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Petrology and Petrography of the Intrusive Igneous Rocks of the Levan Area, Juab County, Utah*

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ABSTRACT.—The intrusive igneous rocks of the Levan area are intermediate to basic in composition. Small stocks, bosses, dikes and sills make up 28 separate intrusions into the Arapien Shale and Green River Formation. Chemical and mineralogical composition shows six rock types that in order of predominance are: porphyritic leucomonzonite, monzonite porphyry, hornblende monzonite porphyry, biotite-augite monzonite, diabase, and syenodiorite porphry. Relative ages of intrusion were diabase, monzonite porphyry, hornblende monzonite porphyry, porphyritic leucomonzonite, and syenodiorite porphyry. Biotite-augite monzonite is the result of deuteric alteration of hornblende monzonite porphyry. Age of intrusion is post-Green River Formation, that is, post-middle Eocene.

Alterations consist of contact metamorphism, hematite and silica metasomatism, and low temperature hydrothermal alteration. No evidence of economic metallization was found.

Chemical and mineralogical data indicate a probable correlation between the intrusive rocks of the Levan area and the extrusive rocks of the Moroni Formation.

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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 of Master of Science, May 15, 1964.

INTRODUCTION

The Levan area is in Juab County, Utah, in the northwestern part of the Gunnison Plateau (San Pitch Mountains, text-fig. 1) about 100 miles south of Salt Lake City, Utah. The Gunnison Plateau is on the west edge of the Colorado Plateau Province and is bounded on the east and the west by Basin and Range faults.

U.S. Highway 91, north of Levan, and State Highway 28, south of Levan, parallel the west side of the Gunnison Plateau. These highways and secondary roads from them into the canyons at the edge of the plateau afford access to the area.

The area ranges in altitude from 5,400 feet at Levan to 8,487 feet at Horse Heaven Mountain about four miles southeast of Levan. The topography is rugged. Four major and several small canyons are cut almost perpendicular to the mountain front. These canyons and many tributaries make travel in the area laborious.

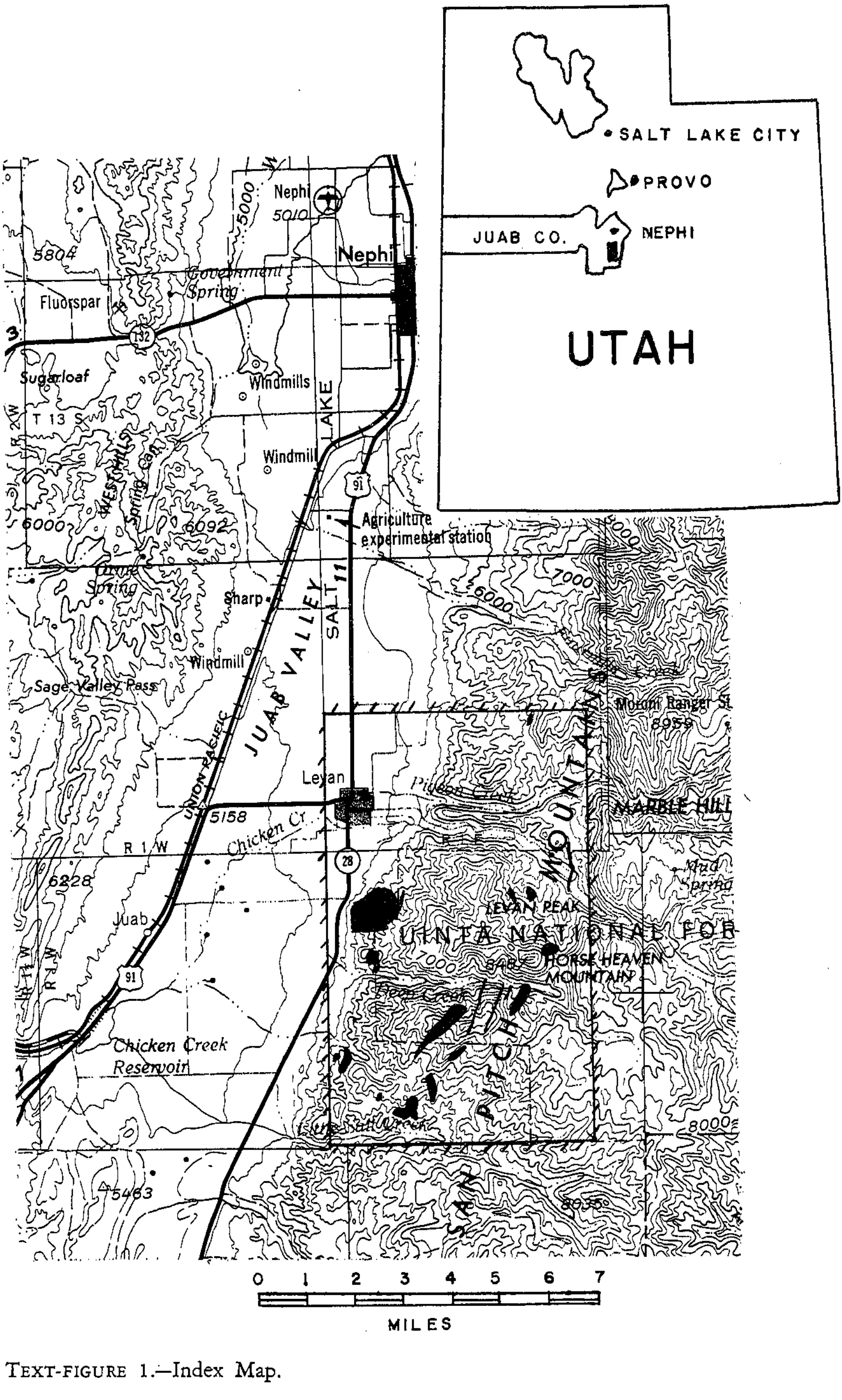
Sagebrush grows on the valley floors, cottonwood and willow along the streams, and thick stands of scrub oak, aspen, fir and underbrush on the higher slopes. The vegetation is particularly dense on the north slopes and often masks the outcrops.

Field work was done during the springs of 1962 and 1963 and consisted of mapping and sampling the intrusions and alteration zones. Data were compiled in the field on U.S. Department of Agriculture aerial photographs, scale about 1:20,000. These data were then transferred, in the office, to a base map, scale 1:24,000. The base map was compiled from the U.S. Geological Survey Nephi Quadrangle, scale 1:62,500 and the U.S. Department of Agriculture, Soil Conservation Service semi-controlled mosaic of the Axtell 2 Quadrangle, scale 1:31,360.

Standard petrographic techniques were employed in describing thin-sections of representative samples. The universal stage was employed to determine 2V angles, optic signs, twinning laws, and mineral classification. A systematic collection of thin-sections of each intrusion has been curated by the Geology Department of Brigham Young University. In the description and classification of the rock types, Johannsen's method was employed. In the tabulations of the rock types shown in Table I, Johannsen's rock name and number is given in the heading.

Occasional samples taken from prospect pits and alteration zones were qualitatively checked for various metals.

Six samples of rock were analyzed for potassium, sodium, magnesium, calcium, and iron content by the U.S. Geological Survey, Water Resources Division, Quality of Water Laboratory, Albuquerque, New Mexico. The samples were taken into solution by the method given by Sharpiro and Brannock (1956), and analyzed by standard methods used in the laboratory as described in U.S. Geological Survey Water Supply Paper 1454. Total iron was divided into ferric and ferrous percentages by the proportion of each in the minerals of the samples. Silicon was determined indirectly as the loss of weight following digestion of the samples and evaporation to dryness. Aluminum was taken as the remaining percentage, minus percentages of the elements phosphorus in the apatite, titanium in the titanite, and zirconium in the zircon. Thus, percentages of ferric and ferrous iron, silicon, and aluminum are rough determinations. Analyses and comparisons of the analyses



TEXT-FIGURE 1.—Index Map.

with the average analysis for each rock type as given by Wahlstrom (1947) are shown in Table 2.

Norms of the analyzed rocks were calculated by the method of Cross, Iddings, Pirsson, and Washington as outlined by Wahlstrom (1947, p. 228). These norms were then compared with the observed mode of the rock. The norms and modes are tabulated in Table 3.

Previous work in the area was concerned mainly with the sedimentary rocks and the complex structure. Dutton (1880, pl. facing p. 162) included several cross sections of the Gunnison Plateau, drawn by E. E. Howell. Meinzer (1911, p. 67-74) briefly described the western margin of the Gunnison Plateau. Spieker (1946 and 1949) was interested in the regional structure. Zeller (1949) and Hunt (1950) mapped the sedimentary rocks, the local structure, and did some work on the igneous rocks. The geology of the sedimentary rocks and extrusive igneous rocks as noted by these workers is left generally unchanged in this report, but the geology of the intrusive igneous rocks has been considerably revised. Evidence of prospecting for economic mineralization is indicated by the numerous prospect pits throughout the area.

ACKNOWLEDGMENTS

Dr. Kenneth C. Bullock suggested the Levan area as a thesis problem and served as chairman of my committee. Drs. Wm. Revell Phillips and Lehi F. Hintze gave valuable assistance in completion of the problem. Members of the U.S. Geological Survey Staff and of the geology faculty of the University of New Mexico gave assistance by the loan of petrographic equipment, by encouragement, and by constructive criticism. U.S. Geological Survey chemists, Richard Lepp and Harry Keoster, aided in the chemical analyses of the rock specimens. Leon V. Davis read and criticized the manuscript. My wife, Eleanor, gave constant encouragement in the completion of the project.

SEDIMENTARY ROCKS

Rocks of the Paleozoic and early Mesozoic eras are not exposed in the Levan area; however, they are exposed in areas nearby and are assumed by the writer to underlie the Levan area. The Paleozoic rocks are probably more than 7,000 feet thick and are predominantly limestone containing some sandstone and shale (See Hintze, et al, 1962 for summary of Paleozoic stratigraphy). Early Mesozoic rocks (Triassic and Jurassic below the Arapien Shale) may be as much as 4,800 feet thick and are largely sandstone and shale interbedded with some limestone.

