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Dikes of the Clear Creek Area, Wasatch Plateau, Utah

William Dennis Thomas
Utah State University

DIKES OF THE CLEAR CREEK AREA,

WASATCH PLATEAU, UTAH

by

William Dennis Thomas

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of

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Approved:

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Committee Member

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Committee Member

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Dean of Graduate Studies

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William Dennis Thomas

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ABSTRACT

Dikes of the Clear Creek Area,

Wasatch Plateau, Utah

by

William Dennis Thomas, Master of Science

Utah State University, 1976

Major Professor: Dr. Donald R. Olsen
Department: Geology

The area, covered by this report, includes about 108 square miles in the northeastern part of the Wasatch Plateau in central Utah. Clear Creek, Utah, is near the center of the area.

Stratigraphy of the area is characterized by 18,000 to 20,000 feet of sedimentary rocks above the Precambrian basement. The oldest exposed stratigraphic unit is the Mancos Formation of late Cretaceous age; the youngest exposed stratigraphic unit is the North Horn Formation of Cretaceous-Tertiary age. The sedimentary rocks are mainly sandstone, shale, and coal. Sandstone and shale are the most abundant.

Structure of the area is characterized by folds and normal faults. Folding began in mid-Cretaceous time. A later impulse occurred in late Cretaceous to early Tertiary. Folding was again rejuvenated in Eocene. The normal faults mostly trend north-south and east-west. The faults that trend north-south have more displacement and greater extent than those that trend east-west. North-south-trending faults have up to 2,500 feet of displacement. Maximum

displacement, on the east-west-trending faults, is 90 feet. The north-south-trending faults are the main structural control of the topography. In many cases, they outline uplifts separated by graben. Faults that trend north-south and east-west are considered to have formed at the same time. The age of the faults is considered to be late Oligocene to Miocene.

The dikes are biotite orthoclase pyroxene lamprophyre. The igneous rock of the dikes resembles the lamprophyre type called minette. The presence of olivine and more augite than diopside probably places the rock between minette and kersantite. All dikes in the area are of the same mineral composition. Typical mineral composition of fresh dike rock is 33 percent biotite, 11 percent augite, 8 percent olivine, 4 percent magnetite, 38 percent groundmass, traces of apatite, and up to 5 percent secondary materials. The most common secondary materials are chlorite, calcite, quartz, and iron oxides. The groundmass is 85 to 90 percent orthoclase. The remainder of the material in the groundmass is plagioclase, probably albite, and mafic minerals including biotite and augite. A feldspar-staining technique was used to determine the composition of the dominant feldspar.

The dikes are localized along faults and joints parallel to the faults. All but two of the 28 mapped dikes in the area are localized in east-west-trending fractures.

Effects of the dikes on adjoining rocks are minimal. Dike temperature was not sufficiently high to melt the adjoining rocks. Effects on the coal are also minimal. Coke has been reported in the old underground mines of the area but was not recognized on the surface. Anthracite has formed locally near some dikes.

The lamprophyric magma is considered to have originated by the melting of hydrous peridotite in the upper mantle. Melting of the hydrous peridotite produced appreciable amounts of water, CO_2, SO_2, and Cl. The volatile pressure increased as melting continued. At some point, the volatile pressure was sufficient to cause a rise of gaseous magma into pre-existing normal faults and joints. Mafic phenocrysts were carried in the melt until the volatile pressure was sufficiently reduced and the magma rapidly solidified to produce the extremely fine-grained groundmass. Emplacement of dikes by volatile pressure relates them to a nonexplosive diatremic type of intrusion. Emplacement of the magma occurred at a temperature between 600° and 1,000° C.

The dikes of the Wasatch Plateau are middle to late Tertiary in age. Most evidence indicates them to be late Oligocene to Miocene.

(83 pages)

INTRODUCTION

General Statement

The objective of this investigation is to map and describe the igneous dikes in part of the northern Wasatch Plateau. Until now, these dikes have not been described in detail. The geologic history of the dikes will be reconstructed. The investigation will also deal briefly with the effect that these dikes have had on the adjoining sedimentary rocks.

Field work was done during June and July of 1976. Most of the work done in the field was to describe and remap the igneous dikes mapped by Spieker (1931). Several unmapped dikes were located and described, but an extensive search for unmapped dikes was not carried out because of the limited time available.

Location and Accessibility

The Wasatch Plateau is the northernmost of the high plateaus of central and southern Utah. The area with which this study is concerned includes about 108 square miles in the northern part of the Wasatch Plateau (Figure 1). The northern boundary of the study area is about lat. 39°45'00" N., and the southern boundary is lat. 39°33'00" N. The eastern boundary is long. 111°05'00" W., and the western boundary is long. 111°15'00" W. The area lies within parts of Carbon and Emery Counties. The town of Clear Creek, near the center of the area, lies about 50 miles southeast of Provo, Utah, and about 18

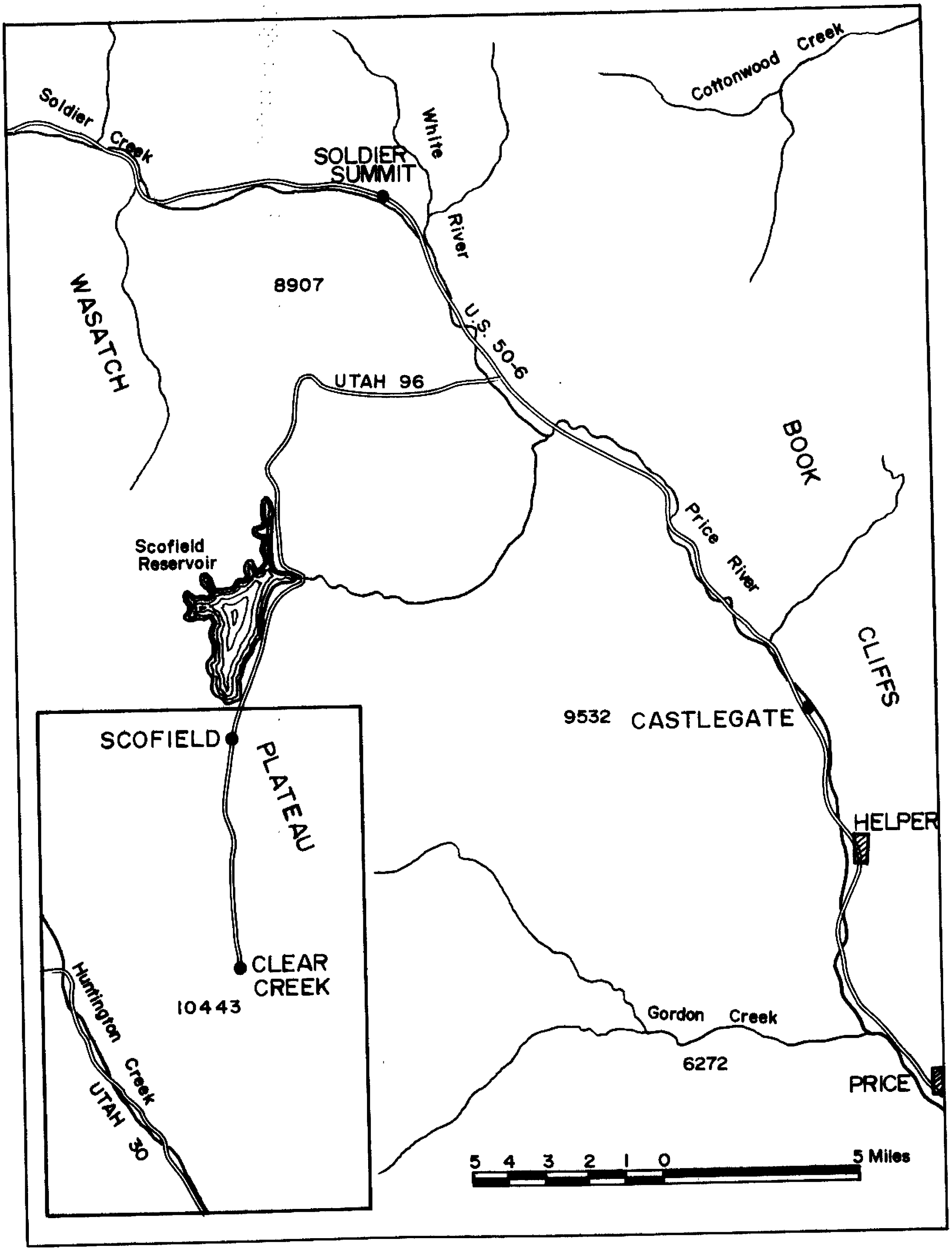

Figure 1. Index map of part of central Utah showing location of the study area.

miles northwest of Price, Utah. The area described above is within the Scofield Quadrangle of the U.S. Geological Survey 15-minute topographic quadrangle series.

The area can be reached by two main access routes. These are Utah State Road 30 and Utah State Road 96. Utah State Road 30 is the most convenient route approaching the southern part of the area. It extends from Huntington, Utah, on the eastern side of the Wasatch Plateau, to Fairview, Utah, on the western side of the plateau. The northern part of the area is most easily reached by means of Utah State Road 96. This route intersects Utah State Highway 50-6 about 6 miles south of Soldier Summit, Utah, and extends to the town of Clear Creek.

The area between Utah State Road 30 and Utah State Road 96 is accessible by means of unimproved roads. These unimproved roads provide access across Castle Valley Ridge and Trough Springs Ridge. They connect the two state roads. Unimproved roads also provide access to many other parts of the area. The unimproved roads are generally in good condition; however, they become rough and nearly impassable at isolated places. During wet periods, these roads can become slick and muddy. A brief rainstorm can cause quite hazardous driving conditions.

The remainder of the area is accessible only by jeep trails or by walking. The jeep trails are generally steep and rough and are limited to travel by four-wheel drive vehicles. Walking is sometimes difficult due to steep slopes and thick vegetation. Few established pack trails are available, but small trails formed by deer and sheep are abundant.

Topography and Drainage

The topography of the area is similar to that of all of the high plateaus of central and southern Utah. The topographic pattern generally consists of highly dissected ridges that are separated by deep canyons with fairly steep walls.

In general, the elevation of the area is between 8,000 and 10,000 feet; however, some exceptions are present. The highest point, within the area, is Monument Peak. It rises to 10,443 feet. Candland Mountain, in the southwestern part of the area, rises to 10,330 feet. The lowest elevation in the area is in Pleasant Valley, near the town of Scofield, at slightly less than 7,700 feet.

Most of the area is drained by two main streams. The largest of these is Huntington Creek, which drains the southwestern part of the area. Pleasant Valley Creek drains the northern part of the area.

Huntington Creek originates about 1 mile west of the mapped area near the summit of the Wasatch Plateau. It then flows southeastward through the southwestern part of the area and continues down Huntington Canyon until it enters Castle Valley, near Huntington, Utah. Huntington Creek is joined along its length by numerous small tributaries. The gradient along Huntington Creek is generally about 125 feet per mile. The gradient along the tributaries to Huntington Creek approaches 1,000 feet per mile in many places. Huntington Creek and most of its tributaries usually flow all year due to numerous springs and melting snow on the summit of the plateau.

Pleasant Valley Creek originates at Trough Springs Ridge and terminates 2 miles north of the town of Scofield at Scofield Reservoir. The overall length of Pleasant Valley Creek is about 12 miles. The gradient along Pleasant Valley Creek, near the point where it originates, is about 700 feet per mile. The gradient near its terminus in Pleasant Valley is about 50 feet per mile. Pleasant Valley Creek is joined by numerous tributaries. These tributaries have gradients approaching 1,000 feet per mile. Pleasant Valley Creek, like Huntington Creek, is a perennial stream.

The eastern side of Castle Valley Ridge is drained by numerous small streams. The most prominent of these are Jump Creek, Beaver Creek, North Fork of Gordon Creek, and the creeks in Bob Wright and Second Water Canyons. These small streams flow into Castle Valley where they enter the Price River. Some of these streams flow continually and some are intermittent.

Field and Laboratory Methods

The mapping of the dikes in the field was done on the U.S. Geological Survey Scofield topographic quadrangle map at a scale of 1:62,500. The dikes were also plotted on aerial photographs at a scale of 1:15,840. The dike locations were then plotted on the geologic map which accompanies this report (Plate 1). The geologic map is an enlargement of Spieker's map of the northern part of the Wasatch Plateau coal field (Spieker, 1931). The map was enlarged from a scale of 1:62,500 to a scale of 1:24,000. Samples of the dikes and adjoining sedimentary rocks were collected for later laboratory analysis.

