UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
AFFILIATED WITH
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
UNIVERSITY OF UTAH
SALT LAKE CITY, UTAH

NOTCH PEAK INTRUSIVE

Millard County, Utah

Geology, Petrogenesis, and Economic Deposits

by Harry Merrill Gehman, Jr.

Bulletin 62 January, 1958

Price $1.50

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

The Utah Geological and Mineralogical Survey was authorized by act of the Utah State Legislature in 1931; however, no funds were made available for its establishment until 1941 when the State Government was reorganized and the Utah Geological and Mineralogical Survey was placed within the new State Department of Publicity and Industrial Development where the Survey functioned until July 1, 1949. Effective as of that date, the Survey was transferred by law to the College of Mines and Mineral Industries, University of Utah.

The *Utah Code Annotated 1943, Vol. 2, Title 34,* as amended by *chapter 46 Laws of Utah 1949*, provides that the Utah Geological and Mineralogical Survey "shall have for its objects":

1. "The collection and distribution of reliable information regarding the mineral resources of the State.

2. "The survey of the geological formations of the State with special reference to their economic contents, values and uses, such as: the ores of the various metals, coal, oil-shale, hydro-carbons, oil, gas, industrial clays, cement materials, mineral waters and other surface and underground water supplies, mineral fertilizers, asphalt, bitumen, structural materials, road-making materials, their kind and availability; and the promotion of the marketing of the mineral products of the State.

3. "The investigation of the kind, amount, and availability of the various mineral substances contained in State lands, with a view of the most effective and profitable administration of such lands for the State.

4. "The consideration of such other scientific and economic problems as, in the judgment of the Board of Regents, should come within the field of the Survey.

5. "Cooperation with Utah state bureaus dealing with related subjects, with the United States Geological Survey and with the United States Bureau of Mines, in their respective functions including field investigations, and the preparation, publication, and distribution of reports and bulletins embodying the results of the work of the Survey.

6. "The preparation, publication, distribution and sale of maps, reports and bulletins embodying the results of the work of the Survey. The collection and establishment of exhibits of the mineral resources of Utah.

7. "Any income from the sale of maps and reports or from gifts or from other sources for the Survey shall be turned over to the State Treasurer and credited by him to a fund to be known as the Survey Fund to be used under the direction of the Director of the Survey for publication of maps, bulletins or other reports of investigation of the Geological and Mineralogical Survey."

The Utah Geological and Mineralogical Survey has published maps, circulars, and bulletins as well as articles in popular and scientific magazines. For a partial list of these, see the closing pages of this publication. For other information concerning the geological and mineralogical resources of Utah address:

ARTHUR L. CRAWFORD, *Director*

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

College of Mines and Mineral Industries

University of Utah

Salt Lake City, Utah

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F O R E W O R D

The Notch Peak intrusive presents a case study of the whole gamut of magma emplacement, thermal metamorphism, metasomatism, silication, the formation of aplite apophyses, pegmatization and ore deposition.

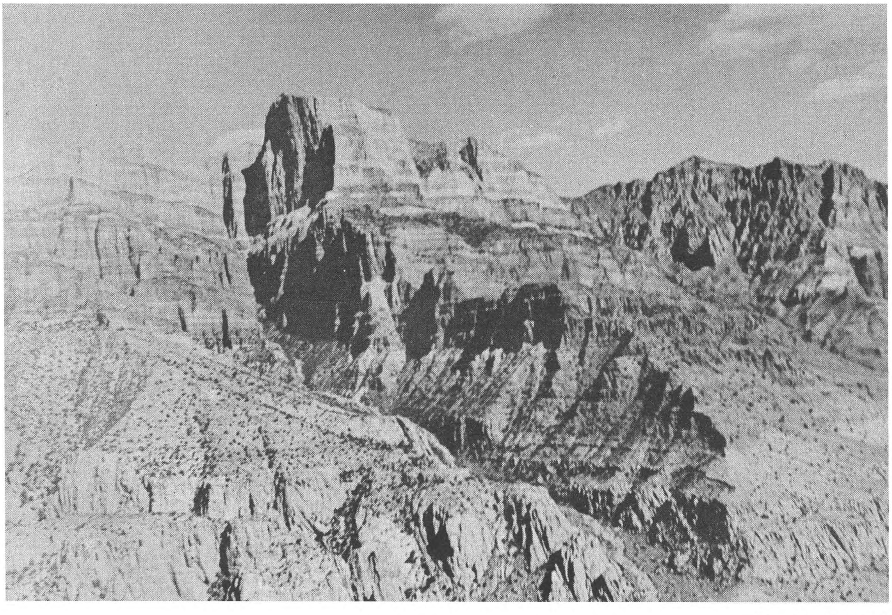
Seldom can one find in so neat an area the geologic record of such a variety of processes generated by a single intrusive body.

The author, Harry Merrill Gehman Jr., son of a distinguished mathematician of the same name, has approached his subject with analytical skill. His logic is convincing. The student of petrogenesis will find his descriptions apt.

The Utah Geological and Mineralogical Survey is fortunate that Cornell University has seen fit to sponsor this investigation in Millard County, Utah, and that the Survey has been able to secure this thesis for publication in its bulletin series.

The geology of Millard County is now being carefully mapped by Dr. Lehi F. Hintze and his associates of Brigham Young University, Provo, Utah. When completed, their results will be published as a county unit in the series begun by our Bulletin 52, THE GEOLOGIC ATLAS OF UTAH--EMERY COUNTY. Studies like this one on the Notch Peak intrusive will lighten the task for Dr. Hintze and prepare the way for the forthcoming more general treatise.

ARTHUR L. CRAWFORD, DIRECTOR
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY



F. Beckwith

Frontispiece A. Notch Peak, elevation 9,725 feet. It rises a mile above the valley floor.

N O T C H   P E A K   I N T R U S I V E

Millard County, Utah

Geology, Petrogenesis and Economic Deposits[1]

by Harry Merrill Gehman Jr.[2]

A B S T R A C T

A porphyritic quartz monzonite body is intrusive into Cambrian limestones and shaly limestones, north of Notch Peak, Millard County, Utah, causing a slight doming of the sedimentary rocks adjacent to it. The quartz monzonite body is about three miles in diameter and is generally stock-like. The contacts are steeply dipping except on the southwest, where a large sill extends outward for a distance of about a mile. Other minor extensions intrude the sedimentary rocks, along with aplite dikes and sills, ranging up to 50 feet thick. These aplite bodies vary widely in composition. The orthoclase phenocrysts of the quartz monzonite and small bodies of diopside monzonite, localized along the contact, have been produced by endomorphism. Aplite and quartz monzonite have recrystallized to form pegmatite zones of variable thickness. Crystal-lined cavities in pegmatites, and in quartz monzonite and aplite, have resulted from solution of the host rock and redeposition of silica at a lower temperature.

Metamorphic effects of the quartz monzonite stock include a widespread isochemical thermal metamorphism, a widespread silica metasomatism, and an iron-silica metasomatism localized with tungsten and molybdenum ore. Thermally metamorphosed rocks, of the amphibolite facies, are interlayered nearly horizontally with silica-metasomatized zones. The silica-bearing solutions were introduced along bedding-plane joints. The silica-metasomatized rocks are characterized by the widespread development of idocrase with grossularite, diopside, wollastonite, albite, and epidote. This mineral assemblage is of the albite-epidote amphibolite facies and represents the reaction between components originally present in the rock, activated and enriched in silica by the circulating solutions.

The general sequence of magmatic activity was intrusion of the quartz monzonite, isochemical thermal metamorphism, silica metasomatism, aplite intrusion, and iron-silica metasomatism by the tungsten- and molybdenum-bearing fluids.

Tungsten and molybdenum ores, of some commercial importance, have been formed in tactite bodies localized at the intersection of favorable beds with the quartz monzonite contact, aplite dikes, and joints. Gold, of unknown origin, forms placer deposits in arkosic sands and gravels lying within the outcrop area of the quartz monzonite stock.

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[1] A thesis submitted to the faculty of the Graduate School of Cornell University for the Degree of Master of Science under the title of "Geology of the Notch Peak Intrusive, Millard County, Utah".

[2] Formerly a Graduate Student of Cornell University, Ithaca, New York. Now with the Research Department, The Carter Oil Company, Tulsa, Oklahoma.

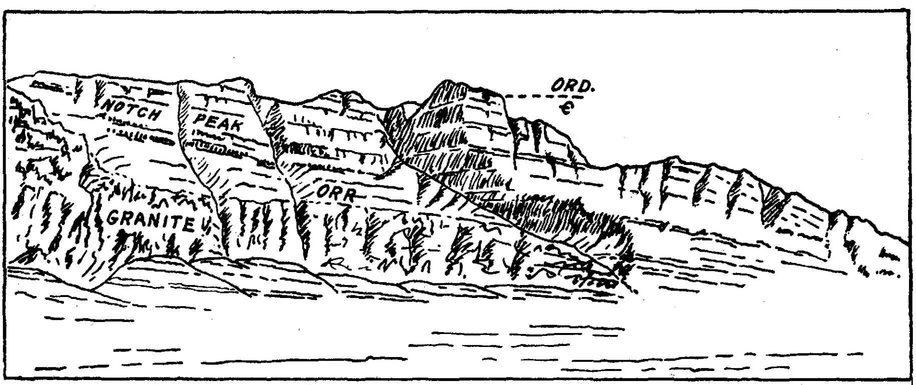
A C K N O W L E D G E M E N T S

The Notch Peak intrusive was suggested as a possible thesis problem by Dr. Harald Drewes of Yale University. The writer wishes to thank him for the suggestion and for his continuing aid during the field season.

The field work was in part supported by a Summer Research Grant from the faculty of Cornell University.

The author is indebted to Dr. Arthur J. McNair of the Surveying Department of Cornell University for his instruction and assistance in preparing the topographic base map.

The preparation of this thesis was under the direction of Dr. William T. Holser, and the writer wishes to express his special thanks to Dr. Holser for his encouragement and constructive criticism in all stages of the development of the thesis. Dr. Alfred L. Anderson contributed greatly to the organization and expression of the material, particularly that concerning economic geology.



Frontispiece B. West face of the southern House Range (after Williams and Steele, adapted from Walcott) showing relationship of granitic intrusive to Cambrian strata.

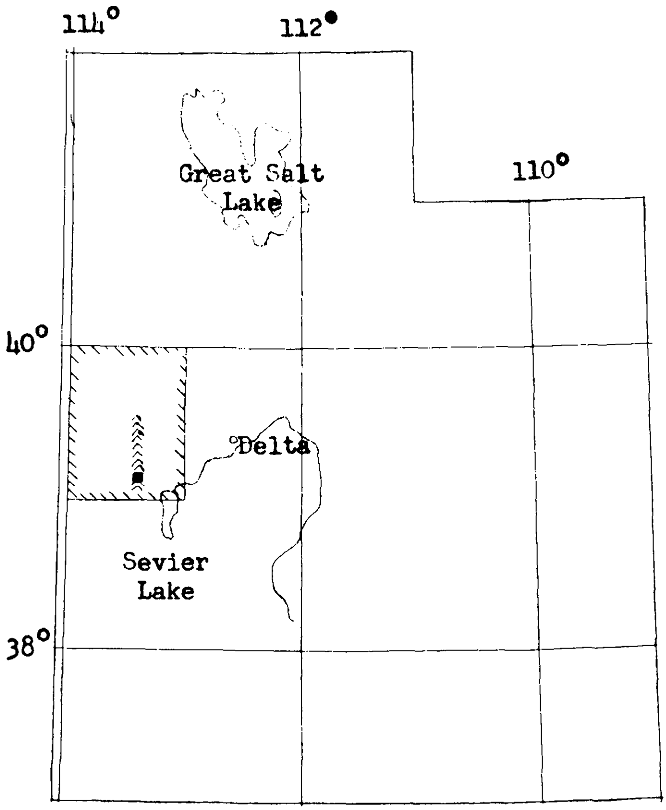


Figure 1. INDEX MAP OF UTAH

Boundary of the Fish Springs quadrangle

• Area of geologic map of Notch Peak intrusive

House Range

INTRODUCTION

SCOPE OF THE PRESENT STUDY

The purpose of this thesis is to describe and explain various geologic features associated with a quartz monzonite stock intrusive into the Cambrian limestones that form the bulk of the House Range, Utah. These features include the internal structure of the igneous body, the associated aplite dikes and sills, the structure of the sedimentary rocks adjacent to the intrusive, the metamorphic effects upon the country rock, and the tungsten, molybdenum, and gold mineralization.

LOCATION AND ACCESSIBILITY

The House Range is in Millard County, west-central Utah, in the southeastern corner of the Fish Springs, Utah, 1:250,000 quadrangle (see index map, fig. 1). The exposures of the quartz monzonite stock on the west side of the range can be reached most easily by following the abandoned U. S. Route 6 eastward from its junction with U. S. Route 6 on the east flank of the Confusion Range. The east side of the House Range can be reached by following the abandoned part of U. S. Route 6 after leaving Delta, Utah. Several ungraded dirt roads extend from junctions with the abandoned U. S. Route 6 east of Marjum Canyon to points near the range divide.

TOPOGRAPHY

The House Range is one of the north-south trending ranges of the Basin and Range Province (Fenneman, 1931). The range is 40 miles long and averages 7 miles wide with a northern extension of another 20 miles called the Fish Springs Range. The Fish Springs Range is offset to the west so that its eastern edge is a direct extension of the western edge of the House Range.

In the area of the accompanying geologic and topographic map, the west side of the range rises steeply from an altitude of 5000 feet at the base to altitudes between 8600 and 9728 feet along the divide. Massive limestone formations form large cliffs, rendering much of the west flank impassable. The quartz monzonite stock is also deeply incised on the west flank. The gently sloping east side is approximately parallel to the dip of the sedimentary rocks and affords poorer exposures.

PREVIOUS WORK

The geologic structure of the range was first studied by G. K. Gilbert (1876), who later (1928) published a more general treatment of the structure, along with that of the province as a whole. W. M. Davis (1905) contributed a physiographic study; C. D. Walcott (1908) measured the Cambrian section; and Charles Deiss (1938) and Grant Steele (Wheeler and Steele, 1951) remeasured the lower part of the section. The quartz monzonite stock was first studied by A. L. Crawford and A. M. Buranek (1941). The tungsten and molybdenum mineralization associated with the stock was discussed by P. F. Kerr (1946).

PRESENT WORK

The writer spent 8 weeks during July and August of 1953 in mapping the contact between the quartz monzonite and invaded rock and in studying the metamorphism and associated mineralization. The mapping was done on aerial photographs on a scale of 1:20,500. Elevation control was obtained by altimeter; and the scale and orientation were obtained by pace and Brunton compass. The accompanying topographic map (plate 1) was prepared from the aerial photographs and ground control data on a Fairchild stereocomparagraph.

