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Geology of igneous extrusive and intrusive rocks in the Sundance area, Crook County, Wyoming

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GEOLOGY OF IGNEOUS EXTRUSIVE AND INTRUSIVE ROCKS IN THE SUNDANCE AREA, CROOK COUNTY, WYOMING

by

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This Thesis submitted by Earl F. Fashbaugh in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

This Thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

Permission

Title GEOLOGY OF IGNEOUS EXTRUSIVE AND INTRUSIVE ROCKS OF THE SUNDANCE AREA, CROOK COUNTY, WYOMING

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Degree Master of Science

Signature Earl F. Tuttlebaugh

Date April 19, 1979

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ABSTRACT

Two major igneous rock types occur in the Sundance, Wyoming area including foyaite of the Bear Lodge Mountain sill and quartz latite of Sundance Mountain and Sugarloaf Mountain. The igneous bodies were mapped on a scale of 1:5000 in an effort to determine petrogenetic relationships between the two rock types.

Sundance Mountain and Sugarloaf Mountain are extrusive in origin. Quartz latite occurs as subparallel units of breccia, tuff, and massive flows without any clear cross-cutting relationships. Fragmental types (breccia and tuff) constitute 41 to 76 percent of the rocks, suggesting that Sundance Mountain is a mixed cone. The quartz latite has a predominantly cryptocrystalline groundmass consisting of alkali feldspar and quartz. Oligoclase occurs as microlites and as zoned phenocrysts. The phenocrysts have distinct, oscillatory zones with narrow ranges in composition, suggesting that the crystals were subject to sudden changes in pressure. Sugarloaf Mountain is interpreted to be a satellite volcano of Sundance Mountain. Rocks from both igneous bodies have similar textures, structures, and compositions.

The Bear Lodge Mountain sill was passively emplaced along the contact between the Pennsylvanian Minnelusa Formation and the Mississippian Pahasapa Formation. Foyaite dikes in the area have similar textures and compositions, and were probably emplaced during the same

intrusive event. Primary analcime is the only feldspathoid present in the foyaite.

The quartz latite is interpreted as being the youngest of the two rock types. A maximum age for the quartz latite is Paleocene, based on the presumed age of plagiofoyaite(?) clasts found in Sugarloaf Mountain breccia. If the rocks are extrusive in origin the establishment of the present erosional character of the Black Hills region gives a younger age of post-early Oligocene.

INTRODUCTION

Location of the study area

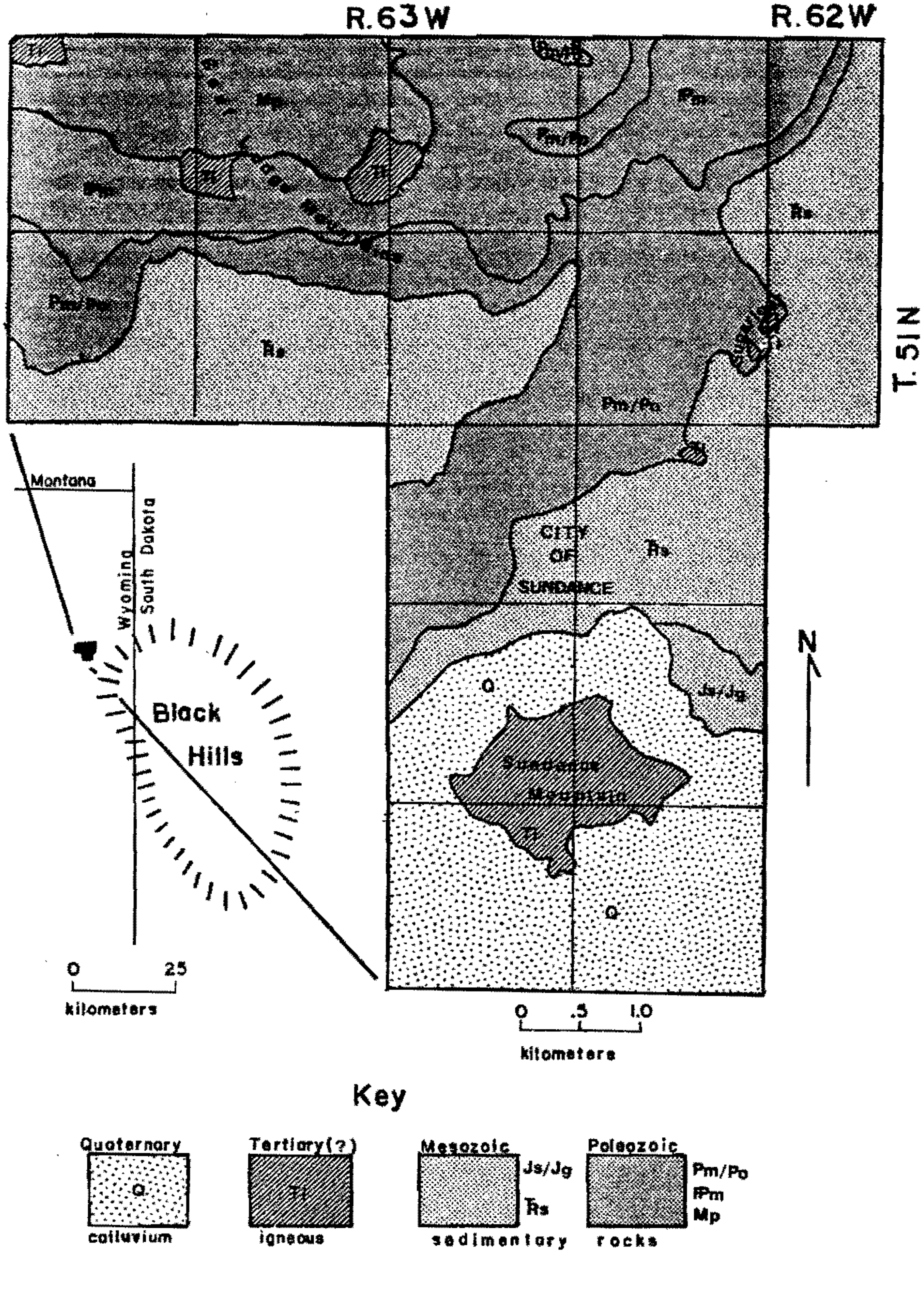
Sundance, Wyoming is located in Crook County, approximately 40 km southwest of Spearfish, South Dakota and about 35 km southeast of Devil's Tower. The study area is in the northwestern part of the Black Hills region (Fig. 1). A general geologic map was prepared on a scale of 1:10000 (Plate 1) which includes the following sections: 1, 2, 3, 4, 9, 10, 11, 12, 13, 14, 23, 24, 25, 26, (T. 52 N., R. 63 W.) and the western halves of 6 and 7 (T. 52 N., R. 62 W.). Detailed maps were prepared on a scale of 1:5000 for the major igneous bodies, including Sundance Mountain (Plate 2; sections 23, 24, 25, and 26, T. 52 N., R. 63 W.), Sugarloaf Mountain (Plate 3; section 12, T. 52 N., R. 63 W. and section 7, T. 52 N., R. 62 W.), and a portion of the southern Bear Lodge Mountains (Plate 4; sections 2 and 3, T. 52 N., R. 63 W.).

Previous work

Darton (1905) mapped the Black Hills region on a scale of 1:125000. Sundance Mountain rocks were mapped as syenite porphyry and igneous rocks of the southeastern Bear Lodge Mountain as phonolite. Darton interpreted Sundance Mountain as being a "remnant of a laccolith on a platform of Sundance Formation".

Brown (1952) attempted to model the igneous history of the Bear Lodge Mountains. He postulated the presence of an earlier trachyte

Fig. 1. Location map of the study area.


R.63W
R.62W
T.51N
Mp
Pm
Pm/Po
Ti
Ћs
CITY OF SUNDANCE
Js/Jg
Q
Ti
N
Montana
Wyoming
South Dakota
Black Hills
0 25
kilometers
0 .5 1.0
kilometers
Key
Quaternary
Q
colluvium
Tertiary(?)
Ti
igneous
Mesozoic
Js/Jg
Ћs
sedimentary
Paleozoic
Pm/Po
IPm
Mp
rocks

magma which separated from a parent phonolitic magma in a '"laccolith"' chamber. According to his hypothesis the trachyte was first emplaced to form a domal structure. Phonolites were subsequently injected into the "ruptured" laccolith.

Chenoweth (1955) did semiquantitative work on igneous rocks from the central and southern Bear Lodge Mountains. He suggested that "older intrusives" could be distinguished from "younger intrusives" by the effects of alteration and mineralization on the former. The "older intrusives" were classified as porphyrytic syenites, while "younger intrusives" were called "aphanites".

Other related studies in the Black Hills are being done by the following University of North Dakota geologists: Don Halvorson (Devil's Tower, Ph.D. dissertation), Stanley White (central and southwestern Bear Lodge Mountains, M.S. thesis), Dr. Frank Karner (Inyan Kara Mountain), Dr. Odin Christensen (central Bear Lodge Mountains), Mike Yaeger (Ragged Top Mountain, M.S. thesis) and John Ray (Tinton District, M.S. thesis).

Of the 39 km^2 area mapped, the sedimentary units comprised about 33 km^2. Chenoweth's (1955) work served as a basis for distinguishing the formations in the study area. Maps prepared in this study differ from Chenoweth's in regard to the relative size and shape of the igneous exposures and the amount of structural detail shown.

Emphasis was placed on igneous extrusive and intrusive bodies in the Sundance, Wyoming area. Particular emphasis was placed on Sundance Mountain and Sugarloaf Mountain geology, since no detailed work has been done on these igneous bodies.

Problem and approach

Prior to this study no attempt has been made to determine the petrogenetic relationships between the igneous rocks in the Sundance area. All of the igneous "intrusives" have been considered to be Tertiary in age (Chenoweth, 1955; Brown, 1952). The close proximity of Sundance Mountain oversaturated rocks and Bear Lodge Mountain undersaturated rocks of similar age presents a petrologic problem.

The approach to the problem involved mapping the sedimentary units and the igneous bodies (Plate 1) to insure that significant cross-cutting relationships were not overlooked. It was necessary to evaluate any structural and stratigraphic control that the sedimentary units may have had over the emplacement of the igneous rocks.

The following information has been compiled on the maps (Plates 1, 2, 3, and 4): outcrops (shown in darker shades), joint sets, partings, bedding, pyroclastic layering, faults, and contacts. A great deal of the structural information has been generalized on Plate 1 for reasons of limited graphic representation on that scale. The outcrop numbers shown on Plates 2, 3, and 4 correspond to rock and outcrop descriptions summarized in Table 1 (Appendices A and B) and Table 2 (Appendices C and D).

Sedimentary rocks were sampled when outcrops were close to contacts with the igneous bodies. Sampling of the igneous rocks was done on the basis of outcrop availability and lithologic variability. Outcrop accessibility was also an important factor on Sundance Mountain where some cliff exposures on the west side could not be safely studied.

General geology of the igneous bodies

Sundance Mountain

Sundance Mountain is located just south of the town of Sundance. The landmark occupies an area of approximately 2 km^2 and obtains local relief of about 170 m. The most notable exposures are on the north and northwest sides where shear cliffs rise above a prominent talus slope. From a distance the rocks are greenish-gray to white on weathered, lichen-covered surfaces. Numerous grass-covered lobes of colluvium extend out from the base of Sundance Mountain while the highest elevations have thick pine groves.

Two prominent joint sets can be identified on the northwest cliff face. Columnar jointing is most strongly developed in the lower two-thirds of the exposure, while subhorizontal joint sets are dominant near the top of Sundance Mountain. The subhorizontal joint set is subparallel to the layered fabric of the rock. It is difficult to distinguish between internal planes of weakness (partings) and the subhorizontal joint set but usually the latter are marked by conchoidal patterns. Near the top the conchoidal pattern is concave out from the interior of Sundance Mountain. Similar joint systems are found throughout Sundance Mountain but are nowhere as well exposed as on the north and northwest sides.

The rock is a light to dark gray, weakly porphyritic quartz-latite with an aphanitic groundmass. Three modes of occurrence include monolithic breccia (Fig. 2), layered sequences (Fig. 3) and massive varieties.

Fig. 2. Monolithic breccia from SE side of Sundance Mountain. Angular clasts are randomly oriented with no apparent grading. The average size of the clasts is about 5 cm.

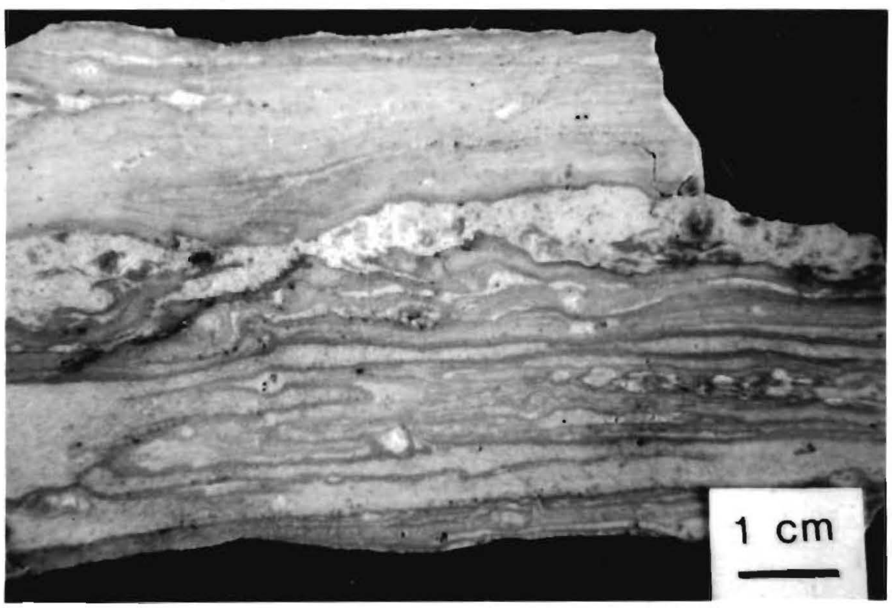


Fig. 3. Layered sequence of quartz latite tuff from Sundance Mountain. Light and dark gray laminations are partially attributed to devitrification of ignimbritic flows. Tabular oligoclase phenocrysts (white) are usually subparallel to the flow layers. Light colored stratum near the middle of the photograph is more porous and forms an irregular contact with the layered sequences.

Individual breccia units thicker than 2.5 m were not observed and aggregate thicknesses never exceeded 5 m. Generally the breccia (Fig. 2) occurs low in a given section (Fig. 4), but it is not uncommon for units 10 to 20 cm thick to be interlayered with massive and layered types.

The layered sequences consist of alternating light and dark gray laminations about 1 mm thick. Commonly the layered sequences dip out from the interior of Sundance Mountain. The layered units are interpreted as being welded ash fall and ash flow tuffs.

Massive quartz latite generally occurs in the middle part of a section (Fig. 4). Thicknesses range from 5 to 36 m but massive units less than 10 m thick are rare. Often the layered sequences grade upward into massive units.