Laboratory work for the investigation included a petrographic analysis of the igneous and sedimentary rock samples. Staining of feldspars to determine the type of feldspar and X-ray analysis of weathered dike material were also undertaken.

The petrographic analysis included descriptions of grain size, mineralogy, texture, and alteration of the igneous rocks. Petrography of the sedimentary rocks was mainly limited to determining effects of the dikes on them. The petrographic descriptions were accomplished by the use of a petrographic microscope with eyepieces to aid in the calculation of percentage of mineral constituents and grain size. Thin sections were standard 0.03 mm thin sections. The thin sections were prepared by Roberts Petrographic Service, Monterey Park, California.

The feldspars were stained to determine whether they are potash or plagioclase feldspars. The staining procedure used was that of Mueller (1967, p. 165-167). The rocks were stained in hand specimen and examined with the aid of a binocular microscope. X-ray analysis of the weathered dike material was done with X-ray diffraction patterns taken at ranges of 2×10^4 and 4×10^4 counts per minute, from 2° to 65°, and at 2° per minute. A copper tube with a nickel filter was used at 35 kilovolts and 16 milliamps.

To aid in the identity of samples, each dike was assigned an identification letter as it was sampled in the field. Each sample was given the letter of the dike that it came from and a number designating location relative to the dike.

Previous Investigations

The lamprophyre dikes, within the study area, were first mapped and described, in general, by Spieker (1931). Igneous dikes, similar in composition to the dikes described in this investigation, have been reported by investigators working in the surrounding area. Pashley (1956) reported lamprophyre dikes in the western Wasatch Plateau. Two lamprophyre dikes were described by Loughlin (1919) in the Mount Nebo area of central Utah.

Several papers concerning the geologic history and general geology of the Wasatch Plateau have been written by Spieker. The original geologic map and report on the general geology of the Wasatch Plateau was made by Spieker (1931). He later published a report concerning geology of the transition zone between the Colorado Plateau and the Basin and Range physiographic provinces (Spieker, 1949).

Walton has published several papers dealing with the gas fields of the northern Wasatch Plateau. The most useful of his papers to this report was Walton (1955). The Utah Geological Association Publication 2 is a series of papers dealing with the geology of the transition zone in central Utah (Baer and Callaghan, 1972). Doelling (1972) made a report on the coal fields of central Utah with a section concerning the Wasatch Plateau coal field. The geology of the Pleasant Valley coal district, in the northern part of the area, was done by Taff (1906).

GEOLOGIC SETTING

Stratigraphy

General statement

The northern Wasatch Plateau is characterized by fairly flat-lying sedimentary rocks that range in age from late Cretaceous to Paleocene. Total rock thickness in the northern plateau, above the Precambrian basement, is 18,000 to 20,000 feet. Total thickness of strata, which crop out in the northern plateau, is about 10,000 feet. Table 1 is a generalized stratigraphic section of the surface formations on the eastern side of the northern Wasatch Plateau. Descriptions of stratigraphic units will include only those formations which crop out within the study area.

Mancos Formation

The oldest formation, in the area, is the Mancos Formation of late Cretaceous age. The Mancos is divided into five members: (1) Tununk Shale Member, (2) Ferron Sandstone Member, (3) Blue Gate Shale Member, (4) Emery Sandstone Member, and (5) Masuk Shale Member.

The Tununk Shale is the darkest in color of the three shale members of the Mancos. It is blue-gray to black marine shale, which represents the first invasion of the late Cretaceous sea into central Utah. According to Spieker (1931, p. 18), the Tununk is about 600 feet thick in the northern Wasatch Plateau. The shale is locally fissile (Katich, 1954, p. 46). On the western side of Castle Valley, the Tununk generally forms gentle slopes and small rounded hills.

Table 1. Generalized stratigraphic section of part of the northern Wasatch Plateau

Age	Formation	Lithology	Thickness (feet)
Tertiary			
————	North Horn	Sandstone	2,500
	Price River	Sandstone	488
	Castlegate	Sandstone	511
	Blackhawk	Sandstone, shale, and coal	700-1,000
Cretaceous	Star Point	Sandstone	600-1,000
	Mancos		
	Masuk	Shale	1,000-1,100
	Emery	Sandstone	800
	Blue Gate	Shale	600
	Ferron	Sandstone	470
	Tununk	Shale	600

The Ferron Member is dominantly sandstone with thin beds of shale and coal. The sandstone is light gray and fine to medium grained. It is usually massive bedded. The sandstone is composed of subangular to rounded quartz grains cemented with calcium carbonate and limonite (Katich, 1954, p. 46). The shale of the Ferron is generally brown to black carbonaceous shale which is locally calcareous and locally sandy. Wells drilled near the town of Clear Creek show the Ferron to be about 470 feet thick. In the Emery area, the Ferron contains several workable coal beds. The coal beds are in the upper third of the member and range in thickness from 22 inches to 22 feet (Katich, 1954, p. 46). The beds of the Ferron are usually lenticular and pinch out or grade into another rock type.

The Blue Gate Member is blue-gray shale containing many sandy layers. The Blue Gate is the shale that forms much of the floor of Castle Valley. Erosion of the Blue Gate often produces a badlands type of topography.

The Emery Member is friable, massive- to thick-bedded, yellow-gray sandstone (Doelling, 1972, p. 56). Near the town of Emery, it is about 800 feet thick. The Emery thins northward and splits into two tongues near Ferron, Utah. The two tongues average about 50 feet in thickness. The upper tongue continues north through the study area, and the lower tongue dies out in the Hiawatha area to the south (Spieker, 1931, p. 20). In the northern plateau, the Emery thickens westward and becomes coal-bearing beneath the plateau (Doelling, 1972, p. 69).

The Masuk Member is blue-gray shale much like the Blue Gate; however, it is much sandier than the Blue Gate (Spieker, 1931, p. 20). It is 1,000 to 1,100 feet thick in the northern part of the plateau. The Masuk is comformably overlain by the Star Point Formation (Spieker, 1931, p. 70).

Star Point Formation

The Star Point Formation is of late Cretaceous age. It is cliff-forming, massive-bedded, yellow-gray sandstone often separated by tongues of the Masuk Shale (Doelling, 1972, p. 69). Spieker (1931, p. 24) indicated that near Scofield the Star Point is 1,000 feet thick and is devoid of shale. Normally the Star Point has numerous shale beds representing tongues of the Masuk below. Spieker (1931, p. 24) also reported a thickness of 600 feet in the central part of Huntington Canyon. Along the eastern side of the Wasatch Plateau, the Star Point crops out and can be traced for 100 miles north-south. Along this exposure, the Star Point is amazingly uniform in thickness and appearance (Spieker, 1931, p. 24).

Blackhawk Formation

The Blackhawk Formation of late Cretaceous age is the most economically important coal-bearing formation of the northern Wasatch Plateau. It consists of alternating layers of sandstone, shale, and coal. The sandstone forms cliffs; whereas, the shale and coal usually form slopes. The Blackhawk is 700 to 1,000 feet thick in the northern plateau. The sandstone is yellow gray to light gray and weathers yellow and brown. It is fine to medium grained and is usually cemented by calcite or silica. Overall, most of the sandstone in the Blackhawk seems to be much the same as the sandstone of the Star Point. Locally, however, the sandstone is cemented by iron oxide (Spieker, 1931, p. 28). In places, under the coal beds, the sandstone is white due to the leaching of iron by organic acids from the covering swamps (Doelling, 1972, p. 69).

Spieker (1931, p. 29) recognized three distinct types of shale within the Blackhawk Formation. Most abundant of the shale types is gray to green clay shale, which is normally quite soft. Next in order of abundance is brown to black carbonaceous shale. Least abundant is gray shale usually associated with the coal. This shale is of continental origin and sometimes grades directly into coal beds.

According to Spieker (1931, p. 29), most of the beds of the Blackhawk are lenticular and have slight lateral extent. One notable exception is the Aberdeen Sandstone Member, which can be traced from Gordon Creek to Gentry Ridge.

Fisher, Erdmann, and Reeside (1960, p. 12) assigned four members to the Blackhawk Formation. These members are: (1) lower sandstone member, (2) middle shale member, (3) middle sandstone member, and (4) upper member. This work was done in the Book Cliffs, to the east, and these members may not be justified on the Wasatch Plateau.

Castlegate Formation

Fisher, Erdmann, and Reeside (1960, p. 13) first recognized the Castlegate Formation as a formation. Previously it was considered as a member of the Price River Formation. The Castlegate is late

Cretaceous in age. Fisher, Erdmann, and Reeside (1960, p. 14) reported that the Castlegate consists of massive-bedded conglomeratic sandstone.

Spieker (1931, p. 41) indicated that the Castlegate is 511 feet thick in Price River Canyon to the north. He also indicated that the Castlegate is separated from the Price River Formation above mainly because the Castlegate forms cliffs. He indicated that the lithologies are similar. Katich (1954, p. 50) described the Castlegate as coarse-grained quartzose sandstone with lenses of conglomerate.

Price River Formation

The Price River Formation of late Cretaceous age consists of gray to light-brown sandstone and gray shale (Fisher, Erdmann, and Reeside, 1960, p. 14). According to Spieker (1931, p. 4), the Price River Formation is widespread in the Wasatch Plateau and, in places, contains lenses of conglomerate. Its thickness, in Price River Canyon, is 488 feet. The Price River Formation usually forms slopes rather than cliffs (Katich, 1954, p. 50).

North Horn Formation

The North Horn Formation, due to its faunal remains, is believed to be latest Cretaceous in its lower part and early to middle Paleocene in its upper part (Spieker, 1949, p. 27). Katich (1954, p. 51) indicated that the North Horn consists mainly of variegated shale with associated sandstone, conglomerate, and fresh-water limestone. In the northern part of the Wasatch Plateau, sandstone is more abundant than shale, and conglomerate is nearly absent. According to Katich

(1954, p. 51), the thickness of the North Horn ranges greatly within the Wasatch Plateau. In the northern part, at Price River Canyon, it is nearly 2,500 feet thick. Except in the western part of the Wasatch Plateau, where it lies in angular unconformity below the Flagstaff Formation, the North Horn is conformable with the Price River below and the Flagstaff above (Katich, 1954, p. 51).

Structure

Folds

Folds within the Wasatch Plateau are broad and have gentle dips. Strata within the plateau generally dip less than 10 to 15 degrees in all directions (Spieker, 1949, p. 39). The most notable exception is the Wasatch monocline on the western slope of the plateau. Following the general pattern of the remainder of the plateau, folds within the study area are limited to two gentle anticlines separated by a syncline. The Clear Creek anticline on the west and the Gordon Creek anticline on the east are separated by the Beaver Creek syncline (Walton, 1955, p. 404). According to Walton (1955, p. 404), the Clear Creek and Gordon Creek anticlines are part of a broad regional uplift. Walton (1955, p. 404) called this uplift the Monument Peak uplift because of the proximity of the peak to the structural apex of the uplift. The Monument Peak uplift is generally parallel to the San Rafael Swell, and Walton (1955, p. 405) considered them to be genetically related.

Walton (1955, p. 404) indicated that the Clear Creek anticline lies along part of an anticlinal trend which extends for 45 miles from

Soldier Summit southward through the South Joe's Valley anticline. The Clear Creek anticline occupies approximately the northern 29 miles of the trend. The southern part of the trend is occupied by the South Joe's Valley anticline. The width of the anticline, from the bottom of the Beaver Creek syncline on the east to the western side, averages about 15 miles. The trend of the axial trace of the anticline is roughly north-south, but it is usually slightly east of north. The anticline is located near the middle of the study area.

The anticline plunges both north and south, but the amount of plunge is difficult to determine because of later faulting. It seems to plunge more steeply on the north (Walton, 1955, Figure 4).

Taff (1906, p. 342-343) described the Pleasant Valley anticline, which was later named the Clear Creek anticline (Walton, 1955, p. 404). Taff (1906, p. 342) stated that the axis of the anticline cannot be clearly defined, but that in its northern part it is roughly coincident with Pleasant Valley. The fold is asymmetrical, but the asymmetry is probably due to later folding. According to Taff (1906, p. 342), the dip of the beds on the eastern side of the anticlinal axis is slight, not exceeding 1° to 2° E. He indicated that, in places, near the head of Gordon Creek (T. 14 S., R. 7 E.), the strata seem to be horizontal. Northward along North Fork of Gordon Creek (T. 13 S., Rs. 7 and 8 E.), the dip is generally 1° to 2° E. (Taff, 1906, p. 342). Along the western limb of the anticline, the direction of dip changes gradually from northwest at the northern end to southwest in the south. Near Scofield, Utah, on the north, the beds dip about 3° NW.

Southward, between the head of Pleasant Valley and Huntington Canyon, the average dip is about 4° SW.

