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# IGNEOUS GEOLOGY OF THE LAKE ALTUS AREA, OKLAHOMA

by
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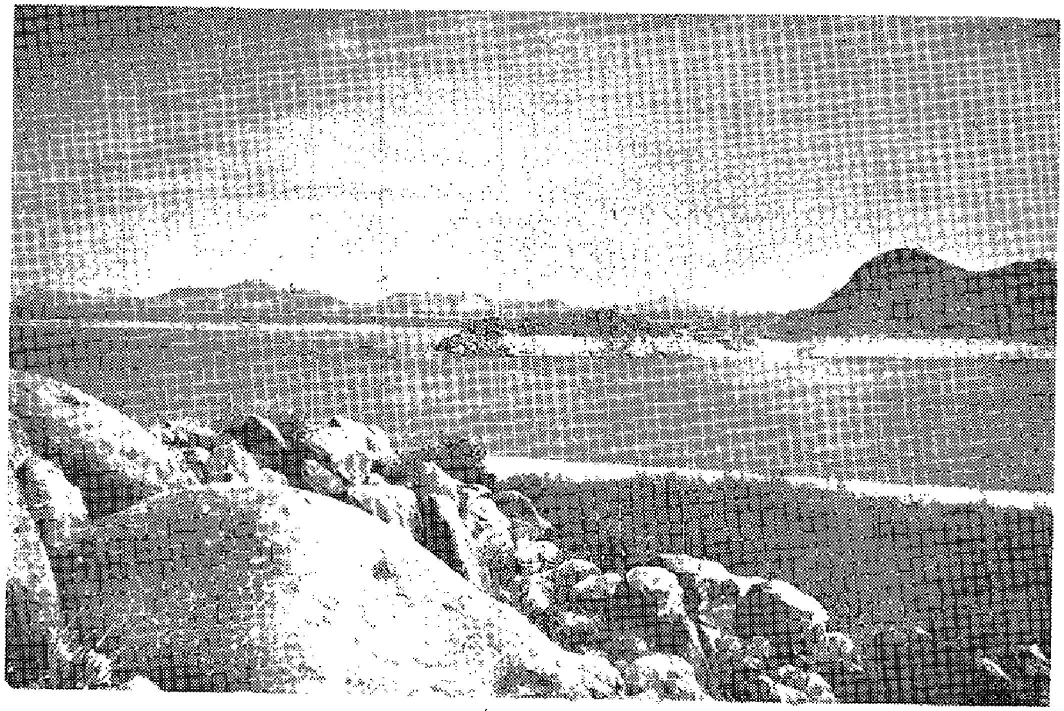
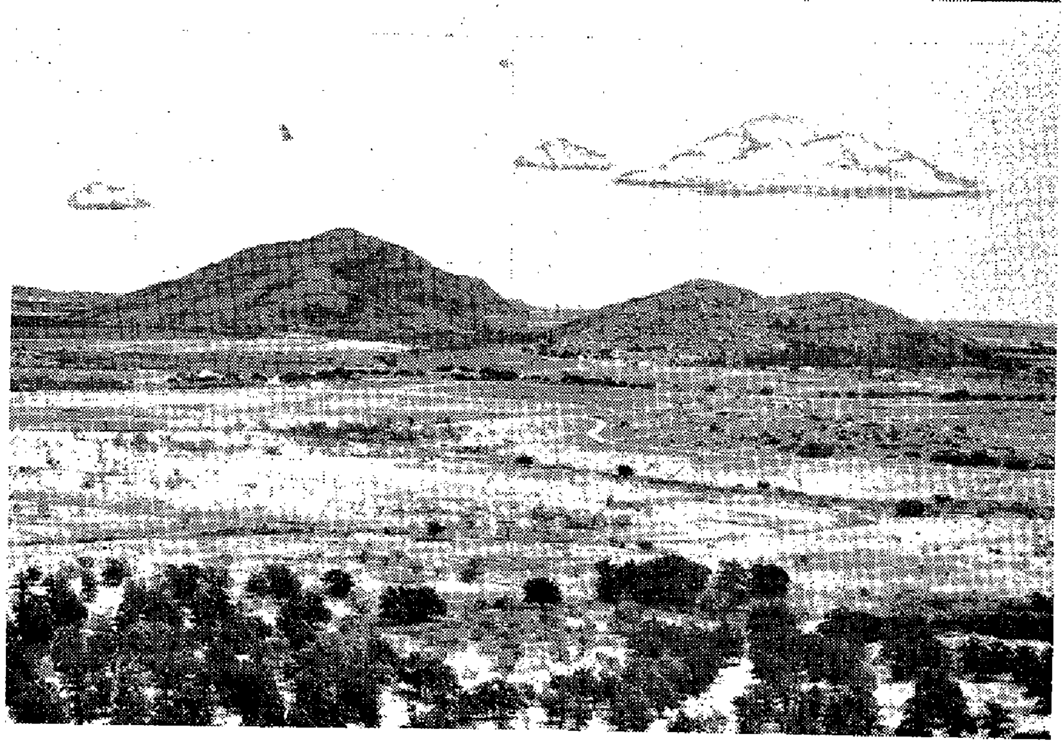




HILLS OF LUGERT GRANITE IN THE LAKE ALTUS AREA

*Upper.* View across Lake Altus from west shore in Quartz Mountain State Park, cen. sec. 23, T. 5 N., R. 20 W. In left background is Dome Mountain, showing rounded peak bordered by flat surfaces interpreted as marine terraces cut in lower Permian time. Photo by W. E. Ham.

*Lower.* Mount Tepee (left) and Little Tepee Mountain (right) looking northeast from Soldier's Spring Mountain, showing typical form of isolated granite hills projecting above flat plain. Photo by R. O. Fay.

## CONTENTS

# ILLUSTRATIONS

# IGNEOUS GEOLOGY OF THE LAKE ALTUS AREA, OKLAHOMA

by

C. A. MERRITT

## Abstract

This report deals primarily with the geology and petrography of igneous rocks in the Lake Altus area, which covers approximately 300 square miles in the westernmost part of the Wichita Mountains in southwestern Oklahoma. The igneous rocks are exposed as groups of mountains, hills, and knobs which rise abruptly above the surrounding plain of Permian red beds. The major physiographic units are known as the Headquarters Mountain group, Quartz Mountain, and Devil's Canyon group.

The igneous complex is divided into (1) a widely distributed series of granites and related dike rocks, Late Precambrian or Cambrian in age, (2) an older series of gabbro and anorthosite that is represented by three small outcrops and by scattered inclusions in the granite, and (3) a still older series of sedimentary rocks consisting of sandstone, arkose, and coarse granite conglomerate, xenolith remnants of which occur locally in the younger granite series as well-rounded boulders, cobbles, and pebbles. Sillimanite-containing quartz sand and rounded tourmaline grains in the granites likewise are interpreted as derivatives from this sedimentary series.

Also occurring as xenoliths in the granites of the Lake Altus area is andesite, not known to crop out except as inclusions as much as 50 feet long. It probably is a late differentiation product of the gabbro.

The granitic rocks are subdivided and mapped as Headquarters microgranite, Reformatory granite, hornblende-biotite granite, and Lugert granite. The Headquarters microgranite is the oldest and occurs as roof pendants and inclusions in Reformatory granite. The Reformatory, the most coarsely crystalline of the granites, occurs in two areas and is interpreted as a batholithic intrusion. It has inclusions of Headquarters microgranite, andesite, and gabbro.

Hornblende-biotite granite, containing a notably higher content of femic minerals than the other granites, occurs in the Powwow Mountain area.

The Lugert, the youngest of the granites, is widely distributed in the eastern part of the map area. Many of the outcrops contain xenoliths of andesite and gabbro, as well as pebbles xenoliths derived from a pre-Lugert sedimentary series. The basic inclusions commonly have been altered hydrothermally and in places have been partly or completely assimilated, yielding a hybrid granite. The Lugert granite is considered a stock or batholith with sill apophyses. Granite porphyry found around a large outcrop of gabbro in Soldier's Spring Mountain is interpreted as a contact zone of the Lugert granite.

The last phase of igneous activity was the formation of dikes and quartz veins. There were three periods of dike injections, the oldest being aplite, pegmatite, and associated quartz veins and miarolitic cavitics. The second phase was alkaline and is represented by aegirine-riebeckite granite dikes; the third was basic and produced diabase dikes.

Lower Permian rocks of the Wichita and Hennessey formations, mainly red, green, and gray shales, surround the Precambrian hills. Small outcrops of a granite conglomerate lithofacies of the Hennessey shale are found in the east flank of Soldier's Spring Mountain and in the Lugert region.

Small outcrops of Tepee Creek sediments composed of zeolite, opal, and dolomite are present in the southeast part of the map area. The age of this unusual rock is not definitely established. It has been described both as Precambrian and as a lithofacies of the Post Oak conglomerate, a member of the Wichita formation of Lower Permian age.

Wave-cut grooves in granite and other wave erosional features, such as flutings, sea caves, and pot holes, are found in this area. These forms were developed in the Permian sea. On the top or flank of some of the granite hills are flat surfaces, in most instances 50 to 300 feet wide, which have been interpreted as remnants of Permian wave-cut platforms.

# Introduction

The writer has been interested in the geology of the Wichita Mountains during the last two decades and has had the opportunity of directing several Master's theses at the University of Oklahoma on various phases of the geology as well as pursuing independent studies. The theses, of Berton Scull, Thomas Polk and Glenn McKinley, involved field mapping and microscopic studies of the rocks of the western part of the mountains. These theses and map data supplied by Gerald Chase along the eastern edge of the area form the basis for the map accompanying this report. The writer wishes to acknowledge the valuable contributions of these geologists to this report and also to express his personal pleasure in having had the opportunity of working with them on these investigations.

Some changes have been made in the mapped contacts, in the names and correlations of the rocks, and in the interpretation of their origin; the writer assumes responsibility for all views expressed in this report.

Many members of the School of Geology, University of Oklahoma, and of the Oklahoma Geological Survey have assisted in various ways in this investigation. Robert Fay helped check field data. Elmer Lucas, Hugh Hunter, and Carl Branson edited the manuscript. The compilation of the base and drafting of the map is the work of Roy Davis.

The writer is especially indebted to William Ham of the Oklahoma Geological Survey for his aid in compiling the map, in editing the manuscript, and for the many discussions on the geology of the area.

## Location

This report is restricted to the western part of the Wichita Mountains and the area studied is located in Greer and Kiowa Counties. It covers an area of approximately 300 square miles. It is entitled the "Lake Altus Area" as this lake is in the central part of the described region. The area extends from four miles northwest of the town of Granite eastward to Little Bow Mountain; the northern and southern boundaries were chosen to include the igneous hills and a few square miles of the surrounding sediments.

## Previous Work

The first recorded geologic observations on the area were made by Dr. George G. Shumard, a physician on Capt. R. B. Marcy's expedition which explored the North Fork of the Red River. He noted the presence of horizontal sandstone and shale surrounding the mountains and the common occurrence of granite in the latter. Marcy's party mapped the hill now known as Tepee Mountain as Mount Webster and Tepee Creek was designated Spring Creek.

T. B. Comstock and W. F. Cummins in 1899 made a reconnaissance trip to the Wichita Mountains and compared it to the Central Mineral Region of Texas. R. T. Hill in 1891 suggested that the Wichitas structurally were connected with the Ouachita Mountains.

T. Wayland Vaughan visited the Wichita Mountains briefly in 1896, surveyed many of the hills and collected samples of the rocks, including gabbro from Soldier's Spring Mountain. These samples were studied microscopically and described by A. C. Spencer.

H. F. Bain in 1899 examined the mineral deposits of the region and also briefly described the igneous rocks. On a second visit in 1903 he studied and sampled the mineral prospects. The reservation had been opened for settlement two years earlier and many prospectors were active in the Lugert area as well as in other parts of the Wichitas. This activity had been stimulated by reports of high gold, silver, and copper values. The results of assays made from Bain's samples were negative and their publication in 1904 dampened the prospecting fever.

In 1904 J. A. Taff, assisted by Chas. N. Gould and E. O. Ulrich, compiled the first geologic map of the mountains and interpreted the general age relationships and structure of the rocks. The megascopic and microscopic characters of the igneous rocks also were described. This excellent report has been fundamental in all the later investigations of the area.

A. F. Rogers (1907) published a brief paper describing the aegirine riebeckite granite dikes in the Headquarters Mountains near the town of Granite.

In 1915 C. H. Taylor mapped and described the igneous rocks of the Wichita Mountains and subdivided and named the granites of the mountains. In the Lake Altus area he introduced the names Headquarters, Reformatory and Lugert granites. He also described their megascopic and microscopic characters, age relationships, and origin. The quarries and the economic features of the granites were discussed in detail.

Samuel Weidman (1923) and O. F. Evans (1922) published papers on physiographic features and the latter, in 1929, interpreted the groovings on granite as the result of wave cutting. This theory is widely accepted today.

R. L. Clifton, in 1928, described the geology of Greer County. Roger W. Sawyer, in 1929, wrote an article on the geology of Kiowa County. Both of these articles were brief surveys of the existing knowledge and were general in character.

In 1941 C. A. Merritt and W. E. Ham published an article on zeolite-opal sediments, which they named Tepee Creek. These unusual rocks which are found on the flanks of the Raggedy Mountains and in the Little Bow Mountain area were considered Precambrian in age.

Beginning in 1946 several master's theses were completed under the writer's direction on the rocks of the Wichita Mountains. The first was a general study of the pegmatites and miarolitic cavities of the mountains by K. C. Anderson (1946) who described several such occurrences in the Lake Altus area. John Mayes in 1947 made a further study of the Tepee Creek sediments and considered them Permian in age. In the same year a geologic map and report of the igneous rocks of the Granite-Lugert area was compiled by Berton Scull, and a similar investigation of the igneous rocks of the Devil's Canyon group was completed in 1948 by Thomas Polk. In 1950, Glenn McKinley examined and mapped the igneous rocks of the Lake Altus-Little Bow Mountain area.

In 1954, Gerald Chase of the Oklahoma Geological Survey, published a paper on the Permian conglomerates around the Wichita Mountains and considered the Tepee Creek sediments a lithofacies of the Wichita formation. Chase also has compiled for the Oklahoma Geological Survey a manuscript geologic map of the eastern and central parts of the Wichita Mountains. The western edge of this map extends to the Little Bow-Camel Back Mountain area and overlaps the eastern edge of the region included in the Lake Altus area.

# Physiography

The Wichita Mountains are a group of mountains, hills, and knobs which rise abruptly above the broad Permian plain of southwestern Oklahoma. This range trends N 70° W and extends from Fort Sill to a point 4 miles beyond Granite, a distance of approximately 65 miles. This report is limited to the western one-third of this region.

The map area may be divided into the following physiographic units: (a) Headquarters Mountain group, (b) Quartz Mountain and nearby small hills, (c) Devil's Canyon group, and (d) the area east of Lake Altus.

## Headquarters Mountain group

The topography of this area has been well described by Taylor (1915, p. 40-41).

> *"The seven more or less isolated granite outcrops lying chiefly to the northwest of the town of Granite, have been designated the Headquarters Mountain group. Headquarters Mountain, somewhat to the west of the center of the largest outcrop, rises as the highest peak to an altitude of 2260 feet above sea-level, and about 500 feet above the surrounding Redbeds plain. The group as a whole consists of barren dome-like hills which rise abruptly 200 to 400 feet above the Redbeds plains. The different types of granite manifest themselves in the topography. The granite is cut by strong, widely-spaced joint planes. Immense boulders are produced by weathering and are of very common occurrence, but areas of bare, unfractured rock are found. Over much of the Reformatory granite area, which is the most southern of the group, soil, mantle rock, and vegetation are lacking.*
>
> *"The hills composed of Headquarters granite rise abruptly from the plains, but their steep slopes are covered with subangular boulders usually less than 10 feet in diameter, and bare surfaces are rare.*

> *"Drainage in the granite areas is accomplished through short canyon-like valleys which soon reach the bordering plains and widen out into open valleys with low gradients. Much of this drainage is controlled by the strong east-west and north-south fractures."*

### Quartz Mountain area

Quartz Mountain rises abruptly approximately 600 feet above the "Red Beds" plains and is composed of several smooth rounded knobs. The rocks have widely spaced joints which by erosion have developed into steep-sided gorges partly filled with boulder slides. The boulders are angular to rounded and as much as a few feet in diameter.

Lake Altus, formed by damming North Fork of Red River, is east of Quartz Mountain. It has an area of 7,000 acres and its normal water level is 1,559 feet above sea level, but it fluctuates considerably from year to year.

There are four hills north and west of Quartz Mountain which rise 50 to 200 feet above the plains and have the characteristic rounded tops.

### Devil's Canyon group

This group of hills is the most extensive and rugged in the area and includes Bird, King, Flat Top, Suttle, and Soldier's Spring Mountains as well as some small nearby hills. Most of these are a quarter of a mile or more apart but Flat Top and Soldier's Spring are only divided by Devil's Canyon, which is a narrow steep canyon up to 1,000 feet in width. The highest mountains are King and Soldier's Spring which rise some 750 feet above the surrounding plains.

The hills have steep slopes and are partly covered by angular boulders, some of which reach ten or more feet in diameter. Locally talus slopes are present around the base and these have a dense growth of scrub oak and brush. Alluvial fans also occur on the north and east side of Flat Top Mountain where they reach a maximum width of a half mile and a thickness of 200 feet.

Flat terraces, discussed elsewhere in this report, are found at about 600 feet above the plains. On Soldier's Spring Mountain the terrace surrounds a dome which rises 150 feet above it while Flat Top Mountain has a flat terrace top with no protruding peak. The terrace on King Mountain is less pronounced than those on the more eastern hills of this group.

Weathering along joints and other zones of weakness has formed rugged ravines and canyons with intervening spurs.

The drainage goes to North Fork, a braided meandering stream. It is normally a few feet deep and less than fifty yards wide, but in flood time it may broaden to over a mile.

### Area east of Lake Altus

There are approximately sixty igneous outcrops in this area. These range from Mount Tepee, the largest, which is 600 feet high and a half mile in diameter, to knobs only 5 feet high and 25 feet in diameter. The average hill rises 150 feet above the surrounding "Red Beds" plain and covers 20 to 30 acres.

The hills occur as isolated masses, groups, and clusters generally characterized by a dome or elongated top, the latter trending east-west. In Dome Mountain (frontispiece), the dome-shaped knob of the crest, 100 feet or more in height, rises 300 to 400 feet above the plain on a wide terrace of the mountain. The slopes are steep and are partly covered with angular boulders except a few precipitous barren cliffs, like the southwestern side of Mount Tepee. The tops and slopes of the hills normally are covered with short grass and a few scrub oaks. The boulders range from a few inches to 6 feet in diameter and are the result of jointing and exfoliation.

The area is drained by two streams which flow southward to North Fork. The eastern one, called Elk Creek, meanders south from Hobart between Camel Back and Little Bow Mountains. The western stream, known as Tepee Creek, flows south from Lone Wolf between Dome Mountain and Mount Tepee. These streams are small, intermittent, and meandering.

# Precambrian Rocks

## Introduction

Ever since the work by Taff in 1904 the igneous rocks of the Wichita Mountains have been considered Precambrian in age. The oldest Paleozoic sedimentary rock of the region is Reagan sandstone, of upper Cambrian age, which rests unconformably upon the Carlton rhyolite in the Fort Sill area. Since the Reagan is not cut by any igneous intrusion, the rhyolite and associated igneous rocks of the region are considered pre-Reagan and probably Precambrian.

Tilton and others (1957, p. 364) have recently determined the absolute age of biotite from Lugert granite in the Lake Altus area to be 490 million years, obtaining a value of 480 million years from potassium-argon isotopes and 500 million years from rubidium-strontium isotopes.

In this report the igneous rocks are provisionally classed as Precambrian, following long-established usage, although it is recognized that at least part of the igneous rock complex may later be assigned to the Cambrian epoch.

In the Lake Altus area, the igneous rocks are dominantly granites. Small areas of gabbro, anorthosite, and andesite, together with dike rocks of several types, also occur. The age relationships are gabbro (oldest), anorthosite, granites, and dike rocks (youngest). The granites include Headquarters microgranite (oldest), Reformatory granite, hornblende-biotite granite, and Lugert granite (youngest).

There is no classification of igneous rocks which is accepted by all petrographers. This lack of standardization leads to some confusion in interpreting the mineralogical assemblage designated by a rock name, such as granite. To avoid such misunderstanding, Johannsen's rock classification (1939) is used in this report. This classification is adopted as it is widely known and because Hoffman (1930) used it in his bulletin on the igneous rocks of the eastern Wichita Mountains, and a uniform classification facilitates comparisons of these rocks with those of the Lake Altus area.

According to Johannsen's classification, a granite with less than five percent ferromagnesian minerals is a leucogranite. Most of the Wichita Mountains granites are leucogranites, but this term is not widely used and the broader name granite is used in this report.

## GABBRO-ANORTHOSITE ROCKS

The basic rocks of the Lake Altus area occur as "in situ" masses at three localities covering a total area of less than one square mile, and as widely distributed xenoliths in the granites. They are mainly diallage gabbro and anorthosite, together with a little troctolite (olivine-rich gabbro). Diallage gabbro occurs in Soldier's Spring Mountain, the Dome Mountain area, and Little Bow Mountain area, whereas anorthosite and troctolite are restricted to the last area. As determined in the Raggedy Mountains, their relative age is troctolite (oldest), diallage gabbro, and anorthosite (youngest). All these basic rocks are older than the granites.

The gabbroic rocks of the mapped area are related to those of the Raggedy Mountains a few miles to the east, where basic rocks make up most of the exposures in an area approximately 15 miles long and 6 miles wide. This is the largest area of anorthosites and related rocks in the Wichita Mountains, and one of the largest in the United States. Its relatively large area of exposure, compared with the Lake Altus area, is explainable by block faulting which has elevated and exposed these rocks.

