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The Lund Ash-flow Tuff

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THE LUND ASH-FLOW TUFF

BY

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ABSTRACT

The Lund Ash-flow Tuff is the uppermost member of the Needles Range Formation, located in southwestern Utah and eastern Nevada. This member can be correlated over an area of several thousand square miles.

A detailed study of petrographic and physical features of the Lund show vertical and lateral variations in mineral content and welding intensity. Vertical differences are related to changes in the magma chamber during the Lund eruption interval. Several different ash-flows make up the Lund member. All mineral concentrations vary laterally, with concentration decreasing away from the center of the Lund field.

Vertical and lateral variations in physical features of the member are also present. Porosity increases vertically within the member; bulk density decreases. These show that the Lund Tuff had a simple cooling history with only minor welding breaks between successive ash-flows.

Lateral variations in physical features include decreases in bulk density and grain density and an increase in porosity away from the thickest central area of the unit. These decreases are attributed to lateral sorting and a decrease in welding temperature away from the center of the unit.

Possible source areas for the Lund Tuff are suggested from analysis of lateral variations within the member, and consideration of the location of active eruption centers at the time of the Lund deposition.

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I. INTRODUCTION

A. Purpose and Scope

The purpose of this study was to gain detailed knowledge about one member in a complex ash-flow field, and to apply this knowledge to problems associated with ash-flows. These problems include the location of source areas and the determination of genetic processes before, during and after emplacement.

One hundred-twenty samples were collected for the purpose of studying both lateral and vertical variations within the tuff. Methods of study included a detailed petrographic analysis of 86 thin section, use of the five-axis universal stage on selected plagioclase, laboratory determinations of density properties of all samples, and color coding of each rock sample.

The area of study is herein called the Needles Range ash-flow field. Several individuals have worked in this area, but no attempt has been made to study a single member of the Needles Range Formation, in detail, throughout most of its lateral extent.

The member under study is the uppermost unit in the volcanic sequence of the Needles Range. No formal name has been given to this member. For the purpose of this thesis, it will be called the Lund Tuff, named for its presence at the crest of the ridge two miles west of Lund, Utah.

B. Location

The area of study in this thesis is located in Lincoln County in southeastern Nevada, and Beaver, Iron and Garfield counties in southwestern Utah. (see map, Figure 1) The Needles Range Formation extends at least a short distance beyond the boundaries of the map to the north, south and west but has not been identified beyond the eastern boundary.

The Lund member itself has been positively identified a few miles beyond the northern boundary of the map. Several of the localities sampled are accessible by jeep roads only.

C. Nomenclature

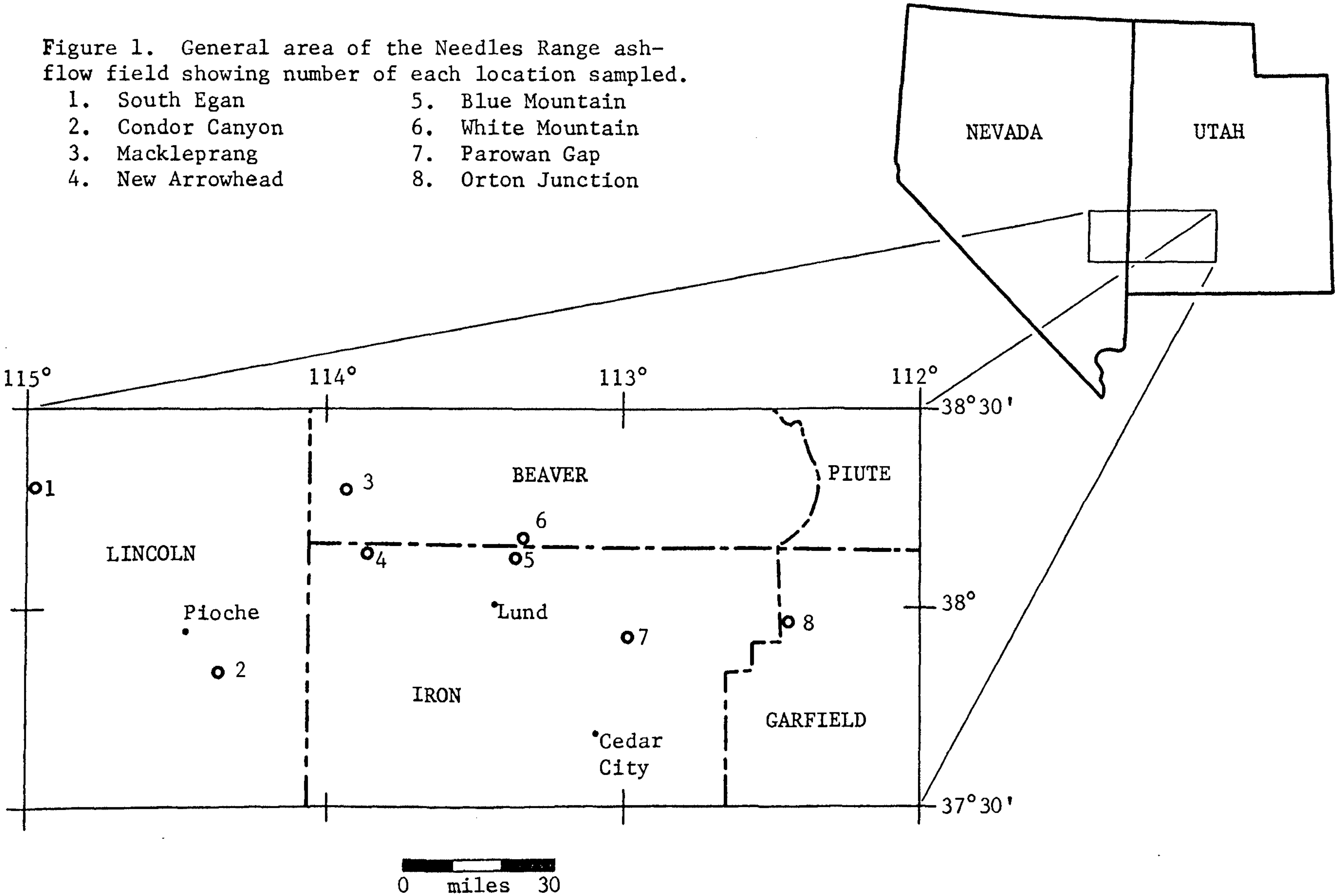
The terminology of ash-flow units used in the paper generally follows that of Smith (1960) and Ross and Smith (1961). It has been suggested in a recent paper by Ratte and Stevens (1967) that the degree of welding of an ash-flow deposit may be expressed by a ratio of the dimensions of pumice fragments. There was no attempt to measure these factors in this paper. Rather, the porosity and overall petrographic features including deformation of shards, and degrees of fusion of the groundmass were taken as a direct indication of welding. Differentiation in types of cooling units is of particular interest. A simple cooling unit is one in which any number of ash-flows within the unit have shared virtually the same cooling history, i.e., cooled as a single unit. A composite cooling unit is one in which a group of ash-flows have shared a similar cooling history with the exception that minor interruptions can be distinguished, either by field evidence or by petrographic, color and density differences (after Ratte and Stevens, 1967).

D. Acknowledgments

I would like to express my deepest gratitude to Dr. S. K. Grant, my advisor, for his assistance during my graduate study. Also, thanks go to the V. H. McNutt Memorial Committee for financial support of my field work, and to Lana Grant, Terri Fielding and John Trapp for their contributions to this thesis.

Figure 1. General area of the Needles Range ash-flow field showing number of each location sampled.

1. South Egan
2. Condor Canyon
3. Mackleprang
4. New Arrowhead
5. Blue Mountain
6. White Mountain
7. Parowan Gap
8. Orton Junction



II. PREVIOUS WORK

The Needles Range Formation was named by Mackin (1960) for exposures in the Needles Range, Utah. Mackin (1963) states that the Needles Range Formation consists of one to three members depending on the locality, and that these members are crystal-rich tuffs of dacitic composition. Mackin, however, names only two members of the Needles Range, the Minersville and Wah Wah Springs Tuffs. Thicknesses of the entire Needles Range Formation, in Utah, were estimated from less than 100 feet to near 2000 feet. Mackin suggests the mapping of individual members within the formation as a step toward the discovery of source areas.

Blank (1959), in the Bull Valley District of extreme southwestern Utah, found 55 feet of Tertiary volcanics interbedded with lacustrine limestone near the top of the Claron Formation, which he indicates may belong to the Needles Range Formation.

Threet (1963), in describing the geology of the Parowan Gap area, found two units of volcanics underlying the Isom Formation which he assigned to the Needles Range Formation.

Cook (1965) assigned up to five members to the Needles Range Formation. The localities mapped occur throughout south-central Nevada, and the formation was estimated to cover at least 9000 square miles. The average thickness reported by Cook for the Needles Range Formation was 617 feet and varied from 53 feet to 1372 feet. Vertical variations in degree of welding were noted by Cook (1965), and he also suggested that mineralogy and crystal percents may vary vertically. Cook recognized the common lateral variations in the degree of welding and emphasized the need for detailed studies in the lateral variations of physical and chemical properties of ignimbrites.

Noble (1968), from experience in and around the atomic test-site in southern Nevada, questions correlations of single cooling units over large distances. This detailed mapping of younger ash-flows and source calderas have shown that similar units can originate at slightly different times from different sources. The question is whether rocks of the same composition and of the same stratigraphic position together should be grouped as a single unit where the source of these rocks is unknown. It would appear that as long as no lithologic differences are apparent, between two ash-flow units in the field or in thin section, and as long as these rocks are in equivalent positions within similar lithologic sequences, then we must correlate them as a single mapping unit, even though the source is unknown. A member or a formation, then, need not have only a single source.

Conrad (1969) has studied the volcanics in the Needles Range of western Beaver County, Utah. He recognized several different ash-flow units, some of which he includes in the Needles Range formation. He suggests that the total amount of crystals and lithic fragments in a member may vary laterally and that a detailed study of these variables might be used to show possible source areas.

Dinkel (1969) made a study of vertical and lateral variations within the Wah Wah Springs Tuff, the most extensive member of the Needles Range Formation. No lateral variations were detected. Vertical variations in mineral concentrations were found. These variations were attributed to successive eruptions in the formation of the simple cooling unit and were believed to represent changes occurring in the magma chamber either before or during eruption. The only vertical variations detected in welding were those characteristic of porosity and bulk density which are normally associated with a simple cooling unit and negligible time between successive emplacement of flows within the unit.

Grant (in press) has done extensive work on the Needles Range Formation. His work is, for the most part, confined to the Needles Range as it occurs in Utah. From other regional studies he has recognized in the formation the following members: Frisco, Escalante, Shingle Springs, Wah Wah Springs, Mackleprang, Indian Peak and Lund Tuffs. Other members occur locally, and a few thin flows, flow-breccias and agglomerates are present within any single sequence. The Minersville member appears to correlate with the upper half of the Wah Wah Springs Tuff, and should no longer be recognized as a separate member.

III. GEOLOGIC SETTING

A. Introduction

The geology of the thesis area associated with the Needles Range Formation is very complex. Sediments exposed in the area of study range in age from Cambrian to Recent and constitute the major exposed rock type. Intrusive igneous rocks are limited in extent and are generally of silicic composition. Most intrusives are of Tertiary age. Extrusive igneous rocks are predominantly of ash-flow origin and range in age from early Oligocene to Recent. Lava flows of varying composition occur throughout the mid-Tertiary extrusive sequence. Formation of the Basin and Range province beginning in mid-Tertiary time has created a giant puzzle for the geologist to solve.

B. Sedimentary Rocks

Sedimentary rocks generally increase in age from east to west. Mackin (1960) shows the Claron Formation covering much of the eastern area of the ignimbrite province, preceding or accompanying Tertiary eruptions. This formation consists of fluvial and lacustrine conglomerate, sandstone and limestone.

Tertiary volcanics generally rest on Paleozoic limestones farther west in the province.

C. Intrusive Rocks

Several Tertiary intrusive bodies of granite to granodiorite composition occur within the area of the Needles Range Formation. In Nevada, small granodiorite intrusions are present in the Ely Range, near the South Egan locality of this study. In Utah, the exposed intrusions are confined to northeast-southwest trending belts but others could be present under nearby sediments. In the northern part of the area of study, intrusives are exposed in all the mountain ranges but large stocks are present south of Indian Peak in the Needles Range and near the old town of Frisco in the San Francisco Range. In the Bull Valley and Iron Springs District to the south, several large stocks or laccoliths are present. All of the intrusives mentioned are potentially related to source conduits for members of the Needles Range Formation, but from known intrusive ages, the stocks near Cougar Spar Mine of the Needles Range and Horn Silver Mine of the San Francisco Range seem to be related to the most likely source areas.

D. Extrusive Rocks

1. Pre-Needles Range. Stone Cabin Formation: The Stone Cabin Formation is the oldest ash-flow unit exposed in the ignimbrite province of southwestern Utah and southeastern Nevada. The rock is a vitric-crystal tuff with crystals of the following relative concentrations: quartz 54%, alkali feldspar 33%, plagioclase 8%, biotite 4%, hornblende 0%. Only 45% of the rock is comprised of crystals. Henceforth similar compositional listings will be given in the form 54/33/8/4/0//45. The order is always quartz, alkali feldspar, plagioclase, biotite, hornblende. The last number is total crystal content of the rock.