The expression of the folds in the topography is minimal. The folds have been so dramatically broken by normal faults that fault blocks almost completely dominate the topography.

The Gordon Creek anticline is part of an anticlinal trend which extends from the Flat Canyon anticline, to the south, northward through the Gordon Creek anticline (Walton, 1955, p. 404). The anticlines make up the eastern part of the Monument Peak uplift. The distance along the trend from the Flat Canyon anticline through the Gordon Creek anticline is 38 miles (Walton, 1955, p. 404). The northern 25 miles of the anticlinal trend is the Gordon Creek anticline. The southern part of the trend is the Flat Canyon anticline. The Gordon Creek anticline, at its apex, is about 10.5 miles wide. The axial trace trends roughly north-south but ranges slightly east of north. The axial trace of the Gordon Creek anticline passes through the southeastern corner of the study area in the vicinity of First Water Canyon.

The Gordon Creek anticline plunges northward 5 to 6 degrees and southward 4 to 5 degrees. Plunge differs along the axial trace and is difficult to determine because of the normal faulting.

The Gordon Creek anticline is asymmetrical and dips less steeply on the western side. Calculating from structure contours (Walton, 1955, Figure 4), the average dip on the eastern side of the axial trace is about 1° to 2° E. The dip on the eastern side changes from northeast in the north to southeast in the south. On the western side of the axial trace, the dip gradually changes from northwest to southwest. The dip, on the western side, averages 3 to 4 degrees, but it is steeper in the northern part than in the southern part.

The Gordon Creek anticline has little effect on the topography. Its topographic expression is disrupted by vertical normal faults.

Separating the two anticlines described above is the Beaver Creek syncline. The western limb of the Beaver Creek syncline is the eastern limb of the Clear Creek anticline, and the eastern limb of the syncline is the western limb of the Gordon Creek anticline. The syncline plunges southward at an average of 2 to 3 degrees. The trend of the axial trace is generally slightly east of north, but it curves rather sharply eastward in the vicinity of Beaver Creek. On Walton's map, the southern part of the Beaver Creek syncline seems to be the same structure as the Crandall Canyon syncline (Walton, 1955, Figure 4). The Beaver Creek syncline averages about 8 miles wide and widens toward the north.

Based on drilling information, Walton (1955, p. 409) suggested that the original folding was post-Ferron-pre-Star Point. Later pulses of folding along the same fold axes occurred after the deposition of the Castlegate Formation and before the deposition of the Flagstaff Formation of Paleocene-Eocene age. The folds were rejuvenated after the deposition of the Green River Formation of Eocene age.

Normal faults

Faults of the area consist of extensive and numerous vertical normal faults. Spieker (1949, p. 39) stated that the Wasatch Plateau is broken by groups of normal faults between which are several prominent graben distributed en echelon from northeast to southwest across the plateau. These fault groups are separated by stretches of largely unfaulted strata.

Within the study area, the dominant trend of the faults is north-south, but east-west-trending faults also occur. The north-south-trending faults have greater displacement and longer extent.

The most important group of faults, within the area, is the one that parallels Pleasant Valley and nearly bisects the area. Among this group of faults, the largest is the Pleasant Valley fault. The Pleasant Valley fault begins north of the study area and continues southward.

The trend of the Pleasant Valley fault is roughly north-south and the strike ranges from about N. 7° E. to about N. 7° W. The Pleasant Valley fault branches several times and has numerous smaller roughly parallel faults associated with it. All of these faults, including the Pleasant Valley fault and associated faults, are vertical or nearly vertical. The associated faults range in length from less than 1 mile to more than 10 miles. According to Taff (1906, p. 343), displacement along the Pleasant Valley fault, west of Clear Creek, is about 1,000 feet. Farther south, where it crosses Nuck Woodward Canyon, the displacement is about 500 feet. Northward from Clear Creek, the fault begins to die out and displacement becomes less toward the north. Along its extent through the area, the Pleasant Valley fault is down on the east and generally has the Star Point Formation on the west adjacent to the Blackhawk Formation on the east. Displacement along the smaller associated faults is usually not enough to move one formation adjacent to another at the surface exposure. These smaller faults are seen at the surface within the Star Point and Blackhawk Formations.

The Pleasant Valley fault forms the western wall of the Pleasant Valley graben. The Pleasant Valley graben is a down-dropped block that extends about 12 miles northward from the town of Clear Creek. The graben is narrowest in its southern part and it widens northward. At the southern end, the graben is about 0.2 mile wide; northward, it widens to about 1 mile. The eastern side of the graben is not a well-defined fault comparable to the Pleasant Valley fault. Faults along the eastern side are smaller branching vertical faults.

Another group of north-south-trending faults is located in the southwestern part of the area. Spieker (1931, p. 57) named this group of faults the Joe's Valley fault zone. He estimated the total north-south extent of the fault zone to be 75 miles. The major faults of the zone have up to 2,500 feet of displacement. Only the extreme northern extent of this group of faults is evident in the study area. Spieker (1931, Plate 31) showed two major faults. These are the Joe's Valley fault and the Valentine fault.

The Joe's Valley fault extends 3.75 miles from the southern boundary of the study area northward to Huntington Canyon. The strike of the Joe's Valley fault along this section ranges from slightly west of north to slightly east of north. Movement along the Joe's Valley fault is down on the west. Blackhawk Formation, on the east, is generally placed in contact with Price River Formation on the west.

The area of Hog Flat, between the Joe's Valley fault and Cleveland Reservoir, is shown by Spieker to be largely unfaulted. Unpublished research by Robert Q. Oaks, Jr., and Jerome V. DeGraff (DeGraff, 1976, per. comm.), however, shows the area to be complexly faulted with normal faults intersecting the Joe's Valley fault. The intersecting faults trend northeast and parallel the graben at Cleveland Reservoir to the west.

The Valentine fault is located 1 to 2 miles east of the Joe's Valley fault. The Valentine fault extends from the southern boundary northward to about the head of Long Canyon. Total extent, within the area, is about 5.5 miles. The strike of the Valentine fault is about N. 7° E. Exposures, in Huntington Canyon, show that the fault is down on the west. At this locality, the Blackhawk Formation on the west is adjacent to Mancos Formation.

A graben, west of the Joe's Valley fault, is formed by three normal faults. The graben, as shown by Spieker (1931, Plate 31), is about 1.5 miles long in the north-south dimension and less than 1 mile wide. Faults occurring on the eastern and western boundaries of the graben are parallel. These faults strike N. 22° E. A third fault occurs across the northern boundary of the graben. The northern fault strikes N. 25° W. The graben is a block of Price River Formation that has been faulted down relative to the surrounding blocks of Blackhawk Formation.

Another small group of north-south-trending faults occurs in the southwestern corner of the area. This group of faults is almost completely confined to the study area. Total north-south extent of the fault group is about 8 miles. Average width is about 0.75 mile. This group consists of five normal faults. The longest of these is 8 miles, and the shortest is 1 mile. According to Spieker (1931, p. 54), displacement along each of these faults is less than 800 feet. Strike of these faults is N. 1° E. to N. 2° E. Displacement along these faults, as shown by Spieker (1931, Plate 31), is not generally great enough to bring one formation in contact with another at the surface exposure.

The north-south-trending faults of the area are the main structural control of the topography. Examples of this topographic control are the steep scarps and large down-dropped blocks associated with the Pleasant Valley and Joe's Valley faults. Although the fault blocks have been highly dissected by stream flow, they remain as the most outstanding topographic features of the area.

Two known dikes, within the area, are localized along north-south-trending fractures which parallel the faults. One of these crosses Flood Canyon in sec. 25, T. 14 S., R. 6 E. The other is near Winter Quarters in sec. 2, T. 13 S., R. 6 E. (Spieker, 1931, Plate 31).

The north-south faulting is probably later than the Green River Formation of Eocene age. Walton (1955, p. 409) suggested post-Green River folding. Because the faults undoubtedly cut the folds after all major folding had occurred, the faults also must be post-Green River. Walton (1955, p. 409) suggested the faulting to have been as late as Miocene. Spieker (1949, p. 78) showed post-Green River normal faulting, which probably continued into late Eocene or early Oligocene. He indicated late Eocene as the time of formation of the Wasatch monocline. The major north-south-trending faults, which produce the extensive graben in the Wasatch Plateau, are probably contemporaneous with formation of the Wasatch monocline. Recent movement along some of these faults was suggested by Spieker (1949, p. 81). Evidence for recent movement was obtained from fault scarps within glacial cirques near the main divide of the Wasatch Plateau.

The east-west-trending faults of the area generally have much less displacement and shorter extent than the north-south-trending faults. Spieker (1931, Plate 31) mapped several east-west-trending faults in the Winter Quarters area. These faults are all less than 1 mile long. Coal mine maps of the Winter Quarters area (EMCO, 1925?) show the east-west-trending faults mapped by Spieker (1931, Plate 31). Maximum displacement along these faults is 90 feet. The fault having 90 feet of displacement is near the bottom of Winter Quarters Canyon on the southern side. The fault with 90 feet of displacement has a dike localized along the fault plane. Displacement along the remainder of these faults ranges between a few inches and 45 feet. Two other dikes are located among this swarm of small faults. They are parallel to the faults and are presumably along associated fractures. Most of these faults are down on the south. The largest, however, is down on the north. At the surface, these faults are evident in the Blackhawk Formation. Displacement is not sufficient to alter surface expression of formations. Effect on topography by these faults seems to be minimal. The strike of these faults ranges from N. 60° W. to N. 80° W.

A group of faults, parallel to the faults of the Winter Quarters area, is located north of the study area (Walton, 1955, Figure 4).

These faults are up to 20 miles long. They form Fish Creek graben.

South of the Winter Quarters area, the dominant strike of the east-west-trending faults seems to become more westerly. This concept is illustrated by dikes localized along the faults. The fault-localized dikes, south of Winter Quarters, range between N. 80° W. and due west. This is also illustrated by Walton (1955, Figure 4). Although the east-west-trending faults mapped by Walton have some diversity in strike, the majority are parallel with those containing dikes. Robert Q. Oaks, Jr., and Jerome V. DeGraff (DeGraff, 1976, per. comm.) mapped several faults cutting Candland Mountain. Strike of these faults is N. 85° W. to N. 90° W. Displacement along most of the east-west-trending faults is unknown. It is believed that few of these faults have displacement greater than 50 feet. One fault, north of Clear Creek, Utah, near the mouth of Magazine Canyon in an open-cut coal mine has approximately 50 feet of displacement according to Dan Guy (1976, per. comm.). This fault has a highly weathered dike localized along the fault plane.

The age of the east-west-trending faults has not been completely worked out. Walton (1955, p. 411) indicated that the east-west-trending fractures containing dikes cut the graben fault zones after the latter formed. It seems likely, however, that the east-west-trending faults are more probably genetically related to the north-south-trending faults. The east-west-trending faults were probably formed contemporaneously with the north-south-trending faults. No good evidence has been located which indicates two separate periods of faulting.

More evidence for the faults that trend north-south and east-west being the same or nearly the same age appears at Flood Canyon and in the Winter Quarters area. At Flood Canyon, a dike is located along a north-south-trending fracture. Near Winter Quarters Canyon, intersecting faults that trend east-west and north-south both contain dikes (EMCO, 1925?). These two diverse trends of dike emplacement indicate that fractures, which trend east-west and north-south, formed prior to or concurrently with the period of igneous activity.

Joints

Two major joint sets are present within the area. These joint sets run roughly north-south and east-west and are parallel to the dominant trends of faulting. Many of the dikes are located along joints rather than faults. The joints parallel the faults with which they are probably genetically related. They were certainly produced by the same fracturing mechanism. Evidence for the relation of joints and faults is apparent in the dikes. Closely related dikes occur in faults as well as joints.

Major fractures of the northern Wasatch Plateau obviously extend to great depths within the Earth's crust. Some of the fractures must extend into the upper mantle and must have provided conduits for the rise of magmatic fluids. The fractures are probably extremely complex at depth due to the many impulses of orogenic activity that have affected the area throughout its geologic history.

DIKES

General Description

Within the study area, 28 igneous dikes have been mapped. The majority of these dikes were previously mapped by Spieker (1931, Plate 31). A few others were located as a result of the current study (Plate 1). At least five of the dikes mapped by Spieker were located on the basis of underground exposures. These dikes could not be located in surface exposure. Dikes which were not seen at the surface include the three westernmost dikes of Trough Springs Ridge, the dike which parallels Green Canyon, and the southernmost dike in the Winter Quarters area. The remainder of the dikes were seen in surface exposure.

