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Contents

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Geology of the Southern Part of the Little Drum Mountains, Utah*

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ABSTRACT.—The Little Drum Mountains are a northwest-trending range characteristic of the Basin and Range physiographic province and consists of sequences of intermediate lava flows, breccias, ash-flow tuffs, and lahars emplaced during late Eocene-early Oligocene time. Erosion of these volcanic rocks preceded emplacement of ash-flow tuffs of the Oligocene Needles Range Formation which partially filled many drainages and low areas on the western flanks of the range. This entire volcanic sequence has undergone subsequent tilting to the west and extensive erosion.

Tentative correlation is made between one of the older ash-flow tuffs in the Little Drum Mountains and a similar unit at Chicken Creek Reservoir southwest of Levan and the lower tuff in Leamington Canyon west of Nephi.

Lahars are the most widespread and voluminous units exposed in the volcanic sequence. It is likely that they were emplaced as fluid suspensions resulting from water-saturated avalanches and eruptive material entering streams.

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*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, April 1973. Myron G. Best, thesis chairman.

INTRODUCTION

The Cenozoic volcanic history of the eastern Great Basin can be divided into two major periods. Radiometric age data (McKee, 1971) indicate that the initial period of igneous activity began approximately 35 to 40 million years ago and continued for about 20 million years. It was characterized by voluminous eruptions of calc-alkaline volcanic rocks. After a hiatus of a few million years, a second period of volcanic activity began about 16 million years ago and has continued until the present. This later period is dominated by basalts and minor rhyolitic rocks.

The Little Drum Mountains are a northwest-trending range characteristic of the Basin and Range physiographic province. The range is composed of volcanic rocks of the early stages of Great Basin volcanism and represents some of the oldest Cenozoic volcanic rocks exposed in Utah. The rocks in the range are of intermediate composition and consist of sequences of interbedded lava flows, breccias, ash-flow tuffs, and lahars erupted from a composite volcano in the northern portion of the range (Leedom, 1974). The entire volcanic sequence has undergone subsequent tilting to the west and extensive erosion.

The objectives of this study are to produce a geologic map of the southern half of the range, present petrographic and stratigraphic data on the individual rock units, and, as far as possible, determine their origin and the geographic conditions at the time of their deposition.

Location

This study is concerned with a 35-square-mile area in the southern portion of the Little Drum Mountains characterized by prominent eastward-facing vertical escarpments of interbedded ash-flow tuffs and lahars. The area is located approximately 30 miles northwest of Delta, Utah, and is accessible by improved dirt roads from Delta (Text-fig. 1).

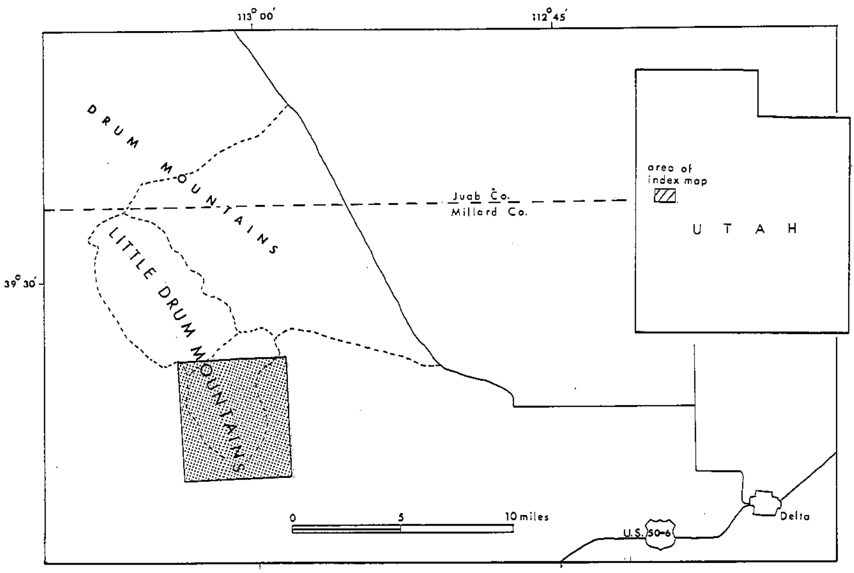
Previous Work

Although the stratigraphy of middle Tertiary ash-flow tuffs of southwestern Utah and eastern Nevada has been studied by Mackin (1960) and Cook (1960, 1965), similar rocks in west-central Utah have received scant attention from either a stratigraphic or petrologic standpoint.

The geology of the Little Drum Mountains is shown in reconnaissance fashion on the Geologic Map of Utah at a scale of 1:250,000. Mackin (1963) tentatively correlated two ash-flow units in the southern Little Drum Mountains with the lower two units of the Needles Range Formation. Staatz and Osterwald (1959) and Staatz and Carr (1964) described extensive volcanic sequences in the Thomas and Dugway Ranges, and compositionally similar units may occur in the northern portion of the Little Drum Mountains (Leedom, pers. comm., 1973); however, according to Staatz and Carr (1964, p. 117) volcanic activity probably began in the Thomas and Dugway Ranges during early Miocene time, indicating a considerable lapse of time between emplacement of volcanic rocks exposed in the southern Little Drum Mountains and the beginning of volcanic activity in the Thomas and Dugway Ranges.

Method of Study

Data collected from field mapping were recorded on 1:20,000 aerial photographs and later transferred to U.S. Geological Survey preliminary 7½-minute topographic quadrangles.



TEXT-FIGURE 1.—Index map showing location of study area in the Little Drum Mountains, Utah.

Petrographic study of representative thin sections from each lithologic unit was supplemented by chemical analyses of several of the rock units utilizing a Perkin-Elmer model 303 atomic absorption spectrophotometer (see Appendix).

Acknowledgments

The writer would like to acknowledge the assistance of M. G. Best, who provided advice and suggestions throughout this study; L. F. Hintze, who read the manuscript and offered advice and critical comments; and Steve Leedom, who shared data and ideas obtained during concurrent study in the northern part of the Little Drum Mountains. Appreciation is expressed to my wife, JoLynne, who served as both secretary and field assistant and offered frequent encouragement.