Rocks of late Mesozoic and Cenozoic age crop out in the area and have been studied by Spieker (1946 and 1949), Zeller (1949) and Hunt (1950). The section on rocks of these ages is summarized from their works.

Magma of the intrusives in the Levan area moved through these strata by forceful intrusion and assimilation. It is probable that the character of the magma has been affected by these rocks, and that the rocks have been altered by the intrusions and solutions from the intrusions.

Late Mesozoic and Cenozoic Eras

Late Mesozoic and Cenozoic rocks are comprised of the Arapien Shale, Indianola Group, North Horn Formation, Flagstaff Limestone and Green River Formation.

Arapien Shale

Arapien Shale, of Jurassic age, consists of two members, a lower Twelvemile Canyon member and an upper Twist Gulch member. The Twelvemile Canyon member is gray limestone, having some interbedded gypsum in the lower part, a succession of gray and red shales having some interbedded gypsum in the middle part, and a succession of gray shale and sandstone having some interbedded limestone in the upper part. The Twish Gulch member is composed of reddish gray sandstone, red siltstone, and some red shale. Arapien Shale is approximately 5,500 feet thick.

Indianola Group

The Indianola Group of Cretaceous age is a sequence of conglomerates having interbedded sandstones and shales, and it overlies the Arapien Shale along the eastern edge of the area. The thickness is approximately 3,600 feet.

North Horn Formation

The North Horn Formation of Cretaceous and Tertiary ages, is a sequence of red calcareous siltstone, gray and red sandstone, conglomerate, and red shale. It overlies the Indianola Group and the Arapien Shale with angular discordance in the southeastern part of the area. Its thickness ranges from 0 to 100 feet.

Flagstaff Limestone

Eocene Flagstaff Limestone is composed of a lower conglomerate and an upper gray arenaceous limestone. This unit overlies the North Horn Formation, the Indianola Group, and the Arapien Shale in angular discordance. The thickness ranges from 0 to 300 feet.

Green River Formation

The Green River Formation, of Eocene age, is composed of a light gray argillaceous limestone in the lower part and a "tawny" arenaceous limestone in the upper part. This unit overlies the Arapien Shale with angular discordance on the south and west sides of the area. The thickness ranges from 0 to 1,000 feet.

REGIONAL AND LOCAL STRUCTURE

The Gunnison Plateau is in the transition zone between the Basin and Range Province and the Colorado Plateau Province (plate 1). Spieker (1949, p. 72) discussed the structure of the Gunnison Plateau concentrating on the large syncline east of the Levan area and on the broad regional structure. Zeller (1949, p. 67) describes the structure of the west central portion. Hunt (1950, p. 116) describes the structure of the north end of the plateau. The general structure of the Gunnison Plateau is a large syncline on the east containing Cretaceous and Tertiary age sediments; a large anticline on the west in the pre-Tertiary age sediments; and a westward dipping monocline, overlying the anticline, in the Tertiary age sediments. Basin and Range faults bound the plateau on the east and the west.

The structure in the area of this report is the large anticline in the Arapien Shale on the west side of the Gunnison Plateau. Both Hunt (1950, p. 118) and Zeller (1949, p. 67) recognized the anticline. The anticline is doubly plunging and is elongate north-south. The northern end passes beneath the volcanics north of Twomile Canyon. The southern end passes beneath the Tertiary sediments south of Little Salt Creek. The western limb is faulted by the Basin and Range fault at the edge of the plateau. The eastern limb forms the western limb of the large syncline. Zeller (1949, p. 67) notes the regular strike and dip of the beds in the southern third of the area. The strike is northeast, changes to north and to northwest; dip is about 40 degrees eastward. The structural high is near Deep Creek and structural relief is at least 4,000 feet. For ease of designation this anticline is termed the Levan Anticline in this report.

Structure of the west side of the anticline is complex and consists of tightly folded beds of Arapien Shale which have a general dip to the west. Structure of the east side is the arcuate pattern of strike described above. Progressively younger sediments overlap the anticline from the east. These sediments have been folded downward on the west to form a monocline which is superimposed on the anticline.

Placement of intrusions has been controlled by the anticline. A majority of the intrusions are in the southern half of the anticline and many are sills and dikes on the limbs. Grain size of the intrusions generally increases toward the center of the anticline and iron rich intrusions form a group around the southern nose of the anticline.

IGNEOUS ROCKS

Numerous small igneous masses are intruded into the sedimentary rocks of the Levan area. Counts show 28 separate intrusions and six different rock types. Two moderate-sized stocks make up about half of the volume of the intruded rock. Small stocks, bosses, dikes, and sills comprise the other half. The igneous rocks are generally intermediate in composition and are variations of monzonite and monzonite porphyry, syenodiorite porphyry, and diabase. Gilluly (1932, p. 66) discusses the similarity of chemical composition and mineralogy of the igneous rocks of central and western Utah and concludes that there is a regional magmatic character. He notes a general lack of orthoclase phenocrysts in the porphyritic rocks, a similarity between chemical content, such as the roughly equivalent amounts of Na_2O and K_2O, and the parallelism of differentiation throughout the region. These general statements on the region apply well to this area.

Intrusive rock types are described in the following section. A general introduction of the mineralogy of each rock type and a discussion of the chemistry of a representative sample is followed by the description of each outcrop of that rock type. Specific mineralogy is given in Table 1. Intrusive names are given to the rocks although the texture indicates an extrusive name for some of them. All of the igneous rocks are hypabyssal, therefore the intrusive names are appropriate.

Porphyritic Leucomonzonite

General Statement

Porphyritic leucomonzonite is the most abundant igneous rock type of the area (Plate 1). It comprises the Water Hollow Stock immediately south of Levan, the western dike north of the mouth of Deep Creek, the small

TABLE I -- MINERAL COMPOSITION BY PERCENT OF THE IGNEOUS ROCKS

Rock Type and Location	Texture	Essential					Accessory							Alteration						Other
		Or Sa	Ol	An	La	Q	Hb	Bi	Ag	Mg	Hm	Ap	Ti	Ze	Ca	Cl	Li	Ch	Se	
PORPHYRITIC LEUCOMONZONITE -- Johannsen No. 1211''H																				
Stock south of Levan, east of central portion	Porphyritic	33	60			1	1	1		1		1			3	3				
Stock south of Levan, northwest corner	Porphyritic	33	60			3		1		1		<1	<1						<1	
Stock south of Levan, south central portion	Porphyritic	33	55			4		1		2	2	<1	<1		1					
Stock south of Levan, southwest corner	Porphyritic	30	42			1				2	2	1		1	15		5			
Stock south of Levan, central portion	Porphyritic	28		40		1		3			2	1			5		<1		10	
Sill on Chicken Creek	Porphyritic	37		55		1		2			2	<1			2		1			
Stock, west side of Maple Creek	Porphyritic	30		45		4				1	2	1			7	10				
Sill on Horse Heaven Mountain	Porphyritic	37		50		4		2		2	2	1				2				
Boss on Deep Creek	Porphyritic	37		55		1		2			2	1							2	
MONZONITE PORPHYRY -- Johannsen No. 2211''H																				
Stock, Burnt Ground Hollow	Porphyritic	33		45		3	10	1		2	2	<1	<1		<1	<1				Ep<1 Zr<1 Al<1
Stock, Green Grove Hollow	Porphyritic	30		42		3	10	3		1	2	1	<1	1	2				3	Zr 1 Pi 1
Dike, mouth of Deep Creek	Porphyritic	35		45		4	3	2		2	3	2		1	5			1		
Dike, mouth of Deep Creek	Porphyritic	30		45		4	7	2	1		3	1	<1	2	2				3	
Stock south of Deep Creek	Intergranular Porphyritic	32		48		3	7	2		1	2	<1	<1	1	2					

Or - orthoclase
Sa - sanidine
Ol - oligoclase
An - andesine
La - labradorite
Q - quartz
Hb - hornblende
Bi - biotite
Ag - augite
Mg - magnetite
Hm - hemitite
Ap - apatite
Ti - titanite
Ze - zeolite
Ca - calcite
Cl - clay
Li - limonite
Ch - chlorite
Se - sericite
Ep - epidote
Zr - zircon
Al - albite
Pi - pideonite
Ru - rutile
Py - pyrite
Nt. - natrolite
Ov - olivine
Ca- clinozoisite

Table I cont.

Rock Type and Location	Texture	Essential					Accessory							Alternation						Other
		Or Sa	Ol	An	La	Q	Hb	Bi	Ag	Mg	Hm	Ap	Ti	Ze	Ca	Cl	Li	Ch	Se	
SYENODIORITE PROPHYRY -- Johannsen No. 2211 H																				
Dike, south side of leucomonzite stock	Porphy-ritic	15		50			5	7	10		7	1		<1	<1			3		Zr 1
Contact zone of horn. mon. por., Little Salt Creek	Porphy-ritic	15		55			15		3	1	3	1	<1		<1	2		3		
Dike, south of Deep Creek	Inter-sertal	7		38		8	5	15	2	3	4	<1			15			2		Ru<1 Zr<1 Py<1
DIABASE--Johannsen No. 2312 H																				
Boss, Maple Canyon	Inter-sertal				50		3	1	15	1	2	2	2	2	5			7	10	
Dike, west of Maple Canyon	Inter-sertal				43		5	1	27	9	1		<1	2	2	5		2		Nt 2 Ov<1
HORNBLENDE MONZONITE PORPHYRY --Johannsen No. 2211"H																				
Stock, center portion, mouth of Broad Canyon	Porphy-ritic	25		30		2	25	1	7	3	4	1		2						
Stock, contact zone, mouth of Broad Canyon	Hypauto-morphic granular	33		40		4	1		7	2	3	<1	1			3				Cz 3
Stock, contact zone, Maple Canyon	Hypauto-morphic granular	42		40			7		1	1	2	<1		2		3		1		Cz 1
Stock, center portion, Little Salt Creek	Porphy-ritic	20		27		1	25	1	7	3	4	3	<1	2	1	3		1	1	
Stock, contact zone, Little Salt Creek	Porphy-ritic	20		40			15		3	2	3	1	<1			4		3	1	
Plug, south of Broad	Porphy-ritic	28		32		1	20		9	1	2	2	1			1		1	2	
BIOTITE AUGITE MONZONITE -- Johannsen No. 2211'H																				
Stock, north fork of Deep Creek	Hypauto-morphic granular	25		45		2		12	7		2	2			3	2				
ANDESITE -- Johannsen No. 2212 E																				
Northeast corner of area	Trachytic	3		73			<1		<1	3	4				3	10	2			