Osterwald and others (1971, p. 8-9) indicated the presence of two light-colored igneous bodies along the northwestern wall of Tie Fork Canyon about 6.2 miles south of the mapped area. A photograph, published by Osterwald and others (1971, Figure 12), indicates the presence of a so-called igneous mass localized along a north-trending fault. The fault is on the eastern side of a graben forming Wild Cattle Hollow. The area illustrated in this photograph was studied by the author. The light-colored material along the fault was determined to be calcareous tufa. Another photograph, shown by Osterwald and others (1971, Figure 12) indicates the presence of a light-colored dike on the northwestern wall of Tie Fork Canyon. This feature was also inspected by the author. Rather than being a dike, it is simply a thin crust of calcium carbonate deposited by water draining along a fracture. No light-colored igneous rock has been reported at any other location.

Unlike the dikes of Loughlin (1919) and Pashley (1956), the dikes studied by the author are biotite orthoclase pyroxene lamprophyre. According to the classification of Williams and others (1954, p. 85), this rock falls into a lamprophyre type called minette. Hyndman (1972, p. 190) indicated that current practice is to name the lamprophyres according to common granitic rock classification. Following the classification given by Hyndman (1972, p. 34), the rock name is biotite syenite lamprophyre.

The dikes, described by Pashley (1956, p. 72-79), were classified as between kersantite and spessartite. Both are members of the lamprophyre rock group. The major difference between the rocks of Pashley and the rocks of this report is the groundmass. On the basis of staining the feldspars, the groundmass of the dike rocks of this report was identified as alkali feldspar. Pashley (1956, p. 77) indicated that the groundmass is plagioclase with a composition between oligoclase and labradorite. Pashley (1956, p. 77) also recognized lamprobolite that makes up 15 percent of the rock. No lamprobolite was recognized in the rocks of this report. Some small bladed minerals tentatively identified as amphibole were recognized in the groundmass.

Loughlin (1919, p. 104) identified most of the groundmass in the dikes near Santaquin, Utah, as albite. Other than the albite groundmass, the mineral constituents of the dikes near Santaquin are the same as the dikes of this report. Although Loughlin (1919, p. 104) recognized no free orthoclase in his samples, he did have a relatively high K_2O content in the chemical analysis. The high K_2O content places the rock with alkaline rather than normal basalts (Loughlin, 1919, p. 105). Loughlin (1919, p. 106) indicated that the K_2O in excess of that required for the formation of biotite belongs to the glassy part of the groundmass. The dikes near Santaquin were classified by Loughlin (1919, p. 107) as albite minettes.

Chemical analyses given by Loughlin (1919, p. 107) show that rocks classified as minette range considerably in composition. Few rocks are found which exactly fit the classification of minette or kersantite. Most lamprophyres classified as either minette or kersantite are actually a gradation somewhere between the two. According to the above study, it seems that the difference between minette and kersantite is a simple matter of the relative abundance of K or Na present. The amount of either ion present can be dictated by the amount of the ion assimilated as the magma passes through the country rock. Under these conditions, it may be that a small change in the environment of crystallization would cause the difference between minette and kersantite.

If the above data are accurate, the classification of rocks as minette or kersantite seems to be rather useless. A much more practical method of classification is to name the rock according to its actual composition. Thus, the rocks of this report are named biotite orthoclase pyroxene lamprophyre or biotite syenite lamprophyre.

In hand specimen, the fresh rock is gray to black. Not uncommonly, the darker colors seem to have a greenish tint. Minerals recognizable in hand specimen are biotite and olivine. Biotite seems to be much more abundant. The biotite appears as shiny flakes set in a dull groundmass. The olivine is difficult to recognize in some samples due to alteration. Olivine in all of the samples is seldom recognized without the aid of a hand lens. Weathered edges of the fresh rock are generally yellow to brown and are devoid of recognizable minerals except for a few flakes of biotite. Some of the dikes are extremely weathered and appear as clay-like material, which is yellow to brown. The only recognizable mineral is biotite. The biotite occurs as flakes disseminated throughout the clay-like material and appears rather fresh and unaltered.

The fresh material and the weathered material both commonly have veinlets of calcite cutting them. These calcite veinlets range up to 2 inches wide. Calcite commonly occurs in the weathered material as nodules up to 3 inches in diameter.

The majority of dike outcrops, in the area, are located on the western and southern slopes of the ridges. The northern and eastern slopes, as a result of being wetter, are covered with heavy stands of timber and deep soil. Undoubtedly dikes occur on those slopes, but location of them in surface exposure is impossible.

A general description of each dike in the study area follows. The descriptions begin with the northernmost dike and end with the southernmost. A sill, west of the study area, and a dike, east of the study area, are also discussed because of their significance in this investigation.

Dike C is located near the bottom of Winter Quarters Canyon, on the northern side, in sec. 1, T. 13 S., R. 6 E. It strikes N. 55° W. The extent, as shown by Spieker (1931, Plate 31), is about 0.5 mile. Based on the surface debris, it can be extended westward making a total extent of 0.75 mile. The width of the dike seems to be somewhat irregular. At its eastern end, at the point where it was sampled, it is 2.9 feet wide. Westward, it is about 2 feet wide. It crops out near the bottom of Winter Quarters Canyon. Westward, it extends diagonally up Granger Ridge. The rock is somewhat weathered to clay at the surface. Digging 3 or 4 feet into the dike will produce fairly fresh material. This dike is located along a fault as indicated by the mine map of the Winter Quarters area (EMCO, 1925?). Sandstone and shale, along the dike contact, are enriched in iron oxides and silica. Discoloration and hardening occur up to about 9 inches laterally from the contact. Sedimentary rocks adjacent to the dike do not seem to be fractured. Apparently dike injection was not forceful enough to cause extensive fracturing or deformation of sedimentary beds in contact with the dike.

Another dike occurs near the bottom of Winter Quarters Canyon, on the southern side, in sec. 1, T. 13 S., R. 6 E. This dike was not lettered and sampled because an outcrop could not be found. Surface evidence for the dike is limited to scattered boulders in the regolith. The dike strikes parallel with Dike C (Spieker, 1931, Plate 31). Extent of the dike, as mapped by Spieker, is about 0.25 mile. According to the Winter Quarters mine map (EMCO, 1925?), this dike is located along a fault with 90 feet of displacement.

Two dikes occur in the coal mines operated by EMCO, about 2 miles south of Scofield, Utah. Location of these dikes is inferred on the map accompanying this report (Plate 1). Neither dike is visible at the surface.

Another dike, which does not crop out, is located about 0.5 mile south of Winter Quarters Canyon in sec. 6, T. 13 S., R. 7 E. It is plotted on Spieker's map (1931, Plate 31) and on the Winter Quarters mine map (EMCO, 1925?). In its northern part, the dike trends east-west. In its southern part, it trends north-south. East-west extent is about 0.3 mile. North-south extent is about 0.4 mile. The dike seems to curve from east-west to north-south with no interruption. As mapped (EMCO, 1925?), the north-south part of the dike is located along a fault with unknown displacement. The east-west part is not plotted along a fault. Rather than gradually curving as shown on the map, the dike is probably located along the intersection of the fault with a joint. The actual point where the trend changes is probably sharp and nearly perpendicular.

A dike, located about 1.5 miles south of Winter Quarters Canyon, roughly parallels Green Canyon. Strike of the dike is about N. 60° W. Spieker (1931, Plate 31) mapped the dike for a distance of about 3.25 miles from sec. 12, T. 13 S., R. 6 E., to sec. 16, T. 13 S., R. 7 E. Surface exposures of the dike could not be located. Evidence for mapping of the dike by Spieker (1931, Plate 31) was based on exposures in coal mines. The western end of the dike was located in the Winter Quarters mine and the eastern end was located in the Utah mine near the mouth of Green Canyon. In the area between the two exposures, the dike was inferred (Spieker, 1931, p. 96). Spieker (1931, p. 95) described the dike in Green Canyon as a zone of dikes which is, in places, over 100 feet wide. Illustrations by Spieker (1931, Figure 12) show an aureole of coke and swelling of the dike into the coal bed. According to the above description, this is the largest known dike in the area. Likewise, it has caused the greatest amount of alteration in the coal.

In Boardinghouse Canyon, a small swarm of seven dikes was located. These dikes crop out in a road cut in sec. 30, T. 13 S., R. 7 E. Figure 2 shows the road cut containing dikes. They all strike east-west and are parallel. Strike of these dikes is N. 85° W. These dikes were lettered collectively as I and numbered from 1 to 7 from south to north. Extent of the dikes cannot be determined because exposure is limited to the road cut. If these dikes are projected across Pleasant Valley, they seem to be in line with dikes near the mouth of Magazine Canyon. Thickness of the dikes in Boardinghouse Canyon ranges from 4 inches to 2.5 feet. Dike I-1, shown in Figure 3, is located along a fault, which seems to have about 2 feet of displacement. Figure 4 shows a dike located along a joint. One small fault with 4 to 6 inches of displacement was located with no dike along it. The beds of sandstone and shale adjacent to the dike seem to be physically undisturbed by dike injection. Slight hardening and discoloration of the sedimentary rocks occur up to 7 or 8 inches from the dike contact. All dikes of this group are weathered to clay-like material. Dike E, on the northern side of Boardinghouse Canyon about 500 feet east of the swarm of dikes, is severely weathered.

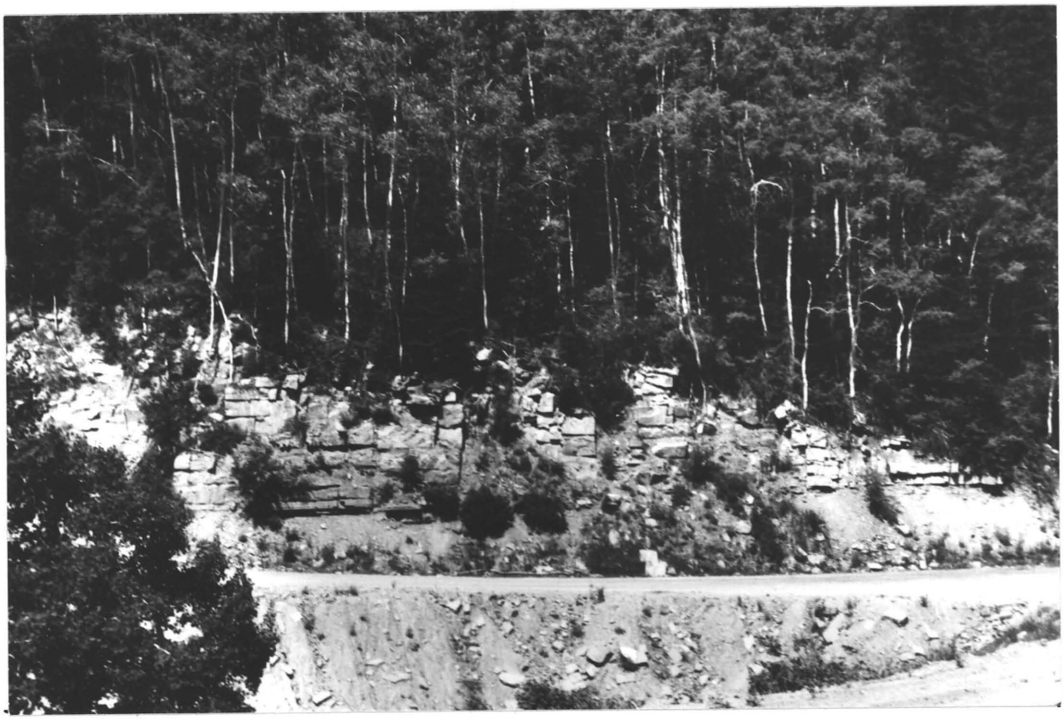

Figure 2. Several small dikes exposed along road cut in Boardinghouse Canyon, west of Clear Creek, Utah; view west. Dikes are weathered and are recessed relative to the sandstone of the Star Point Formation. Two of the largest dikes are also illustrated in Figures 3 and 4.

Figure 3. Dike exposed in road cut in Boardinghouse Canyon, west of Clear Creek, Utah; view west. Dike is weathered and is located along a small fault. Fault is down on the right. Dike is also illustrated in Figure 2.