### Soldier's Spring Mountain

This outcrop of basic rock was first mentioned by Spencer in 1899. He wrote, "No. 11, Soldier's Spring Mountain-Gabbro, ophitic structure, is from a narrow dike in the granite. Its structure is different from that of the other rocks being plainly ophitic, otherwise it is similar to the other gabbros. It consists of basic labradorite and pyroxene with large amount of ilmenite. Apatite is also present."

This outcrop later was studied by Polk (1948, p. 19) and the following description is modified from his work.

The gabbro outcrop is in a small valley on the northeast side of Soldier's Spring Mountain in the NW¼ SE¼ sec. 6, T. 4 N., R. 19 W. It is a lenticular mass approximately 2,400 feet long with a maximum width of 800 feet. Prospect pits and trenches expose the rock on the valley floor. Loose angular blocks of gabbro can be found on the valley on the west side, some of them more than a hundred feet above the valley floor, showing that the original gabbro outcrop was at least that thick. It is more readily eroded than the granite and the valley is thus cut in the gabbro. In one of the prospect pits three small granite dikes each two feet wide intrude the gabbro and in one exposure the gabbro grades eastward into Lugert granite porphyry through a contact zone. This latter locally is dark gray and resembles the gray granite at Little Bow Mountain, which is interpreted as a hybrid rock formed by Lugert granite magma assimilating gabbro. Most of the granite-gabbro contacts are covered by talus or soil and cannot be observed.

The gabbro is dark gray to black on fresh surface, medium-grained, and has a diabasic texture, the femic minerals filling the interstices between labradorite laths. Locally it has a porphyritic appearance owing to the presence of large milky white feldspar laths some of which are 10 mm long and 4 mm wide. Most of the outcrop is partly or highly altered hydrothermally, intense alteration producing a light gray friable mass with a clayey appearance. The northeastern portion of the outcrop is more finely crystalline and less altered.

The rock is composed of a mixture of labradorite, diallage, hornblende, and biotite with minor amounts of magnetite, pyrite, garnet, and zircon (Plate III, B). Some chlorite, serpentine, and calcite also are present. The composition of the gabbro from the contact zone with granite is given in Table I, column 3.

The principal constituent is labradorite ($An_{56}$), slightly altered to clay and calcite, which microscopically shows albite and pericline twinning. Some laths have carlsbad twinning in addition. Generally 2 mm long, the crystals are as much as 10 mm long in the locally porphyritic phases.

Diallage is abundant and occurs as anhedral masses up to 1.8 mm in length. It exhibits both (100) and (001) partings. The extinction angle Zac is 44°. It is partly changed to uralite, the alteration being most intense in the contact zone between the granite and gabbro. In the formation of uralite, hornblende was developed along the edges and cleavage cracks and later was changed to chlorite.

A small amount of hypersthene is present. It has schiller structure resulting from numerous minute opaque fiber inclusions oriented parallel to the c-axis. It is partially changed to serpentine. The unaltered mineral is slightly pleochroic: x=pink, y=colorless, and z=faint green.

Most or all of the hornblende originated secondarily by the uralization of diallage. It is light brown, slightly pleochroic, and has an extinction angle Z∧c of —26°. It occurs along the edges and as irregular masses in the diallage. In some fragments it shows relict diallage cleavage and clearly is an alteration product of the pyroxene. Part of the hornblende has altered to chlorite. One grain of the amphibole has an inclusion of anhedral garnet. The uralization probably originated hydrothermally from solutions derived from the intruding Lugert granite magma.

Biotite is present as anhedral grains having a maximum length of 1.25 mm. It is highly pleochroic in shades of light to dark brown. The mica has inclusions of garnet, magnetite, feldspar, and zircon and shows some pleochroic halos around zircon. The mica is locally associated with magnetite and it is partly altered to chlorite and serpentine.

The accessory minerals are garnet, zircon, sphene, magnetite and pyrite. Garnet occurs as subhedral grains, as much as 2 mm in diameter, in hornblende, biotite, serpentine, and chlorite. Magnetite occurs as irregular masses 0.5 to 1.0 mm long and also as veinlets. It contains inclusions of the other minerals and at least in part is a late hydrothermal product. Except for minor alteration to hematite, the mineral is unaltered.

The dikes of Lugert granite porphyry cutting gabbro show that the gabbro is older, which is in agreement with the granite-gabbro age relationship established in other parts of the Wichita Mountains. The granite dikes invalidate Spencer's (1899) reconnaissance interpretation that the gabbro is a dike cutting the granite.

Polk (1948, p. 67) explained the outcrop of gabbro as the result of faulting which raised it from a lower level as a horst. The gradation of gabbro through contact phases into granite prophyry on the east side of the outcrop disproves a fault on this side. The rock on the west side is granite porphyry similar to that on the east and no evidence of a fault is observable. The writer believes that the gabbro is a large inclusion in the Lugert granite and that the granite porphyry surrounding the basic rock is a contact phase of the Lugert. The gabbro inclusion must have been a hundred feet or more thick. In this locality gabbro inclusions also are found in the Reformatory granite in the C NE¼ SE¼ sec. 6, T. 4 N., R. 19 W., on a ridge which forms the northwest side of the valley. The xenoliths are rounded and have a maximum diameter of four feet.

Another interpretation of the gabbro outcrop is that it is an "in situ" high knob of gabbro rising above the main basic mass, the Lugert granite magma flowing around it and below or through the overlying Reformatory granite. Such a movement of the magma should have developed magmatic banding in the granite parallel to the gabbro contact, but no banding was observed.

Dome Mountain locality

One small outcrop of gabbro was found and mapped by McKinley (1950) on the south side of Dome Mountain and two were found a short distance south, in sec. 16, T. 5 N., R. 19 W., as shown on the map. The adjacent rock is Lugert granite which contains some small inclusions of altered gabbro. The basic rock in the exposures grades from a diallage gabbro into a contact phase which contains numerous small irregular stringers of granite cutting the gabbro, and this in turn grades into the granite.

These outcrops are interpreted as xenoliths of gabbro in Lugert granite. The composition of the least-altered gabbro is shown in Table I, column I. The rock is dark gray to black, medium- to coarse-grained, and inequigranular. Labradorite has albite twinning coarse enough to be seen by the unaided eye on a fresh surface. It is subhedral to euhedral and ranges from 1 to 5 mm in length. On weathering the plagioclase becomes grayish-white and is easily detected as it is in contrast with the darker diallage crystals. Microscopically the labradorite shows schiller structure. It is somewhat altered to calcite and zoisite, the latter occurring as fibrous aggregates up to 0.5 mm long. The rock approaches an anorthosite in composition, having more than 80 per cent labradorite.

Diallage forms 18.4 per cent of the rock. It is subhedral, less than 2 mm in length, and has well developed polysynthetic twinning.

The contact zone of gabbro injected by granite is variable in character. Relatively unaltered gabbro grades through a zone with numerous dikelets of granite into one with marked hydrothermal alteration. This contact zone varies in color but mainly is a mixture of black and white minerals with local pinkish feldspar patches. Diallage is altered to uralite and magnetite and there has been an introduction of some hydrothermal quartz and albite. The labradorite in part has been replaced by a myrmekitic intergrowth of quartz and albite.

Little Bow Mountain area

The basic rocks of this locality have been described by Taylor (1915), Chase (1950), and McKinley (1950). The following is compiled from these works supplemented by field and thin section studies by the writer.

The outcrops in this locality total less than a quarter of a square mile and most of this area is in the southernmost exposure. The outcrops apparently are erosional remnants of a once-continuous much larger mass.

A low isolated hill in the SW¼ SW¼ sec. 6, T. 4 N., R. 18 W., is composed of gray to white anorthosite, which in places resembles a quartzite megascopically, but careful examination reveals the feldspar laths with their albite twinning. In composition (Table I, column 6) it is 98 per cent labradorite ($An_{65}$), with a little diallage and a trace of magnetite. The rock is unaltered, shows no foliation, and is cut by several dikes of granite aplite, each a few inches wide.

Tepee Creek sediments are exposed on the southern and southeastern flanks of the hill, resting unconformably upon the anorthosite. These unusual sediments are described later in detail.

Two small outcrops of diallage gabbro occur on the east and north side of a hill known locally as Powwow Mountain, SW¼ sec. 32, T. 5 N., R. 18 W. The rock is dark gray to black, medium- to coarse-crystalline and in part is highly altered to a friable gray clay-like material in a zone cut by several small dikes of Lugert granite. The gabbro also is in contact with a hornblende-biotite granite. The mineralogical composition of the basic rock is given in Table I, column 2.

Labradorite comprises 82 per cent of the rock and occurs in lath-shaped crystals generally measuring 3 x 5 mm, but locally as much as 8 mm in length. Microscopically, schiller structure is noticeable in the feldspar, which is somewhat altered to clay and calcite.

Diallage generally occurs as 2 x 4 mm subhedral grains and commonly shows twinning and herringbone structure. It is partly altered to uralite. A little hornblende and chlorite are present. Accessory minerals are magnetite, pyrite, and apatite.

A second specimen from a nearby outcrop was described by Chase (1950) as containing bytownite 83%, olivine 12%, magnetite 4%, hornblende 1%, and traces of diallage, which would place it in the troctolite family, Table I, column 4. The troctolite and diallage gabbro outcrops are separated by hornblende-biotite granite and their relationship to one another is not apparent.

Some exposures of basic rocks are found east of Elk Creek in sections 29 and 32, T. 5 N., R. 18 W. Little Bow Mountain is the largest hill in this area. The basic rocks include both anorthosite and diallage gabbro. A considerable part of these rocks has been assimilated by Lugert granite magma with the formation of a dark gray granitic rock which is shown separately on the map and is discussed later. If this interpretation of the origin of the gray granite-like rock is correct the original gabbro-anothosite mass in this area was considerably larger than the present exposures.

Anorthosite crops out in the NE¼ NE¼ sec. 32, T. 5 N., R. 18 W. as a dark gray to black rock, showing well developed foliation of the planar type. The feldspar laths all lie on their 010 face but the laths have no particular orientation in the foliation plane. This feature probably developed by gravity settling of the crystals and has been reported by Chase (1950, p. 23) in other parts of the Wichita Mountains. The plagioclase occurs as thin laths having an average length of 3 mm and a maximum length of 5 mm. The mode of the rock is 96 per cent labradorite, slightly altered to clay and calcite, and 3 per cent diallage, partly altered to chlorite. Traces of apatite, magnetite, and zoisite also are present (Table I, column 5).

Diallage gabbro also is present in the Little Bow Mountain area and is similar to that described for Powwow Mountain.

The intrusion of Lugert granite into gabbro and anorthosite caused changes in the basic rocks. Locally the gabbro was altered hydrothermally to a gray, friable, clay-like mass but in most places the temperature of the granitic intrusion seems to have been sufficiently hot to assimilate the gabbro, forming a gray granitic rock which resembles the Cold Springs granite. This latter, according to Walper (1951), resulted from the assimilation of andesite by a granite magma. The gray granite of the Little Bow area probably has a similar origin and is a hybrid rock resulting from the assimilation of gabbro by the Lugert magma. It is discussed further in the section on Lugert granite.

TABLE 1

Mineral percentages of gabbro, anorthosite, and troctolite

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| labradorite | 80.6 | 82.0 | 64.0 | | 96.0 | 98.0 |
| bytownite | | | | 83.0 | | |
| olivine | | | | 12.0 | | |
| diallage | 18.4 | 15.0 | 14.0 | tr. | 3.0 | 1.0 |
| hypersthene | | | 2.0 | | | |
| hornblende | tr. | 3.0 | 5.0 | 1.0 | | |
| biotite | | | 3.0 | | | |
| apatite | | tr. | | | tr. | |
| zircon | | | tr. | | | |
| garnet | | | 1.0 | | | |
| magnetite | | tr. | 6.0 | 4.0 | tr. | 1.0 |
| pyrite | | tr. | tr. | | | |
| calcite | | tr. | tr. | | tr. | |
| zoisite | | tr. | | | tr. | |
| chlorite | | tr. | 3.0 | tr. | tr. | |
| serpentine | | | 2.0 | | | |
| anorthite content of plagioclase | | | 56 | 74 | | 65 |

1. Diallage gabbro, south of Dome Mountain, SW¼ NW¼ NE¼ sec. 16, T. 5 N., R. 19 W. (McKinley, 1950, p. 21)
2. Diallage gabbro, Mount Powwow, SW¼ SW¼ SW¼ sec. 32, T. 5 N., R. 18 W. (McKinley, 1950, p. 21)
3. Diallage gabbro from contact zone with granite, Soldier's Spring Mountain, SE¼ SE¼ sec. 6, T. 4 N., R. 19 W.
4. Olivine gabbro (troctolite), Mount Powwow SE¼ SE¼ SE¼ sec. 31, T. 5 N., R. 18 W. (Chase, 1950, p. 46)
5. Anorthosite, Little Bow Mountain, SW¼ NE¼ NE¼ sec. 32, T. 5 N., R. 18 W. (McKinley, 1950, p. 21)
6. Anorthosite, SW¼ SW¼ sec. 6, T. 4 N., R. 18 W. (Chase, 1950, p. 25)

Subsurface band of gabbro-anorthosite

An aerial magnetometer survey indicates the presence of a large basic mass below the "Red Beds" east of Mangum, and a few wells drilled on the northern flank of the mountains have encountered gabbro or anorthosite. The areal extent of the basic rocks is not definite but the subsurface data indicate that they extend at least a few miles west and north of the Wichita Mountains. An igneous mass of this magnitude must have originated as a batholith, a sill, a laccolith, or a lopolith. Gabbro-anorthosite masses in several places in the world have the form of a lopolith and the Wichita basic rocks may be of this type.

In a few hills in the eastern part of the Wichita Mountains, such as Mount Sheridan, granite forms the upper part of the hill and gabbro the lower part, the relationship being due to the intrusion of a granite sill into or on top of the basic rock. Apparently a similar relationship is present in the western part of the Wichitas, for granite was encountered at 1,630 feet and anorthosite at 1,797 feet in the Tidewater, Smith #1 well a few miles northwest of Lone Wolf in the SW¼ SE¼ sec. 23, T. 7 N., R. 20 W.

These facts give some support to the hypothesis that the gabbro-anorthosite mass originated as a lopolith and underlies the granites in all parts of the region except where the gabbros have been intruded by granite in the form of a batholith or stock. All the granitic rocks are younger than gabbro, and some, such as the Reformatory, appear to be batholiths as their outcrops are large and they have associated pegmatites. Thus there may be large areas in the Wichita Mountains where gabbro-anorthosite does not underlie the granitic rocks.

As mentioned above an aeromagnetic survey of the Mangum district indicates the existence of a large body of basic igneous rocks below the "Red Beds." This survey by the U. S. Geological Survey as reported by Vacquier is an important contribution to the geology of the Wichita Mountains. One of the maps (figure 1) and some of the conclusions are included here although the survey covers an area just west of that described in this report. The basic band apparently extends into the map area, as gabbro was encountered in the Rogers Brothers, Graumann #1, NW¼ NE¼ sec. 11, T. 5 N., R. 21 W., at a depth of 994 feet.

In interpreting the survey Vacquier (1951, p. 29, 31) writes as follows:

> "*Granite crops out as a small hill with the negative anomaly on the west edge of plate 6 (sec. 18, T. 5 N., R. 20 W). Evidently the zone of higher intensities is caused by a change in lithology and not by a change in the slope of the Wichita Mountains. Probably a band of gabbro about 3 miles wide lies buried on the southwest slope. Furthermore this band probably has a larger development of magnetite along the western rim.*
>
> "*The lengths of the sharpest gradients were measured and labeled on the three aeromagnetic intensity maps (Pl. 6). The measurements on the eastern margin of the high zone yield an estimated burial of 600 feet. Four estimates along the western margin indicate this edge is buried to a depth of 2300 feet although the range of values is from 1800 to 2900 feet (Table 6a). The zone is 3 miles wide, and the computed slope of 600 feet per mile is reasonable.*

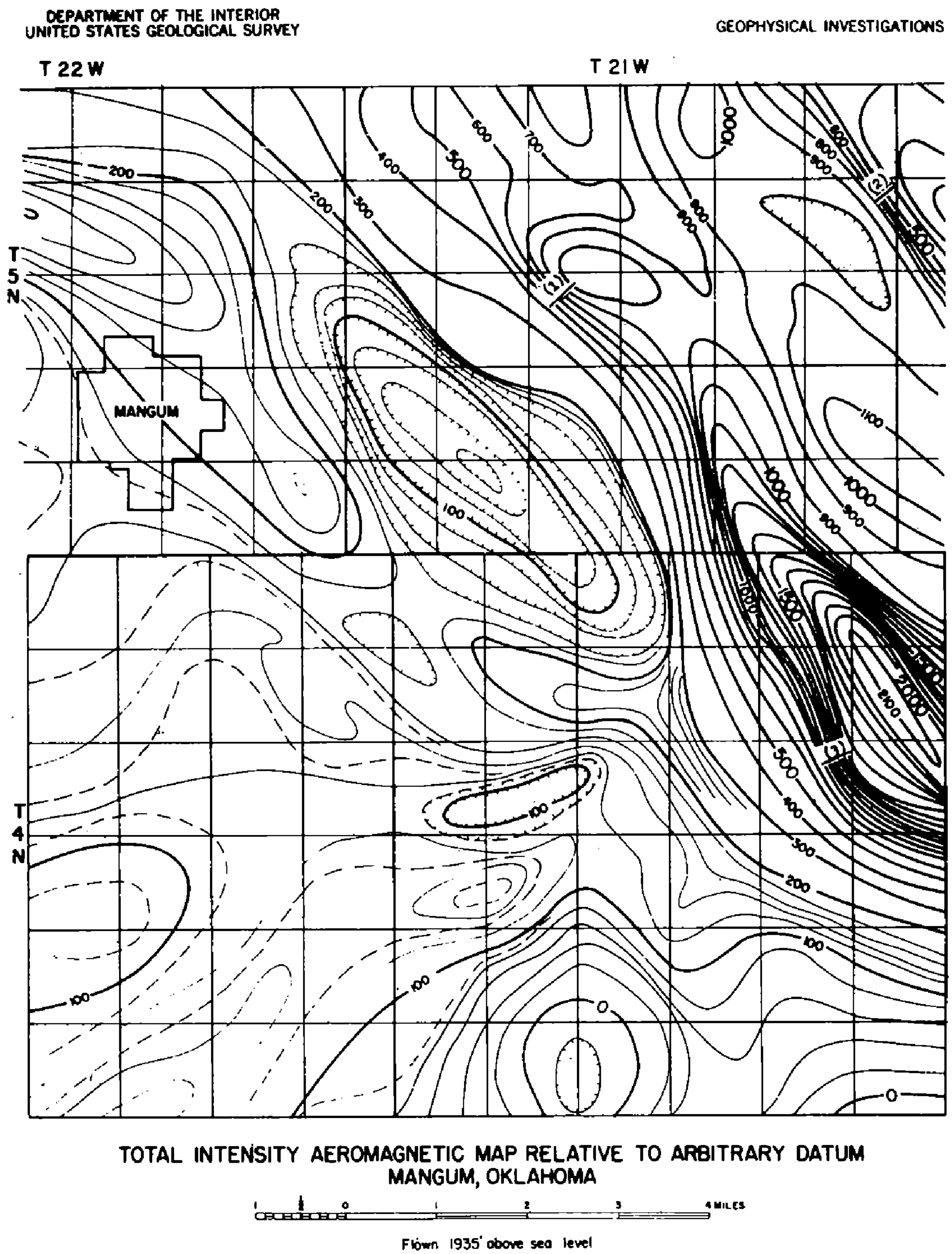



*Figure 1.* Aeromagnetic map showing high positive anomaly east of Mangum, in Ts. 4 and 5 N., R. 21 W., immediately southwest of the Lake Altus area, interpreted as a buried belt of basic igneous rocks. Geological Society of America, Memoir 47, 1951, Plate 6.

*"The consistency of the estimate of depth of burial based on the flight of 6300 feet in the two dimensional analysis, suggests the band of gabbrolike rock extends approximately to a depth of a mile or more."*

Magnetite generally is insignificant in the anorthosites of the Wichita Mountains but comprises 6 per cent of the gabbros. This basic band thus is interpreted as composed of anorthosite in the eastern part and gabbro in the western part. Chase (1950) pointed out that anorthosite overlies diallage gabbro in the eastern and central sections of the Wichita Mountains and this relationship would indicate an eastern dip for the gabbro and overlying anorthosite in the subsurface mass of the Mangum area.

It is interesting to note that the subsurface basic band parallels the trend of the westernmost granite outcrops of the Wichita Mountains and also borders them on the west. These features, as well as the eastern dip of the basic rocks and the common occurrence of gabbro-anorthosite in lopoliths, may mean that this mass forms the extreme western edge of a basic lopolith. The granites are younger and may extend farther west. Considering the present status of knowledge this interpretation must be regarded only as a suggestion to stimulate further investigation.

The subsurface band of basic igneous rocks is bordered on the east by granite and outcrops of the latter have many inclusions of gabbro. These xenoliths show that the contact between the rocks is intrusive and not a fault contact.

## ANDESITE

Andesite sills and dikes are common in the eastern and central parts of the Wichita Mountains but no outcrops of this rock were found in the Lake Altus area. Xenoliths of andesite in granite, however, are present in the western part of the Wichita Mountains, normally as small fragments but in a few localities as large masses. Most of the large masses are in quarries and in an irrigation canal cut, and they do not crop out on the surface of the hills. It is likely that many large inclusions of andesite are present below the surface in the granite hills and that quarries, road cuts, or other excavations will expose additional masses.

Xenoliths of andesite are rare in the Headquarters microgranite, but a few an inch in diameter were noticed in the SW¼ SW¼ SW¼ sec. 9, T. 6 N., R. 21 W. Probably more detailed field investigation would detect other occurrences.

Andesite xenoliths are found in many outcrops of the Reformatory granite. Generally they are a fraction of an inch to a few inches in diameter, but in the quarry at the State Reformatory there are several larger inclusions, the maximum size being 18 x 12 x 8 feet. These larger masses were described as diorite by Scull (1947, p. 34) but the texture is fine-grained and the name andesite seems more appropriate on the basis of grain size. The following description is modified from his work.