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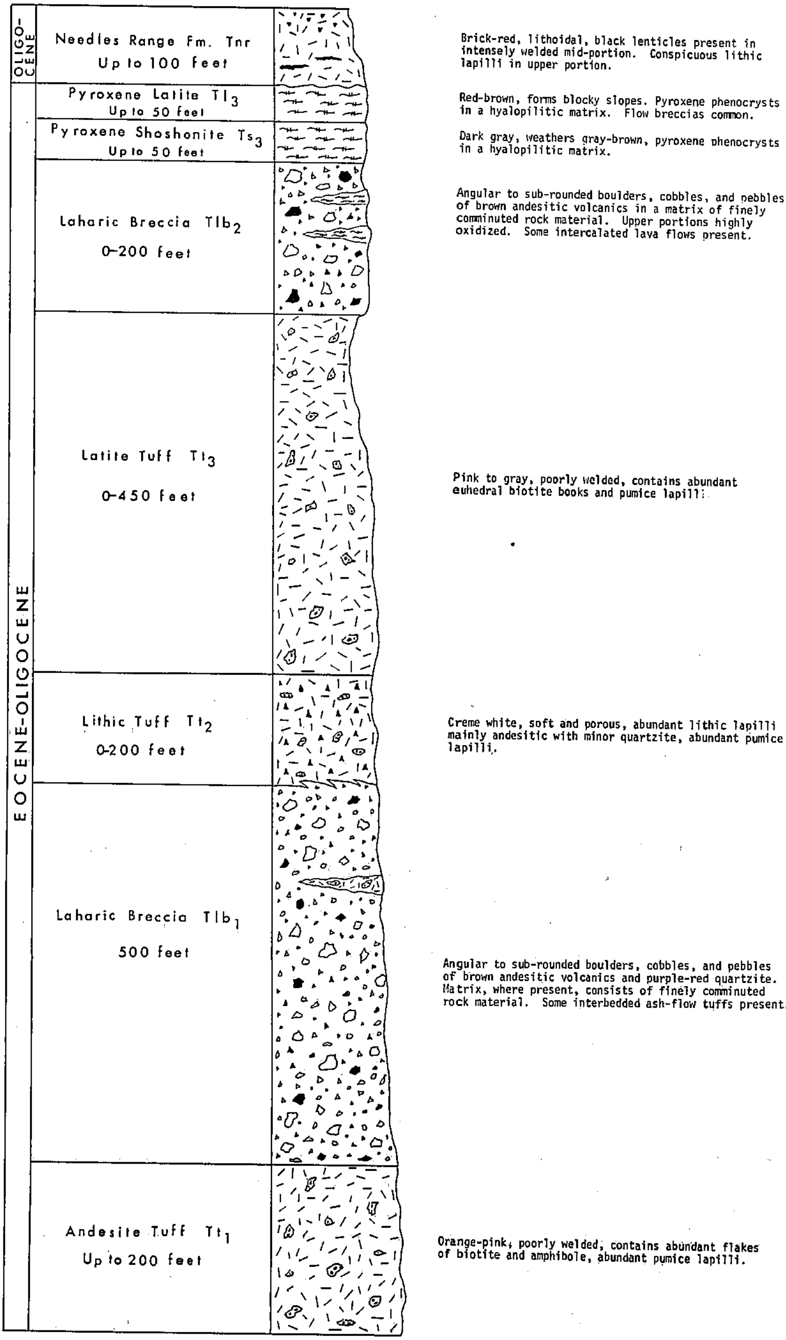
LITTLE DRUM VOLCANIC CENTER

The Little Drum Mountains represent a deeply eroded stratovolcano complex comprised of alternating lava flows, flow breccias, ash-flow tuffs, and laharic breccias. Leedom (1974) demonstrated that the lavas and probably the laharic breccias originated in a vent complex in the northern portion of the range. The source of the ash-flow tuffs is uncertain.

The lahars were considerably more mobile than the associated lava flows and were able to travel greater distances from the eruptive center; consequently, the southern portion of the range consists predominantly of lahars and ash-flow tuffs with only minor lavas (Text-fig. 2). Ash-flow tuffs form prominent es-



TEXT-FIGURE 2.—Stratigraphic section, southern part of the Little Drum Mountains.

carpments along the eastern edge of the range but are covered by laharic material elsewhere. The lahars are the most widespread units within the study area and account for large volumes of volcanic material. They commonly contain interbedded lava flows and tuffs and represent a number of separate depositional events. Lava flows are younger than the ash-flow tuffs and lahars and are restricted mainly to the northern portion of the study area. A much younger ash-flow tuff of the Needles Range Formation is not related to the Little Drum Mountain volcanism and is likely a product of volcanic activity to the southwest.

Older Ash-Flow Tuffs

Andesite tuff (Tt_1).—The oldest volcanic unit exposed in the Little Drum Mountains is a crystal-vitric andesite tuff (Tt_1). Its maximum thickness is about 200 feet, and it is well exposed for approximately 4 miles along the southeastern flank of the range. The tuff is typically exposed in steep to rounded cliffs that commonly attain heights of 100 feet. These orange pink cliffs form a prominent escarpment that rises abruptly from the valley floor and is visible for several miles. The tuff is overlain by a laharic breccia, and its lower contact is covered by alluvium (Pl. 1, fig. 1).

Megascopically the andesite tuff (Tt_1) is moderately lithoidal, orange pink in color, and contains scattered small phenocrysts of biotite and amphibole. Large euhedral biotite books, so conspicuous in other ash-flow units in the sequence, are not present. Welding is not apparent, and the tuff is generally rather soft and porous. This soft porous nature appears to have provided a favorable environment for deposition of secondary cryptocrystalline quartz present locally. Small angular felsitic lithic fragments are common, although their maximum size rarely exceeds 2 cm. White- to cream-colored pumice fragments up to 4 cm long are also common. Most of the pumice fragments contain crystals of biotite and amphibole, and some minor flattening of the pumice fragments is observable.

In thin section the andesite tuff (Tt_1) contains about 40 percent phenocrysts and up to 3 percent lithic fragments enclosed in a matrix of brown gray glass shards and pumice fragments. Most of the pumice fragments are slightly flattened, and some molding of pumice and glass shards around phenocrysts is observable. Devitrification has produced axiolitic structure in many of the pumice fragments. The modal composition of this unit determined from two thin sections is as follows:

	Percentages
plagioclase	34
biotite	3
amphibole	2
pyroxene	1
oxides	3
lithic fragments	3
matrix	54

The plagioclase is moderately zoned andesine, and many crystals contain small blebs of yellow brown glass. Both the biotite and the amphibole are dark red brown and are relatively undeformed, although a few are bent. The pyroxene is hypersthene (En_{75}), badly decomposed and frequently enclosed by oxide rims. The lithic fragments are invariably andesitic.