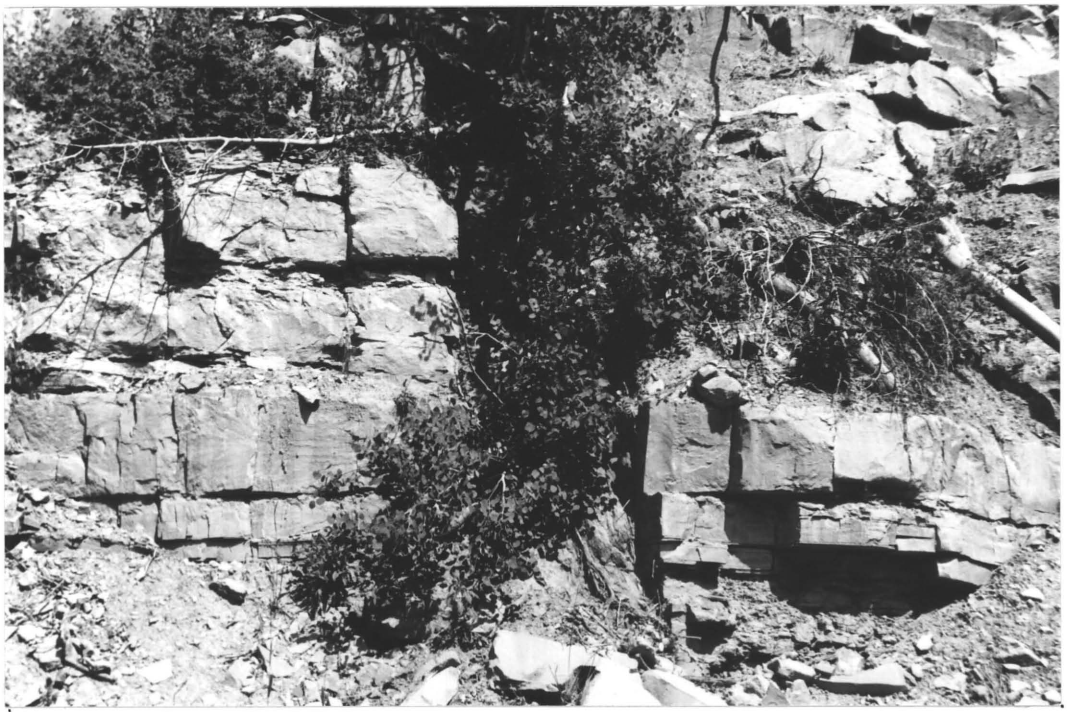

Figure 4. Weathered dike exposed in road cut along northern side of Boardinghouse Canyon, west of Clear Creek, Utah; view west. Dike is along a joint. Dike is also illustrated in Figure 2.

A group of dikes occurs north of Clear Creek near the mouth of Magazine Canyon in sec. 33, T. 13 S., R. 7 E. At this location, two dikes are present in an open-cut coal mine. These two dikes were designated collectively as F. The strike of the dikes is N. 78° W. Extent of the dikes cannot be determined because outcrops are limited to the mine cut. Spieker (1931, Plate 31) mapped three dikes in this area. His information probably came from underground mine exposures. As mapped by Spieker, all dikes are less than 0.75 mile in extent. The northernmost dike of the two located ranges in thickness from 1 foot to 2 feet. Variations in thickness are due to swelling of the dike into less competent beds, including coal. This phenomenon was observed by Spieker (1931, Plate 12) in the dike parallel to Green Canyon. Samples with F designation were collected from the northern dike. The width of the southernmost dike, exposed at the surface, is extremely difficult to determine. Good exposure of the dike could not be located. Along its outcrop, the dike seems to swell and split in the incompetent beds. Figure 5 illustrates the swelling and splitting. In places, the dike is up to 2 feet wide. In other places, it seems to split into several thin dikes.

The northern dike is located along a fault with about 50 feet of displacement according to Dan Guy (1975, per. comm.). Figure 6 shows the dike and the fault along which it is located. Amount of displacement along the fault was determined by offset of the coal bed and cannot be determined in surface exposure. Whether the southern dike is along a fault could not be determined.

Figure 5. Dikes in open-cut coal mine north of Clear Creek, Utah, near mouth of Magazine Canyon; view east. Weathered dikes, near center, are light colored. Several small dikes branch from larger dike below. Dikes cut the Blackhawk Formation.

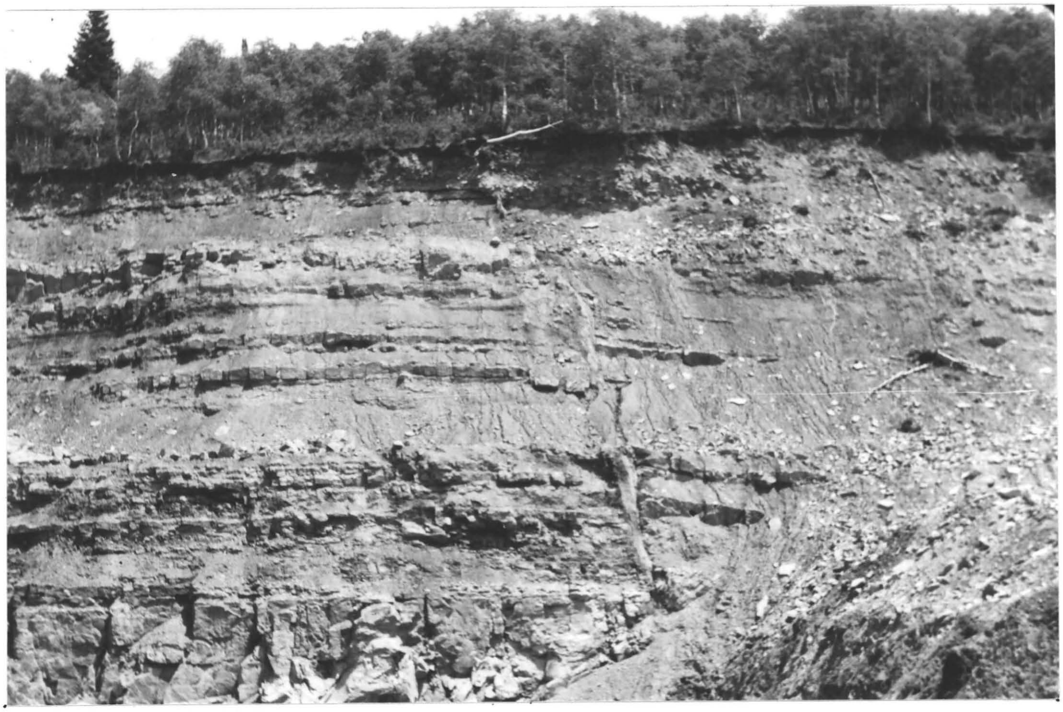

Figure 6. Dike in open-cut coal mine north of Clear Creek, Utah, near mouth of Magazine Canyon, view east. Dike is along a normal fault at right center. Fault is down on the right. Dike cuts the Blackhawk Formation.

Injection of the dikes was not forceful enough to greatly disturb the shale or sandstone beds adjacent to them. The only effects observable in outcrop are discoloration and hardening of the beds. The beds adjacent to the dike are darker in color and slightly harder than the unaltered beds. Alteration seems to have affected the beds only up to 1 foot from the dikes.

A dike occurs about 1.5 miles southeast of Clear Creek, Utah, in Snider Canyon in sec. 4, T. 14 S., R. 7 E. This dike strikes N. 80° W. Spieker (1931, Plate 31) mapped it as having an extent of 0.75 mile. The dike could only be located near the road which traverses the top of Castle Valley Ridge. Evidence for location of the dike was based on surface debris, which follows the trend of the dike, as mapped by Spieker (1931, Plate 31). No samples were taken from the dike in Snider Canyon, and the structural relationships could not be determined.

Dike H was mapped by Spieker (1931, Plate 31) near the head of the right fork of Hughes Canyon (unsurv. T. 14 S., R. 7 E.). Strike of the dike is nearly due west. As mapped, the extent of the dike is about 0.63 mile. Evidence is limited to debris so width, structural relationships, and exact extent could not be determined. In this report (Plate 1), the dike is mapped as plotted by Spieker (1931, Plate 31).

About 0.5 mile east of Dike H, Spieker (1931, Plate 31) mapped three dikes parallel to Dike H. These dikes are lined up on the map and nearly appear as one dike with covered intervals. These dikes could not be located in the field. Evidence for mapping by Spieker

(1931, Plate 31) is unknown but these dikes probably do not have surface exposure.

Dike J crops out on the crest of Trough Springs Ridge, 0.75 mile southeast of Dike H (unsurv. T. 14 S., R. 7 E.). Outcrop is limited to that on the crest of the ridge. This dike is 8.5 feet wide and strikes N. 85° W. The dike is located in a topographic low, which may indicate weakness in the sedimentary rocks due to faulting. As shown in Figure 7, the dike outcrop is surrounded by colluvium. The sedimentary rocks adjacent to the dike do not crop out. Relationships to the sedimentary rocks, therefore, could not be determined.

Between Dikes H and J, two dikes were located on the basis of scattered debris. These dikes are plotted on Plate 1, but extent and width could not be determined due to lack of exposure.

Dike G is located in Flood Canyon in sec. 31, T. 14 S., R. 7 E. The dike strikes due north. Width of the dike, where it crosses Flood Canyon, is 3.75 feet. Figure 8 illustrates the dike in Flood Canyon. As mapped by Spieker (1931, Plate 31), the extent of the dike is about 1.25 miles. The dike was located where it crosses Flood Canyon, but it could not be followed laterally by the author. No dike could be found at the location Spieker mapped (1931, Plate 31). The dike is located about 0.5 mile east of the one mapped by Spieker (1931, Plate 31). Presumably it is the same dike, but it was mapped incorrectly in the earlier report.

Sandstone beds are recognized at the same level on both sides of the fracture in which the dike is localized. Shale adjacent to the dike seems to be undisturbed by dike injection. The shale beds

Figure 7. Dike exposed on top of Trough Springs Ridge, south of Monument Peak; view east. Dike is surrounded by colluvium. Dike cuts the Blackhawk Formation.

Figure 8. Dike exposed in bottom of Flood Canyon; view south. Dike extends from distinct contact on left to prominent joint blocks on right. Dike cuts the Star Point Formation.

do not seem to be broken or moved by dike emplacement. Alteration in the adjoining rocks is no different than that of earlier descriptions. A small fault, 200 feet east of the dike, has about 1 foot of displacement. This fault exactly parallels the strike of the dike and is down on the west. No dike is present along the fault.

Dike B is the northernmost dike on the northern end of Candland Mountain in sec. 23, T. 14 S., R. 6 E. The east-west-trending dike has a strike of about N. 85° W. As mapped by Spieker (1931, Plate 31), the extent of the dike is 0.35 mile. Based on surface debris, the dike was extended westward (Plate 1) to make the total extent about 0.45 mile. An outcrop is present only as the dike crosses the crest of Candland Mountain. At this location, the dike is 10.7 feet wide. This dike is composed of fairly fresh rock that forms a prominent outcrop within the sedimentary rocks.

Exposures of the sedimentary rocks adjacent to Dike B are limited as they are generally covered by colluvium. It was not determined whether the dike is located along a fault or a joint. Robert Q. Oaks, Jr., and Jerome V. DeGraff (DeGraff, 1976, per. comm.) mapped several faults parallel to the dike cutting Candland Mountain. They did not determine whether the dike is located along a fault. The dike is located in a saddle on the ridge top. This may be an indication of weakness along a fault. If a fault exists, the dike may or may not be located along it.

Sedimentary rocks adjacent to the contact of Dike B were located by digging 2 to 3 feet into the colluvial deposit along the edge of the dike. The sandstone and shale beds in contact with the dike seem to be undisturbed by dike emplacement. Effects by the dike are essentially the same as those described for previous dikes. The contact zone in sandstone seems to be more highly weathered than surrounding exposures. This may be due to iron enrichment along the contact with the development of limonite.

Dike A is located 0.4 mile south of Dike B in sec. 26, T. 14 S., R. 6 E. The dike is parallel to Dike B. Spieker (1931, Plate 31) mapped the extent as 0.45 mile. A dike located by Robert Q. Oaks, Jr., and Jerome V. DeGraff (Oaks, 1975, per. comm.) can be inferred to be the same dike. Based on this assumption, the total extent of the dike is about 0.9 mile. Figure 9 is an illustration of the dike located by Robert Q. Oaks, Jr., and Jerome V. DeGraff (Oaks, 1975, per. comm.).

At the crest of Candland Mountain, Dike A is 10.5 feet wide. The outcrop pattern, structural relations, and alteration of sedimentary rocks are the same for Dike B. The saddle in which this dike is located, however, is much smaller and has less topographic expression than that of Dike B. Robert Q. Oaks, Jr., and Jerome V. DeGraff (Oaks, 1975, per. comm.) indicated that the eastern end of the dike, which they located, is along a fault with unknown displacement. The Blackhawk Formation is on both sides of the fault according to Spieker (1931, Plate 31).

