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PLUTONIC IGNEOUS GEOLOGY OF THE WICHITA MAGMATIC PROVINCE, OKLAHOMA

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PREFACE

A few introductory remarks, we feel, are in order as a preface to this guidebook. In fields of endeavor wherein new data are collected, new information obtained, and, as a consequence, new thinking develops into new ideas, it is all too easy for the pioneering efforts of earlier workers to become forgotten or at best to be relegated to a bibliography. All too often one tends to forget, or fails to realize in the first place, in the effort of developing new points of view or attempting to interpret new results, that by and large the project would never have gotten started but for the groundwork and frame of reference provided by earlier investigations. As relative newcomers in the Wichitas, we feel deeply indebted to individuals such as Joseph A. Taff, C. H. Taylor, Jack L. Walper, Walter T. Huang, Warren B. Hamilton, Gerald W. Chase, William E. Ham, Rodger E. Denison, Clifford A. Merritt, and Hugh E. Hunter and his students, who collectively have made it possible for us to define specific problems and recognize (hopefully) rational methods of solution.

Responsibility for mistakes and (or) errors of interpretation that may be present in this work rests, of course, with the authors. Responsibility for certain sections has been individually assumed, while other sections have been prepared jointly by B. N. Powell and J. F. Fischer as indicated: Introduction and Geologic Overview (B.N.P.), Geophysical Interpretations (contribution by M. A. Pruatt), Paleomagnetic Studies (J.F.F.), Wichita Granite Group (B.N.P. and J.F.F.), Raggedy Mountain Gabbro Group (B.N.P., with a section on Layered Series by Powell and D. W. Phelps), Discussion (B.N.P. and J.F.F.), Detailed Stop Descriptions (J.F.F. and B.N.P.), Road Log (arithmetic and text by J.F.F., driving by B.N.P.).

Acknowledgments

We have expressed thanks above to some of those earlier workers who have brought knowledge of the Wichita Province to its present state. Here we wish to acknowledge the specific assistance, equally valuable, of those who have enabled us to pursue these efforts. We are especially indebted to Roger D. Johnson and the staff of the Wichita Mountains Wildlife Refuge, U.S. Department of the Interior, for their friendly cooperation and permission to work on refuge property. We are equally indebted to several local landowners in the area who have been uniformly friendly and cooperative in permitting us access to their property. B.N.P. and D. W. Phelps are grateful to J. Elbert King of the Ardmore Sample Cut Library for the loan of well samples. Finally, we wish to extend our great thanks to the staff of the Oklahoma Geological Survey, without whose help in editing, printing, and general preparation this guidebook would never have seen the light of day. Any mistakes, however, are our own.

B.N.P.
J.F.F.

PLUTONIC IGNEOUS GEOLOGY OF THE WICHITA MAGMATIC PROVINCE, OKLAHOMA

INTRODUCTION

In the past 15 years several guidebooks for field trips in the Wichita Mountains have been prepared, including one by Walter T. Huang in 1962 (sponsored by Texas Christian University and the Baylor Geological Society), one edited by George T. Stone in 1967 (sponsored by The Geological Society of America, South-Central Section), and one by Kenneth S. Johnson and Rodger E. Denison in 1973 (sponsored by The Geological Society of America and the Oklahoma Geological Survey). A fourth guidebook in so short a time may seem to the casual observer redundant. We respectfully disagree for several reasons.

As a result of pioneering work by those mentioned in the Preface and others, a number of problems have come into focus within the past three years while others perhaps have only recently been identified. Some of these we will mention here.

One ongoing problem concerns the specific relationships of the recognized rock types and bodies to one another in a petrogenetic sense. A past tendency, owing no doubt to a relative scarcity of information, to lump the basic rocks of the Raggedy Mountain Gabbro Group together and assume a certain consanguinity is most probably erroneous. The detailed mutual relationships as well as relations in space, time, and petrogenesis of these rocks to the Wichita granites must be clarified in order to develop an understanding of the magmatic and tectonic history of the southern Midcontinent. The recognition of the Southern Oklahoma geosyncline as an aulacogen structure (a type specimen, no less) provides an important new framework for petrologic investigations. The geochronologic story of the magmatic rocks remains incomplete, as the most volumetrically significant member of the plutonic assemblage, the layered series, remains largely undated. The possibility that this body is indeed Precambrian, as originally thought, is real and, if true, highly significant to the tectonic evolution of the region.

This guidebook emphasizes the presentation of new information: new data, new interpretations, and new ideas relative to previous publications. Many old ideas remain unchallenged and necessarily are presented also. New analytical data include electron-microprobe analyses and paleomagnetic results. Some newly *printed* field observations are included (we hesitate to say these observations were never *made* before). The paleomagnetic data and geophysical interpretations are also new and provide some valuable new insights.

Most of the trip stops, although probably familiar to those who have done extensive work in the area, are nonetheless here included for the first time in an official guidebook. Our Stops 2, 4, 5, 8, and 9, specifically, were *not* listed in the guidebooks mentioned above, and only Stops 1 and 6 *were* listed in the two Geological Society of America sponsored trips. Consequently we are confident this trip will be somewhat novel and hopefully informative to a majority of those attending.

The apparent overemphasis of basic rocks relative to granites results from the fact that most new information we have to present is derived from investigations of members of the Raggedy Mountain Gabbro Group. Inasmuch as our description of the Wichita Granite Group represents basically a summary of previously published accounts, we have kept this section brief and refer the reader to the literature. We do not mean to imply that the granites are unimportant.

Finally, we would like to emphasize that ideas put forth in the Discussion section and elsewhere represent the current state of our thinking and are therefore somewhat tentative. We hope our enthusiasm will not be mistaken for dogma.

GEOLOGIC OVERVIEW

Wichita Magmatic Province

The Wichita Magmatic Province of southwestern Oklahoma extends west-northwest approximately from the Wichita Mountains in the vicinity of Lawton, Oklahoma, into the panhandle of Texas (fig. 1). Igneous rocks that characterize the province include anorthositic, gabbroic, and granitic plutonic rocks of Early Cambrian and possibly Precambrian age (see below) and associated volcanic rocks including basalts, spilites, andesites, and rhyolites. Small intrusive bodies of microdiorite, tonalite, granodiorite, and various other types of intermediate rock also are present, although in minor abundance and sporadic areal distribution.

Collectively the plutonic rocks make up the Wichita Complex, which consists of a core of basic rocks intruded and capped by sills and irregular bodies of granite. The basic rocks have been collectively named the Raggedy Mountain Gabbro Group, and the granites, the Wichita Granite Group (Ham and others, 1964). Stratigraphically above the Wichita granites is a series of rhyolitic flows and pyroclastics called the Carlton Rhyolite Group. Rocks of these three groups can be seen in outcrop and have an extensive known distribution in the subsurface. A fourth group, known only in the subsurface, comprises the extrusive and tuffaceous basaltic, spilitic, and andesitic rocks of the Navajoe Mountain Basalt-Spilite Group.

The Carlton Rhyolite Group is considered to be the volcanic equivalent of the Wichita Granite Group. The two groups are essentially isochemical. Ham and others (1964) have proposed that the Navajoe Mountain Group may be effusive equivalents of the Raggedy Mountain Gabbro Group. However, the evidence in support of this contention is sketchy at present.

The Wichita Granite Group has a known subsurface distribution (from numerous oil- and gas-exploration drilling throughout the region) of at least 65 km by 250 km, with an average estimated thickness of 300-500 m. The basic rocks have subsurface dimensions of at least 40 km by 175 km, while one well revealed a minimum thickness of 2,400 m (Ham and others, 1964). The distribution of the

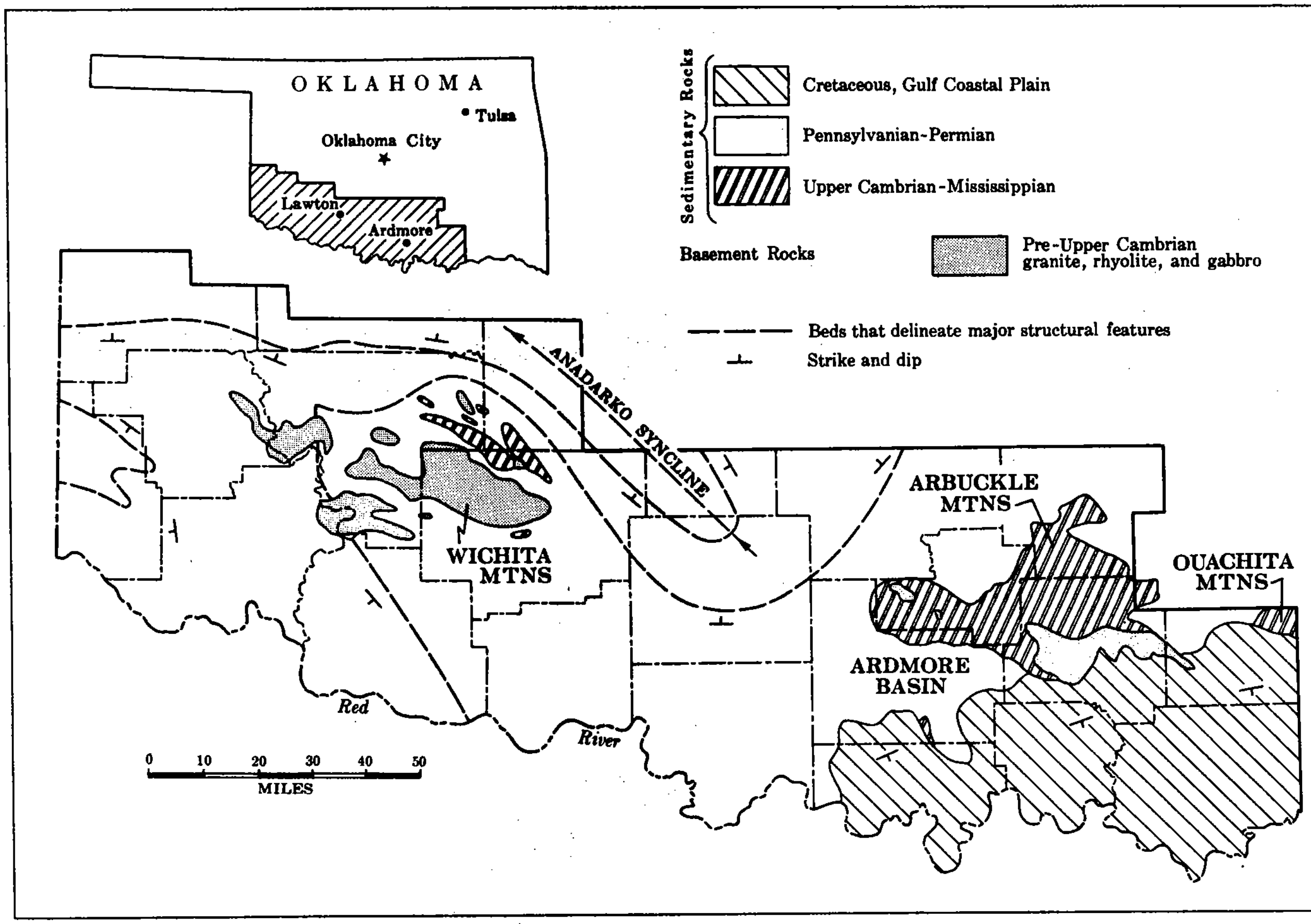

Figure 1. Index map of southern Oklahoma, showing principal outcrop areas. (Fig. 1 of Ham and others, 1964.)

Navajoe Mountain Group is restricted to discontinuous belts along the southern and northern flanks of the Wichita Mountains. The maximum drilled thickness is 320 m (Ham and others, 1964, p. 80). Distribution of Carlton rhyolite in the subsurface is much larger than that of the plutonic rocks, extending more than 160 km farther east, beyond Ardmore, Oklahoma. Thicknesses of the rhyolitic rocks exceed 1 km. Thus the Wichita Province itself can be considered to range from (but not include) the Arbuckle Mountains into the Texas Panhandle.

The Wichita Complex is exposed over approximately 1,000 km^2, chiefly in Kiowa and Comanche Counties, Oklahoma (fig. 2). The attitude of the complex is close to horizontal, and maximum vertical exposures range only from about 230 m (basic rocks) to 300 m (granites). Although the maximum relief in the Wichita Mountains is only on the order of 320 m, the effect is striking because of the tremendous expanse of relatively flat topography surrounding the mountains.

Paleozoic Sedimentary Rocks

The country rocks into which the intrusive rocks of the Wichita Province appear to have been emplaced, in part at least, include the Tillman Metasedimentary Group of Precambrian or Early Cambrian age. This group is dominated by graywacke with lesser amounts of shale, siltstone, sandstone, arkose, and bedded chert (Ham and others, 1964, p. 105). The rocks are known only in the subsurface, with one possible exception, and occur over approximately 3,500 km^2. The outcropping exception is the Meers Quartzite, which is known exclusively as large inclusions in the Mount Sheridan Gabbro of the Raggedy Mountain Group and in Wichita granite. Rocks of the Tillman Group have been converted regionally into biotite-bearing metasediments, schists, and hornfelses as a result of thermal effects accompanying widespread intrusion of granitic rocks of the Wichita Complex.

Surrounding the outcroppings of igneous rocks of the Wichita Province and stratigraphically overlying them is a thick sequence of Late Cambrian to Mississippian sedimentary rocks, largely shallow-water carbonates (summarized in fig. 3). Late Paleozoic uplift of the Wichita block and erosion of the igneous rocks during the Early Permian (Wolfcampian) gave rise to clastic sediments during this time. Subsequently the entire area, probably including the highest peaks of the Wichita Mountains, was covered by Late Permian sediments (Johnson and Denison, 1973). Conceivably the Wichita Mountain topography at the present time is not too dissimilar to that of the earliest

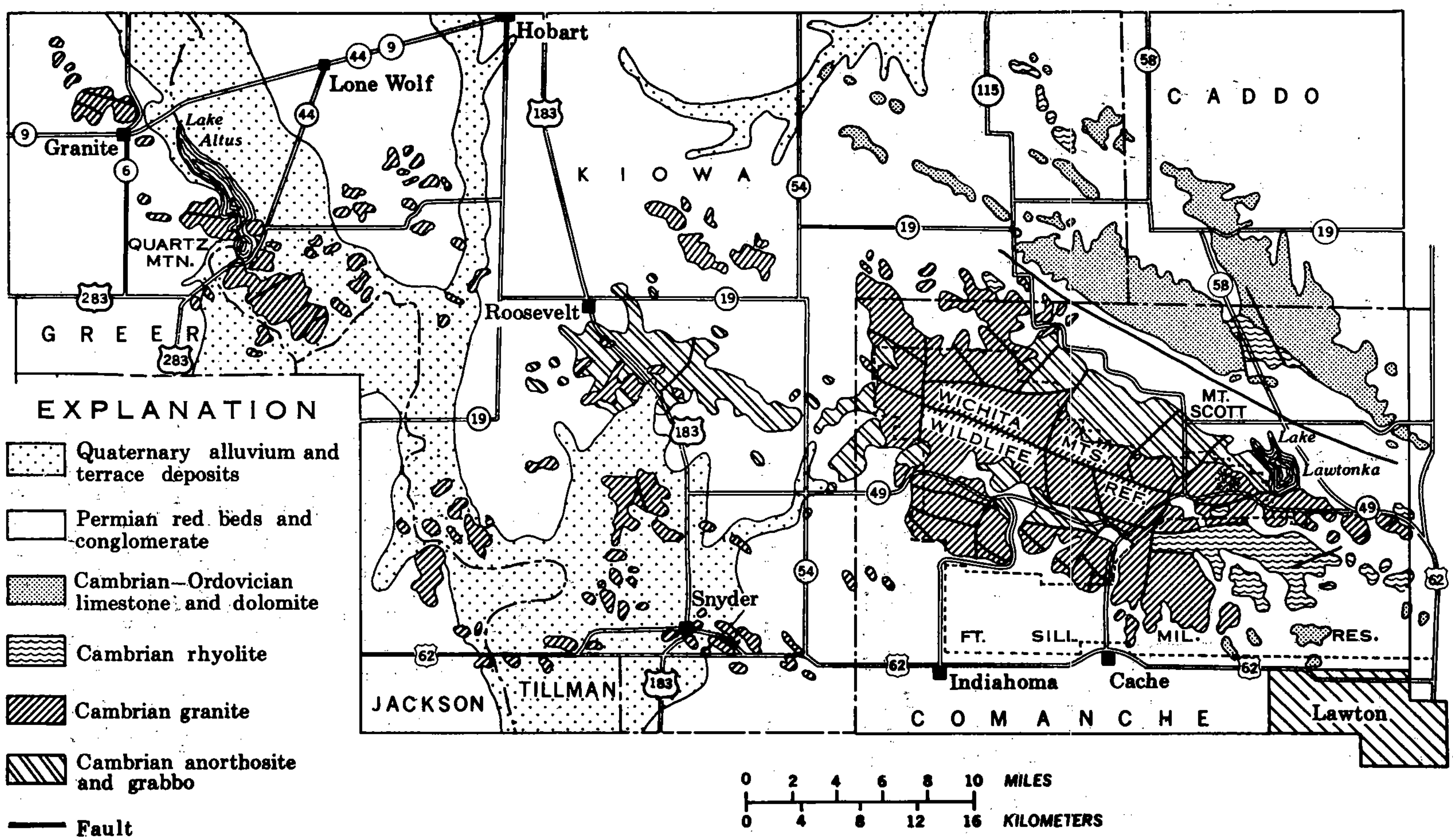

Figure 2. Areal geologic map of Wichita Mountain area, Oklahoma. (Fig. 2 of Johnson, 1974; modified from Chase and others, 1956, fig. 1.)

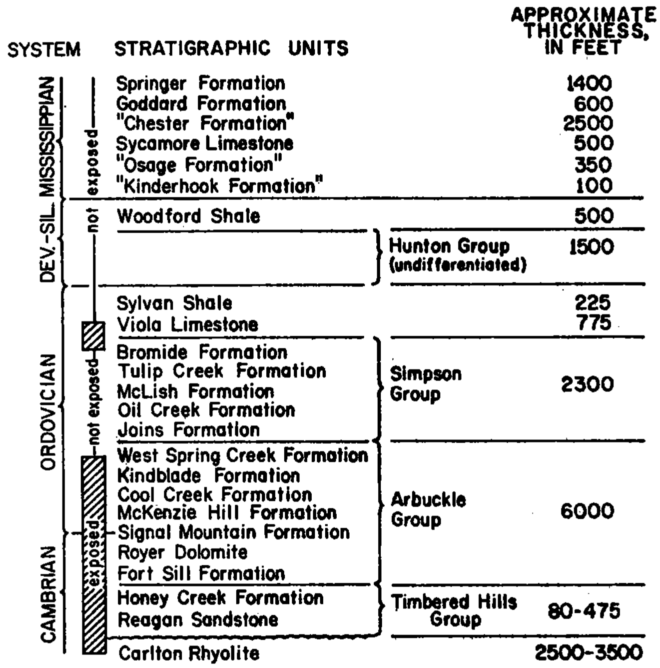

Figure 3. Generalized pre-Pennsylvanian stratigraphic sequence in Wichita Mountain area. Informal names for Mississippian subsurface units are in quotations. (Fig. 3 of Johnson and Denison, 1973.)

