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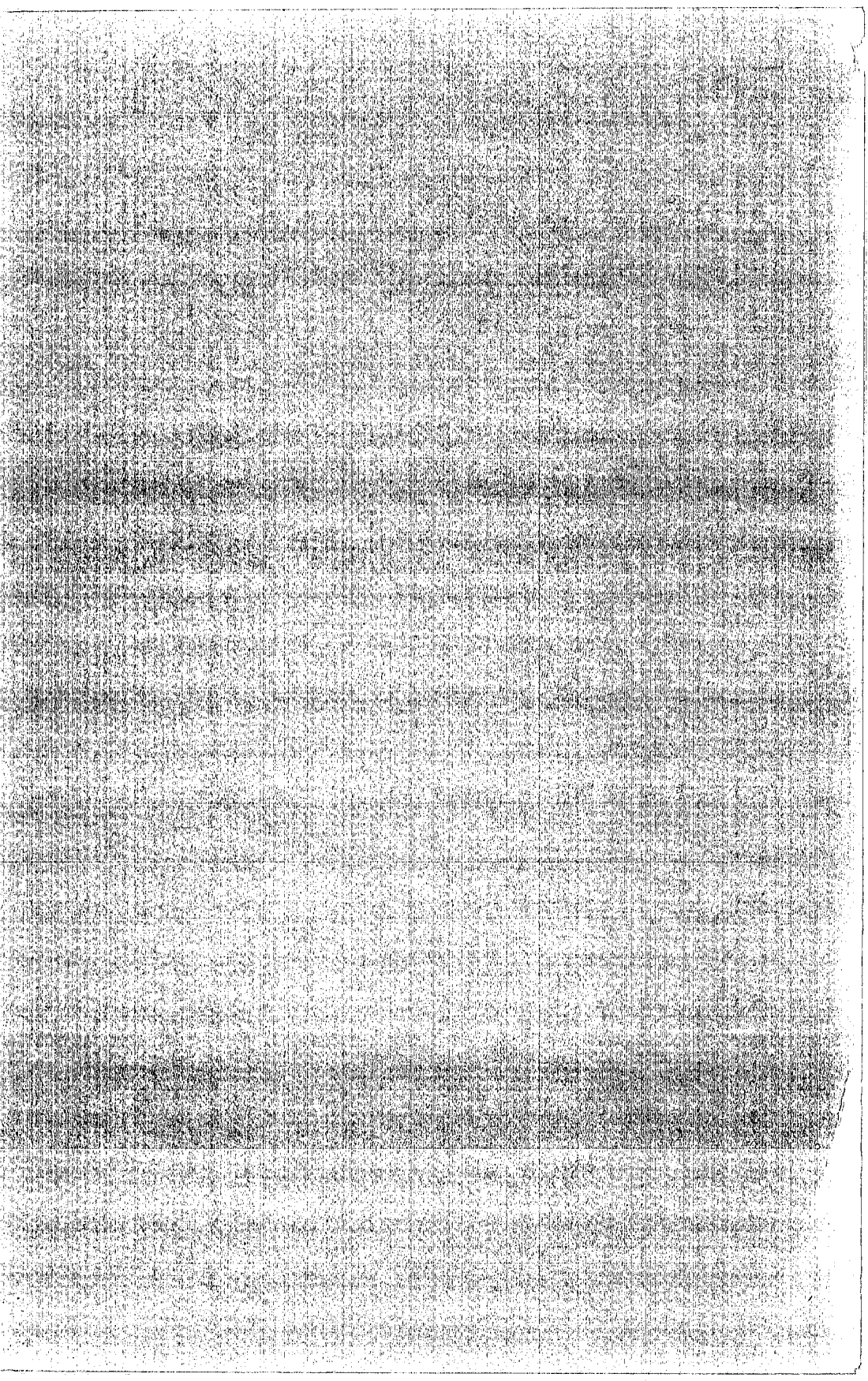
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The Mineral Alteration Products of the Keetley-Kamas Volcanic Area, Utah*

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ABSTRACT.—Types and areal extent of the hydrothermal alteration products in the volcanic rocks of the Keetley-Kamas area were determined by differential thermal analysis and thin section study. Chloritization was widespread whereas silicification, alunitization, kaolinization, and montmorillonization were localized in a few square miles around a diorite porphyry intrusion.

Quantitative spectrochemical analysis confirmed the introduction of moderate amounts of manganese in the alternation but failed to show any consistent major addition of lead, zinc, gold, copper, or silver. Copper and silver, however, were observed in local areas to be present in unusually large amounts.

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

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INTRODUCTION

Location and Accessibility

The Keetley-Kamas area lies mainly in the northernmost part of Wasatch County, Utah, but also includes a small portion of Summit County. It includes T. 2 S., R. 5 E., with the exception of sections one through six.

The volcanic rocks of this area are a small segment of a larger volcanic field which extends from south of Heber northward to Silver Creek Canyon and westward from the Uinta Mountains to the east edge of the Wasatch Mountains.

Accessibility is provided by U.S. Highway 189 and 151 which bound the area on the west and south sides, and by a graded dirt road that traverses the area.

Acknowledgments

The writer is indebted to Dr. Wm. Revell Phillips who suggested this problem, supervised the laboratory work, and criticized the manuscript.

Spectrographic equipment was made available by the Brigham Young University Physics Department under the supervision of Dr. John Eastmond.

Physical Features

Due to the eastward dip of the volcanic beds, the hills rise rapidly from the Keetley Valley floor on the west to their maximum height and then gently slope toward the Kamas Valley on the east. Maximum relief between the valleys bounding the area and the crests of the hills rarely exceeds 1,000 feet and is usually much less.

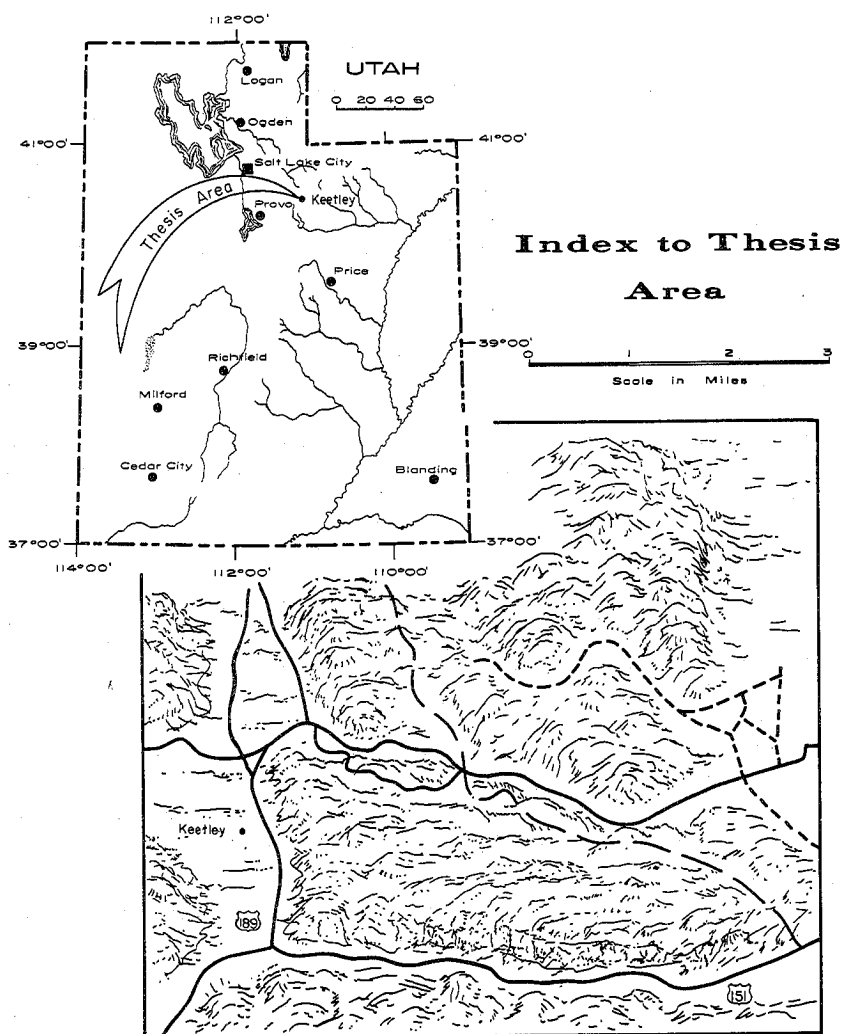
Previous Work

General Area

Because of economic mineral deposits in the nearby Park City Mining District, this general area has been the subject of considerable work. J. M. Boutwell (1912) made a detailed study of the geology and ore deposits of the Park City Mining District. J. P. Forrester's (1937) work in the neighboring Uinta Mountains and A. J. Eardley's (1944) work in the Wasatch Mountains to the north of this area clarify the regional geology. More recently C. W. Berge (1960) studied the Alta, Little Cottonwood, Clayton Peak, and Park City stocks.

Specific Area

O'Toole (1951 *ms.*) did the only geologic work specifically concerned with the area considered in this paper. His stated purpose was to determine



TEXT-FIGURE 1.—Index and location map.

the structure between the Wasatch and Uinta Mountains and he mapped the area and made a limited gravimetric survey.

Purpose and Scope

Important considerations developed in this investigation are twofold: first, to determine the types of hydrothermal alterations present in the area and the areal extent of each; second, to suggest possible relationships between alterations and ore bearing solutions.

SEDIMENTARY ROCKS

Relationship to Problem

Mineralogy of sedimentary rocks controls, in large part, the ore deposition which occurs in them, especially in replacement ores. At the Tintic Mining District, for example, Lovering (1949) found that the rock type not only controlled the ore deposition but also controlled the non-ore-bearing rock alteration. His study indicated that almost all of the ore occurred in replaced limestones and that the quartzite strata were not mineralized except for some introduced pyrite. He stated, however, that "a substantial amount of pyritic copper-gold ore has been mined from veins in the Tintic Quartzite" in some mines. Boutwell's (1912) work in the Park City Mining District confirms the idea that the large ore bodies are located as replacements in limestone whereas ores in quartzites are due to vein filling.