The rock is black, fine-grained and non-porphyritic, with augite filling the interstices between andesine crystals. The texture thus is diabasic. The mode of the rock is andesine 58%, augite 30%, biotite 8%, and magnetite 4%, with traces of apatite, clay, chlorite, and calcite. The last three minerals are alteration products.

Andesine occurs as subhedral to euhedral lath-shaped crystals averaging 2 mm in length. It shows albite, pericline, and carlsbad twinning and is slightly altered to calcite and clay.

Anhedral augite fills the interstices between the andesine laths and is slightly altered to chlorite. Biotite is present as irregular strongly pleochroic brown to green flakes that are partly altered to chlorite.

Magnetite occurs as disseminated grains in andesine and augite and has a little leucoxene along the borders, indicating its titaniferous character. Apatite is present as minute needles.

Chlorite, calcite, and clay are the result of augite, biotite, and andesine reacting with hydrothermal solutions from the Reformatory magma; the rock, however, is compartively fresh and has not undergone intense alteration.

In addition to the andesite xenoliths, the quarry at the State Reformatory also has inclusions of old sedimentary material which is described in the section on xenoliths in the granitic rocks. The Reformatory magma must have intruded country rocks composed of sediments and andesite.

Inclusions of andesite are found in several of the outcrops of Lugert granite. These xenoliths range from a fraction of an inch to a few inches in diameter, but exceptionally they are a foot or several feet in length. In a small outcrop in the SE¼ SW¼ NW¼ sec. 1, T. 5 N., R. 20 W., there are several large xenoliths of andesite, one being 24 feet long and 5 feet wide.

The largest andesite xenolith in Lugert granite that has been found to date is in a vertical cut of an irrigation canal in the NE¼ SW¼ SE¼ sec. 33, T. 5 N., R. 20 W. This occurrence was first mentioned by Polk (1948, p. 46) and the following description is modified from his work. The inclusion is at least 50 feet wide and 30 feet thick. Its length is unknown as it does not crop out at all on the surface above the cut. It is surrounded by Lugert granite and is cut by several fine-grained dikes of this granite. A few smaller xenoliths separated from the main mass also are present. The Lugert granite is porphyritic at the contact, probably the result of chilling. The xenolith is partly weathered to spheroidal boulders.

The andesite is black, aphanitic, and weathers dark pink or dark gray. A few pink orthoclase crystals may be detected on fresh surfaces; these are sections of small granite stringers. In thin section the rock is seen to be highly altered but a poorly defined diabasic texture is still evident.

In places calcite and granite stringers cut the andesite xenolith, producing a lit-par-lit appearance. The calcite veins are believed to have been formed by crystallization from hydrothermal solutions derived from the Lugert magma.

In general the contact of the andesite inclusion with the surrounding granite or porphyritic phase is sharp, but some of the smaller xenoliths have been partly assimilated producing a dark, granite-like rock rich in hornblende and biotite. Some specimens of andesite contain small pink feldspar stringers and crystals which give the rock a porphyritic appearance. The feldspar has been introduced from the invading granitic magma.

The andesite in the canal cut is composed of andesine, quartz, hornblende, augite, biotite, magnetite, zircon, and apatite. Alteration of the feldspar and the femic minerals has been intense and there is a considerable amount of chlorite and serpentine, and a small amount of hematite and clay. This alteration makes it impractical to determine the percentages of the different minerals, but andesine is the dominant primary mineral and quartz is present in minor amounts. The primary rock may have been dacite as described by Polk (1948, p. 46), but it seems more likely that it is a silicified andesite as at least part of the quartz is secondary and has been introduced from the Lugert magma. Occurrences of andesite are common in the Wichita Mountains whereas dacite has only been reported at one other locality (Smith, 1951, p. 18).

Andesine occurs in subhedral laths, less than 1 mm in length, that are partly altered to clay. Quartz is present in anhedral grains. Hornblende, the most abundant of the femic minerals, forms irregular masses between the andesine laths and is highly altered to chlorite and serpentine.

Biotite, pleochroic light to dark brown, occurs as anhedral flakes with a maximum length of 0.7 mm. It is especially abundant at the contact with the granite and is probably hydrothermal in origin. A few anhedral grains of augite are present and these are highly altered to chlorite and serpentine.

The accessory minerals are magnetite and zircon. Magnetite occurs mainly in small anhedral grains but also as skeletal crystals in andesine. It is slightly altered to hematite.

Inclusions of andesite in Lugert granite are present in a road cut in the C S½ NW NE sec. 26, T. 5 N., R. 20 W. The exposure is some 60 feet deep and 500 feet long and is composed of a dark granite-like rock which shows some shadow inclusions with hornblende-biotite reaction rims. This dark rock appears to be the result of assimilation of andesite by the Lugert magma.

The widespread occurrence of andesite xenoliths in the Headquarters, Reformatory, and Lugert granites indicates that the original andesite mass was extensive. It may have been a sill of large areal extent.

## Granitic rocks

The granites of the Lake Altus area—Headquarters, Reformatory, hornblende-biotite, and Lugert—differ somewhat in texture and color but their mineral compositions are quite similar. The abundant primary minerals are microperthite, orthoclase, quartz, and albite-oligoclase; the femic constituents, hornblende and biotite, are present in very small amounts. The granites have a similar suite of primary accessory minerals, although some of the biotite of the Headquarters microgranite is different in having

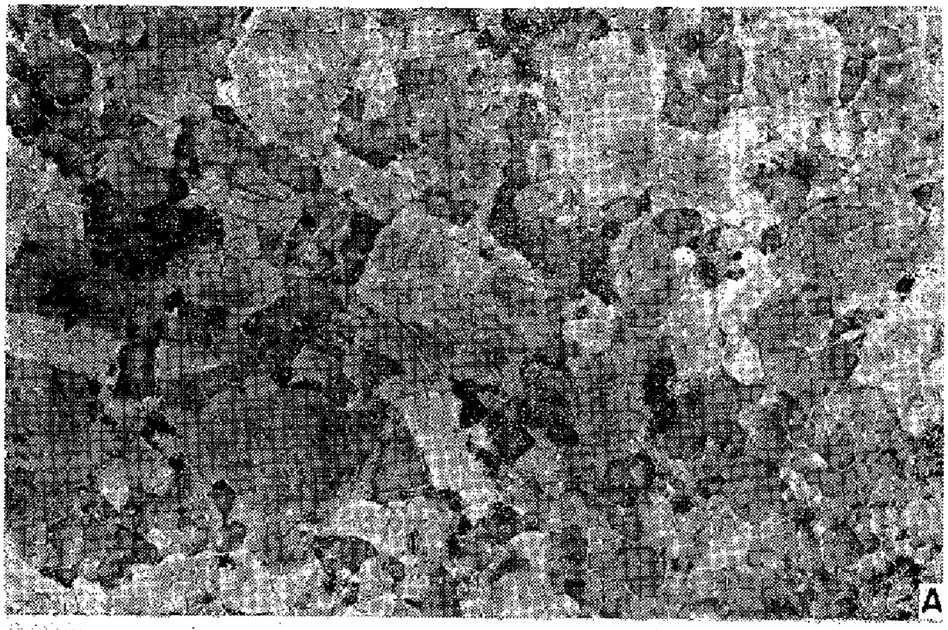
PLATE II

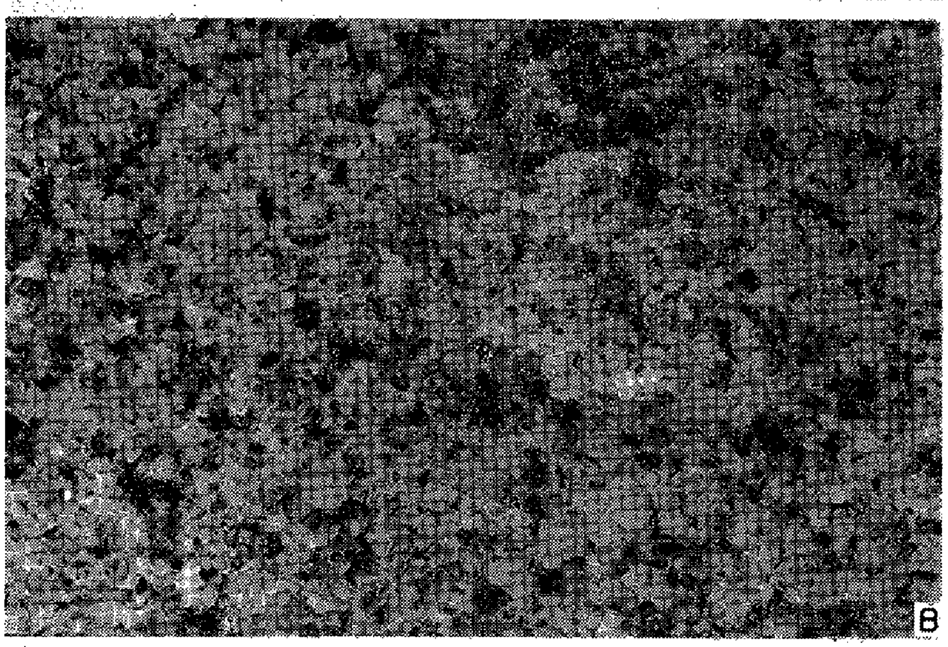
Polished specimens, 1½ times natural size. Light-colored mineral is feldspar and the dark is quartz.

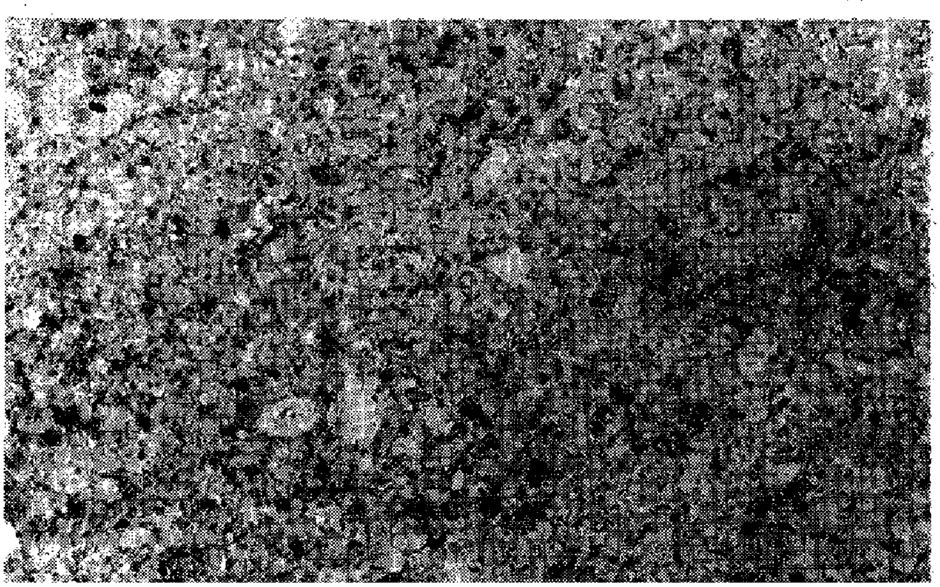
*A*. Reformatory granite showing coarsely crystalline texture and subhedral feldspar crystals. From quarry of Pellow Brothers Monument Works at Granite, SE¼ SE¼ NW¼ sec. 26, T. 6 N., R. 21 W.

*B*. Lugert granite showing uniform, medium-crystalline texture. From Century Granite Co. quarry on Camel Back Mountain, NE¼ NE¼ SW¼ sec. 19, T. 5 N., R. 18 W. Plate III, figure *A* is a photomicrograph of a thin section of this rock.

*C*. Headquarters microgranite showing fine-grained texture with a few larger feldspar crystals. From quarry in SW¼ SW¼ sec. 9, T. 6 N., R. 21 W.







pleochroic halos. It is possible that this biotite is present as inclusions, but this is not established. The mineralogical similarities indicate that the different granites are derivatives of the same magma.

Where one granite has intruded another the contact normally is sharp, as though the older rock were still hot when the younger one was intruded. Hydrothermal alterations around Lugert intrusions appear to be somewhat more marked than around the other granites; and the Lugert magma, which is the youngest, may have had a greater amount of dissolved gases than the other granitic magmas.

The primary mineralogical character of the granites, with their high percentage of feldspar and quartz and extremely low percentage of femic minerals, indicates a high potash, soda, and silica content. The aegirine-riebeckite granite dikes are the youngest of the silicic dike rocks and their sodic character indicates that differentiation produced an increase in the sodium content in the magma. Hydrothermal albite and quartz replacements of feldspar also show this increasing sodic and silicic differentiation trend.

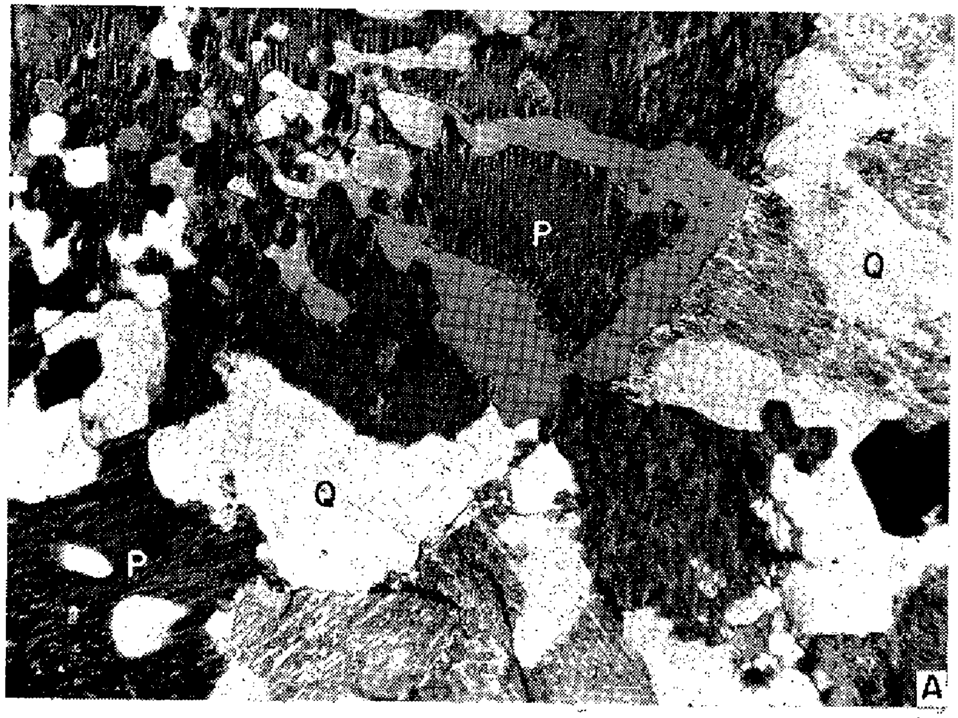
The hydrothermal changes which have taken place followed a similar pattern in the different granites. The replacement of feldspar by quartz, forming micropegmatite (some of which is myrmekitic), is the dominant feature. Silicification is second in importance. At least part of the albite, hornblende, biotite, sphene, and magnetite was deposited from hydrothermal solutions. The quantity of these minerals formed was generally small. In some instances fluorite and apatite also were developed and indicate fluorine-containing solutions. Some aegirine and riebeckite are hydrothermal in origin and probably originated from late soda-rich solutions. Part of the riebeckite is an alteration product of aegirine.

Where the granite magma intruded an older granite or a granite conglomerate, orthoclase was precipitated, commonly replacing older quartz or feldspar. Sodium in this orthoclase separated as albite by exsolution on cooling and formed perthite or microperthite. Later some hornblende and biotite were precipitated from hydrothermal solutions and partly replaced the primary feldspar and quartz.

Where the country rock or xenoliths were basic in character, the mineralogical changes have ranged from minor hydrothermal to major assimilation effects. The hydrothermal or magmatic changes mainly consist of the alteration of pyroxene to chlorite, olivine to serpentine, and plagioclase to clay and calcite. Less common alterations are the change of plagioclase to prehnite, the alteration of femic minerals to epidote, and the change of pyroxene to hornblende and then hornblende to biotite. The assimilation effects of granite magma on gabbro or andesite in places were pronounced and produced a gray hybrid granite-like rock.

### Xenoliths in the granitic rocks

*Igneous xenoliths.* One of the outstanding features of the granitic rocks in the Lake Altus area is the presence in many outcrops of igneous and sedimentary xenoliths. Igneous inclusions of gabbro, anorthosite, andesite, and microgranite, as well as of other types, are found in the Reformatory and Lugert granites. Andesite xenoliths occur in the Headquarters granite. Most of the basic igneous inclusions range from a fraction of an inch to a few inches in diameter but some are much larger. In the quarry at the State Reformatory several inclusions of andesite occur in the Reformatory





Photomicrographs of granite and gabbro.

*A.* Lugert granite showing micropegmatitic texture. Crossed nicols, x 15. From Century Granite Co. quarry on Camel Back Mountain. The micropegmatite is composed of quartz (Q) and microperthite (P); the latter is an intergrowth of microcline and oligoclase. Quartz has replaced microperthite. Note the introduction of quartz along the contacts of adjacent feldspar grains.

*B.* Diallage gabbro. Crossed nicols, x 15. NW¼ SE¼ SE¼ sec. 8, T. 4 N., R. 19 W., Soldier's Spring Mountain. Labradorite laths (L) show carlsbad and albite twinning, and are slightly altered to clay minerals. Diallage (D) occurs partly as anhedral masses between the feldspar laths and partly as euhedral crystals. The diallage is appreciably altered to chlorite.

granite, the largest being 18 x 12 x 8 feet. In a small outcrop in the SE¼ SW¼ NW¼ sec. 1, T. 5 N., R. 20 W., there are several large xenoliths of andesite in Lugert granite, the largest being 24 feet long and 5 feet wide. A still larger andesite inclusion is exposed in a vertical cut of an irrigation canal in the NE¼ SW¼ SE¼ sec. 33, T. 5 N., R. 20 W. The xenolith is 50 feet wide, 30 feet high, and has unknown length. It is surrounded by Lugert granite and is not exposed at the surface of the hill. It is probable that many inclusions of basic rocks are hidden in the depths of the granitic hills.

Large gabbro inclusions also are known. A lenticular mass of gabbro 2,400 feet long and 800 feet wide, present in a valley on the northeast side of Soldier's Spring Mountain, appears to be a xenolith surrounded by a porphyritic phase of the Lugert granite. In this locality gabbro inclusions which are rounded and as much as four feet across are found in the Reformatory granite on a ridge on the northwest side of the valley in the NE¼ SE¼ sec. 6, T. 6 N., R. 19 W. Three outcrops of gabbro totalling a few acres in areal extent are found in the Dome Mountain area surrounded by Lugert granite and are interpreted as inclusions. These andesite and gabbro occurrences have been described previously.

Inclusions of silicic igneous rocks may be observed in many outcrops of the Reformatory and Lugert granites. Microgranite is the most abundant type and is especially common in Lugert outcrops. The microgranite xenoliths show a great range in size and shape but commonly are ellipsoidal, a few inches to a foot in length and half as wide, but they may reach several feet in length. Some of these fine-grained xenoliths are fragments of Headquarters microgranite and others are microgranite pebbles derived from a granite conglomerate.

*Sedimentary xenoliths*: Inclusions which have the form of pebbles, cobbles, and boulders, and are composed mainly of microgranite, are common in many outcrops of the Lugert granite. These exposures have been interpreted by Polk (1948) and McKinley (1950) as intrusion breccias formed by the Lugert magma intruding and brecciating an older granite and solidifying as the cement between the broken fragments. The writer, however, believes that the xenoliths are pebbles, cobbles, and boulders of granite conglomerate into which the Lugert magma was intruded.

A good exposure showing pebble inclusions in Lugert granite is a small hill in the NE¼ NE¼ NE¼ sec. 26, T. 5 N., R. 20 W. The xenoliths stand out in relief on the weathered surface and range from a fraction of an inch to four feet in length, (Plate IV, C). In shape some are subangular, many are elliptical, and a few are rounded. The inclusions show a crude orientation N 80° W to N 35° W (average N 67° W) and are horizontal or have a low dip. In the NW¼ NW¼ SE¼ sec. 25, T. 5 N., R. 20 W. the xenoliths also are horizontal and trend N. 70° W. The orientation of these inclusions is the result of magmatic flowage.

The features which indicate that the xenoliths were derived from a granite conglomerate are given below:

1. Several of the rounded silicic xenoliths (Plate IV, C) studied microscopically show no marked reaction rims or other evidence that the rounding was due to assimilation. Silicic minerals would be stable in a granitic

magma and it is unlikely that magmatic reactions of cognate silicic xenoliths would be sufficient to produce rounded forms. The rounded xenoliths are interpreted as sedimentary pebbles.

2. Some of the silicic xenoliths have rounded quartz resembling sand grains and these contain sillimanite needles (Plate IV, D). In some instances the needles extend from one grain across the boundary into an adjacent grain. Microperthite has replaced the quartz in part. Some feldspar grains, altered to microperthite, also contain sillimanite needles. These features show that at least part of the quartz and feldspar is older than the sillimanite and perthite.

Sillimanite may develop from a granitic magma by assimilating argillaceous material which normally would be present as a matrix in granite conglomerate.

3. A few xenoliths contain fragments composed of orthoclase and quartz which appear to be arkose grains. These have been partly replaced by microperthite, which has obscured their original character and the identification as arkose is not definite.

4. In some inclusions hornblende, sphene, and magnetite surround and partly replace quartz and feldspar, showing the older age of the latter two minerals (Plate IV, A, B).

5. Some inclusions show quartz and feldspar grains with a younger micropegmatite cement. The quartz of the Meers quartzite also shows this type of cement as well as inclusions of sillimanite. The similarity of these mineralogical features in the two occurrences suggests a similar origin, namely magmatic reaction with clastic sedimentary material.

*Petrography of the silicic xenoliths.* Xenoliths composed of microgranite are the most common type. These are light pink and have a fine-grained to aphanitic texture. Their contacts with the Lugert granite are sharp, although some hornblende, sphene, and magnetite locally have been introduced into the contact zone. Some specimens show appreciable silicification.