Or - orthoclase
Sa - sanidine
Ol - oligoclase
An - andesine
La - labradorite
Q - quartz
Hb - hornblende
Bi - biotite
Ag - augite
Mg - magnetite
Hm - hemitite
Ap - apatite
Ti - titanite
Ze - zeolite
Ca - calcite
Cl - clay
Li - limonite
Ch - chlorite
Se - sericite
Ep - epidote
Zr - zircon
Al - albite
Pi - pideonite
Ru - rutile
Py - pyrite
Nt - natrolite
Ov - olivine
Cz - clinozoisite

dike at the head of Hartlys Canyon, the sill on Chicken Creek, the sill on the flank of Horse Heaven Mountain, the bosses at the north and south ends of the biotite monzonite porphyry on Deep Creek, the small stock on the west side of Maple Canyon and a small outcrop on the southeastern corner of the hornblende monzonite porphyry on Little Salt Creek. All of these intrusions appear to have been derived from the same source, except the small mass at the southeast corner of the hornblende monzonite porphyry which appears to be the result of migration of the iron out of the contact zone of the intrusion.

Physical properties of the porphyritic leucomonzonite are a light color, a fine texture having few phenocrysts, and a general resistance to weathering. Color of fresh samples is light gray to medium light gray and color of altered or weathered samples is pale yellowish brown. Texture of the rock is porphyritic having an aphanitic groundmass. Phenocrysts comprise ten percent of the rock and are eight percent plagioclase and two percent biotite. Hydrothermal alteration of the large stock occurs along faults and contacts. Areas of little or no alteration are resistant to weathering and stand above the countryrock, whereas altered areas erode faster.

Petrographic examination of thin-sections show the mineralogy to be similar for all of the outcrops. The texture is holocrystalline porphyritic. The plagioclase phenocrysts are oligoclase, composition $An_{28}Ab_{72}$, in the stock; and andesine, composition $An_{32}Ab_{68}$, in the other outcrops. The plagioclase phenocrysts have normal and oscillatory zoning, albite and carlsbad twinning, a size range from one-fourth mm. to three mm. and comprise seven to ten percent of the section. Hornblende pheoncrysts were found in several sections, always badly altered to hematite, calcite, and zeolite. Biotite phenocrysts average one mm. in size and two percent of the section. The groundmass is composed of fine-grained oligoclase or andesine and orthoclase. Size of the minerals in the groundmass make identification and separation of the feldspars difficult. Quartz forms three to four percent of the groundmass, and is partly resorbed. Embayments in the quartz indicate that it was out of equilibrium with the melt at the time of intrusion. Accessory minerals are apatite, titanite, magnetite, and hematite. Much of the hematite is the result of alteration of the ferromagnesium minerals. As indicated by the name, none of the rocks have ferromagnesium minerals in amounts of five percent or greater.

Rock alteration consists of sericitization, kaolination and carbonation plus the change of the ferromagnesium minerals in part to hematite. Samples of fresh rock have less than five percent alteration, whereas surface outcrops show up to ten percent.

Chemical analysis of a sample from the stock south of Levan gives a composition which resembles that of an average syenite (Wahlstrom 1957, p. 293) more closely than that of the average monzonite (Wahlstrom 1957, p. 302). The almost total lack of dark-colored silicates accounts for the low content of FeO, Fe_2O_3, MgO and CaO; and the relatively high content of SiO_2, Na_2O, and K_2O. It can be seen from both the norm and the mode that the rock is a monzonite, although the norm indicates that quartz should be present in an amount larger than five percent. The chemical analysis of the rock is given in Table 2. Complete mode and norm of the rock are given in Table 3.

Description of Outcrops

The stock to the southeast of Levan is approximately one mile in diameter. It is bounded on the west and on the north by the Basin and Range fault at the west of the Gunnison Plateau, on the south by an east-west fault contact and on the east by a large dike of monzonite porphyry. Several faults cut the stock and have served as conduits for hydrothermal solutions which have altered some of the countryrock. A small sill is found east of the stock parallel to the lower contact of the monzonite porphyry dike and the Arapien Shale.

Fresh rock samples are difficult to find in this large intrusion largely due to alteration. The observable difference between the fresh and altered rock in hand specimen is in color and type of ferromagnesium mineral present in the rock. Fresh samples are light-gray and have biotite; altered samples are yellowish gray to pinkish gray and have hematite and limonite staining. Thin-sections show the alteration to be carbonation, kaolination and sericitization and to be between 15 and 25 percent of the rock.

A contact metasomatic aureole of hematite in the countryrock exists along the southern edge of the intrusion for distances of up to 300 feet from the contact. Limestone of the Green River Formation is the most receptive to the hematite enrichment and the Arapien Shale the least receptive. From the existence of the small iron deposits within and adjacent to the stock, it is apparent that the iron was mobile at or near the time of emplacement of the intrusive.

Emplacement of the intrusive was along a zone of weakness roughly coincident with the dip of the west limb of the Levan Anticline. The lower contact is roughly parallel to the strike and dip of the Arapien Shale. The magma appears to have moved upward along a zone of weakness to the upturned beds of the Arapien Shale and thence along the beds of the present position. Faulting and dialation of the beds overlying the stock were the main methods of providing room for intrusion. A breccia of mixed country and intrusive rock is found in the contact at the southern edge of the stock. The stock probably broke through to the surface and became the source of some of the volcanic rocks of central Utah.

North of the mouth of Deep Creek, west of the monzonite porphyry dike, a small dike of porphyritic leucomonzonite intrudes along the contact between the Arapien Shale and the Green River Formation. A fault cuts the intrusion, downthrowing the western part. The eastern part lies on the Arapien Shale and has no overlying beds. The physical properties, the mineralogy and the close proximity of outcrop suggest that this dike and the stock to the north are from the same influx of magma.

Along the eastern edge of the area here are five outcrops which, though separated by considerable distance, appear to be related to each other and to the stock described above. These occurrences are all approximately on strike along the eastern limb of the Levan Anticline.

The small dike at the head of Hartly's Canyon is about ten feet thick and 100 feet long. It is terminated on the south by faulting and pinches out to the north. Contacts are obscured by slopewash from the Arapien Shale.

The sill on Chicken Creek is exposed for about 4,200 feet and has a thickness of about 100 feet. The southern end is obscured by the alluvium of Maple Hollow and the northern end pinches out along strike. The sill stands

TABLE 2 -- CHEMICAL ANALYSES AND COMPARISONS WITH AVERAGE ANALYSES

	1	2	3	4	5	6	7	8	9	10
SiO_2	46.6	48.6	57.4	57.2	56.6	56.2	57.0	58.0	63.5	60.5
Al_2O_3	15.2	16.8	15.2	17.0	15.1	15.3	16.7	18.2	17.2	16.5
FeO	9.3	6.1	4.1	3.5	4.7	4.9	4.0	2.9	0.6	3.0
Fe_2O_3	5.9	4.3	3.9	4.0	4.2	3.2	2.5	3.0	0.8	2.6
MgO	5.87	6.8	2.08	3.5	4.39	4.48	3.2	1.16	0.66	1.7
CaO	8.58	10.0	7.04	6.2	7.40	7.56	6.1	4.22	1.76	3.6
Na_2O	5.00	2.8	5.94	3.4	3.14	3.39	3.6	5.08	5.00	4.2
K_2O	0.83	1.2	2.93	2.2	4.22	4.07	4.1	3.92	6.03	5.0

1. Diabase, dike, southeast part of area.
2. Average diabase, Wahlstrom (1957) p. 311.
3. Hornblende syenodiorite porphyry, contact zone of hornblende monzonite porphyry, Little Salt Creek.
4. Average diorite, Wahlstrom (1957) p. 307.
5. Hornblende monzonite porphyry, sill, mouth of Broad Canyon.
6. Biotite augite monzonite, boss, Deep Creek.
7. Average monzonite, Wahlstrom (1957) p. 302.
8. Monzonite porphyry, stock, Burnt Ground Hollow.
9. Porphyritic leucomonzonite, stock, south of Levan.
10. Average syenite, Wahlstrom (1957) p. 293.

TABLE 3 -- NORMS AND MODES OF THE CHEMICALLY ANALYSED SPECIMENS

NORMS							MODES						
	1	2	3	4	5	6		1	2	3	4	5	6
ORTHOCLASE	4.5	16.7	24.4	23.9	23.4	35.6	ORTHOCLASE		15	25	25	33	33
ALBITE	16.3	45.4	30.0	29.3	43.9	41.9	OLIGOCLASE						60
ANORTHITE	12.5	6.8	14.5	14.5	15.0	6.9	ANDESINE		55	30	45	45	
DIOPSIDE	24.8	20.2	17.7	19.3	4.6	1.8	LABRADORITE	43					
WOLLASTINITE		2.0					QUARTZ			2	2	3	1
MAGNETITE	7.6	5.5	6.0	4.6	4.4	1.2	HORNBLENDE	5	15	25		10	1
NEPHALINE	19.8	2.7					BIOTITE	1		1	12	1	1
OLIVINE	9.8						AUGITE	27	3	7	7		
HYPERSTENE			7.9	8.3	5.8	1.2	MAGNETITE	9	1	3	2	2	1
QUARTZ			2.4	0.1	1.7	7.1	HEMATITE	1	3	4	2	2	

1. Diabase, dike, southeast part of area.
2. Hornblende syenodiorite porphyry, contact zone, of hornblende monzonite porphyry, Little Salt Creek.
3. Hornblende monzonite porphyry, boss, mouth of Broad Canyon.
4. Biotite augite monzonite, boss, Deep Creek.
5. Monzonite porphyry, stock, Burnt Ground Hollow.
6. Porphyritic leucomonzonite, stock, south of Levan.

as a resistant ridge, except to the south of Chicken Creek. Columnar jointing is present. In the canyon to the north of Chicken Creek there is an inclusion of siltstone in the sill. Alteration of the inclusion is mainly the addition of hematite. The lower contact of the sill is exposed on the ridge north of Chicken Creek. Metamorphism of the countryrock at this outcrop is slight. Clay is found included in the sill due to stoping of the wallrock by the moving magma and no hornfels was noted. This sill represents a cool magma which was forcibly injected into the countryrock.

