bedded character.

Rock types vary to some degree within the Deseret Limestone, but both are closely related and occur intermixed. One type is a crystalline dolomite, and the other is a dolomitized skeletal limestone that contains large quantities of fossils. Both have some porosity and permeability but lack the high porosity and permeability of the Gardison Limestone. All rocks are 90 to 100 percent dolomite.

A fossil assemblage similar to that found in the Gardison Limestone is present. However, corals and brachiopods are more common. Also, fossils do not occur so abundantly as in the underlying Gardison Limestone. Deseret fossils are more highly replaced and distorted and lack the distinctness of those in the Gardison Limestone.

Humbug Formation.—The Humbug Formation is exposed on the ridge northwest of Steamboat Tunnel at the head of Snake Creek. Exposures are highly altered, and most of the formation is covered by talus. For this reason, the following description of the unaltered Humbug Formation is summarized from U.S. Geological Survey Professional Paper 201. Because only the lower part of the formation is present in the study area, the upper portion will not be described.

The lower beds consist of dark to light gray limestone with subordinate sandstone and minor shale. The limestone is mostly blue gray and calcitic, though very dark and very light beds occur. The interbedded sandstone is about one-quarter as abundant as the limestone, occurs in beds less than 5 feet thick, and is fine grained. It is a light grayish brown on weathered surfaces but gray on fresh surfaces. Cross-bedding occurs.

The contact between the Deseret Limestone and the Humbug Formation is arbitrarily drawn at a persistent sandstone bed that marks a distinct upward change from the black cherty dolomite of the Deseret Limestone.

Although total thickness of the formation has been estimated at 800 feet by Calkins and Butler (1943), no more than 200 feet of altered rocks are seen in the study area.

Quaternary Deposits

Quaternary deposits consist of four types: (1) glacial deposits, (2) landslides, (3) talus, and (4) alluvium.

Glacial deposits consist of one well-preserved end moraine that occurs above Albion Basin, near the springs, and ground moraine which occurs in and above Albion Basin and in Dry Fork Canyon. The end moraine consists of large angular blocks several feet in diameter. The clasts are all limestone and dolomite apparently derived from the Gardison and Deseret limestones. The end moraine is about 50 yards wide and 100 yards long. Ground moraine consists of large limestone and dolomite boulders with intervening patches of cobbles and soil that form beautiful meadows. The Lake Catherine amphitheater and the head of Albion Basin are both cirques produced by glaciation. Associated glacial rock scouring and polishing is seen.

A landslide occurs at the head of Albion Basin and was probably produced by the over-steepening effects of glaciation and the subsequent instability of the cliffs. Large boulders of Gardison and Deseret limestones cover the bottom of the basin. According to Calkins and Butler (1943), the slide is about three-quarters of a mile across at its head, from which a narrowing tongue extends northward for a mile. It is distinguished from talus and glacial debris by the length and gentle slope of its tongue. Near the lower end of the tongue blocks are 20 feet in diameter.

Talus has accumulated below the steep cliffs and slopes. An abundance of water and the alternate freezing and melting have no doubt been responsible for this. Most talus deposits in the area occur below oversteepened cliffs caused by glaciation. The largest and most conspicuous talus accumulations are above Dog Lake, Lake Catherine, and Albion Basin. Talus ranges in size from sand to angular boulders and consists of the rock type making up the cliff. The talus makes mapping difficult, and walking across it is hazardous.

Alluvium forms a thin veneer over many parts of the area. It is mostly reworked glacial debris or erosional material brought down by streams or rain wash. It consists of sand and silt and forms most of the soil cover, but it did not hinder mapping because it is not thick or extensive enough to map.

IGNEOUS ROCKS

Igneous rocks in the area consist of dikes and the Alta and Clayton Peak stocks. The sedimentary rocks of major concern are bounded on the north by the Alta Stock and on the east by the Clayton Peak Stock. The dikes cut across the southern portion of the area.

The Clayton Peak and Alta stocks are similar petrographically: the Alta Stock is a diorite, and the Clayton Peak Stock is a granodiorite. They are also similar in age, although the Clayton Peak Stock is slightly older. Both are Tertiary in age, probably Eocene.