The major constituent is microperthite, in which respect it resembles the granites of the area. Quartz is common and minor amounts of orthoclase, oligoclase, and hornblende are present. Accessory minerals are magnetite, zircon, and sphene.

Microperthite occurs as euhedral to anhedral grains, ranging from 0.3 to 0.8 mm in length, that have been partly replaced by quartz to form micropegmatite. The microperthite is composed of orthoclase and albite, the latter at most places being altered to clay and a fine hematite dust which gives a red color to the feldspar. A small amount of oligoclase and free orthoclase also are present in some slides.

The amount of quartz varies with the degree of hydrothermal alteration. Quartz content is markedly increased in the micropegmatite phase, whereas in some of the unaltered types there is so little quartz that the rock could be labelled microsyenite.

Hornblende is the chief mafic mineral, but rarely makes up 5 percent of the rock. It is pleochroic, light to dark green, and commonly is altered to chlorite. The amphibole surrounds some of the microperthite grains and is most abundant in the contact zones. It is a late magmatic or hydrothermal mineral.

Magnetite generally is less than 0.5 percent but may reach a few percent in the contact zones. It is anhedral, commonly occurring in irregular grains less than 0.2 mm in diameter or as stringers cutting quartz. It is titaniferous and has partly altered to leucoxene and hematite. Magnetite is a late magmatic or hydrothermal mineral.

Sphene normally occurs in minute amounts but some specimens may have two or three percent. It is present as anhedral grains up to 0.15 mm long and is associated with magnetite, in some instances surrounding the latter mineral. It is younger than the magnetite and must be a late magmatic or hydrothermal mineral.

Zircon is present in minor amounts as euhedral grains with a maximum size of 0.1 mm. Sillimanite needles are common in both the quartz and feldspar of many specimens. Some of the needles extend from one grain into the adjacent grain and must be younger than the host mineral, quartz or feldspar.

Porphyritic-appearing rocks are common in many outcrops. The pink feldspar "phenocrysts" in most instances have been introduced from the Lugert magma into the host rock. In places minute feldspar stringers can be traced from the Lugert granite into a terminal "phenocryst." The rocks are pseudo-porphyries. The most common of the porphyritic-appearing rocks is microgranite "porphyry" but medium-grained granite, andesite, and basalt also show this feature. The pseudo-phenocrysts range in size from 1.5 to 5 mm, the average being 1.5 mm, and are composed mainly of micropegmatite or microperthite.

The most common xenoliths are microgranite, the next are the pseudo-porphyries and basic rocks (gabbro, andesite, and basalt). Medium-grained red granite, muscovite-biotite granite, and granite aplite are also present.

## PLATE IV

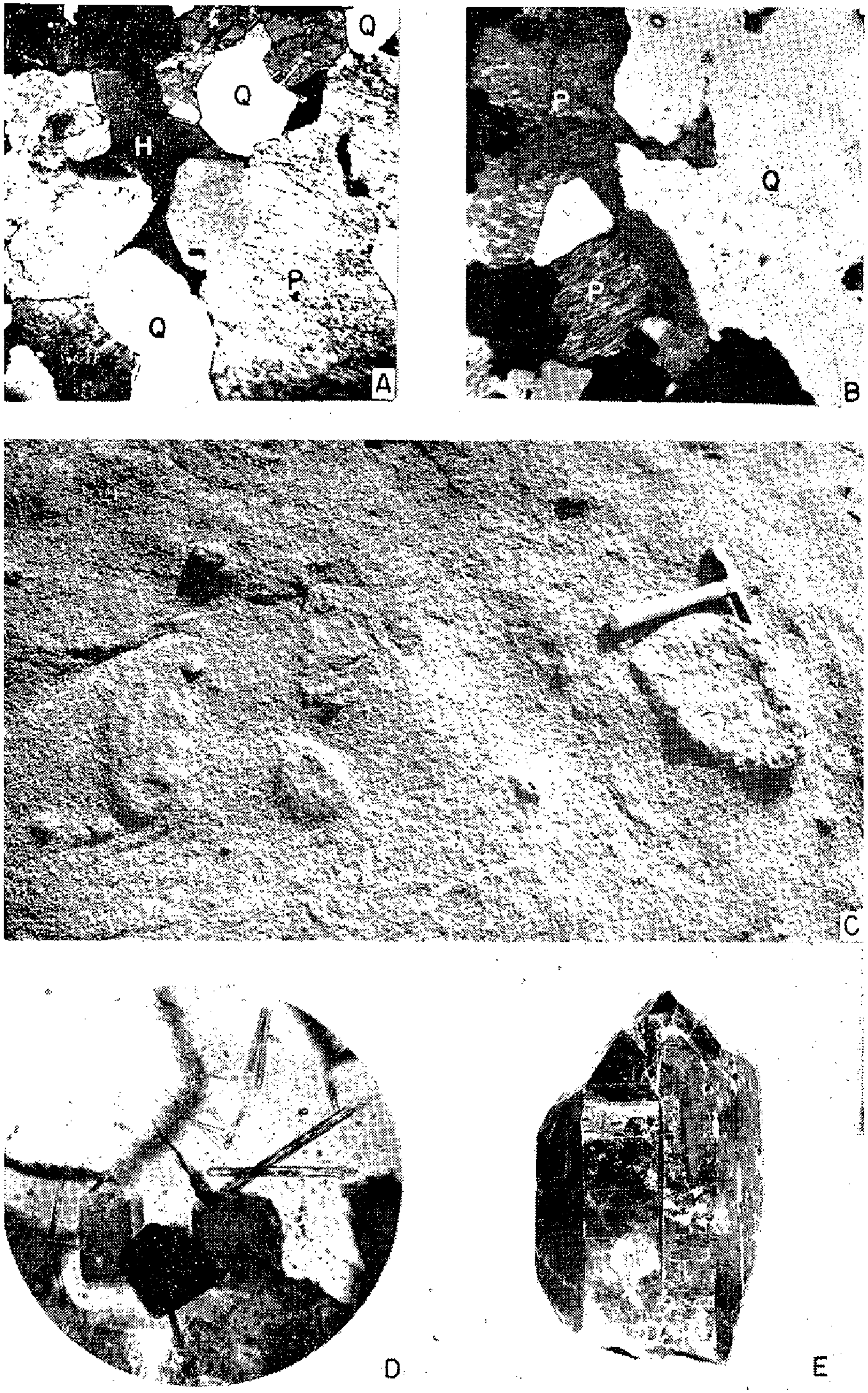
*A* and *B*. Photomicrographs of thin sections of granite conglomerate pebbles which occur as xenoliths in Lugert granite. Crossed nicols, x 15. The specimens are from the outcrop shown in figure *C*. The rocks are composed mainly of quartz (Q) and microperthite (P). In figure *B* a stringer of feldspar replaces quartz. The feldspar was deposited as orthoclase from the invading Lugert magma and was converted to microperthite by exsolution of albite.

In figure *A*, hornblende (H) has been introduced along the contacts of feldspar and quartz, probably as a late hydrothermal mineral.

*C*. Rounded pebble, cobble, and boulder xenoliths incorporated in Lugert granite, NW¼ NE¼ NE¼ sec. 26, T. 5 N., R. 20 W. Xenoliths consist of granite and granitized sediments derived from a Precambrian boulder conglomerate into which the Lugert magma was intruded. Photomicrographs *A*, *B*, and *D* are from thin sections of the pebbles. Photo by W. E. Ham.

*D*. Photomicrograph of a thin section of a granite conglomerate pebble xenolith showing sillimanite needles in quartz and feldspar. From outcrop shown in figure *C*. Crossed nicols, x 90. Some sillimanite needles may be seen traversing the quartz and feldspar boundaries indicating the younger age of the sillimanite.

*E*. Large smoky quartz crystal from a miarolitic cavity in Lugert granite, Government quarry, NE¼ SW¼, SE¼ sec. 26, T. 5 N., R. 20 W. The specimen was donated by E. D. Jenner, superintendent of the quarry, to the School of Geology, University of Oklahoma. The crystal is 17 inches long, 9 inches wide, and weighs 75 pounds. It is the largest crystal of quartz so far reported from Oklahoma. Photo by Thomas Polk.




Special features of the Lugert granite.

Some of the xenoliths, which on microscopic examination show sand grains and arkose, have been partly altered by microperthite and macroscopically resemble microgranite or microgranite "porphyry."

*Age of the granite conglomerate.* Omitting the Tepee Creek sediments whose age is questionable, the only described Precambrian sediment in the Wichita Mountains is the Meers quartzite, which occurs in the eastern region as inclusions in gabbro and granite. Only three xenoliths of quartzite have been mapped and the largest of these is a few acres in area. It is older than the enclosing gabbro and granite and is generally considered to be the oldest rock in the Wichita Mountains.

There is some evidence that old Precambrian sediments once were widespread in the Wichita Mountains. In the Cold Springs area, sillimanite and spinel occur in minute amounts in anorthosite and may be the result of assimilation of argillaceous material. Rounded zircon and tourmaline grains have been detected in thin sections of the Reformatory granite and may be relict sedimentary detrital grains.

The sillimanite needles in quartz, and the micro-pegmatitic cement in both the Meers quartzite and the pebble xenoliths of granite conglomerate in Lugert granite, show a similarity in origin but do not prove a similar age. The relatively pure sandstone which formed the quartzite must have originated in a different sedimentary environment from that of the granite conglomerate. The latter, however, may have been a near-shore lithofacies or a different bed in the Meers series. The pebble xenoliths of granite conglomerate are mainly microgranite, but some are gabbro, andesite, and basalt. The basic pebbles must have been derived from an older igneous complex which was composed of granitic and basic rocks. Whether the older gabbro in this complex is the same as the gabbro exposures of the Wichita Mountains is not known. If it is the same age, the Meers is older than the gabbro and the granite conglomerate is younger.

Detailed studies of the area between Meers and Lake Altus are needed to answer this problem.

Headquarters microgranite

The name Headquarters granite was introduced by Taylor in 1915 for the fine-grained rock which forms the northwestern exposures of the Wichita Mountains. It is intruded by the Reformatory granite and Taylor considered it the oldest granite in the Wichitas. He also considered it to be batholithic in form. Later Scull (1947) studied the area and described the Headquarters as inclusions and roof pendants in the Reformatory granite and suggested that it may have been emplaced as a laccolith, but considered the evidence indefinite with respect to the form of the intrusion.

The Headquarters microgranite is restricted to the western part of Headquarters Mountain and to the small hills north of this locality. The total areal extent of these outcrops would approximate one square mile. Most of the exposures are a mixture of both Headquarters and Reformatory granites, the former occurring as angular to sub-angular stoped blocks averaging 25 feet across but some reaching 150 feet in length. The blocks are cemented by apophyses of Reformatory granite generally less than 5 feet wide but in places reaching 50 feet. The contacts between the granites are sharp.

Many of the outcrops are such an intimate mixture of the two granites that it is impractical to map them separately and these are shown on the map as mixed Headquarters-Reformatory. Locally, however, the apophyses of Reformatory are less numerous and the outcrop is mainly Headquarters and is so designated on the map. The largest of these exposures is in the eastern half of the hill in the SE¼ sec. 16, T. 6 N., R. 21 W., locally known as Brown's Mountain. Another outcrop of relatively pure Headquarters is in the western part of Headquarters Mountain where a roof pendant one-fourth mile long is surrounded by mixed Headquarters-Reformatory granites.

The Headquarters rock is cut by several types of dikes in addition to the above mentioned Reformatory apophyses. In the quarry in the SW¼ SW¼ sec. 9, T. 6 N., R. 21 W., pegmatite stringers are present along the contact of the Headquarters and Reformatory and represent a contact phase of the latter granite. In the same quarry two aplite dikes each 4 inches wide intrude the Headquarters microgranite. In the most northern hill an aplite dike 6 inches wide, and in the northeast part of Brown's Mountain an aplite dike 0.5 to 3 inches wide, cut both the Reformatory and Headquarters. The strike of the latter dike is N. 10° W. and the dip is nearly vertical.

In the quarry in the SW¼ SW¼ sec. 9, T. 6 N., R. 21 W., in addition to pegmatite stringers and aplite dikes, there is a dike of medium-grained light gray granite, discolored by limonite and ranging from 1 to 16 inches in width, which cuts both the Reformatory and Headquarters.

A diabase dike intrudes the mixed Headquarters-Reformatory in the northwestern part of Headquarters Mountain.

The Headquarters microgranite is brownish red on fresh surfaces and weathers light brown. In the most northern outcrop a portion of the exposure is a dark brown, aphanitic rock which is considerably richer in hornblende than the normal Headquarters and is a hybrid phase which developed by assimilation of basic igneous material. In the outcrop in the SW¼ SW¼ SW¼ sec. 9, T. 6 N., R. 21 W., a few inclusions of andesite an inch in diameter occur.

The Headquarters is fine-grained (Plate II, C) but locally, especially in the northern outcrop, it has a porphyritic appearance with phenocrysts of quartz and feldspar which commonly stand out in relief on a weathered surface. The quartz phenocrysts are rounded, colorless, smoky or yellowish, and average 1 mm in diameter; the feldspar phenocrysts are flesh-colored to brownish, tabular and approximate 3 mm across. The groundmass is a mixture of microperthite and micropegmatite.

These porphyritic rocks vary somewhat in texture and appearance, some having a dense aphanitic groundmass while others have a microphaneritic groundmass. These resemble the microgranite "porphyry" xenoliths in the Lugert granite in the area east of Lake Altus which are interpreted as pebbles of granite conglomerate. It seems probable that the Reformatory magma picked up fragments of the overlying country rock which was mainly Headquarters microgranite but in part gabbro, andesite, and a granite conglomerate. Only the non-porphyritic microgranite should be considered Headquarters, the other types being associated xenoliths in the Reformatory granite.

Minerals in the typical Headquarters microgranite have an average grain size of 0.3 mm. Grain size shows a considerable range, however, being coarsest in the hill in the SE¼ sec. 9, T. 6 N., R. 21 W., where the average is 1.2 mm.

The rock breaks with a conchoidal fracture, has an average specific gravity of 2.63, and takes a good polish. It alters less readily than the Reformatory granite and does not exfoliate but forms smooth surfaces on weathered exposures. It has several systems of irregular joints and locally a poorly developed columnar jointing. In the latter the rock is broken into four-, five-, and six-sided angular blocks, a few inches to several feet across. In places nearly horizontal joints have developed and these dip from 0° to 5° east.

The jointing, association with xenoliths of other rocks, and the intimate mingling with the Reformatory granite make it difficult to find suitable quarry sites but locally uniform rock may be obtained and small quarries have been operated from time to time.

Taylor (1915, p. 48) described the Headquarters granite as follows:

> *"Estimates by the Rosiwal method on a thin section which seemed to be average for the Headquarters granite showed the following mineral percentages: Microperthite and orthoclase, 57.6%; quartz 33; biotite 5.2; albite-oligoclase 3.7; hornblende .30; and magnetite .20. This is probably a little below average in magnetite and a little above average for biotite, but it represents as well as any single specimen can, the mineral composition of this rock in an unaltered condition. The hematite is present as fine dust-like particles disseminated through the feldspar and its quantity cannot be estimated. More or less sericite, kaolin, hematite, muscovite, and chlorite have developed in the process of alteration."*

The rock is so variable, owing to associated xenoliths and injection by the Reformatory granite magma, that a typical composition is difficult to determine. Perhaps that given in column 8 of Table 2 as determined by Scull (1947, p. 35) may be considered as representative, although it differs somewhat from the composition given above by Taylor.

The data in Table 2 show that the contact phases become markedly enriched in micropegmatite and slightly enriched in hornblende.

The minerals of the unaltered Headquarters microgranite in the order of their abundance are microperthite and orthoclase, quartz, albite-oligoclase, biotite, magnetite, and hornblende. Accessory minerals are microcline, zircon, sphene, apatite, and fluorite, together with the alteration products kaolin, sericite, calcite, epidote, and hematite.

The major constitutent is microperthite, which is an intergrowth of orthoclase and albite and is considered to have been formed by exsolution of albite from the potassium feldspar on cooling. The albite occurs as irregular blebs in parallel planes of the orthoclase host, giving the crystals a laminated appearance. Except for variations in the size of the crystals, this microperthite is similar to that found in other granites of the western Wichitas.

Zoned feldspar is a common megascopic feature in the Headquarters microgranite. Thin sections show that the outer zone is microperthite or micropegmatite and the inner zone microperthite, orthoclase, or albite-oligoclase.

In the Headquarters, orthoclase, whether occurring as free grains or in microperthite, exhibits carlsbad twinning and the plagioclase of the intergrowth shows albite twinning. Both orthoclase and microperthite are in euhedral crystals, the potassium feldspar being fresh or only slightly altered whereas albite is highly altered to clay.

Quartz is present in two types, which are interpreted as magmatic and hydrothermal. The older primary quartz occurs as rounded generally corroded grains with wavy extinction and many inclusions, probably of water. The inclusions have no linear arrangement. Much of this quartz is partly surrounded by a corona of microperthite. Veinlets of microperthite locally penetrate and replace quartz. In the second type, quartz is partly free and partly intergrown with feldspar to form micropegmatite. This type is considered to have originated from late hydrothermal siliceous solutions emanating from the Reformatory magma depositing free quartz or replacing feldspar of the Headquarters to form micropegmatite. The quartz mainly replaced microperthite and orthoclase but albite-oligoclase also was affected, though the latter occurs in minor amounts.

The amount of micropegmatite ranges up to 85 percent of the rock and is most abundant near the Reformatory contacts, especially near its pegmatitic phases. Thin sections of Headquarters microgranite made from specimens taken more than 50 feet from the contact with Reformatory granite show little or no micropegmatite. These relationships furnish additional evidence of the hydrothermal origin of the micropegmatite. The intergrowth normally is composed of quartz in orthoclase or microperthite host but a small amount of quartz in albite-oligoclase also is present. The average size of the micropegmatite grains is 2.0 mm. In places it is vermicular and is myrmekite.

A minor amount of plagioclase is not intergrown with orthoclase of quartz. It is albite-oligoclase ($Ab_{90}$-$An_{10}$), exhibiting albite, pericline, and carlsbad twinning and occurring in subhedral grains partly altered to kaolin.

Biotite is in the form of small flakes and thin tabular masses rarely more than a millimeter long. There are two types, one a greenish brown to brown pleochroic variety which is found around the edges of hornblende and seems to be a replacement of the latter mineral, probably by hydrothermal solutions. The other type is pleochroic, light to dark brown, and contains minute inclusions of zircon surrounded by pleochroic halos. It has irregular borders, perhaps due to resorption by the magma, and is slightly altered to chlorite. It appears to be a primary mineral.

Hornblende is a minor constituent in anhedral grains with irregular edges. It is partly altered to biotite or chlorite. Some of the hornblende forms coronas around quartz and feldspar and must be a late hydrothermal mineral. A little of the amphibole is associated with late magnetite.

Accessory minerals are zircon, sphene, apatite, fluorite, and magnetite. Zircon with pleochroic halos occurs as inclusions in biotite and as anhedral grains, some of which are rounded and have a detrital appearance. Sphene is present in euhedral to anhedral grains; apatite forms minute prisms which are most abundant near the contact with the Reformatory granite. Fluorite is present in one thin section and is considered to be hydrothermal in origin.

Magnetite occurs as anhedral to euhedral grains. It shows no alteration to leucoxene and apparently is non-titaniferous, which is in contrast to the magnetite of the Reformatory granite. The magnetite commonly is associated with hornblende and also forms small veinlets in the other minerals. It is a late hydrothermal mineral.

Calcite veinlets traverse hornblende. Hematite is present in small amounts along cleavage lines of the feldspar and as disseminated dust in these minerals giving a reddish color to the rock. A little epidote occurs along the edges of the feldspar grains. A few small inclusions of andesite were noticed in the Headquarters. These are fine-grained and show a concentration of biotite, hornblende, apatite, zircon, and fluorite. In the most northern outcrop a hydrothermally altered xenolith of andesite has 10 percent hornblende, largely euhedral, and 1 percent apatite.

The microscopic study reveals that the primary minerals of the Headquarters microgranite are mainly microperthite, orthoclase, and quartz, with a small amount of albite-oligoclase and biotite, the latter having inclusions of zircon with pleochroic halos. Reaction of the plagioclase with the intruding Reformatory magma formed orthoclase coronas. This potassium feldspar also was precipitated around the grains of microperthite and

TABLE 2

Mineral Percentages of the Headquarters Microgranite (Scull, 1947, p. 35)

| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. |
|---|---|---|---|---|---|---|---|---|
| Microperthite and orthoclase | 7.7 | 24.2 | 30.9 | 42.1 | 53.6 | 51.1 | 57.6 | 52.4 |
| Quartz | 2.1 | 12.7 | 21.2 | 34.7 | 34.3 | 36.2 | 33.0 | 35.3 |
| Micropegmatite | 85.1 | 51.5 | 39.8 | 20.2 | ---- | ---- | ---- | ---- |
| Albite-oligoclase | 1.6 | 5.6 | 5.2 | 6.8 | 6.4 | 5.7 | 3.7 | 6.1 |
| Biotite | 1.1 | 4.1 | 0.7 | 3.1 | 3.2 | 3.3 | 5.2 | 3.3 |
| Magnetite | 0.5 | 0.9 | 1.3 | 0.3 | 0.4 | 1.4 | 0.2 | 0.9 |
| Hornblende | 1.2 | 0.2 | 1.1 | 0.2 | 0.3 | 0.5 | 0.3 | 0.4 |
| Microcline | tr. | tr. | tr. | ---- | tr. | 0.8 | ---- | 0.4 |
| Fluorite | ---- | tr. | tr. | tr. | 0.3 | tr. | ---- | 0.1 |

1, 2, 3, and 4 are from contact zones with the Reformatory granite.