Since this investigation concerns the relationship of alteration to ore deposition, it must be kept in mind that the proper rock type as well as the proper ore-bearing solutions must be available if ore deposition is to occur. Alteration could possibly indicate ore solutions and the ore bodies could still be absent if the proper host rock was not encountered, hence, a lack of ore bodies does not necessarily mean that no ore-bearing solutions have penetrated that area.

Stratigraphy and Lithology

Although sedimentary rocks crop out over little of the area, they underlie the more recently deposited volcanics and hence must be considered as possible ore prospects where ore-bearing solutions have contacted them.

Sedimentary rocks found within this area include sediments of Pennsylvanian, Permian, Triassic, and Jurassic age. Granger (1953), Boutwell (1912), and O'Toole (1951 *ms.*) have discussed the stratigraphy of the sedimentary rocks within the general area of the present work. The stratigraphic descriptions are based on information from these writers and from personal observation in the field. Measured thicknesses listed are from Boutwell (1912).

Weber Quartzite

The Weber Quartzite, of Pennsylvanian age, is a yellow-brown quartzite formation with thin beds of cherty limestone and is 3,500 feet thick.

Park City Formation

Overlying the Weber Quartzite is the Park City Formation of Permian age. This formation is predominantly limestone, some of which is cherty, and it contains a phosphatic shale member near the middle. The total thickness is approximately 700 feet.

Woodside Shale

The Woodside Shale, of Triassic age, overlies the Park City Formation and is a pale brown, thin-bedded shale with a thickness of 700 feet.

Thaynes Formation

The Thaynes Formation, of Triassic age, lies directly above the Woodside Shale and is a gray-blue, fossiliferous limestone interbedded with yellow-brown shale and sandstone. Thickness of the formation at Park City is not definitely known but at Big Cottonwood Canyon its thickness is 1,290 feet.

Ankareh Shale

The Ankareh Shale, as defined by Granger (1953), includes what has been called the Ankareh Shale, Shinarump Conglomerate, and Chinle Formation. This formation is Triassic and includes reddish-purple shale interbedded with red sandstones in the lower part (Ankareh Shale), a very coarse or gritty, quartzose sandstone in the central part of the formation (Shinarump Conglomerate), and red siltstone and shale in the upper part (Chinle Formation).

Nugget Sandstone

The Nugget Sandstone, of Jurassic age, overlies the Ankareh Shale and consists of 500 feet of medium to coarse-grained, pink sandstone.

Statement of Economic Production

In the nearby Park City Mining District, most of these formations have shown mineralization, but two formations, the Park City and Thaynes, have had the most productive ore bodies.

EXTRUSIVE IGNEOUS ROCKS

Relationship to Problem

Since volcanic rocks crop out over the major part of the area and because they display conspicuous alteration, they are the major rock type studied in this investigation.

Volcanic rocks display different alteration products, depending upon the type of solutions which invade them and upon their original mineralogy. By carefully considering the change in mineralogy which occurs, the gains and loss of elements can be determined, and, hence, the type of invading solution is determined. By determining the areas of most intense alteration in these volcanic rocks, it may be possible to predict hidden ore bodies.

Stratigraphy and Geologic Age

Andesite flows and andesite tuffs and breccias compose a thick section of volcanic material which has filled in the valleys of an older erosional surface. O'Toole (1951 *ms.*) says that at least 1,000 feet is present in places. Variable thickness of the volcanic section produced from this old surface makes it difficult to determine an accurate thickness at any one place unless the contact between the sedimentary and volcanic rocks is exposed. The sedimentary-volcanic contact can be observed at an elevation as low as 6,000 feet at a road cut in Section 33 of T. 2 S., R. 2 E., and as high as 7,500 feet in Section 16 of T. 2 S., R. 5 E., where a window of Nugget Sandstone is exposed in the volcanic rocks. This variable thickness is one problem in determining depth to and possibility of hidden ore bodies in the sedimentary rocks.

Eardley (1944) considers the tuffs in the Park City and Kamas area to be equivalent with the Norwood Tuff. Geologic age, based on vertebrate remains in sand channel fillings within the tuffs, for the Norwood Tuffs is Early Oligocene. Eardley, however, indicates that there is some question whether the Norwood Tuff and the Park City Tuffs are equivalent.

O'Toole (1951 *ms.*) names the tuffs (which underlie the andesite flows)

the "Peoa Tuff" but says that "it is expected that this bed will correlate with the Norwood Tuff of the north central Wasatch Mountains."

If it is assumed that the age of the tuffs is Early Oligocene, it becomes apparent that any hydrothermal alteration within the volcanics must be post-Early Oligocene.

Petrographic Descriptions

Two rock types are considered to be representative of the volcanic deposits in the area, andesitic-tuff breccia and andesite porphyry. Photomicrographs of representative samples of these rock types are shown on Plate 1.

Andesite Porphyry

Megascopic Description.—Although the numerous andesite porphyry flows are generally similar in mineralogical composition, a fairly wide variance of general appearance in hand sample can be seen.

These rocks range in color and may be purple, red-brown, brown, dark or light gray and various shades of green, with the greens and grays being the most common. Generally, they are aphanitic with conspicuous phenocrysts of plagioclase and ferromagnesian minerals (usually hornblende or biotite), however, for some, the rock term felsite could apply since there are almost no phenocrysts.

Microscopic Description.—Microscopic description of 15 samples reveals the presence of a rather consistent mineralogical composition of these rocks over a large areal extent. The phenocrysts, which in almost all instances are only about 35 to 40 percent of the total rock volume, are plagioclase, amphibole, magnetite, and either pyroxene or biotite. In some rare cases, badly resorbed quartz is present. Oriented plagioclase laths are the most abundant constituent of the groundmass although in some cases a cloudy or turbid glass containing a few plagioclase laths predominate. Boutwell (1912) considered the groundmass of the andesites, a few miles to the west of this area, to be potash feldspar and quartz in those samples where the ground-mass was holocrystalline but this was found not to be the case in this area.

Plagioclase is the most abundant single phenocryst mineral and is of andesine composition. Oscillatory zoning is present in almost all samples observed. The plagioclase is subhedral to euhedral, badly crushed in some instances, and twinned by combinations of albite, carlsbad, and pericline twinning.

Amphiboles, either in the form of green or brown hornblende, or lamprobolite, are present in all samples observed. They are usually observed as well defined, euhedral crystals showing the common amphibole cross-section. Probably the most unusual occurrence of the amphiboles is as green hornblende containing irregular patches of lamprobolite. This same phenomena was apparently observed, but not explained, by Boutwell (1912) when he described the volcanics several miles to the west and reported an unusual mixture of "pink" and green hornblende. The amphiboles represent 10 to 15 percent of the phenocrysts by volume.

A definite relationship exists between augite and biotite in which either the biotite or augite are in the rock to the exclusion of the other (biotite being more common than augite), and only occasionally do both minerals occur to-

gether. They comprise about three or four percent of the phenocrysts by volume. Magnetite is universally present.

Alteration appears to have several origins with weathering, dueteric, and hydrothermal alterations all being present. The majority of the alteration is due to dueteric or weathering effects and forms calcite from plagioclase, and magnetite or hematite from the ferromagnesian minerals. Hydrothermal alteration is considered in a later section.

Andesitic Tuff Breccia

Megascopic Description.—Megascopically, these rocks are medium to light gray and are composed of mineral and rock fragments. The pieces of ferromagnesian minerals are easily observed but the rock fragments are not readily noticed and many samples do not show visible rock fragments.

Microscopic Description.—Both matrix material and rock fragments have the general composition of an andesite. The rock fragments make up approximately 30 percent of the rock and have a groundmass of microlitic plagioclase and finely divided quartz with phenocrysts of plagioclase (andesine), magnetite, and green hornblende. These fragments appear as sub-angular masses, with an average size of one millimeter.

The matrix has an aphanitic groundmass, much like that observed in the andesite porphyry, but with fragmented and crushed phenocrysts. The groundmass constituents of the matrix typically vary from one sample to the other but usually consist of plagioclase from devitrifying glass, finely crushed plagioclase, amphibole and pyroxene, and small amounts of quartz. Flow structure can be observed in some cases in the groundmass. Badly fragmented and crushed phenocrysts of plagioclase (andesine), green hornblende, augite, and magnetite appear in the groundmass. The phenocrysts comprise approximately 30 percent of the total rock volume with plagioclase phenocrysts being most abundant, green hornblende next abundant, with augite and magnetite as minor constituents.

INTRUSIVE ROCKS

Relationship to Problem

It has long been recognized that ore deposition is commonly associated with the intrusion of igneous rocks and that hydrothermal solutions from the intrusion are the agency by which the ore is brought to the site of deposition. Therefore, in order to understand hydrothermal alteration of sedimentary or volcanic rocks and any ore deposition, the plutonic rocks must be considered in the light of time and space relationship to the other rocks in the area.

A diorite porphyry stock is the only intrusive which crops out in the area under study; it is exposed in sections 28 and 29 of T. 2 S., R. 5 E.

Relationship to Extrusives

O'Toole (1951 *ms.*) considered the exposed diorite porphyry to be older than the andesite flows. He based his decision on finding what he considered to be fragments of the diorite porphyry incorporated in the andesite flows. A few miles to the west, Boutwell (1912) encountered the same evidence when considering a neighboring stock.

The writer, however, has found hydrothermal alteration centered around

the diorite porphyry which suggests that the diorite porphyry is younger than the extrusives.