Measurement of the natural remnant magnetism of this unit with a portable field magnetometer reveals normal polarity.

Vitric-lithic tuff (Tt_2).—A younger vitric-lithic tuff (Tt_2) is separated from the andesite tuff (Tt_1) by a sequence of laharic units. This younger tuff varies in thickness from 0 to 200 feet and is well exposed in the south-central portion of the range. It is exposed in low-lying hills, with vertical exposures restricted to those areas where the tuff has been dissected by recent stream erosion. The tuff is locally interbedded with the lahar which underlies it, and it is overlain by an extensive ash-flow tuff; the contact between these two tuffs is relatively sharp, although it is obscured locally by alluvial material.

The vitric-lithic tuff (Tt_2) is cream white and so soft and porous that large pieces crumble when touched. Angular andesitic lithic fragments are abundant (Pl. 1, fig. 2), with some brown andesite boulders up to 1 foot in diameter occurring locally; however, most fragments are fewer than 4 cm in diameter. Small, rounded to subrounded purple quartzite pebbles are also locally present. Large (up to 4 cm), white, chalky, unflattened pumice fragments are abundant. The almost complete absence of visible phenocrysts is distinctive and serves as a useful criterion for distinguishing this vitric-lithic tuff from the younger crystal-rich tuff that overlies it.

In thin section, the vitric-lithic tuff (Tt_2) contains about 5 percent phenocrysts and 20 percent lithic fragments in a semiopaque mixture of very fine ash and comminuted rock material. Pumice fragments are unflattened, and some contain plagioclase phenocrysts. The modal composition of this unit as determined from two thin sections is as follows:

	Percentages
plagioclase	2
quartz	trace
pyroxene	1
oxides	1
lithic fragments	21
matrix	75

The plagioclase is moderately zoned andesine, and the pyroxene is augite. The lithic fragments are predominantly pyroxene or hornblende andesite; rounded quartzite fragments are less common.

The magnetic polarity of this unit is also normal.

Latite tuff (Tt_3).—The vitric-lithic tuff (Tt_2) is overlain by a crystal-vitric latite tuff (Tt_3) that varies in thickness from 0 to 450 feet. It is well ex-

EXPLANATION OF PLATE 1

FIELD VIEWS OF TUFFS, BRECCIAS, AND NEEDLES RANGE FORMATION

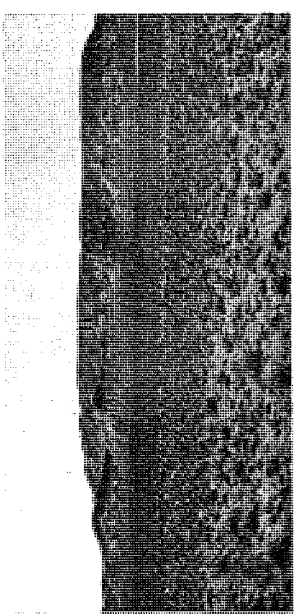
FIG. 1.—Eastward-facing escarpment, showing andesite tuff (Tt_1) overlain by laharic breccia (Tlb_1).

FIG. 2.—Vitric-lithic tuff (Tt_2): note abundant angular lithic fragments and pumice lapilli.

FIG. 3.—Latite tuff (Tt_3) center, with vitric-lithic tuff (Tt_2) below and laharic breccia (Tlb_2) above.

FIG. 4.—Columnar jointing in Needles Range Formation.

PLATE 1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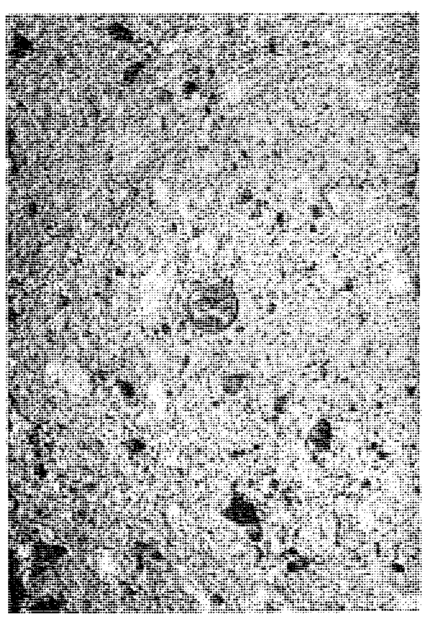
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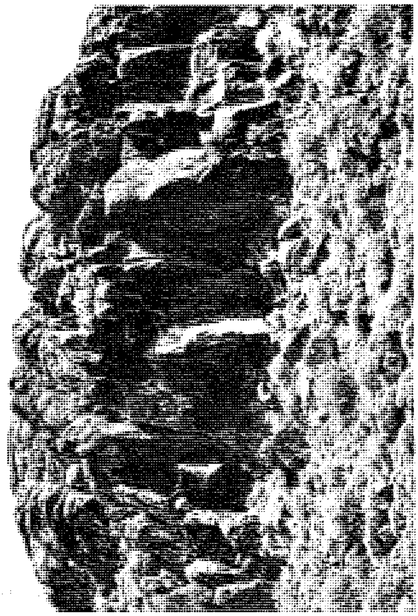
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posed for approximately 5 miles along strike from the central portion to the southern tip of the range in steep to rounded cliffs up to 250 feet high, on steep slopes, or in rounded low-lying hills. It is overlain by a sequence of laharic units. The contact is commonly obscured by weathered material from the lahars; but where exposed, it appears to be sharp (Pl. 1, fig. 3).

The tuff (Tt_3) is moderately lithoidal and light pink to light gray in color. Euhedral biotite books as large as 4 mm are common. Smaller grains of biotite, amphibole, and plagioclase are scattered throughout the rock. Angular andesitic lithic fragments less than 1 cm long occur throughout the unit, and larger brown andesite boulders up to 1 foot in diameter are locally present. White to pink unflattened pumice fragments as large as 10 cm are abundant, and most contain euhedral biotite and smaller biotite and amphibole grains. The tuff is unwelded and rather soft and is easily broken. Veins of secondary calcite occur locally.