To the south, on the northeast flank of Horse Heaven Mountain, there is a probable extension of the above sill. This outcrop is the least defined of the outcrops in the area because a dense cover of scrub oak makes access difficult and soil covers most of the outcrop. It is concluded from the shape and position of the outcrop that it is a sill. Physical and mineralogical properties are the same as the sill on Chicken Creek and the stock south of Levan.

At the north and south ends of the biotite-augite monzonite in Deep Creek, porphyritic leucomonzonite has followed and caused alteration of the former rock type. The two rock types are mixed at the northern contact and dikelets of leucomonzonite are found in the biotite-augite monzonite. The contact between the two rock types is a zone of easily eroded altered rock. Alteration of the older rock type is more intense on the north than on the south, probably due to the larger size of the leucomonzonite on that end. Size of the leucomonzonite on the north is approximately 1,500 feet by 800 feet, and on the south it is approximately 700 by 500 feet. Both outcrops are slightly elongate east-west. No alteration was found in the leucomonzonite.

The small stock on the west side of Maple Canyon is about 4,000 feet long and 1,400 feet wide. Contacts with the Arapien Shale are obscured by rubble from the intrusion. The intrusion weathers to a low-rounded hill which stands slightly above the surrounding shale. This intrusion is younger than the diabase which it cuts. Physical properties, mineralogy and position indicate that this outcrop is related to the other leucomonzonites.

Occurrence of porphyritic leucomonzonite on the southeastern edge of the hornblende monzonite porphyry along Little Salt Creek poses the problem of the exact relationship between the rock types. Samples of the leucomonzonite collected at this site and from the large stock south of Levan are identical. The change from leucomonzonite to the chilled border on the hornblende monzonite porphyry is gradational. Except for the lack of mafic minerals the rock is the same as the fine grained border. Thus, this outcrop of leucomonzonite implies migration of iron out of the rock.

Monzonite Porphyry

General Statement

Monzonite porphyry is the second most abundant igneous rock type in the area (see plate 1.) Dikes and two small stocks along the west of the area, a small stock in Burnt Ground Hollow, a small stock along Green Grove Hollow, the three sills crossing Deep Creek and the stock south of Deep Creek named the Broad Canyon stock comprise the outcrops of monzonite porphyry. These outcrops are similar in appearance and mineralogy having a porphyritic texture with phenocrysts of feldspar, hornblende and biotite. The groundmass of all specimens is aphanitic. Size and percentage of the feldspar phenocrysts increase, whereas size and percentage of the hornblende phenocrysts decrease away from the contacts. In the larger intrusives and in the centers of the smaller ones, feldspar phenocrysts range from about 1 mm. to 10mm., and comprise from 15 to 20 percent of the rock. Hornblende phenocrysts range from less 1 to as much as 5 mm. in length and 3 mm. in width and comprise from 5 to 10 percent of the rock. In the smaller intrusives and near the contacts the feldspar phenocrysts range from less than 1 mm. to about 4 mm. in size and form about 10 percent of the rock. Hornblende phenocrysts near the contacts range from less than 1 to 10 mm. in length and from less than 1 to 6 mm. in width, and comprise from 7 to 15 percent of the rock. Color varies with grain size. Color of the fresh broken surface ranges from pinkish gray to light gray in the larger grained portions of the intrusions, and from greenish gray to dark greenish gray in the fine grained portions. Weathered surfaces vary in color from yellowish gray to grayish orange in the large grained portions and from light gray to light brownish gray in the fine-grained portions.

Thin-sections of the monzonite porphyry have a porphyritic texture with a holocrystalline groundmass. Phenocrysts are plagioclase feldspar and hornblende, and have an average size of $1\frac{1}{2}$ mm. and a range in size from 1 to 8 mm. The plagioclase phenocrysts are andesine with a range in composition between $An_{28}Ab_{72}$ and $An_{34}Ab_{66}$ and an average composition of $An_{32}Ab_{68}$. Andesine comprises 45 percent of the rock. The usual potassium feldspar is orthoclase, but some sanidine is found in samples taken from near the contacts. Orthoclase comprises 30 percent of the rock and is mostly in the groundmass. Hornblende, with pleochroism in shades of green and brown has a $Z \wedge C$ angle of 13 degrees, and comprises 7 to 10 percent of the rock. Two sections contained pyroxene; one having augite and the other pigeonite in amounts near 1 percent. Accessory minerals consist of apatite, 1 to 2 percent; hematite and magnetite, 3 to 5 percent; titanite, less 1 percent; and zircon, less than 1 percent.

Chemical analysis of a sample from the monzonite porphyry stock on Burnt Ground Hollow has a composition near the average monzonite as given by Wahlstrom (1957, p. 302). Low CaO and MgO content and high Na_2O, Al_2O_3, and SiO_2 content as compared with the average monzonite analysis indicate that the rock is slightly more acidic than the average monzonite. Chemical analysis of the sample and the average monzonite is given in Table 2; and the comparison of the norm and mode are given in Table 3.

Description of Outcrops

Two dikes along the western front of the Gunnison Plateau are monzonite porphyry over most of their length. These dikes join and become one near Broad Canyon. The westernmost dike maintains a uniform thickness of about three feet, and is traceable from the alluvium at the mouth of Broad Canyon northward almost to Deep Creek. The easternmost dike can be traced northward to the southern edge of the large Water Hollow leucomonzonite stock. From Broad Canyon to just south of Deep Creek the dike is three to four feet thick and closely resembles the sub-parallel dike to the west. Near the gypsum mine between Broad Canyon and Deep Creek the dike is replaced by a small intrusion of hornblende monzonite porphyry. South of Deep Creek a small outcrop of biotite-rich syenodiorite overlies the dike. The dike enlarges into a small stock at Deep Creek, measuring 800 feet, then thins to a dike of 20 feet in the small canyon north of Deep Creek and extends on northward to the southern edge of the Water Hollow leucomonzonite stock.

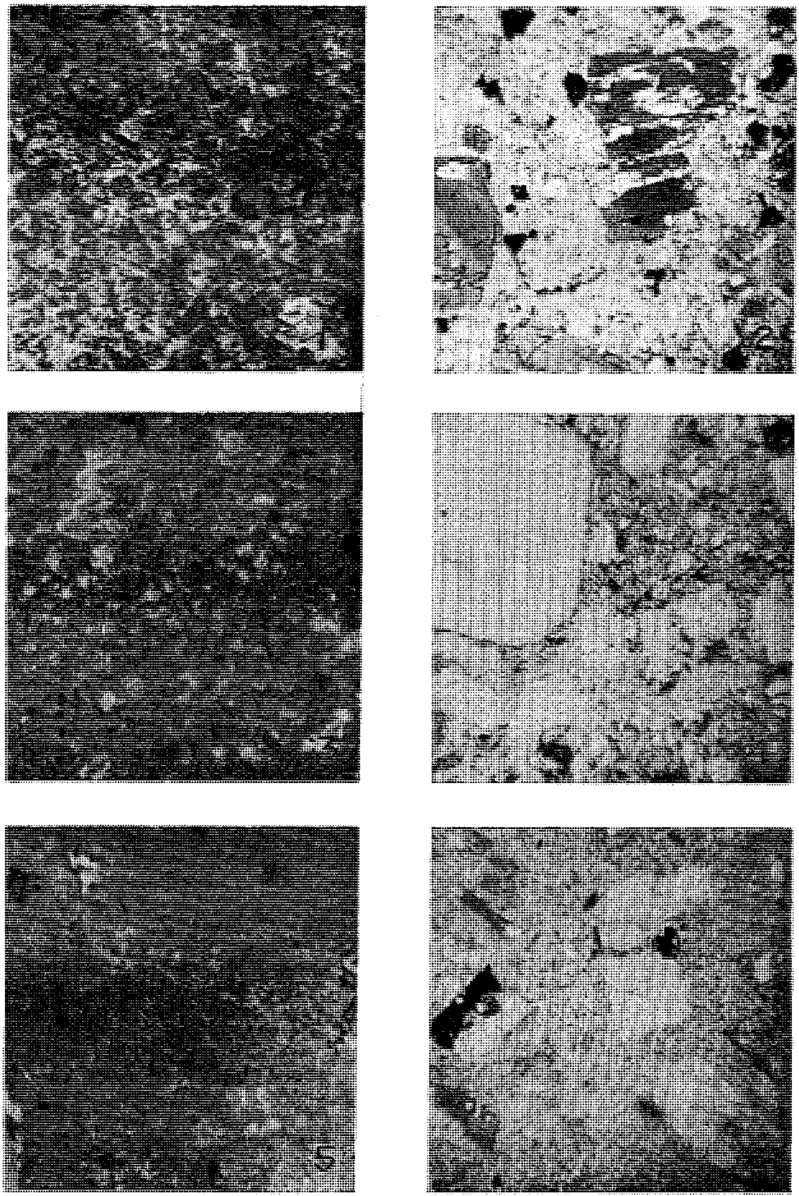


PLATE 2.—Photographs and photomicrographs of specimens.
1.—Specimen of hornblende monzonite porphyry, X2.
2.—Photomicrograph of hornblende monzonite porphyry, uncrossed nicols, X10.
5.—Specimen of leucomonzonite porphyry, X2.
4.—Photomicrograph of monzonite porphyry, uncrossed nicols, X10.
5.—Specimen of leucomonzonite porphyry, X2.
6.—Photomicrograph of leucomonzonite porphyry, uncrossed nicols, X10.