Relationship to Other Intrusives

The major stocks to the west (i.e., the Little Cottonwood, Alta, Clayton Peak and Park City stocks) seem to be related in time and origin with the small stock of this area. Although Boutwell (1912) was not conclusive about the relationship of the major igneous masses to each other, Berge (1960) gives evidence which indicates that they may be closely associated both in time and origin. He points out that "from west to east, the stocks become more basic—smaller, more highly altered (hydrothermal) and have solidified at a shallower depth." He considered the possibility of the stocks being connected at depth and that the type of rock now exposed in each stock is partially a function of the depth to which erosion has progressed. He concluded that it is likely that other more basic stocks may be found to the east of Park City and that ores might well be found associated with them. The diorite porphyry of this investigation could be considered to be a small outcrop of such a stock. It generally conforms to Berge's (1960) concept as it is more basic than those described to the west and the fine-grained nature of the rock indicates that it has solidified at a shallow depth.

Since hydrothermally altered volcanic rocks can be observed, and because it has been proposed that the diorite porphyry is younger than the volcanic rocks which show the alteration, it seems reasonable to assume the possibility of hydrothermally introduced ore bodies within the area around the intrusion.

Petrographic Descriptions

Diorite Porphyry

Megascopic.—Megascopically the diorite porphyry is generally a gray, fine-grained rock with phenocrysts of plagioclase and pyrite randomly arranged throughout the rock. In hand sample, the rock appears to be relatively unaltered with the exception of an oxidation halo around each of the pyrite crystals. The fine-grained nature of the rock gives it the appearance of being extrusive but from field relationship it is determined to be a shallow intrusion.

Microscopic Description.—Observation under the microscope shows the rock to have a granitoid groundmass which is, by volume, about 37 percent of the rock, and the remainder is phenocrysts of amphibole, pyroxene, plagioclase, magnetite, and pyrite. The groundmass is composed primarily of anhedral grains of plagioclase (35 percent of the rock) with an average diameter of two millimeters and minor amphibole, pyroxene, and magnetite (total of two percent).

Phenocrysts comprise approximately 63 percent of the rock. Plagioclase phenocrysts of andesine composition are the most common of the phenocrysts making up about 46 percent of the rock. They show twinning by the albite, carlsbad, and pericline laws. The Michel-Levy albite twin extinction angle method was used to determine the composition of the plagioclase. The crystals show oscillatory zoning which is emphasized by differential limonite staining and weathering along the various zones in the crystal. Although the crystals are generally subhedral to euhedral, many are corroded. Approximately 12 percent of the rock is composed of yellow-green pleochroic hornblende. These

MINERAL ALTERATION PRODUCTS, KEETLEY-KAMAS AREA 11

crystals are anhedral and are highly resorbed. Pyroxene is only sparingly present making up less than one percent of the rock volume. Composition of the pyroxene appeared to be augite as determined by the birefringence, extinction, and lack of color, but identification was difficult because of the extreme resorption and alteration of the crystals. Magnetite and pyrite comprise four percent of the phenocrysts. The major alteration in the minerals was argillic although the oxides of iron were also relatively common.

TABLE 1*

65-1 m	65-27 m	136-4 m	138-8 m
65-2 m		136-5 d,sp	138-9 m
		136-6 d,sp	
65-3 m,d,sp	65-28 m,d,sp	136-7 m	138-19 m
65-4 m	66-1 m	136-8 m	138-11 m
65-5 m	66-2 m,d,sp	136-9 m,d	138-12 d,sp
65-6 m	66-3 m	136-10 m	138-13 m
65-7a m	66-4 m	136-11 m	138-15 m
65-7b m,d,sp	66-5 m,d	136-12 m	138-16 m
65-10 m	66-8 m	136-13a m	138-18 m
65-11 m,d,sp	66-9 m	136-13b m	138-19 m
65-12 d,sp	66-10 m	136-14 m	138-20 m
65-13 m,d,sp	66-11 m	136-15 m	138-21 m
65-14 m	66-12 m	136-16 m	182-1 m
65-15 d,sp	66-13 m	136-17 m	182-2 m
65-16a d	66-14 m	136-18b m,d,sp	182-3 m
65-16b d,sp	66-15 m	136-18c m,d,sp	182-4 m
65-17 d,sp	66-16 m	136-19 m,d,sp	182-5 m
65-18 sp	66-17 m	138-1 m	182-6 m
65-19 m,d,sp	66-18 m,d	138-2 m	182-7 m
65-20 d,sp	66-20 m	138-3 m	182-8 m
65-21 d,sp	66-21 d,sp	138-4 m	184-1 m
65-22 m	66-23 m	138-5 m	184-3 m,d
65-23 m,d,sp		138-6 m	184-4 m
65-24 m	136-2 m	138-7 m	

*The table shows all samples examined by the author and the method by which they were studied. m-petrographic microscope, d-differential thermal analysis, sp-spectrograph.

"SAND" DIKES

In the southwest corner of the area, small "sand" dikes with near vertical dips can be found cutting the flow rocks. They extend for only short distances along strike and are only a few inches thick. The greatest thickness observed was ten inches.

Rounded and angular fragments of plagioclase, magnetite, and ferromagnesian minerals as both fine powder and larger clasts ($\frac{1}{2}$ millimeter to one millimeter) are the dike materials. These fragments show a flow structure cutting across the andesite flows both in field occurrence and under the microscope.

Apparently the andesites were crushed and broken along fissures, and these fragments were carried along by rising hydrothermal solutions and thus produced flow structure.

No fragments of sedimentary rocks were identified within the dikes.

ALTERATION

Field Work

In order to obtain necessary data for an understanding of the alteration, hand samples were taken from selected sites within the area. A systematic approach to the collection of the samples was obtained by using 1:20,000 scale contact prints upon which a grid pattern with an approximate density of six and one half squares per square mile and had been superimposed. Samples of the altered rocks were taken from the grid squares according to the apparent usefulness of each sample. One sample was collected from each grid square except in areas where two or more seemed to be important to the understanding of the problem; where no sample seemed to be meaningful, none was collected. Each sample was labeled by marking it with the number of the contact print on which it was recorded, a hyphen, and the number to indicate its sequence of collection (example: 65-1). The collecting locations were marked on the appropriate contact prints for future reference. Contact prints which were used included Department of Interior numbers: CVY-4K-65, 66, 136, 138, and 182, and DRU-4K-184.

Since a geologic map was available for the area, field mapping was not attempted, but the author field-checked the geology and some minor unrecorded outcrops were noted on the contact prints for the purpose of annotating the geologic map.

TABLE 2*

<i>Sample</i>	<i>Plagioclase alteration</i>	<i>Ferromagnesian alteration</i>
65-1	clay	
65-2	calcite	chlorite (intense)
65-4		chlorite
65-5		lamprobolite-green hornblende
65-7a		chlorite (slight)
65-7b	clay (intense)	
65-11	kaolin (?)	
65-13	clay	
65-14		chlorite, calcite
65-19	alunite	
65-22		chlorite, magnetite
65-28	kaolin (?)	
66-2	kaolin (?)	
66-3		chlorite, magnetite
66-5	montmorillonite (?)	
66-9		chlorite
66-17		chlorite, hematite
66-23		chlorite, hematite
136-4		chlorite (intense)
136-8		chlorite, hematite
136-17		chlorite, calcite, epidote
136-18a	clay (slight)	chlorite
136-18c	clay, silicification	
136-19	kaolin (?)	
138-1,2,3		lamprobolite-green hornblende
138-7		chlorite (slight)
138-16		chlorite
138-18		chlorite

*The above table shows the important mineral alterations as determined by petrographic microscope. Question marks indicate that the alteration mineral was not definitely identified.

Laboratory Work

The laboratory work consisted of quantitative spectrographic analysis, differential thermal analysis, and petrographic microscopic analysis. From the samples collected in the field, 95 samples were each subjected to one, two or all three of these analytical procedures. Table 1 shows the treatment given to each sample. Eighty-three samples were examined microscopically, 26 samples were examined by differential thermal analysis, and 22 samples by quantitative spectrographic analysis. Briefly the results showed hydrothermal alteration in 33 samples as observed microscopically (see Table 2), and in 14 samples as observed by differential thermal analysis (see Table 3). All results of the spectrographic analysis are listed in Table 5.

TABLE 3*

<i>Sample Number</i>	<i>Alteration Type</i>	<i>Minerals Involved</i>
65-3	silicification	quartz
65-7b	kaolinization	kaolin (?)
65-12	silicification	quartz
65-15	silicification	quartz
65-16b	silicification	quartz
65-17	halloysitization	halloysite
65-19	alunization	alunite
65-20	alunization	alunite
65-21	kaolinization	kaolin-disapora (?)
65-23	silicification	quartz
136-5	montmorillonization	montmorillonite
136-18b	kaolinization	dickite-kaolinite
136-18c	kaolinization	kaolinite
138-12	silicification	quartz

*The above table shows the major hydrothermal alteration product of the highly altered rock samples as determined by differential thermal analysis. The question marks indicate that the thermal curve varies slightly from normal.

Petrographic Analysis

Purpose

The petrographic microscope was used to aid in the identification of alteration products. This form of analysis also helps distinguish the mechanics involved in the alteration process and enables the investigator to recognize whether the alteration is hydrothermal, deuteric, or weathering.

Methods

Standard thin-sectioning techniques, as described in Kerr (1959), were used to cut and grind the rock thin-sections. In some cases the rocks were so badly altered to clays that all grinding had to be done using kerosene to prevent swelling of the clays and the resultant loss of the section.

About 90 thin-sections were cut from samples obtained in the field and systematically studied to determine the type and extent of alteration.