Sugarloaf Mountain

Sugarloaf Mountain, located northeast of Sundance, consists of a northern and southern hill. The southern hill has exposures of light and dark gray, laminated rocks (outcrop numbers 77-80) which are considered to be equivalents of the Sundance Mountain layered tuffs. The layering is very irregular and is often folded. Tuffs occur at the base of the northern hill and are overlain by graded breccia (Fig. 5). The graded breccia is highly weathered and ranges in color from a bleached, "chalky" white to a dark greenish-gray. A maximum thickness of about 13 m is present along the southernmost exposure of the northern hill (outcrop number 65). The clasts appear tc have a bimodal size distribution, with one set ranging from 0.1 to 1.0 m in diameter, while

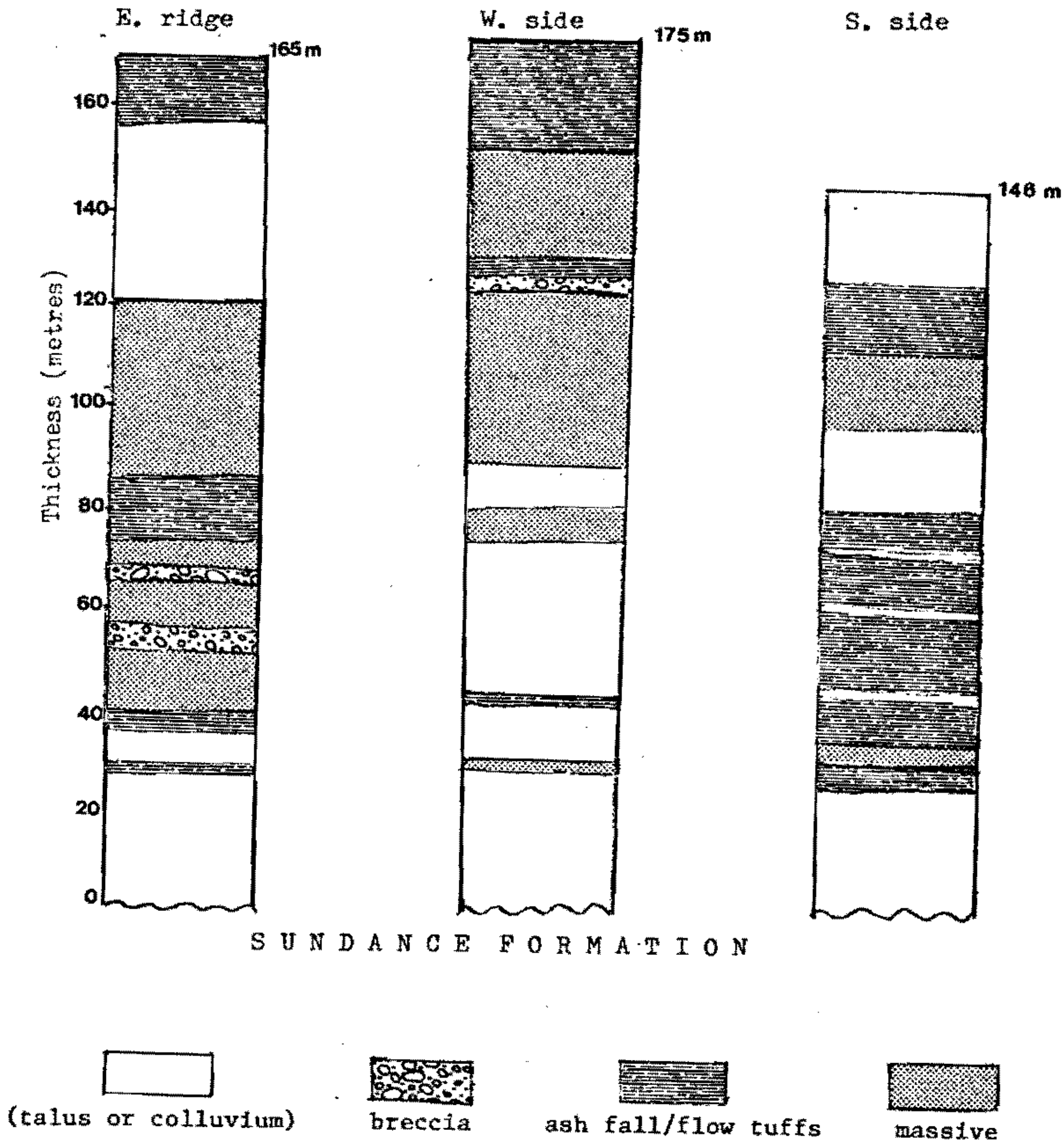


Fig. 4. Generalized measured sections from Sundance Mountain. Breccias are usually found in the lower part of the section, massive quartz latite in the middle, and tuffs throughout. Much of Sundance Mountain bedrock is unexposed.

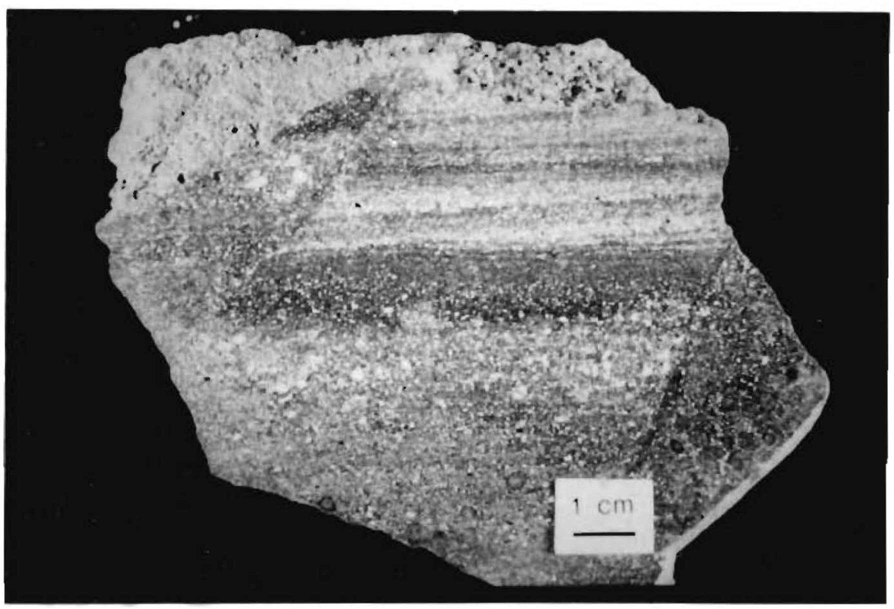


Fig. 5. Graded breccia from Sugarloaf Mountain. Grading is generally normal with clasts about 2 mm in diameter at the base of the bed (light gray) and microscopic clasts near the top (dark gray). Note the reverse faults.

another set ranges from .02 to .04 m. Clasts make up 30 to 40 percent of the rock.

Bear Lodge Mountains

Sundance is located a few kilometres south of a 40 km long domal structure known as the Bear Lodge Mountains. Brown (1952) and Chenoweth (1955) have described the structure as a laccolith formed by two stages of igneous activity. Primary igneous activity resulted in the laccolithic structure. A second stage of igneous events is marked by the emplacement of dikes on the periphery of the structure (Brown, 1952). The study area includes the extreme southern part of the intrusive complex.

The igneous rocks are black to dark green, strongly trachytic foyaite. Generally the groundmass is aphanitic but phaneritic textures are occasionally observed. A foliation is produced in the foyaite by subparallel arrangement of tabular alkali feldspar phenocrysts. Elongated phenocrysts are aligned parallel to the dip of the foliation.

Two joint sets can usually be observed. The dominant set is vertical and columnar, while the other is less distinct and subhorizontal. The intersection of the joint sets produces a blocky cleavage.

Two crescent-shaped foyaite bodies have been mapped in sections 2, 3, and 4 (Plates 1 and 4). The igneous exposures conform to the regional strike of the sedimentary units, and although no actual contacts were observed, it appears that the foyaite assumes a stratigraphic position between the Missippian Pahasapa Formation and the Pennsylvanian Minnelusa Formation. Good exposures are found in the SE ¼ of section 3 and in the SW ¼ of section 2. The two crescent-shaped exposures have similar stratigraphic relationships and it is likely that they are part of the same igneous body. Since the underlying and overlying sedimentary units have the same structural attitude the igneous body is interpreted as being a sill. Emplacement of the foyaite probably preceeded formation of the laccolithic structure.

The sedimentary rocks of the Bear Lodge Mountains have more distinct joint patterns on the flanks of the uplift than near the sill. Joints are especially well developed in the Permian Goose Egg Formation (sections 9, 10, 11). Generally the strike of the joints is subparallel to the bedding and dip at high angles to the south. There is no apparent relationship between the jointing in the sedimentary units and the position of the sill.

A foyaite dike is located on the northeast end of Sundance (section 13; T. 51 N., R. 63 W.) and will be referred to as the Sundance dike. The dike strikes parallel to the contact between the Minnekahta Formation and the Spearfish Formation and dips from 75 to 85 degrees north. A foliation is produced in the foyaite by subparallel arrangement of tabular alkali feldspar phenocrysts. Vertical, columnar joints intersect the foliation at high angles, producing a blocky cleavage similar to that of the Bear Lodge Mountain sill.

An inferred dike is located in section 9 (Plate 1). The dike is mapped on the basis of high concentrations of boulders at the surface (Plate 1).

All of the foyaitic rocks in the study area have similar textures and compositions and were probably emplaced during the same igneous event.

FIELD RELATIONSHIPS

Introduction

Four principal igneous bodies have been described--Sundance Mountain, Sugarloaf Mountain, the Bear Lodge sill and the Sundance dike. With the possible exception of Sundance Mountain, the igneous bodies have geologic settings which suggest that the sedimentary units provided stratigraphic control over magmatic emplacement. The Bear Lodge sill is the most obvious example, where foyaite was emplaced along the contact between the Pahasapa and Minnelusa Formations. The Sundance dike was emplaced along the contact between the incompetent Spearfish siltstone and the competent Minnekahta limestone. Sugarloaf Mountain quartz latite was deposited along the same contact (Plate 3).

No intermediate rock types between the quartz latite and the foyaite have been identified. With similar stratigraphic controls over magmatic ascent some hybrid might be expected. The different modes of emplacement may partially account for the two distinct lithologies. Magmas that ascend rapidly through the crust would probably not assimilate the host rock as readily as magmas that are passively injected. Structures and textures observed in the field provided most of the evidence for the modes of emplacement. Petrographic and petrologic evidence is included in the following section of the thesis.

Sundance Mountain and Sugarloaf Mountain

The breccias of Sundance Mountain consist of angular to subangular clasts of quartz latite set in a weakly anisotropic groundmass (Figures 6 and 7). The clasts constitute over 60 percent of the rock and range in size from .01 mm to 0.5 m (outcrop number 230). The breccia contains layered clasts of tuff that were deposited before formation of the breccia.

The contact between a given breccia unit and overlying tuff is always a sharp disconformity (Fig. 7). Layers tend to fill in spaces between the angular clasts in the breccia. Similar contacts are present between breccia and underlying tuff. An example is found on the west side of Sundance Mountain (outcrop number 230) where a block 0.5 m in diameter appears to have depressed the tuff layers by 10 to 15 cm. The block apparently caused deformation of the layers as opposed to the contact shown in figure 7 where overlying tuff layers conform to the shapes of the breccia clasts.

A similar relationship occurs within layered tuff. Oligoclase phenocrysts often have layers wrapping around them (Fig. 3). In some instances individual layers a few millimetres thick form spires around the crystals. The structures resemble those of soft sediment deformation but differ in that the distorted layering in the tuffs is probably produced by mechanisms of transport and deposition and is not the result of density differences within a deposited sedimentary sequence. The phenocrysts are often rotated in the downslope direction, suggesting that passive transport occurred after deposition.

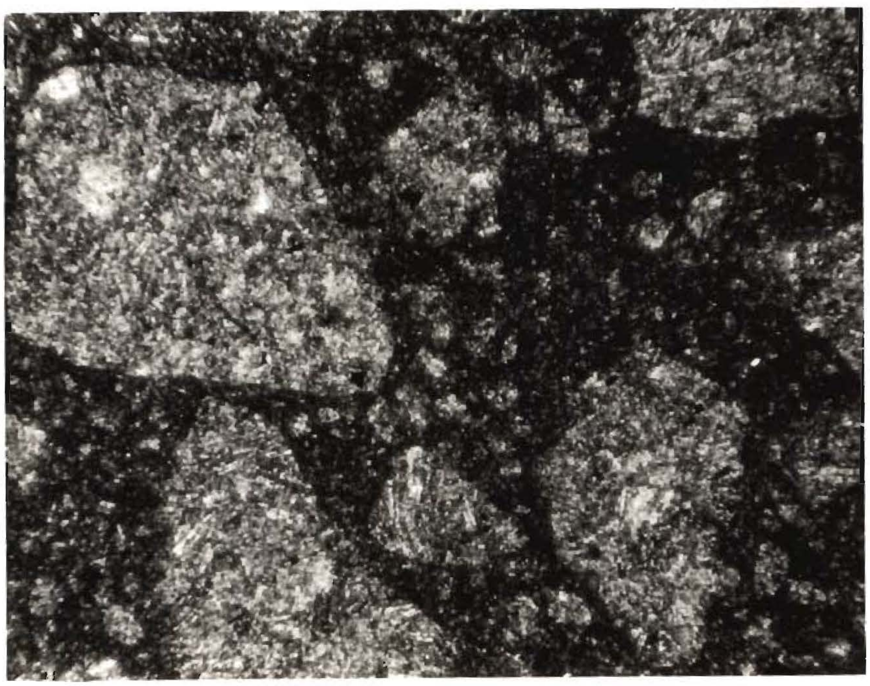


Fig. 6. Sundance Mountain breccia (SD-98) under plane polarized light. Distinct resolution between the groundmass and the clasts is possible. Clasts have trachytic textures, produced by subparallel arrangement of oligoclase microlites. Magnification: 27X

Fig. 7. Contact between breccia (lower unit) and layered sequence (upper unit). The layering is continuous and wraps around the clasts at the contact.

Small scale folds, 5 to 8 cm in amplitude are often present. Good examples occur in the southern hill of Sugarloaf Mountain and on the northwestern cliff face of Sundance Mountain. The folds are asymmetrical and often overturned in the direction of dip.

Porous, light yellow colored layers of quartz latite may interrupt the tuff sequence (Fig. 3). Thickness varies from .5 to 5 cm, but beds about 3 cm thick are most common. The porous material consists of angular cavities, sometimes elongated subparallel to the layering. The cavities range in length from .01 to .5 mm. Often the cavity walls are surrounded with magnetite(?). Wedges that appear to be torn from the layered material project upward into the porous strata. The contact between the porous strata and overlying layered material is not nearly as irregular and often forms a sharp break in a tuff sequence (Fig. 3).

Elongated pods, composed of the same porous material sometimes occur in the layered sequences (Fig. 3). The structures are usually less than a centimetre in length.

Striations, generally parallel to the direction of dip, are sometimes present within the layers of tuff (Fig. 8). These striations may be analogous to parting lineations found on sedimentary bedding surfaces.

Two kinds of xenoliths are present in the Sundance Mountain rocks. Sandstone xenoliths are sometimes found in the massive quartz latite. The inclusions are angular and range from 7 to 20 cm in diameter. A second variety of xenolith is a dark green, porphyritic rock. These xenoliths are rounded, less than a centimetre in diameter and highly altered. The most abundant optically determined mineral is chlorite

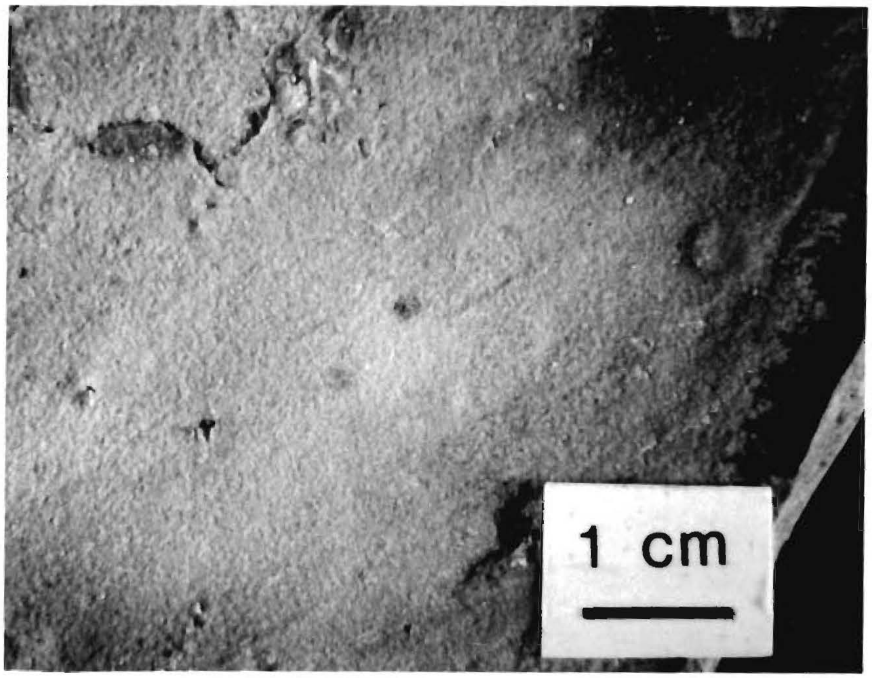


Fig. 8. Pyroclastic parting lineations. Striations in the bedding surfaces of the tuffs form lineations parallel to the direction of the dip. Lineations trend from lower left to upper right-hand corner of photograph.

which occurs as fibrous groundmass material and as an alteration product of biotite. Alkali feldspar occurs as subhedral crystals with resorbed margins. Pseudomorphs of epidote after feldspar(?) are present. Magnetite(?) occurs as a secondary exsolution product on the margins of chloritized biotite and as subhedral grains. It is not certain whether these xenoliths represent material derived from the Bear Lodge intrusive complex or if they are from the metamorphic Precambrian basement.

Both varieties of xenoliths occur in the Sugarloaf Mountain sequence. In addition to these inclusions Sugarloaf Mountain has plagiofoyaite(?) xenoliths (samples 62, 62a, and 175). The xenoliths are dark green, subrounded and strongly porphyritic. A more detailed discussion of the xenoliths is included in the following section.

PETROGRAPHY AND CHEMISTRY

Analytical techniques

Five samples were chemically analyzed including S-7, BL-27, SL-67b, SD-114 and SD-134. Two fused pellets were prepared according to techniques described by Welday et. al (1964) using USGS standards (Flanagan, 1967; Fleischer, 1969). A Philips X-ray spectrometer was used, following procedures outlined by Malick (1977). Sodium analyses were obtained from microprobe work (Karner, personal communication). The results are summarized on Table 6. Microprobe analyses of an oligoclase crystal (Table 4) and cryptocrystalline groundmass material (Table 5) were also obtained.