Windous Butte Formation: The Windous Butte Formation is generally a crystal-vitric phenorhyodacite. Its average composition is 45/12/41/2/tr//37.

2. Needles Range Formation. The Needles Range Formation has been estimated by Cook (1965) to cover at least 13,000 square miles. The age of the formation is early to middle Oligocene. Potassium-argon biotite dates obtained on the Needles Range Formation from Condor

Canyon, Grant Range and Needles Range sections give best estimate of age for the formation at 28 or 29 million years (Armstrong, 1963).

Mackin (1960) originally defined the Needles Range Formation as consisting of two prominant members. These members were the Wah Wah Springs and Minersville Tuffs. Cook (1965) recognized five members and Grant (in press) mapped four members. Subsequent work (Grant, personal communication) has established the following members: Frisco, Escalante, Shingle Springs, Wah Wah Springs, Mackleprang, Indian Peak and Lund members.

Frisco Tuff Member: The Frisco Tuff is a vitric-crystal or crystal-vitric phenodacite which is pale brown in color (14 YR 5.5/2). Color code numbers are explained in Methods of Investigation. Its average composition is 17/1/62/15/5//25, with gross quartz and traces of sphene. Some lithic and pumice fragments are present. Its type section is two miles southwest of the Horn Silver Mine in the San Francisco Range. It overlies Pennsylvanian Ely limestone and is overlain by hornblende andesite flows. At the south end of Blue Mountain, the Frisco member overlies an agglomerate and underlies the Escalante member. At this latter locality it is cut by a dense dike which does not pass into the younger Escalante Tuff. Its thickness ranges up to 300 feet.

Escalante Tuff Member: The Escalante Tuff is a vitric-crystal phenoandesite, grayish pink in color (13 YR 6.5/2). Its average composition is 3/tr/72/15/10//14 with traces of pyroxene. Some lithic and pumice fragments are present. Its type section is two miles west of Lund, Utah in the Escalante Valley. It overlies an agglomerate and underlies the Wah Wah Springs Tuff along the eastern flank of the prominant ridge west of Lund. Its thickness ranges up to 525 feet.

Shingle Springs Tuff Member: The Shingle Springs Tuff is a crystal-vitric phenocacite which is light grayish pink in color (12 YR 6/1.5). Its average composition is 14/3/55/15/8//39 with gross quartz, gross biotite and traces of pyroxene. Its type section is just northwest of Shingle Springs in the Egan Range, where it overlies the Windous Butte Formation and underlies the Wah Wah Springs member. Its thickness is as large as 450 feet. The Shingle Springs Tuff is the lower member of the Needles Range Formation where Highway 21 crosses the Needles Range.

Wah Wah Springs Tuff Member: The Wah Wah Springs Tuff is a crystal-vitric phenodacite which is pale reddish brown in color (12 YR 5/1.5). Its average composition is 5/tr/64/9/18//34 with traces of pyroxene. A moderate amount of lithics is present. Its type section is just south of Wah Wah Springs where Utah Highway 21 crosses the Wah Wah Range. There it overlies flows and agglomerates and is overlain by a young basalt. Its thickness ranges to 750 feet.

Mackleprang Tuff Member: The Mackleprang Tuff is a crystal-vitric phenorhyodacite which is pale yellowish brown in color (21 YR 5/1). Its average composition is 12/7/46/20/10//41 with gross quartz and gross biotite. It may be an ash-flow from the Shingle Springs' source that erupted after Wah Wah deposition. Its type section is two miles west of the old Mackleprang Homestead, central Needles Range, Utah. This, its only known locality, is a narrow strip from one to three miles north of Indian Peak. It overlies the Wah Wah Springs member and underlies the Indian Peak member. Its thickness is 150 feet.

Indian Peak Tuff Member: The Indian Peak Tuff is a vitric phenoandesite which is pale red in color (11 YR 7/1). Its average composition is 1/0/81/14/tr//9 with traces of pyroxene. Moderate amounts of lithics are present. Its type section was established by Conrad (1969) just north of Indian Peak, Needles Range. There it overlies the Mackleprang and Wah Wah Springs and underlies the Lund Tuff. Its thickness may be as much as 900 feet.

Lund Tuff Member: The Lund Tuff is a crystal-vitric phenodacite which is pale brown in color (13 YR 5.5/2). Its average composition is 15/tr/64/8/9//42, with gross quartz and traces of sphene and clinopyroxene. Its type section is at the crest of Lund, Utah. There it overlies a thin porphyry flow and the Wah Wah Springs Tuff and underlies a complex Isom sequence. It thickness ranges up to 1800 feet.

The composition of the plagioclase in all members was originally near that of andesine, but occasionally in the Escalante and some other members, the plagioclase has been partially to completely altered to more sodic plagioclase.

The mid-Tertiary extrusive sequence also includes lava flows. These flows are particularly abundant north of Modena, where a thick series of hornblende andesites overlie the Escalante Tuff, in place of all younger Needles Range members; at Frisco, where similar flows overlie the Frisco Tuff and extend to the Isom Formation; east of Minersville, where they are younger than the Needles Range Formation; and north of Wah Wah Springs, where flows similar in composition to the Wah Wah Springs and Lund members were intimately mixed while both were molten.

3. Post Needles Range. Isom Formation: The Isom Formation is a vitric tuff composed of many thin but extensive ash-flows. It has several striking characteristics which make it easy to identify in the field. It is deep reddish brown in color with only a small quantity

of crystals, predominantly plagioclase and biotite. Large tubular vesicles are always present. These lie in the plane of foliation and their trend varies with locality, but a northwesterly trend is quite common. The Isom lies directly on the uppermost member of the Needles Range Formation, sometimes with striking unconformity due to pre-Isom channeling of the soft upper Lund. The Isom sequence often contains as many lava flows as it has ash-flows, and the total thickness can be over 1000 feet.

Several formations consisting of mainly ash-flows overlie the Isom Formation. They range in age from late Oligocene to early Miocene. The formations are, from oldest to youngest, the Quichapa, Page Ranch and Kane Wash. There are several members present in each formation.

4. Structure. The ash-flow field occurs within the Basin and Range province. The area is characterized by large fault blocks which generally have an easterly tilt due to uplift on northerly trending faults. Some faulting may have occurred concurrent with deposition of the Needles Range Formation, as some members are abruptly terminated laterally. Mapping of the Lund Member (see Figure 2), as well as other members, indicates that relief at the time of deposition was not great, but possibly a general depression trending east-west may have been present. However, ash-flows do not necessarily require a basin for deposition. Deposits should build up around the source, even if the pre-eruptive surface was a horizontal plane. Cook (1965) and Conrad (1969) suggest that subsidence may have been associated with deposition of the ash-flow field. Such a supposition is entirely compatible with withdrawal of material below the vent, but is not required to explain the post-depositional expression of many of the ash-flows.

The Lund distribution, though, is rather peculiar in that is is significantly elongated east-west. Directed eruption from a single source might be the answer, but subsidence and multiple sources cannot be ruled out.

IV. METHODS OF INVESTIGATION

A. Sample Collection and Preparation

During June of 1969, the author collected samples from the Lund ash-flow tuff in southwest Utah and eastern Nevada. The location of each suite is shown in Figure 1. Samples were collected in a restored vertical succession at each locality, noting their positions in the ash-flow above the base of the unit. Field characteristics were noted, such as the abundance of lithic fragments, presence of faulting, and resistance to erosion as reflected in the topographic relief.

From each sample collected, a thin section was prepared, color determinations were made, and density measurements were obtained. These data constituted the basis for geological interpretation in this study.

B. Mineralogy

A detailed petrographic study of 86 selected thin sections was undertaken, using a Leitz SM-POL microscope. Each thin section was carefully analyzed with respect to minerals present and their abundance, textures observed for minerals, grain sizes for the abundant minerals, and types and amount of alteration. Also noted was the amount of pumice fragments or lenticles and the degree of their devitrification, whether any paragenetic sequence was evident, the abundance of lithic fragments, and the preservation of any shard structure.

Mineral percentages were calculated through the use of a grid ocular (10x) in combination with a low power objective (3.6x). Random fields were viewed and the minerals falling on the intersections of the grid lines were counted. Four fields (1300 points) were counted for plagioclase, quartz, iron-oxides, pyroxene and sanidine. Hornblende, biotite, and sphene required more potential points to obtain a sufficient degree of precision in calculating their percentages. Therefore, six additional fields (1950 points) were counted for these minerals.

The relative error in grain counts was taken to be $\frac{1}{\sqrt{n}}$, $\underline{n}$ being the number of points counted for a particular mineral. For example, if 400 points out of four fields were counted for plagioclase, then the percent plagioclase would be 30.8 and the relative error would be $\frac{1}{20th}$ of this 30.8 percent.

The composition of the plagioclase was determined using a Leitz five-axis universal stage. The anorthite content was determined by measuring the angles between the principal optic directions and the (010) pole. To interpret these angles, and to obtain the possible temperature of crystallization, charts from Slemmons (1962) and an adjusted chart from Muir (1955) were used, taking an average of the two values given.

C. <u>Density Measurements</u>

The bulk density, grain density, i.e., the density of the solid portion of the rock, excluding pore spaces, and percent porosity were determined for each of 97 samples by water-absorption techniques. Their weight ranged from 6 to 23 grams. The samples were weighed after drying and again after soaking in water for 24 hours, using a Sartorius direct reading balance. The soaked weight of the samples was obtained as quickly as possible after removing them from water and blotting off any excess water. Next, the soaked density was measured using a Jolly balance, again being careful not to allow any drying or excess water to bias the reading taken in air. Bulk density was calculated by use of the following formula:

$$D_b = \frac{\text{dry weight}}{\text{wet weight}} \text{ (x) soaked density}$$

The formula for grain density, as derived, was found to equal

$$D_g = \frac{\text{dry weight}}{\frac{\text{wet weight}}{\text{soaked density}} - \text{weight of } H_2O \text{ absorbed}}$$

Finally, percent porosity was obtained by use of the following equation:

$$\text{Por} = \frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}} \; (x) \text{ soaked density } (x) \; 100$$

As a check on precision, five analyses of the same sample were compared and found to vary by $\pm$ .02 gms/cm^3. Precision, then, was within a tolerable range, but the accuracy of all calculations related to grain density may be affected to an undetermined degree by sealed pore space within the samples, which could not be filled with water by simple soaking.

D. Color Coding

To each sample a color code number was assigned by use of a 130-chip rock-color chart published by the Geological Society of America (1951). A typical number, based on the Munsell system might be 10 R 5/2. Both the first number and letter represent the hue of the rock. For example, reds on the color chart range from 1 to 10, yellow-reds from 11 to 20, yellows from 21 to 30, yellow-greens from 31 to 40, etc. The second number represents the shade of gray (value) on a 1 to 10 scale, black being 0 and white being 10. The third number represents the chroma or the amount of color saturation.

It was postulated that certain physical and mineralogic changes would be indicated merely by noting a rock's color code. For instance, secondary oxidation might manifest itself by a change in the basic color of a sample, or welding in a tuff might be shown by a change in the shade of gray or by the amount of color saturation.

V. DESCRIPTION OF THE LUND TUFF

A. General Description

There has been some question in the past as to whether ash-flow units such as the Lund Tuff and other members of the Needles Range ash-flow field could be correlated over distances in excess of ten miles. However, after careful analysis of mineralogy, physical features such as density and porosity, and field relationships, there is no doubt that the Lund Tuff could be recognized and correlated as a stratigraphic unit of large areal extent.

The Lund Tuff member of the Needles Range formation has a large areal distribution. Its recognized outcrops occur in an area 140 miles east-west from Orton Junction, Utah, to just south of Sunnyside, Nevada, and as much as 47 miles north-south. Within this area its thickness ranges from 20 to 1800 feet. Figure 2 is an isopach map of the Lund Tuff. This drawing was prepared from information at 27 locations within the Needles Range formation. At these locations the Lund Tuff was either absent from the regular volcanic sequence, or present in which case its thickness was measured or estimated.

The average color of the rock is pale brown (13 YR 5.5/2), but extreme variations from black to red and to white are present. Pumice fragments give the rock a streaky or blotchy appearance.

The Lund Tuff is a crystal-vitric rhyodacite welded tuff. The modal composition of the member is quartz 6.4% ± 3.6%, plagioclase 27.1% ± 6.7%, biotite 3.4% ± 1.5%, hornblende 3.9% ± 2.1%, iron-oxides 2.0% ± 0.9%, sphene 0.1% ± .03%. The average amount of crystal fragments is 42.5% ± 8.2%. The variability expression after each mean is the standard deviation.

