Geochemical and Petrological Studies of the Lost Creek Gneiss, Mason and McCulloch Counties, Texas

by

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INTRODUCTION

Potassium feldspar porphyroblasts in metamorphic rocks have been designated by various terms in the literature. They are referred to as "insets," "eyes," and more commonly, "augen." These porphyroblasts have often been the subject of broad speculation by metamorphic petrologists. The controversy concerning augen gneisses may exist because the porphyroblasts have no one common mode of formation and because each augen gneiss should be studied with the thought in mind that it has its own particular genesis.

The problem, therefore, involves a study of an augen gneiss in Mason and McCulloch Counties and a comparison of this gneiss with the Red Mountain gneiss of Llano County to determine whether there is a genetic relation between the two bodies. The Red Mountain gneiss, mapped by Paige (1912) and studied by Boyer and Clabaugh (1959), is also an augen gneiss and in the field appears to be very similar to the augen gneiss of Mason and McCulloch Counties. The Red Mountain gneiss is located 17 air miles southeast of Llano and approximately 50 air miles southeast of the augen gneiss studied in this report. Paige, as well as Boyer and Clabaugh, concluded that the type Red Mountain gneiss is a metamorphosed igneous intrusion. Having not seen the area in the field and having looked at very few thin sections and hand specimens, the writer can only tentatively accept their hypothesis.
In this paper the writer has attempted to propose a feasible origin of the augen gneiss of Mason and McCulloch Counties. This augen gneiss has been tentatively named the Red Mountain gneiss by Barnes (personal communication) because of the similarity of the two bodies in the field. However, if the two bodies do not seem to be genetically related, another name should be proposed, or the Mason-McCulloch gneiss should be included with an already-defined Precambrian unit. For the sake of brevity and because the writer believes that there is a difference in the two gneisses, the augen gneiss of Mason and McCulloch Counties shall hereafter be referred to as the Lost Creek gneiss, named after a small creek along which the best outcrops are found.

Location

The area studied is located along the county line of Mason and McCulloch Counties in the Llano Uplift or Central Mineral Region, Texas (Figure 2). The approximate boundaries of the area mapped are: 30°50' - 30°59' north latitude and 99°05' - 99°08' west longitude, roughly 10 by 3 1/2 miles. The gneiss crops out in a long linear belt which follows along Farm Road 734 and Ranch Road 386 between the towns of Mason and Brady, Texas. The southern boundary of the area mapped is approximately 8 air miles northeast of Mason.
Figure 2. Map showing location of the Lost Creek gneiss area.
Although within the confines of the Llano Uplift, the area has always been referred to as "undifferentiated Precambrian." Sidney Paige's classic map of the Llano and Burnet quadrangles (1912) only extended west to 99°00' west longitude.

General Description

The Lost Creek gneiss is in reality a composite of five bodies in the area mapped—in reference to size only, two larger and three smaller bodies (Figure 1). The Lost Creek gneiss trends north-northeast, parallel to the major trend of the faulting. The gneiss is Precambrian in age.

The area in which the gneiss crops out is generally of low relief. In the northern part of the area, the rock has developed a thick soil profile that has been extensively cultivated. To the south, the rock is more durable and crops out in low, rounded knobs and ridges. To the west, the Precambrian Town Mountain granite weathers to form large exfoliation domes that stand high in relief over the rest of the area. The largest of these hills, locally referred to as "Spy Rock," is shown in figure 3 (see also Plate i). To the east, the Cambrian Cap Mountain limestone crops out in low ridges which trend north-south and stand well above the interior cultivated fields. The soil developed on the Cambrian Hickory sandstone is also extensively
Figure 3. Sample locality map of the Lost Creek gneiss area.
cultivated and forms the interior lowlands along with the Lost Creek gneiss. Along fault zones, however, the Hickory sandstone tends to stand in low ridges. To the southeast, the Precambrian Valley Spring gneiss crops out in ridges trending east-northeast. Therefore, because of its weathering characteristics, the Lost Creek gneiss lies in a small interior valley with granite knobs to the west and Valley Spring gneiss and Cambrian ridges to the east and southeast.
GEOLOGIC SETTING

In general, the Llano Uplift is a structural high and a topographic low, flanked on every side by Cretaceous sediments and with a core of Paleozoic sediments and extensively intruded Precambrian metasediments. Paige (1910) summarized the geology of the Llano Uplift and in 1912 published the Llano-Burnet Folio, which included a large portion of the Uplift. Paige recognized two Precambrian rock units:

II. Packsaddle schist
I. Valley Spring gneiss

He believed that these units were the metamorphic products of a thick sequence of sediments of rather uniform composition. Stenzel (1934) found gneiss sills in the schists and schist lenses in the gneiss and concluded that the Packsaddle schist was the older unit and that the Valley Spring gneiss had intruded it. However, Bridge, Cloud, and Barnes (1947) have substantiated Paige's theory, and most workers in the Llano Uplift believe that both units are metasediments.

Paige described the Valley Spring gneiss as follows:

The Valley Spring gneiss is dominantly light colored and pinkish toned and comprises feldspathic and quartzitic schists, quartzites, wollastonite bands, granular acidic gneisses, and rare amphibolitic portions.

The light-colored portions are as a whole more or less schistose, are sugar-granular or aphanitic in texture, and are in many places
distinguished with difficulty from rocks which may be granular granitic gneisses. The quart-sites are light-colored, fine-grained, recrystallized equivalents of very quartzose sediments, and the amphibolites are not materially different from those in the overlying Packsaddle schist.

He concluded that the Packsaddle schist is composed of a sequence of:

- mica, amphibole, and graphite schists and crystalline limestone. Some lighter-colored, more feldspathic bands, resembling quartzites, are included. . . .

As a whole the schists are characterized by an excellent cleavage, which in the main coincides with the original bedding of the sediments. . . .

Two other gneisses have been mentioned in the literature concerning the Llano Uplift. One of these is the Big Branch gneiss, which crops out in the northwest corner of Blanco County, northeast corner of Gillespie County, and part of Llano County. This gneiss is believed to be derived from an igneous rock of quartz diorite composition.

Barnes (1945) described the Big Branch gneiss as follows:

- The Big Branch gneiss intruded the Packsaddle schist and Valley Spring gneiss. Swarms of inclusions, most of Packsaddle schist, are arranged parallel to the foliation. The granites of the area and the pegmatites and aplites intruded the Big Branch gneiss.

The other gneiss which has been mentioned in the literature and which is mapped on the Llano-Burnet Folio is the Red Mountain gneiss.

Paige remarked that:
Gneisses formed almost certainly by the metamorphism of intrusive granites occur in the region. For example, a granitic cross-cutting dike possesses much the same shistose nature as the beds which it cut. Red Mountain, a granite ridge in the southeast corner of the Llano quadrangle, is a noteworthy example of the same phenomenon. The granite of this ridge becomes progressively more gneissoid northwestward, until, at a point near Walker Peak, laminated structure is so evident that were the rock exposed only in this phase it could not be distinguished from beds that are believed to represent sedimentary strata.

Barnes et al. (1950) noted that "a description of the rocks and a description of the type locality should have been given in the text of the Ramberg-Barnes paper (1949) but was inadvertently omitted."

Claybaugh (1959), as well as the preceding workers, believes the Red Mountain to be a metamorphosed igneous intrusion.

Intruded into these metasediments are principally granites and quartz monzonites, the larger bodies generally accompanied by pegmatites, aplites, and aplogranites. Small intrusions, however, include such rocks as granodiorite, quartz diorite, and gabbro. These bodies were intruded either during or after the metamorphism of the previously existing rock and bear no relation to the previously existing metaigneous gneisses.

Stenzel (1934) divided the larger intrusions into three types, based upon their probable age relationships:
III. Sixmile granite - fine-grained, gray, biotite granites

II. Oatman granite - medium-grained, gray to pink, cataclastic granites

I. Town Mountain granite - coarse-grained to porphyritic granites, commonly with large, flesh-colored, feldspar phenocrysts

Keppel (1940), in a reconnaissance report on the granites of the Llano-Burnet region, reported a concentric arrangement of three textural varieties within the granite "massifs." These three concentric zones are, in order of their crystallization:

I. outer - coarse-grained
II. intermediate - porphyritic
III. core - medium-grained

Keppel proposed that the "massifs" were intruded vertically into the crust and that differentiation into the textural phases accompanied the intrusion. He included a reconnaissance map (Figure 11, page 990) of the Katemcy body, which crops out along the western portion of the area mapped by the writer. Keppel's map, however, shows almost no detail.

Goldich (1941), in interpreting the physiochemical data obtained from a study of the granites of the Llano Uplift, concluded that all of the granites came from a single magma of composition similar to ilianite, a quartz-feldspar porphyry dike rock exclusively found in the Llano region.
Hutchinson (1956), while studying the structure and petrology of the Enchanted Rock Batholith, concluded that "internal structures of the batholith and its relation to the country-rock structures indicate intrusion during the late, most severe stage of regional compression." He also noted that "the most probable mechanism of magma generation is selective fusion of random rock material."

After the intense folding and metamorphism of the sediments and intrusion of the granite, the Precambrian rocks were reduced to a surface with very little relief except for isolated hills of more resistant gneiss and granite. As far as is known, the first sediments deposited upon this old erosion surface were Upper Cambrian continental deposits. These deposits, represented by the lower Hickory sandstone, grade upward into marine limestone, shale, and sandstone. The marine sediments are represented by the Cap Mountain and Lion Mountain members of the Riley formation and the Wilburns formation. Cambro-Ordovician marine sediments are represented by the Ellenburger formation. Over this sequence was deposited a thick series of Carboniferous marine sediments (one estimate of the Paleozoic system in the Llano area is 3,500 feet, Cloud and Barnes, 1948). The entire Paleozoic system is represented by basal continental sediments conformably overlain by marine sediments, the complete section resting unconformably on the old Precambrian basement.
Late in Paleozoic time (Strawn time, Stenzel, 1934), the entire Llano area was dissected by normal faulting. The Permian, Jurassic, and Triassic sections are absent. At the beginning of the Cretaceous, erosion had exposed the Precambrian rocks in parts of the Uplift. A thick sequence of Cretaceous marine limestones overlaps the older rocks. By the end of Cretaceous, a widespread uplift resulted in the retreat of the Cretaceous sea. The Cretaceous cover was subsequently eroded away, exposing the older rocks. The Precambrian basement, less resistant to erosion than the surrounding rocks, was more rapidly eroded away, forming a geographic low and a structural high. This is the form in which it is now seen, the main relief being offered by isolated intrusive bodies.
FIELD RELATIONSHIPS

General Relationships

The Lost Creek gneiss is in fault contact with the Hickory sand¬stone to the east, in gradational contact with the Packsaddle schist to the west, and in questionably conformable contact with the Valley Spring gneiss to the southeast. The contacts of all three Precambrian rock units in the area are conformable, the foliation in the three units trending roughly parallel and parallel to the contacts. The Hickory sandstone lies unconformably over the Lost Creek gneiss or is faulted against it.

The Lost Creek gneiss apparently lies along the contact between the Valley Spring gneiss and the Packsaddle schist (Figure 1). Much of the eastern boundary of the Lost Creek gneiss is either in fault con¬tact with, or is overlapped by, the Hickory sandstone; therefore, in the immediate area, all of the Precambrian rock to the east is covered. However, this cover seems to be only local, for the majority of the rocks exposed in the general area to the east are Valley Spring gneiss.

Local Lithologies

The Valley Spring gneiss, which is the oldest rock unit in the area, is a fine-grained, quartzo-feldspathic gneiss. Banding and foliation are generally well developed, and the rock commonly exhibits a sugary
The gneiss is commonly pink to white in color, with only minor mafic constituents.

The Lost Creek gneiss is a medium- to coarse-grained quartzofeldspathic gneiss with pink porphyroblasts of microcline up to 2 centimeters in diameter. In general, the Lost Creek gneiss contains a higher percentage of mafic minerals (biotite and hornblende) than does the Valley Spring gneiss. Banding and foliation are very well developed to the north in the Lost Creek gneiss and are poorly developed to the south; i.e., the rock becomes more granitic in appearance to the south.