Thin sections, fragment mounts, and insoluble residues were studied at Cornell University during the winter of 1953-1954.

MAP COORDINATES

Localities mentioned in the text are referred to an arbitrary grid system marked along the margins of the geologic maps in thousand-foot intervals (plate 1) or hundred-foot intervals (plate 3). At five thousand-foot intervals (plate 1) or one thousand-foot intervals (plate 3), grid lines are numbered and continued across the map.

The coordinate system is based upon the map scale as determined by pace and Brunton compass and uses as its base point the triangulation station on Notch Peak. This station was given the coordinates 0000N-20000E so that all points referred to in the text would fall within the northeast quadrant of the system.

S T R A T I G R A P H Y

FORMATIONS EXPOSED IN THE HOUSE RANGE

The House Range exposes over ten thousand feet of Cambrian and Ordovician sedimentary rocks. The following formational descriptions are adapted from wheeler and steele (1951).

Lower Cambrian

Prospect Mountain quartzite. -- 1000' exposed. Red-brown, pink, gray to dark green, generally cross-bedded, unfossiliferous quartzites and quartzitic sandstones, interbedded with tan, thin, micaceous and arenaceous shale partings.

Middle Cambrian

Pioche shale. -- 265'. Lithologically similar to the underlying formation, but with a greater number of interbedded arenaceous to calcareous, greenish shales.

Busby quartzite. -- 150'. Primarily a calcareous, coarse-grained, reddish, brown quartzitic sandstone with thin lenses of green-gray, calcareous to arenaceous shales.

Millard limestone. -- 275'. An almost black, fine-grained, thick- to thin-bedded, somewhat fossiliferous limestone with tan clay nodules and thin clay lenses.

Burrows limestone. -- 340'. Pale pink-gray to medium-gray, fine-grained, thick-bedded to massive limestone containing numerous calcite blebs.

Burnt Canyon limestone. -- 200'. Dark gray, fine-grained, thin- to thick-bedded limestone with some thin dull gray and tan fissile shales.

Dome limestone. -- 325'. Dark gray, fine- to medium-grained, thick- to massive-bedded, arenaceous limestone.

Swasey limestone. -- 395'. Dark to medium gray, fine- to medium-grained, thick-bedded argillaceous limestone with the basal

117' a tan to gray-green, thin-bedded limestone and tan, finely arenaceous, calcareous shale (Condor member).

Wheeler formation. -- 440'. Dull, sooty-gray, fine-grained, thin, fissile, shaly limestone and calcareous shales.

Marjum limestone. -- 1530'. Dark gray, argillaceous, fine-grained, thin-bedded limestone with sooty-gray to almost black, fissile and platy, calcareous irregularly bedded shale.

Upper Cambrian

"Weeks" and "Orr" formations. -- 3500'. Mostly medium gray, thick- to thin-bedded arenaceous limestones and shales.

Notch Peak limestone. -- 1490'. Dark gray, thick-bedded, fine- to medium-grained arenaceous limestone.

Ordovician

Chokecherry limestone. -- 285' exposed at the summit of Notch Peak.

For more detailed descriptions of the formations, and for faunal lists, see Deiss (1938) and Walcott (1905).

SEDIMENTARY ROCKS IN CONTACT WITH THE QUARTZ MONZONITE STOCK

The south contact of the quartz monzonite is with the "Orr" and "Weeks" formations and possibly with the lower part of the Notch Peak limestone. A specimen of *Olenoides superbus* found in the limestone along the north contact indicates that the quartz monzonite intruded rocks are at least as old as the Marjum limestone. The low foothills that border the range on the west side also yielded fossils of *Agnostus cf. A. interstrictus*, which is, according to Wheeler and Steele (1951), a zone fossil of the lower part of the Marjum limestone.

There was insufficient time to locate and map formational boundaries; but, from the faunal evidence that was obtained, it seems likely that the stock is in contact at the ground surface with the Marjum, "Orr" and "Weeks", and Notch Peak formations only.

G E O L O G I C   H I S T O R Y

Western Utah was part of the Cordilleran geosyncline and received large thicknesses of Paleozoic and Mesozoic sediments. At the close of the Paleozoic this area was uplifted and some of the Permian sediments were removed by erosion before the beginning of Triassic deposition. According to Christiansen (1951), the deformation and uplift that produced the internal structure of the ranges of this part of the province began during Late Jurassic time and lasted into the Early Cretaceous. The House and Fish Springs Ranges are unusual in that they lack the complex internal structure common to many of the ranges.

Normal faulting during the Tertiary period probably resulted in most of the present topographic relief and certainly outlined the present western boundary of the range.

It is not possible to date by structural relations the exact time of intrusion of the quartz monzonite stock. Lindgren (1915) states that the small stocks common to eastern Nevada and western Utah may range in age from Late Jurassic to Tertiary. Nolan (1943) considers the most probable age for these stocks to be early Tertiary.

Erosion following the block-faulting has exposed the quartz monzonite through a vertical distance of about 4000 feet. The uppermost part of the intrusive is exposed along the divide with one small part of the roof cover still remaining near the center of the mass. Deep canyons cutting the west flank of the range expose the lower parts.

S T R U C T U R A L   G E O L O G Y

STRUCTURE OF THE HOUSE RANGE

The House Range is carved in the gently dipping east limb of an anticline; the crest and west limb of which have been relatively downdropped along a high angle fault. The steep west face of the range is the eroded fault scarp, and presumably the crest and west limb lie beneath the bolson deposits of White Valley on the west side of the range.

STRUCTURAL RELATION TO THE FISH SPRINGS RANGE

The Fish Springs Range to the north has the same general structure, but with reversed relations. The border fault of that range lies along its east flank, and the range is composed of sedimentary rocks dipping gently to the west. A high angle transverse fault separates the two ranges at Sand Pass. The topographic expressions of the border fault of the House Range may be traced directly across the Sand Pass Fault where it becomes the border fault of the Fish Springs Range. The House Range, White Valley, Fish Springs Range, and Fish Springs Flat may be considered as four separate segments of a large gentle anticline that has been ruptured by two faults. The presence of the north-south fault along the crest of the anticline and the transverse fault striking at right angles to it allowed the blocks to act independently. Thus, the northwest and southeast blocks were relatively uplifted to form the two mountain ranges, while the other two blocks now form the bolson filled valleys.

Near the southern end of the House Range, just north of Skull Rock pass on U. S. Route 6, strata dipping steeply to the west may represent part of the otherwise covered southwestern block.

ORIGIN OF THE PRESENT RELIEF

Davis (1905) and Gilbert (1928) believe that the House Range is a fault block mountain in its first cycle of erosion. Davis considers the truncation of successive beds along the western base of the range as evidence of a border fault. He further mentions deformed rock masses outcropping in the bolson deposits adjoining the western base. These outcrops are not in proper stratigraphic position, and he considers this as further evidence of a structural break paralleling the base of the range.

A more complete discussion of various theories regarding the origin of the ranges of this province is given by Nolan (1941).

DOMING OF THE SEDIMENTARY ROCKS ADJACENT TO THE IGNEOUS STOCK

The monoclinal structure of the House Range is locally interrupted by the body of intrusive quartz monzonite which has produced doming. This can be observed on the geologic map of the intrusive (plate 1) where the strike and dip symbols show a general dip away from the intrusive body. Structure sections along lines A-A' and B-B' (plate 2) show the change in dip near the stock.

The change in direction or magnitude of dip is most apparent along the north contact where, in a zone at least half a mile wide adjacent to the contact, the normally eastward dip has been changed toward north or northwest. Along the south contact the southeastward dip has been increased from the usual 10° to 15-20° and is usually in a more southerly direction. The sedimentary rocks flanking the intrusive on the eastern side have retained their original southeastward to eastward dip with only a slight increase. The general dip of the sedimentary rocks west of the intrusive is toward the west, but in view of the complicated sill relations there, a more complete description will be given below.

FORM AND CONTACTS OF THE QUARTZ MONZONITE STOCK

The intrusive body outcrops in an oval area measuring five by two and a half miles. The long axis of this oval is perpendicular to the trend of the range.

The contact of quartz monzonite is generally discordant and dips outward at angles of 40-50°, except for parts of the original sedimentary rock roof which are nearly concordant. The western contact, where it is exposed at the base of the range, dips 60-70° west. A large sill extends from the southern contact and is exposed for about a mile along the western base of the range. The top of this sill is continuous with the top of the main body, but it is only in the outer mile that the floor of the sill can be observed (see section B-B', plate 2).

Portions of the roof cover that once overlay the intrusive are preserved in two places. On the western flank of the range, between the coordinates 7500N and 14500N, and 10000E and 17000E, a sedimentary rock cover with an area of about a square mile gives a sill-like appearance to the intrusive when viewed from the valley below. The sedimentary rocks are nearly conformable with the intrusive contact. The general dip of both is about 15° west. Although on the accompanying geologic map (plate 1) the contact appears regular, it actually consists of a series of steps as shown in sections A-A' and B-B' (plate 2). These steps consist of several concordant contacts connected by sharply cross-cutting sections each about fifty feet high.

Another smaller patch of sedimentary rock rests upon the quartz monzonite along the divide (19500N-20500E). It is separated from the sedimentary rocks along the north contact by about a third of a mile. The contact is nearly conformable and is offset by a vertical fault of small displacement.

OTHER STRUCTURES OF THE SEDIMENTARY ROCKS

Joints

Joints are abundant and well developed in the sedimentary rocks, particularly in the dense siliceous beds. Four or five sets are exposed in any one large outcrop. Time was not available for a detailed study of these joints, and no simple relation between these joints and the adjacent igneous contact was evident. Many of these joints localize metamorphism and ore mineralization; therefore they must be at least as old as the early stages of igneous intrusion and are not connected with the tectonic forces that produced the present fault block range.

Faults

Several small faults cut the sedimentary rocks adjacent to the quartz monzonite body. Their displacement is small, and in only

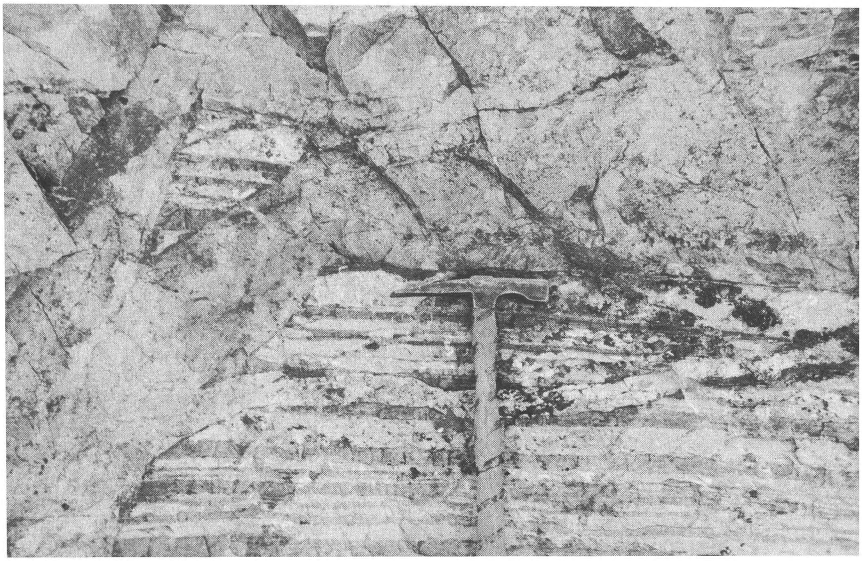


Figure 2. Blocks of metamorphosed limestone included within part of a large aplite sill. Note particularly the precise matching of the borders of the fragments.

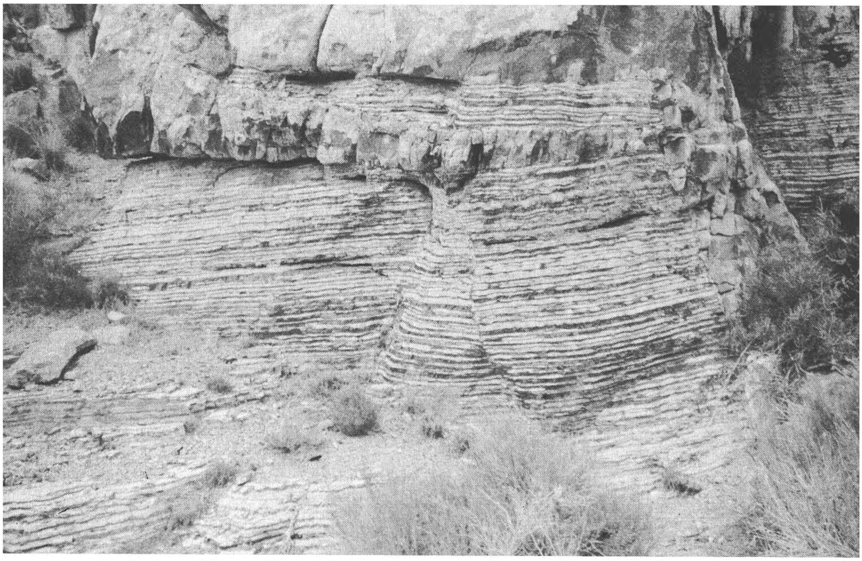


Figure 3. A large metamorphosed block tilted upward by the intrusion of an aplite sill beneath. The included block is about one foot thick.

one case is the contact offset. The fault zones are not mineralized and do not act as loci for metamorphism of the country rock. One of these, exposed in the North Fork of Painter Canyon (21500N-14500E), has a cemented breccia of fragments of metamorphic rock. These faults, which are definitely post-intrusion, may have originated during the faulting that produced the present relief of the range.

INTERNAL STRUCTURE OF THE STOCK

The elliptical quartz monzonite stock has generally cross-cutting contacts and in several localities the igneous rock shows a banding of biotite-rich layers parallel to the contact. A few bands were observed within a yard of the steeply dipping west contact, and similar bands were found beneath the sedimentary rock cover on the west flank of the range.

Aerial photographs of the granite outcrop area show a distinct linear arrangement of outcrops that suggests a strong orientation of joints. In the field, however, joints are not apparent, and the only other structure observed is the concentric sheeting caused by exfoliation.

QUARTZ MONZONITE SILLS

Several sills of quartz monzonite project from the main stock into the sedimentary rocks along the western base of the range. Two of these sills were mapped in detail and are shown in plate 3. A third sill outcrops discontinuously from 8000N to 15000N along the 7500E coordinate. These sills are generally concordant, but may be discordant for small distances. The thickness of the three major sills ranges from 150 to 200 feet where the thickness can be determined, and they extend out from the stock for a distance of about 2000 feet. The third sill mentioned above is sharply terminated causing the discontinuous outcrop. No evidence of faulting is present to account for the abrupt termination, but since the underlying beds are not exposed, it is possible that this is the upper part of a step-like contact as seen under the sedimentary rock cover on the west flank of the range.