1. Quarry face, NE¼ sec. 28, T. 6 N., R. 21 W.
2. Center of SE¼ sec. 21, T. 6 N., R. 21 W.
3. Quarry face, NW¼ SW¼ sec. 15 T. 6 N., R. 21 W.
4. South side of hill, north-central part of sec. 16, T. 6 N., R. 21 W.
5. Quarry face, SW¼ SW¼ sec. 9, T. 6 N., R. 21 W.
6. Northeast end of hill, NW¼ sec. 9, T. 6 N., R. 21 W.
7. Composition given by Taylor, location not listed. He noted that the percentage of biotite was probably high, and the magnetite probably low.
8. Average of 5 and 6. These analyses are considered representative of unaltered Headquarters microgranite.

quartz, and formed veinlets in them. The orthoclase on cooling formed microperthite by exsolution. Late hydrothermal solutions from the Reformatory magma were siliceous, depositing quartz which occurs chiefly as micropegmatite replacement in feldspars of the Headquarters. Quartz also occurs in the form of thin veinlets. Commonly the micropegmatite forms the outer layer of a zoned feldspar. The hydrothermal solutions also produced hornblende, biotite, apatite, and fluorite in small amounts; the last two minerals indicate the presence of fluorine in the invading solutions.

The Headquarters microgranite is intruded by the Reformatory granite and thus is the oldest exposed granite in this part of the Wichita Mountains. Gabbro-anorthosite was not found in contact with the Headquarters and their respective ages cannot be determined directly. Inclusions of andesite are present in the Headquarters. In the central and eastern part of the Wichita Mountains, andesite is later than gabbro-anorthosite but younger than the granites. This relationship probably holds in the Lake Altus area and gabbro-anorthosite is considered to be older than the Headquarters microgranite.

## Reformatory granite

Taylor (1915) mapped the coarsely crystalline granite which is exposed in the Quartz Mountain-Headquarters Mountain area and named it Reformatory after the quarry rock at the State reformatory near Granite. Polk (1948, p. 70) later found large outcrops of what he considered a new granite on Flat Top and Soldier's Spring Mountains and called this rock Flat Top granite. He wrote,

> *"It is possible that this granite is an upper part of the Reformatory granite. Mineralogically there is little, if any difference between the two. However, this criterion is not accurate to determine whether or not it is a separate granite because all the granitic rocks of the area are very similar mineralogically. There is one major difference between these two rocks and that is textural. The Reformatory granite has much coarser quartz and feldspar than the Flat Top granite. Though the feldspar crystals in the latter are often as large as those in a medium-grained phase of the Reformatory granite, the quartz grains were never found to be as large. . . . The field relationship of these two rocks with the Lugert granite also causes the writer to doubt that the Flat Top granite is a part of the Reformatory granite. The Lugert granite is slightly chilled wherever it is found in contact with the Reformatory granite whereas the contact with the Flat Top is not chilled."*

The textural difference between Polk's Flat Top granite and the Reformatory granite are not marked in all localities, for Scull (1947, p. 36) has reported that the Reformatory granite in the southern part of Quartz Mountain becomes finer grained in marginal phases, and the writer has seen Reformatory specimens from a quarry at Granite which cannot be distinguished mineralogically or by texture and color from the typical Flat Top granite. Miarolitic cavities and quartz veins containing milky quartz are common in both the Reformatory and Flat Top granites.

The chilling of the Lugert against the Reformatory is not sufficiently pronounced to be a significant criterion. Also the intrusion of the Flat Top into the Lugert may have been at a different depth and a warmer contact would cause less chilling. For these reasons the writer believes the Flat Top is part of the Reformatory granite and the name Flat Top is not used.

The Reformatory forms the eastern part of Headquarters Mountain, the western part of Quartz Mountain and the hills between them, as well as a large part of Flat Top and Soldier's Spring Mountains. The combined outcrop would be several square miles and if this granite is continuous below the Hennessey shale from Quartz Mountain to the most northwestern outcrop of the Wichita Mountains, as seems probable, the granitic mass would have an areal extent of 20 or more square miles. This size, the coarsely crystalline texture, the presence of pegmatitic phases, and the absence of any evidence of sill or laccolithic form, indicate a batholithic emplacement. This agrees with the interpretation of Taylor and Scull.

The batholith is elongated, with its long axis northwest. It is bounded on the west side by a subsurface band of basic rocks and on the east side by the Lugert granite.

The Reformatory granite is cut by a system of widely spaced vertical joints, four to fifty feet apart. The most marked of these trend northwest and northeast, but other systems trending north and east are present in some outcrops. Sheet jointing is well developed, the joints being spaced 3 to 10 feet apart. These joints produce rectangular or wedge-shaped blocks that are favorable for quarrying. Jointing on Flat Top Mountain is marked and trends N. 20°-30° W. and N. 40°-50° E. In many outcrops, as on Soldier's Spring Mountain, the joints are in several directions and have no discernible pattern, though sheet jointing is well developed. In many outcrops the granite is intensely fractured.

Where the jointing is widely spaced the rock weathers into large subangular blocks, normally a few feet across but exceptionally 100 feet or more in length.

The granite locally weathers to smooth rounded surfaces containing small depressions 1 to 10 feet in diameter. Some of the depressions are due to the removal by weathering of xenoliths of gabbro or andesite which are less resistant than the granite. Some may be potholes formed by eddying stones in the Permian sea. Microgranite xenoliths are more resistant to alteration and stand out in relief as sub-angular to rounded masses surrounded by the smooth-surfaced Reformatory granite.

The Reformatory granite generally is flesh red on a fresh surface. On weathering it develops a light pink, deep red, or reddish brown color and locally, as in the southern part of Soldier's Springs Mountain, it is blood-red.

It has the coarsest texture of any of the granites in the Wichita Mountains but the coarseness varies locally. The normal granite is even-grained, the feldspar ranging from 15 to 20 mm and the quartz averaging 5 to 10 mm (Plate II, A). Somewhat less coarsely grained rocks are found on the south side of Quartz Mountain and on Flat Top and Soldier's Spring Mountains. Miarolitic cavities are common locally.

The mineralogical composition of this granite is given in Tables 3 and 4, its chemical composition in Table 6, and an analysis of the feldspar separated from the granite in Table 5.

Microperthite and orthoclase are the dominant constituents of the rock. The former is an intergrowth of orthoclase and albite. The orthoclase generally is fresh but the plagioclase is thoroughly altered to clay. These feldspars are irregular to prismoidal and range from 15 to 20 mm in size, with carlsbad twinning common. The microperthite is believed to have developed by the exsolution of albite on cooling of orthoclase.

Microcline is a minor constituent in some slides, where it occurs as euhedral grains largely altered to clay. It appears to have been introduced between quartz and microperthite grains and is a late mineral.

Albite-oligoclase, 1 to 2 percent, showing albite, pericline, and carlsbad twinning, is present as euhedral grains intensely altered to clay. A few overgrowths of orthoclase around the plagioclase are noticeable.

According to Scull (1947) micropegmatite in the Reformatory granite is restricted to the west side of Quartz Mountain in a hydrothermally altered zone where quartz has partly replaced albite-oligoclase. Some of the intergrowth is vermicular and could be called myrmekite.

Quartz, which averages 22 percent of the rock, occurs as corroded grains normally 2 to 6 mm in diameter. It has wavy extinction and contains rows of inclusions, probably of water. This quartz is considered primary. Some later quartz occurs as veinlets in the feldspars and in the micropegmatitic phases of the granite; hydrothermal quartz has partly replaced albite-oligoclase to produce the micropegmatite.

Hornblende makes up as much as 4.4 percent of the rock and is the most abundant of the femic minerals. It is euhedral to subhedral, its edges are ragged, and it is partly altered to biotite or chlorite. A thin section from the abandoned B. L. Smith quarry at Granite shows an exceptional occurrence of hornblende in the Reformatory granite. It is present as brown euhedral crystals in stringers traversing quartz and appears to be a late hydrothermal replacement of the latter.

Biotite reaches a maximum of 1.7 percent but generally is absent. Both green and brown pleochroic varieties occur but the mica has no pleochroic halos, which is in marked contrast to the biotite of the Headquarters microgranite.

Aegirine is present in varying but minute amounts as irregular fragments partly altered to riebeckite. The amphibole is strongly pleochroic, X = dark blue, Y = light blue, and Z = green.

Aegirine is more abundant than riebeckite and in part is altered to the latter mineral. It is pleochroic, X = dark green, Y = light green, and Z = yellow. Some aegirine occurs along the edges of feldspar and quartz and also is associated with sphene. The riebeckite and aegirine probably were developed from hydrothermal solutions derived from the magma which produced the riebeckite-aegirine granite dikes that cut the Reformatory granite at the town of Granite.

Accessory minerals are apatite, zircon, augite, sphene, fluorite, and magnetite. Augite found in traces in thin sections from the Oklahoma State Reformatory quarry may be a relict mineral from an assimilated basic inclusion. Zircon and sphene commonly are euhedral and some zircon is late as it encloses quartz. Needle apatite and magnetite are invariably present but the other accessories occur only in some thin sections.

Magnetite commonly is included in feldspar but also it is associated with hornblende and, in one slide, with epidote. At least part of the magnetite is late hydrothermal.

A little sericite can be detected along cracks in quartz. Hematite is present along the cleavage lines of the feldspar and disseminated as dust-like particles. Locally the hematite is concentrated along cleavage planes, giving a banded appearance to the feldspar. The coloring of the rock is due partly to hematite but in part it is due to the color of the feldspar, for it remains red after boiling with concentrated HCl which removes the iron oxide.

Small amounts of epidote, chlorite, and kaolin are present as alteration products.

The Reformatory granite has xenoliths of microgranite, gabbro, and andesite. Microgranite occurring as small, sub-angular to lenticular inclusions is common in many of the outcrops. A large inclusion of andesite is present in the State Reformatory quarry and is described elsewhere in this report. Small inclusions of gabbro a fraction of an inch to a few inches in diameter are common, and in a few places large xenoliths occur. In the NE¼ SE¼ sec. 6, T. 4 N., R. 19 W., on a ridge which forms the northwest side of a valley on Soldier's Spring Mountain, gabbro inclusions up to four feet in diameter are common.

Most outcrops of Reformatory granite show no evidence of sedimentary xenoliths but some thin sections have relict features indicating at least minor assimilation of sediments. A few rounded detrital-appearing grains of tourmaline with light green to blue pleochroism are found in a slide from the south face of the quarry at the Oklahoma State Reformatory. Tourmaline was noticed in only one other granite of the area, namely, the hornblende-biotite granite of Powwow Mountain. The rounded form of the grains suggests a detrital sedimentary origin. In another slide from the south side of this quarry, quartz occurs in an aggregate that in texture resembles quartzite. The quartz grains have numerous inclusions of water and have been strained, as shown by the marked shadowy extinction. These quartzite-appearing aggregates of quartz are partly surrounded by microperthite. In the mixed Headquarters-Reformatory zone on the west side of Headquarters Mountains, C SE¼ sec. 21, T. 6 N., R. 21 W., microgranite porphyry occurs as xenoliths in the Reformatory granite. The porphyry has phenocrysts of oligoclase ($Ab_{83}$) with an outer zone of micropegmatite. Some biotite showing pleochroic halos is present and some late magnetite occurs as stringers cutting the other minerals. As the typical plagioclase of both the Reformatory and Headquarters granites is albite-oligoclase ($Ab_{90}$), the oligoclase ($Ab_{83}$) is believed to be derived from a different source, probably from detrital sedimentary rocks.

In the northwestern outcrop of igneous rock of the Wichita Mountains, Reformatory granite has xenoliths of Headquarters microgranite and andesite, as well as inclusions of microgranite "porphyry." One tan aphanitic specimen from this outcrop has grains of oligoclase ($Ab_{80}$) and oligoclase ($Ab_{88}$) and some rounded detrital-appearing zircon grains. Another thin section from the same outcrop has grains of oligoclase ($Ab_{83}$) and a rounded fragment which is partly quartz and partly microperthite and appears to be an arkose pebble. Apatite needles are common in this specimen. Late euhedral hornblende surrounds older quartz grains.

A fine-grained reddish brown rock in the S½ NE¼ sec. 28, T. 6 N., R. 21 W., is a xenolith in the Reformatory granite. A thin section of this material shows rounded zircon grains and two types of oligoclase ($Ab_{83}$ and $Ab_{88}$), all of which are believed to be detrital grains. This slide has some biotite showing pleochroic halos. The plagioclase and orthoclase are partly changed to micropegmatite and apatite needles have been introduced. Another thin section from this outcrop shows an exceptional amount of sphene, part of which is euhedral, and this is considered a late hydrothermal mineral.

The evidence of old sedimentary material in the Reformatory granite is most noticeable in the area from the State Reformatory quarry to the extreme northwestern outcrop. The Reformatory granite also is more variable in this region, probably owing to assimilation of sedimentary material and the presence of xenoliths of Headquarters microgranite.

Xenoliths in the Reformatory granite show that the Reformatory magma intruded country rocks composed of gabbro, andesite, Headquarters

TABLE 3

Mineral Percentages of the Reformatory Granite West of Lake Altus (Scull, 1947, p. 40)

| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|---|---|---|---|---|---|---|---|---|---|
| Microperthite and orthoclase | 65.9 | 63.5 | 60.7 | 70.3 | 70.5 | 68.8 | 62.3 | 64.4 | 65.8 |
| Quartz | 25.1 | 30.5 | 30.7 | 21.0 | 20.8 | 21.5 | 27.7 | 24.6 | 25.1 |
| Albite-oligoclase | 5.2 | 2.8 | 4.3 | 4.6 | 3.5 | 4.8 | 4.1 | 3.3 | 4.2 |
| Microcline | tr. | tr. | tr. | tr. | tr. | tr. | tr. | tr. | tr. |
| Hornblende | 2.1 | 1.5 | 2.9 | 3.0 | 2.6 | 2.5 | 4.4 | 2.1 | 2.3 |
| Biotite | 0.5 | 0.6 | 0.3 | 0.4 | 0.9 | 1.7 | 0.8 | 0.7 | 0.6 |
| Aegirine-riebeckite | tr. | tr. | — | tr. | 0.5 | tr. | 0.4 | 3.8 | 0.6 |
| Magnetite | 0.1 | 0.2 | 0.4 | 0.1 | 0.5 | 0.2 | 0.2 | 0.3 | 0.2 |
| Augite | tr. | — | — | — | — | tr. | tr. | — | tr. |

1. Oklahoma State Reformatory Quarry, SE¼ SE¼ NE¼ sec. 36, T. 6 N., R. 21 W.
2. Oklahoma State Reformatory Quarry, SE¼ SE¼ NE¼ sec. 36, T. 6 N., R. 21 W.
3. Abandoned quarry, SW¼ SW¼ SW¼ sec. 9, T. 6 N., R. 21 W.
4. Pellow Brothers Quarry, SE¼ SE¼ NW¼ sec. 26 T. 6 N., R. 21 W.
5. B. Smith quarry, SW¼ SE¼ NE¼ sec. 26 T. 6 N., R. 21 W.
6. B. Smith quarry, SW¼ SE¼ SE¼ sec. 26, T. 6 N., R. 21 W.
7. Abandoned quarry 600 feet northwest of Smith quarry, SW¼ SE¼ NE¼ sec. 26, T. 6 N., T. 21 W.
8. Quarry directly behind custodian's house, Quartz Mountain State Park, east line of sec. 21, T. 5 N., R. 20 W.
9. Average mineral percentage of the eight slides.

microgranite, and beds of sedimentary rocks. The large subsurface band of gabbro-anorthosite borders the Reformatory granite on the west and the northwest trends of both the basic and silicic rocks are approximately parallel. It is possible that the Reformatory magma was intruded along the contact between the basic rocks and the adjacent Precambrian sediments.

TABLE 4

Mineral Percentages of the Reformatory Granite* South of Lake Altus (Polk, 1948, p. 36)

| | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| Microperthite and orthoclase | 52.2 | 61.6 | 62.9 | 58.9 |
| Quartz | 19.5 | 20.0 | 17.9 | 19.1 |
| Aegirine-riebeckite | 4.4 | 1.9 | tr. | 2.1 |
| Micropegmatite | 23.8 | 14.9 | 14.3 | 17.7 |
| Hornblende | 0.2 | 0.7 | 3.4 | 1.4 |
| Magnetite | tr. | 1.0 | 1.5 | 0.8 |
| Biotite | tr. | tr. | tr. | tr. |
| Aegirine-riebeckite | tr. | tr. | tr. | tr. |
| Zircon | tr. | tr. | tr. | tr. |
| Sphene | tr. | tr. | tr. | tr. |

*These were called Flat Top granite by Polk.

1. Small hill in C E½ SW¼ NW¼ sec. 8, T. 4 N., R. 19 W.
2. Small hills in NE¼ SW¼ sec. 8, T. 4 N., R. 19 W.
3. Near C NW¼ NE¼ NE¼ sec. 11, T. 4 N., R. 20 W.
4. Average of three slides.

Hornblende-biotite granite

There are only two outcrops of this granite in the map area and at the present time there is no information available to correlate it with any of the described granites of the Wichita Mountains. The two outcrops are in sections 31 and 32, T. 5 N., R. 18 W. This rock was considered Lugert granite by Taylor (1915). McKinley (1950) found that it was intruded by granite dikes and called it Powwow granite after the local name for the low hill in section 31, where it is quarried.

Considering the small area of the outcrops and the lack of information to correlate it with any other granite, the writer does not believe it should be given a formal name at this time. In this report it is designated by its mineralogical composition, hornblende-biotite granite.

In the two outcrops the granite is separated from the Lugert granite by a hydrothermally altered zone. In the exposure on Powwow Mountain it is cut by dikes of Lugert granite. Some of these dikes have a special texture showing well developed tabular crystals of feldspar; McKinley (1950) believed that the dikes are younger than the Lugert granite. The writer, however, was able to trace one of the dikes into the Lugert and thus to show them to be apophyses from this granite magma.

On the east side of Powwow Mountain the hornblende-biotite granite is in contact with diallage gabbro. Dikes of this granite cut the gabbro and alter it slightly. Along the road on the east side of the hill there is more intense alteration of the gabbro around dikes which appear to be Lugert granite containing euhedral tabular feldspar crystals.

The hornblende-biotite granite is flesh pink and contains numerous small dark specks of femic minerals scattered rather uniformly throughout. It is uniformly medium-grained and is characterized by lath-shaped feldspar crystals ranging up to 6 mm in length and colorless quartz ranging from 1 to 3 mm in diameter. The chemical composition of feldspar separated from this granite is given in Table 5.

The mode of the rock is micropegmatite 40%, quartz 23%, microperthite 17%, orthoclase 13%, biotite 4%, hornblende 2%, and traces of magnetite, fluorite, apatite, hematite, tourmaline, zircon, and muscovite. With its 6% ferromagnesian constituents, this hornblende-biotite granite is exceptionally high in dark components in comparison to the normal leucogranites of the Wichita Mountains, which contain no more than 2 or 3 percent femic minerals.

Micropegmatite is the major constituent, comprising 40 percent of the rock. It is mainly an intergrowth of orthoclase and quartz although a small amount is an intergrowth of microperthite and quartz. The quartz occurs as irregular inclusions and as long narrow rods in the feldspar host. Borders of micropegmatite can be seen around feldspar and quartz grains. The peripheral micropegmatite intergrowth originated by hydrothermal quartz replacing orthoclase, which is the common origin of micropegmatite in all the granites studied for this report.

TABLE 5

Chemical Analyses of Feldspar Separated from Granites
(Burwell, 1956, p. 18)

| | *Reformatory granite* | *hornblende-biotite granite* |
|---|---|---|
| $SiO_2$ | 66.07 | 65.69 |
| $Al_2O_3$ | 19.22 | 19.58 |
| $Fe_2O_3$* | 0.85 | 0.52 |
| $TiO_2$ | ----- | 0.13 |
| CaO | 0.56 | 0.99 |
| MgO | 0.05 | 0.16 |
| $K_2O$ | 7.48 | 8.32 |
| $Na_2O$ | 5.93 | 4.56 |
| $H_2O$ | 0.00 | 0.00 |
| L.O.I. | 0.41 | 0.10 |
| Total Oxides | 100.16 | 100.05 |

1. Reformatory granite, sec. 26, T. 6 N., R. 21 W.
2. Hornblende-biotite granite, sec. 32, T. 5 N., R. 18 W.

*Total iron calculated as $Fe_2O_3$.

Microperthite forms 17 percent of the rock and is an intergrowth of orthoclase and albite, probably due to exsolution of albite from the potassium feldspar on cooling. The intergrowth occurs in subhedral grains about 1 mm in diameter and the plagioclase portion exhibits albite and pericline twinning. The microperthite commonly shows an outer micropegmatite layer composed of quartz and microperthite.

Quartz-free orthoclase makes up about 13 percent of the rock and is in the form of euhedral grains generally less than 1 mm wide.

Quartz forms 23 percent of the rock and occurs in two generations, the older of which is considered magmatic as it is in irregular to rounded grains 1 to 3 mm in diameter, has a marked shadowy extinction, and contains rows of minute inclusions, probably of water. The younger quartz is mainly in micropegmatite and lacks the marked shadowy extinction and rows of inclusions. Some of the quartz in micropegmatite is rounded and superficially resembles sand grains, but since adjacent quartz areas are in optical continuity it is interpreted as a late hydrothermal replacement of the feldspar.

Biotite occurs in small green to brown pleochroic flakes averaging 2 mm in width, and contains a few pleochroic halos around minute zircon inclusions. The mica is found around the edges of some of the magmatic quartz grains and as replacements of it, and apparently is a late hydrothermal mineral. Hornblende is present in euhedral grains averaging 2 mm in length and, like the mica, it is later than the magmatic quartz.

Accessory minerals are apatite, zircon, titaniferous magnetite, tourmaline, sphene, fluorite, and muscovite, all of which occur as traces only. Apatite is in the form of minute prisms or needles; zircon occurs as both prisms and euhedral grains. Magnetite is a late hydrothermal mineral, as are apatite, fluorite, and probably sphene. The occurrence of tourmaline is exceptional, it being found elsewhere in the western Wichitas only in a thin section of Reformatory granite from the quarry at the State Reformatory. The tourmaline in this latter occurrence appears to be a relict detrital grain from the assimilation of an old sediment. The tourmaline in the hornblende-biotite granite is an irregular grain and also may represent minor contamination of the granite by sedimentary material.