Permian. A much more detailed treatment of the Paleozoic sedimentary history of the area is presented by Johnson and Denison (1973).

Geochronology

Various isotopic age determinations on igneous rocks of the Wichita Province have been made and have been summarized by Ham and others (1964). Ages for the Wichita Granite and Carlton Rhyolite Groups range approximately from 500 to 525±25 m.y. Methods used include U^{238}/Pb^{206}, U^{235}/Pb^{207}, Pb^{207}/Pb^{206}, Th^{232}/Pb^{208}, Rb^{87}/Sr^{87}, and K^{40}/Ar^{40}, all of which are in fairly close agreement, thereby lending considerable confidence to the age assignments. Only a few rocks from the Raggedy Mountain Gabbro Group have been dated, mostly those of the intrusive group, including biotite-gabbro and diorite. These rocks give ages in the range 500-535 m.y. and were all dated by K/Ar methods save for one Rb/Sr determination on biotite. Only two rocks from the layered series have been dated, both by K/Ar. A troctolite gave 700-750 m.y., and a diallage gabbro, 500 m.y., the former being considered to possess excess Ar (Burke and others, 1969). For reasons developed elsewhere in this guidebook, including the Discussion section, we seriously question the Cambrian age assignment for the basic rocks of the Wichita Complex, particularly the predominantly undated layered anorthositic rocks for which there is increasingly strong evidence for a Precambrian age.

The cratonic basement rocks surrounding the Wichita Province, as represented in the Eastern Arbuckle Province, indicate two episodes of granitic intrusion at 1,100 m.y. and 1,350 m.y. and a dioritic episode of about 1,200 m.y. (Ham and others, 1964). Subsurface basement rocks from the Texas Craton and Panhandle Volcanic Terrane, largely granitic and rhyolitic rocks, range approximately from 1,000 m.y. to 1,400 m.y. (Wasserburg and others, 1962, and Muehlberger and others, 1966). Diabase from the Swisher Gabbroic Terrane of the southern Texas Panhandle has been dated at 1,200 m.y. by K/Ar on pyroxene (Muehlberger and others, 1966).

Regional Tectonic Setting

A wide Paleozoic trough, faulted and mildly folded during the late Paleozoic into a system of fault basins and uplifts, extends along a west-northwest trend from the Ouachita geosyncline in southeastern Oklahoma and northern Texas across the foreland platform of southern Oklahoma into the panhandle of Texas. The principal structural divisions include the Amarillo-Wichita uplift and Anadarko and Hollis basins to the west and the Arbuckle uplift, Criner arch, and Ardmore and Marietta basins to the east (fig. 4).

The Wichita uplift, as it is known in Oklahoma, is a faulted horst structure bordered on the south by the shallow (*ca.* 3 km) Hollis basin. The uplift is bounded on the north by a 10-20-km-wide zone of high-angle reverse and thrust faults known as the Wichita front, which separates the uplift from the Anadarko basin, the deepest (>9 km) Paleozoic basin on the North American platform.

These basins and uplifts were formed primarily during late Paleozoic deformation and developed along the same lines of weakness as those of a late Proterozoic-Cambrian rift system, the origin and subsequent Paleozoic evolution of which have been described as those of a typical aulacogen (Shatski, 1946; Hoffman and others, 1974). Hoffman and others (1974) refer to this "most obvious North American example" as the Southern Oklahoma aulacogen, a term we retain. Burke and Dewey (1973) described the Anadarko basin as the failed rift arm of the Dallas triple junction formed at the margin of the opening "Proto-Atlantic" in the early Paleozoic. It may well develop that the Wichita uplift, structurally elevated in the late Paleozoic, may actually have been the structurally deepest portion of the rift system during the early stages of evolution of the aulacogen. This is at variance with the inference of Ham and others (1964) that the Wichita block was stabilized early, shifting the depocenter northward into the Anadarko basin.

It is clear that the igneous rocks of the Wichita Province represent magmatic activity associated with the early evolutionary stages of the Southern Oklahoma aulacogen. Collectively these rocks represent the most significant exposure of crystalline basement rocks in the Midcontinent south of Minnesota.

GEOPHYSICAL INTERPRETATIONS

The Wichita Mountains exhibit gravity and magnetic anomalies that are second only in magnitude in the continental United States to the Midcontinent gravity high. The anomalies are part of a larger positive trend (fig. 5) associated with the Paleozoic Southern Oklahoma aulacogen. The anomalies follow the aulacogen from its junction with the Ouachita foldbelt in northeast Texas

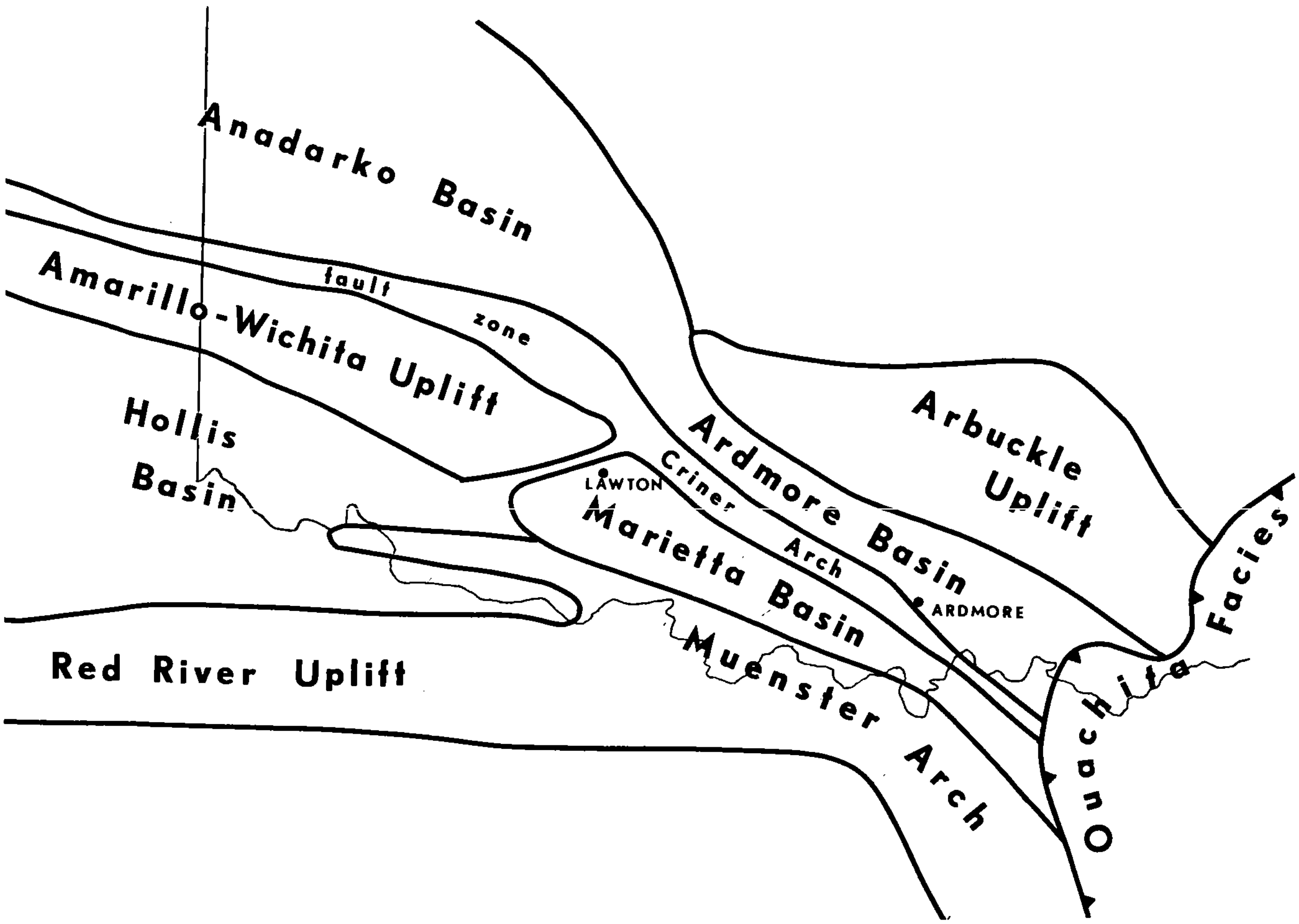

Figure 4. Index map showing major structural divisions in area of Southern Oklahoma aulacogen. (After Pruatt, 1975, fig. 1.)

across southwest Oklahoma and into the Texas Panhandle. In particular, the axis of the positive gravity and magnetic anomalies follows the Wichita Mountains westward into Texas, where they form the buried Amarillo uplift. Southeast of the mountains the trend follows the Marietta basin and its extension into Texas, the Sherman basin.

To interpret the nature of the bodies causing the belt of positive anomalies, four crustal cross sections were constructed from gravity and magnetic data, constrained by other available geological and geophysical data, as part of a study in preparation of the Southern Oklahoma aulacogen. Sections A-A′ and B-B′ are shown in this paper. Data are from the Bouguer gravity-anomaly and vertical-intensity magnetic maps of Oklahoma (Lyons, 1964; Jones and Lyons, 1964). A modified version of the two-dimensional method of Talwani and others (1959) was computerized and used for the model construction. Crustal structure outside the aulacogen was adopted, with modifications, from the seismic interpretation of Mitchell and Landisman (1970).

Gravity modeling requires that some assumptions be made as to the densities of the various rock types. Because of the variability in composition of the igneous rocks exposed in the Wichita uplift, average major rock-type densities from Clark (1966) and Chase and others (1956) were felt to be adequate. Densities were normalized by contrasting them to an average upper-crustal density of 2.67 g/cm^3. Since the stratigraphic column of each basin is well known from well penetration, the density of the major lithologic sequences could be established so that the gravity effect of the sediments is accurately modeled.

Section A-A′ (fig. 6) crosses a large gravity and magnetic anomaly in west Oklahoma where the crystalline basement is buried about 200 m. Figure 6 shows the vertical-magnetic and Bouguer gravity anomalies together with a crustal model which will duplicate the observed gravity data. Depth to basement is taken from Ham and others' (1964) basement map. Stippling represents sedimentary rocks whose densities are not shown in detail.

The main cause of the anomalies is modeled as a body with an average density of 0.46 g/cm^3 (3.19 g/cm^3) greater than the surrounding rocks. The body was modeled in detail as shown in figure 7, as a layered feature that increased in density downward from 2.90 to 3.24 g/cm^3. Petrologically this corresponds to a layered mafic body with a gabbroic composition at the top, grading down to a pyroxenite or peridotite at the base. The gabbroic composition at the top is verified by drilling (Ham and others,

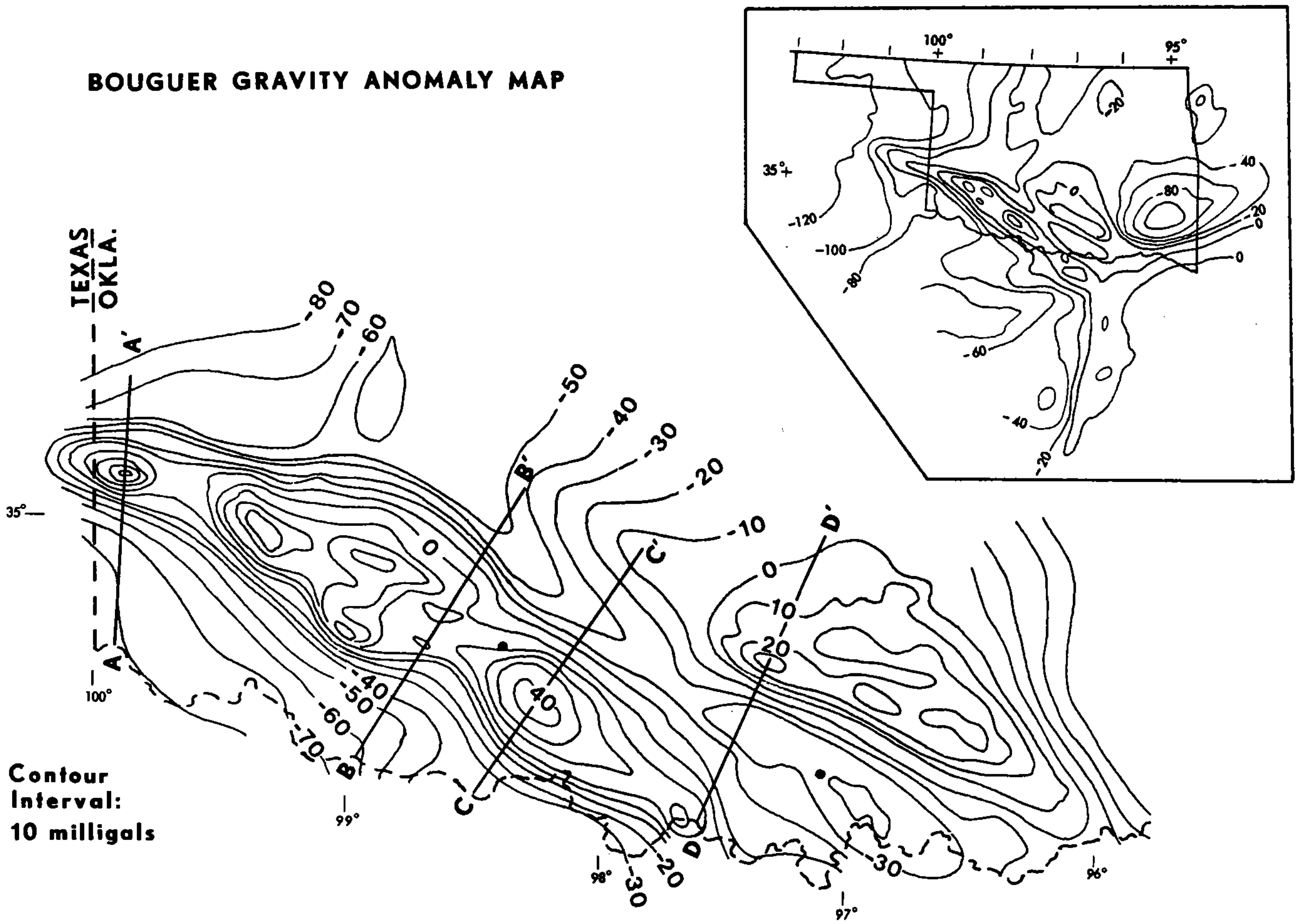

Figure 5. Bouguer gravity-anomaly map of Southern Oklahoma aulacogen, modified after Lyons (1964). (Fig. 3 of Pruatt, 1975.)

1964), but the density must increase with depth in order to produce the observed anomaly and still be a reasonable model.

In trying to model the magnetic anomaly, a magnetization vector of 7° N. inclination and 295° declination was found to produce positive residual vertical magnetic anomalies similar to those observed over the Wichitas. The body shape that duplicates the magnetic anomaly in section A-A' is much narrower than that found by gravity, indicating that the magnetically susceptible minerals are concentrated in areas of the plutonic rocks rather than diffused throughout.

The body in the Anadarko basin with a contrast of 0.25 g/cm^3 (2.95 g/cm^3) corresponds to basalt. Basalts of the Navajoe Mountain Basalt-Spilite Group are known to be present in the subsurface on the northern border of the Wichita uplift (Ham and others, 1964). The 0.24 g/cm^3 (2.94 g/cm^3) and the 0.3 g/cm^3 (3.33 g/cm^3) represent perturbations in the lower crust and upper mantle from an ideal "layer-cake" earth. The crustal thinning and basalts account for the lack of negative gravity anomaly over the Anadarko basin.

Section B-B' (fig. 8) crosses the eastern Wichita uplift in the vicinity of Mount Scott. The gravity anomalies are much broader, even over outcropping mafic rocks, indicating that no narrow, high-density root zones are present in this area. The mafic body in this case is modeled as a south-dipping layered body with an average density contrast of 0.42 g/cm^3 (3.05 g/cm^3). The density varies from 2.90 g/cm^3 (diorite) at the top to 3.20 g/cm^3 (pyroxenite?) at the base. Basalt encountered in wells is modeled at 0.25 g/cm^3 contrast (2.95 g/cm^3). The thickness of basalt in the fault is interpreted from seismic data (Widess and Taylor, 1959). The center peak in the magnetic anomalies corresponds to a zone in the plutonic body with a high degree of magnetization. The other two anomalies are caused by occurrences of basalt. Ferromagnetic minerals appear to be diffuse throughout the basalt, whereas they are concentrated in local areas of the plutonic body.

The gravity and magnetic models provide some idea as to the nature of the igneous core and crust below the Wichita uplift. The main anomalies are due to a layered igneous body or bodies which continue eastward in the subsurface from the Amarillo-Wichita uplift. In the Wichita Mountains, Cambrian rhyolites and basalts surround a plutonic core of mafic and granitic rocks. The rocks were originally emplaced, at least in part, during the Cambrian in a northwest-southeast-trending continental rift valley, marking the first stage of the evolution of the Southern Oklahoma aulacogen. Magmatic activity at this time

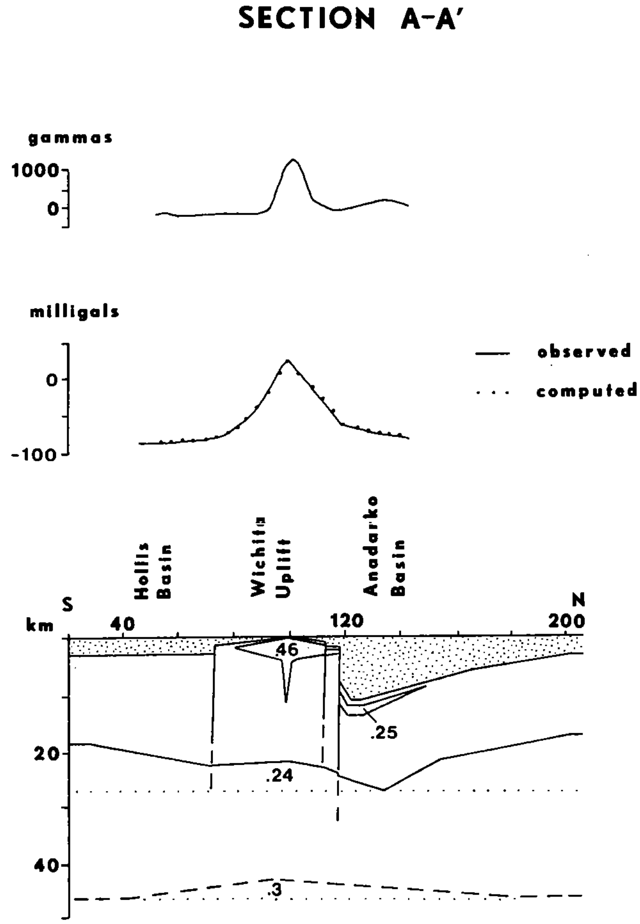

Figure 6. Cross section A-A' of figure 5, showing observed vertical-magnetic and Bouguer gravity anomalies in relation to inferred crustal model. The 0.46 g/cm^3 body is an average density contrast that was modeled as a layered body increasing in density with depth. (Fig. 4 of Pruatt, 1975.)