APLITE DIKES AND SILLS

Aplite dikes and sills are also associated with the quartz monzonite. They occur as small tabular bodies up to four or five feet thick cutting both granite and sedimentary rock, and as larger sills up to 50 feet thick associated with the quartz monzonite sills. Within the stock the aplite dikes tend to be irregular and branching, although their contacts are very sharp. In the border zones of the stock and within the surrounding sedimentary rocks a dike or sill generally maintains the same strike and dip throughout its extent. Again, the contacts are very sharp.

Plates 3 and 4 show a typical occurrence of the larger aplite sills. Aplite overlies quartz monzonite throughout most of the sill. Beyond the abrupt termination of the upper quartz monzonite sill the aplite becomes thicker and forms the entire sill. The contact between aplite and quartz monzonite at the termination of the large quartz monzonite sill is interfingering. The aplite border sills are not always present between the quartz monzonite and limestone, although when present they have the appearance of being a chilled border facies of the quartz monzonite. On the other hand, dikes that may be feeders cut across the quartz monzonite and connect with the aplite portions of the sill.

The large aplite sills contain many inclusions of the country rock. Figure 2 shows a portion of one of these included blocks that has been broken into several fragments which may be fitted precisely onto the main block. The large included blocks, which may measure three or four feet thick and twenty or more feet long, are usually tilted ten or more degrees from their original dip. Figure 3 shows one of these tilted blocks completely enclosed within the aplite.

No attempt was made to record the positions of all of the small dikes and sills which are so numerous in the contact area. Thirteen of the more prominent of these dikes were noted in a distance of fifty yards in the North Fork of Painter Canyon just above its junction with the South Fork. They showed various attitudes, thicknesses, and length of outcrop. A generalization can be made concerning these dikes here and in other portions of the contact zone; the most frequent strike of the dikes is perpendicular to the contact and the dips are nearly vertical.

IGNEOUS ROCKS

Most of the Notch Peak intrusive is composed of porphyritic quartz monzonite. Two compositional variations also occur within the main body and its extensions. A diopside-rich monzonite forms isolated masses along the contact, and hornblende granite occupies the central parts of a few of the sills extending from the quartz monzonite stock. In addition, aplite dikes and sills, showing a wide variation in grain size and composition, cut both the quartz monzonite and the surrounding sedimentary rocks. Pegmatites are associated with aplite and quartz monzonite.

PORPHYRITIC QUARTZ MONZONITE

The quartz monzonite of the Notch Peak intrusive is a coarsely crystalline porphyritic rock with phenocrysts about 2 cm long and the grains of the groundmass about 3 mm in diameter. The phenocrysts are perthitic orthoclase, and their moderate reddish-orange gives a distinct reddish tone to the rock. The groundmass consists of white plagioclase, orthoclase, gray quartz, and biotite.

Minerals

Orthoclase. -- Orthoclase occurs both as phenocrysts and as grains in the groundmass. Those forming phenocrysts have outlines that appear euhedral in the hand specimen, but which are irregular and penegrating on a microscopic scale, while those in the groundmass are anhedral. The orthoclase is perthitic with parallel stringers of albite. Rounded inclusions of quartz, biotite, and oligoclase are common in the border areas of the phenocrysts. The central areas are free from inclusions except for narrow bands of discontinuous grains that parallel the crystal outline. Some of these grains are in optical continuity.

Quartz. -- The quartz grains are highly variable in size and are interstitial to the feldspars. Basal sections of quartz show a faint pattern of light and dark bands resembling microcline twinning.

Oligoclase. -- Plagioclase of oligoclase composition forms nearly half of the total feldspar. The grains are aggregates of individual subhedral crystals complexly intergrown, with each individual having its own twinning and zoning. The zones are shown by slight changes in extinction position, but there is no noticeable change in refractive index. Albite twinning is most common and is accompanied in some grains by Carlsbad or pericline twinning. The composition of the plagioclase was determined by the Tsuboi refractive index method (Emmons, 1953, pp. 30-31). Indices of 001 cleavage fragments gave a composition of 25± one per cent anorthite.

The oligoclase was apparently the earliest mineral to form since it is present as corroded grains within orthoclase and quartz and is penetrated and replaced by biotite.

Albite. -- In addition to the perthitic intergrowths, albite also occurs as subhedral grains bordering, and to a slight degree penetrating, the orthoclase. These grains are small and show polysynthetic twinning.

Biotite. -- The biotite is strongly pleochroic from dark brown to almost colorless. The general occurrence is as anhedral grains interstitial to and penetrating plagioclase and included in quartz and orthoclase.

Minor alteration products and accessory minerals. -- The accessory minerals are sphene, apatite, and magnetite. They are usually clustered together, although apatite seems to have a more widespread distribution. The sphene crystals are both euhedral and anhedral in grains averaging 0.2 mm in length. The apatite usually occurs as small rods about 0.1 mm long, although where concentrated with sphene and magnetite, the grains are several times larger.

A green, weakly birefringent chlorite, probably penninite, replaces some of the biotite. The most common alteration product of the orthoclase is minute opaque particles in the areas bordering the albite zones of the perthite. The clouding here may be the result of exsolution of iron dissolved in orthoclase. Poldervaart and Gilkey (1954) suggest a similar explanation for clouding in plagioclase feldspar. In the specimens, the association of the clouding with albite zones suggests that both are the result of exsolution of material during cooling. Sericite is developed at the expense of oligoclase, and an occasional large grain of muscovite may be present with the sericite.

Mode

The composition of the porphyritic quartz monzonite was determined by sawing several slabs a quarter of an inch thick and smoothing the flat sides on a lap. Transparent acetate sheets with a ruled network of lines spaced a tenth of an inch apart were placed on the smoothed surfaces. Each point marked by the intersection of the lines was recorded as lying either on a phenocrysts or groundmass. By shifting the positions of the nets several times and recounting, it was possible to obtain totals of over a thousand points for each specimen and, from the relative number of points for each, to determine the percentage of phenocrysts in the rock. The phenocryst content ranged from 24 to 34 per cent among the three specimens analysed, and for purposes of further calculation, 30 per cent was assumed as the average phenocryst content of the rock.

The mineral content of the groundmass was determined in thin section by point counter (Chayes, 1949), and results corrected to allow for the presence of the phenocrysts in determining the total mineral composition of the rock.

orthoclase (including albite)	38 per cent
oligoclase	32
quartz	21
biotite	5
others	4

Origin of the Textural Relations Among the Feldspars

The orthoclase phenocrysts assumed their euhedral outlines by growth in the solid rock during the last stages of magmatic activity when the temperature was still high enough for a single potash-soda feldspar to be stable. The temperature at which the orthoclase grew, and replaced all but corroded remnants of plagioclase, biotite, and quartz, must have been above 650° C. (Tuttle, 1952, p. 112).

Exsolution of soda from the single feldspar occurred, as the temperature fell below this point, to form the albite stringers that are uniformly distributed throughout the orthoclase.

Separate albite grains that surround and embay the phenocrysts may be the result of the later introduction of soda, or they may be a further stage in exsolution when a complete separation of albite and orthoclase occurs (Tuttle, 1952, p. 115). The localization of the albite grains around the orthoclase masses indicates that the orthoclase was the source of the soda.

DIOPSIDE MONZONITE

General Features

Small bodies of diopside monzonite were noted between the quartz monzonite and country rock at the following localities: 7800N-9800E, 7100N-12200E, 18300N-8500E. Each diopside monzonite body was between three and ten feet thick and outcropped along the contact for a distance between thirty and fifty feet.

The transition from diopside monzonite to quartz monzonite takes place over a zone a foot thick, with a gradual decrease in diopside and reappearance of biotite and quartz. It is not possible to observe closely the contact between the diopside monzonite and sedimentary rock.

Composition

The rock is composed chiefly of white plagioclase and dark greenish-gray diopside, with minor amounts of hornblende, tourmaline, and apatite. Orthoclase, quartz, and biotite are absent. The plagioclase is an oligoclase, as in the normal quartz monzonite. The composition of the pyroxene as $Di_{95}He_{05}$ was determined by measuring N_y of grains lying on a suitable parting (Hess, 1949). The pyroxene was assumed saturated with calcium. The slight pleochroism from a faint yellowish-green to colorless also indicates a slight iron content. The diopside occurs as anhedral grains of highly variable size interstitial to the plagioclase. Concentrations of sphene and magnetite occur with diopside as they do with biotite in the quartz monzonite, and for this reason it is possible that some of the diopside is a replacement of biotite.

The composition of these rocks is highly variable, but on the average, the rock consists of 60 per cent oligoclase, 30 per cent diopside and 10 per cent accessories.

Origin

The presence of diopside monzonite in border areas only implies that the adjoining sedimentary rocks contributed to changing the original composition of the monzonite. Endomorphism has been suggested to explain the growth of orthoclase phenocrysts subsequent to consolidation of the magma, and a similar process may have resulted here in the formation of additional oligoclase and diopside at the expense of the original orthoclase, quartz, and biotite. The passage of heated fluids, mostly water, may have been concentrated along the contact at isolated spots, enabling the calcium from the adjoining limestone to diffuse into the quartz monzonite to form the calcium-rich diopside monzonite.

HORNBLENDE GRANITE

General Features

Bodies of hornblende- and orthoclase-rich rock occupy the central parts of several 5 to 15 foot-thick sills that appear to be direct extensions of the main quartz monzonite stock. Two of the sills are shown on the large scale geologic map (plate 3) of the area south of Painter Canyon at 18300N-9000E and 17300N-9600E. The central third of the thickness of the sill is hornblende granite, and the transition outward into quartz monzonite takes place over a few inches. The rock appears darker in outcrop than the quartz monzonite and consists of grayish-orange-pink orthoclase, gray quartz, and white plagioclase forming a background for the black hornblende needles. The texture is generally equigranular, although bands containing quartz or orthoclase phenocrysts may be present. The average grain size of the rock is about 1 mm.

Minerals

Hornblende. -- The euhedral needle-like crystals of hornblende average 2 mm in length. The hornblende is strongly pleochroic in the following colors:

X - pale yellowish-brown
Y - dusky yellow-green
Z - grayish-green

The amount of hornblende ranges from 13 to over 50 per cent.

Orthoclase. -- Orthoclase occurs as anhedral interstitial masses and as euhedral grains, both containing albite in perthitic intergrowth.

Quartz. -- Individual grains of quartz may be large enough to be considered as anhedral phenocrysts, or they may be smaller interstitial masses. The quartz commonly shows a lobate pattern penetrating feldspars.

Oligoclase. -- A refractive index determination, following the Tsuboi method, indicates that the plagioclase is oligoclase as in the quartz monzonite. The oligoclase grains here are of the same size and complexity of twinning and zoning as in the quartz monzonite.

Accessories and alteration products. -- Sphene, apatite, and magnetite occur as in the quartz monzonite. Tourmaline prisms up to 1 mm long are present here only. Penninite replaces some of the hornblende. Fractures within grains are commonly filled with calcite, probably resulting from ground water action.

Mode

A modal analysis by point counter using 1682 counts gives for one specimen:

orthoclase (including albite)	61 per cent
quartz	14
hornblende	13
oligoclase	10
others	2

Origin

As mentioned above, the hornblende granite occupies the centers of several small biotite-bearing quartz monzonite sills. The observed sills ranged from four to eighteen feet thick. Because of their small size, it is difficult to apply any of the principles of differentiation in place to account for the orthoclase- and hornblende-rich centers. Other quartz monzonite sills intruding the same rock may range up to 200 feet thick and show no similar central zone.

A late magmatic enrichment by potash-bearing solutions, forming orthoclase at the expense of some of the original plagioclase, should have left traces of the replacement; however, the textural relations of the minerals are typically igneous, and with the exception of the lobate quartz outlines, the minerals do not show replacement textures.

The exposed relations of the hornblende granite to the other igneous rocks were not sufficient to provide evidence for suggesting a mode of origin.

APLITE DIKES AND SILLS

Tabular bodies of fine-grained igneous rock cutting the quartz monzonite and the sedimentary rocks were mapped in the field as aplites. Their xenomorphic granular texture in thin section confirms this broad grouping, although compositional variation among the specimens is great. The aplite dikes that cut the quartz monzonite are the most uniform in appearance and composition.

Aplite Dikes Within the Quartz Monzonite Stock

The dikes within the stock are generally a foot or two thick and do not maintain a constant strike throughout their length. They may pinch out abruptly and may have numerous branches. Their contacts with the quartz monzonite are very sharp and because of their greater resistance to erosion they stand out sharply in relief as shown in figure 4.

The dikes within the quartz monzonite have a uniform grayish-orange-pink color. Examination of three thin sections made from specimens collected from separate dikes shows them to have the same grain size, texture, and composition. The grain size within a single slide is quite variable and averages about 0.3 mm. The individual grains are anhedral in outline. A typical composition is:

orthoclase	57 per cent
quartz	40
oligoclase	3

Magnetite and sericite are present in amounts less than one per cent and were counted with the minerals containing them. The sericite occurs in irregular patches as an alteration product of the orthoclase feldspar, while the magnetite is scattered throughout the rock.

Aplites Cutting the Sedimentary Rocks

Fine-grained dikes and sills that occur within the sedimentary rocks surrounding the intrusive range from a few inches to fifty feet thick. Their structural occurrences have been discussed under Structural Geology.

These tabular bodies vary widely in color and composition although all are xenomorphic granular in texture. The average grain size of the specimens ranges from 0.1 mm in the finest-grained aplite to 1 mm in the coarsest-grained. The relative amounts of plagioclase, quartz, and orthoclase varies widely among the several specimens examined microscopically.

An illustration of the change in color and texture within an individual sill is given by a suite of five specimens collected on the second low hill south of the mouth of Painter Canyon (16000N-7000E). These specimens were collected at intervals through a distance of one hundred yards beginning very near the southernmost outcrop of the sill and proceeding northeastward toward the quartz monzonite sill from which it extends. The specimens collected nearest the intrusive showed the grayish-orange-pink color that is typical of the large aplite sills. Fifty yards farther out the color had changed to a yellowish-gray. At the end of the sill the color was a very light gray. There was no noticeable change in either composition or degree of alteration to account for the change in color. The most noticeable change was in the textural relation of quartz to the other minerals. The specimen collected nearest the outermost outcrop, where the sill is one foot thick, had a typical aplitic texture with all of the mineral grains rounded and interlocking. Fifty yards closer to the stock, where the sill is six feet thick, the relative abundance of each mineral was the same; but the quartz has intricately penetrated the feldspars in a lobate pattern. Two specimens were collected at this point, one from the center of the sill, and the other from within an inch or two of the lower contact. Although the general grain size of the two specimens was the same, the lobate pattern was not so well developed in the lower specimen. At the third locality, nearest the stock, the specimen from the center of the sill showed an even more pronounced lobate quartz pattern, while the specimen from the lower contact showed it to a lesser degree.