The Packsaddle schist exhibits several lithologies:

1. quartz-feldspar-hornblende schist
2. quartz-feldspar-biotite schist
3. hornblende schist
4. augen gneiss

Interbanding of these lithologies commonly occurs. The following section, which was measured along a road cut near locality 113, is an excellent example of this interbanding (Plate ii). Foliation strikes N5°E and dips 72°NW. The section was measured east from the Town Mountain granite-Packsaddle schist contact.

<table>
<thead>
<tr>
<th>Thickness</th>
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<tbody>
<tr>
<td>Top, West</td>
<td>contact</td>
</tr>
<tr>
<td>30'0''</td>
<td>covered</td>
</tr>
<tr>
<td>Thickness</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>1'8&quot;</td>
<td>hornblende schist</td>
</tr>
<tr>
<td>0'1&quot;</td>
<td>quartz vein</td>
</tr>
<tr>
<td>3'4&quot;</td>
<td>quartz-feldspar-hornblende schist</td>
</tr>
<tr>
<td>9'6&quot;</td>
<td>one-fourth inch to 2 inch alternating bands of hornblende schist, quartz-feldspar-biotite schist and fine-grained quartz-feldspathic gneiss</td>
</tr>
<tr>
<td>3'10&quot;</td>
<td>quartz-feldspar-biotite schist</td>
</tr>
<tr>
<td>1'0&quot;</td>
<td>alternating bands</td>
</tr>
<tr>
<td>11'0&quot;</td>
<td>quartz-feldspar-biotite schist</td>
</tr>
<tr>
<td>1'6&quot;</td>
<td>alternating bands</td>
</tr>
<tr>
<td>1'10&quot;</td>
<td>quartz-feldspar-biotite schist</td>
</tr>
<tr>
<td>5'5&quot;</td>
<td>alternating bands</td>
</tr>
<tr>
<td>14'6&quot;</td>
<td>hornblende schist</td>
</tr>
<tr>
<td>4'6&quot;</td>
<td>alternating bands</td>
</tr>
<tr>
<td>4'6&quot;</td>
<td>hornblende schist</td>
</tr>
<tr>
<td>19'0&quot;</td>
<td>aplite dike</td>
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<td>0'11&quot;</td>
<td>alternating bands</td>
</tr>
<tr>
<td>3'9&quot;</td>
<td>aplite dike</td>
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</table>
The Packsaddle augen gneiss is also interlayered with the other lithologies and is very similar in appearance to the Lost Creek gneiss. The Packsaddle schist is generally higher in mafic and plagioclase content and lower in potassium feldspar content than is the Lost Creek or Valley Spring gneiss. The quartz-feldspar-biotite and hornblende schists are well foliated, are generally sugary textured, and are commonly various shades of gray in color. The hornblende schists are somewhat phyllitic and are black in color.

The composition of the igneous rocks in the area is granitic. The largest igneous body, which comprises the western portion of the area mapped, is the Katemcy "massif" (Keppel, 1941). This "massif" is considered to be a part of the Town Mountain granite series (Stenzel, 1934). Along the Town Mountain granite-Packsaddle schist contact the igneous rock is a medium-grained, pink granite that becomes progressively coarser grained and porphyritic away from the contact, toward
the center of the body. Phenocrysts are microcline, commonly with turbid cores, and are up to 1 1/2 inches long.

Other granitic rocks in the area are numerous aplite and pegmatite dikes, which generally trend parallel to the major fracture systems. In places these dikes crosscut the foliation, but they also trend parallel to it. To the southeast, a medium-grained, pink to dark red aplogranite has intruded the Valley Spring gneiss. This aplogranite crops out in a body approximately three-fourths of a mile long (N-S) and half a mile wide (E-W).

Overlying the Precambrian complex is the Riley formation, of which the Hickory sandstone is the basal member. The basal Hickory sandstone is a conglomerate, commonly containing wind-faceted dreikanters (Barnes and Parkinson, 1940) and rounded quartz pebbles in an iron oxide cement. The maximum thickness of this basal conglomerate as seen in the field is about 6 feet. The conglomerate grades upward into a medium-grained sandstone which consists of spherical quartz grains in an iron oxide cement. This lower portion of the Hickory sandstone, characterized by its red color, grades into the middle Hickory which is brown in color. Other than their color, the two units are very similar in appearance. The upper Hickory sandstone is gray and becomes progressively more calcareous upward in the section. The Hickory sandstone passes gradationally into the
Cap Mountain limestone, which conformably overlies it. The Cap Mountain limestone is a white to gray massive limestone.

Contacts

The contacts between the Lost Creek gneiss and the Hickory sandstone are of two general types:

1. apparent gravity fault contact
2. Hickory sandstone overlap

Stenzel (1934) reported that all of the major faulting in the Llano Uplift is gravity faulting, and no contrary evidence has been found in the present study. Where slickensides are observed, the faults are apparently dip slip. The faults appear on the geologic map (Figure 1) as nearly straight lines, indicating that they are near vertical. Their displacement cannot be measured inasmuch as marker beds, dikes, etc., were not observed to be offset. However, because the maximum thickness of the Hickory sandstone is approximately 500 feet, displacement of faults within the Hickory sandstone does not exceed 500 feet. All of the faults, with the exception of two, trend N10°E to N30°E. These two cross faults are in the southern part of the area and trend E-W.

The faults are recognized by silicification along the fault zones (Bridge, Barnes, and Cloud, 1947). Silica cement has replaced the iron oxide cement in the Hickory sandstone, and thus the fault zones
tend to form ridges and the surrounding rocks form valleys (Plate iii). The faults can easily be traced across country, and in the northern part of the area, the silicified zones commonly represent the only outcrop in the central valley. A close examination of the fault zone often reveals slickensides, silica stringers parallel to the trend of the faulting, minor faults offset only a few inches, and minor fault breccia (Plate iv). These fault zones range in width from only a few feet to 200 feet and can be traced in a straight line across country for distances up to 5 miles.

Faulting within the Precambrian rocks is recognized only by remnant Hickory sandstone along the fault zone. This faulting has been noted within the Packsaddle schist to the south, where the Hickory sandstone along the fault zone is surrounded by Packsaddle schist on either side. Along parts of the fault, the Packsaddle schist surrounds a zone of Hickory sandstone less than 10 feet wide.

The second type of contact between the Precambrian and the Hickory sandstone is the Hickory overlap, an angular unconformity. As depicted on the geologic map (Figure 1), the trace of the contact is irregular and is controlled by the topography. The contact is often traced across country by the presence of a basal conglomerate and the different types of soils formed from the two lithologies. The soils overlying the Hickory sandstone are red to deep brown in color and
contain spherical quartz grains, whereas the soils overlying the Precambrian rocks generally contain angular pebbles of vein quartz and weathered-out microcline augen.

The contact between the Lost Creek gneiss and Packsaddle schist is covered by a thick soil profile over much of the area. Where the contact is observed, however, it is gradational. The porphyroblasts in the Lost Creek gneiss become progressively more lenticular toward the Packsaddle schist contact and finally grade into quartz-feldspathic bands of uniform thickness. The bands eventually disappear within the Packsaddle schist (Figure 4 and Plates v, vi, and vii). Commonly this gradation is repeated several times along the contact and the entire sequence covers only 10 to 15 feet. The sequence may cover several hundred feet. The augen gneiss grades upward into the banded gneiss, with a sharp contact between the augen gneiss and banded gneiss as the sequence is repeated. This relationship has not only been noted along Lost Creek gneiss-Packsaddle schist contacts but also within the Packsaddle schist, particularly near locality 99. These transition zones in places exhibit interbanding of augen gneiss, fine-grained quartz-feldspathic gneiss, and hornblende schists (Plate viii).

The contact between the Town Mountain granite and Packsaddle schist is concordant, conformable, and very sharp. The granite is finer grained along the contact, exhibiting a chill zone approximately 6
Figure 4. Idealized block diagram showing gradation from augen gneiss to banded gneiss (foliation strikes N45°E and dips 45°NW).
feet wide where observed. Lineation in the granite trends parallel to the contact, and inclusions of the schist within the granite are oriented parallel to the lineation near the contact. No inclusions were observed at a distance of greater than approximately 20 yards from the contact in the area studied. No evidence of thermal metamorphism or assimilation of the country rock by the granite was noted. The granite seems to have had no effect on the texture or composition of the schist, though small stringers of fine-grained granite, quartz dikes, and pegmatite dikes project into the country rock from the granite.

The contact between the Hickory sandstone and the Cap Mountain limestone is gradational, with the Cap Mountain limestone conformably overlying the Hickory sandstone. As previously mentioned, the upper Hickory sandstone becomes more calcareous and less arenaceous progressively higher in the section until it eventually grades into a limestone. In places a fault contact between the two units was noted.

Foliation and Lineation

Foliation was recorded wherever possible, and several definite trends are apparent. Stenzel (1934) and Paige (1912), along with other writers, concluded that the foliation within the Packsaddle schist and Valley Spring gneiss trends approximately parallel to the original
sedimentary bedding. The writer could find no evidence to the contrary. Measurements of strike of foliation are consistent in particular areas, indicative of uncomplicated structure. However, measurements of dip of foliation are quite variable and range from 15° to 90° throughout the entire area, averaging about 45°. Consistent directions of dip on limbs of the folds indicate few, if any, complicating cross-flexures, even though the angles of dip are quite variable.

The attitude of the foliation in the northern part of the area indicates two broad, open folds which plunge at an unknown angle approximately N60°W (Figure 1). No marker beds were persistent over the entire area, so no evidence other than the attitude of foliation can be cited for the presence of these folds. The northern fold is an anticline with a biotite-augen gneiss at the core which grades upward into a hornblende schist and fine-grained quartz-feldspathic gneiss. The southern fold is a syncline with a core of fine-grained biotite-quartz-plagioclase schist grading downward into a fine-grained hornblende-quartz-plagioclase gneiss. Very little correlation can be made along the strike. Lineation in the plane of foliation in the northern parts of the area, although variable, trends roughly parallel and plunges in the same direction as the axes of the folds. This trend of the lineation has also been noted by Stenzel. The lineation invariably plunges to the northwest.
The foliation in the east central and southwest Lost Creek bodies strikes to the northeast and dips to the northwest. Inasmuch as each of these bodies is separated spatially, it is not possible to correlate lithologies and structures between them.

Foliation in the southern-most body of gneiss is extremely irregular and difficult to detect; however, valid strike and dip measurements indicate a definite structural trend. On many outcrops, foliation was indiscernible owing to the texture of the rock and the tendency for it to weather into low, rounded knobs. Where foliation was difficult to detect, a lineation in the horizontal plane was measured; the lineation probably represents the intersection of the foliation with the near horizontal weathering surface. Measurements of both foliation and lineation indicate two northerly plunging, tight folds (Figure 1). Again no persistent marker beds were observed, and thus the folds were detected only by the strike and dip of the foliation. In this area, the rocks in the field appear to have uniform compositions and textures throughout, a contrast from rocks to the north where lithologies are quite variable over short distances.

Secondary Intrusions

The gneisses and schists are commonly cut by pegmatite dikes, aplite dikes, quartz veins, and small aplogranite intrusives (Plates ix
and x). Two prominent sets of vertical fractures are evident throughout the area, striking approximately N45°E or N60°W. The majority of the pegmatites and aplites trend in these two general directions or parallel to foliation. The pegmatites generally range from 1 inch to 3 feet in thickness and are too small to be mapped. Quartz dikes are commonly associated with the pegmatites and are of the same general dimensions. Aplite dikes range in thickness from 1 foot to 50 feet, the majority about 2 to 3 feet. One aplogranite body is indicated on the map. One basic dike, gabbroic in composition, was observed near locality 40.