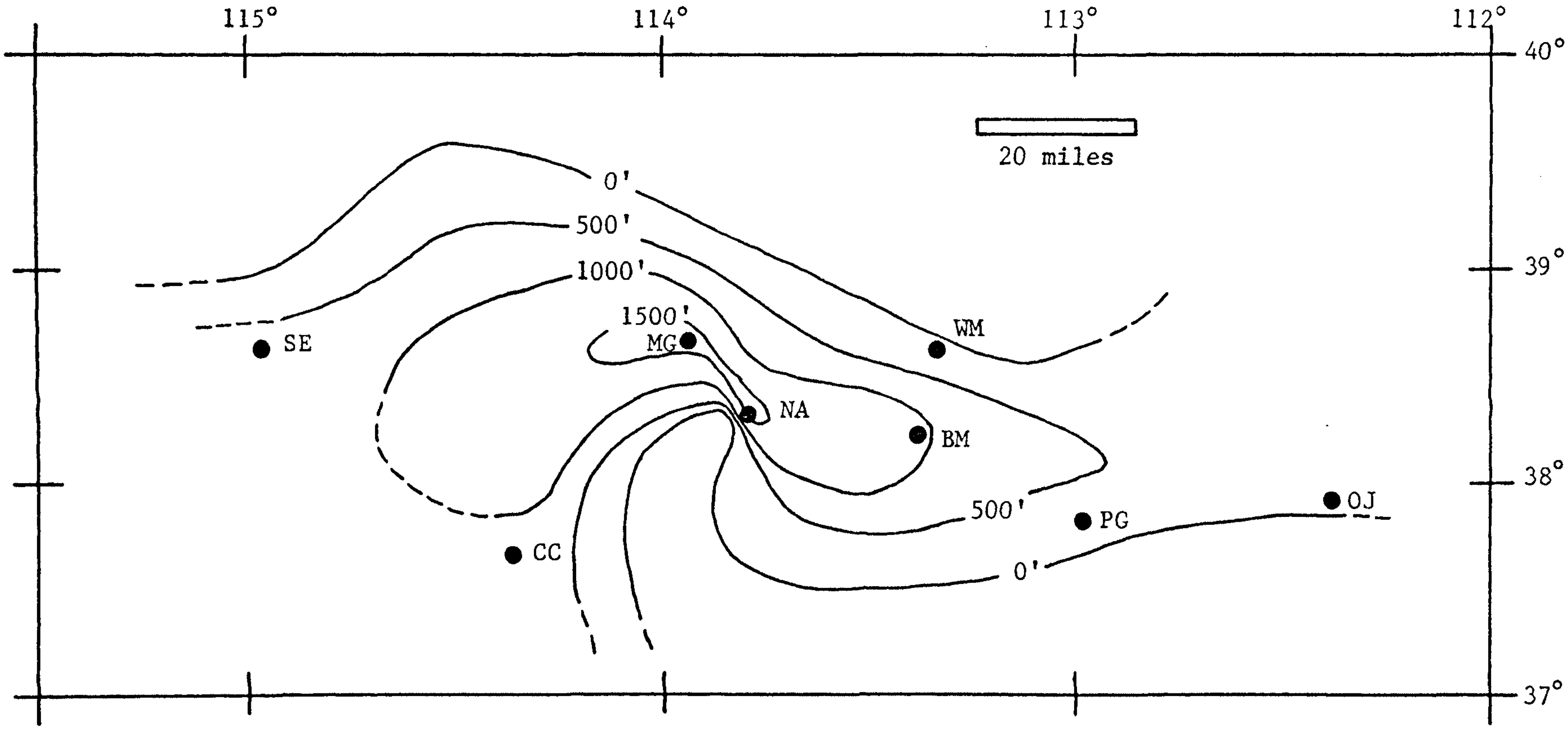


Figure 2. Isopach of Lund Tuff showing each location of samples.

SE - SOUTH EGAN
CC - CONDOR CANYON
MG - MACKLEPRANG
NA - NEW ARROWHEAD
BM - BLUE MOUNTAIN
WM - WHITE MOUNTAIN
PG - PAROWAN GAP
OJ - ORTON JUNCTION

The average anorthite content of the plagioclase is 42.2% ± 2.0% (andesine). From a diagram after Slemmons (1962) the andesine apparently formed at a temperature between that of high and low temperature, near 80% ± 20% of the distance from the low to the high temperature lines. The plagioclase is a transitional type, being neither typical of strictly plutonic nor strictly extrusive environments. The plagioclase formed at depth, cooled somewhat during crystallization of the magma, and the temperature effects were frozen upon extrusion of the magma.

Quartz and plagioclase show two stages of fracturing. The first type is that which reduces the grains to small angular fragments, some with rounded corners. This is caused by the explosive forces of eruption and the expansion of gases which accompanies the eruption. These are the same processes which form the glass shards. The second type of fracturing caused the breakage of large, individual crystals which survived the explosive stage of volcanic activity, with all the pieces remaining together. This is caused by the welding process in the formation of the flow and indeed varies with the degree of welding.

Alteration of the Lund Tuff is generally selective. Plagioclase alters to calcite or a tan clay product. Hornblende and biotite alter to iron-oxides and calcite. Fractures in quartz and plagioclase grains may contain a bright red to yellow iron-oxide, probably limonite. No established horizontal or vertical trends of alteration have been observed.

The mean bulk density of the Lund Tuff is 2.42% ± .18 gm/cc. It may vary as much as 0.51 within a single locality. Lateral changes in mean density range from 1.76 to 2.60. The mean grain density is 2.64 ± .12gm/cc. The most variation measured within a single vertical section is .29. Lateral extremes range from 2.14 to 2.82. Porosity is usually inversely proportional to bulk density. The mean porosity is 9.0% $\pm$ 4.1%, with a maximum of 14% variation (absolute) within a single locality. Extreme values for porosity range from 2.9% to 19.2%.

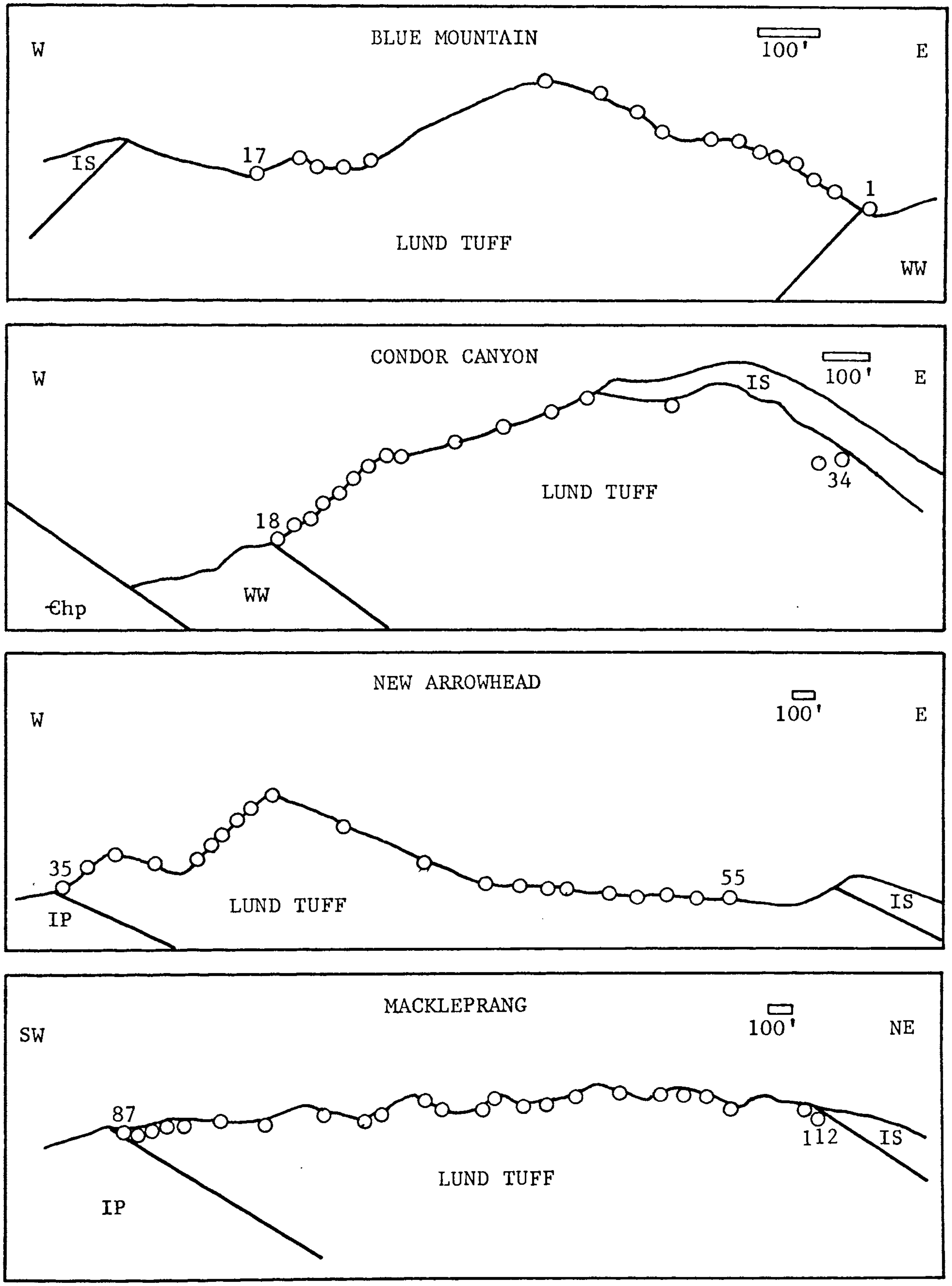


Figure 3. Stratigraphic relationships and locations of samples collected
IS - Isom Tuff
IP - Indian Peak Tuff
WW - Wah Wah Springs Tuff
Єhp - Highland Peak Limestone

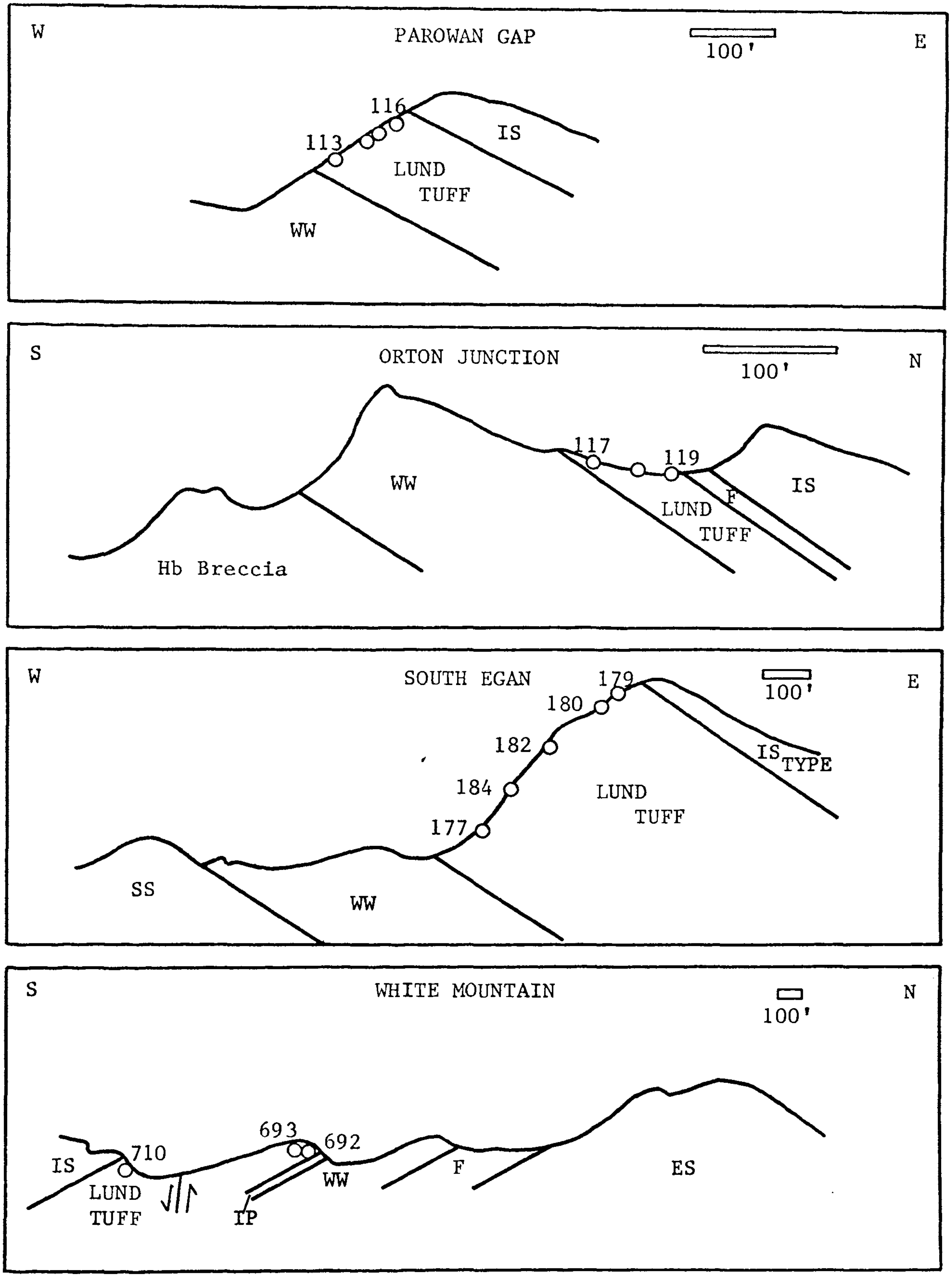


Figure 4. Stratigraphic relationships and locations of samples collected.
WW - Wah Wah Springs Tuff   ES - Escalante Tuff   IS - Isom Tuff
SS - Shingle Springs Tuff   IP - Indian Peak Tuff   F - Flow

B. Mackleprang Locality

1. Introduction. The Mackleprang locality is near the center of known outcrops of the Lund member. Most of the typical features of the Lund Tuff are present here. For this reason, this section has been chosen for detailed description of petrography and physical features, such as color and density. Other areas sampled will be described only to show definite horizontal or vertical differences with respect to the Mackleprang localtiy.