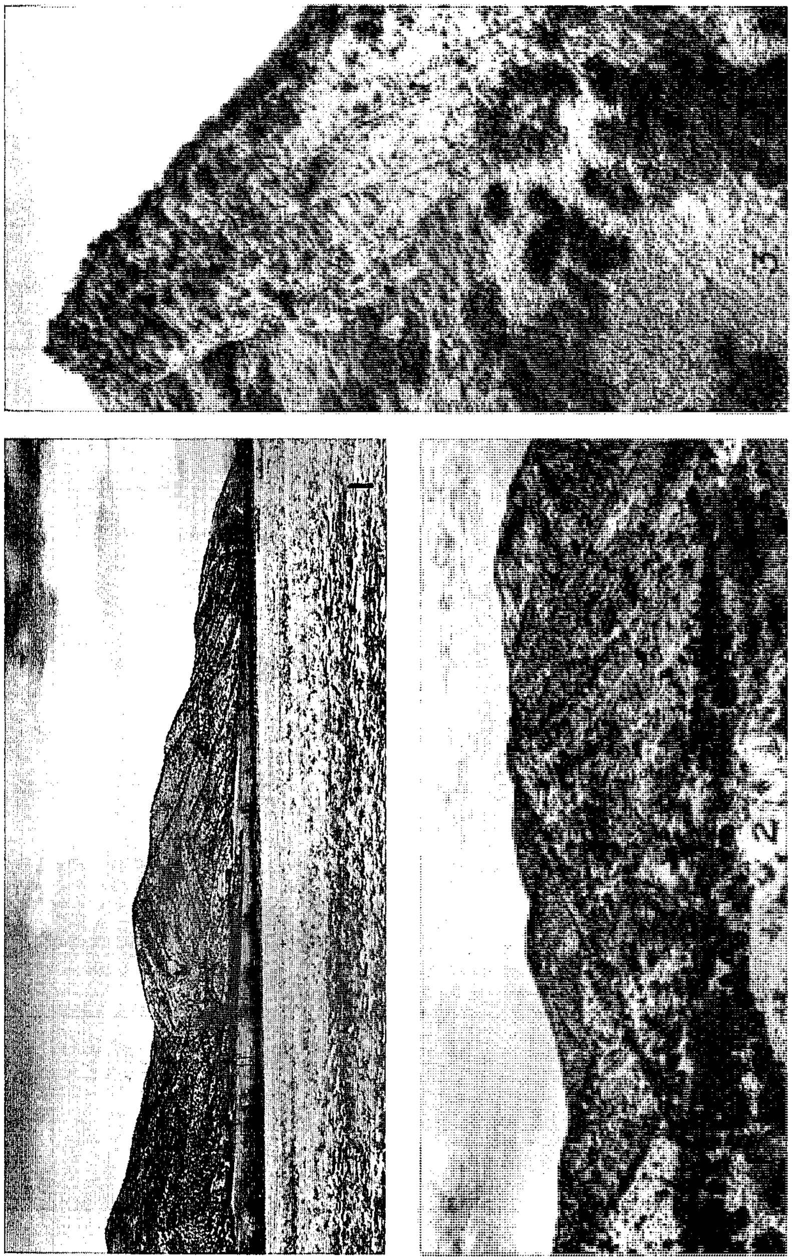


PLATE 3.—Photographs of outcrops

1.—Water Hollow Stock, right side of photo, contact is in divide at left center.

2.—Mouth of Deep Creek, Monzonite porphyry at left center overlain by Arapien Shale. Leucomonzonite forms hill at left side of photograph. Background is Arapien Shale.

3.—Sill in Chicken Creek. Note cooling patterns perpendicular to dip. Lower contact with Arapien Shale is exposed in left corner.

The small stock at the mouth of Deep Creek is interesting. On the south side of Deep Creek it encloses a large inclusion of shale about 650 feet long, 75 feet thick. On the north side of Deep Creek the stock contains a zone of hornblende rich rock at the contact and some inclusions of hornblende rich rock occur in the center of the intrusion. On the crest of the ridge to the north of Deep Creek another inclusion or roof pendant of shale is present. This inclusion and the overlying shale on the west side have been altered by the introduction of hematite, limonite and silica. This alteration zone is usually less than three feet thick but in several places where aided by faulting it is more extensive.

Another stock of monzonite porphyry is found on the northeastern side of the large Water Hollow leucomonzonite stock. The western contact is with the leucomonzonite stock and is obscured by slope wash and soil cover. The stock is split near its southern end into two bodies separated by a wedge of Arapien Shale. The rock on the west, which is in contact with the leucomonzonite, contains large feldspar and small hornblende phenocrysts. The rock on the east, which is in contact with the Arapien Shale has small feldspar phenocrysts and large hornblende phenocrysts. The western body weathers and erodes at roughly the same rate as the leucomonzonite and the shale, and the eastern body weathers to cobbles and boulders. Rubble from the easternmost body covers much of the outcrop. This stock extends to the north to Spring Hollow.

Along Green Grove Hollow there is a small stock and a sill of monzonite porphyry. Size of the main body of the intrusion is about 2,000 feet long and 500 feet thick on the north thinning to about 100 feet at its southern edge. Arapien Shale overlying the sill has been baked to hornfels which resists erosion and forms the crest of the ridge to the south of the main body. Alteration of the underside of the sill has left a zone of weakness along which a stream has eroded. This alteration has changed the ferromagnesium minerals to limonite. The feldspars have been altered to clay minerals. This alteration appears to be hydrothermal in origin, but no gossan or metallization was found.

In Burnt Ground Hollow there is another small monzonite porphyry stock. Size of the stock is about 500 feet by 2,100 feet with the greater length being north-south. Dikes extend north and south from the stock. Contacts are difficult to find, due to the talus and dense underbrush cover. Weathering and erosion of the intrusion progresses at about the same rate as erosion of the shale. Near the center of the intrusion weathering is to large boulders, but elsewhere weathering is to low subdued outcrops. Miarolitic cavities are rather numerous in this stock suggesting a shallow depth of emplacement and/or abundance of gases. Quartz crystals have formed in many of the cavities and in one a hornblende crystal was found.

Three monzonite porphyry sills cross Deep Creek near the east edge of the area. The largest, on the west, has an enlarged portion at the north end about 700 feet in diameter, whereas it is about 200 feet thick over the rest of the length. This sill is about 7,000 feet long. The two other sills are ten to thirty feet thick. The center sill is about 4,500 feet long, and the eastern sill is about 2,300 feet long. All of the sills extend for a longer distance south of Deep Creek than to the north. Mineralogy of the sills is the same as the other monzonite porphyry outcrops.

The center sill, where it crosses the road along Deep Creek, is brecciated and contains much altered countryrock. The breccia consists of shale baked to hornfels, fine-grained monzonite porphyry, grossularite and epidote. The minerals and hornfels are the result of contact metamorphism of the rock. This is the only outcrop of such breccia which was found in the sills.

The large monzonite porphyry stock to the south of Deep Creek, named the Broad Canyon stock, is the second largest intrusive of the area, and is approximately 9,000 feet long and 3,000 feet wide. A dike about ten feet thick extends southward from the stock for an additional 2,900 feet. The northern end of the stock is on the south side of Deep Creek, where steep slopes, heavy underbrush, tree growth, and rubble from the intrusion make the exact location of the contact with the Arapien Shale difficult to determine. At the west center, a slump of shale obscures the contact. On the southwest side, the contact is sharp and only a few inches of hornfels are found in the shale. On the east side, an intermittent stream channel follows the contact. Weathering and erosion generally are at about the same rate as the shale. Rubble consisting of sand, cobbles, and boulders has eroded off the intrusion and has formed boulder trains in several places. At the southern edge a boulder field is formed of boulders which have formed in place. Several outcrops near the center rise above the surrounding rock because of the resistance to weathering. Mineralogy of the stock is close to that given in the general statement on monzonite porphyry. There is little evidence of a chilled border at any of the contacts and only a few feet of hornfels are found in the shale. Feldspar phenocrysts remain near the same size and the hornblende phenocrysts do not increase in number or size at the contact.

Hornblende Monzonite Porphyry

General Statement

Hornblende monzonite porphyry is defined as monzonite porphyry in which hornblende is a prominent mineral. A lower limit of 20 percent hornblende was arbitrarily set for rocks of this area to be classed as hornblende monzonite porphyry. Hornblende monzonite porphyry is found at five localities in the southern portion of the area (see plate 1). These sites are at the mouth of Broad Canyon to the west of the gypsum mine north of Broad Canyon, on the ridge between Broad Canyon and Alger Hollow near the junction of Little Salt Creek and North Fork, and at the head of Maple Canyon. Close proximity and similar mineralogy indicate that these intrusives are of similar ages and represent the same phase of magma differentiation. The intrusives are found around the southern nose of the Levan Anticline near the contact of the Arapien Shale and the overlying Green River Formation. All of the intrusives are small. The largest is about 2,500 feet in diameter and the smallest is about 500 feet in diameter.

Specimens from the five intrusives are similar in appearance and mineralogy. Texture is porphyritic with phenocrysts of hornblende which average near 3 mm. in length and make up 20 to 25 percent of the rock. The groundmass has a fine-grained phaneritic to aphanitic texture and a composition of mostly feldspar. Color of the groundmass in fresh samples is grayish orange pink to greenish gray and color of the phenocrysts is grayish olive green. Color of the weathered surfaces is light olive gray to light brown. All specimens appear fresh and unaltered except for surfical weathering.

Petrographic studies of thin-sections show that samples from each intrusion have similar mineralogy. Texture of the rocks is porphyritic with a holocrystalline groundmass. Crystal shape is euhedral for the accessories and ferromagnesium minerals and is subhedral for the feldspars. Crystal size averages $1\frac{1}{2}$ mm. for the phenocrysts and $\frac{3}{4}$mm. for the groundmass. Average mineral composition is andesine, of composition $An_{31}Ab_{69}$, 37 percent; orthoclase, 25 percent; hornblende, with a $Z \wedge C$ angle of 13 degrees, 25 percent; augite, 7 percent; quartz, 2 percent; biotite, 1 percent; and apatite, 1 percent. There is some perthite intergrowth between feldspars. Quartz and augite have been resorbed. Alteration has changed feldspars to clay minerals and a zeolite identified as thompsonite, and hornblende to chlorite and hematite. Total alteration averages less than five percent.