Dike D is located on the western side of Candland Mountain about 1.25 miles south of Dike A in sec. 35, T. 14 S., R. 6 E. This dike strikes nearly due west. Extent of the dike is about 0.5 mile. As mapped by Spieker (1931, Plate 31), the dike does not extend to the

Figure 9. East-west-trending dike exposed north of Flood Canyon on Candland Mountain; view southeast. Dike appears as a line in upper right. Dike connects with Dike A to right of view. Dike cuts the Blackhawk Formation. Photo by Robert Q. Oaks, Jr.

top of Candland Mountain. Debris, however, extends over the crest and a few feet down the eastern side. The eastern slope is heavily timbered and covered with deep soil. These conditions make dike location on the eastern slope impossible.

Dike D is seen in outcrop only where it crosses a small canyon. At this location, it is about 9 feet wide. The dike is weathered on the surface to a clay-like coating. By digging into the dike more resistant rock is found; however, it is nevertheless highly weathered.

Dike D is located along a joint. Sandstone layers are recognized at the same level on both sides. The sandstone and shale adjacent to the dike are unbroken as a result of dike emplacement. The contact of the dike with the sandstone is sharp and not gradational.

A sill is located about 2.5 miles west of the study area in secs. 18 and 19, T. 14 S., R. 6 E. The sill is mentioned here because it is the only reported sill of the northern Wasatch Plateau. The sill was located by Robert Q. Oaks, Jr., and Jerome V. DeGraff (Oaks, 1975, per. comm.). It extends for about 0.5 mile along the ridge south of Spring Canyon. Actual extent is unknown due to covering by regolith. Rocks above and below the sill are beds of the North Horn Formation. The bed above is a fossiliferous limestone, and the bed below is a sandstone. The sill is 1.5 feet thick. The rock of the sill was examined in thin section and is of the same mineral composition as the dikes of the study area.

In a road cut along Utah State Road 10 about 8 miles south of Price, Utah, a dike occurs in the Blue Gate Member of the Mancos Formation in sec. 30, T. 15 S., R. 10 E. This dike is interesting because it is offset horizontally by movement along bedding planes in the shale. Figure 10 illustrates the horizontal offset and a curve of the dike in the upper part of the outcrop. Figure 10 is also an excellent illustration of the hardening in the sedimentary rocks adjoining the dikes, which has been discussed earlier. The darker colored rock in contact with the dike in Figure 10 is shale, which has been hardened and discolored by dike emplacement. In this case, the zone is about 4 inches thick. Figure 11 illustrates a termination of the dike, against shale, as a result of horizontal offset. Nonforceful dike emplacement is also well illustrated in Figure 11. The shale to the left of the dike is not fractured and is largely undisturbed by dike emplacement.

The horizontal offset along this dike may be attributed to one of three factors. Offset may have occurred because of differential movement of the shale during downslope movement. The offset could also be explained by differential horizontal tectonic movement. A third, and perhaps more valid explanation, is that horizontal movement was caused by compaction of the shale as it was buried by overlying sedimentary rocks.

This dike has been extremely weathered to yellowish clay-like material. The only recognizable mineral in the altered material is biotite. X-ray analysis of the weathered dike material is presented later.

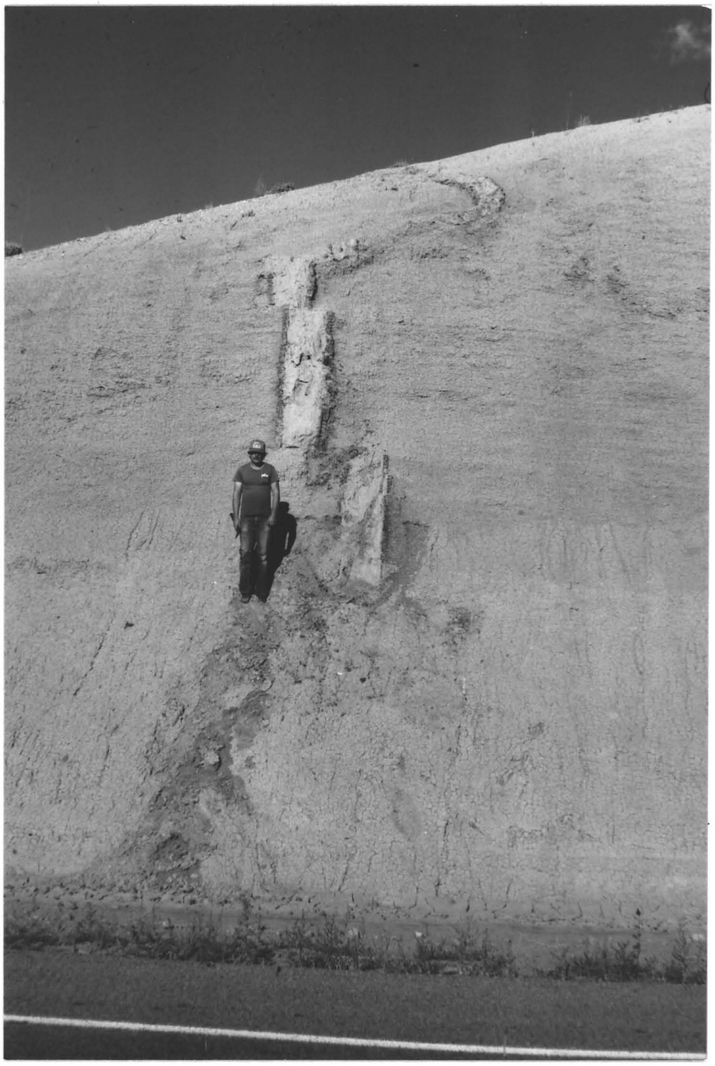

Figure 10. Dike exposed in road cut along Utah State Highway 10, about 8 miles south of Price, Utah; view west. Dike is offset horizontally and curves at upper right. Adjoining rock is shale of the Blue Gate Member of the Mancos Formation. Dike is also illustrated in Figure 11.

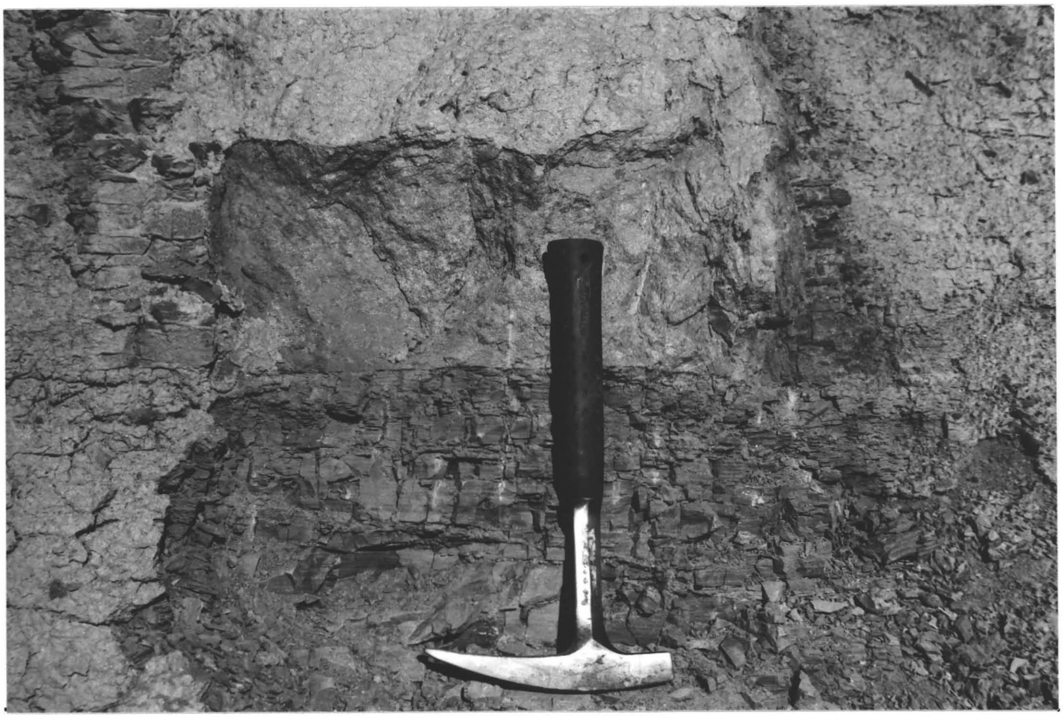

Figure 11. Termination of dike, against shale, at horizontal offset; view west. Dike is also illustrated in Figure 10 where it is next to the man's head.

Petrographic Description

One dike was selected as representative of all dikes in the area. This dike was studied petrographically and is described in detail. To describe each dike would be repetitious and unnecessary. The dikes and their compositions are listed in Table 2. One severely weathered dike is also described in detail in order to illustrate the weathering products. The dike chosen as representative of fresh rock is the dike on the northern side of Winter Quarters Canyon. The weathered dike described is the southernmost dike on Candland Mountain. This dike, although severely weathered, is nevertheless fairly competent. Two dikes, which are weathered to clay-like material, were selected for X-ray studies. X-ray studies of weathered material were made on the dikes of Boardinghouse Canyon and the dike at Magazine Canyon.

The dike, on the northern side of Winter Quarters Canyon, was designated as Dike C. Samples from this dike include C-4 and C-1. C-4 is from the center of the dike and C-1 is from the edge of the dike.

Sample C-4, as seen in thin section, has a lamprophyric texture. Lamprophyric is a textural term used by Williams and others (1954, p. 17) to describe the panidiomorphic-granular texture of lamprophyres.

The most abundant mineral in Sample C-4 is biotite, which composes 33 percent of the rock. The biotite is present in unoriented subhedral to euhedral crystals. Birefringence in the biotite ranges from brown to second and third order colors. When it appears brown, the actual color of the biotite is masking the birefringence. Many

Table 2. Thin-section examination of dike rocks

Sample	% Biotite	% Augite	% Olivine	% Ground-mass	% Magnetite	% Chlorite	% Calcite	% Quartz	% Apatite	Remarks
A-1	19	13	18	34	7	8	Tr.	Tr.	Tr.	
A-4	21.5	10	18.5	32.5	6	8	1	Tr.	Tr.	
B-2	20	15	5	42	5	9	2	Tr.	Tr.	
B-3	23	12	16	31	3	11	1	Tr.	Tr.	
C-1	14	8	4	58	2	8	3	Tr.	Tr.	a
C-4	33	11	8	38	4	4	1	Tr.	Tr.	b
D-3	12	11	4	43	5	17	6	2	Tr.	c
D-4	35	6	3	33	3	14	5	Tr.	Tr.	c
G-2	14	21	4	51	5	4	Tr.	Tr.	Tr.	
G-4	32	15	10	30	5	5	2	Tr.	Tr.	

[a] Groundmass up to 15 percent biotite and augite.

[b] Biotite with red rims and yellow cores.

[c] Primary rock severely altered.

biotite flakes not oriented parallel to the thin section give interference figures which appear uniaxial. Without crossed nicols, many of the biotite flakes have reddish rims surrounding yellowish cores. Williams and others (1954, p. 86) considered reddish rims to be rich in iron and titania enclosing the yellowish cores rich in magnesia. This, they consider to be a characteristic of minette. The biotite also has battlemented ends like those of minette described by Williams and others (1954, p. 86). The biotite ranges in size from minute crystals in the groundmass to 4 mm flakes. Average size is about 1 mm. Many of the biotite crystals are cut by veinlets of secondary calcite. A few have veinlets of a clay-like mineral tentatively identified as chlorite. Aside from the relatively small amounts of calcite and chlorite, the biotite flakes are free from alteration. Growth of the biotite crystals had to have been later than that of augite and olivine.

Augite is the second most abundant mineral and makes up 11 percent of the rock. It occurs as randomly oriented subhedral to euhedral crystals. A more accurate name for the augite may be diopsidic augite. In most crystals, it is difficult to separate augite and diopside. The average extinction angle is 45 degrees. Extinction angles range from 37 to 50 degrees. Birefringence of some pyroxene crystals reaches upper second order. The majority of the pyroxene crystals are tentatively identified as augite. Some of the crystals are probably closer to diopside. Most of the pyroxene crystals are free from alteration. A few are partially replaced by mixtures of calcite, iron oxides, and what seems to be amphibole. The augite crystals range in size from extremely small needle-like crystals, in the groundmass, to up to 1 mm. Average size of the augite is 0.21 mm. The augite crystals seem to be of earlier growth than the biotite.