2. Field Characteristics. The Mackleprang localtiy is two miles west of Mackleprang Homestead and 700 feet north of Pine Valley--Hamblin Valley Road. The base of the Lund Tuff here has a 38°20' Latitude and 113°56' longitude. It strikes N 20°-40°W and dips 28°-33°E. The Lund is underlain by the Indian Peak, Mackleprang, and Wah Wah Springs Tuffs, a dense flow complex and the Shingle Springs, Escalante and Frisco Tuffs. It is overlain by the Isom Tuff and a volcanic sandstone or conglomerate. The measured thickness of the Lund Tuff at this location is 1800 feet. The stratigraphic relationships and positions of samples collected are shown in Figure 3. At Mackleprang, the Lund Tuff shows considerable variation in degree of welding. The lowest 10 feet are only slightly welded but grade into a densely welded black vitrophyre approximately 20 feet thick. The next 1300 feet of the section are moderately welded with little visible variation. The upper 450 feet of the section are slightly to moderately welded. The average color of the rock at Mackleprang is pale brown (15 YR 6/1.5), but much variation is present. This variation generally follows the degree of welding. The base of the section is very lightly colored in contrast to the nearly black vitrophyre just above the base. The bulk

of the section is pinkish brown with the top 450 feet being much lighter in color than the middle portion. Two distinct lithic zones are present in the section. The first is near the base where the lithics are small and only minor in abundance. The second is approximately 400 feet above the base. Here, lithic fragments are very abundant and may be one or two inches in diameter. Pumice fragments are abundant throughout the section, but they are not easily seen in most of the hand samples.

3. Petrography. The complete mineralogy for each thin section studied from the Mackleprang locality is given in Table I of the Appendix. A summary of these data is presented here in addition to other petrographic characteristics observed.

The crystal content of the rocks ranges from 39% to 59% and averages 48%. Quartz ranges from 2% to 16% with an average of 8%. The average grain size for quartz is 1.3 mm with noticeably smaller values occurring near the base. Quartz generally occurs as subhedral, fractured grains often showing embayment. Near the top of the section some grains are distinguished by a reddish iron-oxide stain. Plagioclase makes up 21% to 39% of the rock with an average of 30%. The average grain size for plagioclase is .9 mm with grains again being smaller near the base. Grains are usually lath shaped, but many small crystal chips are present. The average composition of the plagioclase is andesine (An_{43}), and the composition of individual unzoned crystals ranges from An_{41} to An_{45}. In zoned crystals the anorthite content may show as much as 10% total variation. Biotite is present in amounts from 2% to 7% with an average of 4%. Its average grain size is .6 mm with the smaller values being in the lower one-fourth of the section. Elongated grains are often bent around adjacent grains of quartz or plagioclase. Biotite flakes show a preferred orientation in which the flakes are parallel to the layering of the entire unit as manifested by flattened pumice. Pleochroic colors are dark brown to light reddish brown and show little vertical variation. Hornblende ranges from 1% to 9% with an average of 5 %. Its average grain size is .4 mm with only minor variation. The colors of pleochroism for hornblende are X = pale greenish brown, Y = greenish, Z = dark green. Some grains show simple twinning. Primary iron-oxides are present as small rounded grains in quantities from .5% to 2.5% with an average of 1.1%. Sphene makes up from traces to .8% of the rock with an average of .2%. Grains are either perfectly sphenoidal in shape or fragments of an original euhedral grain. Apatite and clinopyroxene occur throughout the unit in amounts of less than 1%. Traces of an alkali feldspar were present near the top of the section. This feldspar is a transitional type between sanidine and anorthoclase.

Several alteration products are present. Plagioclase shows crystallographically controlled alteration to kaolinite in slight to moderate amounts. Secondary iron-oxides are present as alteration products of hornblende and biotite. Biotite varies from very fresh to almost completely altered. Hornblende shows the most alteration, mainly to iron-oxides. Often only a ghost remains which makes the hornblende difficult to identify.

In thin section, lithic fragments are generally small (.5 mm or less) and not very abundant. There is, however, a concentration near the base of the tuff. These lithics consist of fine grained volcanics, not present in other rocks of the Mackleprang area.

Pumice fragments or lenticles are abundant throughout the section but are most easily seen near the top of the section where they are lighter in color compared to the rest of the rock. Through most of the section pumice is darker than the rock matrix. Lenticles are completely collapsed and greatly elongated in the vitrophyre portion near the base. The pumice lenticles have fewer crystals than the fragmented rock, and crystals present in the lenticles are larger than grains in the groundmass. Each lenticle often exhibits only a single mineral, but the lenticles as a group exhibit the same composition as the fragmented portion of the tuff. Lenticles show only slight devitrification in the lower two-thirds of the section, but well-developed microspherulites occur in the upper one-third.

Shard structure is well preserved in the loosely welded rock below the vitrophyre in typical Y and V shapes. The shards in the vitrophyre show an elongated, fused structure. There is only slight evidence of shard structure above the vitrophyre.

The following relationships indicate a possible paragenetic sequence of mineral development in the magam. The pyroxene is usually in an intermediate stage of replacement by hornblende. Small grains of biotite, hornblende and plagioclase occur in quartz. Small grains of plagioclase which exhibit simple twinning and no zoning are often found in larger grains of zoned plagioclase and biotite and are usually oriented in one direction. Plagioclase also occurs in hornblende. Biotite is found in hornblende and vice versa. Inclusions of quartz occur in alkali feldspar. From these relationships it is evident that pyroxene crystallized first, followed by the first generation of small plagioclase grains. The larger zoned grains of plagioclase crystallized accompanied by hornblende and biotite. Quartz and finally alkali feldspar are the youngest.

4. Density. A complete listing of density and porosity measurements is given in Table II. Certain correlations exist between density and composition. Figure 5 is a summary of physical and petrographic properties in stratigraphic section at Mackleprang. Column A of Figure 5 shows the vertical changes in percent porosity. The porosity profile is the most direct indication of the welding process. In a simple cooling unit with a vitrophyre, one would expect a high porosity for the loosely welded tuff at the base (samples 87-88), a very low porosity for the vitrophyre itself (samples 89-90), and then a gradual increase in porosity toward the top of the unit. In the section surveyed this is not entirely true. There is a definite reversal at sample 95, where a gradual decrease in porosity begins. This departure from simplicity is reinforced by field evidence, where the tuff above the vitrophyre has a different appearance from the lower portion and is characterized by a lithic-rich zone and a much larger crystal size.

Profile B indicates bulk density. For a simple cooling unit this profile is normally thought to be a mirror image of the porosity curve, i.e., as the porosity decreases, the bulk density increases denoting more complete welding. Again, there is some deviation from the expected. At the base, for instance, porosity reaches a minimum at sample 90, part of the vitrophyre, but bulk density reaches a maximum at sample 91, some distance above the vitrophyre. Evidently bulk density values are affected not only by porosity, but also by grain density.

Grain density as explained earlier is the density of the solid portion of the rock, excluding pore volume. A direct relationahip may be seen between the profiles for grain density (profile C) and bulk density.

The average measured index of refraction for the glass portion of the rock at the Mackleprang locality is 1.52 - 1.53. This corresponds to a density of roughly 2.5. This is very close to the calculated density obtained for the glassy portion of the rock, knowing the percent of crystals and the grain density of the rock. It is expected that a relative increase in the percentage of crystals in the tuff would have a corresponding effect on the grain density since the crystals have a density higher than that of the glass. This relationship may be seen by comparison of profiles C and D. The crystal concentrations and the grain density were obtained independently, the former was calculated from porosity and bulk density and the latter obtained by microscopic point counting.

The average diameter of crystal fragments (profile E) shows a general increase from the base to the top of the section, and this profile shows a moderate correlation to the percent of crystals (profile D).

One interesting aspect of the profiles is that some of the discontinuities which occur in profiles B, C, D, and E do not appear in profile A. Perhaps the welding process was more nearly continuous than the processes that led to the other physical and petrographic properties.

Dashed lines between columns in Figure 7 emphasize the previously discussed relationships between physical and petrographic properties at the Mackleprang locality. Each dashed line does not represent an individual ash-flow, but rather indicates discontinuities which may be caused by the additional emplacement of one or several ash-flows to the cooling unit.

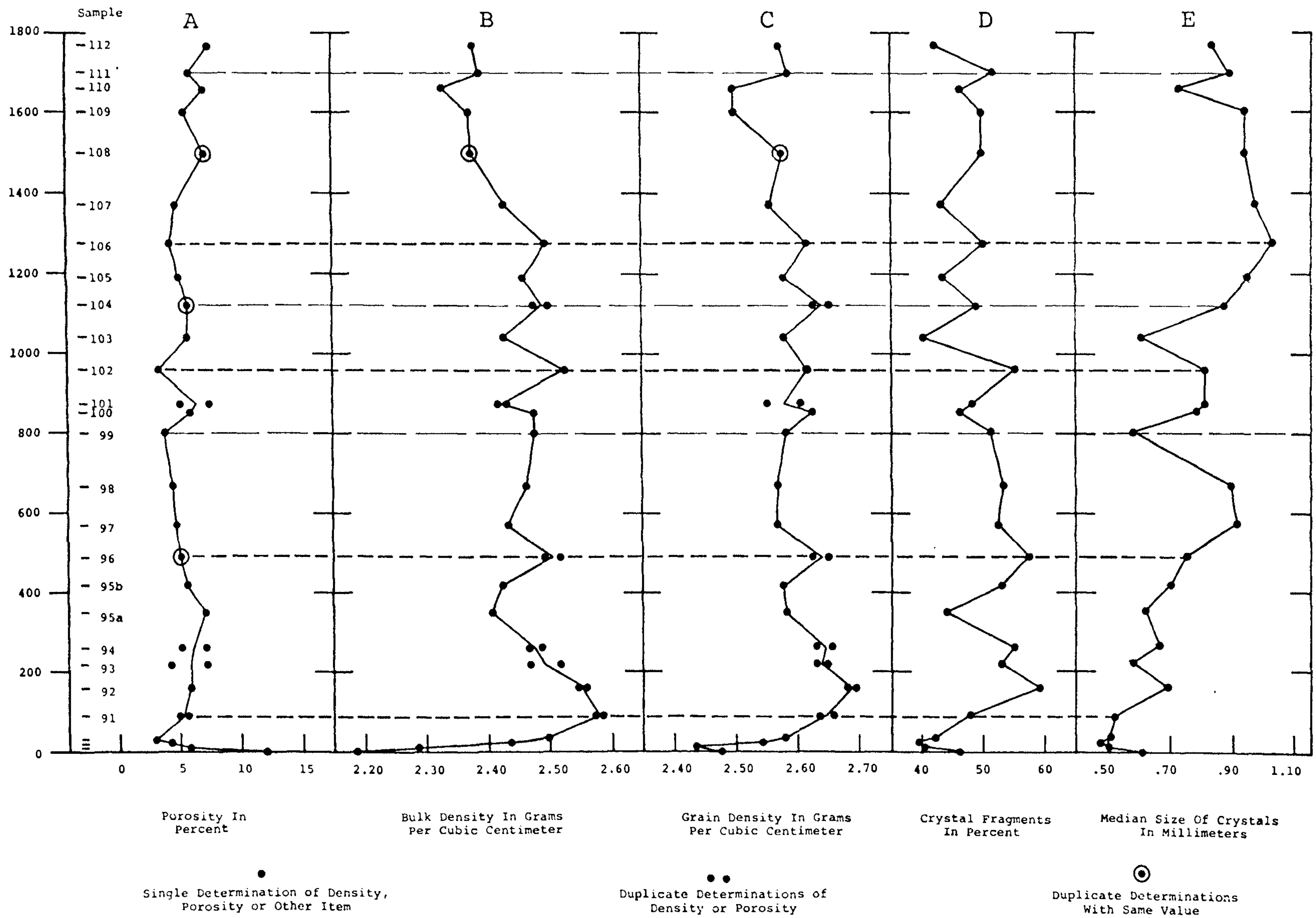


Figure 5. Discontinuities within the single cooling unit at the Mackleprang locality.

C. Condor Canyon Locality

1. Field Characteristics. The Condor Canyon section is located six miles north of Panaca, Nevada. It coincides with that named by Cook (1965). The base of the Lund Tuff here is at 37°50' latitude and 114°21' longitude. The formation strikes N 12 ° W and dips 35° E. The Lund is underlain by the Wah Wah Springs Tuff and the Cambrian Highland Peak Limestone. At Condor Canyon there is no sharp contact between the Wah Wah Springs and Lund Tuffs, but rather a blending of one unit into the other. There is an angular unconformity between the Lund and Isom Tuffs. The measured thickness of the Lund Tuff at this location is 913 feet. The stratigraphic relationships and positions of samples collected are shown in figure 3. At Condor Canyon, the lower 200 feet appear moderately welded and the upper 700 feet somewhat less welded. Several possible breaks in this general trend are apparent in hand samples. Small lithic fragments are moderately abundant. Pumice fragments are abundant and range in color from pink to white. The average color of the tuff at Condor Canyon is pale red (9 R 6/2). Samples which are more welded generally show darker shades of gray or an increase in color saturation.

2. Petrography. For the complete mode from Condor Canyon thin sections see Table I. There is no significant variation in either the types or percentages of minerals present at Condor Canyon as compared with the Mackleprang locality. Each mineral is, however, slightly less abundant at Condor Canyon.