Chemical analysis of a sample of the hornblende monzonite porphyry at the mouth of Broad Canyon is very similar to the average monzonite as given by Wahlstrom (1957, p. 302). A sample of the biotite monzonite on Deep Creek has a very similar chemical composition, and suggests that these two rock types probably came from the same source. Chemical analysis of the rock type and the average monzonite are shown on Table 2. Comparison of the mode and norm is made on Table 3.

Description of Outcrop

The hornblende monzonite porphyry intrusion at the mouth of Broad Canyon has a mineralogy similar to that given in the general statement. It measures about 2,600 feet by 1,000 feet, elongated north-south. The most intense weathering occurs near the contacts. The contacts appear nearly concordant with the Arapien Shale and suggest a sill-like configuration. The northern and southern limits are obscured by alluvium. The eastern contact is marked by the erosion of a stream bed in the shale alongside the intrusion. The western contact is marked by an interesting occurrence of rounded light green and yellow quartzite pebbles and cobbles, some as large as three inches in diameter. These pebbles and cobbles closely resemble those found in the conglomerates of the Indianola Group and the basal beds of the Flagstaff Limestone, but these formations are younger than the Arapien Shale, and another source of the pebbles must be visualized. The pebbles and cobbles appear to have risen with the molten magma into their present position. A chilled border zone about 150 feet thick was mapped on the southwestern edge of the intrusion. A thin section from this zone shows that the rock has a microphaneritic texture, and is essentially devoid of hornblende. Contact between the porphyritic rock and the fine-grained rock is gradational. Mineralogy of the contact zone indicates that the later rock was richer in iron.

Immediately west of the above intrusion there is a small oval-shaped hornblende monzonite porphyry cupola which probably joins at shallow depth with the above described intrusion. The outcrops of this mass resemble a volcanic neck. Movement of the magma is indicated by the fact that the rock is an agglomerate and at least two stages of movement are represented by slightly different rock types in the agglomerate. Cooling and cracking between magma advances account for the agglomeratic appearance.

West of the gypsum mine, between Broad Canyon and Deep Creek, the monzonite porphyry dike is displaced by a hornblende monzonite porphyry, approximately 200 feet in diameter. Mineralogy is the same as described above. This is a small cupola from the hornblende rich magma which has intruded along the same zone of weakness as the dike.

A small hornblende monzonite porphyry intrusion stands as a small peak on the ridge between Broad Canyon and Alger Hollow. The rock has a broken appearance in thin section indicating the forceful nature of injection. Diameter of the intrusion is above 500 feet, and its shape is slightly oval. The small size, nearly round shape, and broken texture of this outcrop suggest that this outcrop may be a volcanic neck.

The largest outcrop of hornblende monzonite porphyry occurs just north of Little Salt Creek. Size of the intrusion is about 2,600 feet by 2,000 feet. Shape is elongate east-west with a dip toward the south. Contact with the shale on the southern edge is roughly concordant, whereas the other contacts are disconcordant. On the northern edge there is a probable roof pendant of shale about 500 feet in diameter. A dike on the west side of the roof pendant thins in places to three feet. On the north side the intrusion weathers rapidly and two small canyons are cut into this zone of weakness. A breccia dike of mixed intrusive and countryrock is exposed along the eastern edge. This breccia stands as hoodoos above the more easily eroded rocks on either side.

The occurrence of hornblende syenodiorite porphyry, leucomonzonite and a chilled border on the southern edge of this intrusion are of particular interest. Occurrences of the different rock types are discussed under each heading and mentioned here only in review. A chilled border zone of mappable extent occurs on the southern edge. As in the intrusion at the mouth of Broad Canyon, the chilled zone has less hornblende than the main mass, and contact between the chilled border and the main rock type is gradational over a zone of about five to ten feet. The leucomonzonite is gradational from the chilled contact zone and represents movement of iron out of the rock. Hornblende syenodiorite porphyry was found in one location as described in the section on syenodiorites. This rock type is a basic border of the hornblende monzonite porphyry and represents either a more basic original magma or contamination of the magma by countryrock near the contact.

The prominent intrusion along Maple Canyon is a hornblende monzonite porphyry. A chilled border surrounds the intrusion and, as in the other intrusions with a chilled border zone, contact is gradational between the border and the main mass. One outcrop was noted in which inclusions of the chilled border were found in the main rock type. The contact between the chilled border and the main intrusive can be readily approximated by the change in weathering characteristics; the chilled border weathers readily and the porphyry stands as bold outcrops. Mineralogy of both the chilled border and the main mass is the same. Size of the outcrop, including the chilled border is about 2,100 feet long and 700 feet wide. Contacts are disconcordant on all sides but elongation is roughly parallel to the strike of the sedimentary beds. A small diabase outcrop was found at the southern edge of the stock, and diabase inclusions are found in the chilled border zone.

Biotite-Augite Monzonite

A biotite-augite monzonite intrusive is found on Deep Creek where Right Fork joins the main stream. The intrusion is elongate north-south and has overall dimensions, including the porphyritic leucomonzonite at the north and south ends, of approximately 4,200 feet by 1,300 feet. Size of the biotite-augite monzonite is approximately 3,000 feet by 1,300 feet.

A specimen of fresh rock from the intrusion has a fine grained phaneritic texture and a mineralogic composition of plagioclase, orthoclase, biotite, and augite. The feldspars are approximately 1 mm long and comprise about 80 percent of the rock. Biotite is ½ to 2 mm. wide in clusters which retain a hornblende outline and comprises about ten percent of the rock. Augite is 2 mm. square and comprises about ten percent of the rock. Color of the fresh surfaces is white with greenish gray grains. Color of the weathered surface is pale yellowish brown, due to weathering of the iron minerals to limonite.

A thin section of the rock has a hyautomorphic granular and intersertal texture with grains of augite and biotite between feldspar laths. Average crystal size is near ½ mm. Biotite and augite crystals range from ½ to 3 mm., and feldspar crystals range from .3 mm. to 1 mm. Mineral composition is andesine, composition near $An_{35}Ab_{65}$, 45 percent; orthoclase, 25 percent; biotite, 12 percent; augite, 9 percent; and quartz, 2 percent. Accessory minerals are apatite, 2 percent; hematite, 2 percent; and magnetite, 1 percent. Alteration minerals are calcite, 3 percent; chlorite, 1 percent; and clay mineral, 2 percent.

Much of the intrusion is highly altered. Along Deep Creek no fresh samples are found and the rock weathers to a sugary aggregate of crystals. Right Fork, Deep Creek, and the canyon immediately east of the intrusion have eroded along zones of altered rock. The ridge on which the fresh rock sample was taken is near the center of the intrusion where unaltered rock stands in bold relief above the altered zones. Alteration of the rock consists of the change of hornblende to biotite throughout the intrusion, and the change of augite to phlogopite in the more intense alteration zones. Cause of the alteration is probably the emplacement of the porphyritic leucomonzonite at the north and south ends of the mass. Alteration is most intense at the contact between the two rock types and on the northern outcrops.

Chemical analysis of a sample from the unaltered portion of this intrusion shows a composition similar to that of the hornblende monzonite porphyry at the mouth of Broad Canyon. The main difference between the rock types is the mineralogic change from hornblende to biotite and augite to phlogopite. It is probable that the intrusions represent the same magma and that alteration of the mass created the difference. The alteration is of a deuteric nature as indicated by the fact that the hornblende has selectively altered to biotite while other minerals were left unaltered.

Contact relationships are obscured, but this intrusion is sill-like in form. The western contact apparently is concordant with the shale. The stream channel of Right Fork follows the contact and is parallel to the strike of the beds. The northern end of the intrusion terminates rather abruptly against the shale and sandstone beds of the Twist Gulch member. The southern edge pinches out between the beds. The eastern contact parallels the beds in the southern part, crosscuts in the east center, and again parallels the beds in the northern part.

Hornfels is more abundant near this intrusion than at any other. A thin-section of hornfels from the western edge, about 30 feet from the contact, showed that the rock was mostly a siltstone with some clay and sand. Very little alteration of the sample was noted, except the addition of pyrite. No large concentration of pyrite, nor contact metasomatic minerals were found near this intrusion. The hornfels zone measures up to 75 feet wide.

Syenodiorite and Syenodiorite Porphyry

General Statement

Four small outcrops of syenodiorite and syenodiorite porphyry were found in the area (see plate 1). Locations of these outcrops are: at the southern edge of the hornblende monzonite porphyry in Little Salt Creek; at the southern edge of the stock at the mouth of Deep Creek; in the canyon north of Broad Canyon; and at the south-central edge of the Water Hollow Stock south of Levan. Origin, mineralogy and texture of the isolated outcrops are sufficiently different that each outcrop is discussed separately.

Description of Outcrops

Size and extent of the syenodiorite porphyry in Little Salt Creek is indefinite. A sample was collected from a prospect pit within two feet of the contact with the shale. Mapping indicated that this outcrop is a basic derivative of the main rock type and that no positive separation of the two rock types can be made in the field. A part of the main intrusion has cut through the chilled border and has extended into the shale. Numerous small dikelets, some up to three inches thick, extend for several feet into the shale from the main outcrop. The specimen from the pit has the following properties: color, light greenish-gray; texture, porphyritic. Phenocrysts are hornblende measuring to 5 mm. long forming 15 percent of the rock; and feldspar measuring to 1 mm. square forming five percent of the rock. The groundmass is fine grained aphanitic. Specular hematite occurs in the joints and cracks of both the intrusive and the countryrock.

A thin-section of the rock has a porphyritic texture, and a fine grained holocrystalline groundmass. Mineralogy is andesine, composition $An_{42}Ab_{58}$, 55 percent; orthoclase, 15 percent; hornblende, with a $Z \wedge C$ angle of 13, 15 percent; augite, 3 percent. Accessory minerals are magnetite and hematite, 4 percent; apatite, 1 percent; and titanite, less than 1 percent. The feldspars are altered to clay minerals and calcite, and augite is altered to hornblende on the edges and to chlorite throughout. Total alteration is less than three percent.