Modal analyses of several specimens showed that the composition does not vary more than a few per cent from average:

oligoclase	45 per cent
quartz	35
orthoclase	20

Since there is no compositional difference between the outermost specimen in which the quartz shows a normal igneous occurrence and the inner specimens where a definite lobate penetration of the feldspars by quartz has developed, the lobate pattern must have resulted from the reworking of silica already present. It is possible that where the sill was thicker and close to the main intrusive body, late-crystallizing siliceous solutions remained fluid long enough to replace the feldspar in part, rather than being rapidly chilled as they would be near the end of the sill.

Although the mineral composition of a particular body may be constant, there is wide variation between bodies. One specimen, collected along the north contact at 22000N-17500E, consists almost wholly of orthoclase feldspar. Instead of the usual 40 per cent quartz, this specimen contains only 5 per cent.

Another small dike, which is fine grained and white in color, cuts the limestone just north of Painter Canyon (20100N-9800E). This dike consists almost entirely of oligoclase with only a little quartz. Microscopic examination failed to reveal potash feldspar even after etching with hydrofluoric acid and application of sodium cobaltinitrite to reveal the potassium.

The wide variation in composition was not apparent in the field although it was noted that the very small aplite dikes and sills cutting the sedimentary rocks were usually white and, as in the case of the specimen described above, were probably dominately oligoclase. The calcium enrichment here is an endomorphic process, during which calcium diffused from the adjoining limestone into the aplite, causing the development of additional oligoclase at the expense of the original orthoclase and quartz.

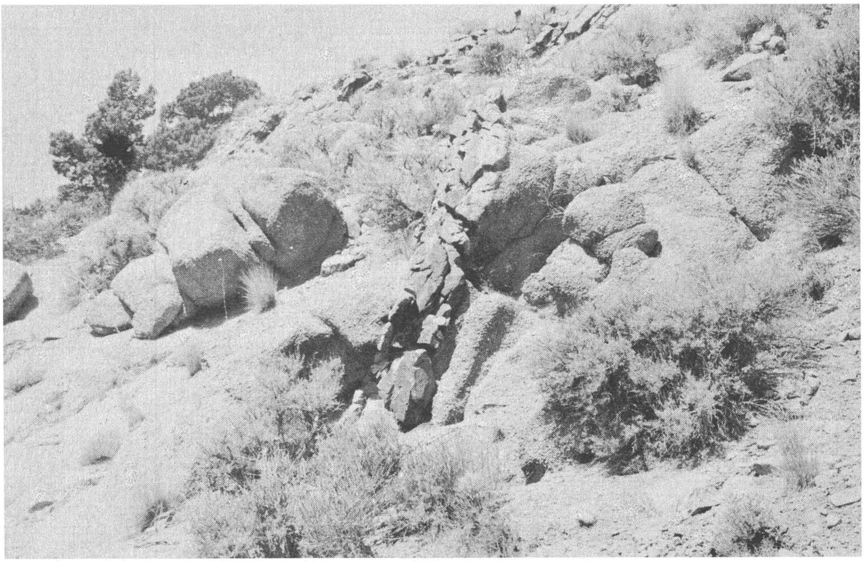


Figure 4. Aplite dike cutting quartz monzonite. Note the greater resistance of the aplite to weathering. The dike is one foot thick.

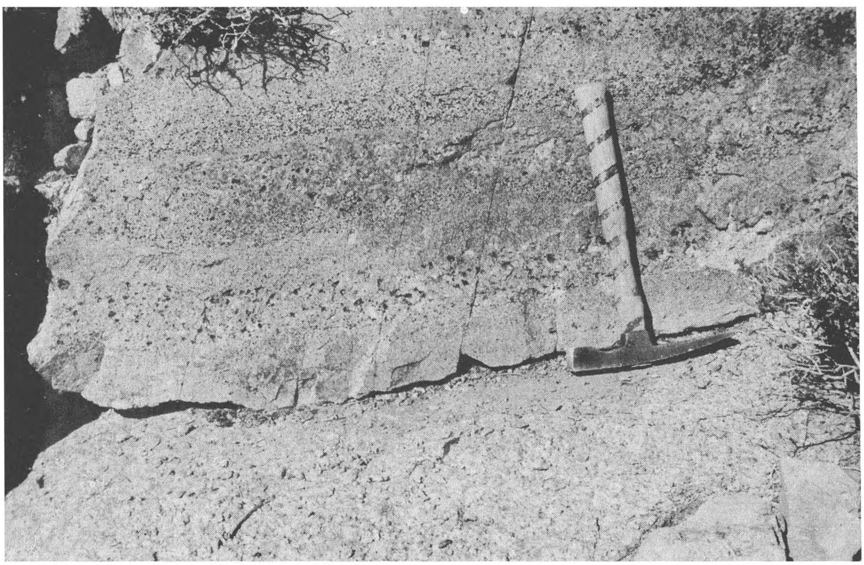


Figure 5. Aplite porphyry dike cutting quartz monzonite, with bands of phenocrysts paralleling the contact. The pitted surface results from differential weathering of feldspar phenocrysts.

APLITE PORPHYRY DIKES

Fine-grained dikes with a pitted weathered-surface cut the marginal areas of the quartz monzonite. The pitted surface results from the preferential weathering of orthoclase and oligoclase phenocrysts. In color, in resistance to weathering, and in microscopic texture, the groundmass is identical to the normal aplites that cut the quartz monzonite.

The type of phenocryst varies widely in separate bodies. The most common variety contains phenocrysts of quartz, orthoclase, and oligoclase averaging 5 mm in diameter. Some contain only oligoclase and quartz, while a third dike contains only euhedral biotite phenocrysts 1 mm in diameter.

The phenocrysts are commonly in bands parallel to the contacts as shown in figure 5.

These dikes apparently result from the rapid crystallization of aplite injections bearing intratelluric phenocrysts. The rapid crystallization may be due to the sudden loss of volatile matter since it is unlikely that the country rock had cooled sufficiently, at the time of aplite injection, to chill the magma.

PEGMATITES

Zones of coarsely crystalline microcline perthite and quartz occur within the quartz monzonite stock, within aplite sills, and as extensions of aplite sills in the limestone bordering the stock. Biotite, tourmaline, and pyrite are the only other minerals occurring in the pegmatites.

Pegmatites Within the Quartz Monzonite

The pegmatite bodies within the quartz monzonite stock are irregular in thickness and have many branches. The pegmatites are usually less than a foot thick and rarely as much as two feet. A rough zoning is present in many cases, with the borders predominately microcline perthite and the centers predominately milky quartz. Quartz may be the sole constituent of this central zone, or there may be intermixed microcline perthite, biotite, or pyrite. Cavities within the central zone may contain euhedral crystals of quartz, microcline, or tourmaline.

Pegmatites Within Aplite Dikes and Sills

Pegmatite masses within the aplites are common and are very irregular in thickness and trend. Figure 6 shows a typical pegmatite within a large aplite sill. The large masses of microcline perthite and quartz are several inches in diameter and show no zoning within the pegmatite. Figure 7 is a field sketch of the relations of a pegmatite within a small aplite sill to the contact between the sill and the surrounding marble. The pegmatite here is irregular in thickness, but is generally parallel to the aplite and marble contact.

Pegmatites as Extensions of Aplite Sills

In several places, as in the North Fork of Painter Canyon (23500N-15500E), an aplite sill becomes entirely pegmatitic when traced laterally away from the quartz monzonite stock. Near the stock the sill contains a typical thin pegmatite layer, but near its extremity the entire fifteen-inch thickness is composed of coarse white feldspar and milky quartz. The amazon stone- and tourmaline-bearing pegmatite described by Crawford and Buranek (1941) also seems to be an extension of an aplite sill. No pegmatites were found in the sedimentary rock that could not be traced into an aplite sill.

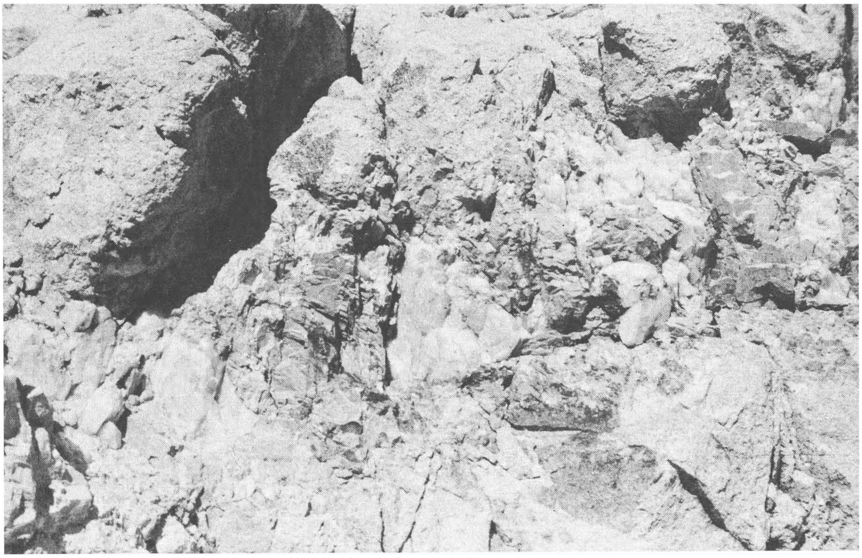


Figure 6. Pegmatite vein in aplite showing intergrowth of milky quartz and microcline perthite. Quartz mass in the center is three inches in diameter.

Origin

A microscopic study of the contact relations between the pegmatite and aplite in figure 7 (14300N-7500E) gives some information about the origin of the pegmatites. The aplite has a typically fine-grained xenomorphic granular texture with an average grain size of 0.2 mm. Between the normal aplite and the pegmatite there is a zone several millimeters wide consisting of anhedral grains 1 mm in diameter. The transition from normal aplite to the coarse zone is abrupt and is also accompanied by a change from orthoclase to perthitic microcline as the potash feldspar. Large lobate masses of quartz are present in the intermediate zone penetrating and replacing feldspar. The change from the intermediate zone to the pegmatite is again abrupt, but isolated inclusions and interstitial masses of the intermediate phase are present among the centimeter-long microcline perthite crystals of the pegmatite. Plagioclase, with a composition of 15 per cent anorthite, occurs as stringers and lenses within the microcline and as small grains bordering the microcline.

The presence of the intermediate zone and the evidence of replacement of the intermediate zone by pegmatite indicates that the pegmatite may have resulted entirely by the recrystallization of the original aplite.

Uspensky (1943) suggests such an origin for a simple granitic pegmatite in aplite. He describes a quartz and feldspar pegmatite that has a bilateral symmetry around a centerline of discontinuous druse-lined cavities. The cavities lie in a zone of quartz and feldspar that is intergrown in a "quasi-graphic" texture which grades outward into a graphic texture. The outer zone of graphic intergrowth embays the aplite host with sharp contacts.

He postulates that the first step was the intrusion of an aplitic magma which crystallized inward leaving a residue enriched in volatile material. The residual solution was probably a simple alkaline

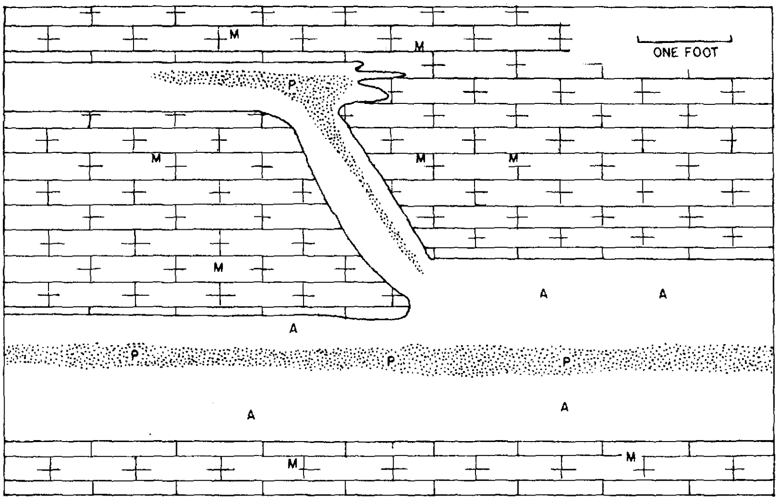


Figure 7. Field sketch of pegmatite and aplite relations.

A Aplite
P Pegmatite
M Banded Idocrase Marble

aqueous fluid containing small amounts of fluorine. As crystallization of the aplite neared completion, the gas pressure became high enough to promote circulation of the fluid residue. Most of this fluid moved along the open passageway marked by the druse-lined cavities, but some of it penetrated the aplite, causing a progressive recrystallization of the aplite into a coarse intergrowth of quartz and feldspar.

The pegmatites of the House Range also have a simple mineral composition and an association with druse-lined cavities. They are also present only in igneous rocks or as direct extensions of aplite sills. The irregularity of their thickness and complete lack of matching walls makes it impossible to imagine that they were formed from a residual magma filling an open fracture. The presence of remnants of aplite within the pegmatite makes a hypothesis of simple recrystallization most satisfactory. The oligoclase in the original aplite is accounted for by the plagioclase in the perthitic microcline. The microcline of the pegmatite, examined microscopically and described above, contains 33 per cent plagioclase with a composition of 15 per cent anorthite.

The recrystallization of aplite or quartz monzonite under the influence of circulating hot water produced quartz and microcline feldspar. The oligoclase present in the original rock was dissolved by the hot solutions and redistributed as a replacement of microcline to form perthite and as small intergranular crystals.

CRYSTAL-LINED CAVITIES

Distribution and General Features

The igneous rocks of the House Range contain crystal-lined cavities in three distinct modes of occurrence. These differ in the type of host rock and in their relation to accompanying pegmatitic zones. The quartz monzonite of the stock contains irregular cavities associated with small amounts of pegmatitic material; the aplite dikes and sills in places contain small rounded cavities with only a small border of pegmatite; and the large pegmatite veins contain cavities.

Quartz-bearing cavities up to eight inches in diameter were observed within the main stock containing quartz crystals two or three inches long. A quartz crystal measuring six inches along the c-axis was found in float, indicating that cavities of larger size exist. These cavities are all surrounded by a pegmatite layer of coarse microcline, usually an inch thick. The pegmatite continues on both sides of the cavity with a thickness of an inch or two; and, if two or more cavities are present, they are connected by the pegmatite.