Fractures and Jointing

Several fracture systems were noted, all apparently related to three different stages in the history of the area:

1. original folding, metamorphism and igneous activity - associated vertical joints trend N45°E and N60°W; associated with aplite, pegmatite, and quartz dikes

2. foliation and original bedding - jointing parallel to foliation; also associated with aplite, pegmatite, and quartz dikes

3. faulting - joints parallel to faults

Banding

Associated with the gneisses and schists are lenses, pods, bands, and non-dilation dikes of quartzo-feldspathic and amphibolitic material which, in almost every case, trend parallel to the foliation. In the
northern part of the area, bands of uniform thickness which exhibit little or no contortion are common (Plate xi). To the south, however, highly contorted lenses and pods are common, in places resembling schlieren or xenoliths in igneous rocks (Plate xii). In the field a dark rim impoverished in felsic constituents can commonly be seen around the bands, as well as around the pods and lenses. Where the bands are consistent in thickness, they range from one-half inch to 1 foot, but they cannot be traced for distances over 50 feet. The various lenses and pods are quite variable in shape but do not commonly exceed 1 foot in diameter. The appearance of these bands in thin section, as well as their origin, will be discussed later.

**Thickness of the Lost Creek Unit**

A maximum or minimum thickness of the Lost Creek body cannot be calculated owing to the fault contacts and the variability in strike and dip of foliation. Along Lost Creek, however, the strike and dip is rather uniform across the entire breadth of the augen body (strike, average N42°E; dip, average 46°NW). Calculations using these figures indicate a thickness of approximately 3,200 feet of Lost Creek gneiss from the Hickory sandstone fault contact to the east to the Packsaddle schist contact to the west.
Relation of Local Structure to Structure of Llano Uplift

Any correlation between the structure of the Lost Creek gneiss area and the structure of the Llano Uplift must be discussed only in broad generalities, for the immediate area around the Lost Creek gneiss has never been mapped and little is known about the detailed Precambrian geology of the surrounding region. Nevertheless, some observations may be made. H. B. Stenzel (1934) reports that:

Valley Spring gneiss and Packsaddle schist are strictly conformable in all outcrops and folded as one unit; their average strike is northwest-southeast; their average dip is steep, around 45°. Bedding and schistosity are parallel. The grain in schists and gneiss is parallel to the pitching axes of the open folds. The rocks of the folded frame are thrown into wide, open folds that trend northwest-southeast and pitch near Llano at an average angle of 16° to the southeast. Sidney Paige shows three such anticlines and synclines between Llano and Burnet. The open folds are by no means very regular and are somewhat complicated by cross-flexures.

Recalling the evidence given concerning the area of study, the two open folds to the north trend to the northwest and may possibly be connected with the northwest-trending folds on Paige's Llano-Burnet Folio. Recalling also the fact that the rock between the area mapped and the Llano-Burnet Folio is predominantly Valley Spring gneiss and that the Packsaddle schist is found near the Katemcy intrusion, a plausible relation of local structure to the structure of the Llano Uplift
can be offered. Hutchinson (1956) states that the granites commonly intrude along synclinal axes and that the Packsaddle schist is found in the core of these synclines. Therefore, the northern portion of the Lost Creek area might represent subsidiary folds on the flank of a larger syncline trending northwest and connected with a northwest trending fold mapped on the Llano-Burnet Folio. The writer realizes that the Lost Creek area and the Llano-Burnet quadrangles are 20 miles apart and are separated by a faulted Paleozoic section. Under such conditions, any correlation would be only tentative. Nevertheless, the fact cannot be overlooked that the structure in the Lost Creek area is analogous to the structure in other parts of the Llano Uplift. In regard to the northerly plunging folds in the southern part of the Lost Creek area, Stenzel's statement that "the open folds are by no means very regular and somewhat complicated by cross-flexures" seems to be a rather inadequate explanation for these folds, though the present writer can suggest no other.

Contacts between the schists and the granites have been described by Stenzel as follows:

Flow structure is noticeable everywhere; the margins especially have very strongly developed "schistose" flow structure. Contacts are chiefly concordant, although cross-cutting offshoots may be found in most exposures. . . . Nearer to the center of these intrusive bodies inclusions of country rock become less common, but they never seem to be absent.
The field evidence in the Lost Creek area tends to substantiate Stenzel's conclusions, with the exception of the last statement concerning the presence of inclusions within the granite. No inclusions were observed, within the limited area studied, in the Katemcy body at any distance from the Packsaddle schist-Town Mountain granite contact.
Plate i - Exfoliation domes of Town Mountain granite at Spy Rock.

Plate ii - Banding of hornblende schist, quartz-biotite schist, and fine-grained, quartz-feldspathic gneiss.
Plate iii - Fault zone within the Hickory sandstone.

Plate iv - Silica stringers and minor faults within a Hickory sandstone fault zone.
Plate v - Augen phase of transition from augen gneiss to banded gneiss.

Plate vi - Intermediate phase of transition from augen gneiss to banded gneiss.
Plate vii - Banded phase of transition from augen gneiss to banded gneiss.

Plate viii - Banding of augen gneiss, fine-grained, quartzofeldspathic gneiss, and hornblende schist.
Plate ix - Contact between pegmatite and augen gneiss
(pegmatite trending parallel to attitude of foliation of gneiss)

Plate x - Quartz dike crosscutting foliation in granitic gneiss.
Plate xi - fine-grained, quartzo-feldspathic band within augen gneiss (band trending parallel to attitude of foliation of gneiss).

Plate xii - Pod of fine-grained, quartzo-feldspathic material within augen gneiss.
PETROGRAPHIC EVIDENCE

The Precambrian schists and gneisses of the Lost Creek area contain three principal mineral assemblages:

1. quartz, plagioclase, microcline, biotite, epidote, hornblende
2. quartz, plagioclase, hornblende, microcline, epidote
3. quartz, plagioclase, garnet, epidote, tremolite, microcline, hornblende

In general, assemblage 1 represents the Lost Creek gneiss; assemblage 2, the Packsaddle schist; and assemblage 3, the Valley Spring gneiss. These assemblages can only be taken as a general rule and exceptions exist in all three cases. The Packsaddle schist is comparatively rich in plagioclase and hornblende, and the Lost Creek gneiss is comparatively rich in biotite and microcline. The Valley Spring gneiss contains two minerals, tremolite and garnet, which are not present in the other two lithologies. Plagioclase composition varies from calcic albite to sodic andesine in the Lost Creek gneiss, varies from sodic oligoclase to sodic andesine in the Packsaddle schist, and remains constant as sodic oligoclase in the Valley Spring gneiss.

General Descriptions

Hand specimen descriptions of all samples from which thin sections were made are given in the appendix. The following descriptions
represent typical examples of the metamorphic rocks and the Town Mountain granite.

Lost Creek Gneiss

Quartz grains are anhedral, subparallel, and elongate parallel to foliation. Undulance is not common, and inclusions are very rare. Plagioclase grains are anhedral, subparallel, and exhibit poorly developed twinning. Plagioclase grains are commonly rimmed by albite near potash feldspar and where they occur as inclusions within potash feldspar. Microcline, the principal constituent of the porphyroblasts, exhibits well-developed grid twinning. Anhedral masses of microcline commonly contain abundant inclusions of albite-rimmed, myrmekitic plagioclase grains and quartz. Subparallel flakes of biotite are clustered in irregular streaks around the porphyroblasts and are pleochroic, light to dark brown. The flakes of biotite contain abundant inclusions of zircon and apatite. Hornblende occurs in minor amounts and appears to have been partially replaced by biotite in some places.

Quartz-feldspar aggregates form mosaic intergrowths. Banding is of two types: between felsic and mafic layers and between coarse-grained quartzose bands and finer grained quartz-feldspar bands. The rock is uniformly medium-grained, with the exception of the porphyroblasts, which may be fifty times as large as the
surrounding grains. Feldspars show turbid cores in some samples. Replacement perthite comprises a large percent of the porphyroblasts.

Packsaddle Schist

In thin section the texture of the Packsaddle schist is very similar to the texture of the Lost Creek gneiss, except that the Packsaddle schist is finer grained and contains no porphyroblasts. As previously noted, augen gneisses occur within the Packsaddle schist; however, they have been described above in the general description of the Lost Creek gneiss. Quartz grains are anhedral, elongate parallel to foliation, exhibit no undulance, and contain few inclusions. Subhedral laths and anhedral masses of plagioclase show well-developed albite and Carlsbad twinning. Microcline is rare and invariably occurs as anhedral masses. Subhedral to euhedral, acicular laths of hornblende are commonly oriented parallel to foliation and are pleochroic light green to blue green. Biotite flakes are oriented parallel to foliation and generally contain zircon and apatite inclusions. Epidote grains are commonly equant and subrounded and are generally found associated with hornblende.

A marked parallel orientation of all grains, with the exception of epidote, is evident. Banding is caused by the aggregation of felsic and mafic constituents. The rock is uniformly fine-grained.
Valley Spring Gneiss

The difference between the Valley Spring gneiss and the Packsaddle schist is apparently compositional, rather than textural. Quartz grains in the Valley Spring gneiss are anhedral and sub-elongate, exhibit no undulance, and contain few inclusions. The subhedral to anhedral laths of plagioclase generally exhibit poorly developed twinning. The mafic constituents, subhedral laths of hornblende or tremolite, are clustered in irregular streaks subparallel to the foliation. Epidote and garnet are commonly subrounded and equant.

Foliation is not as well developed in the Valley Spring gneiss as it is in the Packsaddle schist. Owing to the general lack of appreciable amounts of mafic constituents, banding is commonly very difficult to distinguish; however, a mineralogic banding of quartz-feldspar and the other constituents exists. Quartz-feldspar aggregates generally form mosaic intergrowths, and individual grains are equant. The rock is uniformly fine-grained.

Red Mountain Gneiss (Fine-grained, Sample 25c)

The rock is composed of rounded quartz and plagioclase metacrysts in a very fine-grained, mosaic groundmass of quartz and feldspar. The quartz is highly undulant, both in the metacrysts and
in the groundmass. Plagioclase and quartz grains within the groundmass are equant. Lenses of coarser grained, non-undulant quartz are oriented parallel throughout the thin section. The metacrysts of quartz appear to have been beta-quartz because of their square outline (indicating the absence of a prism, a characteristic of beta-quartz). Plagioclase metacrysts are commonly sericitized. Metacrysts are from 0.1 mm to 0.6 mm in diameter, averaging around 0.3 mm.

Along one edge of the thin section, the rock has apparently recrystallized, forming coarser grains of non-undulant quartz, perthite, and abundant muscovite (Plate xiii).

Little or no foliation is evident in thin section. The rock is apparently a partially metamorphosed felsite porphyry. The extreme undulance of the quartz metacrysts indicates that they have possibly undergone extensive differential stress but have not recrystallized. The coarser grained lenses represent the recrystallized part of the rock.

Red Mountain Gneiss (Coarse-grained, Sample 26c)

The rock contains euhedral to subhedral laths of plagioclase surrounded by anhedral masses of microcline and perthite, fine-grained quartzo-feldspathic material with mortar structure, and medium-grained non-undulant quartz lenses. Plagioclase laths show
well-developed twinning, are extensively sericitized, and are commonly rimmed by albite. The long dimension of the laths averages 0.6 mm. Anhedral masses of replacement perthite, exsolution perthite, and microcline appear to have replaced the plagioclase and occupied the interstitial positions between plagioclase laths. The potash feldspar contains abundant inclusions of rimmed plagioclase and quartz. Large grains of plagioclase, microcline, and perthite are all crosscut by fine-grained stringers of quartz.

No parallel alignment of grains is evident. Cataclastic structures are present in the form of mortar structure of quartz and feldspar and extreme undulance of some of the quartz. Quartz aggregates are mosaic, and individual quartz grains are equant. Similar to the fine-grained Red Mountain sample 25c, this rock seems to have also undergone extreme differential stress, associated with introduction of materials, and has not completely recrystallized.

Town Mountain Granite (Samples 112 and 112c)

The rock is composed of microcline and plagioclase phenocrysts in a coarse-grained, xenomorphic-granular groundmass of quartz, microcline, plagioclase, and perthite. Euhedral to subhedral laths of plagioclase are commonly poorly twinned and sericitized. Near potash feldspar, the plagioclase is commonly rimmed with albite and
is myrmekitic. In places small crystals of plagioclase surround the potash feldspar and occur as inclusions within the potash feldspar. The plagioclase inclusions are of the same composition as the plagioclase in the groundmass (An10). Anhedral masses of microcline and perthite apparently have replaced the plagioclase and quartz and occupy interstitial positions between plagioclase and quartz. The potash feldspar is commonly poikilitic and contains inclusions of embayed, albite-rimmed plagioclase and quartz. Potash feldspar commonly forms subhedral phenocrysts up to 1 inch long. Quartz is anhedral and undulant. Biotite is rare. The rock shows no parallel alignment of grains in thin section.