Alteration products at Condor Canyon show little variation. Small amounts of plagioclase are altered to calcite. Hornblende is rimmed with iron-oxides. Sometimes there is only the remnant shape of hornblende with iron-oxides forming an outline of the altered grains. Small amounts of biotite are altered to iron-oxides.

In thin section, pumice fragments are large and only slightly devitrified. Lithic fragments are small and usually consist of other fine-grained volcanics. Shard structures are not well preserved.

3. Density. Bulk density and grain density values reach a maximum near the base of the tuff, and generally decrease toward the top of the tuff. Porosity values are low near the bottom of the unit and generally increase upward. Less variation in grain density is present, which tends to make porosity and bulk density values more nearly reciprocal.

D. New Arrowhead Locality

1. Field Characteristics. The New Arrowhead locality is two and one-half miles northeast of New Arrowhead Mine, 35 miles northwest of Lund, Utah. The base of the Lund Tuff here is 38°10' latitude and 113° 40' longitude. The member strikes N 15° E and dips 25° SE. Below the Lund are the Indian Peak Tuff, Wah Wah Springs Tuff, and a dense flow complex. Above the Lund is the Isom Tuff. The measured thickness of the Lund Tuff at this location is 1551 feet. The stratigraphic relationships and positions of samples collected are shown in Figure 3. The lower 100 feet of tuff at New Arrowhead is highly welded but is not a vitrophyre. Above this point, welding is not as intense and obvious breaks in the welding are apparent in several places. Near the top of the unit, the tuff is still moderately welded. Pumice fragments are large and easily seen. The color of the pumice ranges from white to pink from the base to the top of the tuff. The average color of the tuff at New Arrowhead is light yellow brown (18 YR 4.5/2). The lower portion of the tuff is dark brown, then reddish and finally, mostly gray. Above 300 feet the tuff is grayish brown in general, but several places are strikingly red.

2. Petrography. The complete mode of all thin sections studied for New Arrowhead locality is given in Table I. Mineralogy at New Arrowhead is very similar to that at Mackleprang. The only significant variation is in the low values obtained for the percent of biotite. Very minor amounts of clinopyroxene and sanidine are present. Noticeable variations in average grain sizes are present, but overall averages for the entire unit do not differ significantly from those at Mackleprang. Sphene crystals are slightly smaller than at the Mackleprang locality.

Alteration is very minor at New Arrowhead. Small amounts of plagioclase are altered to calcite and biotite and hornblende to iron-oxides. A red iron-type staining is present in the fractures on quartz and plagioclase grains.

In thin section, both lithic fragments and pumice fragments are very large. Only minor devitrification of pumice fragments is present, taking the form of snowflake and whale-bone structures. Shard structures are not well preserved, but they occur as tricuspid shapes in a few thin sections.

3. Density. For the complete density and porosity measurements at New Arrowhead see Table II. Bulk density values at New Arrowhead show a general decrease from bottom to top of the unit, but several samples show a marked variation from this general trend. Both the average bulk density and grain density for New Arrowhead are the highest for all localities sampled. The average porosity at New Arrowhead is higher than that at Mackleprang and is, in fact, the same as the average obtained for all Lund samples measured. Porosity data show the base to have the highest degree of welding, and the general decrease in welding above the base has at least three breaks of increased welding, two of which are near the top of the unit.

E. Blue Mountain Locality

1. Field Characteristics. The Blue Mountain locality is eight miles north of Lund, Utah. The base of the tuff lies 2000 feet east from a group of microwave relay towers. The lower-most part of the section is at 38°7' latitude and 113°23' longitude. The tuff strikes N 5° E and dips 45°-54° west. The Lund is underlain by the Wah Wah Springs, Escalante, and Frisco Tuffs, respectively, and is overlain by the Isom Tuff. The Lund Tuff at this location measures 1035 feet thick. These stratigraphic relationships and positions of collected samples are shown in Figure 3. At Blue Mountain, the Lund Tuff has no vitrophyre. The lower 600 feet are moderately welded with the upper 400 feet being less welded. Few lithics are present, but an abundance of lenticles is apparent throughout the section. The average color of the rocks at Blue Mountain is pale grayish red (10 R 5/2), with the upper 400 feet of the unit noticeably lighter than the lower portion.

2. Petrography. The mode for each thin section studied at Blue Mountain is given in Table I. Crystals are slightly less abundant at Blue Mountain than at Mackleprang. The same minerals occur at Blue Mountain with the exception that no pyroxene is present. All minerals show less variation in their abundances.

In the lower portion of the unit, moderate amounts of plagioclase are altered to calcite. In the upper portion, small amounts of plagioclase are altered to a clay product. Grains of hornblende are almost completely altered to iron-oxides. Surprisingly, this same alteration is insignificant on biotite.

Pumice fragments show moderate devitrification in the form of snowflake and whale-bone structures in the lower portion of the unit, and gross devitrification in the form of axiolitic structures or spherulites toward the top of the unit. Lithic fragments are scarce throughout the unit. The groundmass is glassy with shard structures not usually evident.

3. Density. As shown in Table II, the bulk density reaches a maximum 100 feet above the base, decreases abruptly, rises again to a maximum 300 feet above the base, and then gradually declines toward the top of the unit. Average values for both bulk density and grain density are somewhat higher at Blue Mountain than at Mackleprang.

F. White Mountain Locality

1. Field Characteristics. The White Mountain locality is one mile west of White Mountain, which is part of the Southern San Francisco Range, Utah, 21 miles northeast of Lund, Utah. The base of the Lund Tuff here is 38°18' latitude and 113°20' longitude. The member strikes N 50 °E and dips 10° S. Below the Lund are the Wah Wah Springs Tuff, a thick dense flow, and the Escalante Tuff. Above the Lund is the Isom Tuff. Due to faulting of the Lund at White Mountain the minimum thickness was taken to be 370 feet. The stratigraphic relationships and positions of samples collected are shown in Figure 4. Since only samples near the base and top of this section were used, it is impossible to do more than note the vertical variations shown by these extremes. The base of the Lund at White Mountain is densely welded, the top lightly welded. Minor amounts of lithic fragments occur both at the base and top of the unit. The average color of the rocks at White Mountain is pale brown with the base quite dark and the top much lighter.

2. Petrography. The complete mineralogy for each thin section studied from Blue Mountain is given in Table II. Both crystal size and percent of crystals are markedly higher at the bottom than at the top of the unit. The mineralogy of White Mountain is similar to that of the Lund Tuff as a whole with the exception that sphene was not detected. Colors of pleochroism for hornblende change from shades of green to shades of brown.

Moderate amounts of plagioclase are altered to kaolinite. Hornblende and biotite are altered to iron-oxides with more alteration present for hornblende than for biotite.

Structures of devitrification such as spherulites are not evident. Faint shard structures are visible, but not common.

3. Density. Values for bulk density, grain density and porosity are close to those expected for the base and top of a moderately welded tuff.

G. Parowan Gap Locality

1. Field Characteristics. The Parowan Gap locality is one-half mile north of Utah State Road 127 at the Petroglyph Cliff histroical site, 10 miles northwest of Parowan, Utah. The base of the Lund Tuff here lies at 37°55' latitude and 112°59' longitude. The member strikes N 25° E and dips 30° SE. Below the Lund are the Wah Wah Springs Tuff and the Claron Formation, a red and white limestone of early Oligocene age. Above the Lund is the Isom Tuff. The measured thickness of the Lund Tuff at this location is 126 feet. The stratigraphic relationships and positions of samples collected are shown in Figure 4. At Parowan Gap, the Lund Tuff is only lightly welded, with the middle of the unit more welded than the top or bottom. Lithic fragments are not evident. Pumice fragments occur in moderate amounts throughout the unit. The average color of the rock at Parowan Gap is pale red (7.5 R 6.5/2) with very little variations.

2. Petrography. The complete mineralogy for each thin section studies from Parowan Gap is given in Table I. There is little change in mineralogy at Parowan Gap compared with Mackleprang. The amount of crystals is somewhat lower. Clinopyroxene occurs as both twinned and zoned crystals, some of which are rimmed by hornblende. No alkali feldspar is apparent. Grain sizes near the base are larger than the rest of the unit, and the average grain sizes for Parowan Gap are smaller than those at the Mackleprang locality.

Much alteration of plagioclase to calcite is present in the middle of the unit, but only slight amounts of alteration occur near the base or top. Only slight amounts of hornblende and biotite are altered to iron-oxides.

Lithic fragments occur in minor amounts throughout the unit. Pumice fragments are moderately devitrified. Shard structures are not evident.

3. Density. For complete density and porosity measurements, see Table II. At Parowan Gap the Lund Tuff shows little variation in bulk density, grain density or porosity over its 126 feet of thickness. It is slightly less porous in the middle of the unit. Bulk density and grain density values are correspondingly higher in the middle of the unit.

H. Orton Junction Locality

1. Field Characteristics. The Orton Junction locality is one and one-tenth miles west of Orton Junction, Utah, on the north side of State Highway 20. The base of the Lund Tuff here is 37°58' latitude and 112 °25' longitude. The member strikes N 75 ° E and dips 25 ° N. The Lund is underlain by the Wah Wah Springs Tuff and a hornblende breccia, and is overlain by a thin hornblende-rich flow followed by the Isom Tuff. The measured thickness of the Lund Tuff at this location is 59 feet. The stratigraphic relationships and positions of samples collected are shown in Figure 4. Only a few square feet of the Lund Tuff are exposed at the Orton Junction locality. The base of the unit is intensely welded, but has not formed a vitrophyre. The rest of the unit is only slightly welded. Lithic fragments are not apparent, and pumice fragments are small and scarce. The average color of the samples at Orton Junction is grayish orange pink (13 YR 6/1) with the sample from the base having a much higher color saturation than the other samples.

2. Petrography. For complete mineralogic data from Orton Junction see Table I. The rock at Orton Junction has a very low crystal content of only 27 percent. This follows the low abundance of plagioclase. Average grain sizes decrease slightly above the base. There is no qualitative variation in the presence of specific minerals between Orton Junction and Mackleprang. Small amounts of biotite and hornblende are altered to a clay product. Lithic fragments are almost absent and when present, are very small. Moderate devitrification of pumice fragments is noticed throughtout the unit. In contrast to most localities, shard structure is well preserved at Orton Junction.

3. Density. At Orton Junction the average bulk density and grain

density of samples are very low compared to most of the other locales sampled. Porosity is low for the sample at the base, but increases rapidly for the upper part of the unit.

I. South Egan Locality

1. Field Characteristics. The South Egan locality is nine miles south of Sunnyside, Nevada. It was named as such by Cook (1965). The base of the Lund Tuff here is 38°19' latitude and 114°58' longitude. The member strikes northerly and dips 15°-30° E. The Wah Wah Springs and Shingle Springs Tuffs lie below the Lund and an Isom-type vitric tuff lies above the Lund. The measured thickness of the Lund Tuff at this location is 610 feet. The stratigraphic relationships and positions of samples collected are shown in Figure 4. The lower 400 feet of the tuff are poorly welded, the next 100 feet non-welded, and the top 100 feet lightly welded. Lithic fragments are scarce in hand samples, and pumice fragments have a blocky or lens-like shape, not seen at other localities sampled. At places, the pumice disks (some six inches in diameter) have weathered out of the fragmental matrix. The average color of the rock at South Egan is light grayish pink (15 YR 8/1). The lower 400 feet of the tuff show no color other than gray.

2. Petrography. The complete mode for thin sections studied from South Egan is given in Table I. The tuff at South Egan contains only 24 percent crystals, the lowest for any location sampled. The percents of plagioclase, biotite and hornblende are exceptionally low here. These three minerals also have correspondingly small grain sizes. Quartz is relatively more abundant at South Egan, and its average grain size shows little variation from the Mackleprang locality. Grain sizes also vary vertically within the unit. Grain sizes three-fourths of the distance above the base are noticeably smaller than those both above and below.

Very small amounts of plagioclase are altered to calcite. Small amounts of biotite and hornblende are altered to iron-oxides. Pumice fragments are moderately abundant and show only slight deformation or flattening. Small fine-grained lithic fragments consisting of other volcanic rocks are present. Shard structures are well preserved only in the non-welded portion of the unit.

3. Density. The density and porosity values at South Egan represent extremes when compared to the other locales sampled. Bulk density and grain density values are both very low and porosity values are high.

VI. RESULTS

Analysis of data consists of statistical tests and computer analysis. Both vertical and horizontal variations are shown to be present.

The first statistical test is Student's t - test. The purpose of this test is to attempt to prove that significant differences exist between the parameter means obtained at each locality sampled. Mean values are analyzed for the following: quartz, plagioclase, biotite, hornblende, percent of crystals, anorthite content, bulk density, grain density and porosity.

The equation for t is:

$$t = \frac{\bar{Y} - u}{s/\sqrt{n}}$$

in which $\bar{Y}$ is the mean of the group being tested, u is the mean of the total population, s is the standard deviation of the population and n is the number of samples in the group. The applicable t values for the .20 significance level are:

$t_{.2(2)} = 1.886$	$t_{.2(9)} = 1.383$
$t_{.2(3)} = 1.638$	$t_{.2(16)} = 1.337$
$t_{.2(4)} = 1.533$	$t_{.2(26)} = 1.315$

The number in parenthesis is the degrees of freedom which are equal to the number of samples minus one. If the t test gives a value greater than the above values, then one rejects the hypothesis that there is no difference between the means from localities sampled, i.e., lateral variation is present. The following results are obtained by use of the t test.