Calkins and Butler (1943) named the Clayton Peak Stock for the highest summit in the Park City district. It is a dark gray, fine-textured, uniformly granular diorite that contains little quartz, but considerable orthoclase, almost making it a monzonite. Dark silicate minerals are biotite, hornblende, and augite.

The Alta Stock consists of plagioclase, quartz, orthoclase, biotite, and hornblende (Calkins and Butler, 1943). It is lighter colored, coarser, and more siliceous than the diorite of the Clayton Peak Stock. It also differs from the Clayton Peak Stock in containing more quartz and no pyroxene.

Sialic and mafic dikes are found elsewhere in the map area. Calkins and Butler (1943) describe them as lamprophyres and alaskite porphyry dikes. The lamprophyres contain 50 percent ferromagnesium minerals and considerable plagioclase. They are dark gray and fine grained. Their original composition cannot be determined because they have been extensively altered. The alaskite dikes are white, contain very little ferromagnesium minerals, and have an abundance of orthoclase and quartz. They also have been extensively altered.

DESCRIPTION OF THE ALTERED SEDIMENTARY ROCKS

The following is a description of changes to be seen in the sedimentary rocks as a result of thermal metamorphism caused by the Clayton Peak and

Alta stocks. Within twenty yards of the intrusive, metasomatism has produced a new assemblage of minerals. A thesis recently (1973) completed by John Cranor at Brigham Young University is concerned with chemistry and petrology of the contact zones.

Tintic Quartzite

The Tintic Quartzite is fairly stable and has been little affected by thermal metamorphism. Three-quarters of a mile from the contact, at sample locality 107 (Pl. 3), small amounts of tremolite are present. In sample locality 103, next to the intrusive, a slight granoblastic-polygonal texture is seen in conjunction with the tremolite.

Ophir Shale

The lower member of the Ophir Shale has been affected little by thermal metamorphism other than having experienced an increase in mica (primarily sericite). The rock near the intrusion is less fissile, and bedding planes and "wormlike" bodies are obscure. Within one-half mile of the intrusive contact, the rock is a metamorphosed argillite.

Within two hundred yards of the intrusive contact, in Albion Basin, a large number of dikes and sills from the Alta Stock are present (Pl. 1, fig. 1). The light diorite is in striking color contrast to the brown to black Ophir Shale. In some areas diorite exceeds 50 percent.

Only at the intrusive contact is a noticeable change seen in the lower Ophir Shale. Here the rock is a hard, dense, featureless hornfels containing several new minerals: tourmaline, cordierite, and andalusite.

The middle member of the Ophir Shale is exposed to within three-quarters of a mile of the intrusive contact in Albion Basin. Here (sample localities 207-212) it is a red, crystalline limestone that lacks the siliceous laminae evident where it is unaltered.

The upper shale member of the Ophir Shale is altered to a greenish gray hornfels one mile south of the intrusive contact. The rock consists of green and brown bands, in contrast to the black to brown lower member directly underneath, and is composed of quartz and orthoclase, with quartz being slightly more abundant. Subordinate amounts of diopside, hornblende, and biotite are found in a zone that extends six hundred yards in width from the intrusive contact. In the same zone are small pockets of garnet, azurite, malachite, and magnetite. Bedding planes and all other sedimentary features are obscured. The massive rock breaks into rectangular boulders, probably as a result of the transverse joints like those present in the unaltered rock.

Maxfield Limestone

From Devils Castle to sample locality 323, the only alteration seen in the Maxfield Limestone is a slight bleaching. Extreme alteration occurs near sample locality 327 where the rock is a sugary dolomite marble. The normal fault near sample locality 323 must have had a controlling influence in governing the degree of alteration.

The rock is bleached white, as is the overlying Fitchville Formation. All sedimentary features are gone, except some relict mottling. Near sample localities 303 A and B, the rock changes to a dull brownish red. This change may have resulted from an unusually high iron content in this particular part of the limestone or from gaseous or liquid emanations from the magma. The Maxfield Limestone thins towards the Alta Stock and is about 100 feet thick where samples 303 A and B were collected. In the area above sample locality 209, the Maxfield Limestone is white, and it remains white from here to the Alta Stock.