Study of Microcline Porphyroblasts

The porphyroblasts are generally disc shaped, with the long diameter of the porphyroblast (2 mm to 2 cm long) parallel to the foliation. The maximum ratio of the long to short diameter of a single porphyroblast is 3:1. The augen are composed of single microcline or perthite grains, a microcline aggregate or perthite aggregate, or, in some cases, a microcline and perthite aggregate within a single porphyroblast. Foliation planes of mica and hornblende are commonly bent around the porphyroblast, particularly around microcline. In places foliation planes trend into perthite
Porphyroblasts, but exceptions are quite common. Microcline shows grid twinning. Perthite resembles replacement perthite, with irregular patches of albite within the potash feldspar. The outline of the porphyroblasts varies from ragged and irregular to smooth and regular. An apparent interstitial filling between plagioclase and quartz grains by potash feldspar is evident. Plagioclase of similar composition to the groundmass appears as inclusions within the porphyroblast and around the edge of the porphyroblast. The plagioclase inclusions are generally rimmed with albite, are myrmekitic, and may be euhedral to anhedral (Plate xiv). Quartz also appears as inclusions within the potash feldspar. Some porphyroblasts are quite poikilitic, while others are not. The sharper the outline of the porphyroblast, the less inclusions it contains. The anhedral masses of potash feldspar that enclose quartz and plagioclase may represent the initial growth of the porphyroblast. As the porphyroblast grew, it may have replaced and expelled some of the quartz and plagioclase from its core so that it grew from an initial interstitial filling with numerous inclusions to a final porphyroblast with few inclusions and a sharp, regular outline (Plates xv, xvi, and xvii).

Robertson (1959), in describing the orthoclase porphyroblasts in a quartz monzonite of the Boulder Batholith, Montana, reported structures within the potash feldspar similar to those structures in
the Lost Creek gneiss and Town Mountain granite. He noted that "the successive stages of porphyroblastic growth are similar to those noted in metamorphic rocks." He concluded that the first step in the formation of the orthoclase porphyroblasts was the development of optical continuity and poikilitic enclosure of the quartz and plagioclase. The second step involved the gradual replacement of quartz and plagioclase and "clearing" of the core; margins may be ragged, and the porphyroblast may be poikilitic. Relicts of albite-rimmed plagioclase and quartz commonly may have been left as inclusions, as well as around the edges of the grains. Perthite appeared to be replacement perthite. Similarly, Goodspeed (1959) noted that "within the area of a single section, porphyroblasts of the same mineral species may be displayed in several stages of development from initial amoeboid forms through those with ragged crystal outlines with pronounced sieve structure to nearly euhedral crystals which are practically free from inclusions." He also reported rings of inclusions around porphyroblasts which had been apparently pushed outward by the growing crystal.

The features described by Robertson and Goodspeed are almost identical to those noted in the Lost Creek gneiss and Town Mountain granite, and their proposed origin should be given consideration.
Robertson summarizes the formation of the orthoclase porphyroblasts as follows:

1. Plagioclase is attacked and altered to albite, commonly in a narrow zone between the plagioclase and the replacing potash feldspar.

2. Albite is then partially replaced by potash feldspar.

3. The remaining albite blebs appear to be small relics in some instances; in most cases the albite appears to have been reorganized into discrete blebs or strings which resemble those found in replacement perthites.

Thus albite-rimmed oligoclase crystals which are located within and around porphyroblasts are considered by Robertson to be relics of incompletely altered plagioclase, and the replacement perthite is considered to be albite which could not go into solid solution with potash feldspar and was reorganized into blebs.

Robertson's theory explains all of the features within and around the porphyroblast with the exception of the myrmekite and the ultimate site of the calcium in the plagioclase. No mention was made of the anorthite after the alteration of the plagioclase. Additional calcium is apparently not present in the relict plagioclase grains, which are approximately the same composition as the plagioclase in the groundmass. Robertson made no mention of the calcium ion being present in any new mineral form, and it cannot go into solid solution.
with potash feldspar (Tuttle and Bowen, 1958). Robertson also fails to explain the altering of plagioclase to albite by potash feldspar.

Myrmekite was not reported by Robertson from the Boulder Batholith rocks, but it is present in the Lost Creek gneiss. Ljunggren (1957) also reported microcline porphyroblasts rimmed by myrmekitic plagioclase in a banded gneiss from Gothenburg, Sweden, but he offered no adequate explanation for the formation of the myrmekite. If potash feldspar altered a more calcic plagioclase to albite, additional silica would be required. In the Lost Creek gneiss, however, myrmekite was formed, which might indicate an excess of silica within the plagioclase. According to Robertson's theory, the myrmekite does not represent cocrystallization of quartz with plagioclase during the formation of porphyroblasts because the plagioclase is believed to be relict. Moreover, the euhedral myrmekitic inclusions are in all probability not relict (Plate xiv). However, Robertson described no myrmekite and therefore was not required to explain its origin. Robertson's theory as a whole probably has some merit, but some important details have been omitted.

Since the formation of myrmekite is not clearly understood, several mechanisms could possibly explain the presence of myrmekite within and around the porphyroblasts. The potassium-rich solutions, whether hydrothermal or magmatic, may have completely replaced
the plagioclase and quartz. A change in conditions of pressure, temperature, or composition could have then caused the simultaneous recrystallization (precipitation from solution) of plagioclase and quartz as myrmekite. The residual solution would have been enriched in albite, and if the solution contained sufficient silica, the albite might have crystallized out as rims around the myrmekitic plagioclase.

In summary, potash feldspar porphyroblasts might be explained in the following steps:

1. introduction of potassium-rich solution and poikilitic enclosure of plagioclase and quartz.

2. solution of plagioclase and quartz and crystallization of potash feldspar ("clearing the core").

3. change of conditions of temperature, pressure, or composition, which could cause recrystallization of plagioclase (oligoclase) and quartz simultaneously as myrmekite.

4. enrichment of residual solution in sodium, causing crystallization of albite around rims of myrmekitic plagioclase and within porphyroblasts (which forms intergrowth with potash feldspar resembling replacement perthite).

5. continued crystallization of potash feldspar to develop porphyroblasts from initial poikilitic anhedral masses with ragged outlines to porphyroblasts with smooth, ellipsoidal outlines which are practically free from inclusions.
A better knowledge of nucleation processes and the crystal chemistry of such a system is required for further speculation.

Compositional and Textural Variations

Modal analyses of the different Precambrian rocks reported in Tables I through V are based upon 1,000-1,300-point counts per thin section (precision ±10% of individual modal percentage; i.e., quartz in sample 5, 20.1% ±2%). In many localities samples of different lithologic units are more similar in composition than samples of the same unit. A correlation of Table I with the sample locality map (Figure 3) indicates that few, if any, definite compositional trends exist within the Lost Creek gneiss. However, some generalities may be discerned.

The northern half of the northern-most body of Lost Creek gneiss and the three southern-most bodies of Lost Creek gneiss are very similar in composition, as they fall within the Lost Creek mineral assemblage. However, the textures of these four Lost Creek bodies in the field are quite different. Foliation is well developed in the north and poorly developed in the south. Rocks in the southern half of the northern-most Lost Creek body and the Lost Creek body to the east of it are quite different in composition from the rest of the Lost Creek gneiss. These are similar to the Packsaddle schist and
### Table I

Modal Analyses of Lost Creek Gneiss Samples

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<th>94</th>
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<th>11</th>
<th>8</th>
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<td>55.3</td>
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<td>12.0</td>
<td>25.9</td>
<td>24.9</td>
<td>10.2</td>
<td>11.5</td>
<td></td>
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<td>4.8</td>
<td></td>
<td>9.0</td>
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<tr>
<td>% Hornblende</td>
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<td></td>
<td>4.8</td>
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<td>% Dark opaques</td>
<td>0.8</td>
<td>0.4</td>
<td>0.9</td>
<td>1.1</td>
<td>0.5</td>
<td>0.7</td>
<td>0.4</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>% Epidote</td>
<td></td>
<td>0.2</td>
<td>0.9</td>
<td>0.6</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>0.5</td>
<td>tr.</td>
</tr>
<tr>
<td>% Sphene</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>0.2</td>
<td></td>
<td>tr.</td>
<td>tr.</td>
<td></td>
</tr>
<tr>
<td>% Zircon</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td></td>
</tr>
<tr>
<td>% Apatite</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
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</tbody>
</table>

tr. = trace
<table>
<thead>
<tr>
<th>Mineral</th>
<th>110</th>
<th>64</th>
<th>21</th>
<th>78b</th>
<th>60</th>
<th>57</th>
<th>75</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Quartz</td>
<td>24.1</td>
<td>34.6</td>
<td>28.8</td>
<td>28.8</td>
<td>29.2</td>
<td>33.7</td>
<td>30.4</td>
<td>36.5</td>
</tr>
<tr>
<td>% Plagioclase</td>
<td>48.2</td>
<td>28.2</td>
<td>36.6</td>
<td>46.4</td>
<td>40.6</td>
<td>42.6</td>
<td>36.5</td>
<td>32.0</td>
</tr>
<tr>
<td>% Potash feldspar</td>
<td>22.6</td>
<td>32.2</td>
<td>23.0</td>
<td>19.1</td>
<td>25.6</td>
<td>20.6</td>
<td>27.6</td>
<td>29.6</td>
</tr>
<tr>
<td>% Biotite</td>
<td>3.1</td>
<td>4.8</td>
<td>6.2</td>
<td>5.3</td>
<td>4.0</td>
<td></td>
<td>0.4</td>
<td>1.4</td>
</tr>
<tr>
<td>% Hornblende</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.9</td>
<td>4.0</td>
</tr>
<tr>
<td>% Dark opaques</td>
<td>0.8</td>
<td>0.2</td>
<td>0.4</td>
<td>0.4</td>
<td>0.6</td>
<td>0.2</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>% Epidote</td>
<td>tr.</td>
<td></td>
<td></td>
<td>tr.</td>
<td></td>
<td>tr.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Sphene</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>0.1</td>
</tr>
<tr>
<td>% Zircon</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
</tr>
<tr>
<td>% Apatite</td>
<td>tr.</td>
<td></td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td>tr.</td>
<td></td>
</tr>
</tbody>
</table>

tr. - trace
are included in the Packsaddle mineral assemblage. The Lost Creek gneiss, which is compositionally similar to the Packsaddle schist, is much coarser grained than the Packsaddle schist and resembles an augen gneiss in the field; porphyroblasts are composed of plagioclase, rather than microcline. Similarly, the composition of the Packsaddle schist immediately west of the southern half of the northern-most Lost Creek body is quite similar to the composition of the Lost Creek gneiss (Table II). In each case, the rocks in the field appear texturally quite similar to the other rocks within the mapped lithologic unit, but their compositions may be markedly different.

The limited number of thin sections studied and the limited amount of outcrop do not clearly indicate that compositional gradations occur within the Lost Creek gneiss. Considering, however, the Precambrian metamorphics in the northern half of the area mapped, the following generalities may be discerned:

1. To the north, potassium-bearing minerals (microcline and biotite) are more abundant in the Lost Creek gneiss than in the Packsaddle schist.