In thin section, 30-40 percent phenocrysts and about 1 percent lithic fragments are found in a matrix of dark gray shards and pumice fragments. Pumice fragments are relatively undeformed and contain crystals of plagioclase; biotite; amphibole; oxides; and, locally, pyroxene. The modal composition of this unit as determined from three thin sections is as follows:

	Percentages
plagioclase	24
quartz	2
biotite	5
amphibole	2
pyroxene	1
oxides	1
lithic fragments	trace
matrix	65

The plagioclase is moderately zoned andesine. The biotite is dark brown to dark red, and most is bent or strained; some contain oxide inclusions. The amphibole is dark brown and usually is corroded. The pyroxene is hypersthene (En_{65}) and in some instances is partially mantled by reaction rims of amphibole.

Measurement of the natural remnant magnetism of this unit with a portable field magnetometer reveals normal polarity.

Correlation of the upper Little Drum tuff (Tt_3) with similar tuffs from Chicken Creek Reservoir southwest of Levan and Leamington Canyon west of Nephi is only tentative, owing to insufficient data; however, the possibility for conclusive correlation appears encouraging and merits further study. Mackin (1960, 1963) discussed the tuff at Chicken Creek Reservoir and tentatively correlated it with the Needles Range Formation. He also mentions a "dacitic ignimbrite" in Leamington Canyon that is similar to the Chicken Creek tuff, and he suggests that the two units are probably correlative (Mackin, 1963, p. 76); however, radiometric data (Table 1) rule out correlation of either of these tuffs with the Needles Range Formation, which is dated at 29.7 ± 0.9 m.y. (Armstrong, 1970). According to Algate (pers. comm., 1973), there are two distinctive ash-flow tuffs in Leamington Canyon. The lower (probably Mackin's "dacitic ignimbrite") of these two tuffs is latitic and is very similar in appearance to the latite tuff (Tt_3) in the Little Drum Mountains. This lower tuff in Leamington Canyon is overlain by a gray brown, quartz-rich tuff that contains large (up to 10 cm) discoids of black glass.

The latite tuff (Tt_3) in the Little Drum Mountains, the tuff at Chicken Creek Reservoir, and the lower tuff in Leamington Canyon are pink and moderately lithoidal and contain euhedral biotite books as large as 2 mm. Smaller grains of biotite, amphibole, and plagioclase are scattered throughout. Angular felsitic lithic fragments and pink and white pumice fragments that contain crystals of biotite are abundant. Petrographically, all are characterized by the absence of sanidine, by minor amounts of quartz, and by slightly greater amounts of biotite than of amphibole (Table 1).

The tuff at Chicken Creek Reservoir has been age dated at 35.8 ± 0.7 m.y. (Armstrong, 1970, p. 210), and the quartz-rich upper tuff in Leamington Canyon has been dated at 33.8 ± 0.7 m.y. (Armstrong, pers. comm., 1973). Lavas younger than the latite tuff (Tt_3) in the Little Drum Mountains have been dated at 37 ± 0.4 m.y. (Leedom, 1974). Measurement of natural remnant magnetism with a portable field magnetometer shows that all three tuffs possess normal polarity. Tentative correlation of the Little Drum Mountain tuff (Tt_3), the tuff at Chicken Creek Reservoir, and the lower tuff in Leamington Canyon is made on the basis of petrographic, radiometric, and paleomagnetic polarity data; however, conclusive correlation must await exact age dates for the Little Drum Mountain and Leamington Canyon units and further paleomagnetic data.

Younger Ash-Flow Tuff

Needles Range Formation.—The youngest unit exposed in the southern part of the Little Drum Mountains is a crystal-rich latite tuff (Tnr) that likely correlates with the Needles Range Formation of southwestern Utah and eastern Nevada. It varies in thickness up to 100 feet and is moderately well exposed

TABLE 1
CORRELATION OF (Tt_3) IN THE LITTLE DRUM MOUNTAINS WITH OTHER TUFFS IN UTAH*

Unit and Location	Petrography									Age	Magnetic Polarity
	plagioclase	sanidine	quartz	biotite	amphibole	pyroxene	oxides	matrix	no. of samples		
upper tuff(Tt_3) Little Drum Mountains	24	0	2	5	2	1	1	65	3	older than 37 ± 0.4 m.y.[3]	Normal
lower tuff Leamington Canyon	28	0	1	8	4	tr	1	56	2	older than 33.8 ± 0.7 m.y.[2]	Normal
tuff Chicken Creek Reservoir	22	0	1	4	tr	0	2	71	2	35.8 ± 0.7 m.y.[1]	Normal

*Compositions for all samples determined by thin-section modal analysis (1,000 points/sample).
[1]Armstrong (1970)
[2]R. L. Armstrong (pers. comm., 1973)
[3]Leedom (1974)

for a distance of 6 miles along the western flanks of the range. The tuff typically occurs in relatively flat, low-lying hills from the southwestern tip to the central portion of the range and has an outcrop area of approximately 2 square miles. The tuff unconformably overlies one of the older laharic units.

Generally the unit is brick red, but it is gray to black in areas of intense welding. The tuff is lithoidal, with abundant euhedral biotite books up to 4 mm in diameter. Amphibole phenocrysts of similar dimensions are also locally present. Smaller grains of biotite, amphibole, and plagioclase are scattered throughout the rock, and angular purple red lithic fragments, mostly less than 1 cm in diameter are common. Larger lithic fragments up to 6 cm in diameter containing abundant plagioclase phenocrysts are also present. The tuff is lightly to highly welded; and, where exposures permit, a sequence of moderately welded lower portion, highly welded midportion, and lightly welded upper portion can be distinguished. A distinct planar nature is imparted to highly welded portions of the tuff by black glassy lenticles of flattened pumice. A less striking foliation is present in the lightly welded portions of the unit as a result of parallel alignment of biotite flakes. Moderately developed columnar jointing is present locally (Pl. 1, fig. 4).

In thin section this unit contains up to 60 percent phenocrysts and 3 percent lithic fragments enclosed in a matrix of dark brown glass shards and flattened pumice fragments. Molding of shards and pumice fragments around the phenocrysts is common. The modal composition of this unit as determined from five thin sections is as follows:

	Percentages
plagioclase	31
quartz	3
biotite	7
amphibole	9
pyroxene	1
oxides	3
lithic fragments	3
matrix	45

The plagioclase is moderately zoned andesine, and some crystals are badly broken. The biotite is dark brown to dark red, and most grains are either bent or broken. The amphibole ranges in color from dark green to dark red, and some crystals are enclosed by oxide rims. Most of the pyroxene is euhedral to subhedral and is relatively fresh. Evidence of varying degrees of welding is present throughout the unit.

The tuff has reverse magnetic polarity.