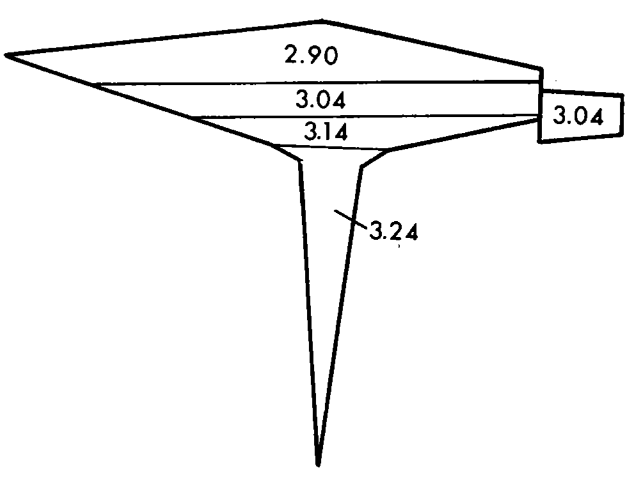

Figure 7. Detail of layered body in cross section A-A', shown in figure 6. Densities are in g/cm^3.

included extrusion of the Navajoe Mountain basalts and the overlying Carlton rhyolite, with emplacement of granite sills below the rhyolite. Ham and others (1964) showed that the rhyolite covered most of the aulacogen area but is confined on the north by the Arbuckle uplift and on the south by the Hollis basin and the Muenster arch. The basalts can be located with the gravity and magnetic data, and are also confined to the ancient rift valley. The basalts thin over the Criner arch and the frontal Wichita fault zone, indicating that these features were probably elevated in Cambrian time.

The rift valley then subsided and was buried under 4 to 6 km of Paleozoic sediments. Pennsylvanian orogeny uplifted the western half of the rift as the Wichita Mountains and reconstructed the eastern half so that the major structural features are in their original topographic positions. The original rift-valley suite, with volcanic rocks covering an igneous core, may be preserved in the Marietta basin, whereas erosion has removed much of the Cambrian volcanic cover in the Wichita Mountains.

Crustal thinning, as modeled in the sections, may account for seismic anomalies observed along the aulacogen. High velocities and early seismic-arrival times are observed from this area (Hales and Herrin, 1972) and may be due to crust and upper-mantle changes that took place along the rift zone in Cambrian or earlier times. The presence of an anomalous crust is observed in other aulacogens (Hoffman and others, 1974).

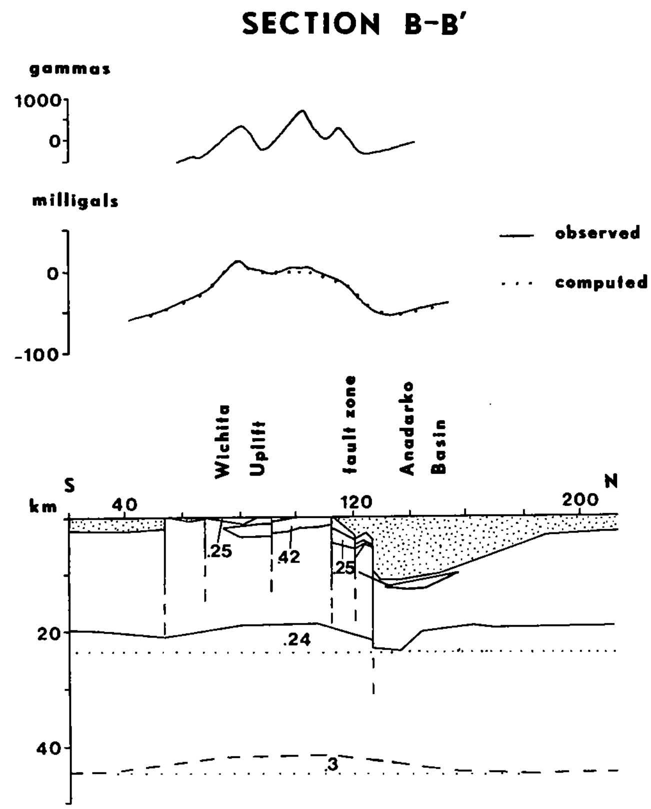

Figure 8. Cross section B-B' of figure 5, across Mount Scott, showing broader gravity anomaly and absence of narrow, high-density root zone. Mafic body is here modeled as south-dipping layered body (average density contrast 0.42 g/cm^3) increasing in density with depth (see text). (Fig. 6 of Pruatt, 1975.)

PALEOMAGNETIC STUDIES

Several investigators have performed paleomagnetic studies on the rocks from the Wichita Mountains (Ku and others, 1967; Spall, 1970; Vincenz and others, 1975). These investigators have concentrated on the granitic rocks and have consistently found relatively unstable remanent magnetization there. The basic rocks have been examined in far less detail.

Roggenthen and others (in press) sampled the layered anorthosites and the Mount Sheridan Gabbro. Samples were collected from six sites: near Meers, at Panther Creek (Burford Lake), the eastern end of the Raggedy Mountains, near Roosevelt, and two localities in the western part of the Raggedy Mountains. The distance between the most widely separated outcrops is 38.6 km. The anorthosites and gabbros sampled all show stable remanent magnetization after AF demagnetization. A diabase dike near Roosevelt is quite unstable magnetically. Five of the sites, with the exception of the Panther Creek locality, have consistent paleopole positions. The position falls near "hairpin 30" on the polar-wandering curve of Irving and Park (1972). The points correspond to polar positions 1,300 to 1,500 million years old. Panther Creek rocks are surrounded by granite at the present time, and may have been strongly affected by the Cambrian intrusions; the pole position is about halfway between the other rocks and the plotted Cambrian pole on the same polar-wandering curves.

Roggenthen and others (in press) propose that the disparity between radiometric dates and the paleomagnetic determinations is due to thermal overprinting at the time of the granitic intrusive activity.

WICHITA GRANITE GROUP

There is little new information to add to knowledge of the Wichita Granite Group from earlier recent published accounts such as those of Ham and others (1964), Merritt (1965, 1967a, 1967b), and Johnson and Denison (1973). We give here only a brief summary and refer to the literature for details.

The Wichita Granite Group comprises several separately named granite bodies, including the Reformatory, Headquarters, Quanah, and Cold Springs, as mapped by Taylor (1915). On Taylor's map the Lugert Granite is distinctly predominant over the others and is shown as abundant in the western and eastern Wichitas. Merritt (1965) distinguished separately and described the Mount Scott Granite (originally the Lugert of Taylor), named for its occurrence at Mount Scott. Johnson and Denison (1973) described two granites cutting the Reformatory Granite in Quartz Mountain State Park, Greer County, Oklahoma, one of which is the Lugert and the other the probable equivalent of the Mount Scott Granite. How the Mount Scott Granite was correlated with one of those at Quartz Mountain is unclear, but in any case there is evidence that the Lugert Granite of Taylor may in fact comprise several bodies.

The Quanah Granite is a relatively localized body in and west of Quanah Mountain in the eastern sector.

The Cold Springs "granite" we have grouped with the intrusive group of the Raggedy Mountain Gabbro Group because of its hybrid origin and intermediate character. There is little doubt, however, that its specific origin is closely related to the magmatism responsible for the Wichita Granite Group.

The Mount Scott Granite is typical of several of the group in its sill- or sheet-like form. According to Merritt (1967b), its thickness is probably on the order of 150 m, and outcrops are found over an area of at least 2,300 km^2. The sill-like shape of the intrusion is most evident on Mount Sheridan. The Reformatory Granite to the west, by contrast, is not in the form of a sill but is evidently an irregular pluton (Johnson and Denison, 1973). The Mount Scott Granite is considered to have been emplaced at relatively shallow levels (epizone) and intrudes the base of the Carlton Rhyolite Group. Xenoliths of Carlton rhyolite occur in Mount Scott granite, which in turn is cut by rhyolite dikes (Merritt, 1967b). In short, the two are broadly contemporaneous. Xenoliths of gabbro and anorthosite as well as some of the Meers Quartzite are present within the Mount Scott Granite.

The granites generally intrude at the unconformity between rhyolite and the underlying basement. The rhyolites belong to the Carlton Rhyolite Group in the Wichitas and have similar petrography and stratigraphic position to the Colbert porphyry in the Arbuckle Mountains, 100 km to the east. The felsic rocks show similar relationships over an area of at least 18,000 km^2, from south-central Oklahoma into the Texas Panhandle. The igneous activity apparently represents an early stage of extensive rhyolitic outpourings, primarily pyroclastic, with late-stage activity having become dominantly intrusive rather than extrusive. The granites that have been drilled show chilled upper and lower margins, and we can walk the upper and lower contacts of parts of the Mount Scott Granite. It seems fairly clear that the granites and rhyolites are a part of the same igneous episode. Chemical compositions and isotopic ages bear this out (Ham and others, 1964).

The Wichita granites are typically reddish pink in color with a low proportion of mafic minerals. Textures range from hypautomorphic-granular to porphyritic, and grain sizes, from phaneritic to aphanitic. Fine-grained groundmasses are often granophyric in texture. The Mount Scott Granite, as described by Merritt, is medium grained, slightly porphyritic, with a granophyric groundmass, the latter texture being more abundant near intrusive contacts. An average mode reported by Merritt (1967b) shows: micropegmatite, 59.4 percent; microperthite and orthoclase, 27.0 percent; quartz, 9.2 percent; hornblende, 2.4 percent; titaniferous magnetite, 1.6 percent; sphene, 0.4 percent; and trace amounts of apatite, biotite, garnet, allanite, chlorite, and augite. The latter mineral was a relict phase from a partially assimilated gabbroic xenolith.

Most of the granitic bodies contain neither alkali pyroxene nor amphibole except for some 2.5 percent of riebeckite in the Quanah Granite and a riebeckite-bearing pegmatite south of State Route 49 just west of the boundary of the Wichita Mountains Wildlife Refuge. Other occurrences of accessory alkali ferromagnesians have been reported, but the principal mafic phase of the group is common hornblende.

RAGGEDY MOUNTAIN GABBRO GROUP

The name Raggedy Mountain Gabbro Group as introduced by Ham and others (1964) was originally applied "to all gabbros and allied rocks of the Wichita Province" (p. 91). We retain for the purpose of discussion the term as originally defined to comprise all of the mafic igneous rocks of the province, other than the extrusive basic and intermediate flow rocks of the Navajoe Mountain Group, despite increasing evidence, discussed below, that the rocks so encompassed may not be strictly cogenetic nor necessarily of comparable age.

A more useful classification of these mafic rocks was developed for field-mapping purposes by Gilbert (1960) and Spencer (1961) and was summarized by Hunter (1967, 1970). Rock units mapped by these workers in the Raggedy Mountains east and south of Roosevelt, Kiowa County, Oklahoma, were divided into two groups, the layered series and the so-called intrusive group. This classification and its subdivisions have proved a useful framework for description of the rocks and for discussion of general genetic relationships.

Layered Series

Field Occurrence

The layered series comprises a sequence of feldspathic cumulate rocks characterized by a commonly pronounced igneous lamination (fig. 9) and a variably developed rhythmic layering manifested in vertically repeated gradational variations in the modal proportions of plagioclase, olivine, and pyroxene (figs. 10 and 11). Regionally the igneous layering dips gently to the north some 5-15°. Four mappable stratigraphic units of the exposed layered series were recognized by Gilbert (1960) and subsequently were designated the K, L, M, and G zones by Spencer (1961) and Hunter (1967, 1970). The M zone conformably overlies the L zone, which in turn conformably overlies the K zone, contacts being gradational between zones. The stratigraphic relationship of the G zone to the other zones remains unclear. Gross characteristics of the four zones are summarized in table 1.

Figure 9. Pronounced igneous lamination in plagioclase-olivine adcumulate (troctolitic anorthosite) of layered series of Raggedy Mountain Gabbro Group. Olivine is most visible on light-gray, weathered surface, and plagioclase cleavage reflections on darker, fresh surface. Penny for scale.

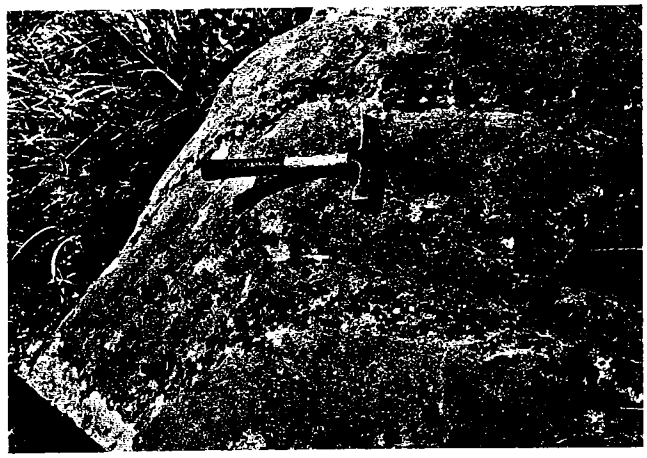

Figure 10. Crudely developed rhythmic layering in M zone of layered series of Raggedy Mountain Gabbro Group southeast of Roosevelt, Oklahoma. Dark, rounded grains of fine ophitic augite are concentrated in bands broadly parallel to lamination and stand out in relief. Small dark pits are weathered-out olivines. (After Phelps, 1975, fig. 4a.)

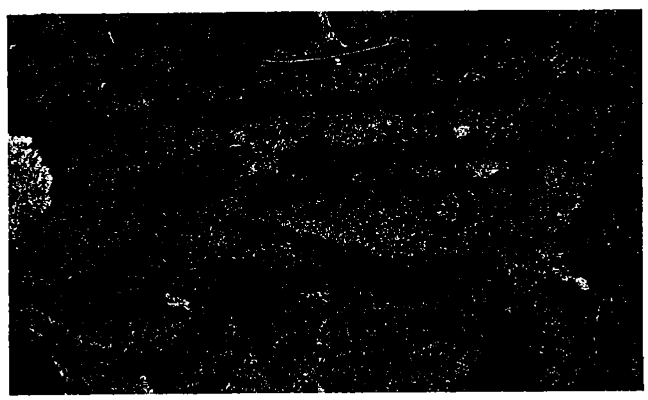

Figure 11. Rhythmic layering in M zone of the layered series of Raggedy Mountain Gabbro Group southeast of Roosevelt, Oklahoma, characterized by alternating layers of gabbroic anorthosite (light) and pyroxene gabbro (dark). (After Phelps, 1975, fig. 4b.)

Approximately 20 m above the base of the L zone is a 5-m zone of anomalous rock relative to the rest of the L zone. This material, called L-a zone by Phelps (1975), is texturally similar to the "fine-ophitic" M zone with the addition of olivine oikocrysts. (See table 1.)

Rocks of the G zone are somewhat finer grained than other units of the layered series. Furthermore, they lack igneous laminations, rhythmic layering, and ophitic intergrowths, all of which are more or less characteristic of the other zones. There is the possibility that the G zone is actually intrusive into the layered series rather than conformable with it. Alternatively the G zone may reflect local perturbations of the cumulus mechanisms and crystallization sequence of the sort more clearly discernible in the Skaergaard or Bushveld intrusion. At present, field relationships of the G zone to the rest of the layered series are insufficiently known to clarify the picture. Broadly similar mineralogy and phase chemistry (Hunter, 1970) do suggest a close genetic relationship of the G zone to the remainder of the layered series.

TABLE 1. PRINCIPAL LITHOLOGIC CHARACTERISTICS OF MAPPED ZONES OF THE LAYERED SERIES (Modified from Hunter, 1970, with additions.)

M zone: *(>60m)**	Largely anorthosite with local concentrations of pyroxene and/or olivine producing lenses and layers of anorthositic-gabbro and -troctolite. "Fine ophitic" augite oikocrysts with randomly oriented plagioclase chadacrysts of smaller size than laminated external plagioclase. Plagioclase, olivine <u>and</u> augite are cumulus. (See text.) Rythmic layering and lamination modest.
L zone: *(40m)*	Largely anorthosite with irregular masses of pyroxene gabbro and rare troctolite. "Coarse ophitic" augite oikocrysts with plagioclase chadacrysts of size and preferred orientation comparable to external plagioclase. Plagioclase and olivine are cumulus, augite intercumulus. (See text.) Rythmic layering poorly developed or lacking; igneous lamination pronounced.
L-a zone: *(5m)*	Narrow zone of gabbroic anorthosite 20m above the base of the L zone and characterized by "fine ophitic" texture similar to that of the M zone, with addition of olivine oikocrysts. Plagioclase, augite and olivine are cumulus.
K zone *(>40m)**	Alternating anorthosite and troctolite with notable rythmic layering. Olivine in small individual grains and as larger poikilitic grains analogous to "fine ophitic" augite. Orthopyroxene-magnetite symplectic coronas around olivine common. Plagioclase and olivine cumulus. Augite intercumulus. Igneous lamination notable.
G zone:	Anorthositic-gabbro and -troctolite with abundant magnetite (5-15%) and an absence of igneous lamination and ophitic textures.

*Minimum thicknesses as upper (M) or lower (K) boundaries not observed.

TABLE 2. CUMULATE ROCK TERMINOLOGY (After Wager and Brown, 1967.)

Adcumulus growth: overgrowth on cumulus (or intercumulus) phases, after accumulation, of material of the same composition, presumably by diffusional exchange between crystal and magma overlying the crystal pile. Trapped liquid tends to be eliminated during the process.

Adcumulate: rock in which adcumulus growth on cumulus crystals has been sufficiently extensive that only small amounts of trapped pore liquid remained to crystallize in situ.

Orthocumulate: rock with minor adcumulus growth and an abundance of trapped liquid (crystallized) including zoned (lower temperatures) overgrowths on cumulus phases.

Mesocumulate: rock intermediate in character to adcumulate and orthocumulate.

Heteradcumulate: rock in which adcumulus growth has enlarged both cumulus phases *and* intercumulus crystals nucleated in interstices between cumulus crystals. Commonly gives rise to poikilitic textures wherein chadacrysts are cumulus and oikocrysts are intercumulus.

In the eastern sector of the exposed Wichita Complex, in the Wichita Mountains Wildlife Refuge and in the Meers vicinity, layered rocks similar to those of the Raggedy Mountains also occur. Detailed field work remains necessary to establish whether or not the same stratigraphic zones and relationships are present. Tentatively such relationships would seem likely. At least, rocks can be seen in the outcrop that display similar lithologic features to the described L and M zones.

Petrography

Several petrographic descriptions of rocks of the layered series have been published (e.g., Huang and Merritt, 1954; Ham and others, 1964; Hunter, 1970; Scofield, 1975). Our description is based largely on the detailed treatment by Phelps (1975) and the summary by Powell and Phelps (in preparation).

The rocks of the layered series are characteristically highly feldspathic, varying locally from troctolitic and gabbroic anorthosite to nearly pure anorthosite. True gabbros and troctolites (plagioclase <65 percent) are rare. All of the rocks are igneous cumulates. Calcic labradorite or bytownite is the dominant cumulus phase, occupying 60-99 percent of the mode. Olivine and (or) augite may be cumulus or intercumulus and vary from 0 to 25 percent and 0 to 40 percent, respectively. Minor amounts of post-cumulus orthopyroxene and accessory magnetite and ilmenite are generally present. Accessory apatite and quartz are observed but are rare. A variety of accessory minerals, all in trace amounts, was reported by Huang and Merritt (1954).