In an aplite dike, easily accessible from the road leading into the mouth of Painter Canyon (18125N-8400E), cavities up to an inch in diameter may be observed. These cavities are lined with tiny quartz crystals and are surrounded by a coarser microcline layer 2 mm thick.

The crystal-lined cavities within large pegmatites have been noted above.

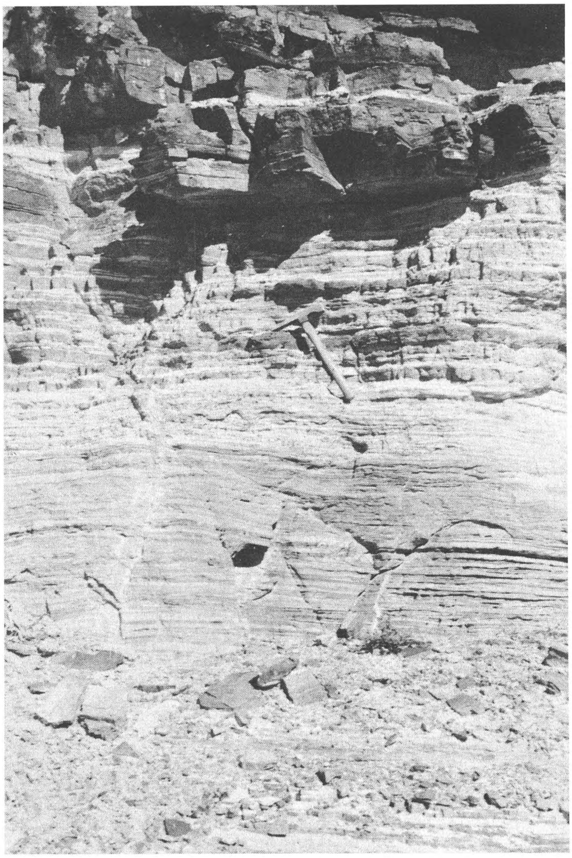


Figure 8. Typical outcrop of metamorphic rock showing layering of biotite-anorthite hornfels, banded idocrase marble, and gray limestone.

Origin

Crystal-lined cavities have been reported from many granitic bodies (Landes, 1925; Gillson, 1927; Gallagher, 1937; Pecora and Fisher, 1946). They have a wide range of size and have originated under a variety of conditions.

The small cavities described by Pecora and Fisher from a monzonite dike have no observable interconnection and are considered to be the result of entrapment of gas bubbles within a nearly crystallized magma. Cavities large enough for a man to enter, as described by Gallagher, also have no observed connection and are the result of entrapped bubbles.

Gillson and Landes both cite cases in which the cavities are associated with pegmatites or pegmatitic zones within a granite. In the granite at North Conway, New Hampshire, Gillson notes the occurrence of a set of large cavities showing a crustification of minerals lining the openings and a set of smaller, irregular vugs. These cavities lie in a vertical pegmatite vein cutting granite. Deposition from entrapped volatiles yielded the layers of minerals within the large cavities, while later hydrothermal solutions both dissolved some of the old minerals in the large cavities and formed the small vugs. Landes, in describing the paragenesis of some pegmatites in Maine, describes open cavities produced by corrosion of pegmatitic microcline followed by deposition of hydrothermal minerals.

The predominately quartz-lined cavities in the igneous rocks of the House Range are the result of solution at irregular intervals by fluids moving along small open fissures. The interconnection of the cavities rules out the entrapment of bubbles because this passageway would have formed an easy escape for the volatiles. The accompanying coarse microcline layers surrounding the cavities were formed by the impregnation of the surrounding rock by the fluid, causing a recrystallization of the minerals of the wall rock. Solution by the hot aqueous fluid ceased when it became saturated with silica and potash. Cooling allowed the deposition of the dissolved silica in the cavities as quartz crystals, and when other components were present locally, as tourmaline and biotite.

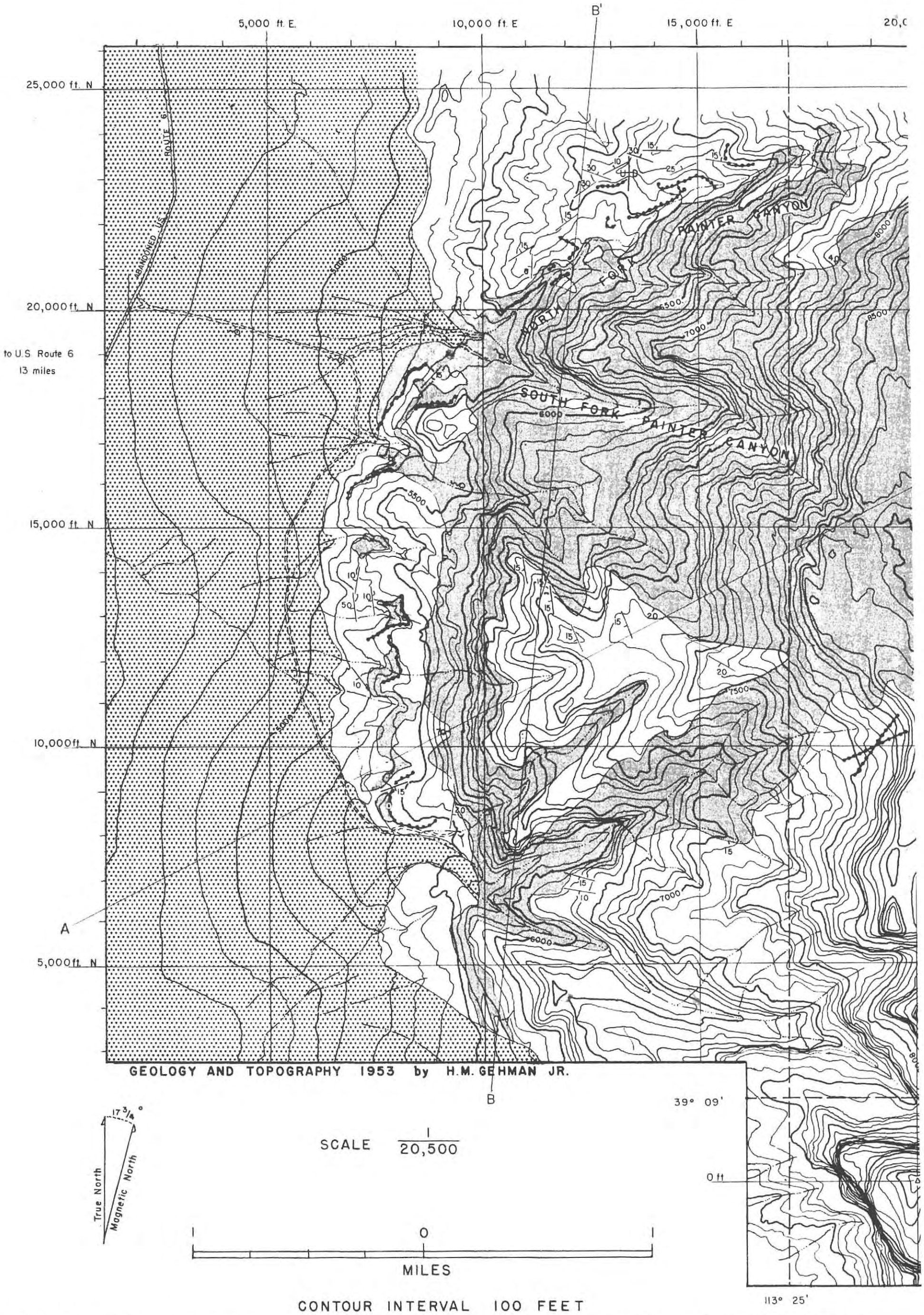
METAMORPHIC ROCKS

General Features

Metamorphic minerals have developed in all of the sedimentary rocks examined as far as a mile from the quartz monzonite stock. The rocks include marbles that contain large crystals of metamorphic minerals, as well as apparently unaltered gray limestones that show these minerals only under the microscope.

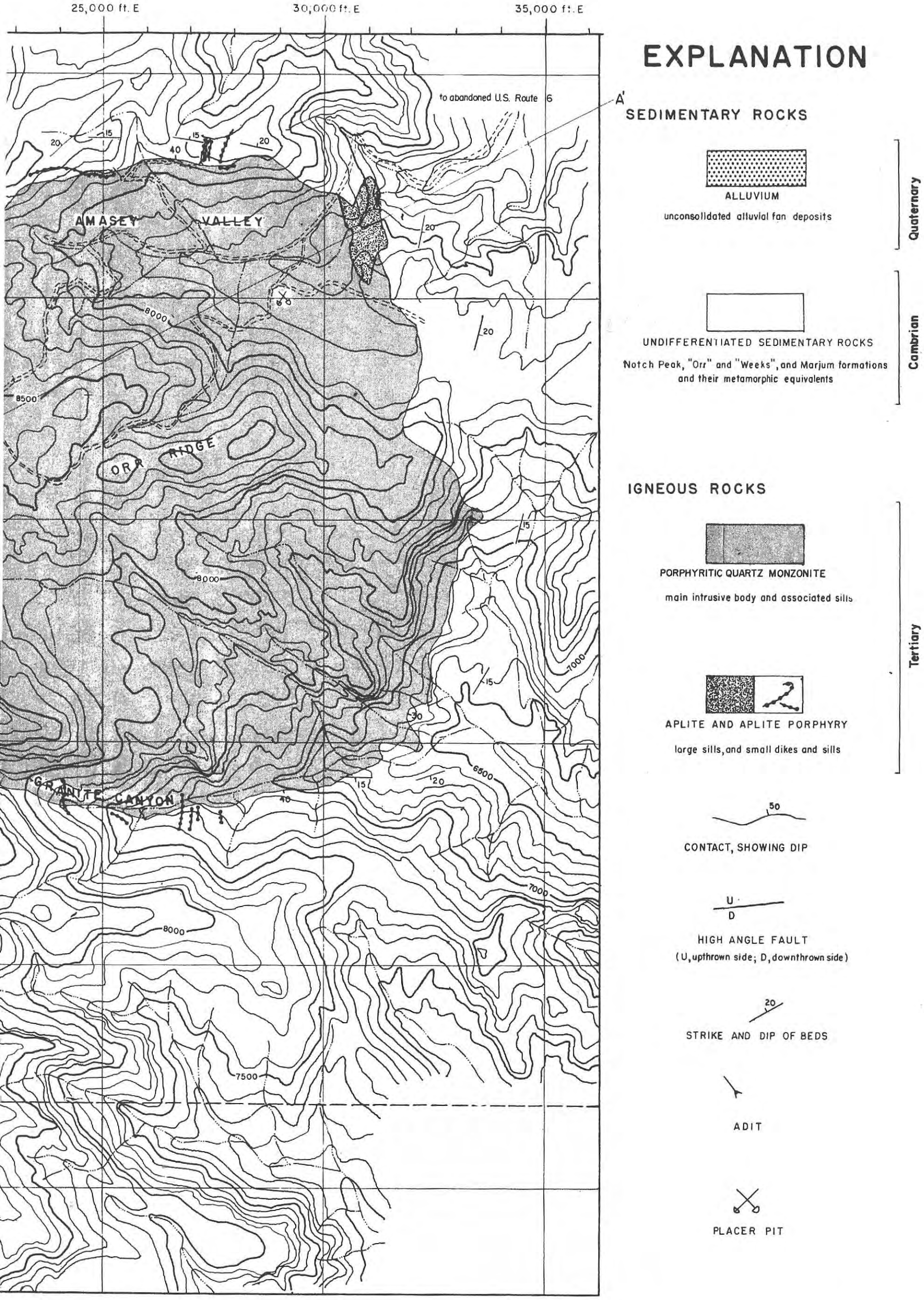
A notable feature of the metamorphic assemblage is an interlayering of rocks of widely differing aspect. The bedding of the sedimentary rocks around the intrusive dips gently, and the layers of differing metamorphic development generally parallel the bedding. Some contacts between two of these litholigies are exactly conformable with the bedding; others are irregular and crosscutting.

A typical outcrop is shown in figure 8. This locality (17700N-9800E) lies within fifty feet of the main quartz monzonite contact. As the beds are traced to within a few feet of the concealed contact, no change is apparent. The uppermost beds are a dense, brown-weathering biotite anorthite hornfels. Idocrase and grossularite crystals have developed on the interface with calcite interbeds. Below the overhanging



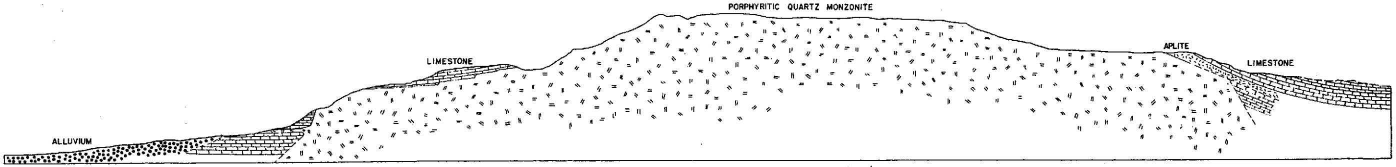
GEOLOGIC MAP OF THE NOTCH PEAK INTRUSIVE
HOUSE RANGE, MILLARD CO., UTAH

PLATE I

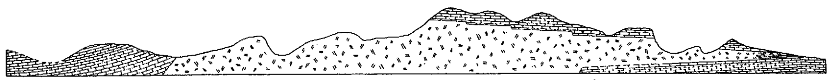


GEOLOGIC MAP OF THE NOTCH PEAK INTRUSIVE
HOUSE RANGE, MILLARD CO., UTAH

PLATE 2

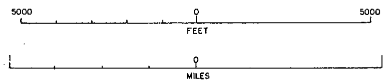


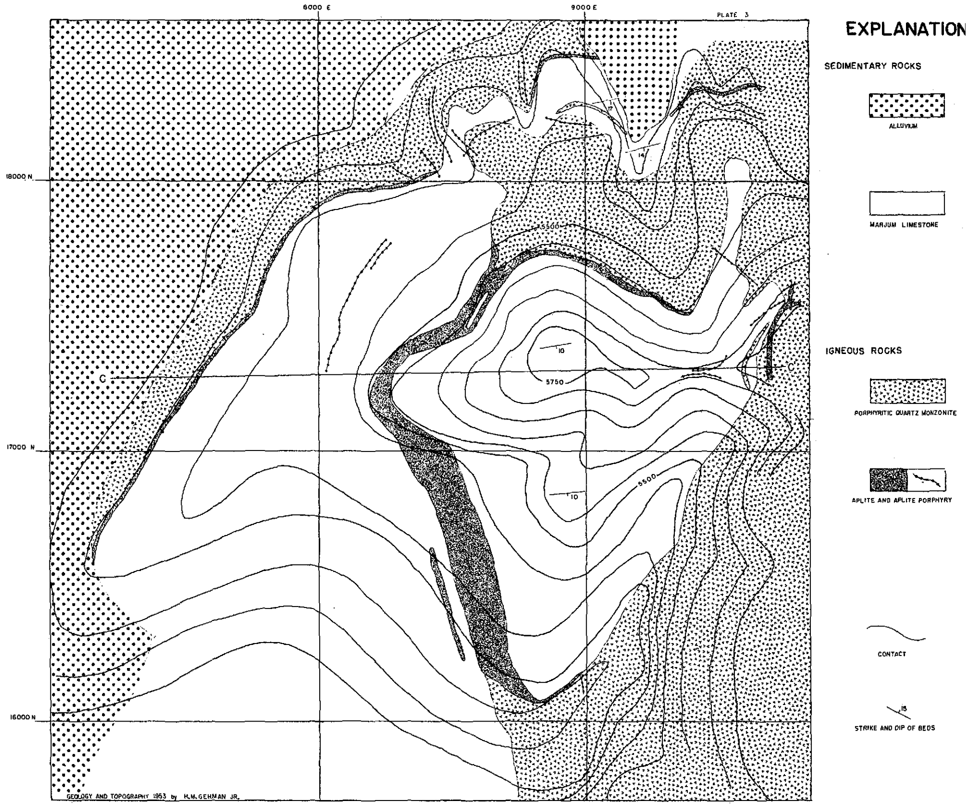
SECTION ALONG LINE A—A'