Results

Study by petrographic microscope shows four main alteration products to be prevalent in the area. Several types of clay (identified with the aid of differential thermal analysis), calcite, chlorite, and magnetite, either alone or in combinations, were the alteration products observed. Table 2 lists the samples which are hydrothermally altered and the type of alteration shown by

each. The table is limited to those samples which contain either alunite, clays or chlorite, because these minerals are most suggestive of hydrothermal alteration. The lamprobolite-green hornblende alteration is also listed on the table.

Magnetite, as an alteration product, was present in most samples studied. The ferromagnesian minerals alter to rims of magnetite in most samples, and in some, the entire mineral was altered to magnetite or hematite. Amphibole and biotite were most frequently altered to magnetite. Pyroxene showed considerably less tendency to do so.

Calcite, as veining or alteration, was not widespread in the samples investigated; where present, it forms the major part of the altered rock. Calcite results from the alteration of both plagioclase and ferromagnesian minerals; plagioclase is generally more affected.

The most intense alteration was argillic alteration in which the entire sample was changed to kaolin or montmorillonite. Many of the clay samples were not suitable for thin-sectioning, but, in cases of lesser alteration, thin-sections showed the alteration to be most severe in the plagioclase but present in the ferromagnesian minerals also. Some samples (65-11, 65-28, 66-2, 66-5, and 136-19) did not lend themselves to thin-section study and, when subjected to differential thermal analysis, did not give recognizable curves. These samples were crushed and optically examined in index oils for identification.

Chloritic alteration was less conspicuous than the other types even though it was more widespread. The ferromagnesian minerals frequently show chloritic alteration which started within the crystals and moved toward the edges. In few instances did the alteration product (chlorite) completely replace the original crystal but in sample 65-2 it was nearly complete.

One unusual alteration situation exists in the amphibole lamprobolite which is partially altered to green hornblende. In some samples it is possible to see lamprobolite only slightly replaced along the cleavage planes by green hornblende, which suggests that lamprobolite was the original mineral and green hornblende was secondary. This alteration more commonly appears as crystals of green hornblende containing scattered and resorbed patches of lamprobolite.

Alunite was present in only one slide, but it made up about 50 percent, by volume, of that sample.

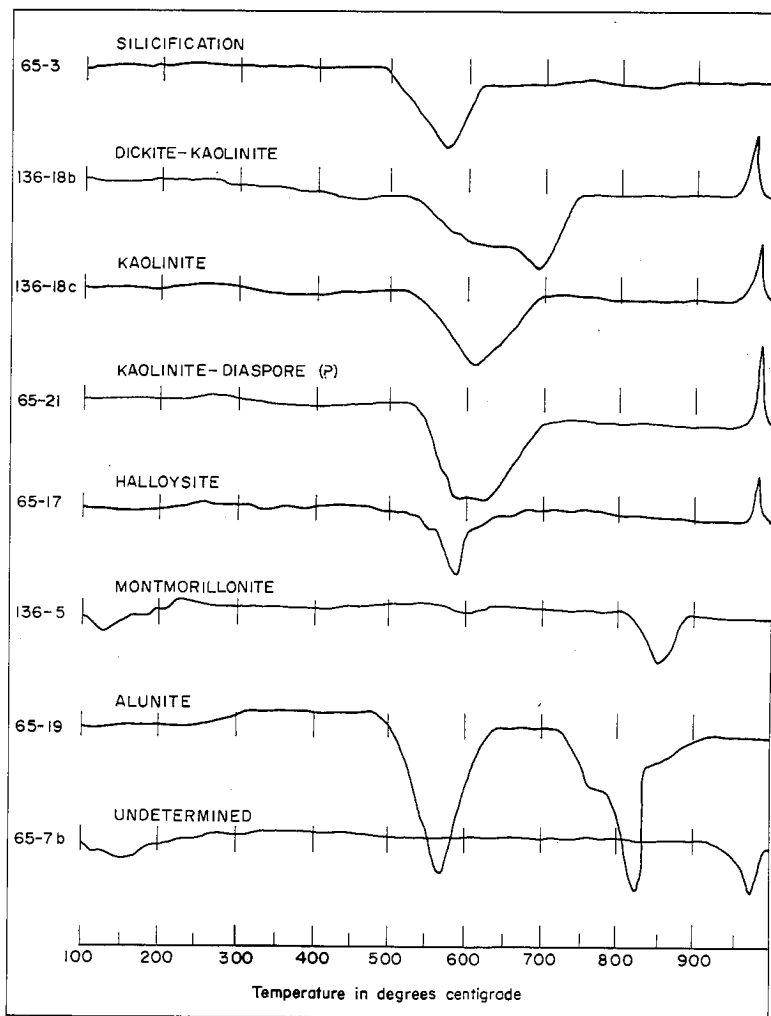
Minor alteration products include epidote in the ferromagnesian minerals, sericite and the hydrous oxides of iron.

Conclusions

Only three of the alteration products are considered to be hydrothermal; the clays, alunite, and chlorite. Although sericite is commonly accepted as being a product of intense hydrothermal alteration, it may also appear as a weathering alteration. Since the sericite observed in this investigation was not found in significant amounts nor was it consistent with the hydrothermal alteration patterns, it is considered to be a weathering product. Calcite and epidote may be associated with hydrothermal alteration, weathering, deuteric alteration, or may even be primary but the lack of any consistency with the hydrothermal alteration suggests a weathering origin. Limonite is associated with both weathering and hydrothermal action. The lamprobolite-green hornblende alteration is of undetermined origin. Magnetite from the alteration of ferromagnesian minerals is so universally present and widespread beyond the hydrothermal zones, that it is likely to be due to weathering.

Boutwell (1912) considered the alteration in flow rocks located immediately to the west of the studied area to be due to weathering. He indicated that chlorite and epidote were widespread and due to weathering although he said they could be found at great depths. Because the writer found chlorite limited to a more or less definite area and associated with the clay and alunite alteration, it is considered that the chlorite is hydrothermal.

Clay alteration was spotty but strongly developed in local areas. Progressively increasing argillic alteration can be observed over short distances. Samples 136-18a and c were taken from only a few tens of feet apart but show a strong variance in clay alteration. The same can be said about 65-7a



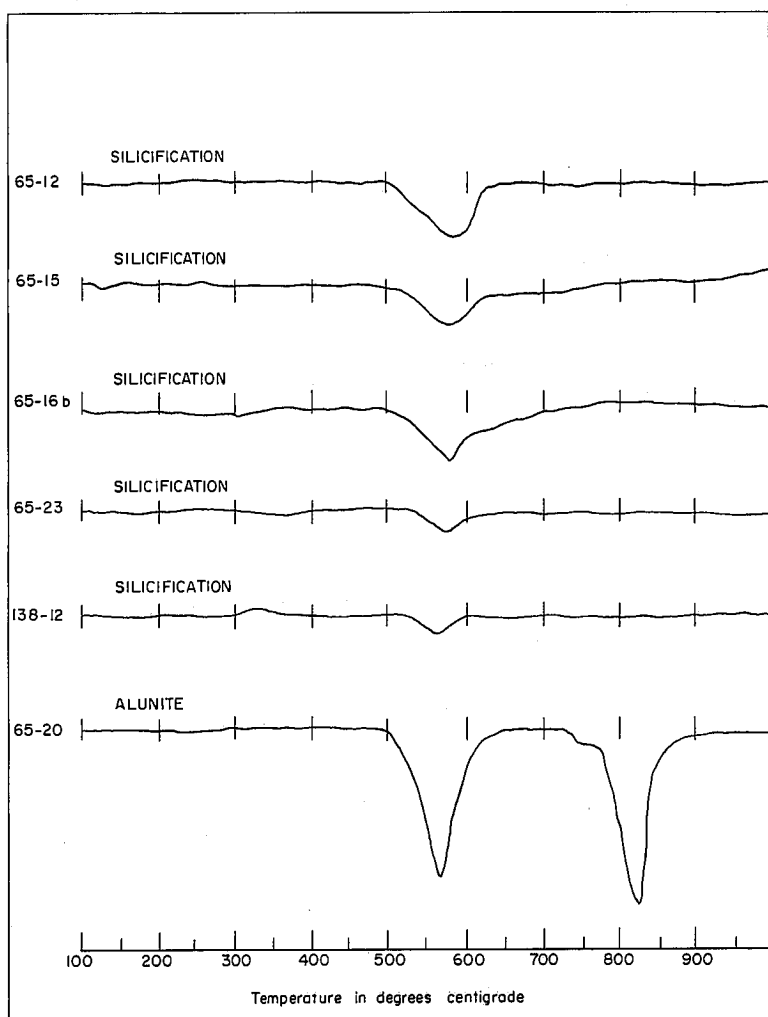
TEXT-FIGURE 2.—The figure shows the differential thermal curves obtained from the rock samples listed and the mineral name which each curve indicates.

and b where a shows only slight chlorite alteration, but b is almost entirely altered to clay. Therefore, the clays are assumed to be of hydrothermal origin occurring in local areas. The localized clay alteration is presumably restricted to faults and fissures or very near the igneous intrusion.

Alunite was only locally observed near the intrusion and is considered to be hydrothermal.

Evidence concerning the green hornblende-lamprobolite alteration is not conclusive. The samples, in most cases, show little additional alteration. This situation might indicate that the alteration was deuteric.

Clays and chlorite have widest distribution of the presumed hydrothermal minerals. (See Table 2, Table 3, and Text-figure 10).



TEXT-FIGURE 3.—The figure shows the differential thermal curves obtained from the rock samples listed and the mineral name which each curve indicates.

Differential Thermal Analysis

Purpose

Since alteration minerals are often very fine-grained and otherwise difficult to examine by conventional petrographic procedures, differential thermal analysis is commonly employed to distinguish the various alteration types. This procedure was employed with the hope that it might enable recognition of specific secondary minerals in the highly altered rocks.