Sundance Mountain

Modal analyses

Sundance Mountain rocks are composed of 40 to 60 percent cryptocrystalline material, making thin section point counting an impractical means of obtaining modal analyses. The remaining microcrystalline material consists of microlites of plagioclase feldspar. Optically identifiable phenocrysts of oligoclase generally constitute less than 5 percent of the rock. Point counting of stained thin sections and a semi-quantitative X-ray diffraction techniques, used to obtain quartz percentages, involved spiking a rock sample with a known weight fraction of quartz (S). The control and spiked sample were X-rayed using

Ni-filtered CuK alph radiation (37 Kv, 18 ma) and scanned at a rate of 1 degree 2θ per minute. The relative difference in the intensity between the control (Cp) and the spiked sample (Cp+s) is inversely proportional to the weight fraction of quartz in the sample (P). This relation is described by Norrish and Chappell (1967) and is summarized in the formula given below:

$$\frac{P}{S} = \frac{Cp}{Cp{+}s - Cp}$$

or

$$P = \frac{S \times Cp}{Cp{+}s - Cp}$$

Three samples from Sundance Mountain and one sample from Sugarloaf Mountain were used. The results given on Table 3 are plotted on Figure 9.

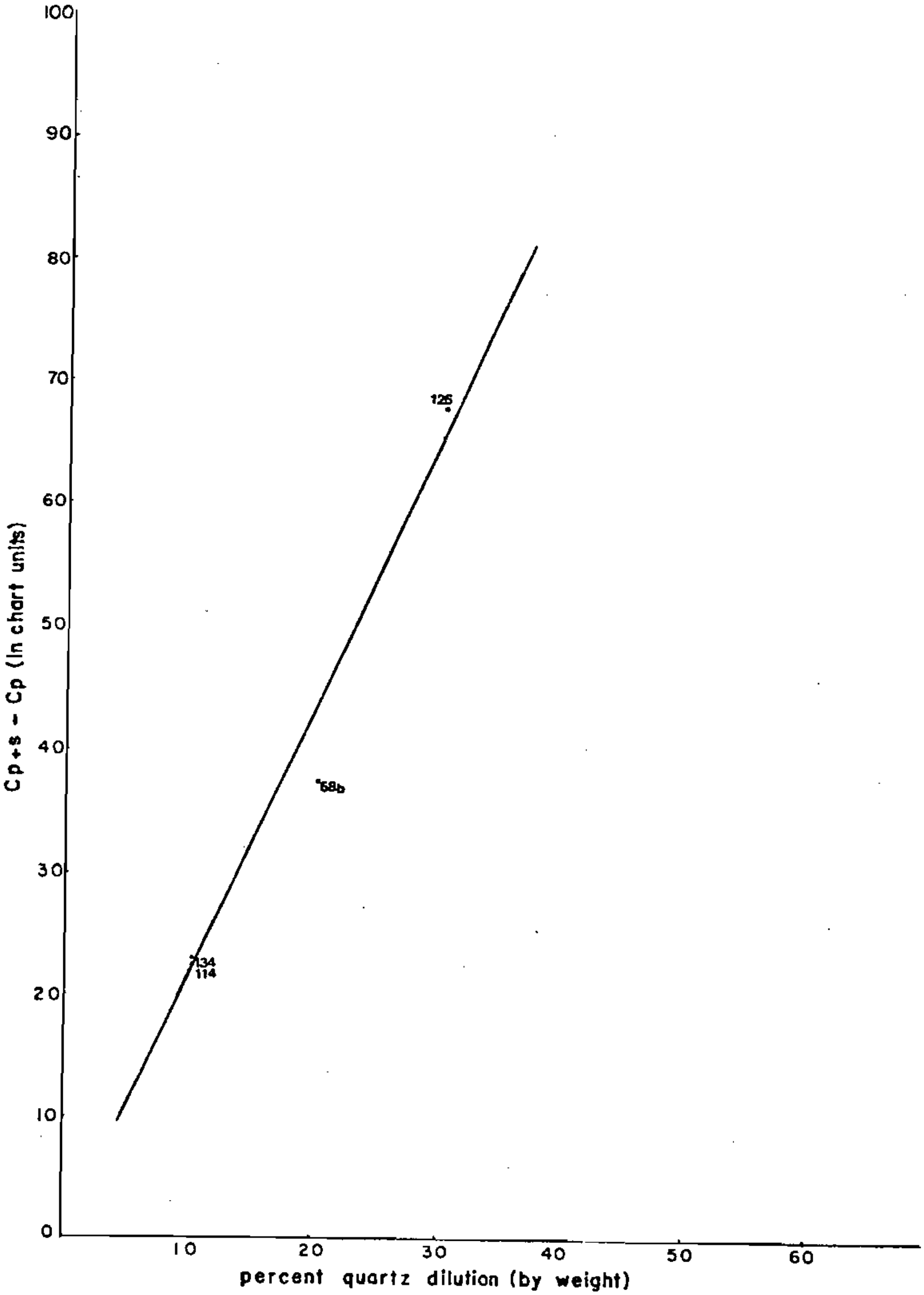
TABLE 3

MODAL QUARTZ DETERMINATIONS USING SPIKING TECHNIQUES

sample no.	SD-114	SD-134	SD-126	SL-68B
outcrop no.	181	202	193	68
Cp	70.6	73.2	64.0	58.3
Cp+s	93.3	95.5	131.	95.7
S	.10	.10	.30	.20
P x 100%	31.1	33.0	28.6	31.1

Figure 9 shows a generally linear relationship between the increase in chart units (Cp+s - Cp) and the percent dilution (S). It is

Fig. 9. Effects of quartz spike on (101) peak intensity. For the five samples there is little departure from the average percent quartz in the quartz latite of Sundance Mountain and Sugarloaf Mountain. C_{p+s} = peak intensity of spiked sample; C_p = peak intensity of unspiked sample.


100
90
80
70
60
50
40
30
20
10
0
Cp+s - Cp (In chart units)
126
68b
134
114
10
20
30
40
50
60
percent quartz dilution (by weight)

reasonable to assume that the quartz content does not vary appreciably among rocks from the two quartz latite bodies. The average percent quartz in the four samples is 31.0. There is about 6 percent more modal quartz than normative quartz.

Staining techniques were employed to distinguish alkali feldspar from plagioclase in thin sections. The technique, as described by Bailey (1960), involves precipitating potassium rhodizonate (red) on plagioclase feldspars and sodium cobaltinitrite (yellow) on alkali feldspars.

The staining technique was useful in distinguishing the crystalline feldspar component from the groundmass. Both, the phenocrysts and the microlites, were determined to be plagioclase. The microlite technique (Heinrich, 1965) was used to confirm that the groundmass crystals are oligoclase. Actual percentages of alkali feldspar in the cryptocrystalline groundmass could not be determined directly from staining techniques. However, the modal percent alkali feldspar can be determined by subtracting the known weight percent quartz (obtained from spiking) and oligoclase (alter converting to weight percent) from 100 percent. Since other minerals are rare, this gives a "reasonable" percent of alkali feldspar in the rock. The rock is approximately 31 percent quartz, 38 percent oligoclase, and 29 percent alkali feldspar. According to Streckeisen (1967) a volcanic rock of this composition is a quartz latite.

General petrography of the quartz latite

In thin section, the breccia is best studied using plane polarized light (Fig. 6). A distinction between clasts and groundmass is not always possible using crossed polars. Broken crystals of oligoclase are present in the breccia but euhedral phenocrysts never occur in the groundmass. The angular oligoclase grains appear to have been broken loose from the clasts during brecciation and transport.

The tuffs are characterized by a strongly trachytic texture. Absence of a fragmental texture is discussed in the following section. Individual layers are best resolved using plane polarized light (Fig. 10) but layer boundaries are sometimes discernible with crossed polars on the basis of contrasting interference colors. In Figure 10 the microlites of oligoclase are continuous across the layer boundaries. It appears that in most instances the layering results from higher concentrations of finely disseminated microcrystalline material in the layers which are darkest in plane polarized light (Fig. 10).

Chemistry and mineralogy of the quartz latite

The chemical compositions of Sundance Mountain rocks (Table 5) are similar to the average composition (Nockolds, 1954) of a dellenite (quartz latite). Sundance Mountain quartz latite has lower iron and slightly more sodium than average. Iron is contained in rare wedge-shaped grains of horneblende and is dispersed throughout the groundmass as very fine grained magnetite(?).

A limited amount of chemical data was obtained on the cryptocrystalline groundmass using microprobe techniques (Table 5). Normative calculations give a mineralogical composition of 57.2% quartz and 41.3% alkali feldspar (from microprobe analyses). This qualitatively agrees with results obtained from spiking and staining techniques but

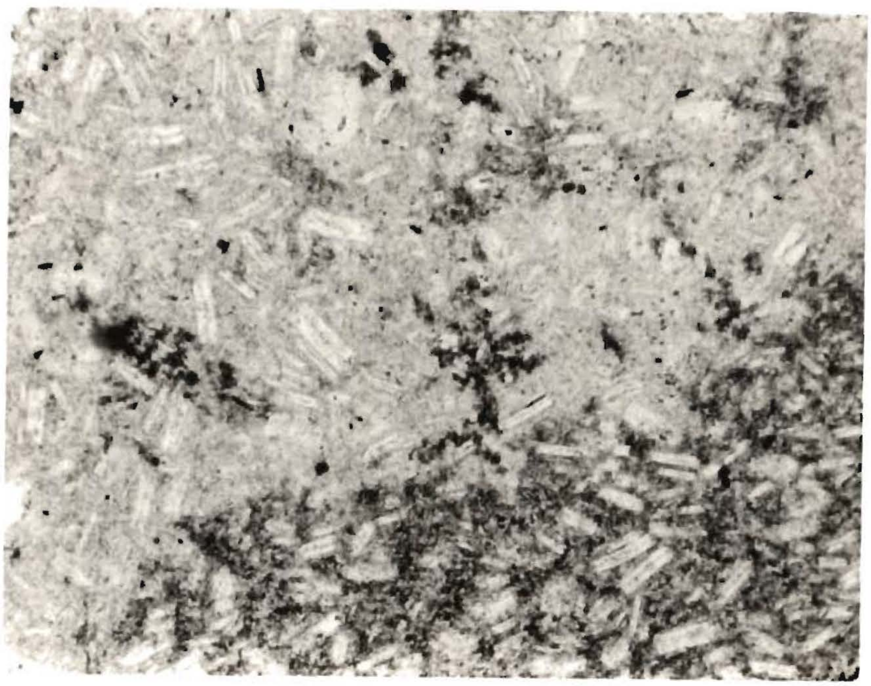
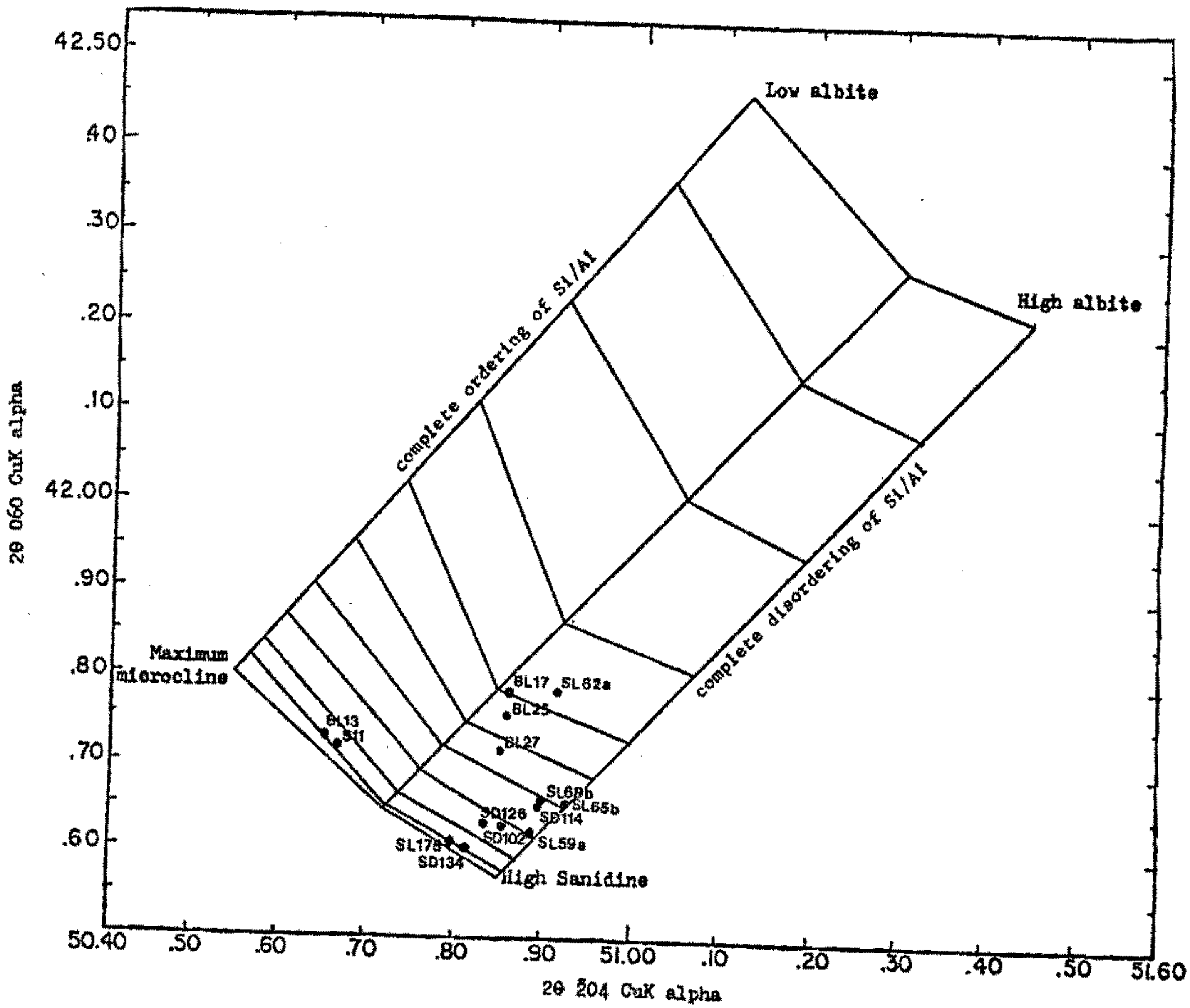


Fig. 10. Layering of quartz latite in plane polarized light (SD-168). Note that the microlites of oligoclase are sometimes continuous across the layer boundary. The layering may be attributed to differences in alteration. Magnification 27X.

Fig. 11. Ordering of Si/Al in alkali feldspars from Sundance Mountain (SD), Sugarloaf Mountain (SL), Bear Lodge Mountains (BL), and the Sundance dike (S) as determined from the $\bar{2}04$ and 060 method (after Wright, 1968). Alkali feldspars from the Bear Lodge Mountain intrusive body are intermediately ordered (orthoclase), while Sugarloaf Mountain rocks are highly disordered (sanidine). Alkali feldspars from Sundance Mountain are slightly ordered.


Low albite
High albite
Maximum microcline
High Sanidine
complete ordering of Si/Al
complete disordering of Si/Al
BL17
SL62a
BL25
BL27
BL13
S11
SL69b
SL65b
SD114
SD126
SD102
SL59a
SL175
SD134
2θ 060 CuK alpha
42.50
40
.30
.20
.10
42.00
.90
.80
.70
.60
50.40
.50
.60
.70
.80
.90
51.00
.10
.20
.30
.40
.50
51.60
2θ 204 CuK alpha

suggests that the area analyzed may have contained a high proportion of quartz.

The alkali feldspar is a slightly ordered sanidine, (Fig. 9). Sugarloaf Mountain samples (SL-65b, SL-59a) have high sanidine, implying that virtually no ordering of the aluminum and silica had taken place in the feldspar crystal structure during the cooling of these rocks.

TABLE 4

CHEMICAL COMPOSITION OF SUNDANCE MOUNTAIN CRYPTOCRYSTALLINE GROUNDMASS, SAMPLE SD-133b

SiO_2	Al_2O_3	FeO	CaO	Na_2O	K_2O	SO_3	TOTAL
85.2	7.2	0.3	0.2	2.2	4.1	0.2	99.4%

Oligoclase megacrysts constitute 4 to 11 percent of the quartz latite. The oligoclase occurs as subhedral to euhedral, tabular laths, ranging in length from about 1 mm to 5 mm. Lengths of 3 mm are most common.

The mineralogic composition of the oligoclase was obtained from oil immersion studies and optically using the Michel-Lévy method (Heinrich, 1965). Compositions vary from Ab_{73} to Ab_{88} but generally are between Ab_{79} and Ab_{88}.

Most of the oligoclase megacrysts examined displayed oscillatory zoning. Earlier formed zones are rounded (subhedral), suggesting that the phenocrysts were partially resorbed before renewed precipitation of successive outer zones. As many as five resorbed surfaces can be observed in a given pheyocryst. Table 5 gives the chemical composition of 6 points in a zoned crystal (Fig. 12). The significance of the data is that even though there are four distinct optical zones, there is a very narrow range in composition (Ab_{73}-Ab_{76}) across the entire crystal.