Olivine is present as subhedral to anhedral crystals, many of which are severely altered. Besides the olivine crystals, there are many pseudomorphs after olivine present. Olivine originally composed about 8 percent of the rock. An axial angle of nearly 90 degrees places the olivine at the forsterite end of the olivine series. Pseudomorphs after olivine crystals are present as mixtures of calcite, iron oxides, and a platy to acicular mineral which is probably talc. The olivine ranges in size from about 0.08 mm to 2.0 mm. Average size of the olivine is about 0.22 mm. The olivine is considered to be of earlier growth than the biotite.

Euhedral magnetite crystals make up 2 percent of the rock. The magnetite crystals are randomly scattered octahedra that range from square to triangular as seen in section. Most of the magnetite seems to be of primary origin as relatively small amounts are found associated with alteration products. The secondary magnetite is only found around the margins of the olivine pseudomorphs. Growth of the primary magnetite seems to have been coincident with, or slightly before, the growth of the biotite. Size of the magnetite crystals ranges from 0.01 mm to 0.1 mm. Average size is about 0.05 mm.

Quartz occurs as a small part of the groundmass. Most of the quartz is considered to be present by assimilation and was not part of the original magma. It is extremely difficult to estimate how much of the glassy groundmass is actually quartz, but it is considered to be a relatively small amount.

Parts of the groundmass are characterized by radiating finger-like growths of a feldspar identified as orthoclase. These radiating growths are considered to be of secondary origin and probably resulted from recrystallization. The radiating feldspars have an index of refraction a little above 1.52. This figure is indicative of orthoclase. Birefringence is typically low and consists of first order gray to white. Positive identification of orthoclase was accomplished by staining of the rock.

Small prisms of apatite were recognized as inclusions in the biotite and in the groundmass. These prisms rarely exceed 0.01 mm in length and are always euhedral.

The most prevalent secondary materials are quartz, calcite, clay minerals, and iron oxides. Quartz occurs as deposits in open spaces of the rock.

Calcite occurs as a vein filling in the biotite and in the groundmass. Rhombohedral calcite crystals are also present in voids and as alteration products. Calcite crystals, up to 0.2 mm across, are found associated with the pseudomorphs of olivine. In small areas of the rock, calcite seems to be a replacement mineral for part of the groundmass. The calcite is entirely secondary in origin and may make up as much as 1 percent of the rock.

Clay minerals, produced by alteration of mafic phenocrysts, make up as much as 4 percent of the rock. The most prevalent of these have been tentatively identified as chlorite and talc. Some clay-size material may represent the tremolite-actinolite series replacing augite. This material is all of secondary origin and extremely difficult to identify exactly. The clay-like material occurs mainly with altered crystals of olivine and augite.

Iron oxide, probably limonite, is a common alteration product. The iron oxide occurs as rims around nearly all of the altered crystals and in isolated patches within the groundmass. It apparently has no crystal shape.

The groundmass makes up about 38 percent of the rock. Most of the groundmass is orthoclase. Other minute crystals in the groundmass are apatite, biotite, and small acicular crystals tentatively called amphibole. Much of the groundmass is glassy and probably contains quartz. A plagioclase, probably albite, occurs with the orthoclase in the groundmass. It is estimated that the feldspar fraction of the groundmass is 85 to 90 percent orthoclase and the remainder is albite. The mafic crystals mentioned above as being part of the groundmass probably make up less than 10 percent of the groundmass. The feldspar of the groundmass was identified on the basis of staining. The groundmass obviously crystallized later than the phenocrysts and at a much more rapid rate. Iron oxides replace small amounts of the groundmass.

Sample C-1 is from the edge of the dike on the northern side of Winter Quarters Canyon adjacent to C-4. Sample C-1 has lamprophyric texture but the average size of the phenocrysts and the crystals of the groundmass is much smaller than in Sample C-4. This is obviously due to more rapid cooling on the edge of the dike than in the center.

The chilled zone does not have a definitive boundary. The grain size is smallest on the edge of the dike and increases toward the center. The groundmass in Sample C-1 is so fine grained as to be somewhat vitrophyric in part. Much of the groundmass is dark under crossed nicols and parts of it show vague flow lines which are characteristic of vitrophyric texture. These flow lines are identified in part by alignment of biotite crystals along the direction of flow.

Biotite is the most abundant mafic phenocryst. The biotite composes about 14 percent of the rock. In much of the rock, the biotite flakes have been oriented more or less subparallel by flow of the groundmass. In the remainder of the rock, the biotite is randomly scattered and unoriented.

Petrographic characteristics of biotite in C-1 are essentially the same as in C-4. Average size of the biotite flakes is the only major difference. In C-1, the biotite flakes average 0.16 mm. This is considerably smaller than in C-4 in which they average 0.4 mm. The biotite of C-1 ranges in size from 0.01 mm to 1.2 mm.

Euhedral to anhedral augite makes up about 8 percent of the rock. The microscopic properties of the augite are the same as those of the augite in C-4. The augite ranges in size from 0.01 mm to 0.7 mm. Average size is about 0.15 mm. Many of the augite crystals are partially replaced by chlorite. A few have calcite mixed with chlorite. For the most part, the augite is completely unaltered.

Euhedral to subhedral olivine makes up about 4 percent of the rock. Size range of the olivine is between 0.02 mm and 0.8 mm. Average size is about 0.2 mm. An axial angle approaching 90 degrees is indicative of a high-magnesium concentration with low-iron concentration. Most of the olivine crystals are unaltered, but a few are partly altered to chlorite and a few are completely changed to chlorite. Associated with the chlorite are smaller amounts of calcite and iron oxides.

Euhedral magnetite is randomly scattered throughout the specimen. The magnetite crystals compose about 2 percent of the rock. Average size of the magnetite is about 0.05 mm and the size range is from 0.02 mm to 0.3 mm. The magnetite crystals are square to triangular in shape, as seen in thin section, and are completely unaltered.

Small euhedral prisms of apatite are enclosed in the groundmass and sometimes included in the biotite. Size range of the apatite is from 0.01 to 0.08 mm. The size averages about 0.04 mm. Apatite crystals cut in cross section are dark between crossed nicols.

Secondary replacement materials, in the specimen, include calcite, iron oxides, chlorite, and quartz. The rock is composed of 3 percent replaced pyroxene and amphibole crystals. These masses range in size from 0.01 mm to 1.1 mm. Average size is 0.3 mm. They consist entirely of calcite and are surrounded by rims of iron oxide. These masses retain their original monoclinic shape and the majority have crystal shapes typical of diopside and augite. A few have crystal shapes typical of the amphibole series. The masses are unlike anything else in the specimen. The difference is that the crystal shape remains unchanged and there is no evidence of partial replacement. No crystals are present in which the original mineral composition can be determined.

Calcite and iron oxides also replace small parts of the groundmass and fill voids in the rock. Quartz is present mainly in vugs, although a relatively small amount is present as primary crystallization in the groundmass. Chlorite locally replaces olivine and augite. In some cases, it forms rims around biotite flakes.

Groundmass composes about 58 percent of the total volume. The groundmass of C-1 has a much higher percentage of mafic crystals than that of C-4. In Sample C-4, the groundmass is at least 85 percent feldspar. In Sample C-1, the groundmass may be up to 50 percent mafic crystals. These include nearly equal amounts of biotite and augite with a relatively small amount of olivine. The feldspar fraction of the groundmass is up to 90 percent orthoclase and contains a small amount of albite. Quartz probably composes less than 5 percent of the groundmass. Much of the quartz is vitrophyric in texture. Glass occurs in patches up to 1 mm across.

Parts of the groundmass are characterized by tabular biotite flakes and augite crystals aligned along the direction of flow. The flow occurred during emplacement of the dike. Flow lines indicate that during emplacement the felsic part of the groundmass was in a subsolid state.

The feldspar part of the groundmass is almost completely devoid of crystals large enough to identify. Sample C-1 was also stained to determine feldspar composition and it seems to be 90 percent orthoclase.

The only variation in fresh rock, from dike to dike, is in relative amounts of each constituent present. In all cases except one, biotite is the most abundant phenocryst. The only exception is

Dike G in Flood Canyon. Dike G is 14 percent biotite and 24 percent augite. Since all dikes are so much alike in mineral composition, these differences are attributed to variations within the same magma.

Dike D is the southernmost dike on Candland Mountain. This dike was selected as representative of severely weathered dike rock. Even though this dike is severely weathered, it is still fairly competent material. It is not weathered to the extreme degree of the clay-like dikes.

Sample D-4 was taken from the center of the dike. Petrography of the fresh rock is exactly the same as that of Sample C-4 described earlier. The only difference between the two rock samples is the degree of weathering.

Magnetite is the least altered of all minerals present. Most of the magnetite is unaltered, but a few grains have reddish rims of oxidized iron. The magnetite crystals range from 0.01 to 0.08 mm in size. They occur as square to triangular crystal sections randomly scattered throughout the section. Average size is about 0.02 mm. In some places where the groundmass is highly altered, the magnetite has been recrystallized into irregular masses and no longer has good crystal outlines. Magnetite makes up 3 percent of the rock.

Biotite is the freshest of the large phenocrysts in the rock. The biotite composes 35 percent of the rock and ranges in size from 0.09 mm to 0.6 mm. Average size is 0.3 mm. A few biotite crystals have veins of chlorite and a few seem to be recrystallized into a more fine-grained biotite. The recrystallized biotite maintains the same optic properties as the original mineral. Many biotite crystals are cut by veinlets of calcite along the cleavage planes.

Augite makes up 6 percent of the rock. The augite crystals range in size from 0.02 to 0.5 mm and average 0.17 mm. Many augite crystals are replaced by chlorite and iron oxides. Augite may originally have been up to 20 percent of the total volume. Some of the augite crystals are only partly replaced. These are generally fresh on the edges and pitted with replacement material in the center. The chlorite occurs as generally green to blue aggregates of scaly to acicular crystals. In many cases, the original augite crystal is completely destroyed, and the chlorite has continued to grow into the groundmass. Small portions, less than 10 percent, of the replacement material are more representative of talc than chlorite. The two seem to intermix without definite boundaries. A few augite crystals have been replaced by rhombohedral calcite with rims of chlorite and iron oxides.

Replacement of the olivine crystals seems to follow the same pattern as the augite replacement. It is mostly replaced by chlorite, and generally a pseudomorph of the original crystal shape remains. Olivine originally made up 7 percent of the rock, but fresh olivine is now about 3 percent. Size range in the olivine is 0.1 mm to 0.3 mm and the average is 0.15 mm.

The original rock seems to have been about 33 percent groundmass. Most of the groundmass is now replaced by iron oxides, calcite, chlorite, and small amounts of secondary orthoclase. Original groundmass material is difficult to identify. Secondary orthoclase differs from primary in that it is in crystals up to 0.5 mm across.

No primary orthoclase occurs in any thin section with crystals greater than 0.01 mm. Parts of the groundmass have been removed by chemical weathering. The remaining voids are usually filled with aggregates of quartz. Smaller amounts of calcite fill the voids. Up to 50 percent of the groundmass now appears brown to red in color and is dark between crossed nicols. This is indicative of a high percentage of iron oxides.

Secondary calcite now makes up about 5 percent of the rock. Chlorite and other replacement minerals are up to 14 percent of the rock.

Sample D-3, from the edge of the southernmost dike on Candland Mountain, is much the same as D-4. The main differences between the two are a smaller original grain size and a greater percentage of groundmass biotite in D-3. Replacement patterns are the same, but D-3 is up to 17 percent chlorite and 6 percent calcite. Quartz seems to be somewhat more prevalent in D-3. A higher percentage of quartz is assumed to be a function of its closer proximity to the sandstone beds.

X-ray studies of the clay-like material produced by weathering of dikes were done on the dikes of Boardinghouse Canyon and on the dike of Magazine Canyon. X-ray traces from the two localities produced the same results. Minerals recognized in the X-ray patterns include biotite, quartz, calcite, and probably chlorite. The X-ray pattern shows a peak at 6.2° 2-theta or about 14.4 angstroms. This peak is considered to be indicative of the chlorite group of minerals. All chlorite peaks were not recognized with their correct relative intensities, but the peaks are more representative of chlorite than of any other mineral. Variation in the X-ray pattern from that of true chlorite is considered to be due to weathering. Even though it could not be recognized as such, the clay may in actuality be a mixed-layer clay. In this case, chlorite and some other clay mineral would alternate layers in the same lattice structure (Carrol, 1970, p. 37).

Effects on Adjoining Rocks

The sedimentary rocks adjacent to the lamprophyre dikes show little change due to the dikes. The changes that do occur are virtually the same for every dike in the area. For petrographic description of the effects on the wall rocks, one dike was chosen as representative. Effects of the remaining dikes can be considered to be the same. Special treatment, however, will be given to effects on the coal beds intruded by dikes. The greatest variety of samples at any one locality was available at Dike F in the mine cut north of Clear Creek. For this reason, Dike F was chosen for petrographic studies concerning effects on the wall rock. Samples of the rocks adjoining Dike F include samples of sandstone and shale from near the contact of the dike, 1 foot from the dike, and 10 feet from the dike.