Methods

Differential thermal analysis is a procedure designed to detect physical or chemical changes which occur within the mineral structure as a result of temperature change. To accomplish this, two opposing chromel-alumel thermocouples are mounted so as to detect any temperature differential between thermally inert Al_2O_3 surrounding one thermocouple and the unknown sample surrounding the other as the entire unit is heated uniformly from room temperature to $1,000^{\circ}C$. Such a thermal differential, resulting from loss of combined water, change in the oxidation state, structural adjustment, etc., causes a net current to flow between the opposing thermocouples. The approximate magnitude and the exothermic or endothermic nature of these thermal reactions and the temperature at which they occur were recorded on a Leeds and Northrup recorder.

Each hand sample was broken into one-half inch pieces; and a few pieces, selected as being representative of the sample, were ground in a porcelain mortar to between 200 and 300 mesh. This powder was mixed by rolling and quartering and was packed around a thermocouple in a cavity measuring one-fourth inch diameter and one-half inch deep in a nickel block. The sample was heated at a rate of approximately twelve and one-half degrees centigrade per minute. Each sample was run twice to enable the author to check the reproducibility of the curves, and the samples were examined with a petrographic and binocular microscope to determine the probable mineral content before they were ground. All curves were reproducible within five degrees and showed only slight variation in height of peaks.

TABLE 4*

<i>Rock Type</i>	<i>Pb</i>	<i>Mn</i>	<i>Ag</i>	<i>Cu</i>
Coats (1952)—andesites and basalts	..	..	..	.004
Fairbairn (1953)—diabase	.0006	..	.0004	.0072
Sandell & Goldich (1943)—augite, andesite	.0010	..	..	.0015
olivine andesite	.0007	..	..	.0010
Rankama & Sahama (1949)— average basic igneous rocks	..	.00135	..	..

*The above table shows the average concentration of several trace elements in andesite or similiar rocks. Concentrations are in weight percent.

Presentation of Data

Differential thermal curves indicate silicification and kaolinization to be the major alterations involved, whereas, alunitization and montmorillonitization are minor. The kaolinization includes the production of kaolinite, dickite, and halloysite. Table 3 lists the sample numbers and the type of alteration product recognized. Text-figures 2 and 3 show the thermal curves for the

TABLE 5*

Sample Number	Pb	Mn	Ag	Cu
65-3	.00073	.014	.0025	.0010
65-7b	.0014	.0138	.0013	.00065
65-11	.015	.0008	.0051	.0041
65-12	.0018	.0031	.00043	.00065
65-13		.014	.00058	.00079
65-15	.0055	.0022	.00093	.00086
65-16b	.00615	.0013	.00028	.00044
65-17	.0022	.0009	.0011	.0002
65-18	.00195	.026	.0072	.0022
65-19	.00195	.0018	.001	.00024
65-20	.0072	.00026	.00055	.0003
65-21	.0056	.00062	.00043	.00021
65-23	.00654	.00335	.0065	.0024
65-28	.0017	.0013	.0065	.0018
66-2	.00298	.003	.00615	.00014
66-21	.00093	.012	.00069	.00044
136-5	.0016	.029	.0024	.015
136-6	.0037	.0075	.18	.01
136-18b	.0024	.0142	.00029	.00045
136-18c	.00124	.000505	.00195	.000442
136-19		.0024	.0015	.00038
138-12	.0019	.01	.001	.001

*The above table shows the weight percent of elements indicated in the Keetley-Kamas samples of andesite as determined by quantitative spectrographic analysis.

samples tested in this investigation, and text-figure 4 contains standard thermal curves obtained from Speil (1944) and Kerr & Kulp (1948).

Thermal curves for each of the major alteration products have been shown in text-figures 2 and 3 and the products listed in Table 3.

Alunite was readily determined by its diagnostic differential thermal curve and was confirmed by microscopic examination. The curve, although easily distinguishable as that of alunite, varied unexplainably from that obtained by Kerr & Kulp (1948) in that it did not display the small exothermal reaction at 735°C.

Kaolinite produced differential thermal curves which were apparently standard with the exception that the peaks were less pronounced than normal and that an extra endothermal peak occurred in sample 65-21, at 582°C. The extra peak indicates that either the sample contains two minerals or else that the mineral was misidentified. Based on the very good similarity of the curve to standard kaolinite, the author accepts the former conclusion and diasporite or possibly halloysite is considered as a possibility for the second mineral.

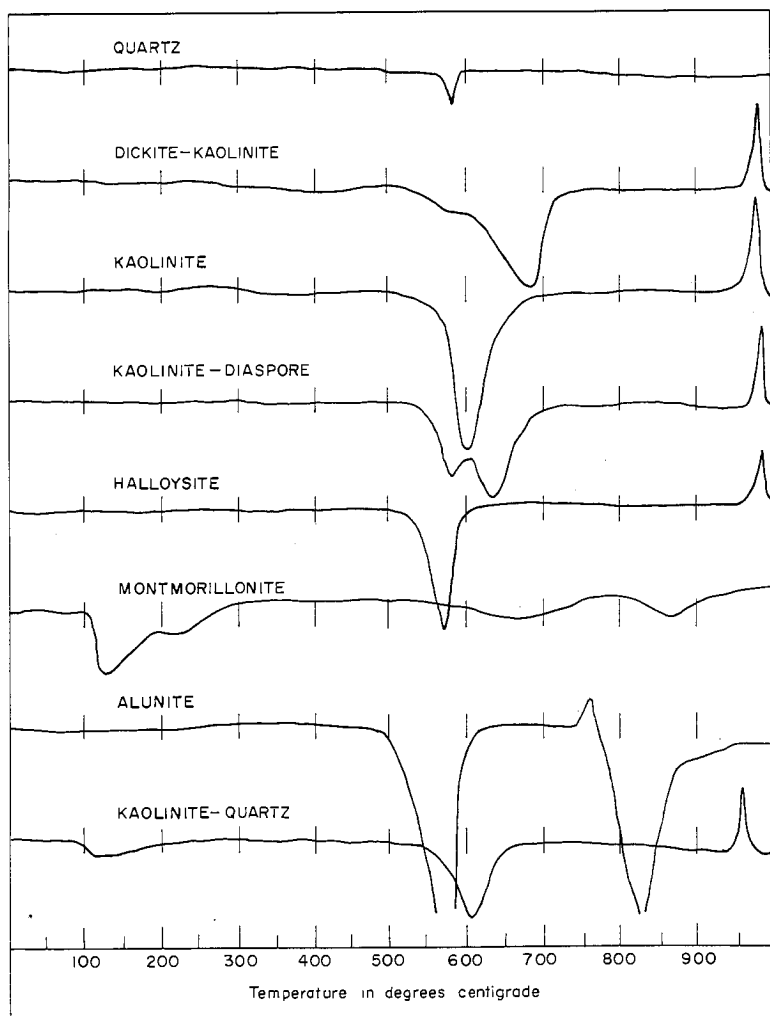
Dickite curves were obtained from sample 136-18b, however, the standard curve was apparently modified by other minerals. This mixture compares with the 10 percent kaolinite, 90 percent dickite curve obtained by Kerr & Kulp (1948). Nacite, however, also gives a curve similar to that of the previously mentioned mixture.

Quartz curves, indicating silicification, were easily determined with no apparent problem except for low intensity and broad peaks.

The curve obtained for halloysite agrees favorably with the standard curve and there seems to be no problem in identifying this mineral.

Sample 136-5 produced a thermal curve which compares favorably with

the one obtained by Kerr & Kulp (1948) for the mineral montmorillonite. Although an endothermic reaction, which occurs on their curve at 700° C, does not appear for sample 136-5, the alteration is still considered to be montmorillonite.



TEXT-FIGURE 4.—The figure shows the differential thermal curves, from Kerr & Kulp (1948) and from Speil (1944), which the author used in identifying the mineralogy of the thermal curves obtained from his own altered rock samples.

The alteration of some samples was not identifiable by differential thermal analysis methods even though the samples were apparently highly altered as seen in hand specimen. The reason for this was that the curves did not have definite peaks but showed broad peaks spread gently over the course of the run. This lack of characteristic curves may be due to the physical problems

of differential thermal analysis such as a combination of several alteration products or to the lack of minerals which can be identified by this means. Since most alteration minerals give some sort of curve, and because a lack of pronounced peaks was observed even in those identifiable samples, this author believes the problem to be one of a physical nature.

Physical problems of differential thermal analysis which might apply to this investigation are: (1) size distribution of grains, (2) rate of temperature increase, (3) mixture of two or more minerals in one sample. If a large number of grain sizes are present in the sample, or if the grain size is very small, the overall effect is one of lessening the height of the curve and of showing the reaction over a much greater period of time.

Speil (1944) showed that the rate of temperature increase also affects the rate of reaction and hence the height of the peaks and the length of the reaction. Kerr & Kulp (1948) demonstrated that the mixture of several minerals greatly increases the problems of mineral identification by differential thermal analysis. Speil (1944) indicates that materials other than the specific reacting mineral tend to depress the curve as is shown by the formula:

$$T = \frac{M (\Delta H)}{Mo C}$$

where

M=Mass of reacting material

T=Temperature change resulting
from the reaction

ΔH =Specific heat of reaction

Mo=Total mass of specimen

C=Mean specific heat of specimens

Approximately one-half of all the samples run gave no distinctive curve even though they were highly altered and apparently had minerals which should have given distinctive curves. They were later identified by optical methods. Since the heating rate (12.5°C/min.) used in this investigation is apparently satisfactory, the author concludes that mixtures of non-reacting minerals, in the samples being tested, caused the poorly pronounced curves.