TABLE 5

CHEMICAL ANALYSES OF ZONED OLIGOCLASE FROM SD-133b

SiO_2	63.32	63.18	63.17	62.12	62.92	62.87
Al_2O_3	22.66	22.73	22.60	22.98	22.59	22.45
FeO	.25	.25	.17	.09	.13	.12
MgO	.11	.11	.17	.23	.32	
CaO	3.91	3.91	3.66	4.22	3.60	3.97
Na_2O	8.59	8.67	9.22	9.05	9.29	9.15
K_2O	.84	.84	.95	.94	1.01	1.06
TiO_2	.09	.09		.08		
P_2O_5				.12		.12
MnO						
Cl O						
SO_3	.15			.11	.08	.20
%Ab	75	75	76	73	76	75
Data point (Fig. 12)	1	2	3	4	5	6

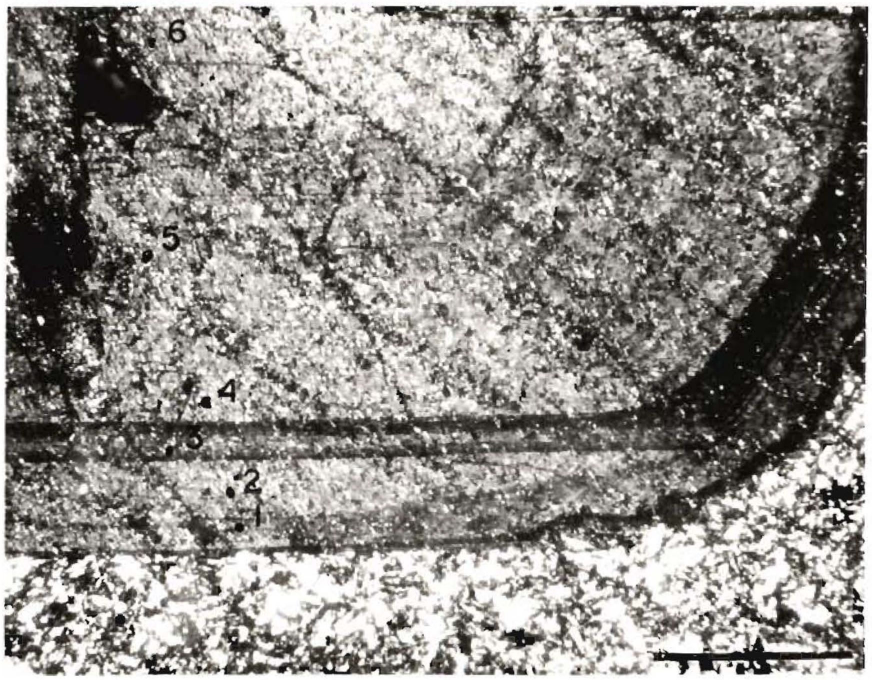


Fig. 12. Zoned oligoclase from SD-133b. Six data points correspond to chemical compositions on Table 6. bar=0.5 mm. (Magnification: 45X)

Sugarloaf Mountain

The petrography and chemistry of Sundance Mountain and Sugarloaf Mountain rocks are nearly identical. Sugarloaf Mountain tuffs have a less anisotropic groundmass than Sundance Mountain tuffs. Microlites are subhedral and are resolved only under high magnification. Sugarloaf Mountain tuffs often have blotchy masses of cryptocrystalline material surrounded by radiating oligoclase(?) microlites. There are no compositional differences in oligoclase from the two igneous bodies, but megacrysts from Sugarloaf Mountain are more often broken.

Some of Sugarloaf Mountain breccias are dark gray (Fig. 4), as opposed to the light gray Sundance Mountain breccias (Fig. 2). In thin section the Sugarloaf breccias are almost isotropic. Diffraction patterns are nearly identical, aside from the montmorillinite peak, which is more intense in Sugarloaf Mountain rocks. Unique to Sugarloaf Mountain breccias, are the distinct bedding surfaces produced by normal grading. Bed boundaries are sharp contacts, often marked by a red, oxidized interface.

Of particular interest are the plagiofoyaite(?) clasts (samples 62a, 63, 65a, 175) found in Sugarloaf Mountain breccia. Optically identified andesine composes 30 to 40 percent of the rock, as determined from visual estimation. Crystals 0.1 to 3.0 mm in length are broken, partially resorbed and sometimes replaced with calcite. Compositions vary from An_{42} (SL-66a) to An_{54} (SL-62a). Augite(?) comprises 5 to 10 percent of the clasts and occurs as subhedral, highly altered (chloritized(?) grains. Crystals are often mantled with hematite(?).

The cryptocrystalline groundmass is largely composed of alkali feldspar and analcime, as determined from X-ray diffraction studies. Calcite (15%) is an abundant secondary mineral. It is interesting to note that the above minerals do not occur in the same proportions. Sample 65a, for example, is composed largely of groundmass analcime, as compared to sample 175, which has questionable analcime diffraction peaks. The occurrence of andesine is especially noteworthy since andesine is not present in Bear Lodge Mountain rocks within the defined study area.

Bear Lodge Mountains

According to Streckeisen (1967) shallow intrusive (hypabyssal) rocks are a subdivision of plutonic rocks. Using this classification scheme, the foidal rocks of the Bear Lodge Mountains are appropriately called foyaite. Several workers in the Black Hills region (Russell, 1896; Irving, 1899; Darton, 1905; Darton and Paige, 1925; Allington, 1962; Kirchner, 1971) have referred to rocks of similar compositions and textures as being phonolite intrusives. The author prefers the term foyaite for Bear Lodge Mountain rocks because the rock name denotes an intrusive origin and usage is consistent with a relatively contemporary and widely used classification scheme (Streckeisen, 1967). This same classification scheme is used for naming oversaturated (extrusive) rocks, also found in the thesis area.

The foyaite of the southeastern Bear Lodge Mountain consists of 50 to 60 percent euhedral to subhedral, tabular phenocrysts of alkali feldspar (2V = 75-85°), ranging in length from 0.1 to 15 mm. A composition of Or_{83}($\pm$3%) was obtained from unit cell dimension calculations (Evans and others, 1963). The feldspar (samples BL-17, BL-25, and BL-27) is an intermediate ordered orthoclase (Fig. 11). Other feldspars, as determined from X-ray diffraction, include sodium-rich alkali feldspar, albite, and anorthoclase. It appears that these feldspars are major constituents of the felted, hypidiomorphic granular groundmass.

Analcime is visually estimated to make up 15 to 25 percent of the rock. Isotropic crystals less than 0.1 mm in diameter are found in the Sundance dike and in rocks from the sill margins (samples S-7, S-11, S-17, BL-25). Occasionally eight-sided crystals, suggesting a trapezohedral habit, are observed. In phaneritic rocks from the sill interior (BL-27) the crystals are weakly anisotropic. Optical discontinuities across grains suggest that the analcime has been altered, possibly to albite and some other feldspathoid(?).

The rock consists of 10 to 15 percent aegerine(?) and aegerine-augite. Elongated crystals range in length from 1.0 to 0.1 mm. Commonly the aegerine-augite occurs in dispersed clusters. Crystals are optically positive and often have light green, weakly pleochroic, aegerine-augite cores (2V = 60–70°) with dark green highly pleochroic aegerine(?) rims (2V = 65–80°). Smaller, unzoned microcrysts of subhedral aegerine-augite are also present. Often crystals are mantled with an opaque mineral (possibly magnetite).

Accessory minerals include biotite, garnet and secondary calcite. The biotite occurs as subhedral laths in the groundmass and is usually chloritized. The garnet, possibly almandine, is typically euhedral and zoned. Calcite replacement of the orthoclase is common.

Other minerals present include sericite and chlorite which are alteration products of potassium feldspar and biotite, respectively.

Chemical composition of the foyaite

Two samples (S-7 and BL-27) were analyzed (Table 6). As compared to other recorded "phonolites" (Nockolds, 1954) the Bear Lodge Mountain foyaite is slightly enriched in silica, aluminum and potassium. The sill rock (BL-27) may be slightly more undersaturated than the dike rock (S-7).

TABLE 6

CHEMICAL ANALYSES AND NORMATIVE MINERAL PERCENTAGES

SiO_2	58.11	57.58	70.38	69.88	68.84
Al_2O_3	21.31	21.51	16.21	16.42	16.48
FeO	2.15	1.90	.12	.31	.29
MgO	.32	.11	.19	.21	.07
CaO	1.69	1.45	1.25	1.12	1.25
Na_2O*	7.70	8.23	4.10	4.22	4.43
K_2O	6.57	7.15	4.36	4.87	4.49
TiO_2	.05	.07	----	----	----
P_2O_5	.12	.11	.11	.11	.11
MnO	.29	.23	.04	.15	.11
Cl O*	.03	.18	----	.04	.07
SO_3*	----	.60	.12	----	----
Total	98.34	99.12	96.89	97.33	96.14

TABLE 6--Continued

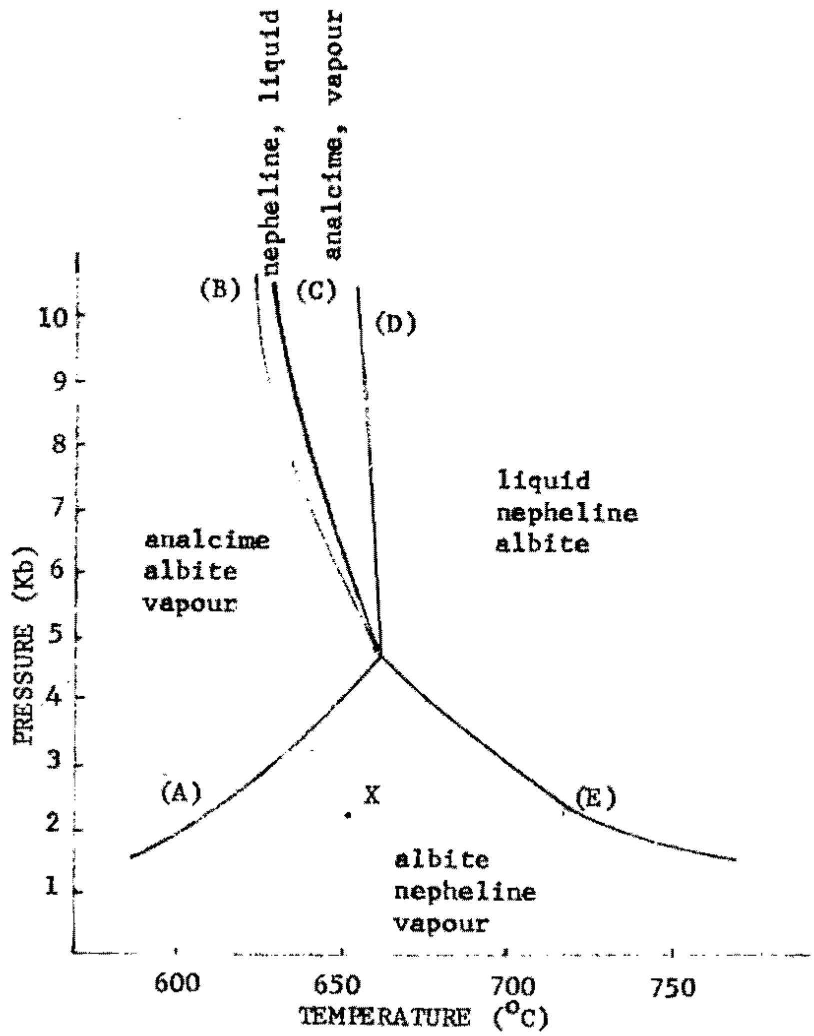
Rock type	Foyaite	Foyaite	Q.latite	Q.latite	Q.latite
Sample	S-7	BL-27	SL-67B	SD-114	SD-134
Quartz	----	----	28.0	24.6	24.0
Corundum	----	----	2.8	2.5	2.4
Orthoclase	39.5	43.0	26.6	29.6	27.6
Albite	30.8	24.7	35.9	36.7	39.0
Anorthite	4.3	0.6	5.7	5.0	5.7
Nepheline	19.2	25.0	----	----	----
Wollastonite	1.5	2.5	----	----	----
Enstatite	0.2	0.2	0.5	0.5	0.2
Ferrosilite	1.3	2.6	0.3	0.9	0.8
Forsterite	0.4	0.1	----	----	----
Fayalite	2.4	1.0	----	----	----
Ilmenite	0.1	0.1	----	----	----

*microprobe analyses

Occurrence of primary analcime

Analcime-rich foyaite has 19.2% and 25.0% normative nepheline in samples S-7 and BL-27, respectively (Table 3). However, the rock contains no optically identifiable nepheline. Studies by Peters et al. (1966) show that analcime of anhydrous composition ($Ab_{50}Ne_{50}$) in the system Ne-Ab-H_2O is in invariant equilibrium with albite, nepheline, liquid and vapour at 665°C and 4.75 Kb. Figure 10 shows the invariant conditions and the stability fields of the components. The effect of potassium on the system is to displace the invariant point to 2.3 Kb at 650°C (Sorenson, 1974). Analcime in this equilibrium situation would contain 2 wt. % K_2O. The significance of the equilibrium relations is that primary analcime can crystallize directly out of a magma at pressures greater than 2.3 Kb and can coexist with residual liquid over a narrow temperature range.

Fig. 13. Invariant and univariant phase relationships as determined by Peters et al. (1966). Univariant reactions include: analcime=Ab+Ne+Vapour (A); analcime+Ab+vapour=liquid (B); Ne+liquid= analcime+vapour (C); analcime=Ab+Ne+liquid; Ab+Ne+vapour=liquid (D). The phase relationships and petrographic observations suggest that primary analcime crystallized directly from the melt over a narrow range of temperatures within the analcime + vapour stability field. Unit cell dimensions suggest crystallization at lower temperatures. A shift in the invariant point to X is caused by the presence of 2 wt. % K_2O. This would broaden the stability field over which primary analcime may crystallize without albite or nepheline. The complete absence of nepheline in the rock suggests that equilibrium conditions between univariant reactions A and D never occurred.


nepheline, liquid
analcime, vapour
(B)
(C)
(D)
(A)
(E)
X
analcime
albite
vapour
liquid
nepheline
albite
albite
nepheline
vapour
PRESSURE (Kb)
1
2
3
4
5
6
7
8
9
10
600
650
700
750
TEMPERATURE (°C)

Calculated unit cell dimensions (Saha, 1963) are a_o = 13.736 Å for analcime from the Sundance dike. From relationships between cell dimensions and temperature of formation (Liou, 1966) it was found that the analcime crystallized at about 550°C. The presence of potassium in the system evidently lowered the invariant point and broadened the analcime stability field. The phase relationships are consistent with observations of primary analcime and groundmass albite (as determined from X-ray diffraction). It was not determined whether analcime is present in the groundmass but it is likely that conditions during final crystallization of the residual liquid were within the albite+analcime stability field (Fig. 10).

INTERPRETATION

The origin of Sundance Mountain and Sugarloaf Mountain

The composite of observations strongly supports an extrusive origin for Sundance Mountain and Sugarloaf Mountain. Conclusive volcaniclastic structures such as shards and pumice fragments are absent. Some mechanism(s) must be incorporated into the extrusive model that will account for the destruction of glassy material and fragmental textures of the tuffs. Structures which have been preserved provide petrographic and field evidence which suggest that the tuffs were welded and devitrified.

It was suggested that the layered units are ash fall and ash flow tuffs and that the layers are not entirely depositional structures. Petrographic evidence for this is the truncation of trachytic textures across layer boundaries. In most cases, however, the trachytic texture is continuous and the layering is evident because of contrasting interference colors. Often the attitude of the tuffs and breccias exceed the angle of repose and it is not uncommon for the units to dip at angles greater than 40°. It is proposed that deposition of ignimbritic flows provided heat for devitrification of pre-existing welded tuffs. Welding of "sticky" glass facilitated the preservation of steeply inclined depositional surfaces. Heat from near vent sources may account for continued devitrification and compaction of the pyroclastic units.

The character of the deformation strongly suggests that heat was retained by the deposits. Deformation of the tuffs resulted from loading of clasts which ranged in size from blocks to oligoclase megacrysts. Asymmetrical folding was also recognized in the tuffs. Some small scale drag faulting (Fig. 4) attests to the partial rigidity of the pyroclastic sequences. A continuous sequence of ignimbritic flows, adjacent to a hot vent, would account for initial devitrification across layered boundaries and total destruction of the vitroclastic character upon burial. Vlodavetz (1966) described similar instances where the close proximity to the vent eventually caused complete compaction and devitrification.

The pyroclastic "parting lineations" (Fig. 8) are supporting evidence for a gas-liquid-solid transporting medium. Parting lineations on sedimentary bedding surfaces are produced at the intersection of parallel vortices (Allen, 1970). The fluid dynamics of ignimbritic flow is controversial (Sparks, 1976; Lock, 1978) but laminar flow ($Re < 1{:}x\ 10^4$) has been identified in pyroclastic rocks (Sparks, 1976).

Field observations

Field observations which support an extrusive model include: 1) the lack of cross-cutting relationships, 2) vertical sequences of breccia, tuff and massive flows, 3) structural relationships between the sedimentary units and the igneous bodies, and 4) lobate ridges radiating out from Sundance Mountain which bear a geomorphic similarity to lava flows.

A fundamental distinction can be made between intrusive breccias and extrusive (pyroclastic) breccias. Intrusive breccias will commonly display cross-cutting relationships with the country rock (Parsons, 1969). Sundance Mountain breccias are concordant with the tuffs. Cavities between clasts in the breccia are filled with continuous layers of vitroclastic material (Figure 5).