SECTION ALONG LINE B—B'

HORIZONTAL AND VERTICAL
SCALE





GEOLOGIC MAP OF SILL RELATIONS SOUTH OF PAINTER CANYON

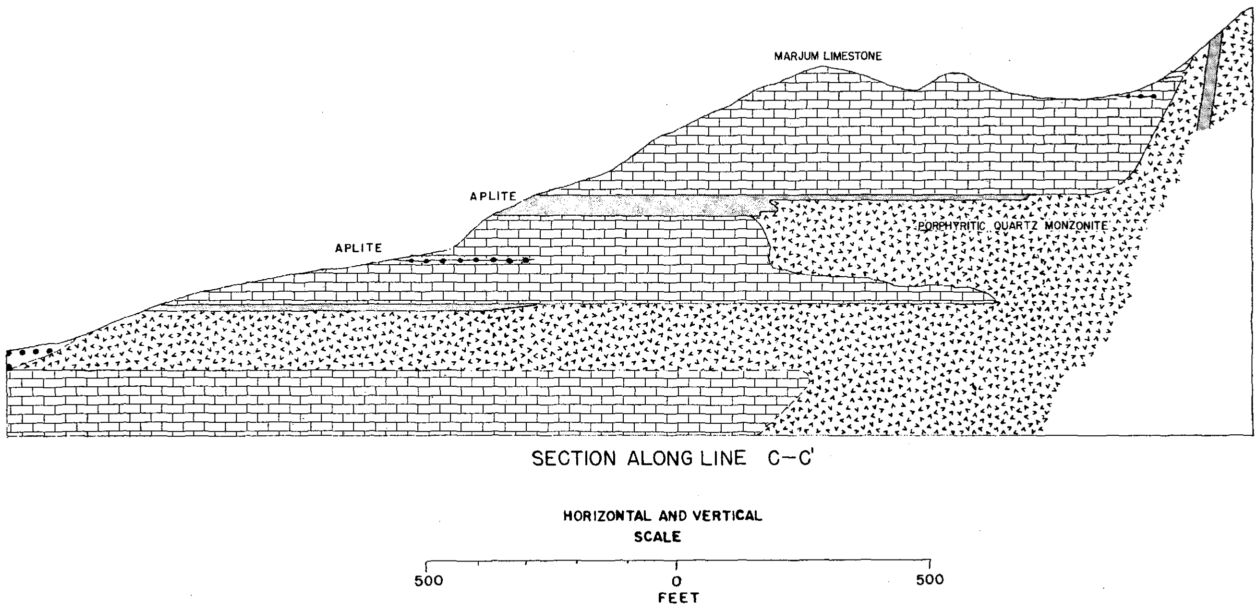
SCALE

500 0 500

FEET

CONTOUR INTERVAL 50 FEET

PLATE 4



SECTION ALONG LINE C–C'

ledge lies a banded idocrase marble with its alternating layers of green idocrase rock and calcite marble. Metacrysts of grossularite in the calcite layers range up to half an inch in diameter. The lower three feet of the cliff expose a gray limestone that contains minute grains of wollastonite, diopside, and oligoclase. Below the rubble, in the lower right hand corner of the photograph, more banded idocrase marble is visible.

MINERALOGY

Metamorphism has resulted in the following minerals, listed in order of their importance: idocrase, garnet, biotite, plagioclase of several compositions, diopside, wollastonite, and tremolite.

Idocrase. -- This is the most abundant silicate mineral. It makes up 40-50 per cent of the volume of the grayish olive bands of the banded idocrase marble. Some moderate olive green tetragonal prisms, as much as an inch long, are sometimes found in the calcite rich layers of the banded idocrase marble.

Garnet. -- Two garnets with distinct modes of occurrence are present in the metamorphic rocks.

The most common garnet has a refractive index of $1.740 \pm .005$, indicating that this mineral is very near the grossularite end of the hydrogrossular series (Yoder, 1950, p. 247). Specific gravity determinations, which would have determined its position in the series more precisely, were impossible because of the large amount of included diopside and calcite usually present. Pale reddish-brown, unzoned dodecahedral crystals of grossularite occur in calcite-rich layers of the banded idocrase marble. In idocrase-rich layers the grossularite is present as anhedral intergrowths with idocrase in amounts generally less than 5 per cent, except on the edges of the bands where calcite and grossularite both become more abundant.

A blackish red garnet occurs in the tungsten- and molybdenum-bearing tactite deposits. Its high index of refraction, color, and birefringent zoning indicate andradite.

Biotite. -- A common mineral of the calcite-deficient siliceous rocks is a brown pleochroic biotite. The grains are very small and show no dimensional orientation.

Plagioclase. -- Three compositions of plagioclase are present in the metamorphic rocks.

Fine-grained, untwinned anorthite makes up, with biotite, the bulk of the dense hornfels. Index of refraction measurements indicate a composition near pure anorthite.

Albite occurs as a minor constituent of some of the idocrase rich bands of the banded marble, where it is associated with small grains of epidote. A faint polysynthetic twinning is shown by these interstitial masses, and an index of refraction measurement indicates a composition very near pure albite.

A mineral with the optical properties of oligoclase, 15 per cent anorthite, was obtained from the insoluble residue of several specimens of gray limestone that also contain wollastonite and diopside.

Diopside. -- This is the second most abundant silicate, although it is usually present as small grains included in idocrase of grossularite. The composition is $Di_{96}He_{04}$, as determined by measuring N_y of fragments lying on a suitable parting (Hess, 1949), and assuming a calcium saturation.

Wollastonite. - Radiating white needles of wollastonite, two or more centimeters long, and quartz grains of variable size make up masses of wollastonite rock. In addition, minute grains are present in several specimens of gray limestone. It is probably more abundant than field study indicated.

Tremolite. -- Tremolite was only noted from one specimen of biotite-anorthite hornfels that came from a large block included in aplite. It has a grain size larger than the associated biotite and shows a distinct diamond-shaped cross section.

TYPES OF METAMORPHISM

Three distinct types of metamorphism have caused the alteration of the original sedimentary rocks. They are a widespread isochemical thermal metamorphism, a widespread silica metasomatism, and a localized iron-silica metasomatism.

Isochemical Thermal Metamorphism

Petrography

Biotite-Anorthite hornfels. -- This dense, brown-weathering rock forms prominent cliffs in the sediments bordering the intrusive. Although the rock weathers to a brownish-gray, its color when fresh is medium- to dark-gray. The predominate minerals are brown biotite and anorthite. The biotite plates are unoriented and average about 0.01 mm in diameter. Anhedral grains of anorthite are slightly larger. Bedding is shown in thin section by the presence of parallel concentrations of black opaque matter. A few lenses up to 2 mm long parallel the bedding and contain large grains of diopside and anorthite.

Gray limestone. -- In the field these limestones appear to be wholly unaltered or, at most, slightly recrystallized. Microscopic examination of their insoluble residue indicates the presence of such metamorphic minerals as wollastonite, diopside, and oligoclase. Minute grains of these silicate minerals may be seen on bedding planes in thin sections. The amount of insoluble residue ranges from 18 to 45 per cent in the specimens examined.

Banded Biotite marble. -- This rock consists of alternating layers an inch or so thick of biotite-anorthite hornfels and calcite marble.

Origin

Biotite-anorthite hornfels, gray limestone, and banded biotite marble are present throughout the area examined by the writer, except where they were altered during the later silica metasomatism. The biotite-anorthite hornfels show no structural localization and occur only in particular stratigraphic horizons. For these reasons they are considered to be the product of thermal metamorphism of siliceous limestones. Disseminated grains of metamorphic minerals within the gray limestone are also the result of heat alone and are concentrated along impure layers.

The common biotite-anorthite mineral assemblage and the rare biotite-anorthite-tremolite assemblage lie within the amphibolite facies (Turner, 1948, p. 78). The assemblage wollastonite-diopside-oligoclase presents an anomalous condition. According to Turner (1948, p. 89), oligoclase is stable throughout much of the range of the amphibolite facies at the low temperature end, while wollastonite is stable over the upper part of the temperature range. The work of Danielsson (1950) indicates that wollastonite has a much wider range of temperature at which it may be present under conditions of equilibrium. Depending on the variation of rock pressure and CO_2 gas pressure, the temperature may range from 280° to 850° C., with low CO_2 pressure and high rock pressure promoting the formation of wollastonite at the lower temperatures. The stratigraphic column of western Utah indicates that between 15,000 and 25,000 feet of Paleozoic and Mesozoic strata overlay the crystallizing quartz monzonite magma after its intrusion. The widespread presence of joints capable of carrying the later silica-bearing solutions indicates that CO_2 could have been easily removed from the reacting system and was not present under high pressures. These factors of high rock pressure and low CO_2 pressure make it likely that wollastonite could have formed under temperatures corresponding to the lower part of the amphibolite facies.

Silica Metasomatism

Petrography

Banded Idocrase marble. -- The most common metamorphic rock consists of alternating grayish olive and light gray bands. The grayish olive bands contain anhedral crystals of idocrase up to 4 mm in diameter, with abundant inclusions of diopside averaging 0.3 mm in diameter. Minor amounts of calcite and albite, and rarely epidote, are interstitial to idocrase. The light gray bands are largely calcite grains averaging 0.1 mm in size. Euhedral crystals of grossularite up to 2 cm in diameter usually are present in the calcite-rich layers. At one locality (6000N-9000E) grossularite crystals 2 cm in diameter occur with idocrase prisms 2 cm long in calcite marble layers.

Massive Idocrase marble. -- The mineral constituents of this rock are the same as in the more common banded idocrase marble. The banding, however, has been entirely erased during recrystallization.

Wollastonite rock. -- A few outcrops of a rock composed almost entirely of wollastonite were seen just south of the mapped area in the low foothills along the west side of the range. The mass of wollastonite

Figure 9. En echelon replacement veins of quartz and wollastonite cutting gray limestone.

rock in one case was fifty feet thick and lay conformably between gray limestone. Small lenses of gray limestone lie in the wollastonite near its contacts with the main gray limestone beds. More wollastonite rock was in veins cutting the gray limestone overlying the wollastonite rock layer. The arrangement of these veins is shown in figure 9. Diopside, idocrase, and quartz are present in small amounts, while calcite from the gray limestone is present in the transition zone, but not in the wollastonite rock itself.

Origin and Control of Silica Metasomatism

The addition of significant quantities of silica and lesser amounts of alumina is evidenced by modal analyses. The silica-bearing solutions also promoted a reaction between the original components of the marbles, which in some cases overshadows the contribution of silica.

Addition of silica. -- Two sets of specimens were collected from outcrops where it was possible to collect from the same bed in both a metasomatized zone and a thermally metamorphosed limestone.

In the first case, a lens measuring five by ten feet of banded gray and dark gray limestone occurs in the banded idocrase marble at 6400N-8800E. One of the darker bands of the gray limestone was continuous with an inch-thick idocrase-rich layer of the marble. Table 1 shows the modal analyses, the oxide compositions derived from the modal analyses, and the number of each of the metal ions present per 100 oxygen ions in the oxide composition. The modal analysis of the idocrase band was made by point counter, while the analysis of the dark gray limestone was made by examining the insoluble residue from a known weight of limestone.

Table 1. Analyses of Idocrase-Rich Band and Dark Gray Limestone

Mode			Composition			Metal ions per 100 oxygen ions		
Mineral	A	B	Oxide	A	B	Ion	A	B
Diopside	47%	10%	SiO_2	44%	17%	Si	26	10
Idocrase	39		CaO	35	47	Ca	23	29
Calcite	10	70	MgO	9	2*	Mg	8	2*
Albite	4		Al_2O_3	9	2	Al	6	2
Oligoclase		10	CO_2	4	31	C	3	24
Wollastonite		10	Na_2O	1	1	Na	1	1

*assuming no Mg in carbonate.

A Idocrase-rich layer of marble
B Dark gray bed of gray limestone

A second set of samples was collected just south of Painter Canyon at 17800N-8400E where the contact between limestone and massive idocrase limestone is sharply crosscutting, and it is possible to obtain samples from the same bed. The idocrase marble consists of equidimensional grains of idocrase and calcite with inclusions of diopside and interstitial albite and quartz. The thermally metamorphosed equivalent is a light gray limestone with silicate rich layers parallel to the bedding. Table 2 gives the mode, oxide composition, and metal ion content of these rocks obtained in the same manner as table 1.

Table 2. Analyses of Massive Idocrase Marble and Gray Limestone

Mode			Composition			Metal ions per 100 oxygen ions		
Mineral	C	D	Oxide	C	D	Ion	C	D
Diopside	28%	10%	SiO_2	38%	23%	Si	23	13
Idocrase	41		CaO	38	41	Ca	24	25
Calcite	21	60	MgO	5	2*	Mg	5	2*
Albite	5		Al_2O_3	10	5	Al	7	3
Oligoclase		20	CO_2	9	27	C	7	21
Wollastonite		10	Na_2O	1	2	Na	1	2
Quartz	2							

* assuming no Mg in carbonate

C Massive idocrase marble
D Light gray limestone

If it is assumed, as Barth (1948) suggests, that the oxygen content of the rocks remained constant during metasomatism, it is apparent that the silica content of each metasomatized rock was approximately doubled. The alumina content was also increased, but it is not a major component of either rock. Carbon dioxide is the chief constituent lost during metasomatism. The discrepancy in magnesia content arises from calculating as calcite all of the soluble matter. The total of lime and magnesia does not change appreciably during metasomatism.