Deuteric-alteration products include bowlingite, hornblende, and biotite after olivine, the latter two also after pyroxene. Serpentine and chlorite replacement of olivine and pyroxene appears to be the product of later, post-magmatic(?) alteration; where present it is commonly abundant and is accompanied by uralitic amphibole alteration of pyroxene. Epidote and (or) prehnite commonly occurs in these altered rocks as well, typically with small amounts of pyrite. The localization of such relatively intense alteration (e.g., near Meers) suggests a latter hydrothermal process (rather than late-magmatic), perhaps associated with younger igneous (granitic?) activity. By and large, the rocks of the layered series are remarkably fresh and show little alteration save for some incipient deuteric effects, as mentioned.

The familiar rock names anorthosite, gabbro, and troctolite are inadequate, in our opinion, to accurately characterize these cumulate rocks, in which the modal proportions and modes of occurrence of the principal minerals are so variable over a vertical scale of centimeters or a meter or so. We much prefer the cumulate terminology defined by Wager (1963) and Wager and Brown (1967) for similar reasons, as it has been found favorable for the Skaergaard and Bushveld intrusions. For those unfamiliar with this terminology, a summary is given in table 2. Adcumulus growth has variably affected plagioclase, augite, orthopyroxene, and olivine, giving rise locally to several varieties of adcumulates and heteradcumulates (figs. 12 and 13). Mesocumulates are rare, and orthocumulates are lacking.

Certain distinctive textural relationships are worthy of some detailed attention. Textural differences between "fine-ophitic" and "coarse-ophitic" augite are given in table 1. Karns (1961) and Phelps (1975) have interpreted these differences in terms of genetic distinctions, with which we concur. The smaller grain size and random orientation of plagioclase chadacrysts in "fine-ophitic" textures (fig. 14), together with wrapping of oriented external cumulus plagioclase around the augite oikocrysts, strongly indicate that the augite and included plagioclase settled as bimineralic clots and thus are both strictly cumulus. Analogous textures involving olivine oikocrysts are present locally in the L-a zone (table 1). In contrast, the "coarse-ophitic" augites are clearly intercumulus, and the rocks in which they occur are plagioclase-heteradcumulates.

Orthopyroxene occurs in several textural relationships. Common in samples from the Glen Mountains are sym-

Figure 12. Photomicrograph of extreme plagioclase adcumulate from L zone of layered series of Raggedy Mountain Gabbro Group. Sample WM-40 from "amphitheater," western Glen Mountains (Stop 8), is from nearby pure anorthosite layer (> 99-percent plagioclase). Adcumulus growth has added to original dimensions of cumulus plagioclase crystals, effectively eliminating all trapped liquid in process. (Cross-polarized light.)

Figure 13. Photomicrograph of plagioclase-olivine heteradcumulate (WM-18) from K zone of layered series of Raggedy Mountain Gabbro Group 4.8 km southeast of Roosevelt, Oklahoma. Plagioclase (white) and olivine (with curved cracks) are cumulus phases. Augite (darkened with opaque exsolution blebs) and magnetite (discrete opaque grains) are intercumulus. All three silicate phases have undergone adcumulus growth, although augite nucleated within trapped liquid. (Plane light.)

TABLE 3. COMPOSITIONAL RANGES OF CUMULUS PHASES AND INTERCUMULUS ORTHOPYROXENE FROM THE LAYERED SERIES, RAGGEDY MOUNTAIN GABBRO GROUP, WICHITA PROVINCE, OKLAHOMA *

Mineral	Composition Range*
Plagioclase	An_{77} to An_{66}
Augite	$Wo_{44}En_{45}Fs_{11}$ to $Wo_{47}En_{38}Fs_{15}$
Olivine	Fo_{75} to Fo_{66}
Orthopyroxene symplectic	$Wo_{1.4}En_{76.2}Fs_{22.4}$ to $Wo_{1.2}En_{71.6}Fs_{27.2}$
intercumulus	$Wo_{1.6}En_{70.1}Fs_{28.3}$ to $Wo_{3.4}En_{60.2}Fs_{36.4}$

*Ranges based on microprobe analyses of grain cores, exclusive of zoned grain rims (which would extend the ranges appreciably).

plectic intergrowths of orthopyroxene and vermicular magnetite in coronas around or completely replacing cumulus olivine (fig. 15). Orthopyroxene also occurs as peritectic reaction rims without magnetite, around cumulus olivine (fig. 16). More commonly in the eastern sector of the complex (Wichita Mountains Wildlife Refuge), orthopyroxene occurs as large ophitic and subophitic intercumulus grains. The symplectic orthopyroxene is more weakly pleochroic and compositionally distinct (see below) than the other types. In the K zone, olivine with both types of reaction corona occurs (fig. 17). In all observed occurrences in the exposed layered series, orthopyroxene is postcumulus. It is the only low-calcium pyroxene present, pigeonite not being observed.

Both augite and intercumulus orthopyroxenes display exsolution of pyroxene phases, low-Ca and high-Ca, respectively. The specific identity of the exsolved phases has not been confirmed by single-crystal X-ray diffraction. However, in light of the coexistence of augite and orthopyroxene host phases it is reasonable that these would also be the exsolved species. Exsolution lamellae are generally very fine, especially within host orthopyroxenes. The latter show exsolution characteristics indicative of a primary condition of the host (not inverted from pigeonite).

Elaborate development of oxide exsolution is typical in host augite, less so of orthopyroxene. Commonly two directions of exsolution are present, one coincident with the low-Ca pyroxene lamellae (fig. 18). The identity of the exsolved phases is not certain but most probably includes ilmenite and (or) titaniferous magnetite. Similar exsolution

Figure 14. Photomicrograph of plagioclase-augite adcumulate (GM-98-R) of M zone of layered series of Raggedy Mountain Gabbro Group from Glen Mountains, showing "fine-ophitic" texture. Note small size and random orientation of plagioclase chadacrysts relative to larger, crudely laminated crystals outside of augite oikocryst. Both plagioclase and augite are cumulus phases. (Cross-polarized light.)

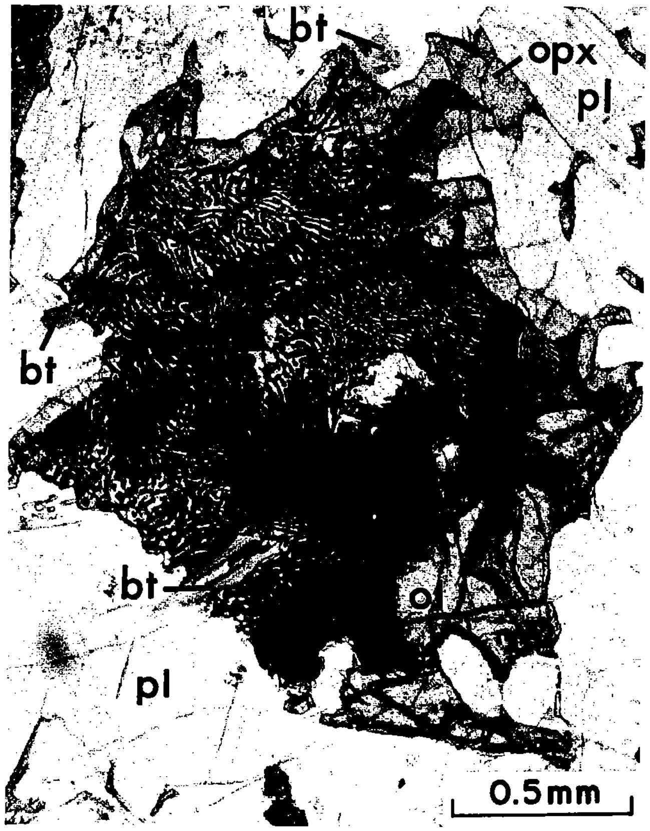

Figure 15. Photomicrograph of plagioclase-olivine adcumulate (WM-11) from layered series of Raggedy Mountain Gabbro Group 2.4 km east of Roosevelt, Oklahoma, showing extensive development of orthopyroxene (opx)-magnetite (black) symplectite at expense of cumulus olivine (ol) grain. Note presence of pale biotite (bt), suggestive of P_{H_2O} buildup in pore fluid toward end of crystallization; pl is plagioclase. (Plane light.)

has been reported in augites of troctolites from the Duluth Complex (Phinney, 1972) and elsewhere.

Being strictly a cumulus phase, plagioclase tends to be subhedral, the tabular habit invariably modified in detail by adcumulus growth. Among discrete cumulus crystals there is commonly a bimodal size distribution. Rare large grains on the order of 1 cm commonly show well-developed oscillatory zoning. More abundant smaller grains (typically 1-4 mm) are generally unzoned or weakly so. Quartz-plagioclase myrmekitic intergrowths at plagioclase-plagioclase grain boundaries constitute up to 1 percent of some samples from the K zone. Myrmekite is less abundant in the other zones. In the absence of any alkalic feldspar, an origin for the myrmekite similar to that proposed for the Bushveld Intrusion seems probable. Myrmekite typically occurs in calcic rims of reverse or oscillatory zoned grains, as in the Bushveld, and may be attributable to increased local P_{H_2O} with crystallization (Wager and Brown, 1967, p. 386-387).

Plagioclase size and orientation relations in coarse- and fine-ophitic relationships, described above and summarized in table 1, are discussed at length by Karns (1961) and Phelps (1975). Rotan (1960) established that oriented plagioclase, responsible for the pronounced igneous lamination (fig. 19), preferentially lie on (010) faces with no lineation.

Phase Chemistry

Limited mineral-compositional data on rocks from the Wichita Complex have been published by several authors (e.g., Huang and Merritt, 1954; Ham and others, 1964; Hunter, 1970, 1973; Scofield, 1975). All of this information is based on optical determinations or on analyses of mineral separates, and most is very general. We report here new information based on electron-microprobe analyses. These results have been presented in detail by Phelps (1975) and have been summarized by Powell and Phelps (in preparation).

Phase-chemical results here reported are based on samples collected from two traverses up section through previously mapped outcrop areas in the Glen Mountains (fig. 20). Traverse A comprises approximately 70 m of section of the upper K zone, the entire L zone, and the lower M zone; traverse B covers 50 m of the lower M zone. Traverses A and B are essentially identical to the Middle and Upper sections, respectively, of Scofield (1973, 1975). Samples were collected approximately every meter, and microprobe analyses were made on samples from every 8 m of traversed section.

Analyses emphasized cores of cumulus phases to establish cryptic variation, if any. Analyses were also made on intercumulus and symplectic orthopyroxenes, interstitial and symplectic oxide minerals, and intercumulus augites.

Compositional ranges are shown in table 3 and plotted in figures 21 and 22. Plotted points represent averages of several analyses, all on grain cores. In table 4 are listed some representative phase compositions.

The Al_2O_3 and TiO_2 contents of the clinopyroxenes are moderate and comparable to those of the Bushveld, Skaergaard, and Duluth complexes. The Fe/(Fe + Mg) ratios of the ferro-magnesians and the plagioclase compositions are similar to those of the Main Zone A of the Bushveld Intrusion and the Anorthosite Zone of the Stillwater Complex. Intercumulus augites are enriched in iron relative to cumulus augite, as expected from the lower temperature of crystallization of the former according to models of adcumulus growth. Fe/(Fe + Mg) ratios in orthopyroxene peritectic reaction rims are in equilibrium with those of adjacent olivines. However, symplectic orthopyroxene is systematically more magnesian than peritectic and intercumulus orthopyroxene (fig. 22). The low Cr_2O_3 and high MgO contents of symplectic magnetite, compared to other intercumulus magnetite, reflect its origin in part at the expense of the olivine.

Orthopyroxene-magnetite coronas around olivine have been reported from several localities (see, e.g., Kuno, 1950; Muir and Tilley, 1957; Snyder, 1959; Irvine, 1974); a variety of explanations has been offered for their origin. The origin of the symplectites in the layered series is discussed in detail by Phelps (1975). To summarize here, we conclude that the intergrowths formed as a result of post-cumulus reactions between olivine and trapped liquid, brought about by increasing oxygen fugacity. The highly variable development of the symplectites (incipient to complete replacement of olivine) reflects a capricious mechanism, most likely involving a post-cumulus olivine-liquid reaction influenced by local availability of trapped liquid and (or) ease of diffusional communication with a liquid supply. Biggar (1974) has shown that at high-oxygen fugacities magnesian pyroxene and magnetite become stable relative to olivine. We postulate that increased f_{O_2} with crystallization of trapped pore fluid resulted in the formation of orthopyroxene-magnetite symplectites by oxidation of existing cumulus olivines and by additional precipitation from the pore fluid. In order to maintain a mass balance (other than oxygen), the orthopyroxene must be more magnesian than the olivine, as shown by the idealized reaction:

$$3(Mg_{.33}Fe_{.67})_2\,SiO_4 + \tfrac{1}{2}O_2 =$$
$$3(Mg_{.67}Fe_{.33})\,SiO_3 + Fe_3O_4$$

Most likely increased P_{H_2O} in the pore fluid during continued post-cumulus growth caused the increase in f_{O_2}, as attested by small flakes of biotite commonly (but not invariably) in intimate association with symplectites (fig. 15).

The oxide exsolution in augite further suggests post-crystallization (of augite) oxidation.

TABLE 4. REPRESENTATIVE COMPOSITIONS (WT.%) OF PRINCIPAL MINERALS OF THE LAYERED SERIES AS DETERMINED BY MICROPROBE ANALYSIS (D. Phelps, analyst)

Analysis	1	2	3	4	5	6	7	8	9
Zone	M	L	M	M	K	M	L	L	M
Phase	Augite	Augite	Opx	Olivine	Plag.	Plag.	Ilmenite	Magnet.	Magnet.
SiO_2	51.0	52.7	53.1	37.8	50.0	50.4			
Al_2O_3	2.78	1.68	0.87	0.00	32.0	31.7	0.26	1.76	1.49
TiO_2	0.89	0.42	0.29	0.00			49.2	1.47	1.98
Cr_2O_3		0.05					0.13	2.31	0.13
FeO	8.86*	9.31*	19.8*	29.2*			46.3*	32.3**	31.6**
Fe_2O_3								61.1**	64.0**
MnO		0.19					2.34	0.12	0.29
MgO	15.1	13.7	24.0	33.3			0.09	0.00	0.89
CaO	21.6	21.3	0.99	0.03	15.4	15.1			
Na_2O					2.59	2.81			
K_2O					0.09	0.15			
Total	100.23	99.35	99.05	100.33	100.08	100.16	98.32	99.06	100.38

* Total iron determined as FeO.
** Ferric/Ferrous ratio calculated assuming stoichiometric proportions.

1. Cumulus augite (defocused beam).
2. Intercumulus augite.
3. Intercumulus orthopyroxene.
4. Cumulus olivine.

5,6. Large cumulus plagioclase.
7,8. Co-existing intercumulus oxide phases.
9. Vermicular magnetite in opx symplectite.

Figure 16. Photomicrograph of plagioclase-olivine heteradcumulate (WM-11-74, 8) from layered series of Raggedy Mountain Gabbro Group, showing orthopyroxene (opx) peritectic reaction rim around olivine (ol); pl is plagioclase. (Plane light.)

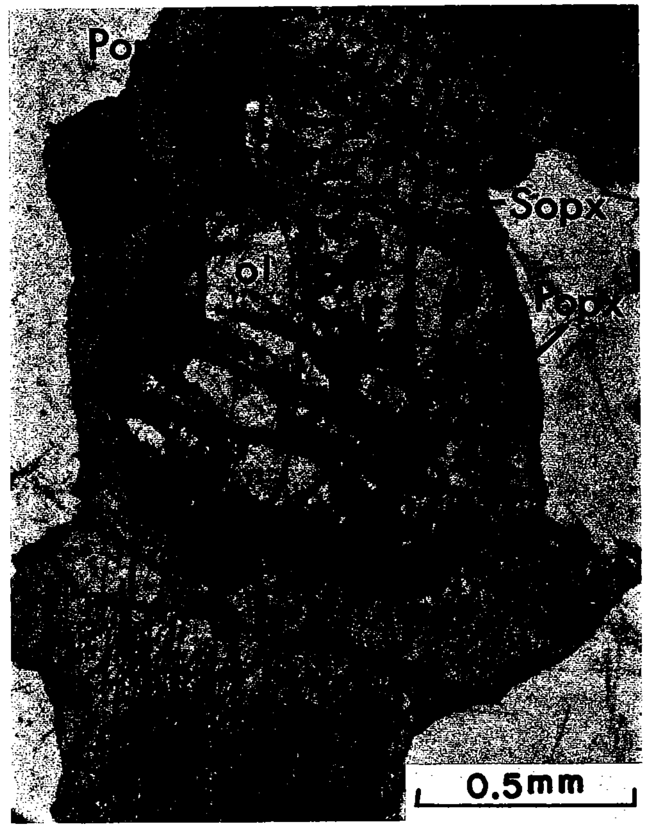

Figure 17. Photomicrograph of plagioclase-olivine heteradcumulate (WM-18) from K zone of layered series of Raggedy Mountain Gabbro Group (see fig. 13), showing both symplectic orthopyroxene (Sopx) and peritectic orthopyroxene (Popx) around olivine (ol). Note ilmenite exsolution (fine-grained opaques) in augite and coarse vermicular symplectic magnetite with orthopyroxene. (Plane light.)

Cryptic Variation

Variations of Fe/(Fe + Mg) ratios in olivine and pyroxenes as a function of relative stratigraphic elevation are shown in figures 21 and 22. Although traverses A and B cannot be accurately correlated, Phelps (1975) has summarized evidence which partially justifies the placement of traverse B stratigraphically above traverse A. Cumulus-olivine compositions display a small but real Fe enrichment, with two local reversals, with increasing stratigraphic height. Both cumulus and intercumulus augite show similar Fe-enrichment trends, with the cumulus more magnesian, as explained above. Symplectic orthopyroxene also shows a real Fe-enrichment trend, reflecting in part its formation at the expense of cumulus olivine. Other intercumulus orthopyroxene appears to display Fe enrichment also, although analyses of this type were done over an insufficient vertical section to characterize this adequately.

Interpretation of plagioclase-compositional variation in terms of cryptic variation is difficult because of complex, variable zoning that characterizes many grains (see Phelps, 1975, for a detailed treatment). Grain cores appear to show a subtle Na enrichment upward in section, but this tends to be obscured by local variation owing to complex crystallization histories. Probe analyses on cuttings from the 3,037-m level of the Champlin Oil 1 Hieber well (2,426 m of penetrated layered-series rocks) fall within the range of compositions from exposed rocks. The possibility of some repeated section because of faulting renders evaluation of stratigraphic depth difficult. However, it is safe to state that no major variation in plagioclase composition occurs over at least some several hundreds of meters of section. This condition is closely analogous to the Stillwater Anorthosite Zone (see Wager and Brown, 1967, fig. 171).

We conclude from these data that the exposed layered series displays *normal cryptic variation* of the general type exemplified by the Bushveld, Skaergaard, and Stillwater complexes. Our analyses reveal no evidence whatsoever of reversed cryptic variation described by Scofield (1973, 1975) from whole-rock major-element analyses.