Quartz $u = 6.4$ $s = 3.6$

t_{BM} (10 samples) =	.525 (1.383)	accepted
t_{CC} (17 samples) =	.342 (1.337)	accepted

t_{NA} (17 samples) =	.915	(1.337)	accepted
t_{MG} (27 samples) =	2.598	(1.315)	rejected
t_{PG} (4 samples) =	- .832	(1.638)	accepted
t_{OJ} (3 samples) =	-1.105	(1.886)	accepted
t_{SE} (5 samples) =	- .930	(1.533)	accepted
t_{WM} (3 samples) =	-1.202	(1.886)	accepted

The results indicate that the average percent of quartz at the Mackleprang locality is significantly higher than the average.

Plagioclase $u = 27.1$ $s = 6.7$

t_{BM} =	.000	acc.	t_{PG} =	-1.224	acc.
t_{CC} =	1.233	acc.	t_{OJ} =	-2.818	rej.
t_{NA} =	.309	acc.	t_{SE} =	-4.072	rej.
t_{MG} =	2.562	rej.	t_{WM} =	.156	acc.

The Mackleprang, Orton Junction and South Egan localities differ significantly from the average plagioclase content. Mackleprang has more plagioclase, Orton Junction and South Egan less.

Biotite $u = 3.4$ $s = 1.5$

t_{BM} =	.629	acc.	t_{PG} =	- .529	acc.
t_{CC} =	.000	acc.	t_{OJ} =	.688	acc.
t_{NA} =	-1.375	rej.	t_{SE} =	-2.079	rej.
t_{MG} =	1.726	rej.	t_{WM} =	- .575	acc.

The New Arrowhead, Mackleprang and South Egan localities differ significantly from the average biotite content. Mackleprang has more biotite, New Arrowhead and South Egan less biotite.

Hornblende $u = 3.9$ $s = 2.1$

t_{BM} =	2.858	rej.	t_{PG} =	- .666	acc.
t_{CC} =	- .981	acc.	t_{OJ} =	1.484	acc.

t_{NA}	= - .783	acc.	t_{SE}	= 2.129	rej.
t_{MG}	= 1.730	rej.	t_{WM}	= .081	acc.

The Blue Mountain, Mackleprang and South Egan localities differ significantly from the average hornblende content. Mackleprang and Blue Mountain have more hornblende, South Egan less hornblende.

Total crystals u = 42.5 s = 8.2

t_{BM}	= .538	acc.	t_{PG}	= 1.780	rej.
t_{CC}	= .449	acc.	t_{OJ}	= -3.209	rej.
t_{NA}	= -1.055	acc.	t_{SE}	= -4.917	rej.
t_{MG}	= 3.138	rej.	t_{WM}	= -2.387	rej.

The Mackleprang, Parowan Gap, Orton Junction, South Egan and White Mountain localities differ significantly from the average total crystal content. Mackleprang is high in total crystals; Parowan Gap, Orton Junction, South Egan and White Mountain are low.

Anorthite content u = 42.2 s = 2.0

t_{BM}	= .520	acc.	t_{PG}	= - .141	acc.
t_{CC}	= - .866	acc.	t_{OJ}	= - .424	acc.
t_{NA}	= 1.386	rej.	t_{SE}	= - .433	acc.
t_{MG}	= 1.265	acc.	t_{WM}	= An not determined	

The average anorthite content of the plagioclase is significantly higher at New Arrowhead than for the other localities sampled.

Bulk density u = 2.42 s = .18

t_{BM}	= 1.373	rej.	t_{PG}	= -1.554	acc.
t_{CC}	= -1.600	rej.	t_{OJ}	= -2.404	rej.
t_{NA}	= 1.520	rej.	t_{SE}	= -5.465	rej.
t_{MG}	= .577	acc.	t_{WM}	= - .577	acc.

The Blue Mountain, Condor Canyon, New Arrowhead, Orton Junction

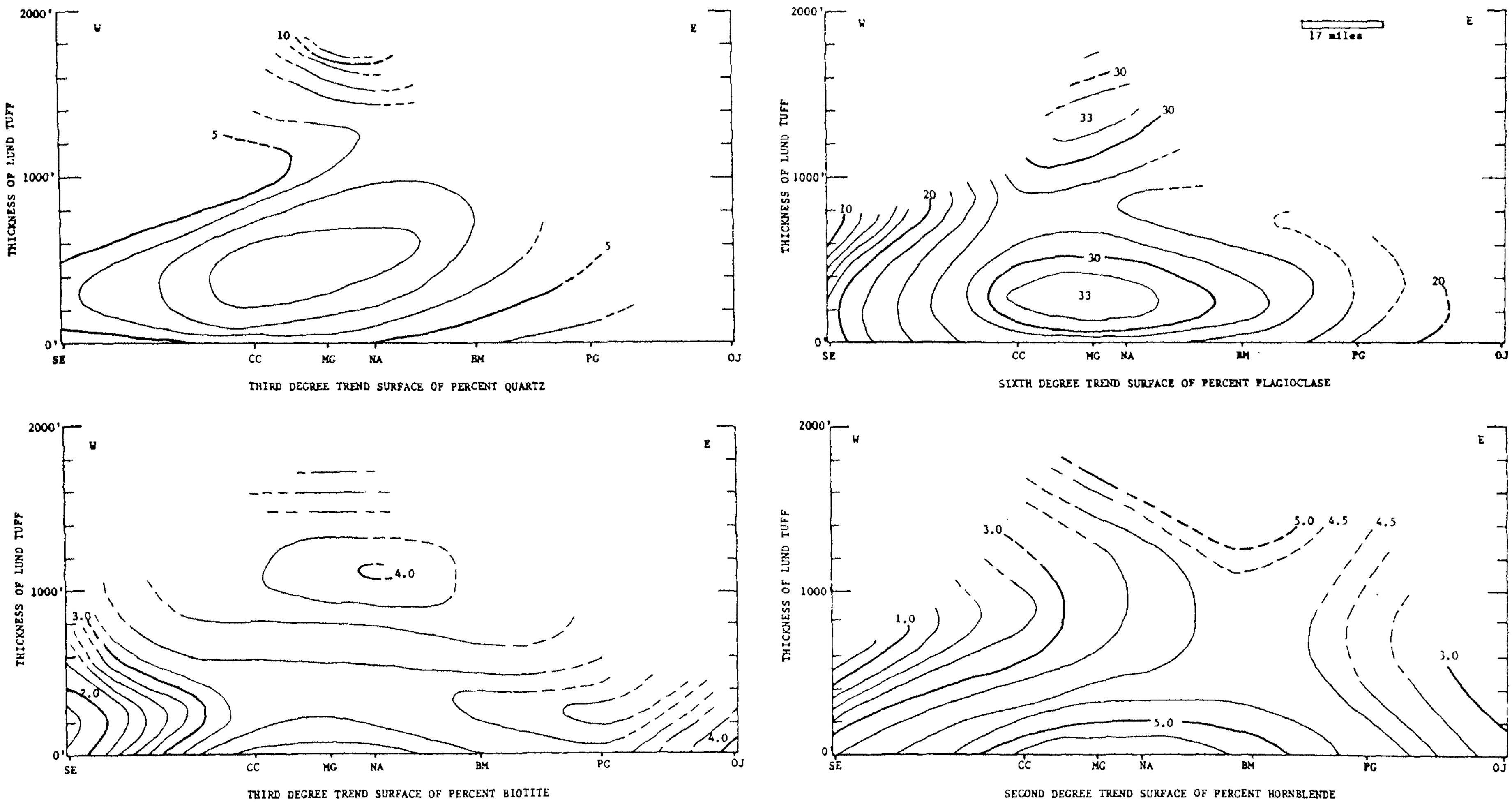


Figure 6. Trend surface analyses of mineralogical data.

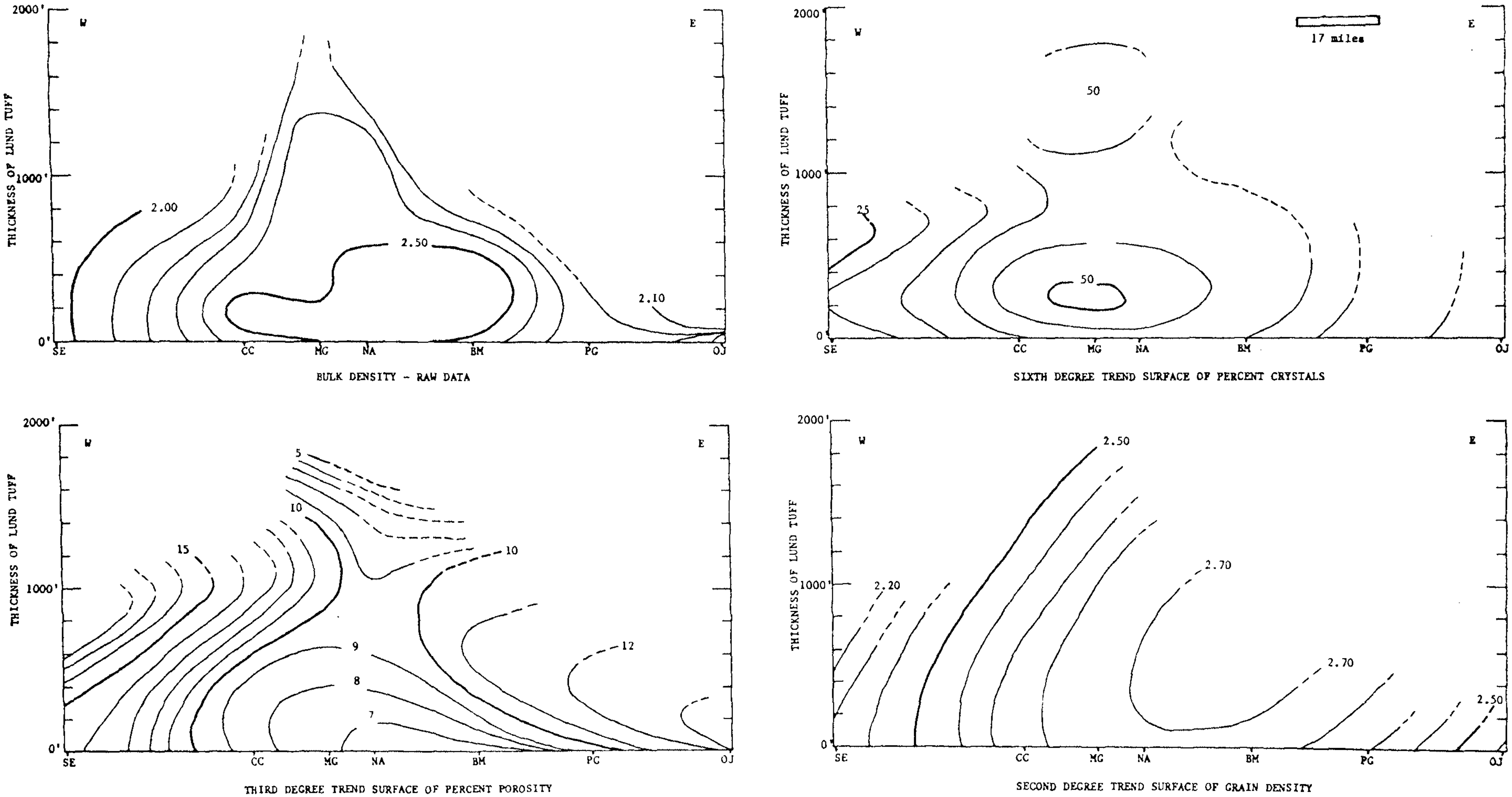


Figure 7. Trend surface analyses of total crystals, grain density and porosity data and contours of bulk density.

and South Egan localities differ significantly from the average bulk density. Blue Mountain and New Arrowhead have a high bulk density; Condor Canyon, Orton Junction and South Egan a low bulk density.

Grain density $u = 2.64$ $s = .12$

$t_{BM} =$	2.750	rej.	$t_{PG} =$	- .832	acc.
$t_{CC} =$	1.031	acc.	$t_{OJ} =$	-2.742	rej.
$t_{NA} =$	3.437	rej.	$t_{SE} =$	-5.590	rej.
$t_{MG} =$	-2.598	rej.	$t_{WM} =$	- .385	acc.

The Blue Mountain, New Arrowhead, Mackleprang, Orton Junction and South Egan localities differ significantly. Blue Mountain and New Arrowhead have a high average grain density; Mackleprang, Orton Junction and South Egan, a low average grain density.

Porosity $u = 9.0$ $s = 4.1$

$t_{BM} =$	- .400	acc.	$t_{PG} =$	1.364	acc.
$t_{CC} =$	3.216	rej.	$t_{OJ} =$	1.013	acc.
$t_{NA} =$	.000	acc.	$t_{SE} =$	3.434	rej.
$t_{MG} =$	-4.307	rej.	$t_{WM} =$	- .464	acc.

The Condor Canyon, Mackleprang and South Egan localities differ significantly from the average porosity. Mackleprang has a low porosity; Condor Canyon and South Egan a high porosity.

Computer analysis is performed with a trend surface program (Esles, 1968), which shows whether both vertical and lateral variations are present. This program is adapted to provide trend surface analyses for a vertical east-west cross-section of the ash-flow unit. Up to six orders are possible. The best fit is chosen from among these six and tested for significance.