Petrographically this unit is similar to the Wah Wah Springs Tuff member of the Needles Range Formation of southwestern Utah and eastern Nevada (Table 2.) Armstrong (1970, p. 223) states that the best age date for the Needles Range Formation is 29.7 $\pm$ 0.9 m.y. All that can be said about the absolute age of the Little Drum Mountain exposure is that it is younger than the 37-million-year-old volcanic sequence which it unconformably overlies. Additional data are necessary for conclusive correlation; however, the petrography and age relations are compatible, and the correlation of the Little Drum Mountain unit with the Needles Range Formation appears possible.

TABLE 2
COMPARISON OF NEEDLES RANGE MEMBERS AND THE NEEDLES RANGE (?) UNIT IN THE LITTLE DRUM MOUNTAINS*

Location and Unit	Petrography									Age	Magnetic Polarity
	plagioclase	sanidine	quartz	biotite	amphibole	pyroxene	oxides	matrix	no. of samples		
*Little Drum Mountains Tnr	31	0	3	7	9	1	3	48	5	younger than 37 ± 0.4 m.y.[4]	Normal
Needle Range[3] $Tvnr_2$ (Wah Wah Springs Tuff Member)	24	1	4	5	6	1	1	58	11	**27.7 ± 0.6; 29.2 ± 0.6 m.y.[1]	Reverse
$Tvnr_1$	23	tr	4	7	4	1	1	61	11	**29.6 ± 0.6; 30.7 ± 0.6 m.y.[1]	Normal
Needle Range[2] Wah Wah Springs Tuff Member	25	0	3	4	9	tr	1	58	4		Reverse
Cottonwood Wash Tuff Member	24	0	5	6	6	tr	1	59	4		Normal

*Compositions for all samples determined by thin-section modal analysis (1,000 points/sample).
**Age dates from Armstrong made compatible with stratigraphic relations of Best et al. (1973).
[1]Armstrong (1970)
[2]Best et al. (1973)
[3]Conrad (1969)
[4]Leedom (1974)

Lahars

Introduction.—The term *lahar* is used by Macdonald (1972) to describe a mudflow of any type and by Mullineaux and Crandell (1962) to designate any unsorted or poorly sorted deposit of volcanic debris that moved and was deposited as a mass and that owed its mobility to water. According to Fisher (1960a), laharic breccias are emplaced by mudflows carrying, dispersing, and depositing coarse- and fine-grained volcanic fragments and/or admixed non-volcanic material. Volcaniclastic debris or nonvolcanic material may become saturated with water and move as lahars. Materials brecciated underground and subsequently extruded as breccia flows, as well as pyroclastic flows of all kinds, may become mixed with surface water and grade imperceptibly into hot lahars, and finally into cold lahars. Since the viscosity of lahars may vary, all gradations exist between laharic breccias and water-laid volcanic breccias and conglomerates (Parsons, 1969).

According to Macdonald (1972), the most common cause of lahars during the last century has been heavy rains on unconsolidated materials on the flanks of volcanoes; dry avalanches that become mixed with surface water and move as lahars are also common. The unconsolidated materials in a lahar may be either recently ejected or older material, hot or cold, fresh or weathered, depending on local conditions. Movement of this water-saturated material may be initiated by volcanic eruptions, by earthquakes, or by the increased weight of the water-soaked debris. Many lahars are directly related to eruption of volcanic material. Ash-flows or block-and-ash flows may enter streams and be transformed into lahars (Taylor, 1958). The entrance of autobrecciated lava flows into streams (Curtis, 1954) or brecciation and subsequent mixing with slush and meltwater of lava flows extruded onto ice or snow (Fiske, Hopson, and Waters, 1963) may also produce lahars. Lydon (1968) believes that lahars of the Tuscan Formation originated in part by the extrusion of material already brecciated in volcanic conduits and dikes before reaching the ground surface, and that much of the water necessary for the saturation and transportation of this debris was derived from magmatic and meteoric sources (see also Anderson, 1933).

Lahars may travel great distances: 5 to 10 miles is common, and some may travel more than 100 miles (Macdonald, 1972). The aggregate volume of laharic complexes may be very large; Lydon (1968) believes that the Tuscan Formation of northern California, which is composed largely of laharic breccias, once covered an area of about 2,000 square miles and had a total volume of 300 cubic miles. The Mehrten Formation in the Sierra Nevada of California, composed predominantly of laharic breccias, once covered an area of approximately 12,000 square miles and had a volume of 2,000 cubic miles (Curtis, 1954).

Deposits produced by lahars are relatively poorly bedded and sorted but commonly have some graded bedding. Thicknesses of individual lahars are usually measured in units of feet or tens of feet, but some exceed 100 feet (Crandell and Waldron, 1956). Angular to subrounded fragments of all sorts are intermixed in a chaotic manner, with blocks weighing many tons intimately mixed with the finest dust-sized particles. Some lahars contain boulders whose diameter is as much as 1,000 times the average diameter of fragments in the enclosing matrix (Mullineaux and Crandell, 1962). The relative proportions and types of fragments present in a lahar are determined by its source area, distance of travel, and mode of origin; however, aphanitic volcanic fragments are probably most common. Materials from stream gravels or other epiclastic debris may also be present (Schmincke, 1967). The proportion of matrix present is variable; it usually consists primarily of fine-grained angular to rounded mineral grains and lithic fragments that are similar in composition to the larger fragments (Parsons, 1969).

In strato volcanic complexes it is possible to distinguish a vent facies from an alluvial facies. The vent facies is a sequence of rocks produced directly by volcanic activity, although the emplacement may have been aided in part by water (Fisher, 1966a). Lava flows and pyroclastic rocks are the most common types of rocks present. The alluvial facies consists of those rocks formed by erosion and weathering of volcanic debris. They are similar in composition to the vent-facies materials, and are properly classified as sedimentary rocks. The rocks of the vent facies grade laterally away from the vent areas into the clastic rocks of the alluvial facies, and interfingering of the two is common. Distinguishing the vent facies from the alluvial facies is often a major problem in studying and mapping volcanic rocks. Laharic breccias may occur in both the vent and the alluvial facies, depending on their mode of origin. They are usually interbedded with pyroclastic rocks or lava flows in the vent facies and with volcanic sandstones and conglomerates, air-fall tuffs, or lake beds in the alluvial facies (Parsons, 1969).