Since the breccia contains clasts which are themselves layered it is probable that the tuffs were deposited and welded before vent explosions and internal gas autobrecciated the material. The breccia was immediately transported and rewelded in a gas-solid-liquid mixture. In acidic volcanic terranes it is not uncommon to find pyroclastic rocks (breccias and tuffs) at the base of a pile with more massive flows near the top (Parsons, 1969). A generalized section of Sundance Mountain can be summarized as follows: 1)monolithic breccia in basal sequences with tuff, 2) tuffs with interstratified breccia, and 3) massive flows and tuffs near the top. The generalized sections (Fig. 4) support a model of explosive felsic volcanism.

Relationships between structural attitudes of the sedimentary units and the quartz latite provide regional evidence supporting an extrusive model. The Permian Goose Egg Formation (Minnekahta Member) dips at low angles away from Sugarloaf Mountain. The Jurassic Sundance Formation dips at equally low angles out from the Sundance Mountain summit. The sedimentary rocks are not altered or recrystallized. If Sugarloaf Mountain were intrusive in origin, one would expect the attitudes of the surrounding sedimentary units to conform to layered structures in the igneous rocks, and evidence for secondary silicification and perhaps anhydrite (after gypsum) in the Spearfish Formation. Within close proximity of the inferred contact there is no distortion of the primary mineralogical and sedimentological character of the gypsiferous siltstone. An extrusive model provides for heat transfer to the surface with little or no metamorphism of the surrounding sedimentary units.

The geomorphology of Sundance Mountain presents a somewhat weaker argument for an extrusive model. Noteworthy, however, are the lobate, rounded ridges that extend out from Sundance Mountain. The ridges are especially common on the east side of the mountain. Usually it is questionable whether the outcrops are intact but the concentrations and orientation of layered rocks suggest that the bedrock is not far below the surface (outcrop numbers 166,167, 168, 215). Since the lobes are often narrower than would be expected for an alluvial fan, it is possible that they are actually ignimbritic flows which were directed away from the summit by prevailing winds and pre-existing geomorphic features (e.g. gullies).

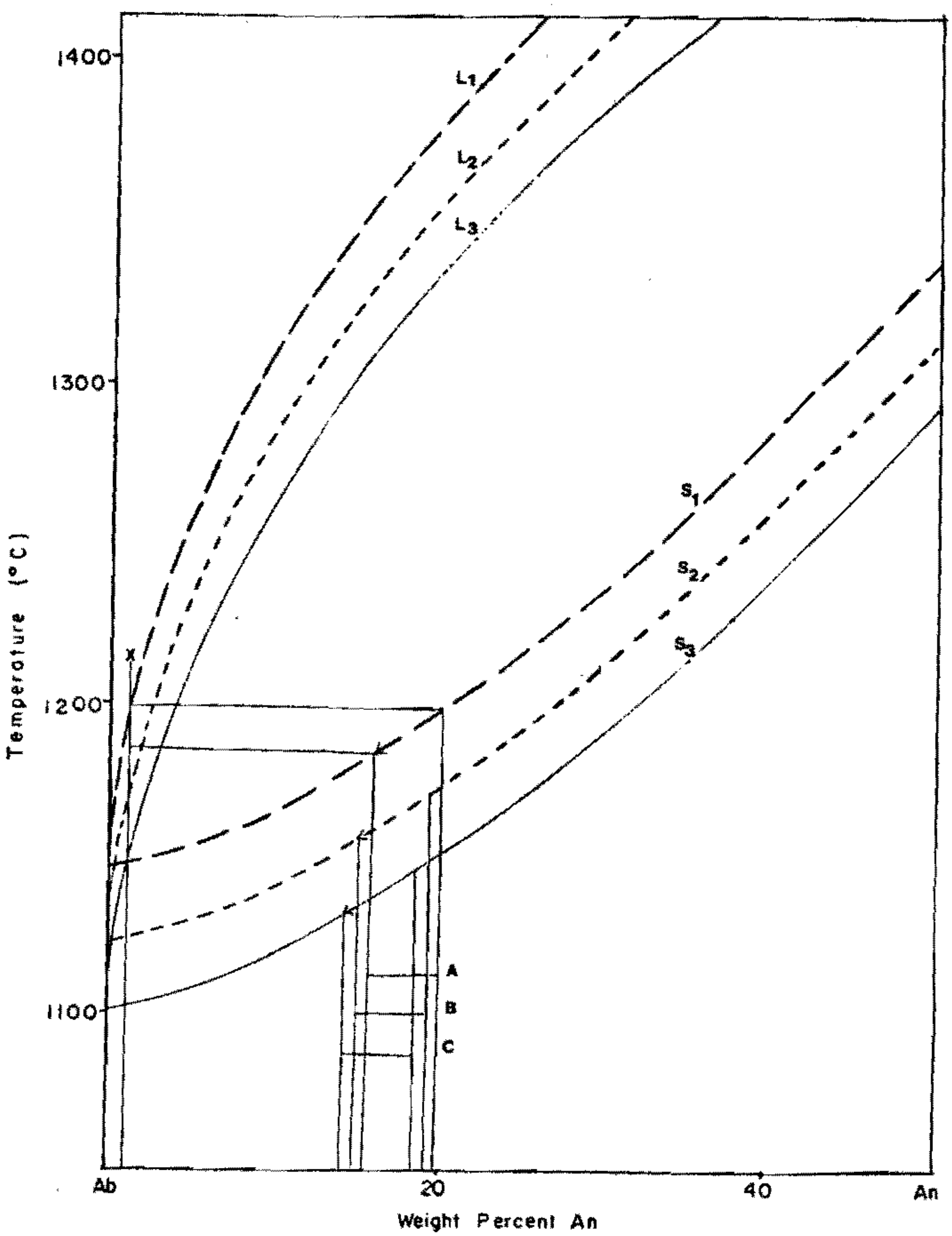
Petrologic evidence for an extrusive model

The oligoclase phenocrysts bear evidence of vertical movement and subsequent pressure release. Crystals may exhibit rounded, resorbed surfaces, around which euhedral overgrowths are precipitated. This resorption effect may be observed five times in a single crystal (sample SL-77). More commonly, three resorption surfaces are present. The phenomena produces oscillatory zoning and an overall tendency for normal zoning from the core to the rim.

Oscillatory zoning of this sort suggests episodic eruptive activity (Smith, 1974). The rapid drop in pressure, associated with the vertical ascent of a parcel of magma caused plagioclase crystal-liquid disequilibrium. Figure 14 (sample SD-95) is a model used to explain the narrow range in composition across oscillatory zones in the oligoclase. The model calls for equilibration at a given set of temperature and pressure conditions. If the system is modified by a sudden drop in pressure the liquidus and solidus will be re-established at a lower pressure. A given parcel of magma would be subject to rapid changes in pressure during explosive volcanic activity. Oligoclase would precipitate on the rounded, resorbed surfaces when eruptive activity slowed or subsided.

Further petrologic evidence supportive of an extrusive model is inherent in the composition of the cryptocrystalline groundmass. It was found that the microlites are all plagioclase feldspar (oligoclase) while the cryptocrystalline component of the groundmass is composed of alkali feldspar plus quartz. Figure 15 (after Carmichael, 1963) illustrates the solidus relationships for a four component system. The liquidus cooling path (L1-U) corresponds to the solidus cooling path (P1-Af). As seen from the figure, plagioclase becomes more sodic until reaching A3, where anorthoclase starts to crystallize. Upon further cooling, the liquid finally reaches a compositional surface, WSGX, where quartz and alkali feldspar precipitate from the remaining melt. Since anorthoclase and quartz do not occur as microscopically identifiable components, it is possible that Sundance Mountain magma (lava) was quenched at some point between P2 and A3 (Figure 15).

Fig. 14. Phase relationships used to explain oscillatory zoning in Sundance Mountain oligoclase. Initial precipitation of oligoclase from bulk composition X occurs and zone A is precipitated as crystals and liquid change compositions along S_1 and L_1, respectively. Eruptive activity causes pressure release and incomplete resorption of zone A. Equilibrium is then re-established between liquid and oligoclase under lower pressure conditions. Compositions change along L_2 and S_2, precipitating zone B. Following partial resorption, the final zone, C, is precipitated at approximately 1 Atm. pressure (L_3-S_c), immediately before the lava is extruded.


1400
1300
1200
1100
Temperature (°C)
L1
L2
L3
S1
S2
S3
X
A
B
C
Ab
20
40
An
Weight Percent An

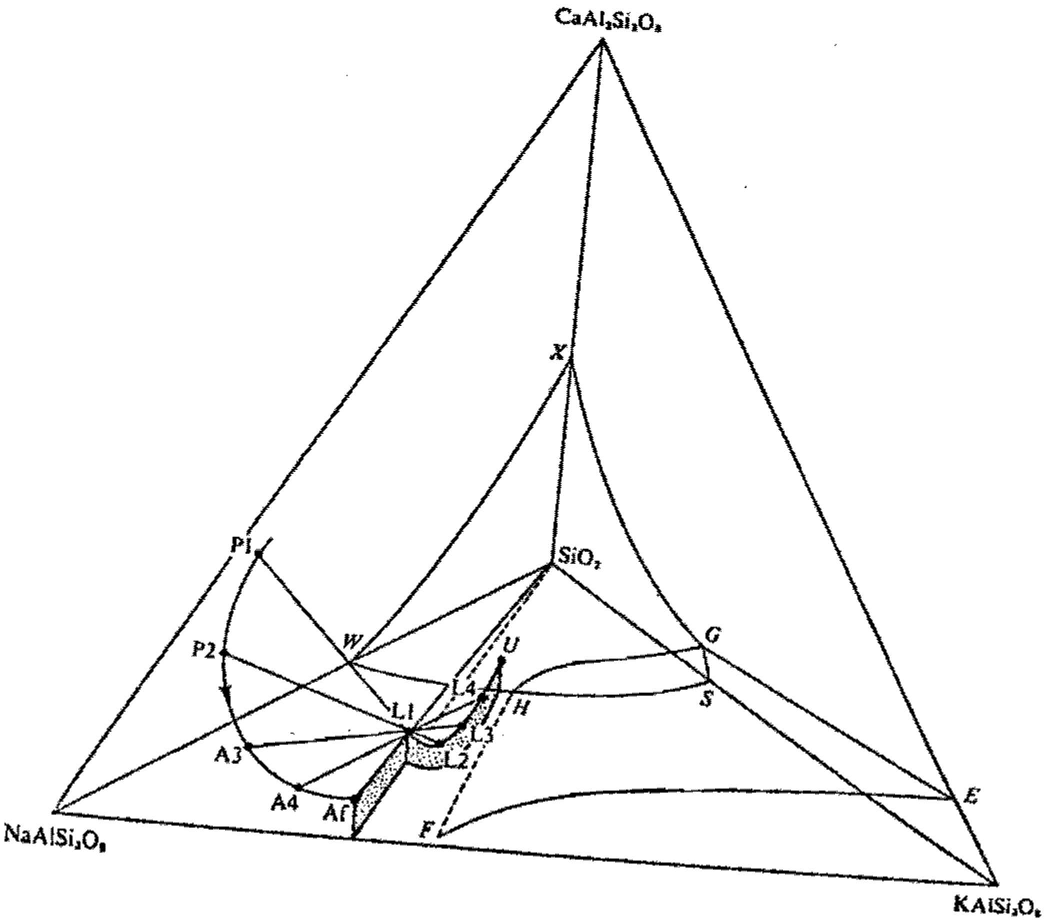


Fig. 15. "Possible relationships in the system $CaAl_2Si_2O_8$-$NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2. WS represents the quartz-alkali feldspar boundary curve; FEGH is the two-feldspar surface extending into the tetrahedron from the boundary curve EF. On the left it curves down to terminate along FH before reaching the base of the tetrahedron. GH is the intersection of the two-feldspar surface with the bounding surface of the quartz field. Compositions of feldspars P1-A4-Af lie in the front face; P1-A4 are joined by ties to their respective liquids L1-L4." (after Carmichael and others, 1963) Sundance Mountain and Sugarloaf Mountain magma may have been quenched at some point between L_2 and L_3, leaving a glassy groundmass that was devitrified to quartz plus alkali feldspar.

Sundance Mountain--a mixed cone

Cones greater than "a few hundred feet high are" (at least in part) "of composite construction" (Cotton, 1944). In larger ash cones the proportion of flows to fragmental material may be extremely low. Rittman (1962) described such cones as "mixed volcanoes" where lava and fragmental materials are important parts. An explosive index (E) was derived which is based on the relative amounts of fragmentary material (Rittman, 1962).

Stratovolcanoes (?)		
	E = 11-33%:	lava rich
Mixed cones	E = 34-66%:	intermediate or normal type
	E = 67-90%:	rich in fragmental material
Cinder cones (?)		

The classification of mixed cones cannot be applied in the strictest sense because good exposures of an entire volcanic section are rare. Based on available exposures and measured sections (Fig. 4) found in Sundance Mountain the following explosive indices were derived: E = 41% (east ridge), E = 34% (west side), E = 76% (south side). These values place Sundance Mountain in the intermediate to rich category of mixed cones.

Examples of known pyroclastic cones with lava flows of similar dimensions include Puy de Lassolas, France and Monte Pelato on the Lipari Islands, Italy (Rittman, 1962). Monte Pelato rocks are rhyolitic--similar in composition to Sundance Mountain quartz latite, while Puy de Lassolas rocks have andesitic compositions. Unlike these volcanic centers Sundance Mountain and Sugarloaf Mountain appear to be the only volcanic centers in an intrusive terrane.

Relative ages of the foyaite and quartz latite

Quartz latite and foyaite occur within a few kilometres of one another and present a difficult petrologic problem. Unfortunately the data available is insufficient to determine the petrogenetic relationship between the two rock types.

It is possible to relate the foyaite of the Bear Lodge Mountains to the phonolite(?) of Devil's Tower. Rocks from both intrusives have analcime as the only feldspathoid (Halvorson et al., 1977) and are similar in chemical composition. Devil's Tower rocks have a fission track date of 53.5 ± 6.8 m.y., while the nearby Missouri Butte rocks have a date of 55.5 ± 7.1 m.y. (Hill et al., 1975). It is likely that the Bear Lodge Mountain rocks are of similar age.

The plagiofoyaite(?) xenoliths present in Sugarloaf Mountain can be interpreted in two possible ways. If the xenoliths are part of the Bear Lodge intrusive complex, then the quartz latite is the younger of the two rock types. The xenoliths are not of the same mineralogic composition as the foyaite but they may have undergone considerable alteration. The possibility that the xenoliths are an intermediate differentiate between the quartz latite and the foyaite can not be disregarded. No exposures of plagiofoyaite were observed in the study area but it may occur elsewhere in the Bear Lodge Mountains.

CONCLUSION

The foyaite of the Bear Lodge Mountains and quartz latite of Sundance Mountain and Sugarloaf Mountain are contrasting rock types with different modes of emplacement. The Bear Lodge Mountain intrusives are sills and dikes that were passively emplaced, while the quartz latite was explosively erupted.

Evidence favoring an extrusive model for the quartz latite is as follows: 1) The breccia, tuffs and massive flows are stratified and occur in crude sequences. 2) There are no cross-cutting relationships. There are, however, unconformities between some of the stratified units. 3) The breccia consists of highly angular clasts of tuff. 4) The tuffs generally dip away from the interior of Sundance Mountain. 5) The oligoclase megacrysts display oscillatory zoning with narrow ranges in composition across the zones. The best explanation for this phenomenon is that, while episodes of eruption were taking place, ascending liquids were momentarily out of equilibrium due to different pressure and temperature conditions. 6) The microcrystalline component of the rock is oligoclase, while the cryptocrystalline groundmass consists of alkali feldspar and quartz. The system may have been quenched before anorthoclase was permitted to crystallize. 7) Pyroclastic "parting lineations" suggest liquid-solid-gas transport by ignimbritic flows.

No glassy volcaniclastic structures were observed but it is possible that such structures were destroyed by high vent temperatures (Vlodavetz, 1966).

Sundance Mountain is a mixed volcano. Eruption probably commenced after the present topographic expression of the Black Hills region was established (Stone, 1973). This would give the quartz latite a relative age of post-early Oligocene. Eruptive activity was initially explosive. Tuffs, deposited by ignimbritic flows, were periodically brecciated and rewelded. Volcanic activity became more continuous and flows were added to the pile.

Sugarloaf Mountain is a satellite volcano of Sundance Mountain. Gas-charged magma was rapidly erupted along the contact between the Minnekahta and Spearfish formations. Ignimbritic flows deposited tuffs at first, but as waning stages of volcanic activity were approached, periodic, explosive eruptions resulted in the graded tuff breccias.

The foyaite intrusive body is a sill that was emplaced after the laccolithic structure was developed. The Sundance dike is the same composition and was probably emplaced at about the same time. Textural observations suggest that the magma cooled quickly. If nepheline had crystallized, partial preservation would be expected in the dike and near the sill margins. It is plausible that the presence of potassium in a water saturated melt had the effect of lowering the stability field and causing direct precipitation of analcime from the residual liquid. Further microprobe studies of the analcime may provide confirmation of 2 weight percent or more K_2O in the analcime. Microprobe investigations on the groundmass may also reveal information about the chemistry and equilibrium conditions of the residual liquid.