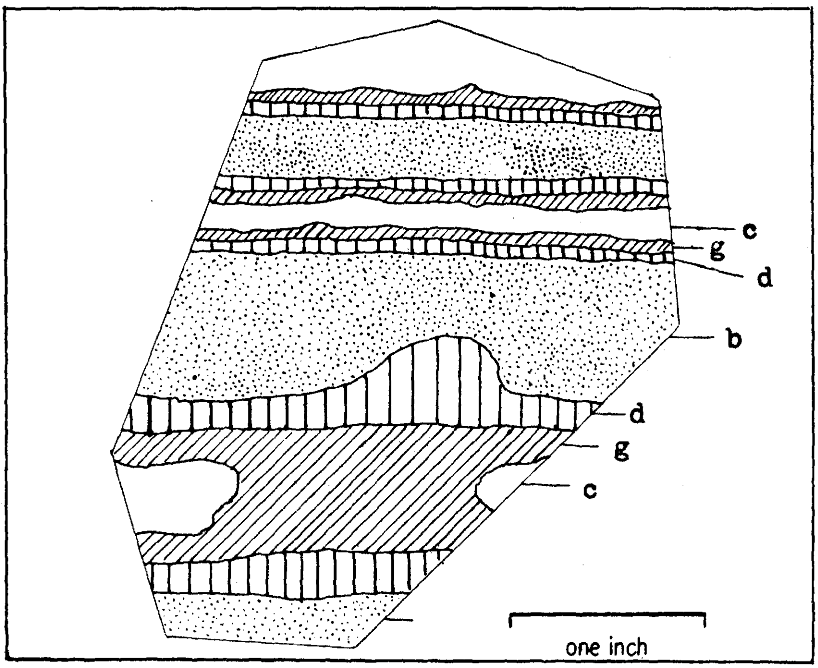


Figure 10. Grossularite and diopside developed between biotite-anorthite hornfels and calcite marble bands of the banded biotite marble.

c calcite marble　　d diopside
g grossularite　　b biotite-anorthite hornfels

Larger amounts of silica have been introduced in forming the interbedded masses and crosscutting veins of wollastonite rock. Limestone lenses within the interbedded mass are quite pure calcite, and the change to wollastonite rock as seen in thin section involves the gradually increasing replacement of calcite with wollastonite and quartz. Calcite is present in the wollastonite rock only in narrow borders adjacent to the limestone lenses.

Reaction between original components. -- Although the addition of silica and alumina has been demonstrated by the previous modal analyses, the importance of original argillaceous material should not be underestimated. In the specimens of tables 1 and 2, half of the silica and a third of the alumina were present in the thermally metamorphosed rock before the silica metasomatism.

In all of the metasomatized rock, except the uncommon massive idocrase marble and wollastonite rock, the original bedding has been preserved as bands of alternating silica-rich and calcite-rich rock. The silica-rich bands represent beds that were originally argillaceous. The scattered metacrysts of grossularite and idocrase in the calcite-rich layers may represent either recrystallized impurities or products of the reaction between calcite and the silica- and alumina-bearing fluids.

A striking example of the importance of original components is found in the development of reaction zones between the inch-thick bands of banded biotite marble. Grossularite and diopside layers have formed between the original bands of biotite-anorthite hornfels and calcite marble. A specimen collected just south of Painter Canyon (17500N-8400E) is shown in figure 10. The specimen came from a sequence of beds lying between banded biotite marble and banded idocrase marble. Beds of this type are present through a thickness of several feet and show an increase in the width of reaction zones with nearness to the banded idocrase marble.

The central calcite layers contain grains 0.05 mm in diameter, with smaller diopside grains. The light brown bands bordering the calcite bands consist of massive grossularite with no zoning to indicate the size of the individual grains. Inclusions of calcite and irregular idocrase masses are common within the grossularite. Greenish bands bordering the grossularite layers are made up almost exclusively of diopside grains averaging 0.1 mm in length. The dark gray central part of the next major band is biotite-anorthite hornfels. The grossularite and diopside layers are somewhat gradational, with inclusions of bordering layers present. In one lower part of the specimen, the calcite band has been entirely replaced by grossularite and idocrase, and the diopside layer has been increased correspondingly at the expense of the biotite-anorthite hornfels. Several grains of sphene 0.1 mm in diameter are in the biotite-anorthite layer adjacent to the thickened part of the diopside layer. The size of the grains is much larger than would be expected of detrital grains in a shale band within limestone, and for this reason they are considered to have resulted from material added by the silica solutions.

There are two possible ways in which the diopside and grossularite layers were formed. The first possibility involves the transfer of ions across the original boundary of the layers to form diopside from the biotite-anorthite hornfels and grossularite from the calcite marble. An estimate of the amount of ions transferred can be obtained from approximate compositions derived by modal analyses. The biotite-anorthite layer consists of approximately 40 per cent biotite and 60 per cent anorthite, and the diopside layer is almost pure. The oxide compositions and derived metal ion content are shown in table 3.

Table 3. Ion Transfer to form Diopside from Biotite-Anorthite

	Composition			Metal Ions per 100 Oxygen Ions		
Oxide	A	B	Ion	A	B	B-A
SiO_2	42%	56%	Si	24	33	9
Al_2O_3	27		Al	19		-19
CaO	12	19	Ca	7	17	10
(Mg,Fe)O	14	26	(Mg,Fe)	15	17	2
K_2O	4		K	3		-3
H_2O	2		H	4		-4

A Biotite-anorthite hornfels
B Diopside layer

It it can be assumed that the boundary between the diopside and grossularite layers represents the original boundary between biotite-anorthite hornfels and calcite marble, then it is evident that silica and calcium were added to the biotite-anorthite hornfels in order to convert it to diopside. The calcium was diffused from the calcite band. Transferal of aluminum, out of the hornfels being replaced by diopside, caused the formation of grossularite in the calcite band. The silica necessary for both reactions must have been furnished by the silica-bearing solutions permeating the rock. Potash contained in the biotite was removed by the same solutions. The solutions were necessary in order to provide a medium for the rapid diffusion of Al^{3+} and Ca^{2+} ions, as well as to add the necessary silica.

The second possible way in which these reaction layers could have formed is through metamorphic differentiation of the diopside and grossularite into separate layers after they have formed through the reaction of biotite and anorthite with calcite. This does not imply, as does the first case, that the boundary separating grossularite and diopside is the original boundary between the biotite-anorthite and calcite layers. The reaction, when balanced chemically, involves the reaction of 168 volumes of anorthite, 504 volumes of biotite, and 360 volumes of calcite to produce 516 volumes of grossularite and 100 volumes of diopside. The volume ratio of grossularite to diopside, about 5 to 1, is not in accord with the observed equal thickness of the two bands. Further, the original biotite-anorthite bands contain biotite and anorthite in approximately equal amounts, and this higher aluminum content would further promote the formation of grossularite.

From these considerations it is apparent that reaction between original components was important in forming the mineral assemblage, but that the circulating fluids were necessary to provide a medium for diffusion of the ions and to provide more silica.

Structural and stratigraphic control of silica metasomatism. — The interlayering of silica-metasomatized rocks with thermally metamorphosed rocks required some feature concordant with the bedding to control the passage of the silica-bearing fluids.

The development of grossularite-bearing marble, adjacent to joints and to certain bedding planes in gray limestone, suggests that small open fractures were present to allow the passage of metasomatizing solutions. Open passages would allow for the widespread distribution of the silicated marbles which occur at least a mile from the intrusive. Further evidence of the existence of nearly horizontal joints is found in the abundance of the later aplite sills, which indicate that planes of weakness were present along certain beds to allow their intrusion.

Similar bedding planes, or nearly horizontal joints, were sufficiently open to provide the major passageways for silica-bearing fluids.

These silica-bearing fluids permeated the rocks bordering the passageway for distances of from 5 to 20 feet, or half the thickness of the ordinary metasomatized layer. Certain beds were unaffected by the metasomatism because of their low permeability. The biotite-anorthite hornfels and some very fine-grained black limestones have very sharp contacts with underlying or overlying metasomatized layers. These contacts represent limits of permeation caused by lack of permeability of the dense rock.

Origin and significance of the silica metasomatism. -- The usual metasomatism, described as following the intrusion of granitic rocks, results in the formation of rocks rich in iron and magnesium silicates. Silica metasomatism, free from iron and magnesium, might go unnoticed unless analyses were made on specimens collected from the same bed. The House Range presents a fortunate condition where such specimens may be collected.

The silica-bearing solutions may represent either material given off by the crystallizing quartz monzonite magma or connate waters carrying silica dissolved from the sedimentary rocks. The apparent absence of iron and magnesium from these solutions may indicate that the sediments provided the water and silica. Schmitt (1948) emphasizes the possible importance of silica derived from sedimentary rocks in forming tactite bodies. He also suggests that much of the water was meteoric and that the chief contribution of the magma was iron, sulphur, and other metals. The position in time of the silica metasomatism of the House Range rocks before aplite intrusion, and much earlier than the tactitization accompanying the tungsten and molybdenum mineralization, makes it seem likely that the silica and water are not the products of the quartz monzonite, but represent silica dissolved from the underlying Prospect Mountain quartzite by heated connate or meteoric water.

Temperature Range of Silica Metasomatism

The mineral assemblages developed during silica-metasomatism are:

(1) grossularite-idocrase-diopside-calcite-albite-epidote
(2) grossularite-idocrase-diopside-calcite
(3) wollastonite-quartz
(4) grossularite-idocrase calcite

These assemblages may lie within the albite-epidote amphibolite as described by Turner (1948, p. 91), with the exception of wollastonite-quartz. The seemingly anomalous presence of wollastonite at low metamorphic grade has been explained in the discussion of the origin of the thermally metamorphosed rocks. Similar arguments hold here, perhaps with more weight, since these wollastonite rocks have been formed in systems open to silica-bearing solutions and hence also open to CO_2, resulting in a lower gas pressure that promoted the formation of wollastonite at low temperatures.

Assemblages 3 and 4 above are equilibrium assemblages with no extra mineral components. Assemblage 1 is not in accord with the ACF diagram (Turner, 1948, p. 91, fig. 24) because of the presence of both epidote and calcite. The presence of calcite here is due to a lack of sufficient silica to make a complete conversion to diopside possible, while Turner's diagram is for rocks with excess silica.

The presence of intergrowths of grossularite and idocrase is an anomalous condition in assemblages 1 and 2, according to Turner

(1948, p. 91, fig. 24). Turner (1948, p. 72) states that idocrase is stable over a wide range of metamorphic temperatures where it may accompany or take the place of grossularite. He also states that the appearance of idocrase has been attributed to magmatically derived fluorine.

The albite-epidote amphibolite facies represented by the silica metasomatism indicates a lower temperature of metamorphism than the amphibolite facies of the preceding isochemical thermal metamorphism. This must be due to a general cooling of the stock and invading rock after the thermal metamorphism accompanying the intrusion.

Iron-Silica Metasomatism

A tactite metasomatism, during the introduction of tungsten and molybdenum, has been superimposed on the general silica metasomatism. These tactite zones may be developed by the introduction of andradite to banded idocrase marble, gray limestone, or aplite.

Petrography

Tactite in Banded Idocrase marble. -- Blackish red andradite garnet has been introduced into the calcite marble layers of the banded idocrase marble, producing a dark rock that contrasts strikingly with the light marble. The idocrase-rich bands were unaffected by the metasomatism. The calcite layers have been recrystallized into crystals up to a centimeter in diameter, which include rounded diopside grains that were originally present as smaller grains disseminated through the marble. Euhedral andradite crystals, up to 2.5 mm in diameter, embay the large calcite crystals. The andradite crystals may contain inclusions of calcite, quartz, and chlorite. Pyrite, scheelite, and molybdenite are also present in the calcite matrix.

Tactite in Aplite. -- Andradite has also replaced the igneous minerals of parts of some aplite dikes adjacent to tactites in the marble. The quartz and feldspar have been replaced equally.

Tactite in Gray Limestone. -- Tactite zones may be developed along joints in gray limestone where the andradite has replaced the original calcite. This is an uncommon occurrence, and the tactite is usually a few inches thick.

Localization and Origin

The localization of the tactite bodies and their significance will be discussed with the tungsten and molybdenum mineralization.

Temperature of Iron-Silica Metasomatism

The mineral assemblages of the tactite bodies are not critical for determination of metamorphic facies. However, development of tactite bodies is usually considered a high temperature form of ore deposition.

TIME OF METAMORPHISM

The time of metamorphism can only be dated with reference to the intrusion of the aplite bodies and the tungsten and molybdenum mineralization. The thermal metamorphism apparently occurred during the intrusion of the quartz monzonite magma when the temperature of the country was elevated by the hot magma. The silica metasomatism followed the thermal metamorphism closely, as a result of the heating of connate or meteoric waters by the intruding magma. There was a reduction in temperature of the rock mass surrounding the intrusive before the silica metasomatism reached equilibrium, as evidenced by the formation in the metasomatized rock of minerals indicative of a metamorphic facies lower than that of the thermal metamorphism.

Various features show that the silica metasomatism took place before the intrusion of the aplite bodies.

(1) The dike contacts, which later served as controlling channels for the tungsten- and molybdenum-bearing fluids, had no controlling effect on the silica metasomatism.

(2) Blocks of metamorphic rock within the large aplite sills have the same mineralogy and textural characteristics as the country rock from which they were detached. These blocks should have been effectively sealed off by the relatively impermeable aplite from the solutions causing the metasomatism, if the aplite intrusions preceded metasomatism.

(3) A reaction zone might be expected between the silica- and aluminum-rich aplite and the calcite, if the aplites had been present before the metasomatism. No change is noted in either the texture or composition of limestones or marbles in contact with aplites, showing that no such reaction took place.