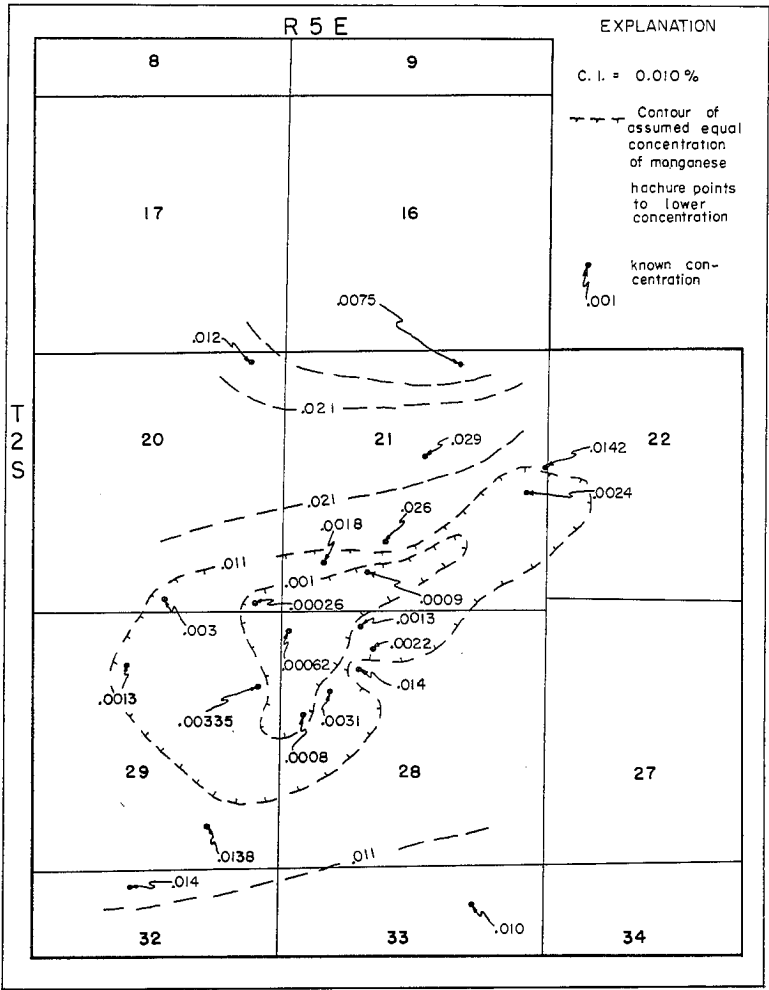
Conclusions

Differential thermal analysis provides evidence of the types of alteration produced by hydrothermal solutions. Kaolinite, dickite, halloysite, quartz, alunite, and montmorillonite were identified as the alteration products of hydrothermal alteration. Differential thermal analysis was so ineffective with other highly altered samples that optical analysis became necessary for identification.

Spectrographic Analysis

Purpose

The elements lead, zinc, gold, silver, manganese, and copper are not normally included in the formulas of the minerals found in andesite rocks. Hence, if they are present in the rock they are trace elements that were



TEXT-FIGURE 5.—Contour diagram of the percent by weight of manganese in the altered andesitic rock.

originally included or are hydrothermally introduced. Since work has been done which lists the amounts of trace elements normally found in rocks of this composition, any substantially greater amount likely means that there has been hydrothermal introduction.

Methods

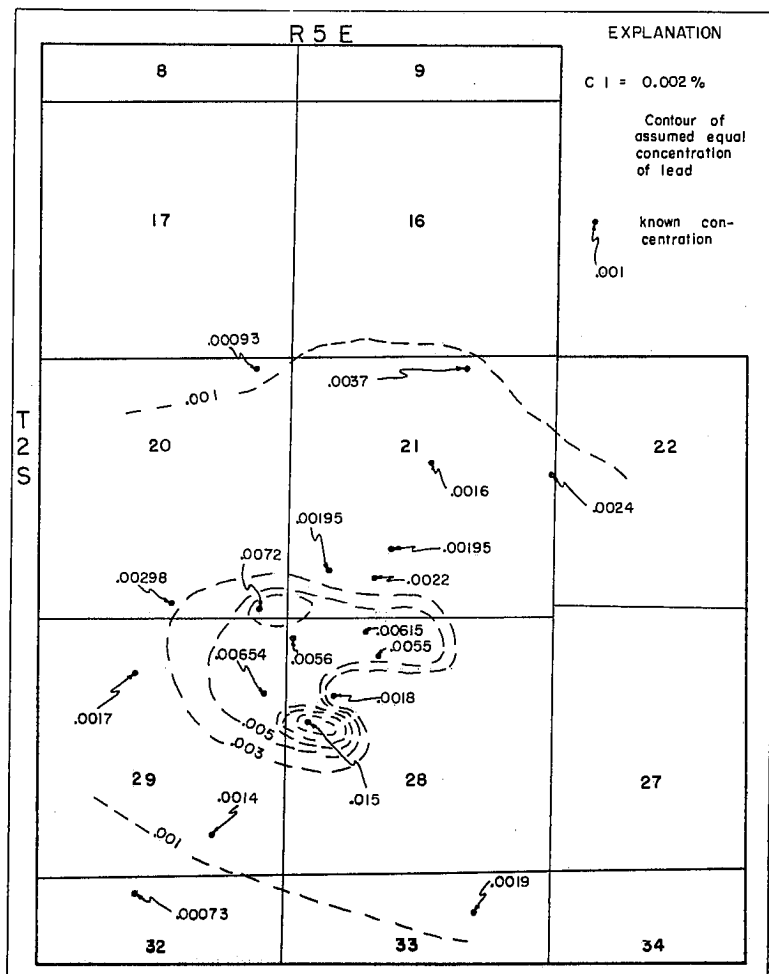
Samples for spectral analysis were obtained in the same manner as described for the differential thermal analysis. In order to be certain that contamination from the porcelain mortar would not affect the results, a test was made by grinding part of the rolled and quartered fragments of a sample in

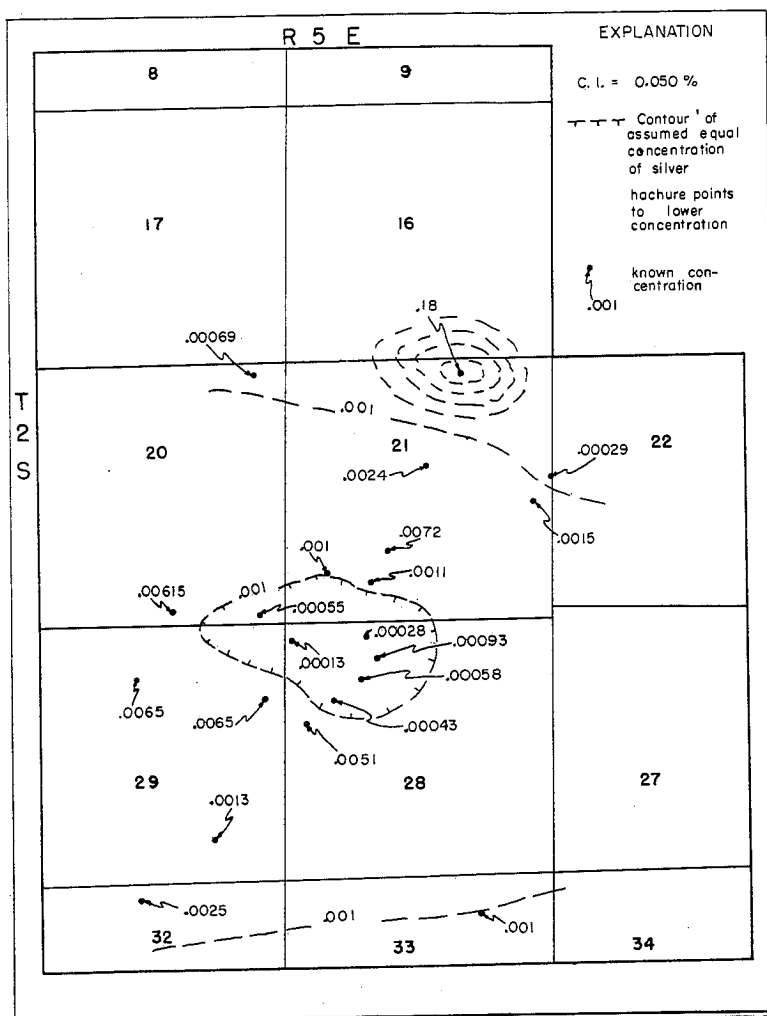
a porcelain mortar and another part in an agate mortar. No significant difference was observed in the spectral analysis of the two samples.

Standard spectrographic procedures, similar to those described by Sawyer (1946) and by Harrison, Richard, & Loofbouroow (1948), were used. Samples of the powdered rock were mixed at a 1:1 ratio with a Li_2CO_3 buffer. Bismuth was used as an internal standard for all of the elements tested.

Results

By comparing Tables 4 and 5, it is possible to see that the concentration of lead, copper, and silver were generally not conspicuously higher than in andesitic rocks of other areas. However, in certain local areas as represented by sample 136-6, substantial increases in silver (.18 percent) and copper (.01





TEXT-FIGURE 7.—Contour diagram of the percent by weight of silver in the altered andesitic rock.

percent) were noted. These increases apparently indicate significant hydrothermal introduction although commercial assay shows this to be really insignificant.

Manganese appears to be significantly higher than normal in about one-half of the samples.