In the thrust sheet the Maxfield Limestone remains unaltered up to sample locality 307 (Pl. 2, fig. 3). Near sample locality 307 the middle member of the Maxfield Limestone is downthrown against the lower member. The middle member continues to be exposed along the ridge southwest of Steamboat Tunnel to where it is terminated against the Humbug Formation by another normal fault.

The lower part of the middle member is not exposed in the altered sequence. The upper 170 feet of the member, however, is a sugary dolomitic marble that has bands of silicic hornfels (Pl. 1, fig. 2). The silicic hornfels is resistant to weathering and forms prominent outcrops. Intervening voids have been caused by the weathering of less-resistant sugary dolomitic marble. The hornfels is a bluish gray on fresh surfaces but turns a dark brown upon weathering. In thin section the hornfels appears to be cryptocrystalline and composed of quartz.

The segment of a thrusted block that extends north to the Alta Stock changes from a white, sugary dolomitic marble at the crest of the hill, near sample locality 307, to a red, grainy rock with relict mottling. One hundred yards from the contact, it changes to a granoblastic sugary dolomitic marble that is very friable.

Some of the Maxfield Limestone, such as sample 316, has been altered to a white marble containing crystals of pyrite and garnet.

Fitchville Formation

In outcrops beyond sample locality 414, the Fitchville Formation is unchanged, except for slight bleaching. Near sample locality 414, however, there occurs an abrupt change in alteration that coincides with a normal fault. Textures and fossils found in unaltered rocks are gone, except for the characteristic vugs and a few tabulate corals on Sunset Peak. The rock has been altered to a granoblastic white, sugary dolomitic marble.

In the thrust sheet, immediately above Albion Basin, the Fitchville Formation is unchanged. Fossils, especially corals that weather out in relief, are found there. At sample locality 413 the Fitchville Formation is a white, sugary dolomitic marble similar to that seen in sample locality 414. This alteration extends north and east to the intrusive contact.

Why the Fitchville Formation and Maxfield Limestone in the thrust sheet maintain their sedimentary features closer to the intrusive contacts than they do below the thrust sheet is unclear. Perhaps the distance from the stocks was great enough to shield portions of the thrust sheet from the intense heat.

Gardison Limestone

Minor metamorphism of the Gardison Limestone has produced a granoblastic, white, sugary dolomitic marble similar to that seen in the Fitchville Formation and the Maxfield Limestone. Bleaching begins near sample locality 524 (Pl. 3) and becomes more intense to the north. Complete alteration is found just beyond sample localities 525 and 620, except for some unaltered remnants. Where alteration is not complete, the fossils are highly silicified and stand out in relief against the more easily weathered dolomitic marble (Pl. 1, fig. 4).

Deseret Limestone

Altered Deseret Limestone covers more of the study area than does any other formation. Its thickness and dip trend and the thrusts and the shallow depth of the underlying diorite account for this large areal extent. Most of the Deseret Limestone within the map area is altered to some degree, except that found in the Devils Castle area.

Alteration of the chert bands and nodules changes with increased metamorphism. Calcite was the first replacement mineral to be altered to tremolite with increased metamorphism. This type of modification is present northward and eastward from sample localities 617 and 610 (Pl. 3) to the intrusive contacts. At Pioneer Peak and near Steamboat Tunnel, where alteration is extreme, vugs are present at the surface where tremolite has been removed by weathering (Pl. 2, fig. 2).

The Deseret Limestone became bleached, as did the underlying carbonates. With increased metamorphism, however, a granoblastic sugary dolomitic marble was produced. Most of the altered rock is very light gray, with some red hues present above Steamboat Tunnel and Lake Catherine. Fossils and sedimentary features have been destroyed. However, as in the Gardison Limestone, remnants of unaltered rock and chert help in identifying and mapping the formation. Alteration of this type occurs at Pioneer Peak, at Steamboat Tunnel and vicinity, and above Albion Basin.