After boiling with concentrated HCl to remove hematite stain, the rock remains red. The original granitic rock appears to have been mainly orthoclase, microperthite, and quartz with traces of accessory minerals. Solutions from the intruding Lugert magma introduced quartz, hornblende, and biotite, minor amounts of fluorite and magnetite, and perhaps other accessories. The quartz replaced feldspar forming micropegmatite. This mineral assemblage is common in the Headquarters and Lugert granites, and the only exceptional feature of the hornblende-biotite granite is its higher content of biotite and hornblende. These minerals were introduced by solutions from the Lugert magma and their abundance in the rock reflects the character of these solutions, which apparently contained more iron and magnesium than the normal emanations.

The hornblende-biotite granite as stated above cuts the gabbro and in turn is cut by Lugert granite dikes, and thus it is younger than the gabbro and older than the Lugert. Its age with respect to the Reformatory granite is not known although both are older than the Lugert granite.

### Lugert granite

Most of the outcrops in the eastern half of the map area are Lugert granite, a name introduced by Taylor in 1915 for the granite he considered the most widespread in the Wichita Mountains. Later studies by Chase (1956) have shown that the so-called "Lugert" of the eastern and central Wichitas is composed of more than one granite. The writer, however, believes the name can be retained by restricting it to the rock of Taylor's type area, the Lugert region, and leave to the future the problem of correlating it with one of the granites of the eastern Wichitas.

A marked feature of the Lugert granite in this western area is its variability in appearance in different outcrops and even in the same exposure. This variation is due to the presence of xenoliths of gabbro, andesite, micrograníte, and pebbles of granite conglomerate. These normally are present in small amounts but locally comprise 30 percent of the outcrops. In addition the ratio of the different petrologic types that occur as xenoliths varies greatly from place to place. The type and intensity of magmatic and hydrothermal alterations of the xenoliths also changes the lithology of the rocks. The writer knows of no exposure of Lugert granite which is entirely free of inclusions or their alteration products, judged when the rock is examined microscopically.

The commonest type of inclusion in the Lugert granite is micrograníte, which is described in the section on xenoliths. Inclusions of this rock normally are associated with other varieties of granite and are believed to be pebbles of a granite conglomerate into which the Lugert magma was intruded. These sedimentary xenoliths make up 30 percent of the exposure in sec. 1, T. 5 N., R. 19 W., and are abundant in other outcrops of the northeastern part of the map area. They also are common in the area from Lake Altus to Mount Tepee, and some of the best exposures are in the vicinity of Lugert in secs. 23, 24, 25, and 26, T. 5 N., R. 20 W. Inclusions of altered pebbles of granite conglomerate occur in small amounts in most areas where the Lugert granite is exposed.

*Normal Lugert granite.* The variability in lithology of the Lugert granite makes it rather difficult to select an outcrop which can be considered typical. Exposures which have no noticeable xenoliths and microscopically show little micropegmatite or other hydrothermal alteration products would approach the original unaltered Lugert granite. The mineral composition of four such rocks, as well as their average, is given in Table 7.

The uncontaminated, unaltered Lugert granite is reddish pink on fresh surfaces and weathers light pink or reddish brown. It is a medium-grained rock containing feldspar crystals averaging 3 mm in length and irregular quartz grains 1.5 mm in diameter (Plate II, B). The marked difference in the size of the quartz and feldspar grains gives the rock a slightly porphyritic appearance. The dominant minerals are orthoclase and quartz and the minor constituents are albite-oligoclase, hornblende, and biotite. The accessories are titaniferous magnetite, sphene, zircon, fluorite, and apatite; the alteration products are kaolin, chlorite, hematite, limonite, and leucoxene.

Orthoclase is the chief constituent and occurs as subhedral to anhedral grains averaging 3 mm in length. It is partly altered to kaolin, calcite, and hematite. Microperthite is present in rather small amounts in the Lugert whereas the other granites of the area are rich in this intergrowth. Quartz occurs as clear to smoky anhedral grains, 1 to 2 mm in diameter, and contains many inclusions.

Hornblende is present in small amounts and has inclusions of magnetite and zircon. The amphibole is partly altered to chlorite but in a few places it is changed to biotite.

Biotite is a minor constituent and seems to be a late hydrothermal mineral, as it is most common in contact zones with the Reformatory granite. In some slides it replaces the edges of hornblende as a fringe around it. The mica flakes are bent, have ragged edges, and are altered to chlorite and limonite.

Magnetite is disseminated in small grains throughout the rock and is slightly altered to leucoxene, indicating its titaniferous character. Some of the magnetite is late hydrothermal as it occurs in stringers cutting the other minerals.

Sphene generally is associated with magnetite and occurs in anhedral grains with a maximum length of 1.5 mm. Zircon is present as minute inclusions in magnetite and other minerals. Apatite is in the form of small prisms and needles, and fluorite occurs as small irregular grains.

Hematite is found in small masses in cavities and also along the cleavage lines of the feldspars. The red color of the rock is partly due to hematite and partly to the color of the feldspar, for the latter remains red after removing the iron oxide by boiling in concentrated HCl.

*Lugert granite porphyry.* Granite porphyry surrounds gabbro in a valley on the east side of Soldier's Spring Mountain. This rock was labeled granite porphyry by Polk (1948), who considered it older than the Lugert granite. The porphyry grades westward into an outcrop which the writer believes is Lugert granite and the porphyry is interpreted as a contact phase of the Lugert granite against the large gabbro mass.

The granite porphyry has rounded to euhedral phenocrysts of feldspar, 10 to 15 mm long, and a few irregular grains of quartz, all in a fine-grained groundmass. Weathering causes the phenocrysts to stand out in relief as darker pink crystals in the lighter-colored groundmass. The phenocrysts are composed of microperthite 14% and quartz 2%, and the groundmass is microperthite and orthoclase 34%, quartz 16%, micropegmatite 33%, and hornblende 0.6%. Traces of magnetite, aegirine, zircon, sphene, apatite, and fluorite are present.

The edges of the microperthite phenocrysts commonly have a micropegmatitic intergrowth with quartz, which would indicate some late hydrothermal alteration. Fringes of aegirine and biotite on the edges of hornblende also suggest late deuteric changes.

*Micropegmatitic Lugert granite.* Many outcrops of Lugert granite contain micropegmatite, locally coarse enough to be detected by the unaided eye. A close examination of most specimens reveals that this intergrowth is in the micrcgranite "porphyry" xenoliths. The Lugert granite cement around the inclusions, and the outcrops free of xenoliths, show little micropegmatite. In describing the rocks of the Devil's Canyon area Polk (1948, p. 53) wrote, "In the examination of this thesis area the writer has found that what is generally considered to be Lugert granite has very little variation in texture and is not graphically intergrown except near pegmatitic lenses and miarolitic cavities."

An outcrop of Lugert granite with no visible inclusions, but rich in micropegmatite, is in the hill known locally as Camel Back Mountain, sec. 20, T. 5 N., R. 18 W., where the Century Granite Co. operates a quarry. This rock is flesh pink to red and has a uniform medium-grained texture, the feldspar averaging 2 to 3 mm and reaching a maximum of 5 mm. Quartz ranges from 1 to 4 mm and averages 2 mm in diameter. The mineralogical composition of this rock is given in Table 7, column 6, and its chemical composition is given in Table 6.

Micropegmatite is exceptionally abundant, making up almost half of this rock. The intergrowth forms outer zones around microperthite and has been developed by quartz replacing microperthite (Plate III, A).

TABLE 6

CHEMICAL ANALYSES OF GRANITES

| | *Lugert granite*[1] | *Reformatory granite*[2] |
|---|---|---|
| $SiO_2$ | 76.79 | 74.14 |
| $Al_2O_3$ | 12.35 | 12.97 |
| $Fe_2O_3$ | 0.90 | 1.07 |
| FeO | 0.43 | 1.20 |
| MgO | 0.03 | tr. |
| CaO | 0.51 | 0.48 |
| $Na_2O$ | 4.23 | 4.61 |
| $K_2O$ | 4.31 | 5.30 |
| $Rb_2O$* | 0.02 | n.d |
| $H_2O+$ | 0.15 | 0.19 |
| $H_2O-$ | 0.04 | 0.12 |
| $TiO_2$ | 0.08 | 0.25 |
| $P_2O_5$ | 0.00 | trace |
| MnO | 0.01 | 0.03 |
| BaO | 0.0 | 0.0 |
| SrO | n.d. | 0.0 |
| Total | 99.85 | 100.36 |

[1] Lugert granite from Century Granite Co. quarry, SW¼ NW¼ sec. 20, T. 5 N., R. 18 W. Analyst, Doris Thaemlitz, Rock Analysis Laboratory, Dept. of Geology, University of Minnesota, 1954.

[2] Reformatory granite (Taylor, 1915, p. 21).

* $Rb_2O$ by flame spectrophotometer. Elwood Horstman, analyst, University of Minnesota. Actual value of $Rb_2O$ is 0.023%.

Microperthite is composed of microcline and oligoclase, an unusual mineralogy for the granites of this area, which normally have an orthoclase-albite intergrowth. The microperthite surrounds older quartz fragments, some of the quartz being rounded and resembling sand grains. Biotite with green to dark brown pleochroism forms one percent of the rock. Euhedral sphene and irregular grains of magnetite are present and the latter forms stringers in the feldspar. The magnetite is a late hydrothermal product.

The high micropegmatite content, the older quartz grains surrounded by microperthite, and the late biotite and magnetite are common features in the pebble xenoliths in the Lugert outcrops to the west. It is possible that the quarry rock represents a more complete assimilation of old sediments of which only some relict sand grains remain. The more complete assimilation may indicate a hotter magma. Perhaps the inclusions sank in a conduit, whereas to the west the Lugert magma intruded a granite conglomerate as a sill. There is some evidence of a Lugert stock conduit in the eastern part of the map area.

*Gray hybrid Lugert granite.* In some outcrops, as in the Government quarry at Lugert, rounded xenoliths of gabbro ranging in diameter from a few inches to about two feet are enclosed in the Lugert granite. In some places gabbro inclusions are surrounded by a reaction rim of dark gray granite-appearing rock containing hornblende crystals. The rock clearly originated by granite magma reacting with basic inclusions.

A similar gray granite is found in small amounts near the contact of the gabbro with Lugert granite porphyry on the east side of Soldier's Spring Mountain, and here also it appears to be a magmatic reaction product.

In the Little Bow Mountain area an analogous gray granite occurs and has been quarried on a small scale. This rock was first mentioned by Taylor (1915, p. 63), who described it as a dark gray granite consisting of microperthite, orthoclase, quartz, plagioclase, hornblende, pyroxene, and biotite. The gray granite occurs as angular xenoliths cut by pink granite dikes.

A similar-appearing rock is found a few miles southeast, near Cold Springs, and is known by the name Cold Springs granite. This rock was studied by Walper (1951), who interpreted it as the result of cross assimilation of an andesite by a granite magma. McKinley (1950) believes the gray hybrid granite of Little Bow Mountain has been formed in an analogous manner excepting that a gabbro rather than an andesite reacted with the granite magma. The gray "granite" contains relict grains of labradorite and in places grades into the adjacent gabbro. Its origin as an assimilation product of a gabbro in a granite magma appears to be well established.

This hybrid granite of the Little Bow Mountain area is fine-grained, granular, and has an average grain size of 1 mm. The rock has a salt-and-pepper appearance owing to approximately equal amounts of light and dark constituents. Feldspar and quartz are the light-colored minerals and biotite is the main dark component, although a little hornblende is present. Microscopically the rock shows little microperthite or micropegmatite, whereas these intergrowths are common in the other granitic rocks of the area. The major constituents are orthoclase, quartz, labradorite, biotite, and hornblende. The minor components are microperthite, magnetite, zircon, apatite, and garnet, and the alteration products are clay, chlorite, muscovite, hematite, limonite, and leucoxene.

Orthoclase is the chief mineral and occurs in subhedral to anhedral grains averaging 1.5 mm. Labradorite forms some 13 percent of the rock in the form of subhedral crystals, commonly zoned. The plagioclase is considered a relict mineral of the assimilated gabbro.

Quartz is in irregular grains, about 1 mm in diameter, that contain many inclusions. Biotite in flakes less than 1 mm across forms 10 percent of the rock and is partly altered to chlorite. Hornblende makes up some 4 percent and occurs in grains 1 mm or less in length, partly changed to biotite and chlorite. Hematite is present as a stain.

*Green Lugert granite.* A gabbro xenolith a foot in diameter, surrounded by a reaction rim of a green granite-like rock two inches wide, was noticed in the Lugert granite in the Government quarry at Lugert. An outcrop of a similar green granite was found in the abandoned quarry on the northwest side of Bird Mountain in sec. 5, T. 4 N., R. 20 W. This latter rock on weathering formed hematite and limonite and is red, yellow, or mottled red and yellow at the surface and along the joints. The rock becomes gray when leached with concentrated HCl.

Taylor (1915, p. 67) described a similar color change in the Parsons Brothers' Granite Co. quarry in NE¼ sec. 22, T. 3 N., R. 17 W., in the Mountain Park area:

> *"When it was first observed that the color of the rock was due to the hematite in the cracks and surrounding the minerals it was thought that secondary iron may have been introduced by circulating waters so that such zones contained above the normal percentage of iron. Chemical analysis, however, shows that the reverse is likely to be the case. Analyses by J. G. Fairchild of the United States Geological Survey, show that the normal granite of this area contains a total of 3.01 percent of iron oxides, while the highly colored variety from the Parsons' quarry contains a total of only 2.58 percent of iron oxides.*
>
> *"The deep-red color is due apparently to the abundance of hematite rather than the total amount of iron oxide present. The change in color is brought about largely by changing the black iron oxide to red hematite.*
>
> *"It appears from investigation that the first change that takes place in the normal rock is the formation of epidote and chlorite, which gives the rock a uniform olive-green color. Later, by the breaking down of the epidote and chlorite and the oxidation of magnetite, red hematite is formed. This changes the rock completely from an olive-green to a deep-red color. Later, on exposure and weathering, the red changes first to yellow because of hydration and later to gray, much of the hematite being removed and the feldspars altering to sericite and kaolin. In support of this theory it was observed at the Parsons Brothers' quarry that the olive-green phase of the granite was never found at the surface or near the joint planes at a depth of 6 feet. The green rock is found in the middle of the larger blocks which do not afford channels of water circulation or ready exposure to the air. In depth the green becomes more abundant because of this fact."*

The green rock at Bird Mountain is medium-grained and slightly porphyritic. Its mode is microperthite phenocrysts 16% and quartz phenocrysts 3%; in the groundmass is micropegmatite 78%, hornblende 2%, and traces of albite, biotite, magnetite, aegirine, riebeckite, zircon, sphene, apatite, and fluorite. The hornblende is partly altered to chlorite, a fact which supports Taylor's interpretation. A noteworthy feature is the prominent micropegmatite zone around orthoclase crystals which originated by quartz replacing the feldspar. Another feature is the presence of aegirine and riebeckite which have replaced hornblende and also occur along quartz-feldspar contacts. Some radiating needles of riebeckite are enclosed in late quartz. Hornblende is unusual in that some of the crystals are twinned, a feature noticed in only a few thin sections of the granites of the area.

The original rock has been intensely altered by deuteric or hydrothermal action accompanied by the introduction of considerable silica to form micropegmatite and free quartz. Albite and fluorite also were introduced and hornblende was changed to magnetite, biotite, aegirine, and riebeckite. The green color is due to chlorite, but the exact character of the original rock is obscure. The green granitic reaction rims around basic xenoliths in the Government quarry at Lugert makes it probable that some basic material was assimilated in the formation of the green rock at Bird Mountain. No definite relicts of basic inclusions are observable in the quarry, but a canal cut in the hill a half mile to the east shows a large xenolith of andesite, measuring 50 x 30 feet and surrounded by Lugert granite.

*Miarolitic cavities, pegmatites, and asphalt.* Miarolitic cavities, pegmatites, and quartz stringers are found in several of the Lugert granite outcrops and are especially prominent in the Lugert region. The cavities commonly are lined with crystals of orthoclase, microperthite, quartz, riebeckite, calcite, and hematite. Asphalt also has been found in some of the miarolitic cavities near Lugert. The hydrocarbon is the residue of petroleum which migrated from the adjacent Permian sediments into openings in the granite rock. These features of the Lugert granite are considered in more detail in a later section of this report.

*Jointing.* The most pronounced joints in the central area of the Lugert outcrops are vertical and strike N. 60°-70° W. A few almost at right angles to these trend N. 30° E. The joints range widely in their spacing, being one to 50 feet apart. In the hills of the Devil's Canyon group the strike normally is N. 60° W. and in the northern part of the map area it is N. 10° W. On Quartz Mountain the trend is north-south, roughly parallel to the Reformatory-Lugert contact.

TABLE 7

MINERAL PERCENTAGES OF THE LUGERT GRANITE

| | 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|---|
| Microperthite and orthoclase | 57.9 | 54.4 | 66.1 | 71.8 | 62.5 | 13.7 |
| Quartz | 35.7 | 37.3 | 22.9 | 24.0 | 30.0 | 34.8 |
| Albite-oligoclase | 4.6 | 6.7 | 4.0 | 0.1 | 3.9 | ---.- |
| Micropegmatite | ---.- | ---.- | 3.0 | 0.2 | 0.8 | 49.7 |
| Hornblende | tr. | tr. | 3.0 | 2.3 | 1.3 | tr. |
| Biotite | 0.9 | 1.4 | tr. | 0.1 | 0.6 | 1.0 |
| Magnetite | 0.1 | 0.4 | 0.2 | 1.2 | 0.5 | 0.7 |
| Zircon | ---.- | ---.- | tr. | tr. | tr. | tr. |
| Sphene | tr. | tr. | 0.5 | tr. | 0.1 | ---.- |
| Apatite | tr. | tr. | tr. | tr. | tr. | ---.- |
| Fluorite | tr. | tr. | tr. | tr. | tr. | tr. |

1. North side of Quartz Mountain, NW¼ NW¼ sec. 16, T. 5 N., R. 20 W. (Scull, 1947, p. 43).
2. South side of Quartz Mountain, SW¼ NW¼ sec. 22, T. 5 N., R. 20 W. (Scull, 1947, p. 43).
3. Large railroad cut near C E½ sec. 27, T. 5 N., R. 20 W. (Polk, 1948, p. 57).
4. Small road cut one-eighth mile west of the SE corner of sec. 24, T. 5 N., R. 20 W. (Polk, 1948, p. 57).
5. Average of thin sections 1 to 4.
6. West side of Camel Back Mountain, NE¼ NE¼ SE¼ sec. 19, T. 5 N., R. 18 W. (McKinley, 1950, p. 46).

Numerous small joints with no discernible pattern are present in many of the outcrops and the rock locally is intensely fractured. Sheet jointing is not as prominent as in the Reformatory granite, but is well developed in a few exposures.

### Dikes and Miarolitic Cavities

A few dikes of igneous rocks are found in all parts of the area. Most of these are a few inches or feet in width and have high-angle or vertical dip. The majority can only be traced a few feet, but some extend several hundred feet, and the larger ones are shown on the map. They strike in various directions and have no observable trend.

There were three periods of dike injections, the oldest being granite aplite and pegmatite with associated quartz veins and miarolitic cavities. The second phase was alkaline and is represented by aegirine-riebeckite granite dikes; the third and last was basic and produced dabase dikes. The Headquarters and Reformatory granites are cut by these three types of dikes and all but the aegirine-riebeckite type intrudes the Lugert granite. The dikes and associated veins thus are younger than the granites and are the rocks of the last phase of igneous activity in the area.

#### Aplite dikes

These are the most common type and they occur in all parts of the area. Generally they are a few inches to a few feet wide and are traceable for only a short distance, but in Quartz Mountain and Headquarters Mountain some are several hundred feet in length. They are fine-grained, have a saccharoidal texture, and are made up of orthoclase and quartz in amounts generally more than 95 percent. The other constituents are albite-oligoclase, hornblende, biotite, and magnetite. Orthoclase is in subhedral grains averaging 0.4 mm in length and quartz occurs as irregular slightly corroded grains of the same size. The plagioclase and hornblende are present as anhedral fragments and biotite as flakes with corroded edges. A small amount of magnetite is disseminated throughout the rock and is slightly altered to hematite and limonite, which give the rock a light-brown to brownish-red color. When boiled with concentrated HCl, which removes the iron oxides, the rock becomes gray.

#### Pegmatite dikes

Closely related in age to the aplite dikes are granite pegmatite dikes and lenses which occur in the Headquarters Mountain group, Quartz Mountain, and Devil's Canyon Mountain group. These have been described by Anderson (1946, pp. 18-29), and the following is modified from his work.

*Headquarters Mountain Group.* In the Headquarters Mountain group a few small pegmatites have been found. Taylor (1915, p. 40) described coarsely crystalline granite dikes near the town of Granite which contained amphibole crystals up to two inches in length. These dikes probably have been removed by quarrying operations as they can no longer be found.

A few small pegmatite lenses are present at the contact of the Reformatory and Headquarters granites in two small abandoned quarries in the SW¼ SW¼ sec. 9, T. 6 N., R. 21 W. The pegmatites are a few inches wide, a few feet long, and are a contact phase of the Reformatory granite. Microcline-perthite is the principal constituent and this is intergrown with quartz in a graphic texture. Clear colorless quartz is present in crystals which reach a maximum length of 3.5 inches. Books of biotite and euhedral hornblende occur in minute amounts. A little albite is present and the accessory minerals are zircon and magnetite. The microcline-microperthite is a deuteric type and has been formed by albite replacing microcline. In places albite has completely replaced the edges of the potassium feldspar.

*Quartz Mountain.* Pegmatite masses are rare in Quartz Mountain except in a zone, 25 to 50 feet wide, on the west side of the mountain in the SE¼ sec. 17 and NE¼ sec. 20, T. 5 N., R. 20 W. Several small pegmatite lenses and many miarolitic cavities are present in this hydrothermally altered zone, which is less resistant to erosion than the adjacent granite and has been weathered into a small depression. The zone strikes east-west. The pegmatite stringers range up to eight inches in width and some quartz veins are associated with them.