Lahars in the Little Drum Mountains belong to the vent facies and are by far the most widespread and voluminous units exposed in the volcanic sequence. Two major laharic units separated by ash-flow tuff consist of thick sequences of individual laharic breccias intercalated with lava flows and ash-flow tuffs. Physically, the Little Drum Mountain lahars conform rather closely to the general characteristics of lahars described above; however, considerable difficulty is encountered in attempting to determine the exact nature of their origin and mode of emplacement. Distinction among types of lahars is everywhere a major problem, especially in older deposits.

Older laharic breccia (Tlb_1).—The older of the two laharic units (Tlb_1) exposed within the southern Little Drum Mountains is an extensive sequence of laharic breccias and some interbedded ash-flow tuffs. Its maximum exposed thickness is about 500 feet. Exposures in steep slopes or low rounded hills (Pl. 2, fig. 1) extend for approximately 4.5 miles along the southeastern flanks of the range in an outcrop area of about 7 square miles. This unit appears to conformably overlie the andesite tuff (Tt_1) and is in turn overlain by the vitric-lithic tuff (Tt_2) with which it is locally interbedded. The exact location of either the lower or the upper contact is difficult to determine, owing to the obscuring effect of weathered materials from the lahar.

The older laharic breccia (Tlb_1) is nonsorted and consists primarily of angular to subrounded fragments up to 6 feet in diameter, although the predominant size range is 10 to 15 centimeters. Proportions of rock types constituting the clasts are variable; however, brown aphyric andesites are always most abundant with subordinate amounts of quartzite, metaconglomerate, porphyritic andesite, and vesicular andesite. The sandy matrix is rarely exposed except in recent stream gullies. Where present, it comprises 50 to 70 percent of the breccia (Pl. 2, fig. 2).

Microscopically, the matrix consists of up to 40 percent mineral fragments and 20 percent lithic fragments enclosed in a very fine grained, dark gray, semiopaque groundmass of comminuted rock material and mineral fragments. Glass shards and partially devitrified fragments that may be relict pumice are locally present. There is considerable variation in the composition of the mineral fragments; however, plagioclase and pyroxene are always present with amphibole, biotite, quartz, and sanidine present in varying amounts. The mineral grains commonly are angular and fresh, although they may be decomposed near the upper portions of the individual laharic units. The modal composition of the sandy matrix of one lahar exposed in a recent stream drainage as determined from two thin sections is as follows:

	Percentages
plagioclase	30
sanidine	trace
quartz	2
biotite	3
amphibole	1
pyroxene	3
oxides	2
lithic fragments	20
groundmass	38

The plagioclase is moderately zoned andesine, and both hypersthene (En_{70}) and augite are present. The lithic fragments present in the matrix are angular to subrounded. Pyroxene andesite is by far the most abundant, although hornblende andesite and very fine grained felsitic fragments are common. Most of the phenocrysts in the lithic fragments are decomposed.

Younger laharic breccia (Tlb_2)—The younger laharic unit (Tlb_2) is a sequence of lahars and interbedded andesitic lava flows and is the most widespread unit exposed in the southern Little Drum Mountains. It varies in thickness from 0 to 200 feet and is exposed throughout the south-central portion of the range with an outcrop area of approximately eleven square miles. This unit is commonly exposed in steep cliffs that form part of the prominent escarpment along the eastern side of the range; it also comprises the major portion of the dissected dip slope which stretches westward from this escarpment. This unit overlies the latite tuff (Tt_3), and the contact is very sharp where exposed; however, it is frequently covered by clasts weathered from the lahar. The laharic breccia (Tlb_2) is capped by a pyroxene latite (Tl_3) flow in the extreme northwest portion of the mapped area.

The lahars in this unit are nonsorted and consist primarily of angular to subrounded fragments up to 7 feet in diameter, although the predominant size range is 5 to 25 cm. Brown aphyric andesite is the most abundant rock type, with lesser amounts of purple to gray pyroxene- and hornblende-andesite (Pl. 2, fig. 3). Minor amounts of vesicular andesite are also present. Although poorly sorted, larger clasts have a slight tendency to be concentrated nearer the lower portions of the individual laharic units, creating a crude stratification. The matrix and clasts in the upper portions of some lahars in the sequence are oxidized, imparting a distinctive red orange color to the lahar. These zones of oxidation are quite widespread and are probably related to the formation of ferric oxides by the exposure of hot laharic material to the atmosphere.

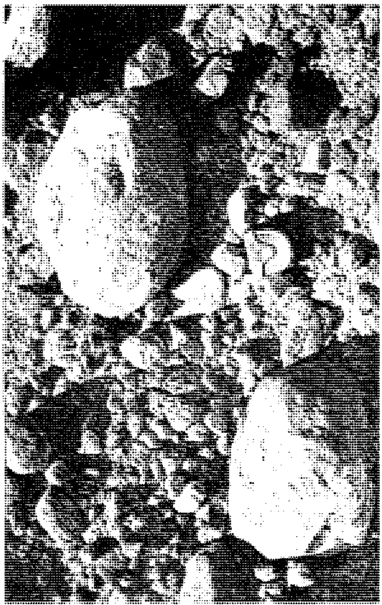
The matrix of the lahars has frequently been removed by weathering processes; but where present, it comprises approximately 75 percent of the deposits. Microscopically, the matrix consists of up to 25 percent mineral fragments and 20 percent lithic fragments enclosed in a fine-grained semiopaque groundmass of comminuted rock material, mineral fragments, clay minerals (?), and devitrified glass(?). There is relatively little variation in the types of minerals present. The composition of the matrix as determined from two thin sections is as follows:

	Percentages
plagioclase	15
sanidine	trace
amphibole	1
pyroxene	6
oxides	3

EXPLANATION OF PLATE 2
FIELD VIEWS OF LAHARIC BRECCIAS

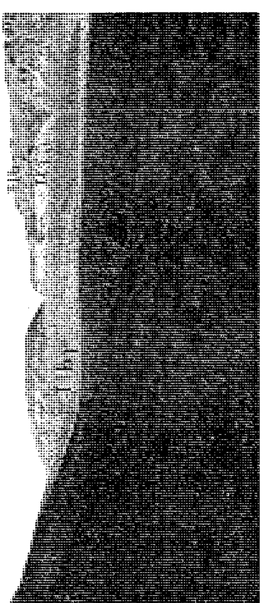
FIG. 1.—Laharic breccia (Tlb_1) exposed in low, rounded hills: note interbedded tuff. Latite tuff (Tt_3) overlain by laharic breccia (Tlb_2) in the background.
FIG. 2.—Laharic breccia (Tlb_1) showing rarely preserved sandy matrix enclosing poorly sorted fragments: note variety of types of clasts present.
FIG. 3.—Laharic breccia (Tlb_2): clasts are predominantly aphyric andesite.
FIG. 4.—Paleochannel in latite tuff (Tt_3) filled by laharic breccia (Tlb_2).