More work is needed to solve the ultimate petrologic problem of how the two major rock types are related in time and space. Local seismic data would be useful in determining major cross-cutting relationships at depth. Furthermore it may be necessary to use trace elements to determine if the rock types are indeed related. Finally, age dates on the sill, Sundance Mountain and the plagiofoyaite(?) xenoliths would be very useful in solving the problem. If the quartz latite is much younger than the foyaite the possibility arises that the two rock types were derived from separate petrotectonic events.

APPENDICES

APPENDIX A

ABBREVIATIONS FOR TABLE 1 (APPENDIX B)

sample number: A prefix is given followed by the number of the sample

SD-Sundance Mountain
SL-Sugarloaf Mountain
BL-Bear Lodge Mountains
S-Sundance dike

outcrop number: corresponds to outcrop numbers on Plates 2, 3, and 4

outcrop location: section number is followed by the numbers 1, 2, 3, or 4, indicating the NE quarter, NW quarter, SW quarter, and SE quarter, respectively.

rock type:

Ql-quartz latite
Fo-foyaite

structures: foliation, layering, parting, joint sets are indicated by "X" if the structural attitude is not certain. For multiple joint sets the "other" category is used. Other structures include: xn-xenoliths; v-vescicles(?).

texture/composition:

<u>general</u>

Po-Porphyritic
Br-breccia
Tb-tuff breccia
Gl-glomeroporphritic
Gp-graded pyroclastic
Ag-agglomerate
Af-ash fall/ash flow layering
Ma-massive: nonlayered and non-brecciated (flows)

Where two or more seemingly contradictory textures are listed it is understood that all of these textures are present at the outcrop but only those textures that are underscored are carried over to hand specimens.

<u>phenocrysts</u> (percentage values are given if available)

mi-minor (less than 5% of the rock)
x-5 to 10 percent
xx-10 to 20 percent
xxx-20 to 50 percent
G-garnet
A-analcime
B-biotite
S-sericite
Sp-sphene
O-opaque(?)

groundmass

grain size

C-cryptocrystalline
M-Microcrystalline
F-fine grained (phaneritic)

shape/arrangement

Hy-hypidiomorphic granular
Tr-trachytic

alteration products

Mt-montmorillinite
Ch-chlorite
Ep-epidote
Ct-calcite
Se-sericite
Lim-limonite
opal

APPENDIX B
TABLE 1

IGNEOUS ROCK AND OUTCROP DESCRIPTIONS

sample number	S-6	S-7	S-8	S-11	S-12	BL-13	BL-16A	BL-16B
outcrop number	18a	18b	18c	18e	18g	19	20A	20B
outcrop location	13-1	13-1	13-1	13-1	13-2	4-2	10-2	9-1
rock type	Fo	Fo	Fo	Fo	Fo	Fo	Fo	Fo
						dike	boulder	boulder
structures								
foliation		N40W,28E	N32W,7W	N0W,54E	x			
layering								
parting								
joint sets	N85E,31W	N35E,86W	N10E,84E	N75W,90	N70W,56E			
other		N57W,69E	N65W,79W			N22W,53W		
texture/composition								
general	Po	Po	Po	Po	Po	Po		
phenocrysts	7	9	8	9	x	30	15	15
alk. feldspar	62	xxx	xxx	65	xxx	xxx		
oligoclase							?	?
aegerine/augite	6	x	x(?)	5	x(?)			
hornblende		x	x(?)	5	x(?)			
other	A25	A,B(?)O	A,B(?),O	A25,B,O	A,B(?),O			
groundmass								
size	M	M	M	M	M	M	M	M
shape/arrangement	Tr,Hy	Tr,Hy	Tr,Hy	Tr,Hy	Tr,Hy	Tr		
alteration products	Se,Hm Ct	Ch,Se		Ch, Se		Lim		

TABLE 1—continued

sample number	BL 17	BL 25	BL 26	BL 27	BL 28	BL 29	BL 30	
outcrop number	24	25	26	27	28	29	30	31
outcrop location	2-3	2-3	2-3	2-3	3-4	3-4	3-4	3-3
rock type	Fo	Fo	Fo	Fo	Fo	Fo	Fo	Fo
structures								
foliation	N73E,90	N76E,78E	N39E,42W	N22E,4W	N30E,11E	N75E,17E	N89E,20SE	N47E,16E
layering								
parting							N89E,20SE	
joint sets			N32W,87E	N59W,78E				
other			N40E,15W	N15W,80E				
texture/composition								
general	Po	Po	Po	Po	Po	Po	Po	Po
phenocrysts	15	x	50	x	x	x	x	x
alk. feldspar	x	xx	xx	x	x	x	x	x
oligoclase								
aegerine/augite	mi	mi	x	x	mi	x	?	
hornblende								
other	A(?)	A25,G,O	A(?)	A(?)	A(?)	A(?)	A(?)	A(?)
groundmass								
size	M	F	F	F	M	M	M	M
shape/arrangement		Hy						
alteration products	Se(?)	Se,Ep, K(?),Lim	Se(?)	Se(?)	Se(?)		Se,Ep	

TABLE 1—continued

sample number		BL-35	BL-44	BL-45	BL-46	Bl-47	59a	59b
outcrop number	33	35	44	45	46	47	59	59
outcrop location	2-3	2-3	3-4	3-4	3-4	3-1	7-3	7-3
rock type		Fo	Fo	Fo	Fo	Fo	Ql	Ql
structures								
foliation		N21E,24E	N85E,25W		N88E,38W			
layering							N10W,25W	N24W,54W
parting								
joint sets		N9E,75W	N85E,57W		N75E,90			
other		lineation N69W			lineation N2W			
texture/composition								
general	Po	Po	Po	Po	Po	Po	Gp,Br	Br
phenocrysts	x	xx	x	x	x	x		
alk. feldspar	x	xx	x	x				
oligoclase								mi
aegerine/augite	?	?	x	x	mi	mi		
hornblende								
other								
groundmass								
size		M	M	M	M	M	C	C
shape/arrangement								
alteration products		Se(?)	Se(?)	Se(?)		Se(?),lc	Ct,Mt(?)	Mt(?)

TABLE 1—continued

sample number	SL59c	SL59d	59e	59f	59g	59h	59i	59j
outcrop number	59	59	59	59	59	59	59	59
outcrop location	7-3	7-3	7-3	7-3	7-3	7-3	7-3	7-3
rock type	Ql	Ql	Ql	Ql	Ql	Ql	Ql	Ql
structures								
foliation								
layering		NO,45W						
parting								
joint sets								
other	Xn	Xn	Xn	Xn	Xn	Xn	Xn	Xn
texture/composition								
general	Gp,Tb	Tb	Gp,Tb	Tb	Gp,Tb	Gp,Tb	Gp,Tb	Gp,Tb
phenocrysts								
alk. feldspar								
oligoclase								
aegerine/augite								
hornblende								
other								
groundmass								
size	C	C	C	C	C	C	C	C
shape/arrangement								
alteration products	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt

TABLE 1—continued

sample number	SL60		SL62A	SL62B	SL62C	SL62D	638	SL63A
outcrop number	60	61	62	62	62	62	63	63
outcrop location	7-2	7-2	7-2	7-2	7-2	7-2	7-2	7-2
rock type	Ql	Ql	Ql	Fo(?)	QL	Ql	Fo(?)	Ql
structures								
foliation								
layering	N75E,53E	N59E,55W	N10W,10W	trough	trough	N0,35W		
parting								
joint sets								
other	Xn	Xn	Xn	L-N40W Xn	Xn		Xn	
texture/composition								
general	Tb,Gp	Tb,Gp	Gp,Ag	Po	Tb	Tb		Tb
phenocrysts				xxx				
alk. feldspar				xx				
oligoclase								
aegerine/augite				x				
hornblende								
other								
groundmass								
size	C	C	C	C	C	C	M	C
shape/arrangement			Tr					
alteration products	Mt	Mt	Mt,Ct	Se	Mt	Mt		Mt

TABLE 1--continued

sample number	SL63	SL63B	SL64		SL65	SL65A	SL66	SL67
outcrop number	63	63	64	64	65	65	66	67
outcrop location	7-3	7-3	7-3	7-3	12-4	12-4	7-3	7-3
rock type		Ol	Ol	Ol	Ol		Ol	Ol
structures								
foliation								
layering		N3E,55W	N5W,45W			N25W,61W	N30W,44W	N32W,52W
parting						N25W,61W		N32W,52W
joint sets								
other	Xn	Xn	Xn	Xn	Xn	L-N25W Xn		
texture/composition								
general	Tb,Gp	Tb,Gp	Tb,Gp	Ag	Po	Po	Ag	Af
phenocrysts					x	xx		
alk. feldspar						xx		
oligoclase					x			x
aegerine/augite					mi	x		
hornblende								
other								
groundmass								
size	C	C	C	C	C	C	C	C
shape/arrangement								
alteration products	Mt	Mt	Mt	Mt	Mt	Se	Mt	Mt

TABLE 1—continued

sample number	SL68A	SL68B	SL69	SL71	SL73	SL74	SL75	SL76
outcrop number	68	68	69	71	73	74	75	76
outcrop location	12-4	12-4	12-4	12-4	12-4	12-4	12-4	12-4
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering		N77W,31E		N18E,77W	N42E,58E		N80E,70E	
parting				N18E,77W				
joint sets								
other	Xn(40)	Xn	Xn					
texture/composition								
general	Ag	Ag	Ag	Af	Af	Af	Af	Ma
phenocrysts								
alk. feldspar								
oligoclase				x	x	?		x
aegerine/augite								
hornblende								
other								
groundmass								
size	C	C	C	C	C	C	C	C
shape/arrangement								
alteration products	Mt	Mt	Mt	Mt,Se	Mt	Mt	Mt	Mt

TABLE 1--continued

sample number	SL77	SL78	SL79	SL80	S18h	S18i	BL83	BL84
outcrop number	77	77	77	77	18	18	136	137
outcrop location	12-4	12-4	12-4	12-4	13-2	13-2	3-3	3-3
rock type	Q1	Q1	Q1	Q1	Fo	Fo	Fo	Fo
structures								
foliation					N11W,11W		x	N85E,56W
layering			N82E,42W					
parting								
joint sets						N52W,71E		N85E,56W
other			Xn-Trs(?)					
texture/composition								
general	Af,Po	Ma	Af	Ma	Po	Po	Po	Po
phenocrysts	mi	mi	mi	mi	5	x	xx	x
alk. feldspar					x	x	20	x
oligoclase	mi	mi	mi	mi				
aegerine/augite					mi	mi	8	?
hornblende								
other							A(8)	AO(3)
groundmass								
size	C	C	C	C(50)	M	M	M	M
shape/arrangement	tr						Hy	
alteration products	Mt,Ct, lim.,	Mt	Mt	Mt,Se	Se,Ch,Ep	Se,Ch,Ep	Se	Se

TABLE 1—continued

sample number	BL85		BL87B	SD94	SD94A	SD96A	SD96B	SD97
outcrop number	138	139	141	155	156	158	158	159
outcrop location	3-3	3-3	4-2	24-3	24-3	24-3	24-3	24-3
rock type	Fo	Fo	Fo	Q1	Q1	Q1	Q1	Q1
structures								
foliation	N85E,65W	N86E,36W	N62W,45N					
layering				N85W,55E	N63W,46E	N39W76		
parting				N85W,55E	N21W,54E		N39W,7E	N35E,73W
joint sets								
other			dike rock					
texture/composition								
general	Po	Po	Po	af	af,br	br	af	Ma
phenocrysts	x	x	x	x	x			x
alk. feldspar	x	x	x					
oligoclase				mi	mi			mi
aegerine/augite	?	?						
hornblende				mi				mi
other	A(?)	A(?)						
groundmass								
size	m	mi	mi	C	C	C	C	C
shape/arrangement								
alteration products	Ch		Ch	Mt	Mt	Mt	Mt	Mt

TABLE 1—continued

sample number	SD98	SD99	SD100		SD101			SD102
outcrop number	160	161	162	163	164	165	166	167
outcrop location	24-3	24-3	24-3	24-3	24-3	24-4	24-4	24-4
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								N75W,90
layering	N33E,14E	N25W,42W	N0,17E	N41E,40E	N75W,71W			N75W,90
parting			N0,17E	N41E,40E	N75W,71W			
joint sets								
other							boulders	
texture/composition								
general	Ma,Po,Br	Af	Af,Br	Af	Po,Af	Af		Ma,Gl
phenocrysts		x	x	x	x			x
alk. feldspar								
oligoclase	mi	5	mi	mi	x			5
aegerine/augite								
hornblende			mi	mi				
other								
groundmass								
size	C(50)	C	C	C	C	C		C(45)
shape/arrangement								
alteration products	Mt	Mt	Mt	Mt	Mt	Mt	Mt	opal,

TABLE 1—continued

sample number	SD103	SD104	SD105				SD107	
outcrop number	168	169	170	171	172	173	174	175
outcrop location	24-4	24-4	24-3	24-3	24-3	24-3	24-3	24-3
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering		N51W,15E	N85W,43W	N15W,45W	N58E,15W	N48W,15N	N8E,65W	
parting				N15W,45W				
joint sets		N60E,90			N62E,54W	N46E,69E	N20W,72E	
other								
texture/composition								
general	Ma,Po	Af	Af	Ma	Ma,Af,Br		Af	Af,Br
phenocrysts	x	x	x	x			x	
alk. feldspar								
oligoclase	x	mi	mi	mi			mi	
aegerine/augite								
hornblende	mi	mi	mi	mi			mi	
other								
groundmass								
size	C	C	C	C	C		C	
shape/arrangement								
alteration products	Mt	Mt	Mt	Mt	Mt	Mt	Mt	Mt

TABLE 1—continued

sample number	SD109	SD110		SD112	SD113		SD115	SD116
outcrop number	176	177	178	179	180	181	182	183
outcrop location	24-3	24-3	24-3	24-3	24-3	24-3	24-3	24-3
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering		N67E,11E	N55W,17W	N46E,60W		N69E,22E		N63W,55W
parting								
joint sets	N20,E58W		N11W,81W	N20E,40W		N89W,56W	N25E,65E	
other			N3W,25E					porous
texture/composition								
general	Ma	Af		Af	Af	Af	Ma	Af
phenocrysts								
alk. feldspar								
oligoclase	mi	mi		mi	mi		x	
aegerine/augite								
hornblende	mi	mi		mi	mi		mi	
other								
groundmass								
size	C	C		C	C		C	C
shape/arrangement								
alteration products								

TABLE 1—continued

sample number	SD117	SD118	SD119A	SD119B	SD119C	SD120	SD121	SD122
outcrop number	184	185	186	186	186	187	188	189
outcrop location	25-2	24-3	26-1	26-1	26-1	26-1	23-4	23-4
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering	N69E,70E	N63E,40E		N40E	N68W,78W	N73W,88E		N26E,20W
parting								
joint sets			N37E,39W					
other			porous	trough structure			Lensoidal layering	
texture/composition								
general	Ma,Af	Af,Po	Ma,Af	Af	Af	Af	Af	Ma,Af
phenocrysts								
alk. feldspar								
oligoclase	mi	x	mi	mi	mi	x	mi	
aegerine/augite								
hornblende	mi	mi		mi	mi	mi	mi	mi
other				Sp				
groundmass								
size	C	C	C	C	C	C	C	C
shape/arrangement								
alteration products			Mt(?) Se(?)					

TABLE 1--continued

sample number	SD123	SD124A	SD124B	SD125	SD126	SD127	SD128	SD129
outcrop number	190	191	191	192	193	194	195	196
outcrop location	23-4	24-3	24-3	24-3	25-2	25-2	26-1	26-1
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering		N34,20W		N59E,36W	N34E,57W	N45W,20E	N55W,53E	N34E,12E
parting							N55W,53E	
joint sets	N60W,7W					N45W,30E		
other			XN				porous	porous
texture/composition								
general	Ma	Af,Ma	Br	Ma	Af,Gl	Af	Af,Ma	
phenocrysts								
alk. feldspar								
oligoclase	mi	mi		mi	mi	mi		mi
aegerine/augite								
hornblende		mi		mi	mi	mi		
other								
groundmass								
size	C	C	C	C	C	C	C	C
shape/arrangement				Hy	Hy,Tr			
alteration products								

TABLE 1—continued

sample number	SD130		SD131	SD132	SD132	SD133B	SD134	SD135
outcrop number	197	198	199	200	201	201	202	203
outcrop location	26-1	26-1	23-4	23-4	23-4	23-4	23-4	23-4
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering		N77W,90	N25W,60E	N21W,58W		N60E,14E		N5W,46W
parting		N77W,90					N17W,39W	N5W,46W
joint sets					N44E,33W		N45E,55E	
other				fractured	fractured	fractured		
texture/composition								
general	Ma	Af	Ma,Af	Ma,Af	Ma,Af	Ma,Af, Gl	Ma	Af
phenocrysts								
alk. feldspar								
oligoclase	mi		mi			4	mi	mi
aegerine/augite								
hornblende								
other						Magnetite		
groundmass								
size	C		C	C	C	C	C	C
shape/arrangement								
alteration products				opal	opal	opal	Mt(?)	