Sample F-1 is shale taken from adjacent to the dike north of Clear Creek. Sample F-2 is shale from the same bed 1 foot from the dike, and F-3 is shale from the same bed 10 feet from the dike. The bed is part of the Blackhawk Formation. The shale is a sandy shale with sand grains up to 0.5 mm in diameter. The rock is up to 75 percent quartz. Calcite is the cement. It makes up about 10 to 15 percent of the rock. Other minerals are magnetite, zircon, hematite, and a few grains of feldspar. Feldspar grains include both orthoclase and plagioclase.

Effects due to dike emplacement occur only in Sample F-1 from the contact zone. Sample F-2, only 1 foot from the dike, seems to be free from dike alteration. Alteration in F-1 is limited to enrichment of iron in the cement. Sample F-1 seems to have more oxidized iron around the quartz grains than do Samples F-2 and F-3. The quartz is unmelted and seems to be unaffected by the dikes. No other alteration was recognized.

Samples F-4, F-5, and F-6 are sandstone of the Blackhawk Formation from near the dike north of Clear Creek. Sample F-4 is from the contact zone with the dike, F-5 is from 1 foot from the dike, and F-6 is from 10 feet from the dike. Rounded to subangular quartz makes up about 60 percent of the rock. Calcite cement composes 30 to 35 percent of the rock. Other minerals include magnetite, hematite, zircon, biotite, and feldspars. This rock seems to have some secondary alteration due to weathering.

Sample F-4, near the dike contact, seems to have a higher percentage of iron in the cement than F-6, 10 feet from the dike. This is presumed to be due to iron enrichment caused by dike emplacement. Calcite is more abundant next to the dike and is up to 40 to 45 percent of the rock. The calcite seems to be replacing minerals other than quartz. It is difficult to tell whether calcite was added from the magma or recrystallized within the sedimentary rock. The cement seems to be the same as in F-6. Patches of glassy material resembling silica occur in Sample F-4. These patches are dark between crossed nicols and appear vitrophyric. The quartz grains in the sandstone have not been melted. Thus, it is assumed that the glassy material was added from the magma. Sample F-5 is nearly free from alteration, but glassy material as seen in F-4 is present in smaller amounts. Thus, the alteration effects seem to be present for slightly more than 1 foot. No other effects by the dike were recognized.

Because of limited surface outcrop, the metamorphic effects on the coal could not be accurately determined. In only one locality can a dike be seen cutting a coal bed at the surface. That locality is in the open-cut mine north of Clear Creek, Utah, at Magazine Canyon. At this locality, the coal is not coked, and the effects of the dike seem to be limited. Physical effects observable at the outcrop are slight hardening of the coal and more extensive fracturing next to the dike than a few feet away. These effects occur only up to one foot from the contact of the dike and coal.

According to the microscopic characteristics for determining coal rank (Murchison and Westoll, 1968, p. 248), it is a bituminous coal probably of low rank. The vitrinites are distinguishable from the exinites, but little cell structure can be recognized. As expected, the coal is largely isotropic and only its impurities transmit light. Impurities within the coal, as seen in thin section, account for less than 20 percent of the total. The most abundant mineral matter seems to be secondary filling of shrinkage cracks. The material filling the cracks has the characteristics of quartz. Other impurities include traces of resin, pyrite, and possibly kaolinite.

According to the classification of Murchison and Westoll (1968, p. 248), the altered coal is probably on the border between anthracite and high-rank bituminous coal. Pronounced anisotropy is considered to be the distinguishing characteristic of anthracite. Coal from the altered zone adjacent to the dike in Magazine Canyon shows much greater reflectance than the unaltered coal. Anisotropic matter composes nearly 50 percent of the total. Near the dike, the coal is enriched with pyrite. Pyrite is up to 2 percent of the altered coal. The altered material is composed of nearly 30 percent quartz and chalcedony. It is assumed to have been present in much lower quantity before dike emplacement. The remaining 50 percent of the rock is isotropic. It does, however, have a much more reddish irridescence than the isotropic material of the unaltered rock. This is attributed to partial breakdown of the organic matter due to the heat of dike intrusion.

Spieker (1931, p. 50) reported that coal beds are coked as much as 10 feet from some dikes in the Pleasant Valley district. The coke that he reported is present in underground mines and was not seen at the surface. As reported by Spieker (1931, p. 50), most dikes have coked the coal for only 1 or 2 feet.

GEOLOGIC HISTORY

Origin of Magma

During middle to late Tertiary, the area of the northwestern Colorado Plateau was subjected to partial melting in the upper mantle and extensive intrusive activity. According to separate studies by McGetchin and Silver (1972) and Smith and Levy (1976), the upper mantle below the Colorado Plateau is fairly constant in mineralogy. It is assumed that the mantle below the Wasatch Plateau is essentially the same as that described in the two papers mentioned above. This assumption is based on the similarity of mineral composition of the igneous rocks of central Utah compared to the composition of the mantle beneath the areas described by McGetchin and Silver (1972) and Smith and Levy (1976). Smith and Levy (1976) also reported the association of minette with the diatremic intrusions that include rocks of the upper mantle at Green Knobs, which is near the Defiance uplift in New Mexico. McGetchin and Silver (1972) reported the occurrence of minette associated with diatremic intrusion at Moses Rock in southeastern Utah. The assumed constancy of mantle composition below the Colorado Plateau and association of minette with diatremic intrusion is supportive evidence that the lamprophyric magma of the Wasatch Plateau was generated and emplaced due to conditions of high-volatile pressure in the upper mantle.

The minette at Green Knobs was produced by partial melting of hydrous peridotite (Smith and Levy, 1976, p. 122). The resultant magma, containing suspended solids, was injected into pre-existing fractures. Smith and Levy consider the lamprophyric fluids to have been generated below a garnet peridotite layer in the mantle. According to their calculation of depth, this would mean that the lamprophyre was initiated at a depth greater than 60 km. Volatiles, necessary for generation and emplacement of the magma, were derived mainly from the hydrous minerals and carbonates of the garnet peridotite layer. Rast (1970, p. 348) suggested that melting of the peridotitic mantle can produce appreciable amounts of water, CO_2, SO_2, and Cl in the upper mantle.

Harris and others (1970, p. 198) indicated that the volatile content of magma is responsible for the association of lamprophyres with diatremic intrusions. They considered the magnitude of volatile pressure in the subsurface to be the determining factor between a diatremic intrusion and a lamprophyric intrusion. A diatremic intrusion has sufficient volatile pressure to overcome lithostatic pressure, which causes a violent explosion up through the overlying rocks. Lamprophyric intrusions are emplaced at a higher temperature and a much lower volatile pressure than the diatremes. Thus, the origin of lamprophyric magmas is essentially the same as that of diatremic magmas. The difference is a much lower gas pressure in the lamprophyric magmas. Lower gas pressure, according to Harris and others (1970, p. 198) may be due to gas escaping at or near the surface. With gas escaping, the volatile content would be lowered and the solid portion of the lamprophyric melt would remain in its conduit for emplacement.

Based on the above evidence, a suggested origin for the lamprophyre of the Wasatch Plateau follows. The magma originated from partial melting of the hydrous peridotite of the upper mantle at a depth near 60 km. As volatile pressure increased in the newly formed melt, the gas-solid mixture began to rise into pre-existing fractures (Harris and others, 1970, p. 197). The melt was transferred upward against gravity by gas pressure in the magma chamber below. It is unknown whether the felsic groundmass was part of the original melt as liquid or gas, or whether it was assimilated from the wall rock as the magma was forced through the fractures. The actual source of the groundmass was probably a complicated mixture of original and assimilated material. Sahama (1974, p. 106) proposed a gaseous transfer of K and Na for selected alkali enrichment in potassium-rich rocks. This would be the factor controlling the type of feldspar predominant in the groundmass. Mafic phenocrysts were carried in the melt as precrystallized solids and were not remelted during dike emplacement. When the melt neared the surface, gas escaped from the system with the result that the driving mechanism for dike emplacement was eliminated. Once the gas was removed, the magma rapidly cooled causing the extremely fine-grained groundmass around the pre-existing mafic crystals. Thus, the lamprophyre may be related to a diatremic type of intrusion. The intrusion, however, was much less violent due to lower gas pressure in the magma chamber.

Dike Emplacement

Structural control

The dikes are predominantly localized along east-west trending-fractures. As mentioned earlier, there are only two known exceptions. These are the dike in Flood Canyon and the dikes near Winter Quarters Canyon. East-west-trending fractures are present as both faults and joints. Both types of fractures serve as conduits for localizing dikes. As discussed previously, the fractures that trend east-west and north-south are considered to be genetically related. It is assumed that they were formed during the same episode of tectonic movement.

Why the dikes are localized along predominantly east-west-trending fractures is a question that may remain unanswered until new information is obtained about the fracture pattern in the basement below the Wasatch Plateau. Perhaps the most logical conclusion that can be reached with present information is that the east-west-trending fractures extend upward from pre-existing fractures in the basement.

Method

The method of dike emplacement has been discussed to some degree in explaining the origin of the magma. As mentioned, the dikes were emplaced by gaseous transfer of solid and probably liquid material along pre-existing fractures which served as conduits for the magma. This explanation seems rather logical considering the generally accepted fact that lamprophyres are associated in some way with abundant volatile material. The mafic phenocrysts formed early and later rapid cooling, after a loss of volatiles, produced the felsic groundmass.

An alternative to the gaseous transfer method is emplacement of liquid magma into fractures. It is much more difficult to explain the textural and mineralogical differences in a single dike by assuming this method of intrusion.

The questions of magma generation and dike emplacement are obviously complicated. Much more work should be done to either support or change the theories discussed here. The theories proposed here were based largely on the resemblance of the mafic minerals to the make-up of the mantle and the required implication of volatiles in the formation of lamprophyric magma.

Temperature

The emplacement temperature of lamprophyric rocks is generally considered to be low. According to McGetchin and Silver (1972, p. 7035), the temperature of the kimberlite of Moses Rock dike, in southeastern Utah, was between 950° and 1,000° C. at its source. Smith and Levy (1976, p. 123) indicated a low temperature of 900° C. for peridotitic nodules at Green Knobs. Harris and others (1970, p. 198) indicated that the temperature of kimberlite dikes is less than 600° C. It is assumed that the dikes remain semiliquid at a low temperature because of volatile gases present. The temperature of lamprophyric intrusion is considered higher than the temperature in diatremes (Harris and others, 1970, p. 198). Based on these indications, the temperature of the dikes of the Wasatch Plateau must have been between 600° and 1,000° C.

Time of Dike Emplacement

Stratigraphic evidence for the time of dike emplacement is inconclusive. The youngest stratigraphic unit that the dikes are known to intrude is the North Horn Formation of Cretaceous-Tertiary age. The dikes can be inferred to be much younger because the fractures in which they are localized are younger and other igneous activity in the surrounding area is younger.

Lamprophyre dikes, associated with the diatremes at Green Knobs, were dated by the K-Ar method at 27 to 31 million years (Smith and Levy, 1976, p. 107). They evidently formed during late Oligocene time. If the dikes of the Wasatch Plateau are related to the same melting episode of hydrous peridotite in the upper mantle, they may be of the same age.

Perhaps the best evidence of the age of the dikes is the age of the localizing fractures. Spieker (1949, p. 80) considered the north-south-trending normal faults of central Utah as Eocene to Oligocene in age. Walton (1955, p. 409) indicated that normal faulting, in the Wasatch Plateau, probably started after Oligocene time. It is assumed that the dikes are of the same age as, or perhaps slightly later than, the fractures. The dates, indicated by the fractures, correlate well with the K-Ar age dates for the dikes at Green Knobs (Smith and Levy, 1976, p. 107).

All other igneous activity, in close proximity to the Wasatch Plateau, correlates well in age with that of the fractures which localize the lamprophyres. The basalts of the Capitol Reef area were dated tentatively as Miocene based on their relationship to other igneous rocks (Smith and others, 1963, p. 42). The dikes of the Wasatch Plateau are probably of the same parent material as the basalts of the Capitol Reef area. Hunt (1956, p. 82) indicated that the volcanic activity, in the western part of the Colorado Plateau, did not begin until Miocene time.

Based on the structural control of the dikes and ages of surrounding igneous activity, the dikes of the Wasatch Plateau are middle to late Tertiary in age. Most evidence seems to indicate them to be late Oligocene to Miocene.

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