PLATE 2

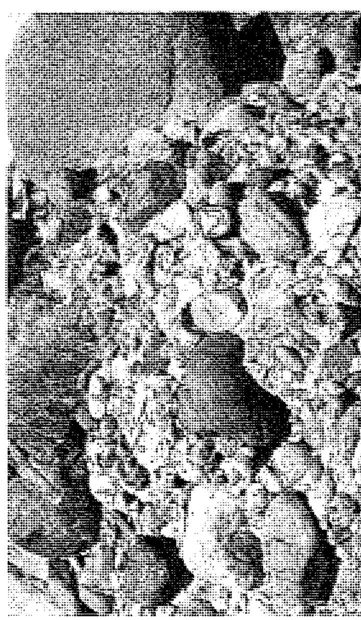


2

4



1



3

lithic fragments	19
groundmass	56

The plagioclase is moderately zoned andesine, and some crystals contain blebs of brown yellow glass. The amphibole is light to dark brown, and the pyroxene is hypersthene (En_{75}) and augite. The lithic fragments present in the matrix are angular to subrounded and are predominantly pyroxene andesite with only minor amounts of hornblende andesite.

Interpretation.—The lack of significant amounts of pumice or glass, and the heterolithologic character of the older laharic breccia (Tlb_1) suggest that it did not originate as an ash-flow, block-and-ash flow, or brecciated lava flow. The individual lahars that comprise this unit were likely deposited as viscous watery mudflows that originated presumably in high areas near the eruptive center in the northern part of the range. These mudflows could have originated as dry avalanches of unconsolidated materials that entered existing streams, or as wet avalanches resulting from saturation of pre-existing debris by torrential rains. Movement of these materials could have been triggered by new eruptions, earthquakes, or gravity; however, the occurrence of interbedded ash-flow tuffs in this unit indicates that intervening periods of eruptive activity separated periods of laharic deposition, and this volcanic activity may have been a major force responsible for their initial movement. The heterolithologic nature of the lahars also suggests that the fluid suspensions moved downhill, picking up additional volcanic debris. Since the quartzite and metaconglomerate clasts present are predominantly rounded to well-rounded, they likely represent alluvial material swept from the existing surface.

The younger laharic breccia (Tlb_2) possesses a rather monolithic character, and some of the individual lahars within the unit exhibit highly oxidized upper portions. These features suggest an elevated temperature at the time of deposition, and an eruptive mode of origin for this unit. Extruded material from vent areas in the northern part of the range may have entered existing streams or become saturated by torrential rains at the time of eruption. These viscous suspensions moved downhill from their volcanic source areas, picking up additional volcanic debris from the surface. As the lahars moved southward, their temperature decreased and they encountered an increasing variety of rock types, accounting for the fewer areas of intense oxidation and greater heterolithologic nature in the southern part of the range. The occurrence of intercalated lava flows in the sequence likely indicates proximity to the vent area. The exact nature of the extruded material that produced the lahars is uncertain; however, the absence of significant amounts of pumice or shards tends to rule out an ash-flow or block-and-ash flow origin.

Lava Flows

Pyroxene shoshonite (Ts_3).—Lava flows are restricted primarily to the northern portion of the Little Drum Mountains, and only two are of any consequence in the south. The older of these two flows, a pyroxene shoshonite (Ts_3) occurs in Oldroyd Valley (Leedom, 1974) immediately east of the Little Drum Mountains and in isolated exposures to the south. It varies in thickness, but rarely exceeds 50 feet. The stratigraphic relations of the flow are obscure; however, Leedom (1974) believes it to be interbedded with the younger laharic breccia (Tlb_2) to the north. In the south it is commonly surrounded by alluvial material, except in certain isolated exposures where it appears to overlie the andesite tuff (Tt_1).

Megascopically the flow is a dark gray aphanitic rock with pyroxene and plagioclase phenocrysts. It weathers light gray but in some areas is bright red, owing to intense oxidation. Flow breccias occur around its margins, and amygdaloidal deposits of green cryptocrystalline quartz are common in the southern portions of the flow. In thin section it contains up to 40 percent phenocrysts of about equal amounts of plagioclase and pyroxene enclosed in a hyalopilitic matrix of dark-gray glass and microlitic plagioclase (Table 3).

Pyroxene latite (Tl_3).—The younger lava flow is a pyroxene latite (Tl_3) on the west-central flanks of the range, and it is more extensive in the northern part of the range than the southern. It is normally about 50 feet thick, although thinner around its margins. This flow directly overlies the younger laharic breccia (Tlb_2) in some areas, forming a distinctive "cap" on the underlying, less resistant laharic material; it is completely surrounded by alluvial material elsewhere. This flow has been age-dated at 37 $\pm$ 0.4 m.y. (obtained by James Hoover at the U.S. Geological Survey, Menlo Park, California, and quoted in Leedom, 1974).

The flow is a dense red brown aphanitic rock containing pyroxene and amphibole phenocrysts. It weathers to a lighter brown color, and intersecting joint patterns give the flow a blocky appearance. Flow breccias are common near its outer margins and account for approximately one-half of its exposed area. Microscopically it contains about 40 percent phenocrysts of plagioclase, pyroxene, amphibole, and oxides enclosed in a hyalopilitic matrix of gray brown glass and microlitic plagioclase (Table 4).

TABLE 3
MODAL COMPOSITION OF PYROXENE SHOSHONITE (Ts_3)*

	Percent	Remarks
Plagioclase	20	Moderately zoned andesine; many crystals contain blebs of brown glass; extensively corroded.
Augite	13	Many contain oxide inclusions.
Hypersthene	6	(En_{65}); many contain oxide inclusions.
Oxides	1	
Groundmass	60	

* Composition determined by thin-section modal analysis (1,000 points).

TABLE 4
MODAL COMPOSITION OF PYROXENE LATITE (Tl_3)*

	Percent	Remarks
Plagioclase	27	Moderately zoned andesine; many crystals contain blebs of brown glass; some contain pyroxene and oxide inclusions.
Augite	2	
Hypersthene	4	(En_{78})
Amphibole	1	Light to dark brown; commonly enclosed by oxide rims and extensively corroded.
Oxides	3	
Groundmass	63	

* Composition determined by thin-section modal analysis (1,000 points).