TABLE 1—continued

sample number	SD136	SD137	SD138		SD139	SD140		SD141
outcrop number	204	205	206	207	208	209	210	211
outcrop location	23-4	23-4	23-4	23-4	23-4	23-4	23-4	26-1
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering	N80E,60E	N60E,40W	N52W,44E	N16E,64E			N75E,17W	N50W,65W
parting	N80E,60E	N60E,40W			N21E,60E			
joint sets	N65E		N17E,32E					
other	V(?)				vuggy		fractured	fractured
texture/composition								
general	Af	Af,Po	Af,Po	Af	Ma	Ma,Af		Af,Ma
phenocrysts		x	x					x
alk. feldspar								
oligoclase		x	x		mi	mi		mi
aegerine/augite								
hornblende								mi
other								
groundmass								
size	C	C	C		C	C		C
shape/arrangement	Tr,Hy							
alteration products					opal			

TABLE 1—continued

sample number	SD142	SD143	SD144	SD145		SD146	SD147	SD148
outcrop number	212	213	214	215	216	217	218	219
outcrop location	26-1	26-1	26-1	23-3	26-1	26-1	26-1	23-4
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering	N60W,15W	N63W,63W	N70W,53W	N50W,27E	N47E,16E	N7E,45E	N20E,48W	
parting	N60W,15W			N50W,27E				N15E,31E
joint sets		N32W,37E	N35W,61E					
other					mico-folds XN		vescicles(?)	
texture/composition								
general	Af	Af	Af,Ma	Af	Af		Af,Po	Ma,Af
phenocrysts	x					x	x	
alk. feldspar								
oligoclase	mi	mi	mi	mi		mi	x	mi
aegerine/augite								
hornblende	mi		mi			mi		mi
other								
groundmass								
size	C	C	C	C		C	C	C
shape/arrangement							Hy	
alteration products							lim.	opal

TABLE 1—continued

sample number	SD149		SD151	SD152	SD153	SD154A	SD154B	SD155
outcrop number	220	221	222	223	224	225	226	227
outcrop location	23-4	23-4	23-4	23-4	23-4	23-4	23-4	23-4
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering	N53W,57E	N60E,8W	N55W,64W		N42E,37E		N31W,76W	N56W,28W
parting		N60E,8W			N42E,37E			
joint sets	N82E,37W	N80E,17W		N50W,28E	N80E,43W	N40W,73W	N40W,73W	
other	N50E,25W	XN				rubbled	vescicles	(?)Parting Lineations
texture/composition								
general	Af		Af,porous	Ma	Af,Ma	Ma	Af,Po,Tb	Br,Af
phenocrysts					x			
alk. feldspar								
oligoclase	mi		mi	mi	mi		x	mi
aegerine/augite								
hornblende	mi				mi			
other								
groundmass								
size	C		C	C	C	C	C	C
shape/arrangement							Hy,Tr	
alteration products								

TABLE 1—continued

sample number		SD157	SD158B	SD160A	SD160B	SD161	SD162	SD163A
outcrop number	227	229	230	231	231	232	233	234
outcrop location	23-4	23-4	23-4	23-4	23-4	23-4	23-4	23-4
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering	N50E,60W	N22W,27W	N62E,33W			N85W,40E	N75E,4W	N54W,85W
parting								
joint sets	N75E,45W		N10W,67E			N10W,58E	N2W,46E	
other		vescicles	(?)Parting lineations			N8W,70E		
texture/composition								
general		Af	Af	Af	Br	Af	Af,Po	Af,Po
phenocrysts							x	x
alk. feldspar								
oligoclase			mi	mi		mi	x	11
aegerine/augite								
hornblende								mi
other								
groundmass								
size		C	C	C	C	C	C	C,mi
shape/arrangement		Hy						Hy
alteration products								

TABLE 1--continued

sample number	SD163B	SD164	SD165	SD166	SD167	SD168	SD169	SD170
outcrop number	234	235	236	237	238	239	240	241
outcrop location	23-4	23-4	23-4	23-4	23-4	23-4	23-4	23-4
rock type	Q1	Q1	Q1	Q1	Q1	Q1	Q1	Q1
structures								
foliation								
layering	N54W,85W	N26W,60W	N14E,36E				N55E,43E	N25E,64W
parting				N5E,8E	N45E,27W	N25E,59E	N55E,43E	N25E,64W
joint sets		N7E,49E	N25W,31W	N14E,75E	N15W,71W			
other			N29E,83W					
texture/composition								
general	Af	Af,Po	Af	Ma	Ma	Po,Ma Af	Af,Ma	Ma,Af
phenocrysts		x				x		
alk. feldspar								
oligoclase	mi	x	mi		mi	x	mi	
aegerine/augite								
hornblende		mi						
other								
groundmass								
size	C	C	C	C	C	C	C	C
shape/arrangement						Hy,Tr		
alteration products								

TABLE 1—continued

sample number	BL171	SL175	SD95					
outcrop number	245	66	157					
outcrop location	3-1	7-3	24-3					
rock type	Fo	Fo(?)	Ql					
structures								
foliation	x	x						
layering								
parting								
joint sets								
other		XN						
texture/composition								
general	Po,H		Gl					
phenocrysts	xxx	xx	x					
alk. feldspar	xx	10						
oligoclase			11					
aegerine/augite	x	3						
hornblende								
other	A(?)	A(10)	Sp					
groundmass								
size	mi	C	C					
shape/arrangement	Tr,Hy	Tr, Hy	Tr					
alteration products		Ch,Se	ep,ch,mt, lim.					

APPENDIX C

ABBREVIATIONS TO APPENDIX D (TABLE 2)

Fm-Formations

Js-Sundance
Jg-Sypsum Springs
-Spearfish
Pm-Minnekahta Member
Po-Opeche Member
-Minnelusa
Mp-Pahasapa

sample number: A prefix is given, followed by the number of the sample

SD-Sundance Mountain area
BL-Bear Lodge Mountain area (includes area surrounding Sugarloaf Mountain)

outcrop location: section numbers are followed by numbers 1, 2, 3, or 4, indicating the NE quarter, NW quarter, SW quarter, and SE quarter, respectively.

rock type

SItst-silstone
Ss-sandstone
Sh-shale
Ls-limestone
Gyp-gyprock
Q-quartzite
additional adjectives: 1. - limey; s. - sandy

example: Ls/Ss means sandstone and limestone occur as distinct lithologies. 1.Ss means limey sandstone.

grain size

F-fine to very fine (0.25 - .062 mm)
Silt-(.062 - .004 mm)
Clay-less than .004 mm (clay-size meterials)
F-n-fine grained, nondetrital
F-r-recrystallized (metamorphosed)
M-medium (0.25 - 0.5 mm)

example: F-n/F means that fine grained, nondetrital materials occur with (e.g. interbedded) fine grained, detrital material

APPENDIX D
TABLE 2

SEDIMENTARY ROCK AND OUTCROP DESCRIPTIONS

Fm	sample number	outcrop number	outcrop location	rock type	structure: bedding	structure: joints	structure: other	grain size
		1	9-4	SItst	N43E,19E		Parting	Silt/clay
		2	9-4	SItst	N78W,7E		Parting	Silt/clay
Pm	BL-1	3	9-1	Ls	N63E,14E		Parting	F-N
Pm		4	9-1	Ls			Parting	F-N
Pm		5	10-2	Ls	N90E,24S		Parting	F-N
Pm		6	10-2	Ls	N60E,11E		Parting	F-N
Pm		7	10-1	Ls	N85E,9S	N75W65W N12W84W	Parting	F-N
		8	9-1, 2	Ss				M
Pm Po		9	9-2	Ls/Ss				F-N/F
	BL-2	10	4-3	Ss	laminated			F
	BL-3	10	4-3	Ss			vugs	F
Pm Po		11	4-3	Ss/Ss	N35W,26W		X-bedding	F/F
		12	4-3	Ls	N85E,26S			F-N

TABLE 2--Continued

Fm	sample number	outcrop number	outcrop location	rock type	structure			grain size
					bedding	joints	other	
Mp		13	4-2	Ls	N75W,38W		Partings fossiliferous	F-N
Mp		14	4-4	Ls/Sh	N42E,22E		Parting	F-N/clay
Mp		15	4-1	S.Ls	N85E,31E			F-N/d
Mp		16	4-1	Sh	N82E,41E			clay/silt
Rs Pm		21A	10-1	S.Ls	N90E,14S			F-N/d
Pm		21B	3-4	1.Ss	N78E,54E		Parting	F-d/N
Mp		21D	3-4	1.Ss	N61W,36W			F-d/N
Pm		22	11-2	Ls				F-N
Po		23	2-3	Ss				M/F
Pm		32	3-4	Ss	N47E,16E			F
Pm		33	2-3	Ls	N62E,34W			F-N
Mp	BL-36	36	2-3	Ls				F-N
Mp		37	3-1	Ls			fossiliferous	F-N

TABLE 2--Continued

Fm	sample number	outcrop number	outcrop location	rock type	structure			grain size
					bedding	joints	other	
Mp		38	3-1	Ls				F-N
Mp	BL-37	39	3-2	Ls				F-N
Mp		40	3-4	Ls		N64W81W	fossiliferous	F-N
Mp		41	3-4	Ls	N64E,17E	N5E,80E		FN
		42	3-4	Ss				F
	BL-41	43	3-4	Ss			Chert Nodules	F
Pm		48	9-1	Ls	N54W,25E			Ls-N
Pm		49	9-1	Ls	N88W,24E			Ls-N
Pm		50	9-3	Ls	N60W,19W			Ls-N
Pm		51	9-3	Ls				Ls-N
Pm		52	9-2	Ls		N63W,10W		Ls-N
Pm		53	9-2	Ls		N10W,21W		Ls-N
Pm		54	9-2	SItst/Ls				Silt/Ls-N

TABLE 2--Continued

Fm	sample number	outcrop number	outcrop location	rock type	structure bedding	joints	other	grain size
Mp		55	4-2	Ss/Ls				F/F-N
Mp		56	4-2	Ls				F-N
Mp		57	4-2	Ls		N75E,40E		F-N
Mp		58	4-2	Ls	N80E,43E			F-N
Pm		70	12-4	Ls	N62E,8E			F-N
Pm		81	12-4	Ls	N60E,11E	N60E,81W		F-N
Pm		82	12-4	Ls	N80E,10E			F-N
Pm		83	12-4	Ls	N40E,90E			F-N
Pm		84	12-4	Ls	N3E,23E			F-N
Pm		85	12-4	Ls	N36E,24E			F-N
Pm		86	12-4	Ls	N35E,31E			F-N
Pm		87	12-4	Ls	N19E,23E			F-N
Pm		88	12-4	Ls	N28E,24E			F-N

TABLE 2--Continued

Fm	sample number	outcrop number	outcrop location	rock type	structure bedding	joints	other	grain size
Pm		89	12-4	Ls	N86E,19S			F-N
Pm		90	12-4	Ls	N45E,9E			F-N
Pm		91	1-3	Ls	N82W,2W			F-N
Pm		92	12-3	Ls	N37E,7E			F-N
Pm		93	12-1	Ls	N62W,24E			F-N
Pm		94	12-1	Ls	N20E,14E			F-N
Pm		95	12-1/4	Ls	N5E,9E			F-N
Pm		96	13-2	Ls	N30E,35E			F-N
Pm		97	13-2	Ls	N30E,25E			F-N
Pm		98	13-2	Ls	N54E,21E			F-N
Pm		99	14-1	Ls	N45E,4E			F-N
Pm		100	14-2	Ls	N59W,18W			F-N
Pm		101	14-4	Ls	N15E,11E			F-N

TABLE 2--Continued

Fm	sample number	outcrop number	outcrop location	rock type	structure			grain size
					bedding	joints	other	
Pm		102	14-4	Ls	N33W,6E			F-N
Pm		103	1-4	Ls	N24E,24E			Ls
Pm Po		104	1-4	Ls/SIlst				F-N/
		105	1-4	Ss	N80E,13E		x-bedding	F
Pm		106	1-4	Ls				F-N
		107	1-4	Ss-congl.				F
Pm		108	1-2	Ls	N8E,30E			F-N
Pm		109	1-2	Ls				F-N
Pm		110	1-2	Ls	N90W,10E			F-N
Pm		111	1-2	Ls	N10E,18E			F-N
Pm		112	1-2	Ls				F-N
Pm		113	1-3	Ls	N40E,9E			F-N
Pm		114	2-1	Ls				F-N

TABLE 2--Continued

					structure			
Fm	sample number	outcrop number	outcrop location	rock type	bedding	joints	other	grain size
Pm Po		115	2-4	Ls/SIlst				F-N/F
		116	2-4	Ls	N67E,11E			F-N
		117	2-4	Ls				F-N
Po		118	1-3	SIlst				F
Po		119	1-3	SIlst				F
Pm		120	1-3	Ls				F-N
Pm Po		121	1-3	Ls	N32E,10E			F-N
Pm Po		122	1-3	Ls/SIlst				F-N/F
		123	1-1	Ss				M
		124	1-1	Ss				M
		125	1-1	Ss	N66E,10E			M
		126	7-3	SIlst/Gyp				F/F-N
		127	7-3	SIlst/Gyp	N40W,29E			Silt/clay

TABLE 2--Continued

Fm	sample number	outcrop number	outcrop location	rock type	structure: bedding	structure: joints	structure: other	grain size
		128	4-4	Ss				F
Mp		129	4-4	Ls				F-N
Mp		130	4-1	Ls				F-N
Mp		131	4-1	Ls/Sh				F-N/F
Mp		132	3-2	Ls				F-N
Mp	BL-82	133	3-2	Ls/Sh	N53E,11E		vugs	F-r/F
		134	3-3	Ss		N87,67E		F
		135	3-3	Ss	N86E,36E		x-bedded	F
	BL85	140	3-3	Ss	N42W,14E			F-r(?)
	BL87A	141	4-2	Q	N75W,49E			F-r
*	BL89A	144	4-2	Q				M-r
Mp		145	4-2	Ls				F-n
Mp	B190	146	3-1	Ls(dol.)				F-r

*May be Cambrian, Deadwood Formation.

TABLE 2--Continued

Fm	sample number	outcrop number	outcrop location	rock type	structure bedding	joints	other	grain size
Mp		147	3-1	Ls	N15E,14E			F-N
Pm		148	9-1	Ls				F-N
		149	3-3	Ss				F
Pm		150	3-3	Ls				F-N
		151	3-3	Ss				F
	BL-91	152	3-3	Ss	N77W,22E			F-r(?)
Js		154	24-2	Ss	N65E,19W		x-bedded	F
		242	2-3	Ss	N49E,25E			F
Pm		243	11-2	Ls	N27W,5E			F-N
Po		244	2-4	Ss	N84W,8W		vugs	F/M
Jg		246	24-1	Gyp/SIlst	N58E,25W		slumped	F-N/silt
Js		247	24-1	SIlst	N6W,4E			Ss/silt/clay
Js		248	24-4	Ss	N2W,5E			F

TABLE 2--Continued

Fm	sample number	outcrop number	outcrop location	rock type	structure bedding	joints	other	grain size
Jg Js		249	24-1		N85E,5E			F
Mp		253	3-1	Ls				F-r

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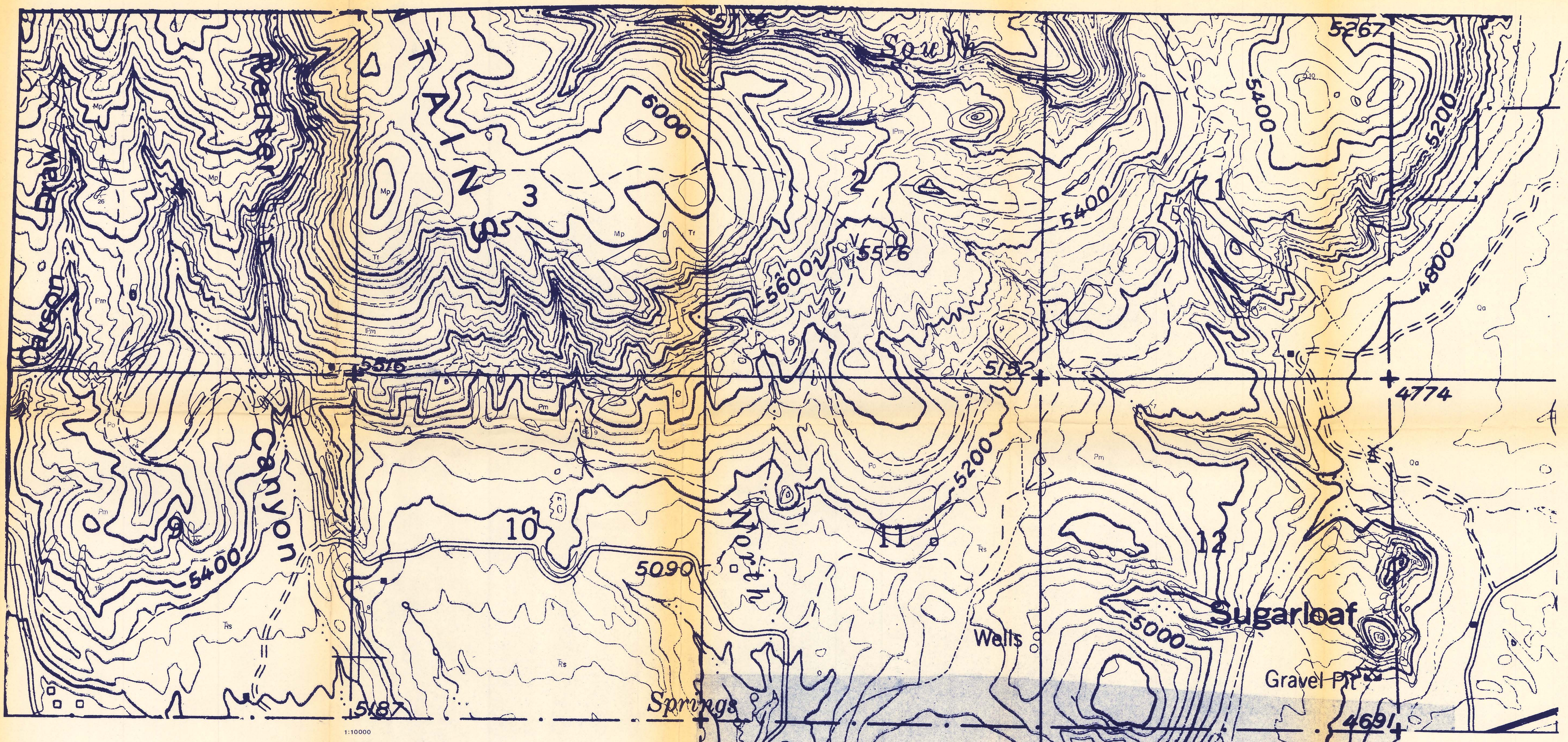