2. To the south, potassium-bearing minerals are more abundant in the Packsaddle schist than in the Lost Creek gneiss.

3. To the north, plagioclase and hornblende are more abundant in the Packsaddle schist than in the Lost Creek gneiss.
## Modal Analyses of Valley Spring Gneiss and Packsaddle Schist Samples

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Sample Number</th>
<th>Valley Spring Gneiss</th>
<th>Packsaddle Schist</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>109</td>
<td>85</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>107</td>
<td>112c</td>
<td>98a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>113</td>
<td>98a</td>
</tr>
<tr>
<td></td>
<td>% Quartz</td>
<td>41.3</td>
<td>34.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27.9</td>
<td>60.0</td>
</tr>
<tr>
<td></td>
<td>% Plagioclase</td>
<td>45.8</td>
<td>40.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28.3</td>
<td>27.9</td>
</tr>
<tr>
<td></td>
<td>% Potash feldspar</td>
<td>0.2</td>
<td>26.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.0</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>% Biotite</td>
<td>0.9</td>
<td>18.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.5</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>% Hornblende</td>
<td>0.9</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.9</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>% Dark opaques</td>
<td>0.9</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>% Epidote</td>
<td>2.9</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>% Tremolite</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>% Garnet</td>
<td>1.5</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>% Sphene</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>% Zircon</td>
<td>tr.</td>
<td>tr.</td>
</tr>
<tr>
<td></td>
<td>% Apatite</td>
<td>tr.</td>
<td>tr.</td>
</tr>
<tr>
<td></td>
<td>% Fluorite</td>
<td>tr.</td>
<td>tr.</td>
</tr>
</tbody>
</table>
4. To the south, plagioclase and hornblende are more abundant in the Lost Creek gneiss than in the Packsaddle schist.

5. Quartz remains relatively constant throughout the body.

An examination of Table III, which shows the composition of plagioclase throughout the Lost Creek area, indicates that plagioclase is more calcic where potash feldspar minerals (microcline and biotite) are least abundant and plagioclase content is the highest. Reasons for these differences are not clearly understood. The three southern-most Lost Creek bodies are relatively uniform in composition and texture.

The Valley Spring gneiss, although similar in appearance to the Packsaddle schist in the field, is quite different in composition from the Packsaddle schist or the Lost Creek gneiss (Table II). The Valley Spring gneiss contains tremolite and garnet, which are not found in the other formations.

Hand specimens were taken at six-foot intervals at locality 98 across the Packsaddle schist-Lost Creek gneiss contact, which appears gradational in the field. Table IV lists the compositions of the samples taken south to north across the contact. Any compositional gradation which exists is over a distance of less than six feet. A sharp difference in composition is evident between samples 98a and 98c, as sample 98a contains only 1 percent of microcline and sample 98c contains 29 percent. On either side of the mapped contact, minor

TABLE III
Composition of Plagioclase

<table>
<thead>
<tr>
<th>Lithologic Unit</th>
<th>Sample Number</th>
<th>Percent Anorthite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>An12</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>An10</td>
</tr>
<tr>
<td></td>
<td>91</td>
<td>An12</td>
</tr>
<tr>
<td></td>
<td>94</td>
<td>An10</td>
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<tr>
<td></td>
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<tr>
<td></td>
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<td>An28</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>An30</td>
</tr>
<tr>
<td>Lost Creek Gneiss</td>
<td>51</td>
<td>An32</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>An24</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>64</td>
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<td></td>
<td>21</td>
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</tr>
<tr>
<td></td>
<td>73b</td>
<td>An12</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>An8</td>
</tr>
<tr>
<td></td>
<td>57</td>
<td>An14</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>An14</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>An12</td>
</tr>
<tr>
<td>Red Mountain Gneiss</td>
<td>25c</td>
<td>An10 (?)</td>
</tr>
<tr>
<td></td>
<td>26c</td>
<td>An12 (?)</td>
</tr>
<tr>
<td></td>
<td>114</td>
<td>An10</td>
</tr>
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<td></td>
<td>112</td>
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<tr>
<td>Intrusives</td>
<td>112c</td>
<td>An8</td>
</tr>
<tr>
<td></td>
<td>84</td>
<td>An6</td>
</tr>
<tr>
<td>Valley Spring Gneiss</td>
<td>100</td>
<td>An10</td>
</tr>
<tr>
<td></td>
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<td>113</td>
<td>An12</td>
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<td></td>
<td>97</td>
<td>An10</td>
</tr>
<tr>
<td></td>
<td>98a</td>
<td>An32</td>
</tr>
<tr>
<td>Packsaddle- Lost Creek Contact</td>
<td>98c</td>
<td>An14</td>
</tr>
<tr>
<td></td>
<td>98e</td>
<td>An12</td>
</tr>
<tr>
<td></td>
<td>98f</td>
<td>An10</td>
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<td></td>
<td>98g</td>
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<td>An12</td>
</tr>
<tr>
<td></td>
<td>97b</td>
<td>An6</td>
</tr>
<tr>
<td></td>
<td>78a</td>
<td>An12</td>
</tr>
</tbody>
</table>

*Determined by Michel-Levy method and relative indices of refraction.
## TABLE IV

Modal Analyses of Samples across a Packsaddle Schist-Lost Creek Gneiss Contact and of Banding

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Packsaddle-Lost Creek Contact</th>
<th>Sample Number</th>
<th>Banding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>98a</td>
<td>98c</td>
<td>98e</td>
</tr>
<tr>
<td>% Quartz</td>
<td>28.5</td>
<td>39.2</td>
<td>35.8</td>
</tr>
<tr>
<td>% Plagioclase</td>
<td>61.3</td>
<td>28.4</td>
<td>30.9</td>
</tr>
<tr>
<td>% Potash feldspar</td>
<td>0.9</td>
<td>29.0</td>
<td>25.8</td>
</tr>
<tr>
<td>% Biotite</td>
<td>tr.</td>
<td>1.9</td>
<td>3.2</td>
</tr>
<tr>
<td>% Hornblende</td>
<td>7.2</td>
<td>---</td>
<td>0.6</td>
</tr>
<tr>
<td>% Dark opaques</td>
<td>1.4</td>
<td>1.1</td>
<td>1.8</td>
</tr>
<tr>
<td>% Epidote</td>
<td>---</td>
<td>---</td>
<td>tr.</td>
</tr>
<tr>
<td>% Sphene</td>
<td>---</td>
<td>tr.</td>
<td>tr.</td>
</tr>
<tr>
<td>% Zircon</td>
<td>tr.</td>
<td>---</td>
<td>tr.</td>
</tr>
<tr>
<td>% Apatite</td>
<td>---</td>
<td>tr.</td>
<td>tr.</td>
</tr>
<tr>
<td>% Chlorite</td>
<td>0.7</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
amounts of augen gneiss and fine-grained schist are interbanded.

The presence of a gradational contact may be questioned from this evidence; however, contacts between bands are sharp, and the bands themselves represent the gradation, for no one sharp contact exists between the two mappable units. If the total composition of the interbanded zone were considered, a gradational zone would probably be evident. The banding may be caused by the segregation of the various components of the system as a result of metamorphic differentiation or original compositional differences.

Three thin sections of these bands were studied, two within the Lost Creek gneiss and one within the Packsaddle schist. Table IV indicates the modal compositions of the three types of banding.

Samples 78a and 90 are from the Lost Creek gneiss and sample 97 is from the Packsaddle schist. All three samples were taken from fine-grained, acidic bands, parallel to the trend of the foliation, with lower percentages of mafic minerals (biotite and hornblende) than the surrounding rock. The thin section analyses also bear out the observation of the lack of mafic constituents. Sample 78a is from a zone approximately 6 feet thick; sample 90, 1 foot thick; and sample 97, 1/2 inch thick. Sample 78a is considerably lower in quartz content than any of the other thin sections examined. Sample 90 represents a contact between a quartzo-feldspathic band and the augen
gneiss. The contact is quite evident in thin section owing to distinct differences in grain size and the lack of dark minerals in the band. These bands seem to be approximately equivalent in composition to the surrounding rock, with the exception of the lack of mafic minerals within the bands.

The two Red Mountain samples are quite different in composition, and neither is compositionally similar to the Lost Creek gneiss. Table V indicates their modal composition. The fine-grained sample contains no potassium feldspar, and the coarse-grained sample is comparatively richer in quartz and potassium feldspar and comparatively poorer in plagioclase than the majority of the Lost Creek samples.
TABLE V
Modal Analyses of Intrusive and Red Mountain Gneiss Samples

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Red Mountain</th>
<th>Sample Number</th>
<th>Intrusives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25c</td>
<td>26c</td>
<td>114</td>
</tr>
<tr>
<td>% Quartz</td>
<td>49.8</td>
<td>43.8</td>
<td>40.9</td>
</tr>
<tr>
<td>% Plagioclase</td>
<td>43.6</td>
<td>16.1</td>
<td>24.7</td>
</tr>
<tr>
<td>% Potash feldspar</td>
<td>——</td>
<td>39.0</td>
<td>34.1</td>
</tr>
<tr>
<td>% Biotite</td>
<td>——</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>% Muscovite</td>
<td>4.9</td>
<td>0.6</td>
<td>——</td>
</tr>
<tr>
<td>% Dark opaques</td>
<td>1.7</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>% Sphene</td>
<td>tr.</td>
<td>tr.</td>
<td>——</td>
</tr>
<tr>
<td>% Zircon</td>
<td>tr.</td>
<td>tr.</td>
<td>——</td>
</tr>
<tr>
<td>% Chlorite</td>
<td>tr.</td>
<td>tr.</td>
<td>——</td>
</tr>
</tbody>
</table>

Sample 114 - fine-grained, granitic intrusive into Lost Creek gneiss.

Sample 112c - Town Mountain granite.

Sample 112 - Town Mountain granite.

Sample 84 - aplogranite intrusive into Valley Spring gneiss.
Plate xiii - Undulant quartz phenocrysts in a fine-grained groundmass which has apparently partially recrystallised (felsite porphyry from Red Mountain gneiss, x-nicols, X20).
Plate xiv - Albite-rimmed, myrmekitic, euhedral plagioclase inclusion and quartz vein within porphyroblast; albite-rimmed, myrmekitic, subhedral plagioclase grains around edge of porphyroblast (x-nicols, X65).
Plate xv - Poikilitic, anhedral masses of microcline with ragged, irregular outlines (x-nicols, X20).
Plate xvi - Microcline porphyroblast with moderately developed outline and abundant inclusions (x-nicols, X22).
Plate xvii - Microcline and perthite porphyroblast with smooth, regular outline and few inclusions; two extinctions possibly because of two centers of growth or Carlsbad twin (X-nicols, X17).
STUDY OF ZIRCON SUITES

Zircons, because of their resistance to abrasion, corrosion, heat, and pressure, are commonly used as environmental indicators. Zircons from extrusive and intrusive rocks are generally euhedral, while zircons from sediments are generally rounded. Because regional metamorphism seems to have little effect on the morphology of zircons, a zircon suite may characterize a certain rock type. Zircons from a recent sediment and from intrusive, extrusive, metaigneous, and metasedimentary rocks from various areas were extracted and studied to determine differences in morphology between different zircon suites and to shed light on the origin of the Lost Creek gneiss. A study of the alpha-track distribution around zircon grains was also made to determine the suitability of a Lost Creek sample for an absolute age determination.

Sampling and Separation Procedures

The following samples (approximately 100 pounds in size) were collected for a possible zircon age determination:

1. augen gneiss from the Lost Creek gneiss (sample 1)
2. felsite porphyry from the Red Mountain gneiss (sample 25c)
3. granitic gneiss from the Red Mountain gneiss (sample 26c)
4. hornblende-plagioclase schist from the Packsaddle schist in the Lost Creek area (sample 65)
5. granitic gneiss from the Lost Creek gneiss (sample 104)

Samples 25c and 26c were collected by Dr. S. E. Clabaugh from the type locality of the Red Mountain gneiss and were chosen to be typical of the lithologies of that area. Similarly, samples 1 and 104 were chosen by the writer as typical of the Lost Creek gneiss, and sample 65 was chosen as typical of the Packsaddle schist.

Each of the samples was then crushed and ground. A preliminary study of an approximately 1 kilogram sample was made to determine whether the zircons were in sufficient concentration for a profitable extraction. Unfortunately, all of the preliminary studies, with the exception of samples 1 and 104, indicated that the concentration of zircon in the samples was too low for a profitable extraction. In each case, over 200 pounds of sample would have had to be processed for at least 1 gram of zircon, generally the minimum amount required for the age determination. Sample 1 required the processing of only 40 pounds for 1.25 grams of zircon; and sample 104, approximately the same.