ERUPTIVE PATTERN

The Little Drum volcanic complex, composed of intermediate lava flows, laharic breccias, and ash-flow tuffs, apparently formed on a gently undulating westward-sloping surface (Crittenden et al., 1961), mainly during late Eocene and early Oligocene time. The first records of activity are the latitic to andesitic ash-flow tuffs that filled existing valleys and are now exposed in thick sequences along the steep escarpment that forms the eastern margin of the Little Drum Mountains. These early eruptions alternated with, and were followed by, eruptions of andesitic lavas and deposition of laharic breccias. The pattern of eruption seems to have been one of rather continuous activity; however, the occurrence of channel fillings in some of the units (Pl. 2, fig. 4) indicates that there were intervening periods of quiescence of indeterminate length during which the surface was being actively eroded. Volcanic activity in the Little Drum Mountains apparently ended during early Oligocene time. Erosion of this westward-dipping sequence produced a moderately dissected mountain range, and the ash-flow tuff of the Needles Range Formation later partially filled many of the drainages and low areas on the western flanks of the range. Subsequently, this entire volcanic sequence was tilted an unknown amount to the west, presumably by Basin and Range faulting.

CONCLUSIONS

The Little Drum Mountains are comprised of lava flows, breccias, ash-flow tuffs, and lahars of intermediate composition emplaced during early Tertiary. Although Mackin (1963) tentatively correlated two ash-flow tuffs in this sequence with the lower two members of the Needles Range Formation of southwestern Utah and eastern Nevada, this study has shown that the tuffs in the Little Drum Mountains are much older than the Needles Range Formation. The much younger ash-flow tuff (Tnr?) exposed around the southwestern margins of the range probably is correlative with the Needles Range Formation.

One of the older ash-flow tuffs (Tt_3) is petrographically similar to a pre-Needles Range ash-flow tuff exposed near Chicken Creek Reservoir southwest of Levan and to an older ash-flow tuff in Leamington Canyon west of Nephi. Correlation of these three tuffs appears possible.

Lahars account for large proportions of the volcanic rocks exposed in the Little Drum Mountains. The occurrence of interbedded lava flows in these laharic units suggests that their deposition was closely associated with nearby eruptive activity. It is likely that these lahars were emplaced as fluid suspensions resulting from water-saturated avalanches and erupted materials' entering streams or being saturated by torrential rains.

APPENDIX

Chemical Analyses

Analytical Methods.—Whole-rock chemical analyses of lava flows and ash-flow tuffs in the southern Little Drum Mountains were made by atomic absorption spectrophotometry, using the method described by Brimhall and Embree (1971). Samples selected for analysis were crushed to pass 60 mesh, and 0.3333 g of this rock powder was thoroughly mixed with 1.67 g powdered anhydrous lithium metaborate ($LiBO_2$). This mixture was then fused in a graphite crucible in a muffle furnace at 1,000° C for 15 minutes and poured into a 500 ml Erlenmeyer flask containing 400 ml of cold dilute nitric acid (1:20). The contents of each flask were then stirred with a teflon-coated magnetic stirring bar for about 20 minutes until the glass resulting from the chilled fusion was dissolved to produce a clear, colorless solution. These solutions were transferred to 500 ml volumetric flasks, diluted to volume, and filtered through a fast filter paper to remove graphite flakes. These solutions were analyzed with a Perkin-Elmer model 303 atomic absorption spectrophotometer equipped with a strip-chart recorder.

Three samples, BCR-1, AGV-1, and GSP-1 (Flanagan, 1969) were prepared and analyzed with the unknown rock samples and used as standards. A fourth sample, U-3-3 (Brimhall, pers. comm., 1969), was also analyzed with

TABLE A-1
PERCENT ERROR COMPUTED FROM INTERNAL PRECISION STANDARDS

	Si	Al	Na	K	Mg	Ca	Fe	Ti
Standard Deviation	0.4549	0.0519	0.0282	0.0509	0.0264	0.0670	0.0984	0.0360
Percent(%) Error	1.61	0.64	1.28	2.20	1.65	1.46	2.39	8.07

TABLE A-2
AVERAGE CHEMICAL COMPOSITION OF LITTLE DRUM MOUNTAIN ASH-FLOW TUFFS AND LAVA FLOWS*

Map unit	Tt_3	Tnr	Ts_3	$*Ts_3$	Tl_3	$*Tl_3$
No. of samples	3	4	2		1	
SiO_2	63.4	60.6	59.9	59.08	61.6	65.10
TiO_2	0.7	1.1	0.8	0.96	0.8	0.56
Al_2O_3	14.8	15.7	14.5	15.36	15.6	15.67
Fe_2O_3	n.d.	n.d.	n.d.	n.d.	n.d.	3.47
**FeO	3.7	1.1	5.6	6.61	4.8	1.14
MnO	n.d.	n.d.	n.d.	0.11	n.d.	0.08
MgO	2.0	2.6	4.3	3.86	2.2	1.61
CaO	4.9	5.5	5.9	6.02	5.0	4.81
Na_2O	2.6	3.0	2.8	3.02	3.1	3.29
K_2O	2.9	2.7	3.1	3.19	3.0	3.44
Ignition Loss	n.d.	n.d.	n.d.	1.68	n.d.	1.49
Total	95.0	96.8	96.9	99.89	96.1	100.66

*Data from X-ray fluorescence (Leedom, 1974).
**Total Fe reported as FeO.
n.d.—no data available.

the rest of the samples for certain elements in order that all data obtained from the unknown samples were bracketed by data from known standards.

One-half of the Little Drum Mountain samples were selected at random and used to make an internal standard by thoroughly mixing together 15 g of rock powder from each sample. Five samples of this internal standard were prepared and analyzed with the samples and standards to monitor precision. The results of these analyses are shown in Table A-1, and for most of the elements the computed error is quite satisfactory.

Analyses were made on three samples from the upper ash-flow tuff (Tt_3), four samples from the Needles Range Formation (Tnr), two samples from the pyroxene shoshonite (Ts_3), and one sample from the pyroxene latite (Tl_3). The results of these analyses are summarized in Table A-2. Analyses of the pyroxene shoshonite (Ts_3) and pyroxene latite (Tl_3) obtained by X-ray fluorescence techniques (Leedom, 1974) are included for comparison.

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