Chemical composition of this basic border is near the average diorite as given by Wahlstrom (1957, p. 307) see Table 2). The analysis of the hornblende monzonite porphyry at the mouth of Broad Canyon is equivalent to the main part of the intrusion. These analyses show that the chief change in composition is the relative decrease in potassium, iron, and magnesium, and the increase of sodium and calcium in the contact zone. The calcium and sodium possibly came from the stoping of countryrock into the magma along the contact. Arapien Shale is known to be rich in calcium and sodium from the included saline deposits. Turner (1951, p. 267) suggests that the origin of some "basified" variants of acid rocks is contamination of magma by argillaceous countryrock. Such an origin for this sample would explain the lower amount of ferromagnesium minerals as well as the increase of calcium and sodium.

The outcrop of syenodiorite south of Deep Creek is distinct in its character and occurrence. This outcrop appears to have intruded along the upper contact of the dike. The syenodiorite is an aphanitic even-textured rock, which in hand specimen appears to consist of biotite and feldspar. The rock is medium gray on fresh surface and brownish gray on the weathered surface. Size of the outcrop is less than 100 feet long and between 20 and 30 feet wide. In contrast to the dike which weathers readily and leaves no prominent outcrop, the syenodiorite stands above the shale and weathers to a blocky rubble.

In thin section the rock has an intersertal texture with biotite grains dispersed between feldspar grains. The individual mineral grains appear to have been broken by the force of injection. Mineral composition is andesine, composition $An_{42}Ab_{58}$, 38 percent; biotite, 15 percent; orthoclase, 10 percent; quartz, 8 percent; hornblende, 15 percent; augite, 2 percent. Accessory minerals are magnetite, 3 percent; hematite, 4 percent; apatite, less than 1 percent; rutile, less than 1 percent; and zircon, less than 1 percent. Alteration consists of feldspars to calcite and clay minerals, and hornblende to hematite, calcite and chlorite. The quartz is in distinct clusters suggesting contamination by stoping of wall rock.

The third outcrop of syenodiorite porphyry is west of the small gypsum mine midway between the mouths of Broad Canyon and Deep Creek. The outcrop is between the two dikes and is about 100 feet by 20 feet. Color is moderate olive brown on the fresh surface and olive gray on the weathered surface. Phenocrysts are augite, 15 percent; hornblende, 7 percent; and biotite, 2 percent. Mineral size is augite, between ½ and 2 mm; hornblende, to 10 mm; and biotite to 3 mm. This rock closely resembles the augite rich syenodiorite outcrop in the Water Hollow Stock.

A dike of augite-rich syenodiorite porphyry stands as a prominent ledge in the porphyritic leucomonzonite near the southern edge of the Water Hollow Stock. This dike is similar in character to the preceding described outcrop. The dike lies to the northeast of a small mine on the contact and is about 6 feet wide and 50 feet long striking northwest. Contacts are obscured by rubble and talus. The ledge is on the north side of a small canyon.

Specimens from the dike have porphyritic texture. Phenocrysts are augite, ½ to 2 mm., 15 percent; and biotite, 1 to 4 mm., 5 percent. The groundmass is aphanitic. Color is greenish gray on the fresh surfaces and yellowish gray on the weathered surfaces.

A thin section has a porphyritic texture and a mineral composition of andesine, composition $An_{46}Ab_{54}$, 50 percent; orthoclase, 15 percent; augite, 10 percent; biotite, 7 percent; magnetite and hematite, 7 percent; apatite, 1 percent; and zircon in the biotite less than 1 percent. Alterations are augite to chlorite and hornblende, and feldspar to calcite and a zeolite closely resembling thompsonite. Contacts between the feldspars are sutured with some microperthite and microantiperthite. Contacts between the feldspars and ferromagnesium minerals are sharp.

Porphyritic Diabase

Two small porphyritic diabase intrusions occur on the west side of Maple Canyon near the southeastern corner of the area. The eastern outcrop is adjacent to a later intruded hornblende monzonite porphyry. Several diabase inclusions in the monzonite and alteration of the diabase along the contact indicate the older age of the diabase. The second diabase outcrop is cut by a leucomonzonite intrusive. Although not connected on the surface the close proximity of outcrop and similarity of appearance suggest connection at depth. These two diabase intrusions are the first intrusive activity of the area as indicated by the relationship to the monzonites.

Specimens have a greenish gray color on fresh surfaces and dark greenish gray color on the weathered surfaces. The texture is porphyritic with phenocrysts of biotite to 6 mm. across, hornblende to 8 mm. long, and feldspar to 5 mm. long, comprising 10 percent of the sample.

A thin section of the eastern diabase has an intersertal texture with grains of euhedral augite, hornblende, and biotite between laths of labradorite. Augite comprises 15 percent of the rock, hornblende (greenish brown) comprises 3 percent, biotite, 1 percent, and labradorite, 50 percent. Accessories are apatite, 2 percent; titanite, 2 percent; and magnetite, 3 percent. Labradorite, composition $An_{52}Ab_{48}$, and andesine, composition $An_{48}Ab_{52}$, are present in the rock. The average composition was determined to be near $An_{50}Ab_{50}$ and the mineral was called labradorite. Size of the grains in the groundmass is .04 to .1 mm. Phenocrysts to 9 mm. in length are found with the average being near 1 mm. Augite, hornblende, apatite, titanite, and biotite are euhedral; and most of the feldspars are subhedral.

A thin section of the western outcrop shows that it is similar to the other mass. The main difference is in the increase of augite and the presence of a few grains of olivine. Alteration of the section is less than that in the eastern dike. Alteration consists of kaolinite and sericite, 5 percent; calcite, 2 percent; natrolite, 2 percent; thompsonite, 2 percent; and chlorite, 2 percent. Alteration of the eastern mass is greater and consists of sericite and kaolinite, 15 percent; calcite, 5 percent; chlorite, 7 percent; and thompsonite, 2 percent. Hornblende in both of the intrusions has been badly resorbed.

Chemical analysis of a sample from the western outcrop shows it to have a chemical composition near that of the average diabase as given by Wahlstrom (1957, p. 311). This analysis is found in Table 2. Comparison of the norm and the mode is shown in Table 3.

The eastern diabase is elongate north-south, measuring about 500 by 700 feet. Outcrops are subdued indicating that the diabase readily weathers. Contacts with the shale and siltstone of the countryrock are in most places obscured by slopewash and talus. Where the countryrock contact is found the effect of metamorphism is slight, and consists of a few inches of hornfels and baked shale. The diabase is largely aphanitic masking the effect of cooling at the borders. The contact of the diabase and hornblende monzonite porphyry is sharp. Inclusions of diabase occur in the monzonite several feet from the contact.

The western diabase is also elongate north-south, measuring about 500 by 900 feet with a dike about 6 feet thick extending northward. The southern edge is terminated by a leucomonzonite stock. No definite contact of the two igneous rock types was found. Contact between the shale and the monzonite are mostly obscured.

Age of Intrusion

Evidence available within the Levan area indicates that the age of intrusion is younger than deposition of the Green River Formation of Middle Eocene age. At the mouth of Deep Creek and on the south side of the large intrusion south of Levan the "tawny" faces of the Green River Formation have been intruded by porphyritic leucomonzonite. Distinct alteration zones mark these contacts. This age of intrusion agrees with other workers in the central Utah area as cited by Gilluly (1932, p. 65), who states that igneous activity was late Eocene or Post-Eocene time. These intrusions are probably correlative with the Moroni Formation to the east.

Relative Age of Intrusion

Relative age of the intrusions from oldest to youngest is diabase, monzonite porphyry, hornblende monzonite porphyry, porphyritic leucomonzonite, and syenodiorite porphyry. The outcrop of biotite augite monzonite on Deep Creek and the outcrop of hornblende monzonite porphyry on Little Salt Creek are considered to be special cases of hornblende monzonite porphyry. Evidence of the age relationships of diabase to monzonite porphyry is not conclusive. Relative ages of the intrusions are given by the sequence of cutting or intruding of one rock type by another.

Diabase is the oldest igneous rock type found in the area. The easternmost diabase outcrop is intruded by hornblende monzonite porphyry and the westernmost outcrop is intruded by porphyritic leucomonzonite. No diabase outcrops are in contact with monzonite porphyry, but the more basic composition of the diabase suggests a younger age for the monzonite porphyry.

Monzonite porphyry represents the second stage of intrusion and the second most abundant igneous rock type of the area. The dike along the western margin of the area is intruded by hornblende monzonite porphyry, approximately midway between Broad Canyon and Deep Creek; and is terminated at the north end by porphyritic leucomonzonite. A dike of leucomonzonite extends from the stock several hundred feet south along the monzonite porphyry dike indicating that the porphyritic leucomonzonite followed the monzonite porphyry.

Hornblende monzonite porphyry represents the third stage of intrusion, although monzonite porphyry and this rock type may be synchronous. The biotite augite monzonite, which was originally of this rock type, has been intruded by porphyritic leucomonzonite. Other contact relationships have been discussed in prior paragraphs. Similarity of chemical composition of hornblende monzonite porphyry and monzonite porphyry suggests that the two rocks represent a single phase of intrusion and that the hornblende rich rock is an iron and magnesium rich portion of a larger stock lying at depth. The presence of hornblende rich contacts on the monzonite porphyry also support this conclusion.

Porphyritic leucomonzonite represents the fourth and largest stage of intrusion. Only the syenodiorite porphyry dike on the south side of the stock is of younger age. The shortage of ferromagnesium minerals in this rock type suggest a depletion of these elements by segregation due to density difference within the magma, or a filtering out of the iron rich minerals. Rate of the process of removing the iron rich minerals is not known, but considerable time may have elapsed.

The last stage of intrusion is represented by syenodiorite porphyry. One small dike cuts the porphyritic leucomonzonite on the south side of the stock, and another cuts the monzonite porphyry south of Deep Creek. This rock type may represent a resurgence of a basaltic magma mixing with the monzonite magma or may represent a squeezing out of a small amount of the basic differentiated rock of the magma chamber. The latter conclusion is supported by the small amount of rock represented, the forceful nature of the intrusions, and the intimate relationship to the other rock types.