The procedure for the zircon extraction is the same for small samples used in the preliminary studies as well as the large-scale extractions. After the grinding of sample 1, the next step involved a
heavy liquid separation. Approximately 500-gram quantities were poured into bromoform in a 2-liter separatory funnel, until approximately 18 kilograms had been processed. The specific gravity of the bromoform was 2.85, so this step removed the two principal constituents of the sample, quartz and feldspar. The magnetite was removed from the remaining heavy fraction by a hand magnet. The remaining material was then run through a Franz Isodynamic Separator in successive stages at 15° inclination. Because of the high magnetic susceptibility of the larger portion of the material, the sample was first run through the separator at 0.2 amperes. The current was then successively raised in steps of 0.2 amperes until a pure non-magnetic separate was obtained. The non-magnetic fraction was separated with methylene iodide (specific gravity, 3.33) in a 200 milliliter separatory funnel. Sample 1 was examined under the microscope and found to be roughly 90 percent pure zircon. The remaining material was run through the methylene iodide a second time, which removed almost all of the remaining impurities. The final sample was 1.25 grams of 99 percent zircon or zircon-like minerals.

Morphology

Zircons were then extracted from other samples from various areas, which included intrusives and extrusives, a recent sediment,
and the type Red Mountain gneiss, using essentially the same pro-
cedure as outlined above. The following samples were studied, along
with these six samples from the Lost Creek area listed previously:

1. granite from Lausitz, Germany
2. granite from Singkep, Indonesia
3. placer deposit from Gebel Gharib, Egypt
4. Town Mountain granite from Lost Creek
gneiss area (sample 112)
5. bentonite from Carters limestone, Tennessee
   (GH-24)
6. bentonites from the Chicamauga limestone,
   Tennessee (GH-12 and GH-14)
7. beach sand from Florida

The zircons were analyzed by means of the petrographic microscope,
and the following characteristics were noted:

1. general form - euhedral, rounded, etc.
2. length of long (c) axis
3. elongation ratio - long axis divided by short
   axis (c/a)

Figures 5 through 10 represent histograms of the thirteen samples
analyzed, plotting length distributions and elongation ratio distributions.

Considering the length distribution histograms (Figures 5, 6, and 7), no apparent correlation is noted between zircons of rocks of
similar type. The two Red Mountain samples, 25c and 26c, are quite
similar; however, the three intrusive granite samples (Lausitz,
Singkep, and Town Mountain) are quite different. It should be noted
that only a maximum of six class intervals is plotted and that there
Figure 5. Length distribution histograms of strom suites from the Lost Creek greiss (Nos. 1 and 104), Petkeadie schist (No. 65), and Town Mountain granite (No. 112).
Figure 6. Length distribution histograms of zircon suites from a Florida beach sand and from some bentonites (Nos. GH-14, GH-24, and GH-12).
Figure 7. Length distribution histograms of zircon suites from the Red Mountain gneiss (Nos. 25c and 26c), from two granites (Lausitz, Germany and Singkep, Indonesia), and from a placer deposit (Gebel Gharib, Egypt).
Figure 6. Elongation ratio distribution histograms of mica suites from the Last Creek gneiss (Nos. 1 and 104), Patsyaddle schist (No. 65), and Town Mountain granite (No. 112).
Figure 9. Elongation ratio distribution histograms of zircon suites from a Florida beach sand and from some bentonites (Nos. GH-14, GH-24, and GH-12).
Figure 13. Elongation ratio distribution histograms of arsenic suite from the Red Mountain placer (Pls. 25c and 26c), from local sources (Lausitz, Gebel, and Singkep), and from the ancient Lower Nile Delta (Egypt).
may be a quite different correlation between samples than is indicated by these histograms. All of the samples have at least four class intervals, and the Singkep sample has six.

The histograms seem to be slightly skewed to the right toward the coarser ranges, and the mode is invariably in the 1/16 to 1/8 or 1/8 to 3/16 mm size range. The sediment and the metasediments might be expected to show the greatest dispersion, but they do not. The Gharib sample has the smallest dispersion, while the Singkep has the largest. The Lausitz granite sample has the overall smallest grain size, while the Florida beach sand has the largest. It is evident, however, that the size distribution histograms indicate no apparent relationship between the zircon from the Lost Creek gneiss and any of the other samples.

An examination of the histograms plotting the elongation ratios (Figures 8, 9, and 10) also indicates no apparent correlation. Again the histograms appear to be skewed to the right, toward the more acicular ranges, and the mode is invariably in the 2 or 3 range. The Lausitz sample shows the greatest dispersion with six class intervals. The zircons of the Lausitz sample are the most acicular, while the zircons of the Gharib sample are the most equant. The two Red Mountain zircon suites are quite similar in both size distribution and elongation ratio. The
histograms of the two Red Mountain samples are almost identical, and the size distribution histograms resemble the elongation ratio histograms. The following general observations are made:

1. The smallest zircons are the most acicular.

2. The Lausitz sample shows the greatest dispersion in both the size distribution and the axial ratio distribution.

3. The Gharib sample shows the least dispersion in both the size distribution and the axial ratio distribution.

4. The Lausitz is the most acicular and shows the greatest dispersion, while the Gharib sample is the least acicular and shows the least dispersion, as would be expected.

Further studies were conducted to observe the general form of the zircon. The grains of each sample were classified as to whether they were euhedral, subhedral, rounded, frosted (abraded or corroded), coated with some foreign matter (commonly limonite or hematite), or a fragment of a whole crystal. Table VI shows the results of this study. Here, the correlation between zircons from the same general rock type is quite evident. The Packsaddle schist zircon suite (sample 65), metasedimentary, the Lost Creek gneiss zircon suite (samples 1 and 104), questionably metasedimentary, and the Florida beach sand, a recent sediment, are similar in all categories.

Discrepancies are noticed in the two Red Mountain zircon samples. Even in this case, however, the zircons are considerably more euhedral
### TABLE VI

**Morphology of Zircon Suites**

<table>
<thead>
<tr>
<th>Morphology</th>
<th>Lost Creek Gneiss and Packsaddle Schist</th>
<th>Sample Number Red Mountain Gneiss</th>
<th>Gharib Placer</th>
<th>Florida b’ch. Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>104</td>
<td>65</td>
<td>25c</td>
</tr>
<tr>
<td>% Euhedral</td>
<td></td>
<td></td>
<td>7</td>
<td>61</td>
</tr>
<tr>
<td>% Subhedral</td>
<td>12</td>
<td>36</td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td>% Rounded</td>
<td>48</td>
<td>40</td>
<td>44</td>
<td>7</td>
</tr>
<tr>
<td>% Fragments</td>
<td>12</td>
<td>12</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>% Frosted</td>
<td>26</td>
<td>4</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>% Coated</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Placer deposit collected by Dr. H. M. E. Schürmann (Gravenhage, Netherlands) from Gebel Gharib, Egypt.
<table>
<thead>
<tr>
<th>Morphology</th>
<th>Lausitz Granite</th>
<th>Singlek Granite</th>
<th>Sample Number</th>
<th>Town Mt. Granite</th>
<th>GH-24</th>
<th>GH-14</th>
<th>GH-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Euhedral</td>
<td>65</td>
<td>57</td>
<td>18</td>
<td>53</td>
<td>50</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>% Subhedral</td>
<td>29</td>
<td>15</td>
<td>31</td>
<td>17</td>
<td>22</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>% Rounded</td>
<td>1</td>
<td>8</td>
<td>12</td>
<td>6</td>
<td>9</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>% Fragments</td>
<td>3</td>
<td>4</td>
<td>8</td>
<td>14</td>
<td>11</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>% Frosted</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>9</td>
<td>7</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>% Coated</td>
<td>—</td>
<td>16</td>
<td>31</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Granites collected by Dr. H. M. E. Schürmann (Gravenhage, Netherlands) from Lausitz, Germany, and Singkep, Indonesia.

Bentonites collected by Gilmor S. Hamill from the Middle Ordovician Carters limestone, west of Dowtown, Tennessee (GH-24), and from the Middle Ordovician Chicamauga limestone in Roane County, Tennessee (GH-12 and GH-14).
than those in the Lost Creek and Packsaddle samples and the Florida beach sand. The high percentage of broken fragments in the extrusive samples may be explained by the forceful ejection of the material from the volcano, while the same phenomenon in the sedimentary and metasedimentary samples is probably best explained by hydraulic action during transportation. Abrasion during hydraulic action may also account for the relatively high percentage of abraded grains in the sediments and metasediments. The higher percentage of frosted grains in the extrusive rocks is possibly caused by corrosion.

Vitanage (1957) studied zircon suites from a Precambrian complex in Ceylon and obtained data similar to those obtained by the writer. He concluded that different types of zircons characterize different rock types and their respective geologic histories and that the two most important parameters in determining the provenance of a suite of zircons is the elongation ratio and the degree of roundness. He determined the elongation ratio by dividing the short axis by the long axis, which is the reciprocal of the elongation ratio plotted on histograms in Figures 8, 9, and 10. His data on zircon suites from biotite granitic gneisses were then recalculated and compared to the suites from the Lost Creek gneiss and Town Mountain granite. No correlation could be made because the zircon suites from the two
areas are quite different. Vitanage pointed out that granitic gneisses vary considerably, but in general, zircons from charnockite-biotite gneisses are commonly equant and rounded, while zircons from microcline biotite gneisses (in places porphyroblastic) are commonly elongate and euhedral. He found that the average elongation ratio of all gneiss suites is \( \frac{55}{2} \) and that the average length varies from \( \frac{49}{13} \) mm. An elongation ratio of \( \frac{2}{1} \) is comparable to the average elongation ratio of zircons studied by the writer, but the overall grain size is considerably larger.

Eckelmann and Kulp (1956) made zircon studies similar to those made by Vitanage and the writer on a coarsely banded, porphyroblastic gneiss of the Cranberry and Henderson gneisses of North Carolina. The frequency diagrams of elongation ratios and lengths plotted by Eckelmann and Kulp are similar to the histograms of the Lost Creek gneiss. Table VII records the average length, elongation ratio, and rounding index (percentage of non-euhedral grains) of zircons in a group of metasedimentary granitic gneisses from the Cranberry and Henderson gneisses and from the Lost Creek gneiss and Packsaddle schist. Many of the values obtained by Eckelmann and Kulp are quite similar to those recorded by the writer. They concluded that the most significant evidence of the history of a zircon suite is the relative roundness. Utilizing this principal, they reported
<table>
<thead>
<tr>
<th>Lithology</th>
<th>Av. length (c-axis) in mm</th>
<th>Av. elongation ratio (c/a)</th>
<th>Rounding Index in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banded granitic gneiss</td>
<td>0.16</td>
<td>2.4</td>
<td>61.5</td>
</tr>
<tr>
<td>Banded granitic gneiss</td>
<td>0.10</td>
<td>1.2</td>
<td>97.0</td>
</tr>
<tr>
<td>Cranberry and Henderson Gneisses (Eckelmann and Kulp, 1959)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banded granitic gneiss</td>
<td>0.13</td>
<td>2.2, 3.0</td>
<td>94.0</td>
</tr>
<tr>
<td>Banded granitic gneiss</td>
<td>0.07</td>
<td>1.4</td>
<td>98.0</td>
</tr>
<tr>
<td>Banded granitic gneiss</td>
<td>0.12</td>
<td>3.0</td>
<td>92.0</td>
</tr>
<tr>
<td>Foliated granitic gneiss</td>
<td>0.12</td>
<td>2.8</td>
<td>94.0</td>
</tr>
<tr>
<td>Augen gneiss (sample 1)</td>
<td>0.10</td>
<td>2.6</td>
<td>98.0</td>
</tr>
<tr>
<td>Lost Creek Gneiss and Packsaddle Schist</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granitic gneiss (sample 104)</td>
<td>0.17</td>
<td>2.7</td>
<td>93.0</td>
</tr>
<tr>
<td>Hornblende-plagioclase schist (sample 65)</td>
<td>0.18</td>
<td>2.4</td>
<td>93.0</td>
</tr>
</tbody>
</table>
that some of the porphyroblastic gneisses of the Cranberry and Henderson gneisses are metasedimentary.

From the above considerations, one may conclude tentatively that the degree of rounding is the principal factor which indicates the history of a zircon suite, and that the length or elongation ratio of a zircon grain is a poor indicator of the history. The degree of rounding indicates that the zircons from the Lost Creek gneiss may be included in the sedimentary and metasedimentary suites.