An example of the lack of control of silica metasomatism by the aplite contacts is shown in figure 11. The aplite dike cuts the banded biotite marble and, just to the right of the area photographed, cuts the banded idocrase marble of the lower part of the photograph. No change in the position of the contact between these two marbles is seen where the dike crosses, although it has been shown that under the influence of the metasomatic solutions the banded biotite marble

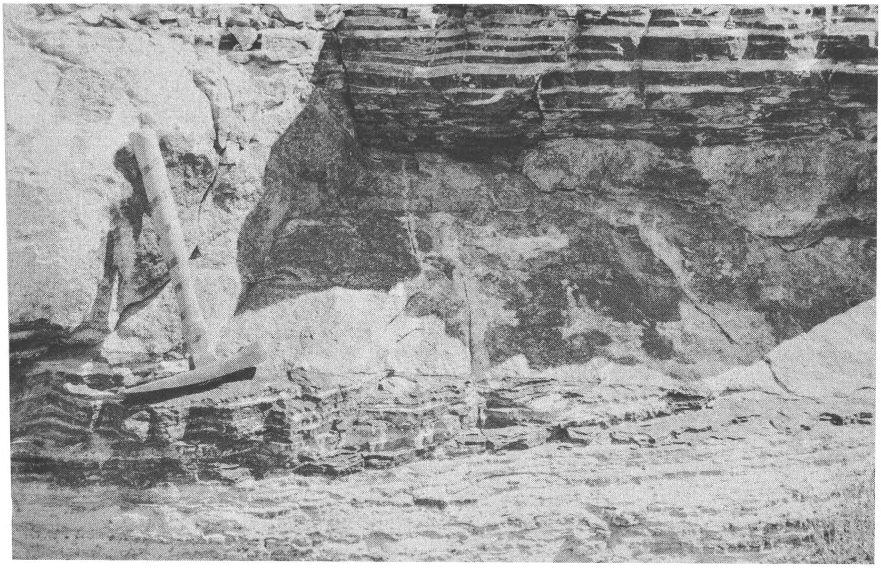


Figure 11. Aplite dike cutting banded biotite marble and banded idocrase marble.

will develop a mineral assemblage similar to that of the banded idocrase marble beneath.

The isochemical thermal metamorphism and the silica metasomatism preceded the aplite intrusion. Furthermore, it will be shown below that the iron-silica metasomatism accompanying the tungsten mineralization is definitely post aplite-intrusion.

E C O N O M I C   G E O L O G Y

Mining is of little importance in the area. Some tungsten and gold have been produced in the vicinity of the Notch Peak intrusive. Some molybdenum is also known to occur.

CHARACTER OF THE DEPOSITS

Tungsten occurs in tactite bodies of the type usually called contact metamorphic, as coatings on joint planes, and in veins of smoky quartz. Molybdenum is present in tactite bodies with tungsten, as disseminated grains in aplite, and in veins of milky quartz.

The gold is in arkosic sands and gravels resulting from the mechanical weathering of quartz monzonite.

DISTRIBUTION

The tungsten- and molybdenum-bearing tactites occur in thermally metamorphosed and silicated limestones adjacent to the contact of the quartz monzonite stock and of the aplite dikes. Veins of smoky quartz with tungsten are in the tactites. Tactites in aplites bearing disseminated molybdenum are localized near tactite bodies in limestone.

The gold placers lie within the outcrop area of the quartz monzonite stock.

MINERALOGY OF THE TUNGSTEN AND MOLYBDENUM DEPOSITS

The deposits contain the following minerals of interest: scheelite, molybdenite, pyrite, andradite, and quartz.

Minerals and Their Relationships

Scheelite. -- The light yellow fluorescence of scheelite under ultraviolet light is the only indication of its presence on joint planes and in tactites. According to McKinstry (1948, p. 425), the yellow color indicates a high molybdenum content. The scheelite grains of the tactite deposits are usually 1 mm in diameter and occupy areas between the calcite matrix and andradite. These grains may truncate the crystal outline and birefringent zoning of the andradite.

Scheelite grains up to a centimeter long are present in smoky quartz, lying along the diopside monzonite, and tactite contact at the Moody prospect (8000N-9500E) (fig. 12).

Molybdenite. -- Molybdenite is usually present in the aplite and tactite as grains about 1 mm in diameter. However, in some tactite bodies, the grains form aggregate masses up to 2 cm in diameter. The molybdenite penetrates the rock minerals in the aplite dikes. In the tactites it is interstitial to calcite and andradite. Its occurrence with milky quartz, of pegmatitic origin, is known only from float found in a gully south of Painter Canyon at 14500N-8500E.

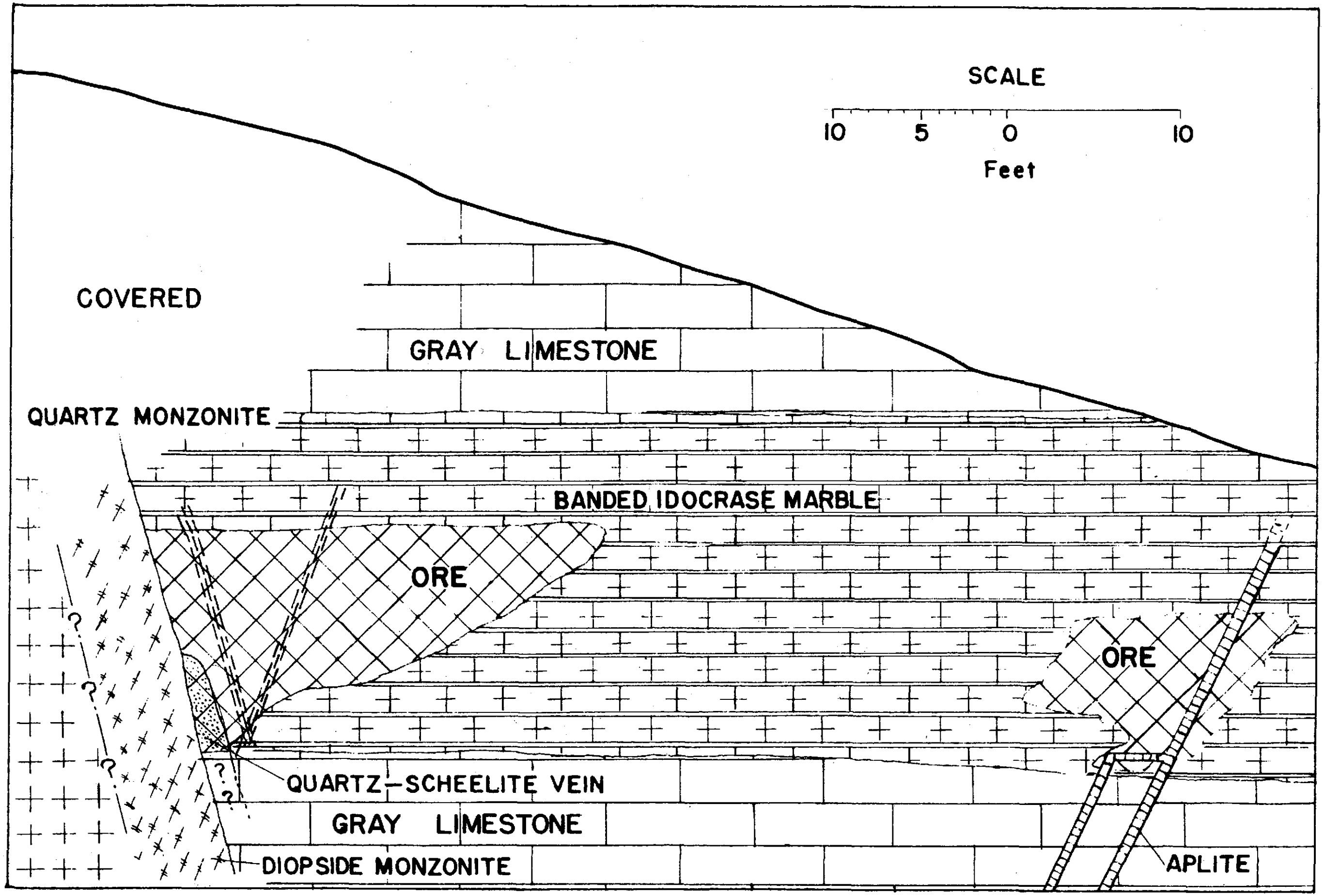


Figure 1[illegible]. Ore relations [illegible]

Pyrite. -- Grains of pyrite several millimeters in diameter occur in all of the tactite deposits, making up from 5 to 10 per cent of the substance of the deposits. The grains penetrate andradite and calcite.

Andradite. -- Andradite is the most abundant mineral of the tactite deposits. It forms euhedral grains in the coarsely crystalline calcite matrix. Andradite is also found in the aplitic dikes as irregular grains and granular aggregates penetrating and replacing the igneous minerals, but without particular localization near concentrations of the molybdenite.

Quartz. -- Quartz is interstitial to andradite in parts of the tactites developed in banded idocrase marble. The quartz occurs where calcite was originally less abundant. Rounded masses may also be present in the interiors of andradite crystals along with calcite and chlorite.

Quartz is the sole gangue mineral in the quartz-scheelite vein along the diopside monzonite contact at the Moody prospect.

Paragenesis

The banded idocrase marble that forms the usual host rock for scheelite and molybdenite developed through the metamorphism of limestone interbedded with shale layers. Some silica was added during metamorphism to produce idocrase- and diopside-rich rock alternating with layers of calcite marble containing tiny diopside grains. The idocrase-diopside bands contain no scheelite or molybdenite.

During the earliest stages of metallization, both the calcite and diopside recrystallized into much larger grains. Iron and silica introduced during this stage induced the formation of andradite at the expense of the calcite.

The scheelite, molybdenite, and pyrite were added shortly thereafter as replacements of andradite and calcite. Molybdenite was also added to the aplite. The sequence of deposition among scheelite, molybdenite, and pyrite could not be determined as these minerals were not in contact. Quartz was introduced with these minerals, and it also replaces andradite and calcite and occurs with the scheelite in the veins.

The chlorite and calcite occurring in the andradite crystals are the products of later alteration.

LOCALIZATION

The ore bodies are localized in favorable beds where intersected by joints, aplite dikes, and the contact between the quartz monzonite and metamorphic rock.

Structural Controls

The contact between the quartz monzonite and the metamorphic rock controls the localization of the tungsten at the Moody prospect. The abrupt tapering of the ore body away from the contact is shown in figure 12.

The contact between an aplite dike and the metamorphic rock may also localize the ore. The second smaller tactite body at the Moody prospect lies on both sides of a small aplite dike. Small tactite bodies are present in many places, developed in certain beds on one or both sides of aplite dikes.

Although joint planes do exert a control on some of the scheelite, the quantity of scheelite actually in joint systems is small. The coated surface gives an erroneous impression of abundance, but the marble is barren except on the few fractures.

Stratigraphic Control

The formation of the tactite bodies depends largely upon the intersection of contacts and fractures with beds favorable for replacement. The tungsten- and molybdenum-bearing tactites are restricted to beds rich in calcite. For example, the banded idocrase marble which is the usual ore host has been replaced only in the calcite-rich beds. These beds show that the scheelite grains are concentrated where calcite has changed to andradite.

GENESIS

Tungsten and Molybdenum Ore

The close association of the silica metasomatism and the tungsten and molybdenum mineralization with the aplite bodies and the quartz monzonite suggests some genetic relation between mineralization and magmatic activity. The tungsten and molybdenum mineralization is late in the time sequence, following the aplite intrusion. It is probable that the tungsten and molybdenum ores are the result of deposition from hydrothermal fluids derived from sources deep within the quartz monzonite magma and given off after the injection of the aplitic fraction.

There are differences of opinion regarding the role of aplite dikes in the ore mineralization. Kerr (1946, pp. 28, 116) states that the aplite magma carried both tungsten and molybdenum. He cites the greater amount of scheelite at intersections of two dikes and the presence of scheelite and molybdenite within the aplites as evidence of this. From the present study, it is evident that the association of tungsten and molybdenum with aplite dikes is structural. The presence of molybdenite replacing the igneous minerals of the aplite indicates that the molybdenite grains were introduced after the consolidation of the aplite. The development of andradite at the expense of the igneous minerals in aplite indicates that this early stage of metallization occurred after consolidation of the aplite. Further evidence is the presence of tungsten-bearing tactites replacing marble along one contact of an aplite body only. This could have occurred only after the aplite had consolidated, enabling a fracture to develop along one contact for the passage of the tungsten-bearing fluid.

Similar fractures along the boundary of the quartz monzonite stock allowed the tungsten-bearing fluids to move along the contact and replace favorable beds.

Some deposition took place along joint planes, as shown by a greater concentration of scheelite in the fractures that cut the tactite at the Moody prospect (fig. 12).

Placer Gold Deposits

The gold-bearing alluvium of Amasey Valley owes its existence to a resistant aplite sill that prevented the rapid downcutting of the valley. Other valleys, such as Granite Canyon, have been deeply eroded; whereas Amasey Valley remains flat-floored down to the edge of the quartz monzonite, where erosion is impeded by the aplite sill.

The source of the gold in the placers is not positively known. Crawford and Buranek (1941) state that the gold comes from quartz veins, but the only quartz is in the pegmatites and in the scheelite-bearing veins. No lode gold has been found.

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RS-14. Location Plot (tabular list) of Wells Drilled in Utah (through 1948).

RS-23. Oil and Gas Wells of Utah (through 1948) plotted on map. Formerly charge items, reprints RS-14 and RS-23 from the "Oil and Gas Possibilities of Utah" are now superseded by our new Bulletin 50, Drilling Records for Oil and Gas in Utah.

RS-28. Plate VII — Geologic Index Map of Utah (showing U.S. Geological Survey Publications in Utah)

RS-29. Plate VIII — Geologic Index Map of Utah (showing other than U.S. Geological Survey Publications in Utah)

RS-30. Utah Raw Materials of Interest to the Chemical Engineer—A reprinted summary by Arthur L. Crawford, published in *Chemical and Engineering News* (Vol. 27, p. 3017, Oct. 17, 1949).

RS-32. Ozokerite — A Possible New Source — A Challenge to Research, by Arthur L. Crawford.

RS-44. List of Samples Available for study at the University of Utah Oil Well Sample Library; samples from Utah and bordering sections of neighboring states.

RS-45. Geology in the Grade Schools, by Dorsey Hager. Reprinted from *Science*, Vol. 114, No. 2949.

RS-48. Perfecting a Claim, reprinted from *Uranium Magazine*, November 1954, for those who do not care to purchase our more exhaustive treatise (RS-52, by J. Thomas Greene).

RS-51. The Mineral Industry of Utah — 1952. The Utah chapter, prepared by Paul Luff, Commodity-Industry Analyst, U.S. Bureau of Mines, under a cooperative agreement with the Utah Geological and Mineralogical Survey, for the "Minerals Yearbook" of the United States.

RS-53. The Mineral Industry of Utah — 1953, by Paul Luff. Sequel to the above, for 1953.

RS-54. Underground Storage of Petroleum Products in Utah, Location and Design, by Arthur L. Crawford. Will our petroleum storage facilities go underground? Some practical considerations.

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