Deseret Limestone in Dry Fork Canyon is moderately to highly altered. Increased alteration occurs to the north, with more of the limestone becoming a sugary dolomitic marble. Extreme alteration occurs near the thrust, which seems to have had some control on the degree of modification.

Humbug Formation

The Humbug Formation has been extensively altered above Steamboat Tunnel, presumably by hydrothermal solutions. On close observation the rock is seen to be extensively weathered. It ranges from a very fine grained limestone to a calcareous, fine-grained sandstone that is friable. It is red on weathered surfaces and is so deeply weathered that the color of the fresh rock is not determinable.

STRUCTURE

Normal faults, reverse faults, thrusts, and folds exist in the area. Much of the structural complication was caused by intrusion of the Alta and Clayton Peak stocks. Thrust faults and some folds were caused by the Sevier Orogeny. Earlier, however, the area was fairly stable, except for minor broad warping during the early Devonian (Morris, 1964), when the angular unconformity between the Maxfield Limestone and the Fitchville Formation was developed.

Faults

Normal Faults.—Many normal faults occur in the area. Because of the alteration, brecciation, and talus cover, it is generally difficult to determine the direction of relative motion. Faulting is most apparent because of stratigraphic separations and the brecciation. Most displacements are 100 feet or less. Many of the faults strike in a northeasterly direction. Normal faulting increases in intensity towards the intrusive contacts where the rocks are extensively faulted, although the amount of movement on any fault is small—usually only a few feet. Emplacement of the intrusions was the probable cause.

Overthrust Faults.—The major thrust sheet is a remnant of the once more widespread Grizzly thrust sheet (Calkins and Butler, 1943). The thrust remnants are composed primarily of Fitchville and Maxfield limestones. One small thrust sheet of Deseret Limestone is present.

There may have been two episodes of thrusting during the late Cretaceous or early Tertiary. The first produced the thrust sheet of Deseret Limestone. The second produced the thrust sheet of Maxfield, Fitchville, and Deseret limestones, the former having only a small remnant on the ridge in the southeast corner of the area (Text-fig. 3).

The thrusts originated from the west and brought older rock over younger rock. The general dip of the fault surface is 15° to the southeast. A noticeable break in lithology, drag folds, and brecciation occurs along the thrust boundaries.

Calkins and Butler (1943) refer to pebble dikes in association with the thrusts. Although they were not mapped, such features do occur in several places above Albion Basin. They consist of fractured pieces of limestone with a calcareous cement. They are a result of brecciation caused by the thrusting and serve as a useful clue to the thrust boundaries.

A noticeable increase in thickness of the Deseret Limestone is seen in Dry Fork Canyon and above Steamboat Tunnel. This is related to the position of the thrust fault. The thrust is marked by an abrupt line of brecciation (Pl. 2, fig. 4). An abrupt change in the degree of alteration is also obvious in Dry Fork Canyon, where intense alteration of the Deseret Limestone occurs at the thrust boundary. The fault must have provided a channelway for hot solutions from the underlying magma.

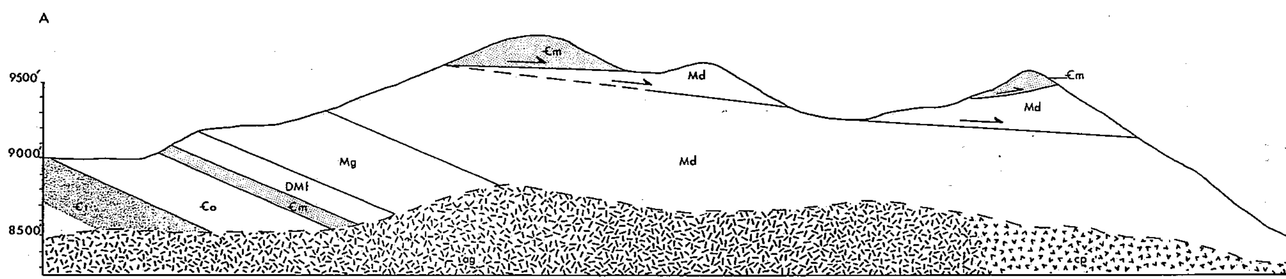
Folds

The most widespread structural feature in the area is a homocline that dips 15° to 20° to the northeast (Pl. 3) from Albion Basin to Steamboat Tunnel. Many minor folds occur near the intrusive boundaries as a result of the introduction of the stocks. A small syncline above Lake Catherine is in the Maxfield Limestone and the Fitchville Formation; and the ridge of Maxfield Limestone, above Steamboat Tunnel, exposes a small anticline.