Radioactivity

Zircons from the Lost Creek gneiss (sample 1) were pressed into a Kodak nuclear track plate. After several weeks' exposure, the plate was developed. A study was then made, utilizing the petrographic microscope, to determine the suitability of the sample for absolute dating. Hamilton (1958) reported that the validity of a zircon age date is dependent upon the site of the radioactive elements, uranium and thorium. If the uranium and thorium are carried in inclusions, or substitute for zirconium in the crystal lattice, the date is probably valid, for such an ideal situation would represent a closed chemical system. There would be very little chance of introduction of more uranium or thorium, or, equally as important, common lead. Conversely, if the uranium and thorium seem to come from coatings
or crack and fissure fillings, the system is not closed, and there is
a good chance that the age determination is not valid. With this theory
in mind, a study of the distribution of the alpha-tracks emitting from
zircon grains in sample 1 was made. Figures 11 and 12 and Table
VIII summarize the results.

Table VIII

Variation of Alpha-tracks per Zircon
with Morphology of the Zircons, Sample 1

<table>
<thead>
<tr>
<th>Morphology</th>
<th>Alpha-tracks per grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>euhedral</td>
<td>4.0</td>
</tr>
<tr>
<td>subhedral</td>
<td>3.7</td>
</tr>
<tr>
<td>rounded</td>
<td>3.8</td>
</tr>
<tr>
<td>fragment</td>
<td>3.5</td>
</tr>
<tr>
<td>frosted</td>
<td>5.3</td>
</tr>
<tr>
<td>&quot;hot&quot;</td>
<td>295</td>
</tr>
</tbody>
</table>

Figure 11 shows the variation of number of alpha-tracks per
grain with the size of the grain. Considering sample 1, it is apparent
that the number of tracks per grain increases with the size of the
zircon. An ideal curve, assuming equal concentrations of thorium
and of uranium within the zircon suite, would show that the average
number of alpha-tracks per grain would increase as the volume of
Figure 11. Graph showing variation of number of alpha-tracks per grain with the length of the grain, sample 1.
Figure 12. Graph showing variation of number of alpha-tracks per grain with the elongation ratio of the grain, sample 1.
the grain increases, until the short diameter of the grain exceeds
the mean free path (distance of penetration) of an alpha particle in
zircon; then the number of alpha-tracks per grain would increase as
the surface area of the grain increases. Therefore, the average
number of alpha-tracks per grain would be expected to increase as
the cube of the size (length of c-axis) of the zircon initially, and
when the short diameter exceeds the mean free path, as the square
of the size of the zircon. Figure 11 indicates a curve which approxi-
mates the equation

\[ y = x^3 + C \]

where \( y \) equals the average number of tracks per grain, \( x \) equals the
size (length of c-axis) of the grain, and \( C \) is a constant. Thus, the
curve in Figure 11 might indicate that the short diameter of the zircon
grains never exceeds the mean free path of alpha particles in the zir-
con of sample 1. Because of the limited number of measurements,
any further comparison between this curve and an ideal curve would
have little meaning. Figure 12 represents the variation of the axial
ratios of the grains with the number of alpha-tracks per grain. The
curve indicates that the average radioactivity is not dependent upon
the variation in elongation of the grains because the number of tracks
per grain remains roughly constant as the axial ratio increases.
An attempt was made to determine whether there was any relation of tracks per grain to the general form of the grains. Table VIII indicates the results. It is apparent that the average radioactivity is not dependent upon the history of the grain since its solidification. Rounded zircon grains are essentially as radioactive as euhedral ones. The exception to the lack of dependence of the radioactivity of a zircon grain on its history since solidification would be due to a coating or secondary overgrowth that is highly radioactive, which was not observed in sample 1.

As to the distribution of the alpha-tracks around the zircons, no conclusive evidence was found. Ninety-eight percent of all tracks seemed to be radiating randomly from the crystals, while only 2 percent was definitely coming from inclusions within the crystals. However, no tracks were noticed coming from coatings or cracks, so it may be tentatively assumed that the suite represents a closed chemical system.

One disturbing note concerns the presence of "hot" minerals, minerals that exhibit approximately 75 times as many alpha-tracks radiating from them as do the zircons. In sample 1 these "hot" grains contain 92 percent of the radioactive constituents but only comprise 13 percent of the total number of grains. At least two minerals seem to be present, the hottest of which has been identified as monazite,
and another mineral which has yet to be identified. The monazite commonly appears as equant, rounded crystals, while the unknown mineral is rounded and acicular, with non-parallel extension, high relief, and high birefringence. The presence of such minerals in a zircon age determination sample may be significant, for the crystallization and subsequent history of the "hot" minerals may or may not be similar to that of zircon.

In conclusion, the sample apparently represents a closed chemical system, and an absolute age determination would be valid. The question then arises as to the meaning of the age date. Assuming a metasedimentary rock and no recrystallization during metamorphism, the age determination would date the original crystallization of the zircon and would indicate nothing as to the actual time of metamorphism. Since the rock has been metamorphosed, it is not related to the igneous activity which intruded the Town Mountain granite (300 to 900 million years, Hutchinson, 1956), which is believed to postdate the metamorphism. Since the rock is probably a metasediment, there is no certain way to determine what event the age determination would date.
HISTORY AND CONCLUSIONS

The foregoing portion of this paper has dealt chiefly with observations, both in the field and through the petrographic microscope. The following portion, however, is largely speculative. The writer is aware of the fact that hypotheses change, depending upon the particular vogue which is in style when the paper is written. Because the observed phenomena will be explained in the light of one concept which is very popular today, the statement in the introduction of the paper that "each augen gneiss should be studied with the thought in mind that it has its own particular genesis" may seem somewhat idealistic. Nevertheless, in the opinion of the writer, the concepts proposed seem to explain best the observations.

Read (1949) commented that "the significance of an augen-texture may be revealed only after detailed field and laboratory studies." Both field and laboratory studies indicate that the Lost Creek gneiss is higher in potassium content than either the Packsaddle schist or Valley Spring gneiss. The Lost Creek gneiss generally contains a higher percentage of both of the major potassium-bearing minerals in the area, microcline and biotite, than do the Packsaddle schist or Valley Spring gneiss. Any discussion of the geologic history of the area should include the reasons for the higher potash content within the Lost Creek gneiss.
Although the mineralogical assemblages of the three Precambrian units are variable, these assemblages appear to be stable under similar conditions of temperature and pressure. Plagioclase composition is quite variable (An8 to An32) within, as well as between, lithologic units; it is not accepted as a criterion of metamorphic rank in this area. The mineralogy of all three units is indicative of quartzofeldspathic assemblages within the lower almandine amphibolite facies (Fyfe, Turner, and Verhoogen, 1959). The entire sequence may well be the moderate depth metamorphic derivative of a series of argillaceous sediments containing admixed dolomites and argillites or graywackes. The rocks are too low in modal quartz to have been derived from arenaceous sediments. The presence of tremolite requires additional calcium, possibly supplied by calcareous shales; while the presence of hornblende may well indicate minor dolomite or possibly graywacke. The presence of potassium in the Lost Creek gneiss may be explained by the composition of the original sediment; for instance, a shale high in illite content is analogous to the overall composition of the Lost Creek gneiss.

The presence of potassium in the Lost Creek gneiss can be explained by two general mechanisms. The potassium either migrated into the rock during or after metamorphism, or it was in the original rock before the metamorphism. Assuming that the potassium was...
in the original rock, the rock could have been a granite. A plot of
the modal compositions of the Lost Creek samples on a ternary
diagram (Figure 13) indicates that the overall composition of the
Lost Creek gneiss is very similar to the average composition of some
200 granites from the United States (Figure 56, page 112, Tuttle and
Bowen, 1958). Assuming an intrusive igneous origin, the interlay-
ering of augen gneiss and schist along the contacts may be inter-
preted as lit-par-lit injection. The conformity of the foliation of the
augen body with the foliation of the surrounding rock can be explained
by the uniform regional metamorphism of the entire area.

Nevertheless, the gradational contacts which are observed,
the bands of augen gneiss within the Facksaddle schist with grada-
tional contacts, bands of hornblende schist and quartz-feldspathic
fine-grained gneiss within the augen bodies, and the lack of intrusive
features such as sharp contacts, apophyses, or chilled borders, all
point to a metasedimentary origin of the augen gneiss. If the augen
gneiss were originally intrusive, it would have had to have been a
sill-like intrusion because it does not crosscut the foliation, which
is assumed to be essentially parallel to the original bedding. The
morphology of the zircons within the augen gneiss body strongly indi-
cates the possibility of a sedimentary origin. Without exception, they
are extremely rounded and abraded, clearly similar to the sedimentary
Figure 11. Modal percentages of quartz, plagioclase, and potash feldspar from the Lost Creek gneiss and the Red Mountain gneiss.

- Valley Spring gneiss
- Red Mountain gneiss
- Hackamet schist
- Lost Creek gneiss
- Intrusives
and metasedimentary zircon suite and quite different from the igneous
and metaigneous zircon suite. The location of the body, between the
Valley Spring gneiss and the Packsaddle schist and conformable to
them, raises the possibility of an original sedimentary formation
higher in potassium content than the overlying and underlying litholo-
gies. Quartz content is too low for an arkose, assuming isochemical
metamorphism, but an illitic shale is a distinct possibility. There-
fore, the possibility exists that the higher potassium content in the
Lost Creek gneiss represents a higher potassium content in the origi-
nal rock.

If the potassium migrated in, it either migrated laterally or
up from depth. A possibility exists that the potassium ions could
have been carried by late stage emanations from the Town Mountain
granite out into the country rock. If this occurred, the fluids would
have had to migrate upward preferentially along the Lost Creek unit.
The contact between the Town Mountain granite and the Packsaddle
schist is sharp, with no evidence of thermal metamorphism, assimila-
tion, or fluids from the Town Mountain granite permeating the
country rock. To the north, the potassium content (contained in bio-
tite and microcline) becomes progressively greater away from the
contact. Just the reverse is true in the central portion of the area,
so no uniform gradation can be cited. However, because the
foliation planes in the gneiss dip toward the granite body, and identical features are observed in thin sections of the Town Mountain granite and Lost Creek gneiss (rimmed, myrmekitic plagioclase, replacement perthite, and inclusions of rimmed plagioclase and quartz within the potash feldspars), there is a possibility that late-stage, potash-rich solutions from the Town Mountain granite migrated upward preferentially along the Lost Creek unit and metasomatized the Town Mountain granite and Lost Creek gneiss, but failed to penetrate the Packsaddle schist. Such a preferential potash metasomatism might be caused by a difference in texture in the original rocks, such as a larger grain size within the Lost Creek gneiss. The gradation of augen gneisses to banded gneisses and the sharp contact between the augen and banded gneiss as the sequence is repeated might be explained in the same manner. If a series of graded beds were metamorphosed and the pressure were later partially released in the presence of potash-rich solutions, these solutions would tend to migrate toward areas of localized lower pressures. At the top of the originally graded bed, the solutions would migrate toward foliation planes; whereas, at the bottom of the beds, no such well-developed foliation planes would be formed, and solutions might tend to migrate toward more localized areas. The net result might be an augen gneiss grading upward into a banded gneiss; the sequence would then be
repeated with a sharp contact between the two units. The potassium may have been introduced from granitic fluids escaping from a body at depth and rising to permeate the country rock. Either hypothesis is difficult to prove or disprove.

Goldschmidt (in Turner, 1948) classified the following reactions as indicative of alkali metasomatism:

1. formation of myrmekite in metamorphic rocks
2. introduction of potassium feldspar into metamorphic derivatives of shales
3. replacement of hornblende by biotite in granitization

All three of the reactions listed above have taken place within the augen body. Buddington (1957) reported that "biotite-quartz-plagioclase gneiss was the major raw material that was modified by granitizing fluids to yield a porphyroblastic granite gneiss." He contended that "the potassium-rich fluids can be considered a volatile-rich magma or ichor, a hydrothermal solution, a cloud of dispersed ions, or a combination of all three." Engel and Engel (1953, 1958) reported the formation of porphyroblastic gneisses by potash metasomatism in the Grenville series of the northwest Adirondack Mountains of New York. The advance guard of granitic fluids ahead of the magma may have reached the northern body, and more complete granitization of the country rock by the magma may have taken place in the south. This
mechanism could explain the retention of the foliation in the northern part of the Lost Creek gneiss and the obliteration of the foliation to the south.