The adjacent rock is Reformatory granite, which microscopically shows a pronounced micropegmatitic texture near the pegmatite lenses but lacks this feature a few feet away. Locally the granite has a porphyritic appearance resulting from feldspar phenocrysts being surrounded by micropegmatite. The intergrowth, however, is the result of hydrothermal replacement and the rock is not a true porphyry.

Quartz ranges from one to eight inches in length and averages two inches, the smaller crystals being smoky. The associated miarolitic cavities range from an inch to a foot in diameter and are lined with quartz and feldspar crystals. The latter reach an inch in length and commonly exhibit carlsbad twinning. The feldspar crystals are well developed and show the base (001), macrodome (101), prism (110), and brachypinacoid (010). They are coated with a heavy iron oxide stain. In some places books of biotite partly altered to chlorite are present and small amounts of albite, zircon, and magnetite occur. A little secondary quartz may be seen as coatings on the feldspar and some small quartz stringers are also found in this zone.

*Government Quarry.* Rock for the Lugert dam was obtained from a large quarry in the SE¼ sec. 26, T. 5 N., R. 20 W. The rock is Lugert granite containing andesite inclusions and their assimilation and alteration products. A few pegmatite lenses and many miarolitic cavities are present. The pegmatite masses reach several feet in length and are composed of feldspar and quartz, with minor amounts of biotite and riebeckite. The feldspar occurs as microcline-perthite together with lesser amounts of micropegmatite.

The miarolitic cavities are similar to those described at Quartz Mountain except that many are larger and the minerals lining the walls in some instances are exceptionally coarse. Not only does riebeckite occur in crystals a few inches long, but the largest crystals of quartz so far reported from Oklahoma were obained, in 1947, from this quarry (Plate IV, E). Polk (1948, p. 41) has described these quartz crystals as follows:

> *"They were discovered during quarrying operations in the eastern end of the Government Quarry located in NE SW SE section 26, T. 5 N., R. 20 W., approximately one mile southeast of*

*Lugert dam in western Kiowa County. These crystals were donated to the Mineralogy Department at the University of Oklahoma by Mr. E. D. Jenner, superintendent of the quarry.*

*"The two crystals . . . are of the smoky quartz varety, which are stained reddish brown by a coating of hematite. The larger crystal is 1 foot 5 inches long, 9 inches wide, and weighs approximately 75 pounds. It shows good prism faces and one end is terminated by rhombohedra. The other crystal is 1 foot long, 7 inches wide, weighs about 30 pounds, and has prism faces euhedrally terminated at one end by six large rhombohedral planes. There are many small distorted faces on the irregular base of both crystals which appear to be the result of secondary crystallization along fracture surfaces."*

Robert Halsted, a geology student at the University of Oklahoma in 1952, discovered some reddish needles in the miarolitic cavities of specimens from the Government quarry at Lugert. Studied by the writer (Merritt, 1952, p. 189), they proved to be brookite. They occur as single or radiate clusters of reddish adamantine needles averaging 1 mm in length. Individual cavities contain from one dozen to a few dozen needles. Some schiller structure of the hypersthene in gabbro of the Wichita Mountains is due to inclusions of minute needles of a mineral with a very high luster and index of refraction, probably brookite.

The feldspar is euhedral, the crystals rarely exceeding an inch in length, whereas riebeckite occurs as thin prisms and biotite occurs as small booklets.

Hematite is present in small amounts in the cavities both as a fine powdery reddish material and as black specularite. The latter type occurs as minute specks and as small hemispherical masses, 0.5 mm in diameter. The hematite is interpreted as hydrothermal in origin and not as the result of surface weathering, as inclusions of the iron oxide in smoky quartz indicate that some of the hematite is older than part of the hydrothermal quartz.

Opal is found at the Government quarry. It occurs as colorless botryoidal masses and thin coatings of hyalite which fluoresces a light green when exposed to 2,537 Å but has no reaction to the long 3,600 Å waves. The fluorescence is more marked than that of any other mineral so far reported from Oklahoma. The opal is considered to have been deposited during the last hydrothermal stages of the Lugert magma.

Some data are available concerning the age relationship of the minerals in the cavities. The quartz crystals commonly are attached to feldspar surfaces; riebeckite needles are enclosed in smoky quartz; brookite and hematite occur both as inclusions in the quartz and as coatings on the crystal faces of the latter; and opal and calcite coat the other minerals. From these relations the paragenesis is interpreted as follows:

1. biotite (oldest)
2. microcline-perthite
3. riebeckite
4. brookite and hematite
5. quartz
6. opal
7. calcite (youngest)

The microcline-perthite is an injection perthite formed by the hydrothermal replacement of microcline by albite and the plagioclase, therefore, is later than the microcline.

The asphalt is the residue of petroleum which migrated from the Permian sediments into the miarolitic cavities of the granite.

*Devils Canyon Mountain Group.* Bain (1904, p. 120) described a pegmatite near Lugert as follows: "In the granite mountains near Lugert there are certain coarse pegmatites showing crystals of quartz three or more inches in length. . . . With the quartz crystals are some small, black semi-vitreous crystals recognized by Dr. Hillebrand, a member of the United States Geological Survey, as belonging to the columbite-tantalite group." Anderson (1946, p. 22) obtained a few small black crystals from a pegmatite in the SW¼ sec. 35, T. 5 N., R. 20 W., which on fusing with borax and dissolving in hydrocloric acid gave a slight blue color characteristic of columbite-tantalite. This pegmatite probably is the one referred to by Bain. A second search by Anderson and one by the writer failed to obtain additional specimens.

This pegmatite dike is two to three feet wide and a few feet long. It has north-south strike and vertical dip, and contains quartz and feldspar euhedra as well as masses of milky quartz. The feldspar is microcline-perthite and is intergrown with quartz producing a graphic texture. A small amount of albite, biotite, magnetite, and zircon are present. The biotite is in the form of pseudohexagonal books and is partly altered to chlorite.

In the SW¼ sec. 15, T. 5 N., R. 20 W., two or three hundred feet west of North Fork of Red River, several miarolitic cavities occur in the Lugert granite. Their maximum diameter is five inches and their mineralogy is similar to that of the others found in this area. Well developed quartz, microcline-perthite, and biotite are present. The Lugert granite becomes coarsely micropegmatitic adjacent to the miarolitic cavities.

In the SE¼ sec. 27, T. 5 N., R. 20 W., a little south of Oklahoma State Highway 44, a few small pegmatite lenses and quartz veins are present in the Lugert granite. The quartz is milky and is partly intergrown with feldspar, which is microcline-perthite with minor albite. Hornblende is the major femic mineral, and traces of zircon and magnetite occur. Albitization has altered microcline to perthite and secondary quartz also was introduced.

Masses of milky quartz are found in the Reformatory granite in Quartz Mountain, Flat Top Mountain, and Soldier's Spring Mountain, and loose crystals some six inches in length have been found in the soil north of Quartz Mountain.

In an abandoned quarry in the SW¼ sec. 33, T. 5 N., R. 20 W. fragments of pegmatite are noticeable, but the rock was not found in place. It apparently has been removed by the quarrying operations.

A few miarolitic cavities in Lugert granite are found in the NE¼ sec. 7, T. 4 N., R. 19 W. These are similar to those of the Lugert Dam quarry, but no amphibole is present.

Aegirine-riebeckite granite dikes

Aegirine and riebeckite are found in some of the granites, pegmatites, and miarolitic cavities of the Wichita Mountains, but granite dikes containing these minerals have been reported only in Headquarters Mountain and

Quartz Mountain. Rogers (1907, p. 283) mentions that seven or eight aegirine-riebeckite granite dikes occur just northwest of the town of Granite. Taylor (1915, p. 40) reports that eight parallel dikes are present in the east-central part of sec. 22, T. 6 N., 21 W., where the dikes dip 30° to 35° NE and range from 3 to 16 inches in thickness.

These aegirine-riebeckite dikes cut across aplite dikes and quartz veins in both Headquarters and Quartz Mountains. At the latter locality a diabase dike intrudes an aegirine-riebeckite granite dike and thus the relative age of these three types of dikes is established.

The alkaline dikes near Granite range from 1 to 16 inches in width and dip 25° to 40° N. They are remarkably persistent, two of them being traceable for more than a half mile, as shown on the map. The rock is fine-grained and aplitic, and its constituents average 1 mm in diameter. The color is pinkish-gray to reddish-gray and is black-speckled with riebeckite.

Quartz and microperthite are the major constituents. The latter is subhedral to euhedral, commonly showing carlsbad twinning, and is an intergrowth of orthoclase and albite. Quartz is mainly anhedral, but a few hexagonal outlines can be detected.

Riebeckite is in aggregates of subhedral crystals, normally small but locally as much as 2 mm along the prism edge. The pleochroic formula is X = dark blue, Y = light blue, and Z = green. In addition to prismatic cleavage, parting parallel to (010) is noticeable.

Aegirine is present as prisms ranging from 0.1 to 0.3 mm in length, with pleochroism X = dark green, Y = light green, and Z = yellowish. The maximum extinction is 6°. Some aegirine needles can be seen as inclusions in quartz but mainly the mineral occurs between quartz and orthoclase grains. Rogers reported that one thin section showed aegirine needles with their long axes parallel to the outlines of the quartz and another slide had pseudomorphs of magnetite after aegirine crystals.

Minor amounts of microcline, biotite, and magnetite are present in the thin sections.

Riebeckite and aegirine seem to be primary magmatic minerals in these dikes. In the miarolitic cavities of the Lugert and Reformatory granites, where riebeckite occasionally occurs, it is a hydrothermal mineral. Riebeckite is present in small amounts in a few outcrops of the granites of the area and in these it replaces hornblende or other minerals and is secondary. In some places aegirine is partly altered to riebeckite.

Riebeckite and aegirine are more common in the Quanah granite and associated pegmatites of the eastern Wichita Mountains. Johnson (1955, pp. 48-57) has made a detailed chemical and optical study of riebeckite from the Hale Springs pegmatite in sections 4 and 9, T. 3 N., R. 15 W., and the reader is referred to his thesis for further details on this mineral.

### Diabase dikes

A half dozen diabase dikes have been found in the western part of the Wichita Mountains but many others probably are present, hidden below the soil layer. These basic rocks are less resistant than the surrounding granites and on erosion form soil-covered depressions which generally are marked by a narrow strip of shrubs that contrasts sharply with the adjacent barren granite. Trees and shrubs also mark joint and fault lines and this criterion must be used with caution. Most diabase dikes are exposed only where some excavation such as a quarry or road cut has been made.

A diabase dike on Quartz Mountain cuts an aegirine-riebeckite granite dike, showing it to be the youngest of the dike rocks and to represent the last phase of igneous activity in the area.

A long diabase dike occurs in the northwest part of Headquarters Mountain, where it cuts the Reformatory and the mixed Reformatory-Headquarters granites. Rogers (1907, p. 286) reported an amygdaloidal diabase in this area, "A short distance east by northeast of Mt. Walsh a fine grained, black, basic dike, about four and one-half feet wide occurs. It has an east-west strike and almost vertical dip. The rock is exposed in a prospect shaft and is much altered. It consists of lath shaped plagioclase, amygdules filled with a chlorite-like mineral (representing original ferro-magnesium mineral), and abundant magnetite. The rock has the typical ophitic structure, and so is a diabase."

Diabase dikes with amygdaloidal structure are rare and only one other occurrence in the Wichita Mountains is known to the writer. It is in sec. 29, T. 3 N., R. 13 W., on Blue Beaver Creek in the Fort Sill Military Reservation.

A diabase dike in Quartz Mountain, 10 feet wide and striking N. 10° W., can be traced more than a half mile by the shrubs which grow on it. A thin section of this rock shows that the plagioclase is labradorite in lath-like crystals, 0.5 to 1 mm in length. It has albite, pericline, and carlsbad twinning. Augite highly altered to chlorite and serpentine is the chief primary ferromagnesian mineral. The rock has a diabasic texture.

In a road cut at the northeast end of King Mountain there is a diabase dike seven feet wide which strikes N. 36° E. and dips 80° E.

In the railroad cut (center E½ sec. 27, T. 5 N., R. 20 W.) near the Lugert dam, there are three diabase dikes. The largest is 8 feet wide, strikes N. 10° E., and dips 66° E.; a second dike is 5 feet wide, strikes N. 32° E., and dips 69° SE; and the smallest is 18 inches wide, strikes N. 40° E., and dips 80° SE. These dikes are offset by a fault striking N. 75° E. along which the rocks on the north side of the cut moved eastward about 20 feet relative to those on the south side. Slickensides show that the movement was horizontal and indicate a strike-slip fault.

The fresh diabase is black and is characterized by a dense aphanitic texture and conchoidal fracture. Most of it has been intensely altered, and the smaller dike is a green mixture of chlorite and serpentine. Relicts of the primary minerals show that the diabase was composed of labradorite and augite with minor amounts of biotite and magnetite. Traces of sphene and zircon also are observable. The labradorite has altered to clay, prehnite, and calcite, and the augite to chlorite and serpentine. Magnetite has weathered to hematite. A faint diabase texture is still discernible.

A dike three feet wide occurs in a prospect pit near the C W½ sec. 5, T. 4 N., R. 19 W. Diabase float is found just east of the mouth of Devil's Canyon and in a prospect pit a few feet east of this draw. No other diabase dikes were noticed in the hills of the Devil's Canyon Group but they probably occur, as the field studies were not exhaustive.

A prospect pit in the NW¼ NE¼ sec. 16, T. 5 N., R. 19 W., south of Dome Mountain, exposes a vertical diabase dike containing some calcite. This is the only exposure of diabase known in this part of the area, but excavations in the future probably will expose additional masses of this rock.

# Permian Sediments

The only Paleozoic rocks exposed in this area are Permian "Red Beds," which were deposited in a sea with many islands. The islands were granitic in composition and varied considerably in size, shape, and height. The upper part of many of the islands is now exposed as granite hills; the lower part as well as the smaller hills are covered with a few feet to several hundred feet of Permian sediments.

The "Red Beds" are mainly shales which overlap the granite and thicken away from the hills. A few wells drilled in this area have penetrated beds of arkose which are interpreted as near-shore lithofacies of the sediments. The shale is exposed in gullies and road cuts and is mainly gray or green, but red and blue colors also occur. The rock is well bedded in thin layers. It mostly is Hennessey in age, but a narrow strip of rocks a few miles wide along the eastern border of the map area is of Wichita age. Both the Hennessey and Wichita rocks are Lower Permian in age.

The dips of the sedimentary rocks in contact with granite are quite variable, generally conforming with the irregularly eroded granite surface. Regionally these sediments dip away from the Wichita Mountains at a low angle. A few wells have been drilled through the sediments into the underlying basement rocks and these are listed in Table 8. These data and the information on the Precambrian surface as revealed by a magnetometer survey (see section on gabbro-anorthosite) show that the dip of the sediments on the south side of the mountains is southwest at approximately 500 feet per mile. The dip on the north side is more gentle near the granite outcrops and must steepen considerably a few miles north, where the rocks dip into the Anadarko basin.

### Arkose facies of the Hennessey shale

A small outcrop of arkosic conglomerate recently was found by Robert Fay and the writer on the eastern flank of Soldier's Spring Mountain. This rock is quite different in appearance from the unconsolidated granite conglomerates and arkoses of Pleistocene age exposed in the Lake Altus area. It resembles the arkoses which grade into granite conglomerate of Post Oak age in the eastern Wichitas, and the writer believes it is a near-shore lithofacies of the Hennessey formation. The arkosic conglomerate exposure is in the NW¼ SW¼ sec. 5, T. 4 N., R. 19 W. It is layered, has a maximum exposed thickness of 10 feet, and can be traced north-south for a distance of 1,000 feet. It rests unconformably upon Lugert granite porphyry at the base of the hill, but cannot be traced eastward into the Hennessey shale as the adjacent plain is soil-covered.

On a fresh surface the rock is gray, fine-grained, and contains angular pebbles, which are mainly granite. Some flesh-colored or red feldspar and quartz grains are present. On weathered surfaces the rock is porous. It has a light brown clay cement and the pebbles average ½ inch but a few are an inch or more in diameter. In places some secondary chalcedony and jasper occur.

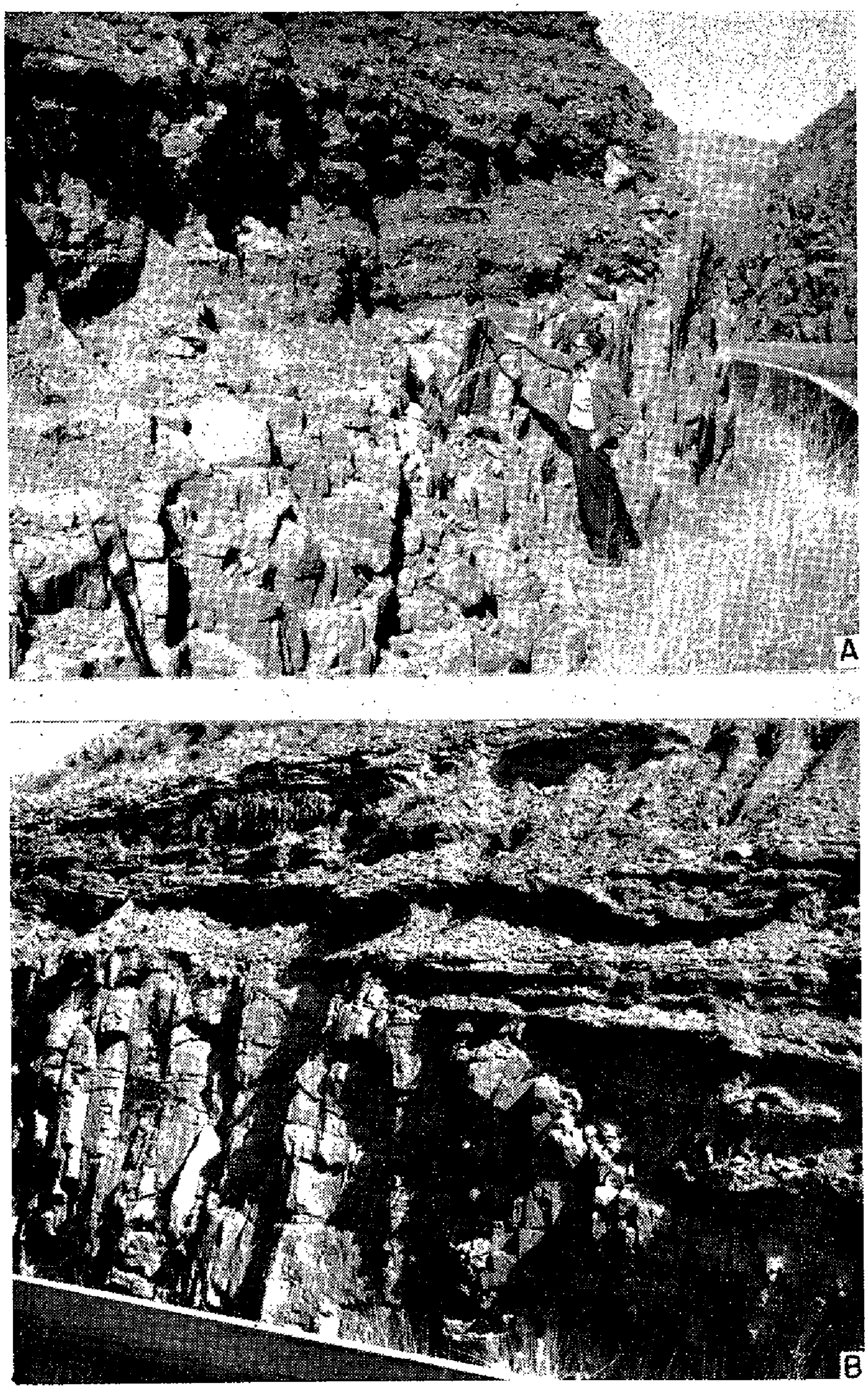
A small exposure of Hennessey granite conglomerate can be seen in a deep railroad cut in the NE¼ SE¼ sec. 26, T. 5 N., R. 20 W., just south of Lake Altus. The pebbles, cobbles, and boulders rest unconformably upon the eroded surface of Lugert granite. The conglomerate is interbedded with maroon shale.

TABLE 8

WELLS DRILLED TO THE PRECAMBRIAN IN THE LAKE ALTUS AREA*

| *Name of Well* | *Location* | *Depth (feet) to Precambrian* | *Precambrian rock type* |
|---|---|---|---|
| Tidewater-Skelly Smith #1 | SW¼ SE¼ 23-7N-20W | 1,633<br>1,797 | granite<br>anorthosite |
| Alert Petroleum Patterson #1 | SE¼ SW¼ 2-6N-19W | 1,404 | granite |
| Briggs Buress #1 | NE¼ SW¼ 5-6N-20W | 950 | granite |
| Potts Bell #1 | NW¼ NE¼ 22-6N-20W | 683 | granite |
| Heiskell Hoover #1 | NW¼ NW¼ 1-6N-21W | 802 | granite |
| Thomason Craig #3 | NE¼ SE¼ 3-6N-21W | 764 | granite |
| S & B Oil Murray #3 | NE¼ NE¼ 4-6N-21W | 610 | granite |
| Edwin G. Gilliam Gaither #2 | NW¼ SE¼ 5-6N-21W | 524 | granite |
| H. W. Porter Dillahunty #1 | NW¼ NE¼ 8-6N-21W | 290 | granite |
| Frederick Oil Co. Armstrong #3 | NW¼ NE¼ 10-6N-21W | 165 | granite |
| M & M Oil Co. Nelson #1 | SE¼ SW¼ 30-6N-21W | 785 | granite |
| Caudill & Bedrock | SE¼ SW¼ 1-5N-18W | 1,188 | gabbro |
| Planteen Bozman #1 | SE¼ NE¼ 14-5N-18W | 1,052 | granite |
| Rogers Bros. Graumman #1 | NW¼ NE¼ 11-5N-21W | 994 | blue granite (gabbro?) |
| Winfrey & Walsh Baumgart #1 | NW¼ SW¼ 15-5N-21W | 929 | black granite wash (gabbro?) |
| Stephens Petroleum John #1 | SE¼ NW¼ 24-5N-21W | 905 | granite |
| Stauffer Petroleum Dillahunty #1 | SE¼ SE¼ 36-5N-21W | 1,016 | granite |
| Robinson & Suppes Walker #1 | SW¼ SW¼ 19-4N-20W | 1,278 | granite |
| Stauffer Petroleum Beaucamp #1 | NE¼ SE¼ 1-4N-21W | 1,105 | granite |

*In addition to wells in the map area, a few from adjacent townships are included.