The Sevier Orogeny produced the thrust sheets and possibly some normal faults and broad warps. The mafic and sialic dikes, faults that cut the thrust sheets, and alteration of the rocks in the thrust sheets indicate that thrusting occurred before the intrusions.

Influence of the Intrusions

More local structures are a result of the sialic intrusions than of the Sevier Orogeny. The general homocline that dips to the northeast was probably produced by the Alta Stock as a result of tilting and stoping. Most of the minor folds and normal faults near the intrusions also were probably a result of stoping by the Alta and Clayton Peak stocks. Alteration of the sedimentary



TEXT-FIGURE 3.—Geologic cross section through the major thrust fault exposed in the Sunset Peak area, along line A-A′ shown on Plate 3, the geologic map.

rocks was caused by direct heat and solutions produced by the intrusions emplaced during the Tertiary, probably the Eocene (Jaffe, 1959).

Although drilling has not been done, the structural features and alteration would indicate that the intrusions are fairly shallow. The Clayton Peak Stock is probably only a few feet beneath the overlying Deseret and Gardison limestones near Steamboat Tunnel, and the Alta Stock is probably no more than 200 or 300 feet beneath the sedimentary rocks in Albion Basin. The overlying sedimentary rocks are probably only a veneer that was highly susceptible to deformation and alteration by the intrusive masses.

MINERALIZATION

The known ore bodies are located at or very near the intrusions. The mines that have been worked out, and the recently operating Mid-Park mine near Steamboat Tunnel, are all located at the Deseret Limestone and Clayton Peak Stock contact. Most of the suspected higher hydrothermal replacement deposits have probably long since been removed by erosion. Slight mineralization is seen at various localities up to a half-mile from the intrusive contacts.

Certain beds are naturally more susceptible to alteration and mineralization. Limestones and dolomites are the most affected, but even here mineralization is confined to a narrow aureole around the stocks. There seems to be no preference for any particular dolomite or limestone beds, nor have bedding planes provided any favorable horizons.

Normal and thrust faults have controlled alteration of the beds to a certain degree. They have provided channelways to the beds for solutions and heat. However, no direct mineralization is associated with them. The homocline and the small folds do not appear to have controlled mineralization.

SUMMARY AND CONCLUSIONS

The Paleozoic rocks exposed in the area are over 2,000 feet thick and consist of the Tintic Quartzite, Ophir Shale, Maxfield Limestone, Fitchville Formation, Gardison and Deseret limestones and Humbug Formation. The section ranges in age from Cambrian to Mississippian.

An unconformity separates Cambrian and Devonian rocks. Folding and thrusting occurred as a result of the Sevier Orogeny during late Cretaceous and early Tertiary time. The Alta and Clayton Peak stocks intruded during the Eocene and produced faults, fractures, folds, and thermal metamorphism in the overlying Paleozoic rocks. The stocks have caused thermal metamorphism of the surrounding Paleozoic rocks. The type and degree of metamorphism is dependent on the distance from the intrusions and rock type. Shales show an increase in sericite, and some become a hornfels near the intrusive contacts. Dolomites and limestones grade from a bleached limestone to a sugary dolomitic marble to a skarn at the intrusive contacts. Only rarely are sedimentary features preserved in the completely altered sediments. Rocks in the thrust sheet of Maxfield and Fitchville formations maintain their identity closer to the intrusions than do the underlying sediments, which suggests that portions of the thrust sheet were shielded from thermal metamorphism.

It is concluded that the normal faulting and thrusting controlled to some extent the metamorphism, but that their effect on mineralization, most of which is within 20 yards of the intrusive contacts in the Deseret Limestone, was negligible.

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