The postulation that the upper surface of an ash-flow is nearly horizontal after the flow comes to rest, has been offered in the past. It was also thought that much variation might exist in the elevation of the base of the unit. For our trend analysis, the opposite point of view is taken, for two reasons. First, the Lund Tuff is the uppermost member of many ash-flow units in the Needles Range Formation. These units, as they were formed, would have the effect of leveling the topography before the extrusion of the Lund. Second, a thickness difference of 2000 feet over an 80 mile distance may be explained by less than a 1° slope in the land surface away from the source area after the Lund eruption was completed. For these reasons, the position of samples at each locality is expressed as a particular distance above a base. For obvious reasons, vertical exaggeration in scale is used.

The sections in Figure 6 show some contoured trend surface modal analyses of the Lund Tuff. All four surfaces show two areas of high concentration and biotite shows three. These paired areas of high concentration occur near the Mackleprang locality. Although the areas of high concentration occur at or near the Mackleprang locality, no two surfaces have exactly the same vertical trend of concentration. When all four sections are superimposed, a vertical sequence of mineral concentrations near the Mackleprang locality becomes apparent. This sequence is, from bottom to top, biotite, hornblende, plagioclase, quartz, biotite, plagioclase and finally, hornblende and quartz together.

There are several possible explanations for vertical variations in mineralogy. The first is a zoned magma chamber. This does not seem to be the case, since the previously mentioned vertical sequence of mineral concentrations does not concur with that from a single zoned chamber. A case could be made, however, for two separate chambers, one contributing to the lower part of the tuff and the other to the upper part. Another explanation might be a sequential crystallization in the magma chamber in which crystallization and extrusion of early mafic components of the magma would underlie the more salic components after emplacement. A simple sequence is not indicated by the vertical sequence of mineral concentrations present, although two separate (in time) source chambers are possible. Vertical trends in density, porosity and petrographic features at the Mackleprang locality (Figure 5) indicate subtle hiatus. Separate ash-flows have been deposited, but cooled essentially as one unit. In the short time between successive pulses or flows, there may have been some changes in the composition of the magma in its chamber, or simply changes in the relative portion of the magma that is tapped. Possible explanations for changes in the crystallized portion of the magma include reaction of the magma with the surrounding wall rock, contamination by a second magma, or replenishing of the chamber with newly formed magma.

Trend surface analyses also point to lateral variations in mineralogy. These lateral variations are, in most cases, the same as are shown by the previously discussed _t_ - tests. Mineral concentrations are slightly asymmetrical with respect to the central area of each section, with a decrease in the percent of each mineral away from the center. This decrease is sharper toward the west than toward the east. Slight lateral differences in relative mineral abundances are also apparent from comparison between the concentrations at each locality. Maximum values for quartz are somewhat shifted toward the Condor Canyon and South Egan localities, and maximum values for hornblende are shifted toward the New

Arrowhead and Blue Mountain localities.

The lateral decrease in the concentration of each mineral, away from the Mackleprang locality, generally follows the same trends as that shown for the total crystal content of the rock (see Figure 7). This decrease in crystal content is due to differential lateral sorting, in which leading portions of the ash-flow contain more of the lighter fraction (shards and pumice) while trailing portions contain more of the heavier portions (crystals and large lithic fragments). An explanation for the sharper decrease in crystal content toward the west than toward the east is only speculative in nature. Perhaps slight differences in topography existed during ash-flow emplacement or the force of expulsion was not symmetrical with respect to the eruptive center.

Trend surface analyses pertaining to physical features of the Lund Tuff are shown in Figure 7, along with the contours of bulk density. Porosity curves show, for most localities, a general vertical increase in porosity. No clear-cut vertical trend in grain density is established. Direct contouring of bulk density shows higher values near the base with a general increase toward the top.

Vertical trends in porosity and bulk density are generally the same as those formerly shown for a single cooling unit (Smith, 1960).

The increase in porosity from the bottom to the top of the unit is directly related to decreased welding caused by lower temperatures and pressures. The decrease in pressure is a function of the amount of overlying material. The decrease in temperature is a function of the porosity of the cooling unit. In the more porous parts of the tuff gases escape more readily, thus allowing the temperature to decrease. Temperature is also related to the ability of the cooling unit to retain heat.

Retention of heat is most effective in the central, insulated portion of the cooling unit. Variations in bulk density contours also point out a vertical decrease in welding.

Lateral variations are well established for porosity, grain density and bulk density. Porosity contours show a higher degree of welding in the thicker, central portion of the tuff, with a more rapid decrease to the west than to the east. Maximum grain density values occur near the New Arrowhead locality and again, decrease more rapidly to the west. Bulk density contours incorporate characteristics of both the grain density and porosity analyses. Bulk density varies directly with grain density and inversely with porosity. Total crystal content is highest near the Mackleprang localtiy and decreases more rapidly to the west. Crystal content correlates well with grain density trends. Perhaps analysis of the glassy portion of the rocks would explain the shifted maximum of grain density concentration, since this is not explained by the slight differences in mineralogy between selected localities.

Much of the previous evidence of lateral variation points to the location of a possible source area for the Lund Tuff. Near the source, crystal content of the rock would be highest because of differential lateral sorting. When the total crystal content of the rock is high, there will be a corresponding maximum in grain density, because crystals are the more dense fraction of the Lund Tuff. Finally, welding should be most nearly complete in the locality where there is the greatest thickness and heat content, i.e., near the center of the field, specifically, the Mackleprang and New Arrowhead localities. There is, in fact, a large stock of granodiorite composition located between the Mackleprang and New Arrowhead localities that may well have followed the same conduit, as did the frothing magma that formed the Lund. Other possible sources that cannot be ruled out could lie in the volcanic flow-complex field centered near the old town of Frisco, Utah, ranging as far west as Wah Wah Pass and as far east as Minersville, and in the flow pile between Modena and Stateline, Utah. In addition, there are unstudied possible source localities in Eastern Lincoln County, Nevada.

VII. CONCLUSIONS

The Lund Tuff is a distinct member of the Needles Range Formation which may be correlated over an area of several thousand square miles.

Both vertical and lateral variations in mineralogy are present within the member. Vertical variations in mineralogy can be best explained by changes in crystal content within the magma chamber between successive ash-flows within the member. Two major crystallization cycles are indicated.

Lateral variations in mineral abundances are consistent for each species. Mineral concentrations decrease away from the central area of the cooling unit. This decrease is due to lateral sorting of ash-flows within the unit.

Vertical and lateral variations are also present in the porosity, bulk density and grain density of the Lund Tuff. Vertical variations in these physical properties coincide with those variations normally observed in a simple cooling unit. Bulk density decreases from bottom to top. Porosity increases from bottom to top in the cooling unit. No clear-cut vertical trends in grain density are obvious.

Lateral variations in physical properties show gradational changes away from the central, thickest portion of the tuff. Porosity increases away from the central area of the cooling unit. Grain density and bulk density decrease away from the central area of the cooling unit. Lateral increases in porosity are a result of a decrease in lateral welding in the unit. Decreases in grain density are explained by lateral sorting of ash-flows within the unit. Lateral decreases in bulk density are related to changes in both porosity and grain density.

The central area of the cooling unit is probably near the source area for the Lund member of the Needles Range Formation.

APPENDIX

TABLE I

MINERALOGIC DATA FOR LUND SAMPLES

BLUE MOUNTAIN SECTION

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-17	755	17.1	13.9	3.8	3.7	.00	.8	39.2	....
K-16	703	34.4	5.2	3.4	5.4	.17	1.4	49.9	....
K-14	602	28.1	4.4	5.2	4.6	.31	1.5	44.1	41.2
K-12	527	30.0	4.7	2.9	6.8	.01	1.6	46.0	....
K-10	387	20.3	5.3	3.6	5.5	.00	1.5	36.2	....
K- 8	287	26.1	5.0	2.7	6.7	.19	1.6	42.3	41.9
K- 6	183	28.5	6.0	4.2	4.9	.04	.8	44.4	....
K- 4	100	26.9	4.1	3.7	6.1	.00	1.7	42.5	....
K- 3	67	30.9	4.4	3.3	7.4	.06	1.6	48.2	45.3
K- 1	0	28.8	4.8	3.8	7.2	.00	1.8	46.4	....
Ave		27.1	5.8	3.7	5.8	.08	1.4	43.9	42.8
Stnd. Dev.		3.9	2.9	.7	1.2	.11	.4	4.1	2.2

CONDOR CANYON SECTION

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-34	903	27.4	5.7	3.4	1.3	.10	.6	38.5	....
K-33	883	26.4	6.2	3.5	1.6	.08	.7	38.5	....
K-32	853	27.4	8.3	2.6	.7	.09	.5	39.6	42.7
K-31	773	25.5	7.8	1.5	.0	.00	.9	35.7	....
K-30	740	21.8	4.9	1.4	.0	.01	.7	28.8	....
K-29	694	29.6	6.6	1.7	.0	.00	1.3	39.2	....

CONDOR CANYON SECTION CONTINUED

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-28	605	22.8	6.7	4.1	3.2	.00	1.0	37.8	....
K-27	554	31.7	4.8	4.2	4.6	.00	1.1	46.4	....
K-26	489	27.1	8.2	5.0	2.0	.00	.8	43.1	....
K-25	415	32.9	5.3	5.9	6.1	.00	.5	50.7	41.8
K-24	364	30.2	4.4	4.1	4.5	.02	.6	43.8	....
K-23	304	40.2	8.4	4.4	6.8	.00	.7	60.5	....
K-22	234	34.1	6.3	3.0	4.9	.08	1.0	49.4	....
K-21	201	26.8	7.8	2.9	5.3	.06	.8	43.7	....
K-20	113	36.0	6.3	3.2	4.9	.08	.7	51.2	....
K-19	52	29.0	11.6	2.8	4.8	.00	.8	49.0	39.0
K-18	20	26.2	4.6	3.3	7.2	.00	1.0	42.3	....
Ave		29.1	6.7	3.4	3.4	.03	.8	43.4	41.2
Stnd. Dev.		4.7	1.9	1.1	2.5	.04	.2	6.6	1.9

NEW ARROWHEAD SECTION

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-55	1127	30.0	6.9	1.4	2.8	.09	.6	41.8	42.2
K-53	956	31.0	2.6	2.0	5.9	.07	.6	42.2	....
K-52	894	20.7	7.4	6.0	1.7	.00	.6	36.4	....
K-51	842	15.5	3.7	6.4	1.2	.09	.4	27.3	....
K-50	785	25.0	17.1	.6	6.8	.09	.5	50.1	....
K-49	693	26.6	4.8	.7	1.6	.09	1.0	34.8	....
K-48	650	27.8	6.9	2.2	2.6	.03	.7	40.2	....
K-47	581	17.8	3.2	1.1	2.4	.03	.9	25.9	....
K-46	517	31.1	5.4	7.5	1.4	.00	.6	46.0	....

NEW ARROWHEAD SECTION CONTINUED

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-45	498	28.1	5.8	2.5	2.5	.09	.5	39.5	42.8
K-44	432	36.4	6.6	3.0	3.1	.04	.7	49.8	....
K-43	388	39.4	9.3	1.6	7.0	.12	1.0	58.4	....
K-41	276	31.8	2.1	1.6	1.7	.04	1.0	38.2	....
K-40	215	29.8	6.7	4.1	4.5	.00	.8	45.9	....
K-39	162	27.1	5.0	2.9	1.8	.00	1.0	37.8	....
K-37	96	25.8	1.0	2.0	7.5	.00	.9	37.2	....
K-35	7	24.5	.6	4.5	5.2	.00	1.5	36.3	46.2
Ave		27.6	5.6	2.9	3.5	.04	.8	40.4	43.8
Stnd. Dev.		6.0	3.8	2.1	2.2	.04	.3	8.1	2.1

MACKLEPRANG SECTION

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-112	1765	25.0	8.4	3.2	4.2	.48	1.1	42.4	....
K-111	1714	28.4	13.6	3.1	5.4	.12	.9	51.5	40.8
K-110	1656	34.0	3.7	1.7	6.1	.20	.6	46.3	....
K-109	1598	27.3	15.7	2.4	3.3	.12	1.1	49.9	....
K-108	1498	36.9	6.2	4.4	1.8	.17	.7	50.2	....
K-107	1368	24.7	9.2	4.9	3.6	.06	.6	43.1	....
K-106	1275	29.1	6.6	6.6	7.3	.00	.9	50.5	....
K-105	1188	30.7	2.1	4.7	5.1	.02	.6	43.2	44.5
K-104	1124	36.8	3.4	3.3	4.1	.42	.5	49.4	....
K-103	1044	27.6	2.5	3.9	4.3	.65	.9	39.8	....
K-102	958	36.5	9.0	3.7	4.1	.44	1.1	54.8	....
K-101	871	28.0	8.4	6.0	4.8	.10	.6	47.9	....