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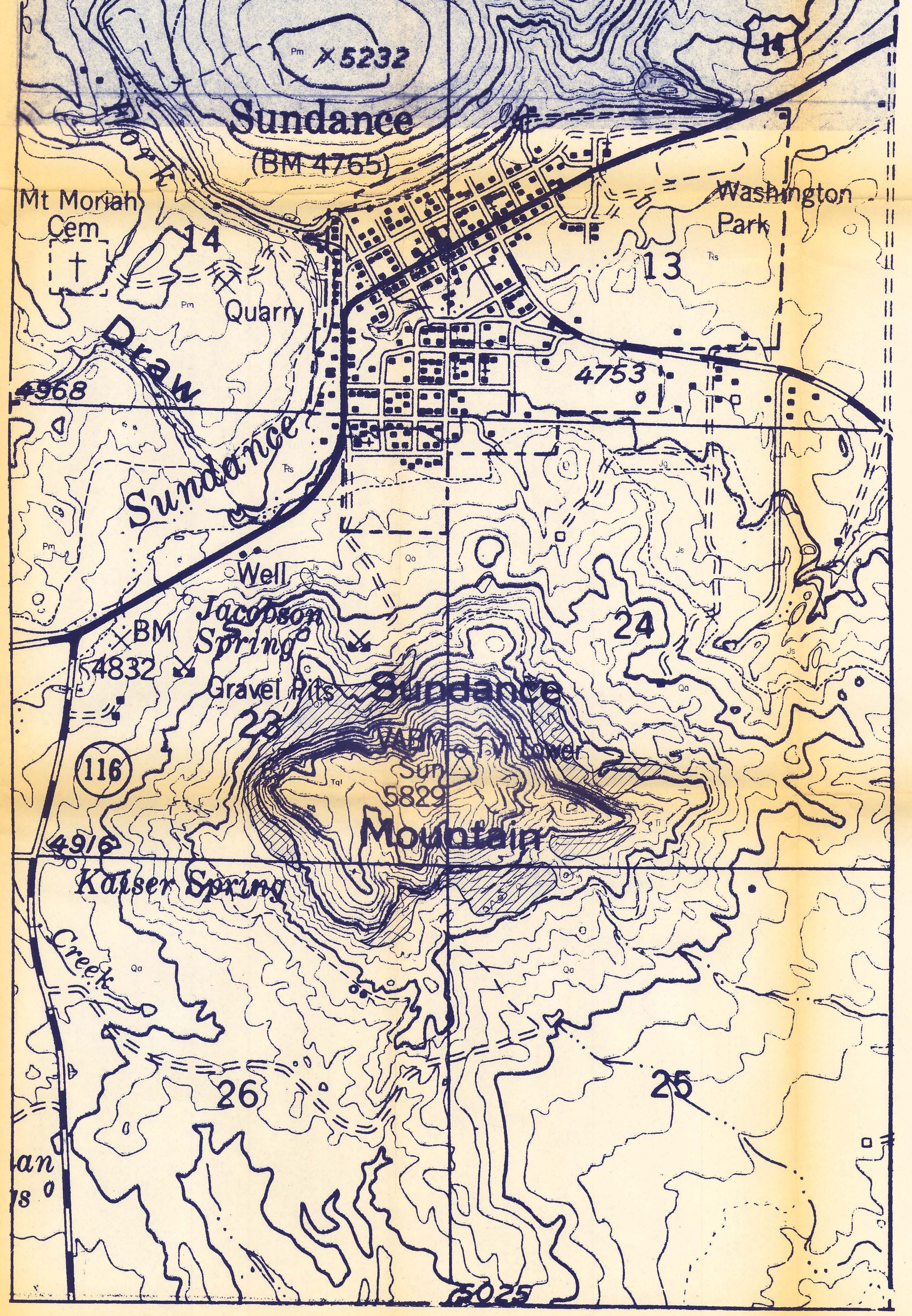
scale in metres

contour interval of 40 feet



GEOLOGIC MAP OF SUNDANCE AREA, CROOK COUNTY, WYOMING

Explanation

QUATERNARY

Qa | Qt

surficial deposits

Qa, colluvium: poorly sorted sand, gravel, and clay, commonly found at the base of Sundance Mountain.

Qt, talus: angular fragments of boulder and cobble size material, too unstable to support vegital cover.

TERTIARY (?)

Tql | Tf

igneous rocks

Tql, quartz latite: light gray, aphanitic, porphyritic, ash fall and ash flow pyroclastics, volcanic breccias and massive varieties. Layers are light and dark shades of gray, usually about 1 mm thick. Breccias consist of angular clasts of quartz latite, ranging in size from 1 mm to over a metre in diameter. Tabular crystals of oligoclase usually compose less than 5% of the rock. Groundmass consists of euhedral to subhedral microlites of oligoclase in a cryptocrystalline matrix of alkali feldspar and quartz.

Tf, foyaite: brown on fresh, greenish brown on weathered surface, trachytic, porphyritic. Foliation produced by subparallel arrangement of alkali feldspar phenocrysts. Aegerine-augite, augite and biotite are mafic minerals.

JURASSIC

Js

Sundance Formation (undivided)

Js, sandstone: yellow-brown, medium to fine grained, interbedded with green arenaceous shales (probably Redwater Shale and Hullet Sandstone members).

Jg

Gypsum Springs Formation

Jg, gyprock: white to gray massive gypsum, usually occurring as slumpped, weathered blocks.

TRIASSIC

Ћs

Spearfish Formation

Ћs, siltstone: red, finely bedded with discontinuous green, shaly beds about 4 cm thick.

PERMIAN

Pm | Po

Goose Egg Formation

Pm, Minnekahta Member: limestone: lavender, finely bedded micrite with pink laminations.

Po, Opeche Member: shale: red, silty, often inferred on basis of red slopes immediately below Minnekahta limestone caprock.

PENN.

IPm

Minnelusa Formation

IPm, sandstone: white to yellow and in places red. Sand consists of saccharoidal quartz grains. In places cherty vugs are present along well developed bedding surfaces.

MISS.

Mp

Pahasapa Formation

Mp, limestone: gray, massive, fossiliferous limestone. Base of unit is an argillaceous limestone.

Contacts

contact actually located

contact, located approximately

contact, located very approximately

darker shades indicate bedrock exposures

planar features
(symbols may be combined and are joined at point of observation)

vertical — inclined (23)

flow layering in igneous bodies or sedimentary bedding

vertical — inclined (25)

foliation

vertical — inclined (74)

joint sets

Base map from Sundance Quadrangle, USGS Topographic map, 1958

by Earl F. Fashbaugh

1979

PLATE 1

Geologic Map of Sundance Mountain

Base map from Sundance Quadrangle, USGS Topographic map, 1958

Scale
1/5000
10 0 10 20 30 40
metres
contour interval 40 feet

T.N.

EXPLANATION

QUATERNARY

Qa | Qt

surficial deposits

Qa, colluvium: poorly sorted gravel, sand and clay

Qt, talus: angular cobbles and boulders of quartz latite from Sundance Mt.

TERTIARY [?]

Tv

Sundance Mountain quartz latite

Tv, quartz latite: light gray aphanitic porphyritic, ash fall and ash flow tuff, breccia and less commonly, massive flows. Tabular crystals of oligoclase typically compose 5% of the rock. Groundmass consists of euhedral to subhedral microlites of oligoclase in cryptocrystalline matrix of alkali feldspar and quartz.

JURASSIC

Js

Sundance Formation (undifferentiated)

Js, sandstone: finely laminated, light brown, fissile, medium to fine grained.

Jg

Gypsum Springs Formation

Jg, arenaceous gyprock: light gray to tan, weathered, often slumped.

TRIASSIC

₸Rs

Spearfish Formation

₸Rs, silstone: red and green, argillaceous, fissile, finely bedded.

PERMIAN

Pm

Goose Egg Formation
(Minnekahta Member)

Pm, limestone: pink to gray, fine grained, fossiliferous limestone with partings well developed parallel to bedding.

Contacts

contact, actually located

contact, located approximately

contact, located very approximately

darker shades indicate exposures

Planar Features

Symbols may be combined and are joined at point of observation. Outcrop numbers indicated by bolder face numbers.

vertical — inclined
flow layering in igneous rock or sedimentary bedding.

vertical — inclined
partings, parallel to subparallel to igneous flow layering

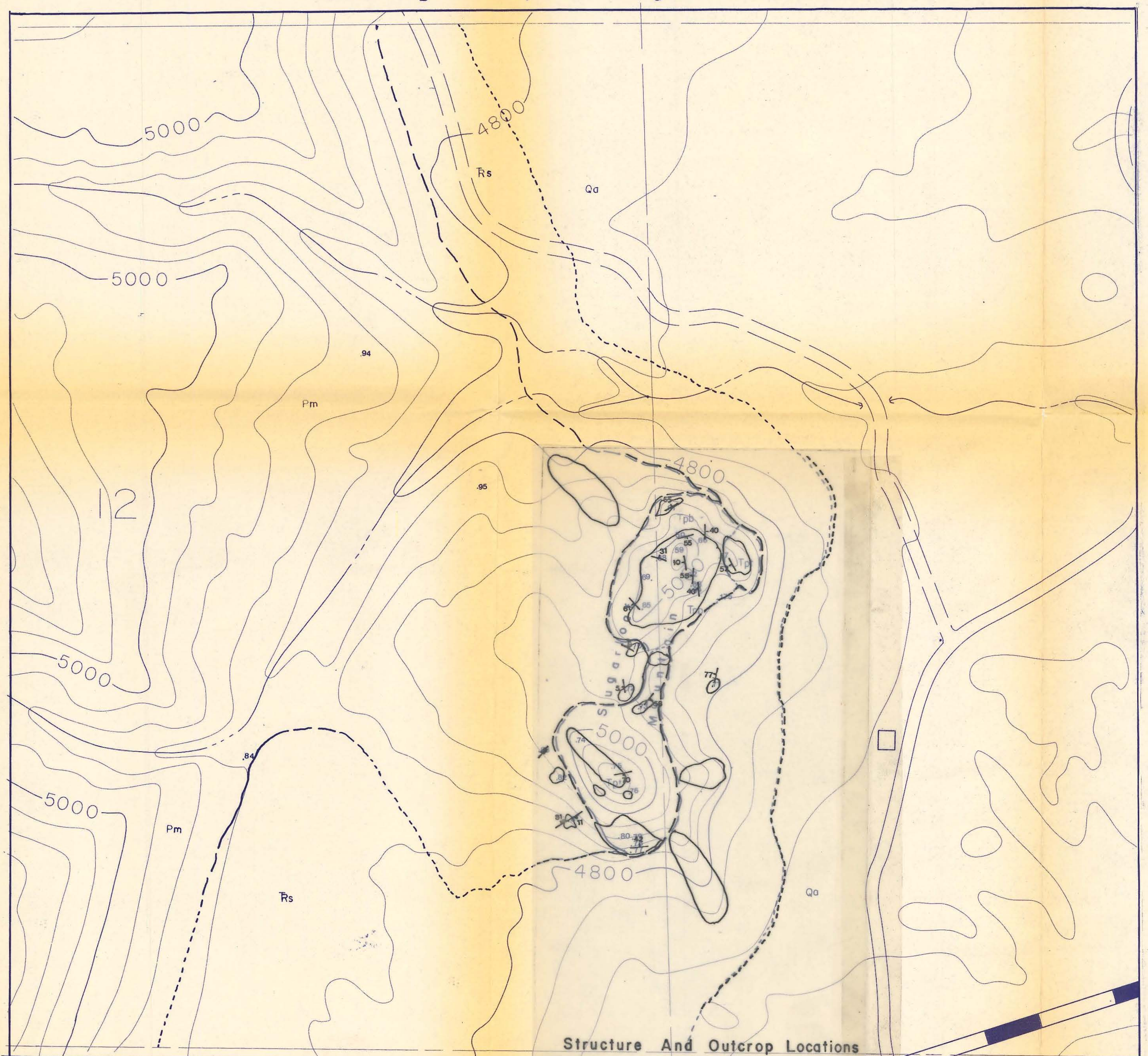
vertical — inclined
joint sets

GEOL T1979 F26 plate 2

Earl F. Fashbaugh, 1979

PLATE 2

Geologic Map of Sugarloaf Mountain Area



Base map from Sundance Quadrangle, USGS Topographic map, 1958

Scale 1:5000

100 0 100 200 300

metres

Contour interval 40 feet

T.N. 11°

EXPLANATION

QUATERNARY

Qa — surficial deposits

Qa, colluvium: poorly sorted gravel, sand, and clay.

TERTIARY (?)

Tpt — ash fall/flow tuffs

Tpb — breccia

Tpb, quartz latite: breccia: dark green to bleached white, stratified. Consists of angular clasts of quartz latite and rare, subangular to subrounded clasts of foyaite. Clasts range in size from 1.0 m to less than 0.1 mm. Individual strata are often graded with coarsest material at the base of a unit. Groundmass is cryptocrystalline.

Tpt, quartz latite: ash fall/flow tuffs: white to light gray, stratified, weakly porphyritic. Light and dark laminations about 1.0 mm thick. Tabular phenocrysts of oligoclase usually compose less than 5% of the rock. Groundmass consists of euhedral to subhedral microlites of oligoclase in cryptocrystalline matrix.

TRIASSIC

T̄Rs — Spearfish Formation

T̄Rs, siltstone: red and green, variegated, argillaceous, fissile, finely bedded. Gypsumiferous, slumped blocks on east side of Sugarloaf Mountain.

PERMIAN

Pm — Goose Egg Formation (Minnekahta Member)

Pm, limestone: pink to gray, laminated, fine grained micrite with partings well developed parallel to bedding.

Contacts

- contact, actually located
- contact, located approximately
- contact, located very approximately
- darker shades indicate bedrock exposures

Planar Features (Symbols may be combined)

- 23 sedimentary bedding or pyroclastic layering
- 75 joint set
- 73. outcrop number

by
Earl F. Fashbaugh
1979

PLATE 3

Geologic Map of Southeastern Bear Lodge Mountains

Scale
1/5000
10 0 10 20 30 40
metres
contour interval 40 feet

T.N.

E x p l a n a t i o n

Tf

Igneous intrusive

Tf, foyaite: light brown on fresh, dark green on weathered surface, trachytic, porphyritic, and foliated due to subparallel arrangement of tabular phenocrysts of alkali feldspar. Feldspathoid is analcime. Mafic minerals include augite, aegerine-augite and minor biotite.

TERTIARY (?)

Pm Po

Goose Egg Formation

Pm, Minnekahta Member: limestone: lavender, finely bedded micrite with pink laminations.

Po, Opeche Member: shale: red, silty, often inferred on basis of red colluvium at base of Minnekahta caprock.

PERMIAN

IPm

Minnelusa Formation

IPm, sandstone: white to light yellow, fine to medium grained, saccharoidal, quartzose. Chert filled vugs parallel to bedding planes.

PENN.

Mp

Pahasapa Formation

Mp, limestone: gray, massive, in places fossiliferous micrite. Base of unit is shaly.

MISS.

Contacts

contact, actually located

contact, located approximately

contact, located very approximately

darker shades indicate bedrock exposures

Planar Features (Symbols may be combined with outcrop number at point of observation)

23 sedimentary bedding or igneous foliation

45 igneous foliation with mineral lineation

76 joint set

38 Outcrop numbers indicated by bold face lettering

By: Earl F. Fashbaugh
1979

PLATE 4