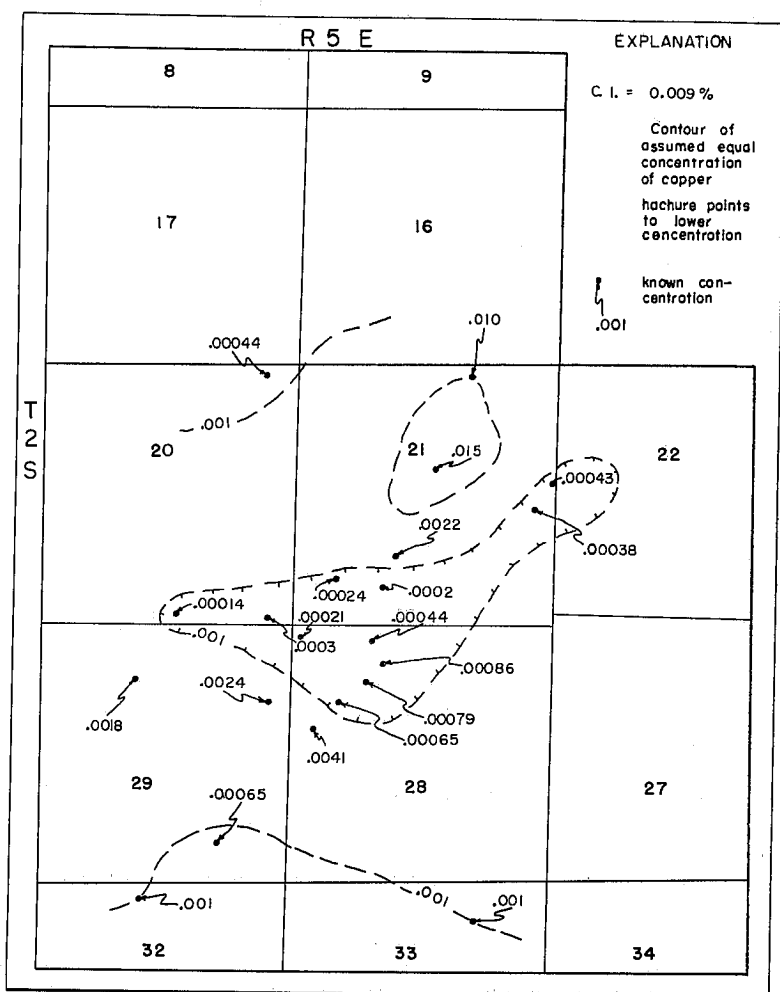
Early trial runs indicated that gold and zinc were either not present or that they were not detectable in the concentrations present. Gold probably was not present in significant amounts, whereas zinc may have been present but its spectral lines were not sensitive with the concentrations present. Trial runs, containing zinc in known concentration, showed zinc to be undetectable when

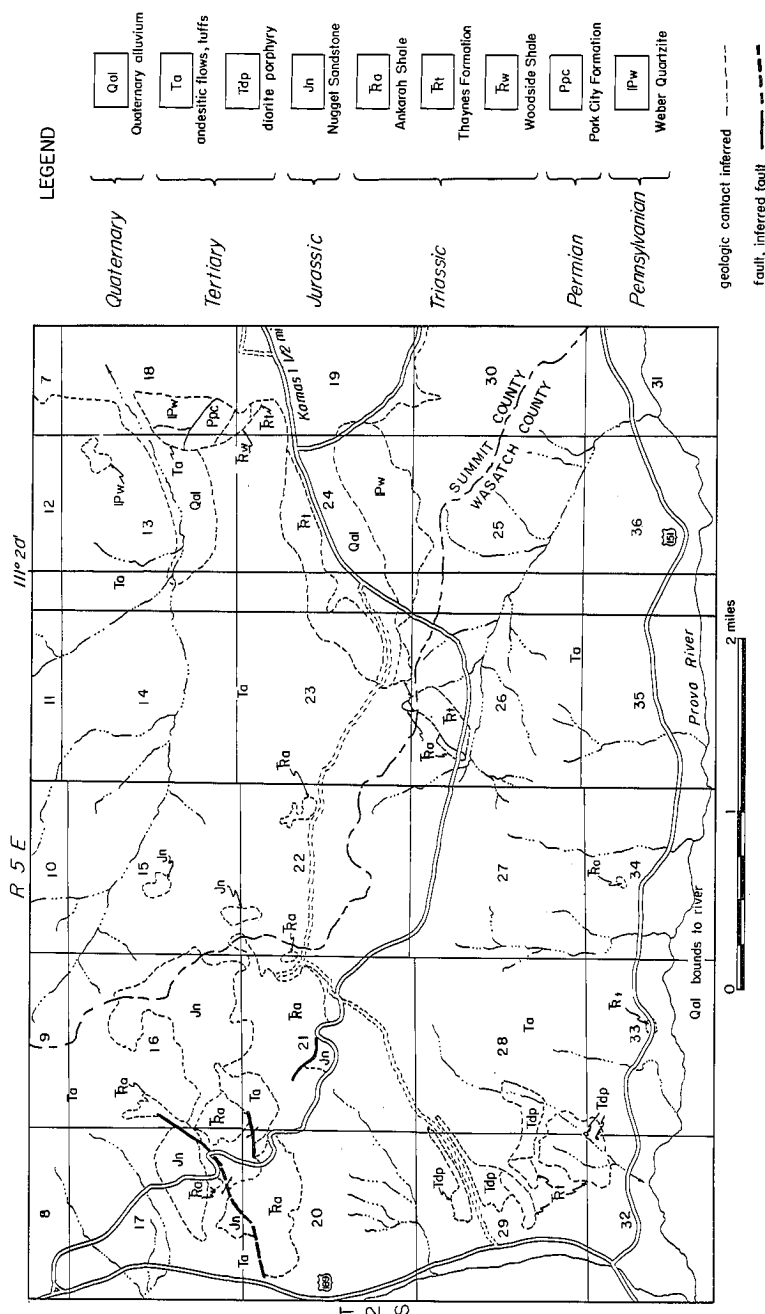
present in concentrations of less than 0.01 percent. Tin spectral lines were observed from sample 136-19 and, although no quantitative values were obtained, the spectral lines were very strong.

Conclusions

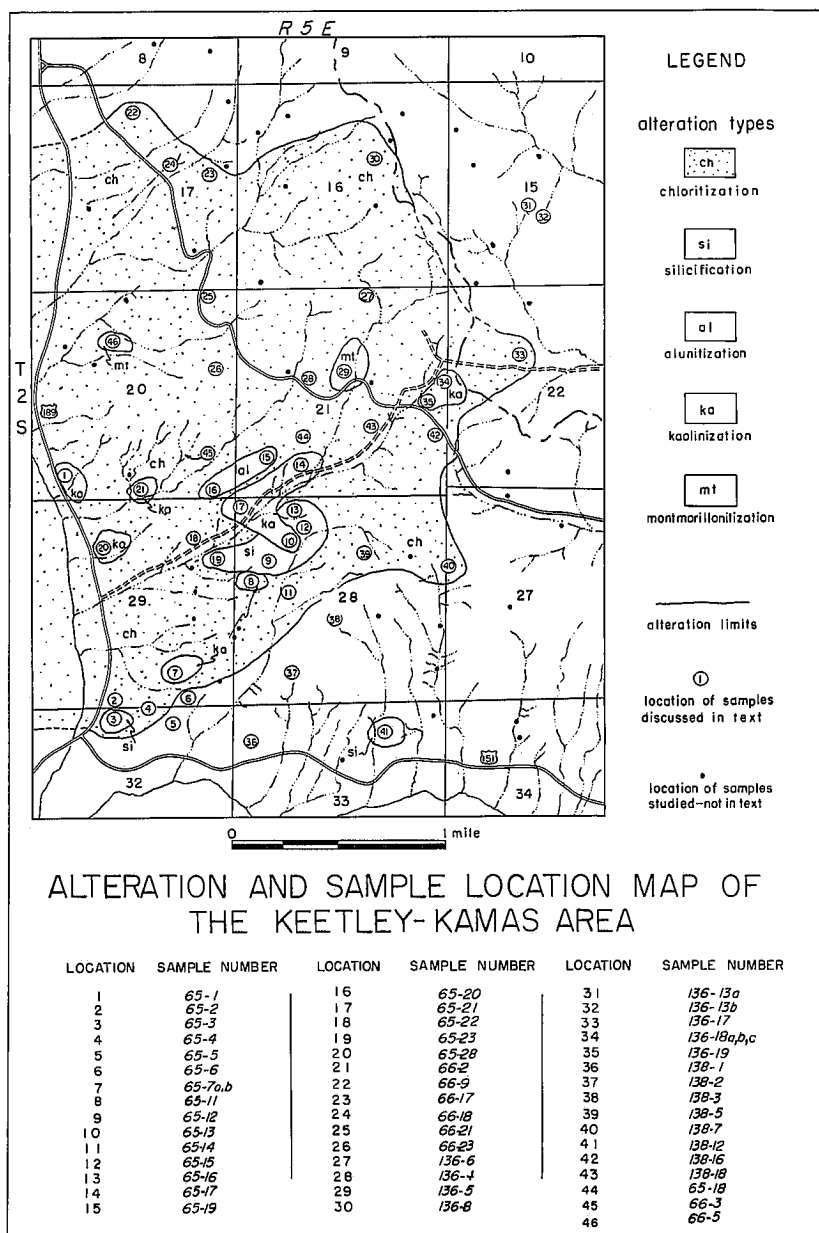
The quantitative accuracy of the spectrographic methods of this investigation is not definitely known but should be good to at least ± 50 percent and therefore is probably good enough to warrant the general conclusion stated below. Probably the major source of error was in weighing the mixtures used in preparing the known standard concentrations.

By referring to text-figures 5, 6, 7, and 8 it becomes apparent that the





TEXT-FIGURE 9. Geologic map of the Keetley-Kamas area. Modified after O'Toole (1951)



TEXT-FIGURE 10.—Alteration and sample location map of the Keetley-Kamas area.

lead concentration is higher at the center of the hydrothermal alteration area (the area around the diorite porphyry) and decreases in concentration outward whereas the reverse is true of manganese, silver and copper. This indicates that the hydrothermal introduction is a higher temperature introduction near the center and becomes lower toward the edges as would be normally expected. However, when the actual percent concentration of these elements (Mn, Pb, Ag, Cu) are considered, it is seen that the manganese is of consistently high concentration whereas silver, lead, and copper are relatively low in concentration. This would indicate that the hydrothermal introduction is definite but of a low temperature.