The interpretation of bulk compositions of cumulate rocks in terms of fractionation trends is fraught with difficulty at the very best because of the interminable influence on such compositions of crystal settling and adcumulus growth. Over the limited exposed vertical section of the layered series, any systematic variation in bulk-rock composition that would result from the small changes in compositions of cumulus phases would surely be overprinted by the local modal variations so characteristic of the rocks, particularly with the very elements most useful to characterize any cryptic variation—Ca, Na, Mg, Fe—being distributed as they are among plagioclase, augite,

Figure 18. Photomicrograph of complex oxide exsolution in augite from L zone of layered series of Raggedy Mountain Gabbro Group, Glen Mountains (GM-60R). (Plane light.)

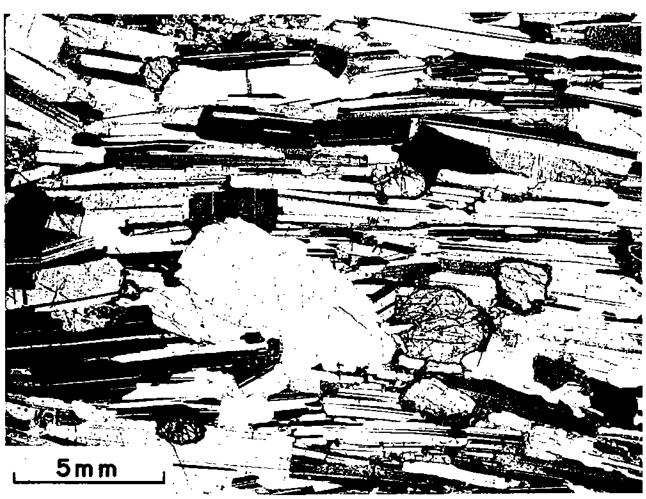

Figure 19. Photomicrograph of plagioclase-olivine heteradcumulate (WM-11-74, 8) from layered series of Raggedy Mountain Gabbro Group near Burford Lake, showing pronounced igneous lamination. Rounded grains with cracks are olivine; remainder visible is plagioclase. (Cross-polarized light.) Same rock in outcrop is shown in figure 9.

olivine, orthopyroxene, magnetite, and ilmenite. We wish to emphasize this point because of the very important implications of the phase chemistry and cryptic variation regarding the nature of the layered body and its level of exposure, as discussed below.

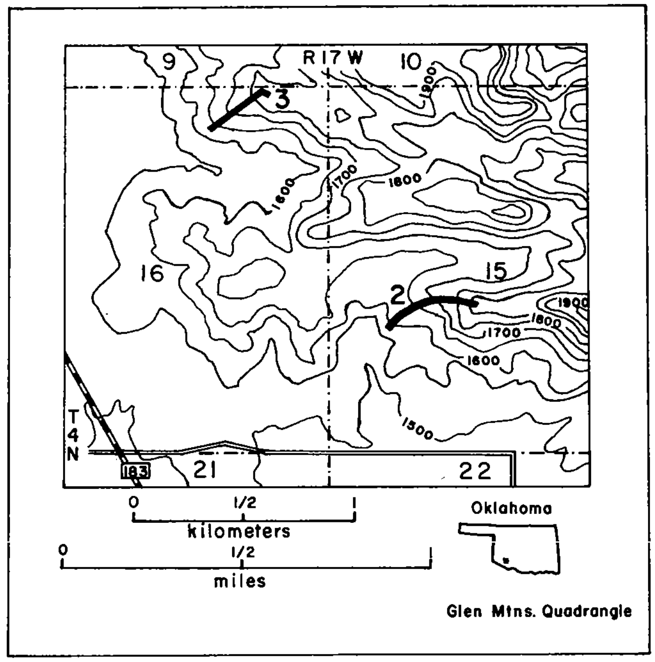

Figure 20. Index map showing location of traverses taken in Glen Mountains for phase-chemical evaluation of cryptic variation in layered series of Raggedy Mountain Gabbro Group. Traverses 2 and 3 are traverses A and B, respectively, referred to in text and in figures 21 and 22. Topography taken from Glen Mountains quadrangle of U.S. Geological Survey 7.5-minute series.

Character of the Layered Body

Even though the fault-bounded character of the Wichita Complex has prevented the availability of chilled marginal rocks that might prove informative with regard to the parental-magma composition of the layered series, nonetheless certain qualitative constraints can be established from mineralogical and phase-chemical data. Several observed petrographic features are characteristic of rocks of tholeiitic affinity: (1) olivine peritectic reaction, (2) two-pyroxene assemblage (Ca-rich and Ca-poor), (3) absence of feldspathoids, (4) presence of accessory interstitial quartz, implying a tendency for ultimate silica enrichment with fractionation. Compositionally the low to moderate contents of TiO_2 and Al_2O_3 in augite are typical of tholeiitic clinopyroxenes. In short, the evidence collectively indicates that the rocks crystallized from a basaltic magma of tholeiitic composition, which, on fractionation, displayed an iron-enrichment trend.

The general phase-chemical, mineralogical, and textural similarities of the layered series to the Main Zone A of the Bushveld Intrusion and to the Anorthosite Zone of the Stillwater Complex have been mentioned. Comparable compositions in the Skaergaard Intrusion, if present, would presumably occur within the upper portion of the Hidden Zone. We see no similarity whatsoever to the Skaergaard Upper Border Group, as implied by Scofield (1975). If the analogies are basically valid, as we believe they are in a general sense, then the exposed level of the layered series represents the approximate midsection of a stratiform body originally much thicker than at present. By analogy, some 3-4 km of cumulates probably exist at depth, becoming

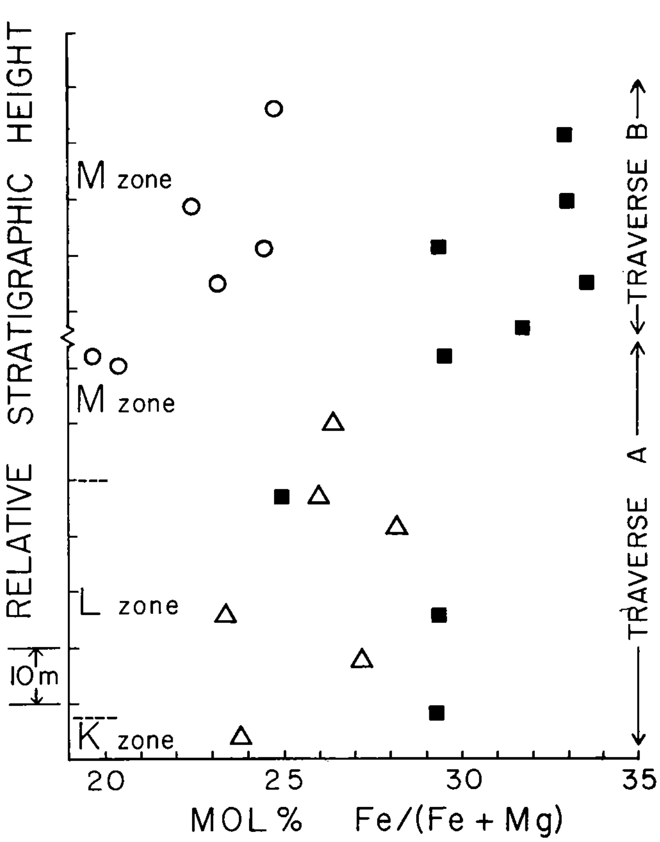

Figure 21. Plot of Fe/(Fe + Mg) in cumulus olivine (solid squares), cumulus fine ophitic augite (open circles), and intercumulus coarse ophitic augite (open triangles) versus stratigraphic height in layered series of Raggedy Mountain Gabbro Group near Roosevelt, Oklahoma. Note separate but similar Fe-enrichment trends for two types of augite.

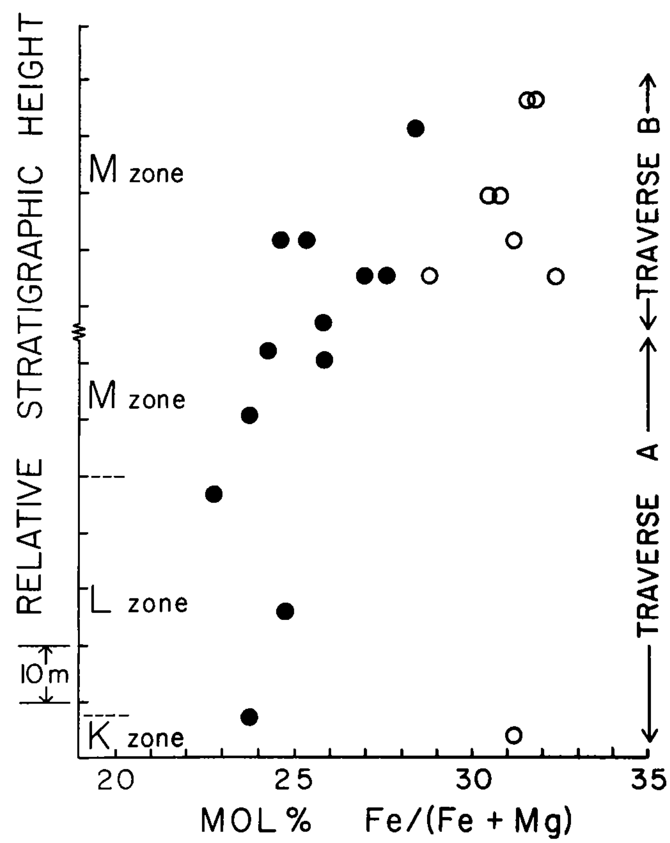

Figure 22. Plot of Fe/(Fe + Mg) in post-cumulus symplectic orthopyroxene (solid circles) and other intercumulus orthopyroxene (open circles) versus stratigraphic height in layered series of Raggedy Mountain Gabbro Group near Roosevelt, Oklahoma.

increasingly mafic downward, and as much as 2-4 km of more highly fractionated cumulates has been removed from higher levels by erosion.

The presence of mafic and (or) ultramafic cumulates at depth is furthermore a constraint that results from petrologic reasoning. Mass-balance considerations—assuming a reasonable parental-magma composition—require a complementary suite of cumulates as broadly mafic as the exposed cumulates are feldspathic. The exposed rocks are much too feldspathic even to approximate a rational magma composition. Geophysical evidence that strongly points to the probable presence of such mafic cumulates at depth is presented elsewhere in this publication. That more fractionated lower-temperature materials must have existed at higher levels is a virtual certainty, considering the extreme adcumulate nature and simple mineralogy of the exposed rocks. That the rocks are gravity-*settled* cumulates (rather than flotational, as proposed by Scofield, 1973, 1975) is clear from the normal cryptic variation and the cumulus fine-ophitic augite-plagioclase clots.

Intrusive Group

The so-called intrusive group of the Raggedy Mountain Gabbro Group comprises several varieties of rock type, including olivine basalt, biotite-olivine gabbro and microgabbro, microdiorite and quartz microdiorite, and fine-grained granite and aplite. Some types compositionally grade into one another, whereas other types are more or less discrete. All or most of the varieties can be seen to intrude rocks of the layered series, and, in fact, this feature may be the *only* sound basis for grouping the rocks together. Granite and aplite intrude not only the layered series (fig. 23) but also other rocks of the intrusive group, particularly microdiorite, giving rise to dikes and sill-like and irregular bodies of mixed rock (figs. 24 and 25). Variable amounts of assimilation between aplite and microdiorite can be seen, and range from negligible effects in sharply contrasted intrusion breccias (figs. 25 and 26) to extensive assimilation resulting in hybridized rock with only relict ghosts of the original invaded mafic microdiorite (fig. 27). Hybrid material of this sort is locally known as Cold Springs granite in the western sector of the Wichita Complex, where it was once quarried near the now-defunct settlement of Cold Springs (about 6.4 km south-southeast of Roosevelt, Oklahoma). A detailed study of assimilation in the Cold Springs area was published by Walper (1951), along with a map showing the distribution of mixed and hybrid rocks.

A group of curious "intermediate" rocks of enigmatic origin occurs sporadically over the area in more or less irregular bodies generally situated between layered-series rocks and the overlying granites of the Wichita Granite Group. Huang (1955) has described these rocks and has given various names, based principally on modal miner-

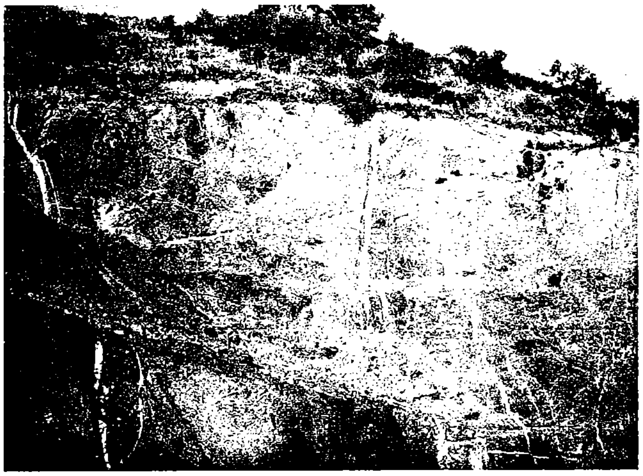

Figure 23. Aplite dikes cutting rocks of layered series of Raggedy Mountain Gabbro Group in magnetite prospect, western Raggedy Mountains.

alogy, including leucogranogabbro, granogabbro, leucosyenogabbro, and syenogabbro. The best exposure is at Twin Mountain, about 11.3 km south-southwest of Roosevelt, where coarse-grained leucogranogabbro can be seen intruded by red Lugert Granite (fig. 28). Specific relationships of these rocks to others in the complex are not sufficiently known in detail. The best existing account is that of Huang (1955). For the purpose of discussion and because of their possible "hybrid" nature, they are here placed within the intrusive group despite their distinctions relative to other rocks so classified.

Although the general relationships of the intrusive group to the Wichita Granite Group and to the layered series of the Raggedy Mountain Gabbro Group are probably broadly consistent throughout the Wichita Complex, there do appear to be some differences in the distribution of specific rock types that may be real and not the result of the more or less fortuitous occurrence of exemplary exposures. Strictly speaking, to group all of the above-mentioned members of the intrusive group together—and, indeed, to regard them as a subgroup of the Raggedy Mountain

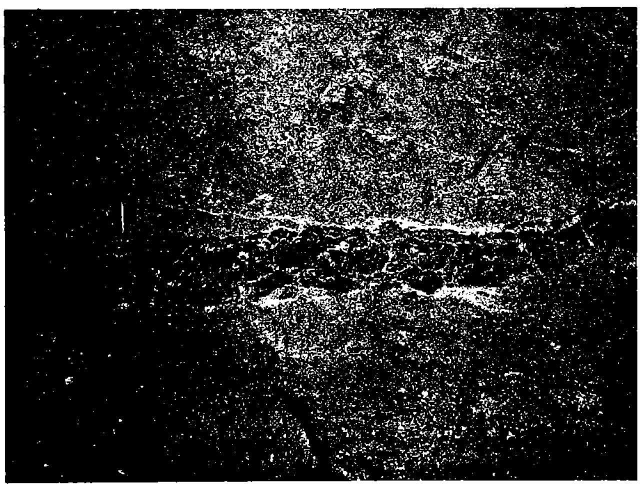

Figure 24. Dike of "mixed rock" (aplite and microdiorite) in magnetite prospect, western Raggedy Mountains. Hammer handle is 44 cm long.

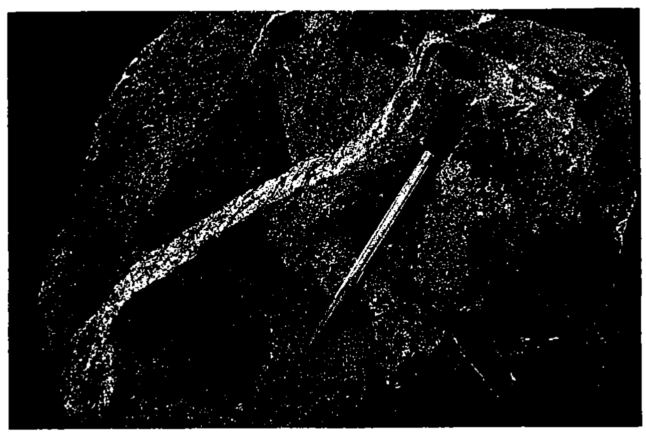

Figure 26. Sharply contrasted intrusion breccias in boulder east of U.S. Route 183 about 4.8 km south of Roosevelt, Oklahoma. Dark-gray, angular block of microdiorite is suspended in medium-gray hybrid Cold Springs "granite." Both are cut by a pink aplite dikelet (white). Pen is 15 cm in length.

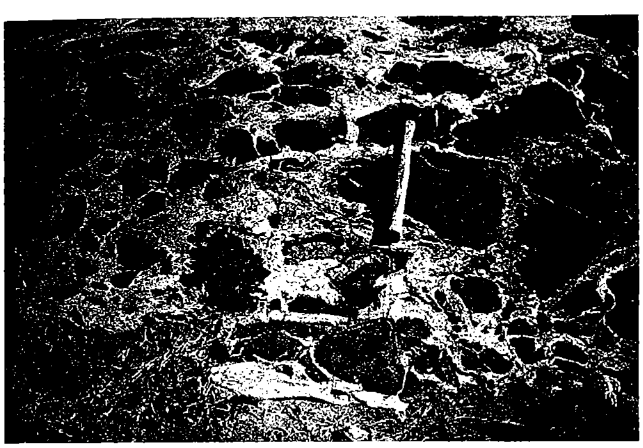

Figure 25. Body of "mixed rock" in "amphitheater" near Roosevelt, Oklahoma (see Stop 8): intrusion breccia formed by invasion of microdiorite (dark) by pink aplite (light). Assimilation has been minimal.

Figure 27. Moderately advanced assimilation in Cold Springs "granite" (adamellite) in Cold Springs Granite Company Quarry near Cold Springs, Oklahoma (Stop 9).

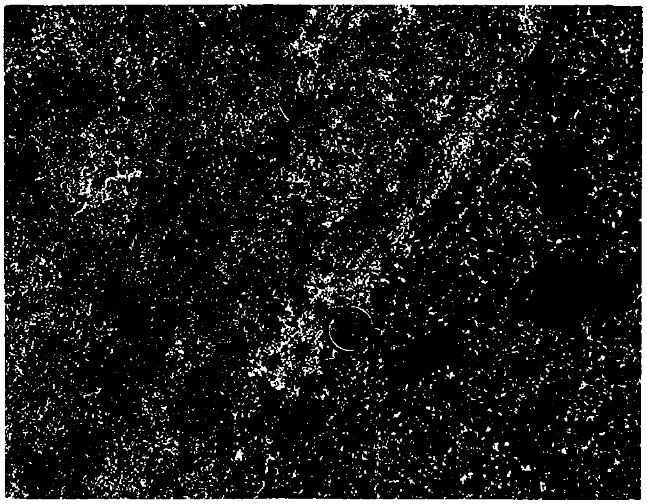

Figure 28. Leucogranogabbro (right), cut by Lugert Granite (left) in Twin Mountain (Stop 10). In lower center of picture a labradorite megacryst of leucogranogabbro is transected by granite. White flecks in leucogranogabbro are quartz and alkali feldspar.