Unconformity separating Lugert granite from Hennessey formation.

*A.* Strongly jointed Lugert granite unconformably overlain by nearshore facies of Hennessey shale as exposed on the north side of an irrigation canal cut in cen. SE¼ sec. 33, T. 5 N., R. 20 W. Hammer held by author is at unconformable contact. Hennessey is overlapping the irregularly eroded granite surface and consists of maroon shale interstratified with beds of arkose and granite conglomerate. Coarse clastics disappear within a short distance down dip, toward observer.

*B.* Same locality; exposure on the south side of the irrigation canal cut. Photos by W. E. Ham.

Near-shore facies of Hennessey shale resting unconformably upon an irregularly eroded surface of Lugert granite is exposed in an irrigation canal cut in the C sec. 33, T. 5 N., R. 20 W. (Plate V). The Hennessey has a low dip to the west and consists of maroon shale interstratified with beds of arkose and granite conglomerate. The coarse clastics disappear within a short distance down dip.

A small outcrop of Hennessey granite conglomerate was noted in the road cut 0.3 mile south of Quartz Mountain Lodge. The conglomerate rests unconformably upon Lugert granite and is composed of granite pebbles, boulders, and cobbles. Only minor amounts of shale are present, which is in marked contrast with the irrigation canal cut exposure.

More detailed field studies probably will reveal additional outcrops of Hennessey granite conglomerate.

Granite conglomerates in the eastern Wichita Mountains have been called Post Oak, a member of the Wichita formation, by Chase (1954). If the conglomerate outcrops of the Lake Altus area are correlated with the Post Oak, the age of the latter would have to be extended into Hennessey time. It seems more advisable to consider the conglomerate a lithofacies of the Hennessey formation.

## Tepee Creek Sediments

Sedimentary beds of unusual mineralogical composition occur in isolated outcrops on the north and south flanks of the Raggedy Mountains, and near the junction of Tepee Creek with North Fork of Red River. These rocks were first described by Merritt and Ham (1941) and given the name Tepee Creek formation.

The typical rock is dense, is dull brick-red speckled with white, and commonly shows small grains of black shiny ilmenite. Approximately half of the rock is composed of zeolites and opal and the minor constituents are hematite, limonite, ilmenite, calcite, and plagioclase. Locally rounded pebbles of pink or white anorthosite, ranging from 1 to 3 inches in diameter, are present and give the rock a conglomeratic appearance.

Only a few small outcrops of the Tepee Creek are found in the map area. In sections 32 and 33, T. 5 N., R. 18 W. a half dozen erosional remnants occur, each a few square feet in area. The exposures are on the flanks of anorthosite or gabbro hills.

The largest outcrop of Tepee Creek in the map area is in the SW¼ SW¼ sec. 6, T. 4 N., R. 18 W., which is the type locality. It covers approximately five acres and rests unconformably on the south and west sides of a low hill of anorthosite. A trench 20 feet long and 8 feet deep exposes the sediments, which have well-defined bedding. Two massive beds, each a foot thick, are present at the top of the trench and appear to be horizontal. A vertical section of the rock, measured with a hand level, was 47 feet. The full thickness is unknown as the base is covered and the top is eroded.

The Tepee Creek in this exposure is exceptionally rich in calcite and dolomite, the average carbonate content of seven layers being 32.95% with a maximum of 64.31% and a minimum of 14.52%. Two analyses of samples from the Raggedy Mountains (a few miles east) which are more typical of the Tepee Creek gave 1.77% and 9.74% carbonate.

The results of chemical and mineralogical analyses of samples representative of two layers from this outcrop are given in Table 9 and an analysis of opal in Table 10.

TABLE 9

ANALYSES OF TEPEE CREEK SEDIMENTS*

| | I | II |
|---|---|---|
| $SiO_2$ | 16.38 | 39.53 |
| $Al_2O_3$ | 10.11 | 17.54 |
| $Fe_2O_3$ | 1.74 | 2.96 |
| $MnO_2$ | 0.05 | 0.03 |
| CaO | 36.80 | 8.46 |
| MgO | 1.02 | 5.50 |
| $K_2O$ | 0.48 | 0.41 |
| $Na_2O$ | 2.36 | 8.66 |
| $CO_2$ | 28.45 | 10.74 |
| $H_2O$ | 2.55 | 6.00 |
| Cl | 0.11 | 0.13 |
| Total | 100.05 | 99.96 |
| MINERAL COMPOSITION COMPUTED FROM THE CHEMICAL ANALYSES | | |
| Calcite | 60.05 | none |
| Dolomite | 4.26 | 22.28 |
| Opal | 10.57 | 11.59 |
| Zeolites | 25.12 | 66.13 |
| Total | 100.00 | 100.00 |

*Table from Merritt and Ham, 1941, p. 294.

I. 15 feet above base, section 6, T. 4 N., R. 18 W.

II. 20 feet above base, section 6, T. 4 N., R. 18 W.

TABLE 10

CHEMICAL ANALYSIS OF OPAL FROM TEPEE CREEK SEDIMENTS*

| | | | |
|---|---|---|---|
| $SiO_2$ | 79.07 | $K_2O$ | tr. |
| $Al_2O_3$ | 4.74 | $Na_2O$ | tr. |
| $Fe_2O_3$ | 1.18 | $H_2O$ | 10.38 |
| CaO | 2.22 | Total | 100.07 |
| MgO | 2.48 | | |

*Table from Merritt and Ham, 1941, p. 293.

Analysis of opal (HCl insoluble fraction) of sample approximately 20 feet above base, sec. 6, T. 4 N., R. 18 W.

The opal is partly an aggregate of minute particles with a dull luster and partly a clear glassy variety. The indices of refraction range from 1.43 to 1.45, indicating a variation in the water content. Some of the opal occurs as veinlets traversing the rock and some as replacements of natrolite. The opal may have developed by acidic ground waters reacting with the zeolites to form gelatinous silica, although in part it may be contemporaneous with the zeolites.

Natrolite is the chief zeolite, commonly in felted needles and fibers scattered throughout the rock and as veinlets replacing anorthosite pebbles. Analcime is minor, occurring in cavities as minute, well developed trapezohedrons, which are colorless and glassy.

Calcite occurs as irregular grains scattered throughout the rock and as rhombohedral crystals in cavities. Stringers of carbonate cut the rock and the mineral appears to be an alteration product of the plagioclase.

Merritt and Ham (1941) considered the Tepee Creek to be Precambrian in age as they found a granite aplite dike a few inches wide cutting a mass of zeolites. This occurrence is in a prospector's inclined tunnel in the SW¼ sec. 6, T. 4 N., R. 18 W. and is only a few feet from a bed of Tepee Creek rock. The zeolite mass cut by the dike was considered to be part of these sediments. In a latter study Mayes (1947) interpreted the zeolite around the dike as altered "in situ" anorthosite and not a part of the Tepee Creek. He concluded that the sediments were not Precambrian, but rather Permian in age. Zeolite rocks are rare and it would be a remarkable coincidence to have two outcrops of these rocks, a few feet apart, one of which is Precambrian and the other Permian.

Chase (1954, p. 2,033) has stated that the Tepee Creek conglomerates with anorthosite pebbles grade in the eastern part of the Raggedy Mountains into a zeolite-opal rock with pebbles of granite. Farther eastward there are exposures of Post Oak granite conglomerate. Chase considers the Tepee Creek to be special lithofacies of the Post Oak conglomerate formed in the Permian sea near a gabbro-anorthosite shore. The Post Oak is a member of the Wichita formation. The writer found granite pebbles in a Tepee Creek outcrop in the NE¼ SE¼ SE¼ sec. 32, T. 5 N., R. 18 W. and this indicates that there was a granite older than the sediments. There is no proof that this granite is the same age as the granite aplite dike, which is surrounded by zeolite masses. In the Lake Altus area pebble xenoliths of granite conglomerate in the Lugert granite indicates that a pre-conglomerate granite was once exposed in the region.

The age of the Tepee Creek is not established and further investigation is needed.

## Wave-Cut Grooves and Platforms

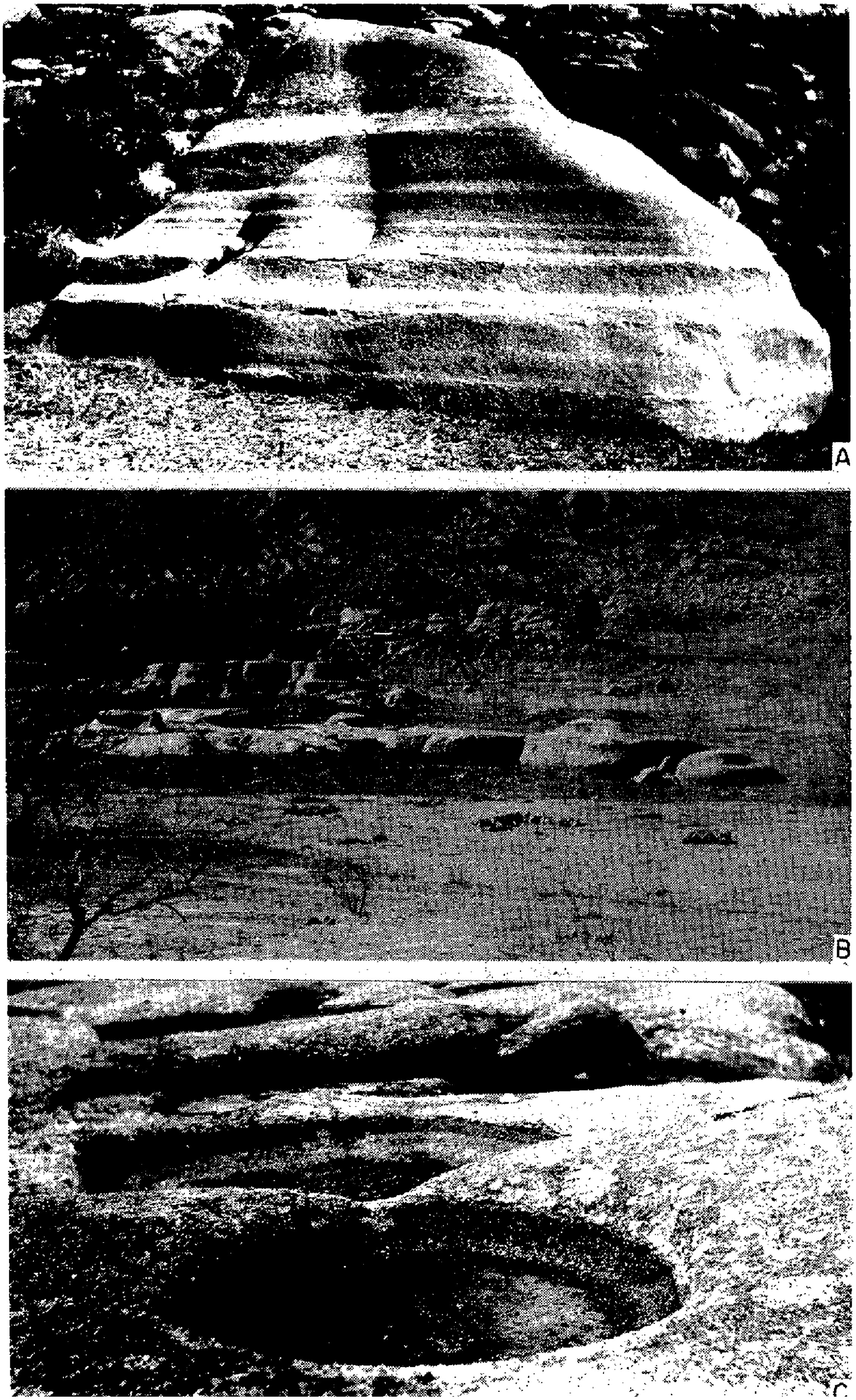
An interesting feature of the western Wichitas is the exceptionally well developed grooves in granite (Plate VI, A), which have been found in several places from Headquarters Mountain to the hills of the Cooperton area. These were described first by Taylor (1915, p. 60) who called them "ancient beach marks"; Weidman (1923) interpreted them as the

### PLATE VI

*A.* Lugert granite showing parallel wave-cut grooves, east side of North Fork of Red River, NW¼ SW¼ sec. 34, T. 5 N., R. 20 W. The flutings encircle the rock (10 feet long) and may be traced back into the joints. The rock was a small granite island on the sides of which the grooves were cut by wave action of the Hennessey (Permian) sea. Oklahoma Geological Survey photo.

*B.* Beach grooves cut on Lugert granite, NE¼ NW¼ sec. 7, T. 5 N., R. 18 W. Granite in foreground has just been exhumed by erosion of shales of Wichita formation, which at this locality contain no conglomerate. Similar markings are visible at base of hill in background but have been destroyed by weathering at higher elevations on the hill. Photo by W. E. Ham.

*C.* Potholes in Lugert granite in one of the small outcrops shown in the foreground of figure *B*. The depressions, three feet in diameter, were formed by eddying stones in the Wichita sea abrading the underlying granite floor. Oklahoma Geological Survey photo.


A
B
C

work of glacial ice. The most comprehensive study was made by Evans (1929, p. 80) who concluded that the flutings were formed by wave cutting. With respect to their age he writes, "The grooves were formed before the present red beds were laid down, because they are now being uncovered by erosion. They could not have been formed very long before deposition of the red beds, else the markings would have been weathered out before being covered, as they are now being weathered rapidly away after being uncovered. It, therefore, seems probable that if they were formed at the edge of a lake, or sea, it was the same body of water in which the red beds were deposited."

The origin of these grooves by wave cutting in the Permian sea is generally accepted.

The notches range from an inch to 5 feet in width, and their depth is one-fifth to one-half their width. In places a series of parallel grooves is present. A good exposure is on King Mountain, south of State Highway 44, in the NW¼ sec. 34, T. 5 N., R. 20 W., where many parallel grooves are exposed through a vertical distance of 90 feet on the side of the hill. Probably higher notches were present originally and have been removed by erosion.

The flutings in the granite range in elevation from approximately 1,575 to 1,650 feet above sea level in the hills of the Devil's Canyon group. The grooves in Headquarters Mountain just north of the town of Granite have an elevation of approximately 1,650 feet. On the small hills east of Lake Altus and in the northeast part of the map area they range from 1,500 to 1,600 feet above sea level. On several of the hills, grooves extend back into joints of the rock and commonly are present on more than one side of the outcrop. These features show that the outcrops once were islands in the Permian sea.

Other erosional features also are noticeable in this area. Evans (1929, p. 79) has described a sea cave on the south side of King Mountain which is 30 feet deep and 6 feet wide with horizontal groovings continuing around the inside of the cave. In the NE¼ sec. 7, T. 5 N., R. 18 W., several pot holes a few feet in diameter are present (Plate VI, B, C.).

On several of the hills of the Devil's Canyon group there is a flat surface some 450 feet above the "red beds" plain, which, when viewed from a distance of a few miles, appears level. On most of the hills it is 50 to 300 feet wide. It generally is present on one side of the hill only, but in some instances it occurs on all sides, as for example on Dome Mountain (see frontispiece). Taylor (1915, p. 59) considered this surface a remnant of a post-Permian peneplain. Tanner (1954) interpreted it as a wave-cut platform and named it the Lake Altus surface. He states that it stands typically 2,200 to 2,250 feet above sea level and that it was formed in Middle Permian times. He also believes there is a second possible erosion surface between 2,400 and 2,500 feet above sea level. Polk (1948, p. 10) noted that the ridges of Quartz Mountain and the other mountains to the east have a uniform elevation of about 1,900 feet.

From a study of electric logs and driller's logs of wells in Ts. 5-7 N., Rs. 18-21W., Tanner (1954, p. 6) concluded that there also are buried erosional surfaces at 500 and 900 feet above sea level.

The proximity of the wave-cut grooves, sea caves, and pot holes to some of these platforms, especially the Lake Altus surface, supports Tanner's interpretation that they are wave-cut platforms. In the eastern part of the Wichita Mountains there are several large flat areas which are not associated with these wave erosion features and it has been suggested these flats are remnants of an old peneplain. If this is correct it is possible that there is an old peneplain surface in the Lake Altus area as well as wave-cut platforms.

### PLEISTOCENE AND RECENT

Adjacent to several of the hills of the area are large deposits of granite "wash" which extend a mile or more from the hills and at places have a thickness of over 20 feet. These are well developed west and south of Headquarters Mountain and considerable gravel has been obtained from this locality. A good example is in NE¼ sec. 34, T. 6 N., R. 21 W. where arkose lenses cover 160 acres and have a thickness of 15 feet and a soil overburden of two feet.

The gravel is composed of angular fragments of granite ranging from ⅛ to ¾ inches in diameter. It has been considered Pleistocene in age (Evans, 1928, p. 8).

Sediments of Recent age are found in the present day stream beds and in the adjacent banks. This material, which is arkose with some sand, becomes somewhat coarser and more angular towards the heads of the streams and locally grades into unconsolidated granite conglomerate.

## Summary of Historical Geology

### PRECAMBRIAN

The oldest rocks found in the Lake Altus area are clastic sediments; these now are represented by xenolith pebbles of granite conglomerate in the granite outcrops. The pebbles were derived by erosion from an older igneous complex which has been removed by weathering. In the eastern part of the Wichita Mountains the oldest rock is Meers quartzite, which occurs as inclusions in gabbro. Small amounts of sillimanite and spinel found in some of the gabbro outcrops in the Roosevelt area may have been formed by basic magmas assimilating argillaceous material. The Meers quartzite, the sillimanite and spinel occurrences, and the xenoliths of granite conglomerate show that Precambrian sediments were widespread in the Wichita area.

The oldest igneous exposures in the Wichita Mountains (excluding xenolith pebbles of granite conglomerate) belong to the gabbro-anorthosite family. Although the form of the basic intrusion is not established, it is known to be large and perhaps is a lopolith. Differentiation produced olivine gabbro, troctolite, diallage gabbro, and anorthosite as well as later sills and dikes of andesite. The basic rocks are older than the granites of the Wichitas, perhaps much older, as pebble xenoliths of gabbro and andesite are incorporated in Lugert granite. If these inclusions are the same age as the gabbro outcrops of the Wichita Mountains, an erosional unconformity must have separated the gabbro from the later Lugert granite.

The granitic magmas in the Lake Altus area appears to have been intruded as batholiths with associated dikes and sills. The various granites resemble one another in their major, minor, and accessory minerals and are considered to be differentiation products of one original magma. Biotite from Lugert granite in a roadcut 1 mile south of Quartz Mountain Lodge gave a potassium-argon age of 480 million years and a rubidium-strontium age of 500 million years (Tilton and others, 1957, p. 364). The close agreement of these two values gives confidence in their accuracy. As the average age is 490 million years, it is not known whether this value will eventually be assigned to Proterozoic or Cambrian.

## Paleozoic

In the eastern part of the Wichita Mountains (east of Cache and in the Limestone Hills), Reagan sandstone rests unconformably upon Carlton rhyolite. In the outcrops of the Wichita area, rhyolite is the only type of igneous rock in contact with the Reagan. Whether the other types of igneous rocks were exposed at the surface by Reagan time is unknown.

Beds from Reagan to Viola (Ordovician) in age rest upon one another with apparent conformity and indicate continued sedimentation during these parts of the Cambrian and Ordovician periods.

The lower Paleozoic sediments are exposed along the southeast margin and northeast flank of the Wichita Mountains and extend as far westward as Rainy Mountain Mission. No outcrops occur in the Lake Altus area, but Ordovician beds have been encountered in wells drilled in southwest Greer county.

No Pennsylvanian rocks occur in the Lake Altus area but wells in southwestern Greer county show that Pennsylvanian sediments lie unconformably below Permian rocks. The latter overlap the eroded and tilted Pennsylvanian beds in the area affected by the Wichita uplift.

The only Paleozoic sediments exposed in the map area are Permian in age. These "Red Beds" belong to the Wichita and Hennessey formations and mainly are flat-lying shales. They form the plains around the Precambrian hills and knobs.

The uplift of the Wichita Mountain area began not later than early Pennsylvanian. In Permian time the exposed pre-Cambrian igneous rocks furnished large volumes of arkosic sediments, which mainly were deposited in the Anadarko and Red River basins. These basins are separated by a high Precambrian mass and were formed during the Wichita uplift. The Anadarko Basin, which is a few miles north of the map area, is a foreland basin with the sedimentary beds dipping steeply into the syncline. The sediments dip more gently into the Red River basin south of the area.

The age of the Wichita Mountain uplift is described by Chase, Frederickson, and Ham (1956, p. 37), as follows:

> *"Orogeny producing the Wichita Mountains evidently began no later than early Pennsylvanian time, because in wells south of the mountains beds of Strawn age (upper part of upper Dornick Hills-lower Des Moines) rest unconformably on Reagan sandstone of Upper Cambrian age. Numerous pulses of uplift and differential folding doubtless affected the Wichita Mountains throughout middle and upper Pennsylvanian time, and continued into Permian time. The last strong pulse is recorded in outcropping rocks in the form of thick conglomerates, made up of granite and lime-*

*stone boulders, that crop out on the margins of the present mountains and grade outward into shales of the Wichita formation. According to Chase these conglomerates are equivalent in age to the upper part of the Pontotoc group, the Wellington formation, and possibly the lower part of the Garber sandstone, all of lower Permian age."*

### Post Paleozoic

The Wichita Mountains may have been affected by earth movements since Permian time but these probably were minor. Weathering and erosion have been the dominant geologic processes since the deposition of the "Red Beds". Wave-cut grooves occur on the granite hills of the Lake Altus area and these show that the present igneous outcrops closely resemble in shape and size the granitic islands in the Permian sea. Erosion, however, has lowered the peaks somewhat.

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