The possibility of anatexis should be mentioned. If temperatures became sufficiently high for partial or complete remobilization, a concentration of hyperfusibles in bands and eventual complete segregation of schist and granitic gneiss might occur. This semi-mobile condition of the rock mass is also offered in explanation for the presence of pods, lenses, non-dilation pegmatites, and bands. Ramberg (1952) indicated how such features may be formed by migration of ions toward a low pressure area, such as a crack or fracture in the rock. He stated that this process can take place by "dry diffusion" of ions. Under conditions of "wet diffusion" the ions would be even more mobile and would be free to migrate more easily.

In summary, the presence of an overall greater percentage of potassium in the Lost Creek gneiss may be explained by two different hypotheses; original variations in composition or permeation by granitic fluids. If the potassium was present in situ, porphyroblasts and associated phenomena were formed by metamorphic differentiation. Conversely, if the potassium was introduced, the porphyroblasts were formed by metasomatic segregation. Present knowledge is not of sufficient quantity to warrant a more detailed discussion of the geologic
history of the area. A more detailed study of the process of alkali
metasomatism, utilizing refined techniques, in an area with good
exposures would be informative.
REFERENCES

Barnes, V. E., and Parkinson, G. S., (1940), Dreikanters from the basal Hickory sandstone of Central Texas: Separate from University of Texas Publication 3945, pp. 665-670.

Barnes, V. E., (1945), Soapstone and serpentine in the Central Mineral Region of Texas: University of Texas Publication 4301, pp. 55-91.


Cloud, P. E., Jr., and Barnes, V. E., (1948), The Ellenburger group of Central Texas: University of Texas Publication 4621, 473 pp.


APPENDIX

Sample No.

5  
General Description. augen gneiss, generally phacoidal, with pink microcline porphyroblasts (maximum long diameter = 1 cm, consistently parallel to foliation) in a medium-grained, mesocratic, granoblastic groundmass of quartz, plagioclase, microcline, and biotite; foliation owing to subparallel orientation of biotite flakes.

Location. in road cut on Farm Road 734 approximately 2 1/8 miles north of intersection with Ranch Road 386.

8  
General Description. augen gneiss, generally phacoidal, with pink microcline porphyroblasts (maximum long diameter = 1 cm, parallel to foliation) in a medium-grained, mesocratic, granoblastic groundmass of quartz, plagioclase, microcline, and minor hornblende; foliation owing to subparallel orientation of hornblende laths, banding of quartz-feldspar and hornblende.

Location. in road cut on Ranch Road 386 approximately 1/2 mile south of Wienecke farm.

11  
General Description. augen gneiss, generally phacoidal, with white to gray plagioclase and pink microcline porphyroblasts (maximum long diameter = 1 cm, randomly oriented) in a medium-grained, mesocratic, granoblastic groundmass of quartz, plagioclase, microcline, and minor hornblende; indistinct foliation.

Location. in road cut on Ranch Road 386 approximately 2 1/8 miles south of intersection with Farm Road 734.

17  
General Description. quartz-feldspathic gneiss, fine-grained, leucocratic, granoblastic gneiss composed of microcline, plagioclase, quartz, and minor biotite; indistinct foliation.
Location, from hillside approximately 20 yards east of Ranch Road 386, 1 1/2 miles south of the Thomas farm.

General Description, augen gneiss, generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 1 cm, randomly oriented) in a medium-grained, leucocratic, granoblastic groundmass of quartz, plagioclase, microcline, and minor biotite; indistinct foliation.

Location, from hillside approximately 1 mile northeast of Capps ranch.

General Description, described in detail in text.

Location, from Red Mountain gneiss, collected by S. E. Clabaugh.

General Description, described in detail in text.

Location, from Red Mountain gneiss, collected by S. E. Clabaugh.

General Description, augen gneiss, generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 0.7 cm, parallel to foliation) in a fine-grained, mesocratic, granoblastic groundmass of quartz, plagioclase, microcline, and minor biotite; foliation well developed.

Location, in field approximately 100 yards northeast of Parker farm.

General Description, banded gneiss, medium-grained, melanocratic, xenoblastic gneiss composed of alternating bands of quartz-plagioclase and hornblende-epidote-plagioclase (bands vary in thickness from 1/2 cm in places to several cm); plagioclase porphyroblasts; foliation moderately developed, parallel to banding.
50 (cont.) Location, in quarry approximately 200 yards south of cemetery on Ranch Road 386.

51 General Description. banded gneiss, medium-grained, mesocratic, granoblastic gneiss composed of alternating bands of quartz-plagioclase and hornblende with minor epidote (bands vary from 1 mm to 1 cm); foliation well developed owing to parallel orientation of hornblende laths; laths exhibit decussate pattern within foliation planes; small plagioclase porphyroblasts (long diameter 2 to 3 mm) common.

Location, in road cut approximately 200 yards north of Sherwood farm.

57 General Description. granitic gneiss, coarse-grained, leucocratic, granoblastic gneiss composed of quartz, plagioclase, microcline, and minor hornblende; foliation indistinct.

Location, in stream bed approximately 1/2 mile east of Ranch Road 386 and 1 mile north of Capps ranch.

60 General Description. quartz-feldspathic gneiss, fine-grained, leucocratic, granoblastic gneiss composed of quartz, plagioclase, microcline, and minor biotite; rare feldspar-quartz bands and rare microcline porphyroblasts; foliation well developed.

Location, in field approximately 3/4 mile north of locality 57 and 1/4 mile east of Ranch Road 386.

64 General Description. augen gneiss, generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 1.5 cm, parallel to foliation) in a medium-grained, leucocratic, granoblastic groundmass of quartz, plagioclase, microcline, and minor biotite; foliation moderately developed.

Location, in pasture approximately 7/8 mile southwest of Ellebracht farm and 3/4 mile east of Ranch Road 386.
75

**General Description.**Augen gneiss, generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 1.5 cm, parallel to foliation) in a medium-grained, leucocratic, granoblastic groundmass of quartz, plagioclase, microcline, and minor hornblende; foliation moderately developed.

**Location.**In stream bed approximately 500 yards east of Ranch Road 386 and 3/4 mile southwest of locality 57.

78a

**General Description.**Granitic gneiss, coarse-grained, leucocratic, granoblastic gneiss composed of quartz, plagioclase, microcline, and minor biotite; foliation indistinct.

**Location.**In pasture approximately 200 yards northeast of Capps ranch.

78b

**General Description.**Quartz-feldspathic gneiss, fine-grained, leucocratic, granoblastic gneiss composed of quartz, plagioclase, microcline, and minor biotite; foliation indistinct.

**Location.**Same as 78a.

84

**General Description.**Aplogranite, pink, medium-grained, equigranular, xenomorphic-granular granite composed of quartz, microcline, plagioclase, and minor muscovite.

**Location.**Approximately 1/4 mile east of locality 85.

85

**General Description.**Quartz-feldspathic gneiss, fine-grained, mesocratic, granoblastic gneiss composed of quartz, microcline, plagioclase, and minor garnet and hornblende; banding of quartz-feldspar common, rare microcline porphyroblasts; foliation well developed.
Sample No.

35 (cont.) Location. in pasture approximately 1 mile north of Brown ranch and 1/2 mile west of road leading north from Dryper ranch.

90 General Description. contact between quartzo-feldspathic gneiss and augen gneiss, contact distinct and regular.

augen gneiss. generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 1 cm, parallel to foliation) in a medium-grained, leucocratic, granoblastic groundmass of quartz, microcline, plagioclase, and minor biotite; foliation well developed.

quartzo-feldspathic gneiss. fine-grained, leucocratic, granoblastic gneiss composed of microcline, plagioclase, quartz, and minor biotite; banding of biotite and quartz-feldspar; foliation well developed.

Location. in Lost Creek approximately 1/2 mile west of Farm Road 734.

91 General Description. augen gneiss. generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 1.5 cm, parallel to foliation) in a medium-grained, leucocratic, granoblastic groundmass of quartz, microcline, plagioclase, and minor biotite and hornblende; banding of quartz feldspar and biotite-hornblende, porphyroblasts commonly incorporated in banding; foliation well developed.

Location. approximately 250 yards west of locality 90 in Lost Creek.

94 General Description. augen gneiss. generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 1 cm, randomly oriented) in a fine-grained groundmass of quartz, microcline, plagioclase, and minor hornblende; indistinct banding; foliation very well developed.
94 (cont.) Location, in Lost Creek approximately 500 yards west of locality 91.

97 General Description, same as 60.

Location, approximately 3/8 mile north of locality 94 in Lost Creek.

98a General Description, quartzo-feldspathic gneiss.

Fine-grained, mesocratic, granoblastic, gneiss composed of quartz, plagioclase, and minor hornblende; banding of quartz-feldspar and hornblende; foliation well developed.

Location, approximately 2 1/4 miles north of Kaiser farm on Ranch Road 386.

98c General Description, quartzo-feldspathic gneiss.

Pink, medium-grained, sugary textured, granoblastic gneiss composed of quartz, plagioclase, microcline, and minor biotite; banding and foliation poorly developed; rare small microcline porphyroblasts.

Location, same as 98a.

98e General Description, augen gneiss, generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 0.5 cm, parallel to foliation) in a medium-grained leucocratic, granoblastic groundmass composed of quartz, microcline, plagioclase, and minor biotite and hornblende; augen structure indistinct; banding of mafics and quartz-feldspar; foliation moderately developed.

Location, same as 98a.

98f General Description, same as 98e.

Location, same as 98a.
98g  General Description. same as 98e except augen structure distinct.

Location. same as 98a.

99a  General Description. augen gneiss. generally phacoidal, with pink microcline porphyroblasts (maximum long diameter - 2 cm, parallel to foliation) in a fine-grained, melanocratic, granoblastic groundmass of quartz, plagioclase, microcline, hornblende, and biotite; banding between quartz-feldspar and mafics; quartz-feldspar bands commonly incorporate porphyroblasts; foliation well developed.

Location. in stream bed approximately 3/4 mile west of Ranch Road 386.

100  General Description. quartzo-feldspathic gneiss. fine-grained, leucocratic, granoblastic gneiss composed of quartz and plagioclase with minor tremolite, epidote, and garnet; banding well developed; foliation indistinct.

Location. near water tank approximately 3/4 mile northwest of Brown ranch.

107  General Description. quartzo-feldspathic gneiss. fine-grained, leucocratic, granoblastic gneiss composed of quartz, plagioclase, microcline, and garnet with minor tremolite; banding well developed; foliation indistinct.

Location. along ridge approximately 1 mile southeast of Capps ranch.

110  General Description. same as 75.

Location. in cultivated field approximately 3/8 mile east of Ellebracht farm.
Sample No.

112  General Description, described in detail in text.

Location. in road cut approximately 100 yards west of Packsaddle schist-Town Mountain granite contact along road to Spy Rock.

112c  General Description, contact between granite and quartz biotite schist, contact very sharp, foliation planes of schist bent along contact.

  granite. same as 112 except medium-grained and non-porphyritic.

  quartz-biotite schist, fine-grained, gray to black schist composed of quartz, biotite, and plagioclase with minor microcline; foliation well developed owing to parallel alignment of biotite flakes.

Location. in road cut at Packsaddle schist-Town Mountain granite contact along road to Spy Rock.

113  General Description, quartz-feldspathic gneiss, fine-grained, sugary textured, leucocratic, granoblastic gneiss composed of quartz, plagioclase, microcline, with minor biotite; foliation poorly developed and banding indistinct.

Location. approximately 50 yards east of locality 112c, on road to Spy Rock.

114  General Description, granitic dike rock, very fine-grained, pink to maroon, xenomorphic-granular dike rock composed of quartz, plagioclase, and microcline.

Location. approximately 200 yards south of road and 1 mile east of Capps ranch.