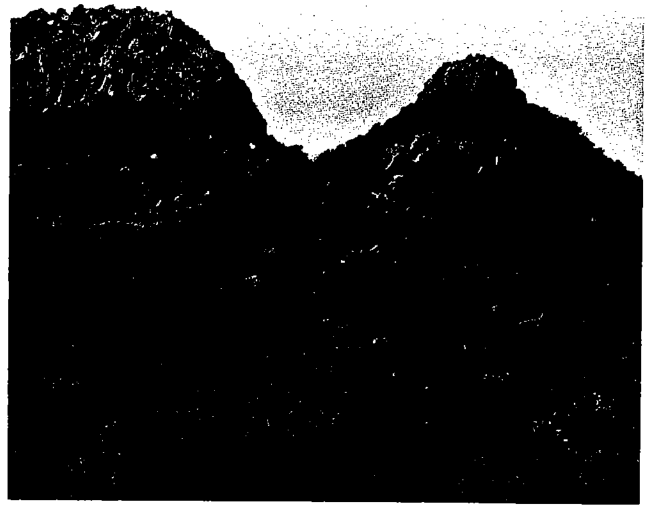

Figure 29. Mount Sheridan (left) and Little Mount Sheridan (knob at right). Tree-covered slopes are underlain by Mount Sheridan biotite-gabbro, grading upward into quartz diorite near base of capping granite sill (bare rock).

Gabbro Group as defined by Ham and others (1964)—tends to obscure important genetic relationships. In fact, there is compelling evidence that many members of the subgroup may be genetically related to the Wichita Granite Group and in any case are in *no way* related to the layered series. We discuss some of this evidence, as we see it, in the Discussion section later in this guidebook. Here we summarize certain distribution features of members of the intrusive group.

Cold Springs "Granite"

Intrusion breccias ("mixed rock") gradational into hybrid quartz monzonite (Cold Springs granite), granodiorite, and tonalite are relatively abundant in the western sector of the exposed complex, around Roosevelt and Cold Springs. Walper (1951) interpreted these rocks to have formed from mixing and variable assimilation resulting from intrusion of pink leucogranite (mapped by Taylor, 1915, as Lugert Granite of the Wichita Group) into sill-like bodies of quartz-bearing "hornblende andesite" (a microdiorite), themselves intrusive into rocks of the layered series. Such distinctive intrusion breccias are not known in the eastern sector (Wichita Mountains Wildlife Refuge and Meers vicinity), nor are gray "intermediate" rocks of the Cold Springs granite type.

Leucogranogabbro

The most accessible exposure of the leucogranogabbro of Huang (1955) is in the western sector at Twin Mountain, as mentioned. Huang attributes this rock to the modification of anorthositic rocks (layered series) by disseminating fluids from later intrusions of granite of the Wichita Granite Group. Eastern occurrences of similar rocks are described by Huang and attributed to similar processes. We are not familiar with some of these localities, but at one important site (Mount Sheridan) it is clear that the contact relations and impregnations discussed by Huang do *not* involve Wichita granite and layered-series rocks but rather Wichita granite and biotite-gabbro of the intrusive group (see below).

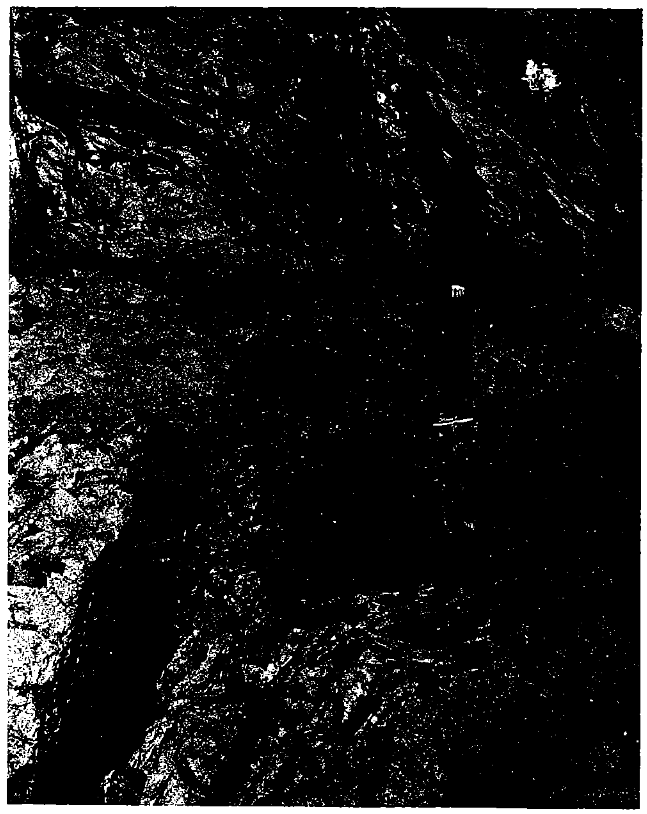

Figure 30. Basalt dike cutting Mount Scott Granite at Lake Elmer Thomas Dam, Wichita Mountains Wildlife Refuge.

Mount Sheridan Gabbro

The tree-covered slopes of Mount Sheridan and Little Mount Sheridan are underlain principally by medium-grained biotite-bearing rocks that grade with continuously changing modes and phase chemistry (see below) into quartz diorites near the contact with the overlying sill of Mount Scott Granite (fig. 29). Along the contact is a narrow zone of hybrid material resulting from reaction and (or) partial assimilation of the mafic quartz diorite by the granite. Huang calls this material granodiorite and lumps it with leucogranogabbro, although clearly the rocks involved in the genesis are not the same.

The biotite-bearing gabbro-diorite of Mount Sheridan also occurs beneath granite on Mount Scott and is definitely intrusive into older layered-series rocks. Chilled margins of Mount Sheridan Gabbro against layered-series anorthosite can be seen north of Rowe's Quarry, south of Meers. Whether the dikes of biotite-olivine gabbro intrusive into the layered series in the Raggedy Mountains (Hunter, 1967, 1970) are identical or genetically related to the Mount Sheridan Gabbro is not known, but it does seem likely. Quartz diorites of Mount Sheridan are clearly fractionated from the Mount Sheridan Gabbro (see below) and may not share a similar origin to that (unknown) of the microdiorite intruded by granite in the Cold Springs area.

Basalt Dikes

Numerous dikes of fine- to medium-grained basalt and diabase occur throughout the Wichita Complex. They can be seen cutting granite of the Wichita Granite Group (Lugert) at the Lake Elmer Thomas Dam (fig. 30), Wichita Mountains Wildlife Refuge, and elsewhere (see road log, mile 15.3). Similar dikes also cut Mount Sheridan Gabbro (directly south of Medicine Creek on Meers road), rocks of the layered series (State Route 19 east of Roosevelt, Stop 7), and leucogranogabbro (Twin Mountain). Whether these dikes are similar in detail or whether they are cogenetic has not been established. Certain of them at least give testimony to minor mafic magmatism following granite emplacement.

Petrography

Rather than attempt a description of all members of the intrusive group, we shall limit ourselves to those rocks that will be seen on this field trip. Additional and more complete descriptions can be found in articles by Walper (1951), Huang (1955), and Hunter (1970).

Cold Springs "granite."—Taylor (1915) and Walper (1951) have described this and related materials in detail. The rock specifically identified as Cold Springs granite typically contains 55-65 vol. percent feldspar, including orthoclase and plagioclase, the former generally dominant. The plagioclase ranges in composition from calcic andesine to calcic oligoclase, according to Walper, and commonly consists of partially sericitized andesine cores with fresh oligoclase rims. Brownish-green hornblende (10-13 percent) and dark-green to dark-brown biotite (5-10 percent) are the mafic phases present. Quartz (17-21 percent) is present as interstitial grains and myrmekitic intergrowths with feldspar rims. Accessories include magnetite, apatite, sphene, and zircon. The modal mineralogy varies with the degree of assimilation. Table 5 shows some average norms from Walper (1951), which illustrate the compositional variation from quartz monzonite to tonalite. Textures are generally hypautomorphic-granular (figs. 31 and 32).

Microdiorite.—Called hornblende andesite by Walper (1951), the dark-gray aphanitic material intruded by leucogranite or aplite in the intrusion breccia common in the Roosevelt-Cold Springs area is a holocrystalline rock consisting predominantly of brownish-green pleochroic amphibole (hornblende) and plagioclase (calcic andesine) in roughly equal proportions. Minor amounts of brown biotite are present, along with accessory magnetite and apatite. The texture is hypautomorphic-granular and is gradational between intersertal and poikilitic (fig. 33). Plagioclase is subhedral and lath shaped, whereas the hornblende is anhedral. Some samples have a microporphyritic texture with the presence of scattered plagioclase phenocrysts 2-4 times the size of laths in the matrix (fig. 34). There is some indication of finer grain size in xenoliths in mixed rock along the margins of the microdiorite bodies relative to that in the interiors, suggesting that the microdiorite had developed chilled margins against layered-series rocks prior to the subsequent invasion by leucogranite.

Leucogranogabbro.—The leucogranogabbro at Twin Mountain is basically an anorthosite with minor amounts of microperthite, orthoclase, and quartz, and with accessory pyroxene, apatite, magnetite, biotite, and uralitic amphibole. The dominant mineral is calcic plagioclase (An_{70}), frequently zoned (An_{70-60}). Huang (1955) gives the following modal analysis of leucogranogabbro from Twin Mountain: labradorite (70.7 percent), microperthite (15.4 percent), quartz (8.7 percent), orthoclase (2.2 percent), apatite (1.5 percent), clinopyroxene (1.0 percent), amphibole (0.5 percent), and trace amounts of biotite, sphene, magnetite, zircon, epidote, and sericite. The rock is porphyritic to inequigranular seriate (fig. 35). The plagioclase is euhedral to subhedral, whereas other phases are generally anhedral and interstitial. Where present, pyroxene (augite and/or orthopyroxene) occupies plagioclase interstices alone, sometimes with a subophitic texture not unlike that of intercumulus pyroxene in the layered series (fig. 36). Biotite, when present, is pale green or brown and is associated with interstitial quartz and (or) microperthite and (or) non-perthitic orthoclase.

Both in the outcrop and thin section, the rock appears to be basically a plagioclase adcumulate or plagioclase heteradcumulate with introduced "granitic" felsic components.

Mount Sheridan biotite gabbro.—A detailed study of relationships of the intrusive biotite gabbro to the layered

TABLE 5. AVERAGE NORMS OF PINK GRANITE AND HYBRID ROCKS FORMED BY ITS ASSIMILATION OF MAFIC MICRODIORITE, COLD SPRINGS AREA, OKLAHOMA (Data from Walper, 1951)

Rock Type:	Invading Leucogranite[1]	Cold Springs "Granite"[2]	Quartz Monzonite[3]	Tonalite[4]
quartz	31.9	19.0	23.8	29.6
orthoclase	49.7	36.2	25.4	3.2
plagioclase	12.3	25.2	33.6	44.2
hornblende	2.6	9.6	8.4	13.2
biotite	2.1	7.3	7.5	7.1
pyroxene	0.1	0.3	0.3	1.2
magnetite	0.8	1.2	0.5	1.2
apatite	tr	tr	tr	0.02
zircon	tr	tr	tr	tr
pyrite		tr		

1. Probably the Lugert Granite.
2. Actually is a quartz monzonite or adamellite.
3. Called granodiorite by Walper (1951).
4. Called quartz-diorite by Walper (1951).

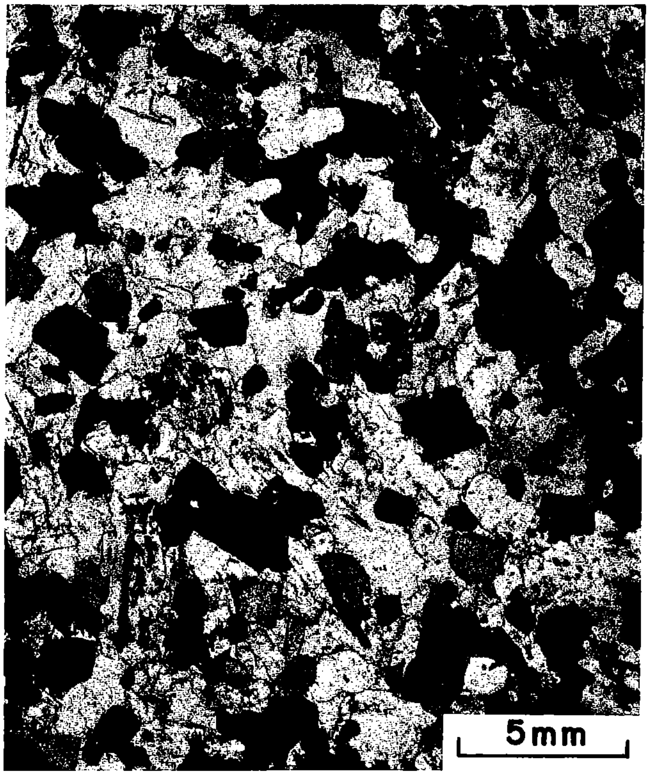

Figure 31. Photomicrograph of mafic variety of hybrid Cold Springs "granite" (WM-19) from 4.8 km southeast of Roosevelt, Oklahoma. The material shown is actually tonalite, relatively rich in hornblende and biotite (dark grains). White is sodic plagioclase and quartz. (Plane light.) (See fig. 32.)

Figure 32. Photomicrograph of felsic variety of Cold Springs "granite" (WM-39) from Cold Springs Granite Company Quarry. Rock is adamellite, with more alkali feldspar (turbid mottled grains) and less mafic minerals than that shown in figure 31. White is sodic plagioclase and quartz. (Plane light.)

series, and particularly to granite capping Mount Sheridan, has been made by Thornton (1975). The petrographic descriptions and phase chemistry presented here are drawn partly from that work.

The principal rock unit at the bases of Mount Sheridan, Little Mount Sheridan, and the north slope of Mount Scott is composed of intermediate plagioclase (~ 50 percent), augite (~ 20 percent), orthopyroxene (15-20 percent), magnetite (~ 5 percent), biotite (3-8 percent), olivine (0-2 percent), and apatite (~ 1 percent). Going up slope on Mount Sheridan, certain systematic gradational changes in modal mineralogy occur, most notably increases in the abundance of biotite (with decrease in orthopyroxene and olivine) and in quartz and alkali feldspar. Biotite reaches 15 percent of the mode, whereas quartz and K-spar reach 15-20 percent. Quartz and K-spar occur as discrete interstitial phases as well as micrographic intergrowths (micropegmatite). Plagioclase becomes more sodic vertically in section, and the mafic rocks in the upper half of the Little Mount Sheridan slope (below capping granite) are, strictly speaking, tonalites and even granodiorites.

Textures of the rocks are typically hypautomorphic-granular (fig. 37) and locally granophyric as the amount of micropegmatite mesostasis increases (fig. 38). The rocks are medium to fine grained, with average grain sizes 0.5 to 1 mm. In Rowe's Quarry, just across Medicine Creek north of Mount Sheridan, the biotite gabbro is slightly coarser grained, richer in plagioclase (60-70 percent), and displays a subtle cumulate texture. Both augite and hypersthene appear to be cumulus phases, along with dominant plagioclase. The latter is generally euhedral and commonly enclosed in large anhedral subophitic pyroxenes (fig. 39), these evidently having undergone much adcumulus growth relative to the plagioclase. A crude preferred orientation of plagioclase is variably discernible but is nowhere nearly as pronounced as in the layered-series rocks. The cumulates in Rowe's Quarry may be termed plagioclase-pyroxene orthocumulates. The abundance of pore material crystallized from trapped liquid is relatively high and includes biotite, ilmenite, magnetite, quartz, alkali feldspar, apatite, and sphene.

Deuteric alteration is abundantly evident in the Mount Sheridan Gabbro in the form of partially uralitized pyroxenes, green biotite and chlorite after primary red-brown biotite, and incipient alteration of feldspars. All of these effects testify to a relatively high content of alkalis, water, and other volatiles concentrated in the residual liquid.

Characteristically present in the Mount Sheridan Gabbro are dikes, stringers, pods, and veinlets of pegmatitic material (fig. 40). The pegmatite is composed largely of green hornblende, alkali feldspar (microperthite), and quartz, with minor and variable amounts of biotite, ilmenite, magnetite, augite, intermediate plagioclase (An_{45-55}), and accessory apatite and zircon. Deuteric and secondary-alteration products are abundantly present, including green biotite, chlorites (various compositions), muscovite, sericite, and clay minerals. Quartz and micro-

Figure 33. Photomicrograph of microdiorite (WM-44) of intrusive group of Raggedy Mountain Gabbro Group from "amphitheater" southeast of Roosevelt (Stop 8). White plagioclase laths are partially enclosed by hornblende (medium gray); magnetite (black) is also visible. (Plane light.)

Figure 34. Photomicrograph showing porphyritic microdiorite (WM-120) of intrusive group of Raggedy Mountain Gabbro Group. Note plagioclase phenocrysts (cf. fig. 33). (Plane light.)

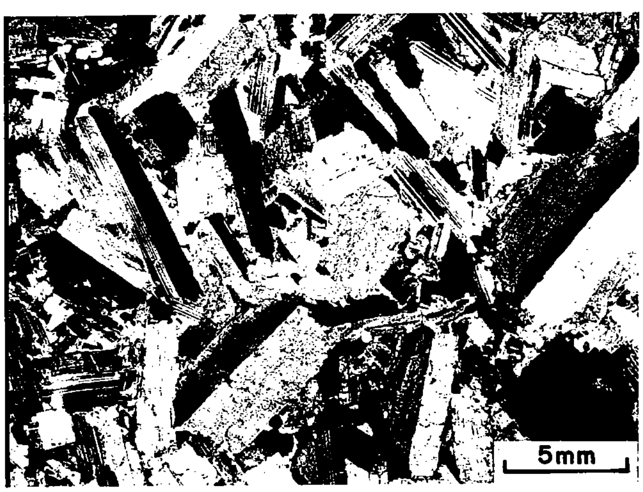

Figure 35. Photomicrograph of leucogranogabbro (T-11) from Twin Mountain. Twinned labradorite predominates over microperthite (small mottled interstitial grains), quartz, and other accessory phases. (Cross-polarized light.)

Figure 36. Photomicrograph of leucogranogabbro (WM-17) from Twin Mountain, showing interstitial subophitic pyroxene. (Plane light.)

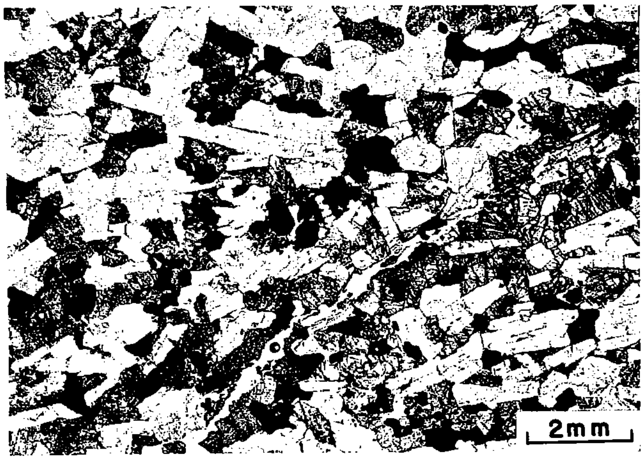

Figure 37. Photomicrograph of Mount Sheridan Gabbro (WM-117) of intrusive group of Raggedy Mountain Gabbro Group. Sample from north of Rowe Quarry, south of Meers, Oklahoma. Crude alignment of plagioclase laths (white) is probably flow structure in this sample taken at contact with layered series. Mafic phases (gray) include augite, orthopyroxene, and biotite. Black is magnetite. Interstitial quartz and apatite are present but not visible in this figure. (Plane light.)

perthite occur in discrete grains and as more abundant micrographic intergrowths.