CONCLUSIONS

Hydrothermal alteration in the area is shown on text-figure 10 with the general limits of each type of alteration. By comparing text-figure 9, the geologic map and text-figure 10, the alteration map, it is evident that the chlorite alteration pattern on text-figure 10 is superimposed over sedimentary rocks which generally show no such alteration. This is done because the chlorite alteration zones surround the sedimentary rocks and it is believed that the altering solutions traversed these rocks; but, because they were sandstones, siltstone, and shales, they were not generally susceptible to that type of alteration.

The highest intensity of alteration is seen in volcanic rocks around the diorite porphyry intrusion although the diorite porphyry is also highly altered.

The alteration minerals alunite, dickite, halloysite, kaolinite, and chlorite are generally considered to be common hydrothermal alteration minerals. Because these minerals, along with montmorillonite, are found localized around the diorite intrusions and are associated with the "sand" dikes and high concentrations of manganese, they are considered as adequate evidence for hydrothermal alteration.

Lovering (1949), at the Tintic Mining District, considered alunite to be the result of the last waning stages of hydrothermal alteration as the solutions became neutral. This concept, along with the generally accepted low temperature introduction of manganese, coupled with the knowledge that this area has been highly prospected by pick and shovel with negative results, indicates that the alteration was caused by waning or barren hydrothermal solutions. This may mean that the hydrothermal solutions were barren of ore or that the ore would be deeper (i.e., closer to the source) where the alteration would apparently be more intense. The implication, of the higher-than-usual concentration of silver and copper in local areas, is that the hydrothermal solutions were ore bearing, and it may well be that ores could be encountered at depth as blind ore bodies.

Taking into consideration the hydrothermal alteration, the introduction of trace elements, and the stratigraphy of the area (all of which were previously discussed) this author suggests a drilling program be conducted in the area where these factors seem to indicate the most likely possibility of ore deposition at depth. This includes the area in the northwest corner of Section 28, northeast corner of Section 29, the southeast corner of Section 20, and the southwest corner of Section 21, T. 2 S., R. 5 E. The most likely ore horizon would be the Park City Formation.

REFERENCES CITED

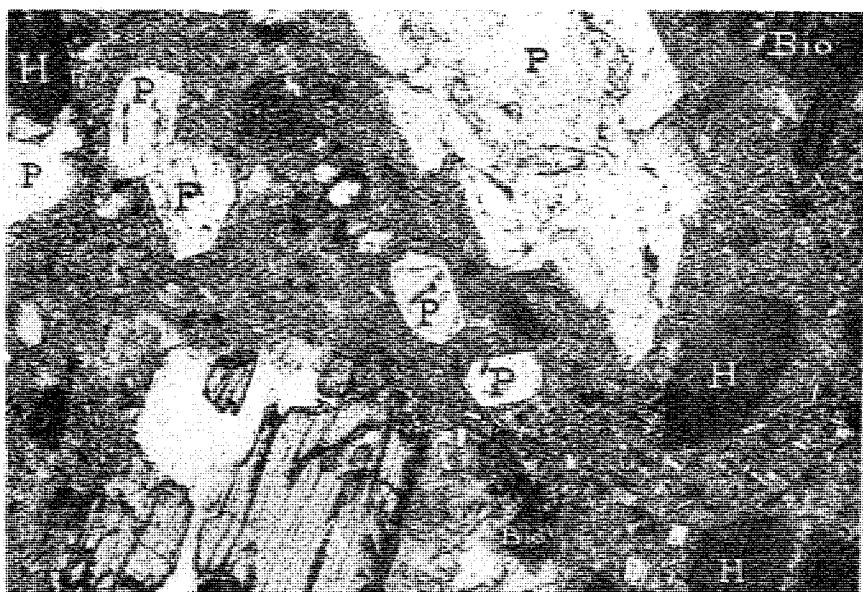
- Berge, C. W., 1960, Heavy minerals study of the intrusive bodies of the Central Wasatch Range, Utah: Brigham Young University Res. Studies, Geol. Ser., v. 7, no. 6, 31 p.
- Boutwell, J. M., 1912, Geology and ore deposits of the Park City District, Utah: U.S. Geol. Surv., Prof. Paper 77, 231 p.
- Coats, R. R., 1952, Magmatic differentiation in Tertiary and Quaternary volcanic rocks from Adak and Kanga Islands, Aleutian Islands, Alaska: Geol. Soc. Amer. Bull., v. 63, p. 485-514.
- Eardley, A. J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. Amer. Bull., v. 55, p. 819-894.
- Fairbairn, H. W., Ahrens, L. H., & Gorfinkle, L. G., 1953, Minor element content of Ontario diabase: Geochem. et Cosmochim. Acta, v. 10, p. 197-223.
- Forrester, J. D., 1937, Structure of the Uinta Mountains: Geol. Soc. Amer. Bull., v. 48, p. 631-666.
- Granger, A. E., 1953, Stratigraphy of the Wasatch Range near Salt Lake City, Utah: U.S. Geol. Surv., Circ. 296, 14 p.
- Harrison, G. R., Richard, C. L., & Loofbourow, J. R., 1948, Practical spectroscopy, New York, Prentice-Hall, Inc., 605 p.
- Kerr, P. F., 1959, Optical Mineralogy, 3rd Ed., New York, McGraw Hill, 442 p.
- & Kulp, J. L., 1948, Multiple differential thermal analysis: Amer. Mineralogist, v. 33, nos. 7-8, p. 387-419.
- Lovering, T. S., 1949, Rock alteration as a guide to ore-East Tintic District, Utah: Econ. Geol., Monograph 1, 64 p.
- O'Toole, W. L., 1951 *ms.*, Geology of the Keetley-Kamas volcanic area: unpub. m.s. thesis, Univ. of Utah, 38 p.
- Ramkana, K., & Sahama, T. G., 1949, Geochemistry, Chicago, University of Chicago Press, 911 p.
- Sandell, E. B., & Goldich, S. S., 1943, Metallic constituents of American igneous rocks: Jour. Geol., v. 51, p. 99.
- Sawyer, R. A., 1946, Experimental spectroscopy, New York, Prentice-Hall, Inc., 323 p.
- Speil, S., 1944, Application of thermal analysis to clays and aluminous minerals: U.S. Bur. Mines, Rept. Inv. 3764, p. 1-36.

Manuscript submitted January 12, 1962.

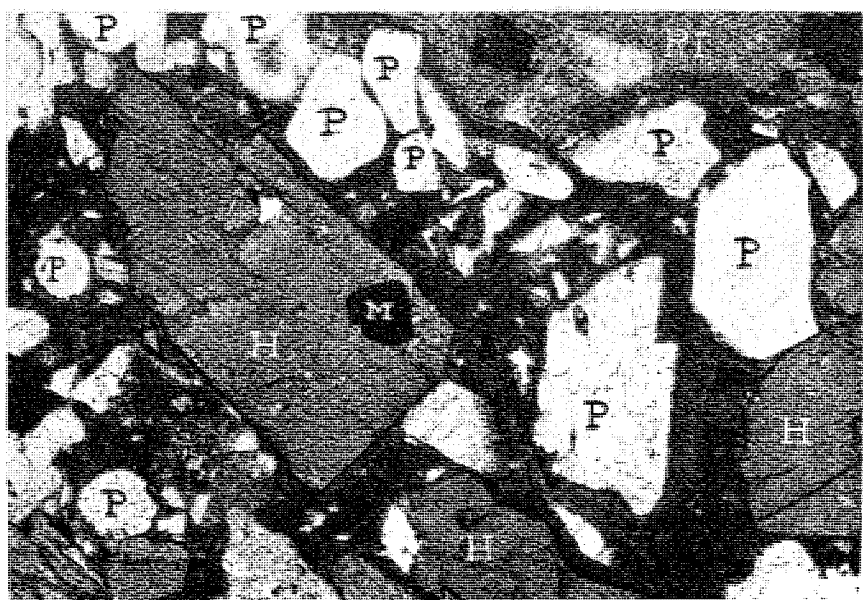
EXPLANATION OF PLATE 1

- Fig. 1. Photomicrograph-representative andesite porphyry. The photograph shows the generalized mineralogy and character of most of the andesite porphyry in the Keetley-Kamas area. X50, Bio-biotite, P-plagioclase, H-hornblende, A-augite.
- Fig. 2. Photomicrograph-representative andesite tuff breccia. The photograph shows the generalized mineralogy and character of most of the andesite tuff breccias in the Keetley-Kamas area. X50, M-magnetite, P-plagioclase, H-hornblende, Rf-rock fragment.

PLATE 1

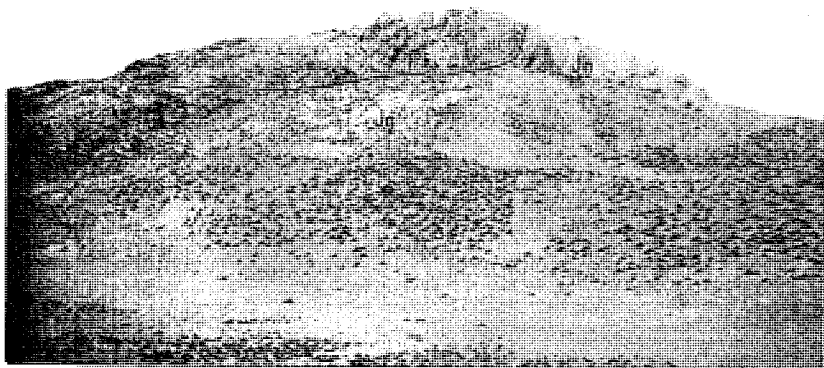


1



2

PLATE 1



1



2



3