Depth of Emplacement

Intrusions of the Levan area are shallow in emplacement, probably less than 3,000 feet. They represent igneous intrusions into the epizone of of the crust. If the full section of Green River Formation and of Tertiary Volcanics was present in the area at the time of intrusion, the overlying beds were greater than 2,000 feet. If the extrusions followed or were the result of the intrusion, depth of emplacement was more shallow, probably near 1,000 feet. It is probable that some of these intrusive bodies are the conduits through which extrusive material moved.

Evidences of the shallow emplacement found within the intrusions include presence of miarolitic cavities, the small groundmass grain size, the presence of agglomerate in several of the intrusions, little contact metamorphism or metasomatism, small size of intrusions, composite composition of intrusions, the presence of roof pendants and chilled zones against the country-rocks.

Alteration

Alteration due to igneous activity consists of contact metamorphism, hematite and silica metasomatism, and hydrothermal alteration of the sedimentary rocks; with deuteric and hydrothermal alteration of the intrusive rocks. Generally, the alterations are slight. Hunt (1953, p. 165) discusses the temperature of the intrusions in the Henry Mountains. After describing conditions of slight alteration and porphyritic texture similar to those found in the Levan area, Hunt concludes that the intrusions were nearly devoid of volatile constituents and temperatures were near the lower limit for magmas (above 573°C). Conditions of alteration of the rocks in the Levan area indicate these conclusions are valid for this area.

Contact metamorphism of the rocks due to heat is slight. Around most of the intrusions the hornfels zone is essentially absent. Exceptions are the shale overlying the monzonite porphyry sill in Green Grove Hollow, the siltstone west of the biotite-augite monzonite on Deep Creek, and the siltstone on the southern edge of the hornblende monzonite porphyry on Little Salt Creek. These intrusions have zones several yards thick of hornfels with addition of pyrite. The rock most readily altered to hornfels is siltstone. One thin section of siltstone hornfels shows the rock to consist of 50 percent silt, 25 percent clay and 25 percent sand. No visible recrystallization was found in the thin section. Addition of pyrite was the major change from the original rock. The breccia in the monzonite porphyry sill in Deep Creek has been metamorphosed to hornfels, garnet and epidote. The outcrop contains the only garnet found in the area.

Silica and hematite metasomatism is found at the contacts of hornblende monzonite porphyry, monzonite porphyry and porphyritic leucomonzonite. The chief minerals involved are hematite, chalcedony and calcite. Hematite is found as specularite and soft hematite, or in jasper. Silica is found as chalcedony and quartz crystals.

The largest enrichment zone is found at the southwestern edge of the Water Hollow Stock where hematite has replaced limestone of the Green

River Formation. The enrichments are in the limestone from the southern edge of the stock southward to Deep Creek indicating a shallow intrusion lying beneath this area. Samples taken from prospect pits south of the contact of the stock show complete replacement of the countryrock of hematite and chalcedony with the formation of quartz crystals in cracks and voids. One sample has considerable calcite and yellow limonite. Another enrichment zone on the contact of leucomonzonite with the Green River Formation is found on the north side of Deep Creek. A zone about 10 feet thick has been enriched in hematite, limonite, chalcedony and calcite, and a zone about 100 feet thick has been mottled by slight replacement with hematite on the western contact of the leucomonzonite.

The Arapien Shale is not as receptive to metasomatism as is the Green River Formation. The contact of the monzonite porphyry dike with the shale on the ridge crest north of Deep Creek has a zone which is a few inches to about 20 feet thick and is enriched in hematite, limonite, calcite and chalcedony. The portions of the alteration which extend for considerable distances are along fissures or permeable sandstone layers. Other similar occurrences are found at the western contact of the hornblende monzonite porphyry at the mouth of Broad Canyon and the southern contact of the hornblende monzonite porphyry on Little Salt Creek. Contacts of the other intrusions are sufficiently obscured that none of the contact enrichment zones which undoubtedly occur are visible.

Deuteric alteration of the igneous rocks is present to some extent in each of the intrusions. Deuteric solutions are hydrous in nature, and alteration effects usually consist of changing anhydrous minerals to hydrous minerals. Examples of deuteric alteration are the changing of ferromagnesium minerals to chlorite and the feldspars to sericite, clay minerals and zeolites. Table I lists the alteration minerals observed in each thin-section. The outcrop with the most pronounced deuteric alteration is the biotite-augite monzonite which has altered from hornblende monzonite porphyry. Hornblende has been changed to biotite throughout the intrusion, augite has been changed to phlogopite near the contact and feldspar has been left essentially unaltered. Source of the altering solutions is not definite, but possibly is from the leucomonzonite which intruded along the north and south ends of the monzonite. A similar occurrence of alteration is the diabase being altered by solutions from hornblende monzonite porphyry. Alteration minerals are chlorite, sericite and clay. These deuteric alterations have resulted from the rock being out of equilibrium with the solutions passing through the rock.

Evidence of hydrothermal activity in the sedimentary rocks was noted at only three locations. One location was along the fault which extends from Deep Creek through the leucomonzonite stock. This fault provided the plumbing for solutions which have silicified the rock. As in the hematite alteration, the limestone is much more receptive to alteration than the shale. The limestone is silicified for distances of up to 30 feet from the fault. Alteration of the shale is limited to the fault zone where shale is brecciated and baked to hornfels and a black chalcedony fills the cracks in the breccia. The silicification along the fault diminishes to the north of the small intrusions along Deep Creek and is absent in the zone between the two leucomonzonite outcrops. Near the syenodiorite porphyry dike at the southern edge of the porphyritic leucomonzonite stock, a mine near the contact is along a small hydrothermal vein. Gangue minerals in the rock are chlorite, biotite and some pyrite. Ore minerals are about 5 percent of the rock and consist of chalcopyrite and galena. Chemical tests show the presence of copper, lead, zinc and possibly silver. This is the only observed occurrence of ore minerals in the sedimentary rocks. The other location of hydrothermal alteration is in Deep Creek north of the monzonite porphyry stock. Alteration is possibly hematite metasomatism, with the introduced minerals being hematite and limonite. The countryrock is a gray limestone which has been recrystallized along the cracks and bedding planes to calcite crystals. Total alteration at this location is slight and consists of about 10 percent of the rock. No ore minerals were found associated with this alteration.

Hydrothermal alteration of the igneous rock is limited to the west side of the porphyritic leucomonzonite stock and to the underside of the monzonite porphyry sill in Green Grove Hollow. Alteration of the stock has occurred along faults, cracks and fissures which cut the intrusion. The main alteration product is clay with introduction of black chalcedony, pyrite and chalcopyrite in the fault zones. Small gossans have developed along the faults from the mineralization. Secondary copper mineralization consisting of azurite and malachite in veinlets about 1 inch wide has occurred in the fault zones and has been prospected thoroughly in the center of the intrusion. West of the faults the stock is extensively altered to clay minerals and calcite from the feldspars and to limonite from the biotite and hematite. Hematite as fissure fillings and rosettes of specularite is found dispersed throughout the western half of the intrusion. The gray intrusive rock is bleached extensively to an almost white rock. No ore minerals, other than hematite and limonite in small amounts, were found in the altered zone outside of the faults.

Hydrothermal alteration of the underside of the sill in Green Grove Hollow consists of extensive conversion of the hornblende and biotite to limonite, and the feldspar to clay. No evidence of movement of the limonite was observed. No gossan or other evidence of mineralization by the hydrothermal solutions was found.

It is concluded from the small amount of alteration found and lack of mineralization that the intrusions were low in volatile content at the time of emplacement.

EXTRUSIVE ROCKS

Hunt (1950) gives a brief description of the volcanic rocks north of this area and gives their source as being from the west. Phillips (1962) summarized the work of S. L. Schoff (1937and 1951) and J. E. Cooper (1956) on the Moroni Formation. It is the present writer's belief that the extrusive rocks of the Moroni Formation have probably been derived from the intrusions of the Levan area. This correlation is proposed on the basis of the proximity of outcrop and the similarity of rock types described. The intrusions are on the west side of the Gunnison Plateua and the Moroni Formation crops out north and east of the plateau.

The description of the rhyodacite of the Moroni Formation (e.g. 80-85 percent glass, 10 percent andesine, minor amounts of sanidine, biotite and quartz) agrees closely with the description of the leucomonzonite.

An outcrop mapped by Hunt (1950) as intrusive is probably extrusive. This outcrop is in the northeastern corner of the area and is marked as Tv(?) (fig. 1). The mineralogy is andesine $An_{45}Ab_{55}$, 77 percent; orthoclase, 3 percent; aegerine, less than 1 percent; and apatite, 1 percent. Alteration products are clay minerals, 10 percent; calcite, 3 percent; and limonite, 2 percent. The trachyitic texture, the distinct mineralogy, the layered appearance of hand specimens and close proximity of the outcrop to the volcanics suggest that this rock is extrusive. No contacts were found with the sedimentary rocks.

ECONOMIC POSSIBILITIES

The main economic product of the Levan area is gypsum. The deposits are discussed by several writers including Hunt (1950) and Zeller (1949) who have mapped the outlines of the larger deposits. There are several large bodies of gypsum in Chicken Creek which have been mined in the past by United States Gypsum Corporation. However, the active mines at the present are on Little Salt Creek and midway between the mouths of Broad Canyon and Deep Creek. There are numerous small deposits along the west front and central portions of the area, but economics at present limit mining to the larger deposits. Total output of gypsum within the Levan area is small at present.

Evidence of mineralization by the igneous rocks is sparse. It is apparent from the small amount of hydrothermal alteration that significant ore deposition has not occurred at or near the surface. The volume of igneous rock suggests a larger stock at depth and the presence of the thick shale sequences beneath the plateau would be an efficient barrier to the rise of hydrothermal solutions. Any mineralization therefore would be at considerable depth, probably in the limestone of Paleozoic or Early Mesozoic Ages.

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