Whether these pegmatites represent late-stage segregations of residual liquid from the crystallizing Mount Sheridan Gabbro or are the products of assimilative reaction and recrystallization of xenoliths of Meers Quartzite is not resolved at present. The presence of pyroxene and plagioclase similar to that of the gabbro and a similar accessory assemblage argue for the former origin. The local concentrations of micropegmatite in the gabbro mesostasis and its increasing abundance vertically in section give testimony to the natural tendency for that magma to fractionate toward an end product similar to the pegmatite. On the other hand, rare needles of sillimanite(?) recognized in scattered pegmatite pods and some partially digested xenoliths of Meers Quartzite suggest the latter origin. Likely enough, both processes have functioned, and a systematic study is needed to characterize the situation properly.

Phase-chemical microprobe analyses by Thornton (1975) on a series of samples of biotite gabbro-diorite from Little Mount Sheridan have revealed systematic changes in phase chemistry with stratigraphic height. These are summarized in figure 41 along with some noted modal changes. This cryptic variation is characterized by increasing Fe/(Fe + Mg) ratios in augite and orthopyroxene and a sodic enrichment in plagioclase. This "normal" variation doubtless resulted from crystal fractionation owing largely to crystal settling, as evidenced by cumulate textures.

Listed in table 6 are some representative analyses of pyroxenes by Thornton (1975) from the Mount Sheridan Gabbro. Also tabulated is an analysis of an augite from the layered-series anorthosite overlying Mount Sheridan Gabbro just north of the Rowe Quarry, plus a ferroaugite and a hornblende from the granophyre, which overlies gabbro at

Figure 38. Photomicrograph of Mount Sheridan Gabbro (WM-13) from northeast slope of Mount Sheridan, showing relatively abundant interstitial micropegmatite between plagioclase euhedra. Note large apatite lath (dark gray) in center of field. (Cross-polarized light.)

Figure 39. Photomicrograph of Mount Sheridan Gabbro (WM-15d) from Rowe Quarry, showing plagioclase crystals (white) enclosed subophitically in pyroxene. Both phases are cumulus, latter more extensively modified by post-cumulus growth. (Plane light.)

Figure 40. Pegmatitic pods in Mount Sheridan Gabbro, Rowe Quarry. Marker is 6 cm long.

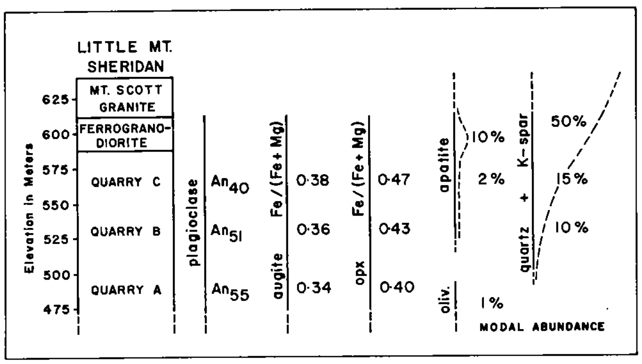

Figure 41. Schematic representation of cryptic variation within Mount Sheridan Gabbro, as revealed by petrographic and microprobe phase-chemical analyses by Thornton (1975) of samples collected on traverse up Little Mount Sheridan. Rock in quarry A is biotite-olivine gabbro, which grades into quartz diorite and granodiorite above quarry C. Normal cryptic variation doubtless resulted from crystal fractionation of Mount Sheridan Gabbro (unrelated to layered series). Mount Scott Granite, however, is younger and not fractionated from Mount Sheridan Gabbro.

the top of Little Mount Sheridan. The TiO_2, Al_2O_3, and Cr_2O_3 contents of augite from the layered-series sample are notably higher than those of pyroxenes with similar Fe/(Fe + Mg) ratios from the Mount Sheridan sequence; this fact suggests compellingly that the two did not crystallize from the same fractionating magma. In further support of this contention (aside from intrusive field relations) are differences in plagioclase composition. Probe analyses of plagioclase grain cores in layered-series anorthosite and Mount Sheridan Gabbro from samples 2 feet apart across a contact reveal that the former average An_{66} and the latter average An_{54}.

In summary, the phase-chemical and petrographic data reveal a normal fractionation pattern within the 160-m-thick sill of biotite gabbro on Mount Sheridan. Furthermore, the crystallization of the body, known to be younger than layered-series rocks from field relations, was from a magma of different composition (most notably in volatile and probably Al and Ti contents).

TABLE 6. REPRESENTATIVE COMPOSITIONS (WT.%) OF PYROXENES AND ONE HORNBLENDE FROM THE MT. SHERIDAN-MT. SCOTT AREA, OKLAHOMA (Edward C. Thornton, analyst.)

Analysis	1	2	3	4	5
Rock Type	anorthosite	biotite gabbro	biotite gabbro	granophyre	granophyre
Phase	Augite	Opx	Augite	Ferroaugite	Hornblende
SiO_2	50.8	53.3	52.3	50.9	43.8
Al_2O_3	2.15	0.88	0.45	0.56	7.72
TiO_2	0.61	0.32	0.10	0.16	1.24
Cr_2O_3	0.09	0.00	0.01	0.00	0.05
FeO	12.4 *	21.8 *	11.5 *	17.7 *	25.1 *
MnO	0.33	0.56	0.36	1.49	1.13
MgO	13.7	20.1	12.5	8.29	6.90
CaO	19.8	2.10	22.7	20.1	10.7
Na_2O	0.04	0.06	0.04	0.68	1.54
Total	99.92	99.12	99.96	99.88	98.18
Fe/(Fe+Mg)	.336	.372	.340	.546	.652

*Total iron determined as FeO

1. From Layered Series anorthosite just north of Rowe Quarry (T-61).
2,3. From Mt. Sheridan gabbro, north slope of Mt. Scott (T-68).
4,5. From granophyre near top of Little Mt. Sheridan (T-32).

DISCUSSION

A certain amount of discussion and interpretation of particular observations has been presented in the previous sections. Our aim in this section is to deduce constraints, draw broader conclusions, and present what we think are some of the more important implications to the geologic and tectonic history of southern Oklahoma. Some deductions are necessarily more tentative and (or) provocative than others. We reserve the right to speculate in the hope of stimulating some discussion.

Petrologic Constraints

A number of petrologic constraints have been established by Powell and Phelps (in preparation), from an ongoing investigation of the layered series, concerning the subsurface and probable original character of the layered mafic body and its relationship to other rocks of the Wichita Province. Some of these constraints were touched upon earlier in this report and are summarized here with some additional discussion.

Layered-series rocks are gravity-settled cumulates precipitated from a tholeiitic parental magma under relatively quiescent conditions, save for the probable presence of convection currents within the magma chamber, under slow-cooling plutonic conditions. The rocks possess no evidence of an alkaline affinity. In mineral assemblages, phase chemistry, and textures, the exposed layered series resembles rather closely certain levels of the Bushveld and Stillwater intrusions and doubtless formed through broadly similar processes. Mass-balance considerations require the presence at depth of mafic cumulate rocks rich in magnesian olivine and pyroxenes as well as the original presence of more fractionated rocks overlying the present level of exposure. The fractionation trend detected by observable cryptic variation is an iron-enrichment trend probably similar to that displayed by the Bushveld, Skaergaard, and Duluth complexes. An ultimate silica enrichment is also suggested. By analogy to other stratiform gabbroic complexes, the level of exposure of the layered series is at the approximate middle, or slightly below, with underlying (hidden) and overlying (missing) sections, each on the order of 2-4 km thick. Geophysical models of Pruatt (1975) compellingly point to the existence of such a stratiform mafic body at depth.

Suggestions by several earlier workers that intermediate rocks of the intrusive group and possibly even the Wichita granites are bodies fractionated from the same parental magma as that of the layered series are no longer acceptable on several counts. For one, the most fractionated of the layered-series rocks are much more primitive (basic) than any of the intermediate rocks, which, in any case, intrude the layered series and are not stratigraphically conformable. The same relationships are borne by the Mount Sheridan Gabbro to the layered series, including significant (but not as great) compositional differences. Secondly, volume proportions are absurd for a fractionation relationship: the intermediate rocks are far too minor in abundance, and the granitic rocks much too voluminous. To put things in perspective, the maximum possible amount of granitic residuum from the Skaergaard fractionation has been calculated to be 7 percent, and the actual amount estimated at about 0.5 percent. The total volume of granitic magmatic rocks, including the probably cogenetic rhyolites, is substantial relative to the mafic rocks in Oklahoma.

One important fundamental conclusion to be drawn from these petrologic constraints is that the layered-series rocks are not genetically related to any of the other igneous rocks in the Wichita Mountains. Ham and others (1964) suggested that the Navajoe Mountain Basalt-Spilite Group is the possible volcanic equivalent of the Raggedy Mountain Gabbro Group. At the present time it is not at all clear how the Navajoe Mountain Group fits into the picture. However, if the estimates of Powell and Phelps (in preparation) regarding the character and level of exposure of the layered series are even approximately correct, the Navajoe Mountain volcanics cannot relate to the layered series. These volcanics might, however, in some way relate to the Mount Sheridan Gabbro, although the question is unresolved.

A second consequence of the above reasoning is that the layered-series rocks are very much older than the Carlton Rhyolite and Wichita Granite Groups and probably than certain members of the intrusive group of the Raggedy Mountain Gabbro Group. Ham and others (1964) interpreted the presence of a period of uplift and erosion between emplacement of the Raggedy Mountain Group (older) and the granitic and rhyolitic rocks (younger), on the basis of an apparent erosional unconformity between the two and a possible 10-20-m.y. difference in determined ages. Quite clearly, uplift and erosion of 2-4 km of mafic igneous rocks plus their substantial (but unknown) overburden should require a considerable time period, even by geologic standards. Thus we conclude that the layered-series rocks are Precambrian in age and considerably predate the remainder of the magmatism of the Wichita Province.

Paleomagnetic Interpretation

Evidence of a somewhat more direct nature for a Precambrian age of the layered series is embodied in the paleomagnetic data and interpretation of Roggenthen and others (in press), summarized in a previous section. Aside from two K/Ar-dated samples of the layered series mentioned earlier, the consistent paleopole position interpreted from these paleomagnetic studies offers the best evidence presently available for the specific age of these rocks and indicates an age of 1,300 to 1,500 m.y.

Samples of the Mount Sheridan Gabbro, dated at 500 m.y. by K/Ar and 535 m.y. by Rb/Sr (on biotite), give the same equally consistent stable 1,300-m.y. pole position.

The apparent disparity between the radiometric age determinations and those inferred from the paleomagnetic study could very well result, in our opinion, from a resetting of the radiogenic systems by a thermal overprint at the time of the abundant granitic magmatism. The matter remains to be resolved.

In any case, the paleomagnetic data strongly reinforce the contention of a Precambrian age for the principal basic rocks. They also suggest a similar age for both the layered series and the Mount Sheridan Gabbro, for which petrologic evidence of consanguinity is lacking. This does not appear to be a major problem at present, considering the 200-m.y. range in the paleomagnetically inferred age.

Tectonic Implications

Slightly south of west from the Wichita Mountains, and extending in a broadly linear trend across the base of the Texas Panhandle into New Mexico, lies a subsurface distribution of mafic basement rocks known as the Swisher Gabbroic Terrane (Flawn, 1956). A diabase core from this terrane has been dated at 1,200 m.y. (Muehlberger and others, 1966). This terrane is flanked on the north and south by the Panhandle Volcanic Terrane (Flawn, 1956), characterized by 1,100-1,200-m.y.-old rhyolites, granites, and lesser basalt-gabbro (Muehlberger and others, 1966). Flawn portrays the Wichita Igneous Province as running diagonally northwestward across the Texas Panhandle. However, the linear distribution of known layered-series rocks of the Wichitas is in fact rotated only a small amount relative to the Swisher Terrane.

We suggest that the layered-series rocks, and possibly the Mount Sheridan Gabbro, belong to the same or a similar tectonic-magmatic cycle that established the Swisher Terrane. (Granitic cratonic rocks flanking the Wichita Province are in the 1,100-1,300-m.y. range.) That an old structural grain existed in the region is very compelling from present evidence, and the distribution of mafic rocks suggests a rift zone. There is a real possibility, then, that the Southern Oklahoma aulacogen developed in the Paleozoic and was somehow influenced in its location, in part at least, by the preexisting structural element—and furthermore that the layered series is a relic of the magmatism associated with that earlier disturbance and not of the Paleozoic-aulacogen magmatism. The latter would be represented by the abundant granitic and rhyolitic rocks characteristically present over the widest known extent of the Wichita Province. The relation, if any exists, of another late Precambrian rift system with known associated tholeiitic magmatism—the Midcontinent gravity high—to that of Texas-Oklahoma is not clear at present but offers food for thought.

DETAILED STOP DESCRIPTIONS

STOP 1: Top of Mount Scott[1]

Mount Scott rises slightly over 335 m above the elevation of the surrounding plains (fig. 42). The view from the top is superb, particularly of the rest of the mountains in the Wichita Mountains Wildlife Refuge. We can get a good overview of the geology from here, but have your coats handy—it always blows up here.

To the east, the granites quickly die out, signalling the easternmost extension of the Wichita Mountains. To the south and southeast are both Wichita granites and Carlton rhyolite. The gentle, grass-covered hills are rhyolite, whereas those with jagged exposures are granite. Practically all of the exposed rhyolite is now behind the fences of the Fort Sill Military Reservation. More rhyolite is exposed to the northeast, particularly on and near Bally Mountain. A measured section there 3,597 feet thick (1,096 m) was designated by Ham and others (1964, p. 42 and following) as the type section, since the original type area is now inaccessible.

[1]Locations by section, township, and range are presented in table 7.

TABLE 7. SECTION, TOWNSHIP AND RANGE LOCATIONS OF FIELD TRIP STOPS, WICHITA MOUNTAINS, OKLAHOMA

STOP 1:	SE 1/4,	Sec. 11,	T. 3 N.,	R. 13 W.
STOP 2:	SE 1/4,	Sec. 5,	T. 3 N.,	R. 13 W.
STOP 3:	NE 1/4,	Sec. 32,	T. 4 N.,	R. 13 W.
STOP 4:	SW 1/4,	Sec. 32,	T. 4 N.,	R. 13 W.
STOP 5:	NE 1/4,	Sec. 21,	T. 3 N.,	R. 14 W.
STOP 6:	SE 1/4,	Sec. 4,	T. 3 N.,	R. 15 W.
STOP 7:	NW 1/4,	Sec. 4,	T. 4 N.,	R. 17 W.
	SE 1/4,	Sec. 33,	T. 5 N.,	R. 17 W.
STOP 8:	SE 1/4,	Sec. 15,	T. 4 N.,	R. 17 W.
STOP 9:	SW 1/4,	Sec. 21,	T. 4 N.,	R. 17 W.
STOP 10:	SW 1/4,	Sec. 1,	T. 3 N.,	R. 18 W.

Figure 42. Mount Scott viewed from the southeast, near Medicine Park. Densely forested slope to lower right is underlain by Mount Sheridan Gabbro; bulk of peak is Mount Scott Granite.

Figure 43. Westward view along northern flank of eastern Wichita Mountains. Granite sills cap hills, while tree-covered slopes are Mount Sheridan Gabbro. Layered-series anorthositic rocks underlie gabbro and exist as large blocks caught up within it.

The wooded northern flank of the Wichita Mountains, including the nearby low, forested hills, is underlain by Mount Sheridan Gabbro and the layered series of the Raggedy Mountain Gabbro Group (fig. 43). These rocks are easily distinguished in the topography from the granites by several criteria. They weather much more readily than the granites, so areas underlain by the basic rocks tend to be low whereas granitic areas are high. The gabbroic outcrops tend to be smooth and rounded, whereas many of the granitic outcrops are sharply angular. Part of this difference may relate to grain size and jointing patterns in the granite, because there are areas of granite with large, smoothly rounded boulders rather than the jagged blocks. Finally, the clay-rich soils of the gabbro provide better moisture retention and are thicker; hence they are more favorable for the scrub-oak forests; the granitic soils favor grass or vegetation of a more shrubby growth.

Farther to the north is a complexly faulted and folded terrain called the Wichita front. This is a transition zone between the uplifted Wichita Mountains and the deep Anadarko basin to the north. The upturned edges of limestones of the Arbuckle Group (Cambrian-Ordovician) form the northwestward-trending ridges in the distance. The Meers fault is the most prominent of the many faults in the area. Vertical offset along this high-angle reverse fault is on the order of 9,100 m, south side up. Most of the faults of the region are reverse in nature; part of our knowledge of the basement rocks has benefited from this, because petroleum-industry explorationists will deliberately drill into the rhyolites and granites in areas where they think they can break through into Paleozoic sedimentary rocks beneath.

Mount Sheridan, about 9.6 km to the west, will be the subject of our next stop. From our viewpoint on Mount Scott the sill-like nature of the granite bodies is most apparent (fig. 44). The lower forested slopes are gabbro; we will climb up to the base of the granite. The granite extends westward and northward from the center of the Wichita Mountains Wildlife Refuge, creating a naturally wild area.

The valley south of Mount Sheridan and continuing westward throughout the refuge is primarily structurally controlled. It is lined by faults with at least part of the valley structurally uplifted, exposing gabbro that has weathered out to form the valley.

The mountains along the southern margin of the refuge and in the Fort Sill Military Reservation are composed of

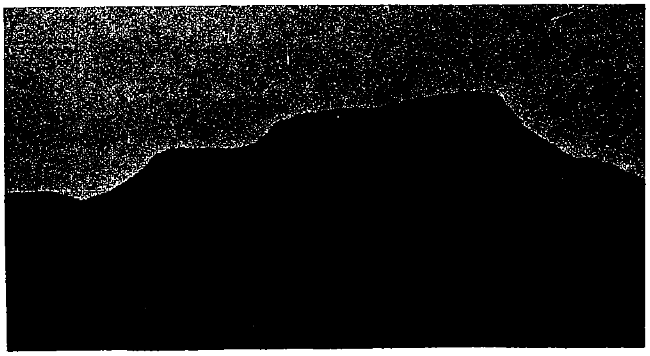

Figure 44. Mount Sheridan, viewed from east. Sill-like character of capping Mount Scott Granite is apparent.

the Quanah Granite, a rock similar to the Mount Scott Granite but with riebeckite (< 3 percent) in it. Outcrops of the Quanah Granite tend to be much more smoothly rounded than those of Mount Scott, giving some spectacular scenery along the road to the southwest exit of the refuge. The Mount Scott Granite was originally classified by Taylor (1915) as the Lugert Granite, a type found in the western sector of the complex in the region of Roosevelt, Snyder, and westward.

STOP 2: Little Mount Sheridan

This stop will require a rather strenuous hike. It isn't long, but the way is very steep. There is no path and lots of brush. Until recently it was thought that the whole slope below the granite contact was Mount Sheridan Gabbro of the intrusive group of the Raggedy Mountain Gabbro Group. Detailed traverses on the north slope of Mount Sheridan indicate that there is some layered-series anorthosite of the Raggedy Mountain Group partway up that slope, and it might extend around to here.