MACKLEPRANG SECTION CONTINUED

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-100	850	30.1	7.0	4.5	3.3	.19	.6	45.7	....
K- 99	799	34.4	5.9	3.6	5.7	.31	1.4	51.3	44.2
K- 98	670	34.1	8.2	5.1	4.3	.41	1.2	53.3	....
K- 97	569	28.8	16.5	2.6	2.2	.09	1.8	52.0	....
K- 96	483	36.2	9.5	5.8	4.8	.08	.7	57.1	....
K- 95b	411	28.2	12.5	5.0	5.6	.81	1.2	53.3	....
K- 95a	338	25.0	14.8	2.6	.6	.23	1.0	44.2	47.0
K- 94	266	37.1	10.5	2.7	3.9	.08	.8	55.1	....
K- 93	216	32.2	13.4	3.3	3.0	.12	.6	52.6	41.0
K- 92	151	39.4	9.8	4.5	3.5	.38	1.5	59.1	....
K- 91	86	30.9	5.8	3.4	5.3	.12	2.5	48.0	41.2
K- 90	22	24.7	3.6	3.5	8.7	.00	1.3	41.8	40.8
K- 89	14	23.6	2.3	2.3	8.7	.00	2.1	39.0	44.2
K- 88	10	20.9	8.9	4.1	4.5	.04	1.2	39.6	42.2
K- 87	0	30.0	3.8	5.1	6.0	.00	1.6	46.5	44.0
Ave		30.4	8.2	3.9	4.6	.21	1.1	48.4	43.0
Stnd. Dev.		4.9	4.2	1.2	1.7	.21	.5	5.5	2.1

PAROWAN GAP SECTION

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-116	110	27.9	4.4	2.6	2.8	.01	.7	38.4	41.6
K-115	79	26.3	4.6	3.6	2.6	.00	1.6	38.7	....
K-114	65	17.8	2.8	2.8	2.9	.14	1.0	27.4	43.3
K-113	12	20.2	7.9	2.8	4.3	.17	.8	36.1	....
Ave		23.0	4.9	3.0	3.2	.08	1.0	35.2	42.4
Stnd. Dev.		4.8	2.1	.4	.8	.09	.4	6.3	.9

ORTON JUNCTION SECTION

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
K-119	35	15.3	3.7	4.3	1.9	.21	.8	26.3	43.2
K-118	23	17.3	4.4	4.0	1.6	.01	1.0	28.3	....
K-117	0	15.9	4.3	3.6	2.7	.17	.7	27.4	40.1
Ave		16.2	4.1	4.0	2.1	.11	.9	27.3	41.6
Stnd. Dev.		1.0	.4	.4	.6	.11	.2	1.0	1.3

SOUTH EGAN SECTION

Smpl No.	Ft/Above Base	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
179	605	12.4	3.4	2.9	2.0	.03	.4	21.1	43.8
180	510	11.6	.4	1.1	3.8	.01	.8	17.7	....
182	400	12.5	10.3	2.1	.8	.06	.5	26.2	40.1
184	260	19.3	6.5	2.5	2.2	.08	.4	31.0	....
177	125	18.9	4.1	1.3	.8	.06	.4	25.5	41.2
Ave		14.9	4.9	2.0	1.9	.04	.5	24.3	41.7
Stnd. Dev.		3.8	1.3	.8	1.3	.03	.2	5.1	1.9

WHITE MOUNTAIN SECTION

Smpl No.	Percent Thickness	% Pl	% Qtz	% Bio	% Hb	% Sp	% Fe Oxides	% XLs	Ave % An
710	98	31.5	1.7	3.3	2.8	.00	.8	40.1	....
693	3	24.0	6.1	2.5	4.7	.00	1.8	39.1	....
692	1	8.4	.1	1.7	2.8	.00	1.5	14.4	....
Ave		27.7	3.9	2.9	4.0	.00	1.3	31.2	....
Stnd. Dev.		14.1	3.5	1.2	1.3	.00	.5	11.8	....

TABLE II

DENSITY AND POROSITY DATA FOR LUND SAMPLES

BLUE MOUNTAIN SECTION

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
K-17	755	2.25	2.78	19.2
K-16	703	2.37	2.75	13.6
K-15	641	2.40	2.74	12.3
K-14	602	2.45	2.63	6.6
K-13	572	2.43	2.70	9.5
K-12	527	2.51	2.73	8.0
K-11	444	2.51	2.70	7.4
K-10	387	2.51	2.72	7.6
K- 9	337	2.57	2.70	5.4
K- 8	287	2.54	2.72	6.6
K- 7	237	2.55	2.75	7.2
K- 6	183	2.49	2.74	9.0
K- 5	133	2.47	2.73	9.5
K- 4	100	2.60	2.74	5.2
K- 3	67	2.58	2.72	5.2
K- 2	33	2.57	2.71	5.3
K- 1	0	2.42	2.66	9.0
Ave		2.48	2.72	8.6
Stnd. Dev.		.09	.03	3.6

CONDOR CANYON SECTION

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
K-34	903	2.19	2.60	15.7
K-33	883	2.03	2.54	19.9
K-32	853	2.11	2.58	16.6
K-31	773	2.31	2.65	13.2
K-30	740	2.19	2.60	15.6
K-29	694	2.25	2.62	14.2
K-28	605	2.34	2.70	12.6
K-27	554	2.30	2.75	16.7
K-26	489	2.41	2.70	10.9
K-25	415	2.45	2.67	8.0
K-24	364	2.32	2.70	13.9
K-23	304	2.50	2.71	8.0
K-22	234	2.52	2.68	7.2
K-21	201	2.50	2.69	7.3
K-20	113	2.54	2.82	10.2
K-19	52	2.50	2.73	8.5
K-18	20	2.47	2.72	9.1
Ave		2.35	2.67	12.2
Stnd. Dev.		.16	.07	4.0

NEW ARROWHEAD SECTION

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
K-55	1127	2.43	2.73	11.0
K-54	1036	2.38	2.70	11.6
K-53	956	2.39	2.74	12.7

NEW ARROWHEAD SECTION CONTINUED

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
K-52	894	2.44	2.65	7.8
K-51	842	2.47	2.66	7.4
K-50	785	2.42	2.76	12.1
K-49	693	2.43	2.77	12.5
K-48	650	2.48	2.76	10.2
K-47	581	2.51	2.82	10.6
K-46	517	2.46	2.69	8.6
K-45	498	2.48	2.72	9.0
K-44	432	2.48	2.73	9.3
K-43	388	2.53	2.76	8.0
K-42	341	2.46	2.65	7.0
K-41	276	2.48	2.73	9.0
K-40	215	2.51	2.79	9.8
K-39	162	2.52	2.77	9.0
K-38	122	2.52	2.70	6.8
K-37	96	2.58	2.75	5.5
K-36	56	2.60	2.74	4.9
K-35	7	2.59	2.76	6.3
Ave		2.48	2.73	9.0
Stnd. Dev.		.06	.04	2.3

MACKLEPRANG SECTION

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
K-112	1765	2.38	2.58	7.6
K-111	1714	2.39	2.59	6.2
K-110	1656	2.33	2.50	7.2

MACKLEPRANG SECTION CONTINUED

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
K-109	1598	2.37	2.50	5.4
K-108	1498	2.38	2.58	7.7
K-107	1368	2.43	2.56	5.2
K-106	1275	2.50	2.62	4.6
K-105	1188	2.46	2.58	5.3
K-104	1124	2.48	2.63	5.7
K-103	1044	2.43	2.58	6.0
K-102	958	2.53	2.62	3.5
K-101	871	2.42	2.55	5.5
K-100	850	2.48	2.63	5.7
K- 99	799	2.48	2.58	4.0
K- 98	670	2.47	2.57	4.3
K- 97	569	2.44	2.57	4.9
K- 96	483	2.50	2.63	5.0
K- 95b	411	2.43	2.58	5.7
K- 95a	338	2.41	2.59	7.2
K- 94	266	2.49	2.63	5.0
K- 93	216	2.52	2.63	4.2
K- 92	151	2.55	2.70	5.7
K- 91	86	2.58	2.72	5.2
K- 90	22	2.50	2.58	2.9
K- 89	14	2.44	2.54	3.8
K- 88	10	2.29	2.43	5.7
K- 87	0	2.18	2.48	11.8
Ave		2.44	2.58	5.6
Stnd. Dev.		.08	.06	1.7

PAROWAN GAP SECTION

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
K-116	110	2.24	2.58	13.1
K-115	79	2.29	2.60	11.6
K-114	65	2.31	2.60	10.9
K-113	12	2.27	2.58	11.8
Ave		2.28	2.59	11.8
Stnd. Dev.		.03	.01	.9

ORTON JUNCTION SECTION

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
K-119	35	2.02	2.46	17.9
k-118	23	2.08	2.36	11.7
K-117	0	2.41	2.53	4.6
Ave		2.17	2.45	11.4
Stnd. Dev.		.21	.08	6.6

SOUTH EGAN SECTION

Smpl No.	Ft/Above Base	Bulk Density	Grain Density	Percent Porosity
179	605	2.14	2.48	13.5
180	510	1.76	2.14	17.6
182	400	2.00	2.22	11.3
184	260	1.99	2.44	18.3
177	125	2.02	2.44	15.8
Ave		1.98	2.34	15.3
Stnd. Dev.		.14	.15	3.2

WHITE MOUNTAIN SECTION

Smpl No.	Percent Thickness	Bulk Density	Grain Density	Percent Porosity
710	98	2.04	2.43	15.9
693	3	2.58	2.70	4.4
692	1	2.52	2.60	3.3
Ave		2.38	2.58	7.9
Stnd. Dev.		.30	.11	7.0

TABLE III

COLOR CODING FOR LUND SAMPLES

BLUE MOUNTAIN SECTION (Ave 10 R 5/2)

Smpl No.	Color Code No.	Smpl No.	Color Code No.
K-17	7 R 7/2	K-8	6 R 5/2
K-16	7 R 5.5/2	K-7	12 YR 4.5/1.5
K-15	7 R 6.5/2	K-6	7 R 4.25/2
K-14	10 R 5.75/2.5	K-5	10 R 4.5/2.5
K-13	10 R 5/2	K-4	10 R 4.25/2.5
K-12	14 YR 4.5/1.75	K-3	7 R 4.25/2.5
K-11	12 YR 5/2	K-2	7 R 4.5/2
K-10	14 YR 4.5/1.75	K-1	10 R 4/2
K-9	10 R 4/2		

CONDOR CANYON SECTION (Ave 9 R 6/2)

Smpl No.	Color Code No.	Smpl No.	Color Code No.
K-34	17 YR 7.5/2	K-25	6 R 6/2
K-33	12 YR 7.75/1.25	K-24	5 R 8/2
K-32	15 YR 7/1	K-23	12 YR 5/2
K-31	6 R 6/1.5	K-22	15 YR 5.5/1
K-30	5 R 6/2	K-21	11 YR 5.5/2
K-29	5 R 6.5/2	K-20	7 R 6.25/2.5
K-28	10 R 6.5/2	K-19	7 R 5/2
K-27	10 R 7/2	K-18	7 R 4/2
K-26	5 R 6/2		

NEW ARROWHEAD SECTION (Ave 18 YR 4.5/2)

Smpl No.	Color Code No.	Smpl No.	Color Code No.
K-55	10 R 5/2	K-44	15 YR 5/1.25
K-54	15 YR 5.5/1	K-43	15 YR 4/1.5
K-53	12 YR 5.5/2	K-42	15 YR 5.25/1.25
K-52	15 YR 5.25/2	K-41	15 YR 5.5/3.25
K-51	15 YR 5.5/1.5	K-40	15 YR 4.5/1
K-50	13 YR 5.5/1.75	K-39	10 R 4/2
K-49	10 R 5.5/2	K-38	15 YR 4.5/1.5
K-48	15 YR 5/1.5	K-37	9 R 3.75/2.5
K-47	15 YR 4/1.5	K-36	15 YR 4/1
K-46	15 YR 5.5/1.25	K-35	16 YR 3.75/1.75
K-45	10 R 5/4		

MACKLEPRANG SECTION (Ave 15 YR 6/1.5)

Smpl No.	Color Code No.	Smpl No.	Color Code No.
K-112	N 7	K-100	15 YR 4.75/2
K-111	35 GY 7.5/.5	K-99	15 YR 5/2
K-110	15 YR 7/.5	K-98	15 YR 5.5/3
K-109	N 7	K-97	15 YR 6.5/1.5
K-108	N 7.5	K-96	15 YR 5.25/1.5
K-107	15 YR 6/1	K-95b	15 YR 6.5/1.5
K-106	15 YR 6.75/1.5	K-95a	15 YR 6.5/2
K-105	15 YR 5.5/3	K-94	15 YR 5/2
K-104	15 YR 5.5/3	K-93	15 YR 6/2
K-103	15 YR 5.5/3	K-92	15 YR 5/2
K-102	15 YR 5/2	K-91	15 YR 5/1
K-101	15 YR 5/2	K-90	N 2

MACKLEPRANG SECTION CONTINUED

Smpl No.	Color Code No.	Smpl No.	Color Code No.
K-89	N 3	K-87	15 YR 7.5/.5
K-88	15 YR 7/2		

PAROWAN GAP SECTION (Ave 7.5 R 6.5/2)

Smpl No.	Color Code No.	Smpl No.	Color Code No.
K-116	5 R 7/2	K-114	5 R 5/2
K-115	15 YR 7/.5	K-113	5 R 7/2

ORTON JUNCTION SECTION (Ave 13 YR 6/1)

Smpl No.	Color Code No.	Smpl No.	Color Code No.
K-119	15 YR 7.5/.5	K-117	10 R 4/2
K-118	15 YR 7/1		

SOUTH EGAN SECTION (Ave 15YR 8/1)

Smpl No.	Color Code No.	Smpl No.	Color Code No.
179	15 YR 8/1	184	N 8
180	15 YR 8/1	177	N 8
182	N 8		

WHITE MOUNTAIN SECTION (Ave 18 YR 5.5/2)

Smpl No.	Color Code No.	Smpl No.	Color Code No.
710	25 Y 7/2	692	15 YR 5/2
693	15 YR 5/2		

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