The bottom part of the slope consists of Mount Sheridan Gabbro with abundant pegmatitic pods and veins. The gabbro is characterized by biotite, easily visible in hand specimen. The pegmatites are composed primarily of hornblende, microperthite, and quartz with or without biotite. The pegmatite relationships described are best seen inside the fence and a little way to the south of the gate.

Upslope, the gabbro slowly changes character, as described earlier in this guidebook. There are fewer pegmatitic pods, and the contents of quartz, alkali feldspar, and biotite increase as the rock changes character to quartz diorite and granodiorite. It is tempting to attribute the compositional changes within the gabbro to a differentiation trend resulting in granite. Two major factors argue against this interpretation:

1. The contact, although obscure, weathered, and covered with lichens, shows clear evidence of intrusion of granite against the gabbro.
2. The volume of granite, both locally and regionally, is far in excess of any possible residuum fractionated from the gabbros present.

The gabbro-diorite contact with granite is a little way above the uppermost of three small quarries exposed on this slope. The slope continues upward into a small knob of granite, commonly called Little Mount Sheridan. The relationships between the granite and the gabbro are not totally clear along this contact, because there exists a hybrid rock, with clear evidence of abundant chemical transfer across the contact. Elsewhere, particularly along the upper slope of Mount Sheridan, the contact can be marked quite precisely, even with the contamination. Also, there are xenoliths of the gabbro in the granite, leaving little room for doubt that the granite is intrusive into the gabbro and that the gabbro was crystalline at the time. The overall distribution of granite leads to the conclusion that an erosional surface of gabbroic rocks existed, which was covered by rhyolite, and that granite subsequently intruded along the base of the rhyolite and the top of the gabbro.

STOP 3: Prehnitized Layered-Series Rocks

Two types of rock of the layered series of the Raggedy Mountain Gabbro Group can be examined at this stop. The loose boulders on the west side of the road show excellent cumulus textures, with sizable pyroxene oikocrysts. These boulders have been variably altered by secondary solutions, resulting in the formation of epidote and prehnite.

In the road cut on the eastern side, the alteration is much more intense, and much of the rock has been reduced to a white clay-rich substance. The remains of oikocrysts can be seen in the soft slope; a certain amount of fabric in the saprolite is controlled by the texture of the original rock.

STOP 4: Quarry at North Base of Mount Sheridan

The Mount Sheridan Gabbro of the intrusive group of the Raggedy Mountain Gabbro Group in this quarry has the best exposures of the various occurrences of the pegmatitic phase associated with the biotite gabbro (figs. 40 and 45). The pegmatite is composed primarily of orthoclase, quartz, and hornblende, with some plagioclase and, in some examples, biotite. One sample with needles of sillimanite 2 cm long has been found. The pegmatites may have two origins. They might well be the normal late-stage residual liquids of crystallization, high in water and alkalis, as discussed elsewhere in this guidebook, or they might be partially assimilated xenoliths of Meers Quartzite (Spencer and Hunter, pers. comm., 1974). The Meers Quartzite occurs in at least two large xenoliths, measurable in tens to

Figure 45. Rowe Quarry, south of Meers. Quarried rock is Mount Sheridan Gabbro with abundant pegmatitic pods.

hundreds of meters. It is not unreasonable that smaller pieces may have been heated to the point of partial or total melting, with partial intermixing of components from the surrounding gabbroic melt. Although the problem is not yet fully resolved, there is some petrographic and field evidence suggesting that certain intermediate-sized Meers Quartzite xenoliths, measurable in meters, are partially replaced by pegmatite. Possibly both origins are involved. In his classic discussion of assimilation, Bowen (1928) convincingly showed that assimilation of material farther down the reaction series than the present liquidus of the assimilating magma has the net result of increasing the amount of final residual melt toward which the magma would tend to fractionate in any case. The Meers Quartzite composition, rich in SiO_2, Al_2O_3, and alkalis, is not unlike the mesostasis of fractionated Mount Sheridan Gabbro at the top of the sill, with its abundance of granophyric micropegmatite.

In the slope of Mount Sheridan, to the south across Medicine Creek, one can see clearly by the nature of the vegetation the contact between gabbro and granite (fig. 46).

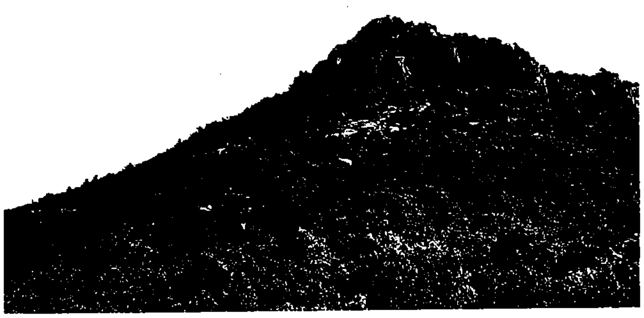

Figure 46. Looking up north face of Mount Sheridan. Granite-gabbro contact is at base of bare cliff. Rocky ledge barely visible through trees in lower left of photograph is lens of layered-series anorthosite caught up in intrusive biotite gabbro.

Most of the slope is Mount Sheridan Gabbro, with one exception. About a third of the way up the slope there is a prominent ledge with a face about 8 m high. This ledge is composed of layered-series anorthosite. There is massive biotite gabbro both below and above. The ledge can be traced eastward to the shoulder of the slope. Beyond that, there is a break in the slope at about the same elevation, suggesting that the layered rocks continue farther, but this part is covered by talus. To the west there is a large break in slope below Poko Mountain, at about the right elevation, suggesting a continuation there. This ledge of layered series is an inclusion in the gabbro, perhaps better described as a "curtain" of country rock in the Mount Sheridan Gabbro. Alternatively we may be looking at a bifurcated sill of gabbro in the slope.

Behind us, to the north, the low, brush-covered hills are in part layered series of the Raggedy Mountain Gabbro Group. If we walk only a few hundred meters, we can pick up the contact between massive gabbro and layered anorthosites, with the latter physically above the gabbro in the exposure (fig. 47). These anorthosites may or may not correlate with the ledge in the slope of Mount Sheridan, but they are much thicker here and to the north.

These rocks have lithologic characteristics similar to the

Figure 47. Intrusive contact between Mount Sheridan Gabbro (smooth darker surface below and to right of hammer handle) and older layered-series anorthosite (lighter mottled material above and left of hammer handle). North of Rowe Quarry.

layered zones mapped in the Raggedy Mountains. Some specific differences may occur, including the presence of better developed igneous lamination (extreme) in this eastern sector. We will examine fresh outcrops of this material at our next stop, inside the wildlife refuge.

The Mount Sheridan Gabbro adjacent to the contact with layered-series rocks at this site is noticeably finer grained than that in Rowe's quarry. Furthermore, it has a more massive fabric and is less rich in plagioclase. All the evidence suggests that this is a chilled-marginal facies of the gabbro, which has a more apparent cumulate texture in the quarry and is enriched in one of the principal cumulus phases, plagioclase. As detailed earlier in this guidebook, the cumulates in the Mount Sheridan Gabbro are clearly orthocumulates with weak laminations at best and are quite distinct from the older layered-series rocks.

STOP 5: Lamination in Layered Series at Burford Lake (Panther Creek)

The boulders visible along the north side of the road are representative of in-place material of the layered series of the Raggedy Mountain Gabbro Group located about 150 m inside the fence. The rocks are characterized by extreme development of igneous lamination (see figs. 9 and 19). The fabric is largely due to tabular cumulus plagioclase crystals preferably lying on (010) faces. Also present are subhedral cumulus olivine crystals and ophitic pyroxenes up to 8 cm in diameter. These rocks are clearly formed by crystal settling likely enhanced by current activity, though no lineation is present. The plagioclase laminae show sag and drape phenomena around individual olivine crystals, possibly somewhat analogous to similar structures of ice-rafted pebbles in varved sediments.

Rocks of the layered series exposed in the Raggedy Mountains to the west are mineralogically and texturally similar, although lamination this pronounced has not been reported.

STOP 6: Ira B. Smith Granite Quarry

This quarry is no longer in operation, although there is quite a large spoils pile. We suspect that operation ceased because of the close spacing of joints, although distance to the mill near Snyder may also have been a factor.

The rock here is similar in appearance to the chilled-margin facies of the Mount Scott Granite. It contains phenocrysts of orthoclase set in a fine-grained matrix of quartz and orthoclase; the main mafic mineral is a pale-green amphibole. In places there are thin pegmatitic veinlets of quartz and biotite, and rare seams have thin coverings of riebeckite. There are rare small, dark xenoliths in the rock, usually only 1 to 2 cm across. Trace amounts of molybdenite have been seen.

Nearby is a riebeckite pegmatite, spectacular by the banding of pegmatitic and aplitic facies. The main minerals are quartz, anorthoclase, riebeckite, and aegirine. This is one of the few rocks in the area that shows a pronounced alkaline affinity: a general lack of alkalic magmatic activity typifies the Wichita Province.

STOP 7: Road Cut East of Roosevelt, Layered-Series Troctolite

This road cut shows one of the best examples of igneous layering that we will see (fig. 48). These rocks are part of the layered series of the Raggedy Mountain Gabbro Group. The casual observer might suppose the rocks to be normal sedimentary rocks from the layering. In a sense they are sediments, but of a high-temperature sort! The rocks are interlayered plagioclase adcumulates and plagioclase-olivine adcumulates, or, if you prefer, anorthosite and troctolite.

Basalt and aplite dikes of the intrusive group of the Raggedy Mountain Gabbro Group can be seen cutting the layered-series rocks here. There is a thick basalt dike on the north side of the road cut, and a thin one on the south side. Several aplite dikes are also present on the south side.

Figure 48. Layered troctolitic anorthosite of layered series of Raggedy Mountain Gabbro Group, probably M zone, on State Route 19 east of Roosevelt (Stop 7). Weathering characteristics resemble sedimentary rocks.

STOP 8: L and M Zones of the Layered Series

The slope directly to the north is the area that we refer to as the "amphitheater" because of the topography. As we climb up this slope, we are traversing up-section through the L and M zones (in that order) of the layered series, as designated by Hunter and his students and described earlier in this guidebook in the section on the layered series of the Raggedy Mountain Gabbro Group.

At the base of the amphitheater is a sill-like body of fine-grained microdiorite, marginally invaded by pink aplite, giving rise to a striking intrusion breccia (fig. 25). Both aplite and microdiorite are intrusive into the layered series and are members of the intrusive group of the Raggedy Mountain Gabbro Group detailed earlier in this guidebook. Intrusion breccia similar to this is widely but sporadically exposed in this general vicinity, most notably around Cold Springs. Assimilation effects here are minimal, doubtless because of the small amount of aplitic material relative to microdiorite. At the next stop more advanced hybridization is readily visible. In addition to sill-like and irregular bodies of this material, dikes of intrusion breccia or "mixed rock" can be seen cutting the layered series. At this locality one of these dikes is present in the highest saddle at the top of the amphitheater and another about 1.5 km east-northeast of the base of the amphitheater, in an iron prospect known locally as Reed's magnetite pit (fig. 24). Aplite dikes also can be found cutting the layered series near the top of the amphitheater and in Reed's pit.

Many of the field characteristics of the L and M zones of the layered series, summarized previously in table 1, can be seen in this type locality. When the rocks are dry the various types of pyroxene oikocrysts stand out visibly in relief, owing to their dark color and weathering characteristics (fig. 49). About 0.8 km southwest of the amphitheater are excellent exposures of the K zone. The intrusion breccia and microdiorite in the lower portion of the amphitheater are intrusive into the lower part of the L zone or possibly along the K-L boundary.

Visible in Reed's pit is a curious rock type not reported elsewhere in the complex. It is basically a magnetite-olivine rock that appears dike-like in its relationship to the layered series, although exposures are inadequate. The rock consists of approximately 40-percent magnetite, 30-percent olivine, 15-percent ilmenite, 10-percent plagioclase, and 4-percent pinkish-brown amphibole. Alteration products of olivine and amphibole include bowlingite and (or) iddingsite, serpentine, and chlorite. The cumulus phases are magnetite, ilmenite, and olivine, all of which range from euhedral to subhedral depending upon the extent of adcumulus-growth modification (fig. 50). Plagioclase is strictly intercumulus, as is the amphibole, the latter commonly rimming the opaques or completely filling interstices. Clearly, if the rock is a mesocumulate, as it appears, then a dike relationship would be most unlikely if not impossible. Possibly it represents a segregation broadly analogous to the magnetite layers in the Bushveld complex, albeit at a lower level within the complex. If this is correct, it is curious that the rock does not have a wider distribution.

STOP 9: Cold Springs "Granite" Quarry

This is one of many small quarries in this area situated within the hybrid rock known commercially as Cold Springs granite. This particular quarry is identified as the Cold Springs Granite Company Quarry, and was included in Walper's (1951) study of assimilation in the area.

Varying degrees of assimilation of microdiorite by leucogranite or aplite can be seen. A block near the

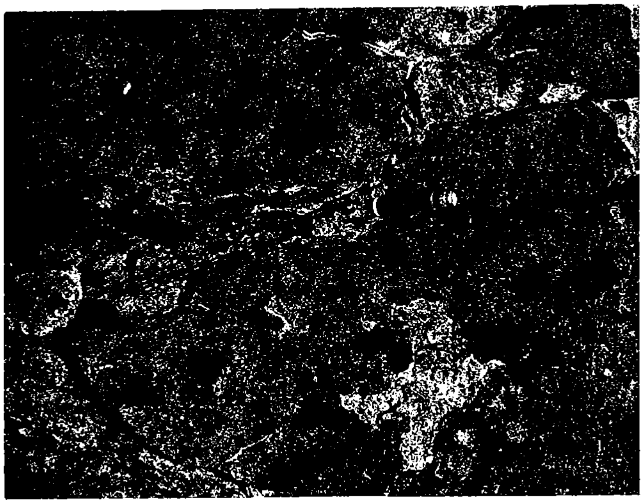

Figure 49. Nubbly fine-ophitic pyroxene oikocrysts (dark spots) in M zone of layered series of Raggedy Mountain Gabbro Group, exposed in "amphitheater" (Stop 8).

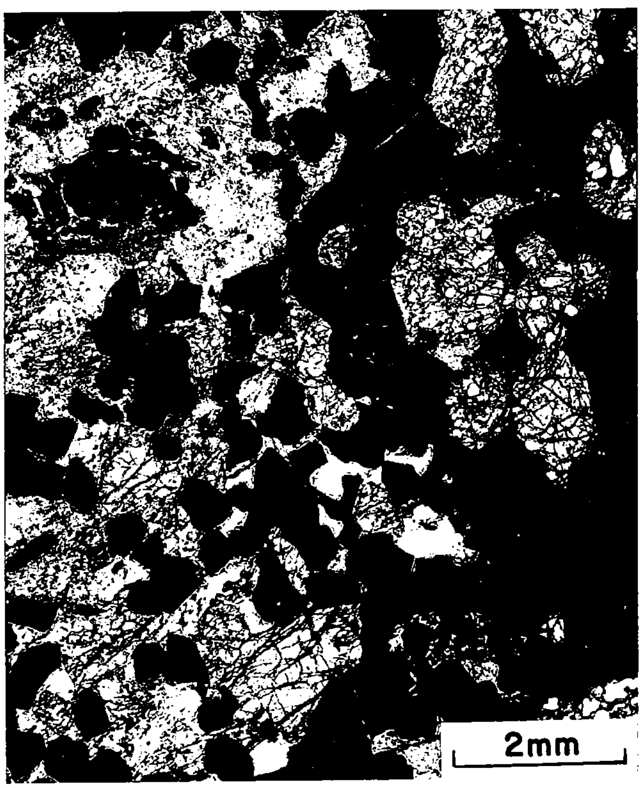

Figure 50. Photomicrograph of olivine-magnetite rock (T-76) from Reed's pit southeast of Roosevelt. Both magnetite and ilmenite (black), as well as olivine (medium gray), tend to be euhedral and are probably cumulus phases. Where opaques are more abundant (on right) they appear anhedral, but grain boundaries, visible in reflected light, show them to be euhedral to subhedral. (Plane light.)

entrance to the quarry shows a sharply contrasted intrusion breccia wherein assimilation has been minimal (fig. 51). In the quarry, assimilative effects have evidently been extensive, and the rock grades compositionally from tonalite to adamellite, as described earlier in this guidebook. In the quarry walls, relict ghosts of more mafic material are evident (fig. 27).

STOP 10: Leucogranogabbro at Twin Mountain

This is one of several occurrences of hybrid(?) or "intermediate" rock described by Huang (1955). A detailed description is given earlier in this guidebook. The rock is exposed in the small outcrop on the east side of the dirt road. Across the road to the west rise the rather subdued outcrops of Lugert Granite, which constitute Twin Mountain. A sharp contact of this granite against leucogranogabbro can be seen, in which individual euhedral plagioclase megacrysts of leucogranogabbro are cut by granite. (See fig. 28.) This would seem to argue against hybridization by the Lugert Granite, as proposed by Huang.

The leucogranogabbro is clearly a plagioclase (labradorite) cumulate and has sporadic intercumulus pyroxenes. The origin of the 25 percent or so of interstitial quartz and alkali feldspar remains something of a mystery. The composition of this mesostasis is not that of expected intercumulus pore material, as low-temperature ferromagnesian phases are systematically lacking. Furthermore, this would be the only orthocumulate in the layered series of the Raggedy Mountain Gabbro Group and the only rock of that group to contain appreciable quartz and alkali feldspar. Yet the gross cumulate texture closely resembles that of the layered series. Perhaps Huang was on the right track when he discussed impregnation by granitic fluids, although the specific mechanisms and details of the processes leading to such homogeneous rock remain obscure.

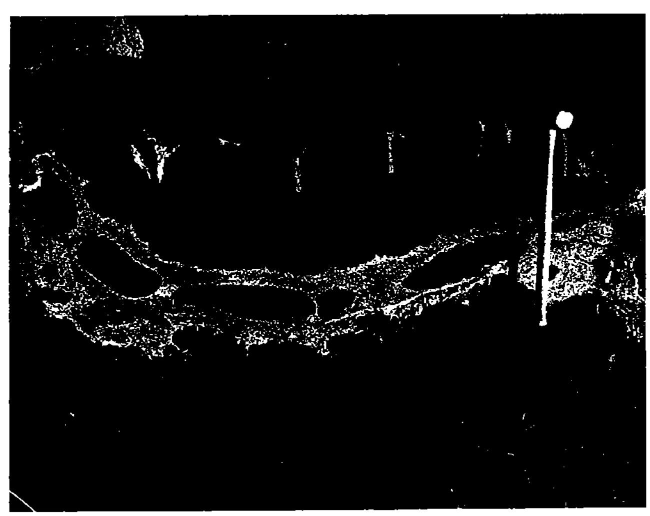

Figure 51. Sharply contrasted intrusion breccia at Cold Springs Granite Company Quarry, SW¼ sec. 21, T. 4 N., R. 17 W. Light-colored aplite has intruded dark microdiorite with minimal assimilation. (Stop 9.)

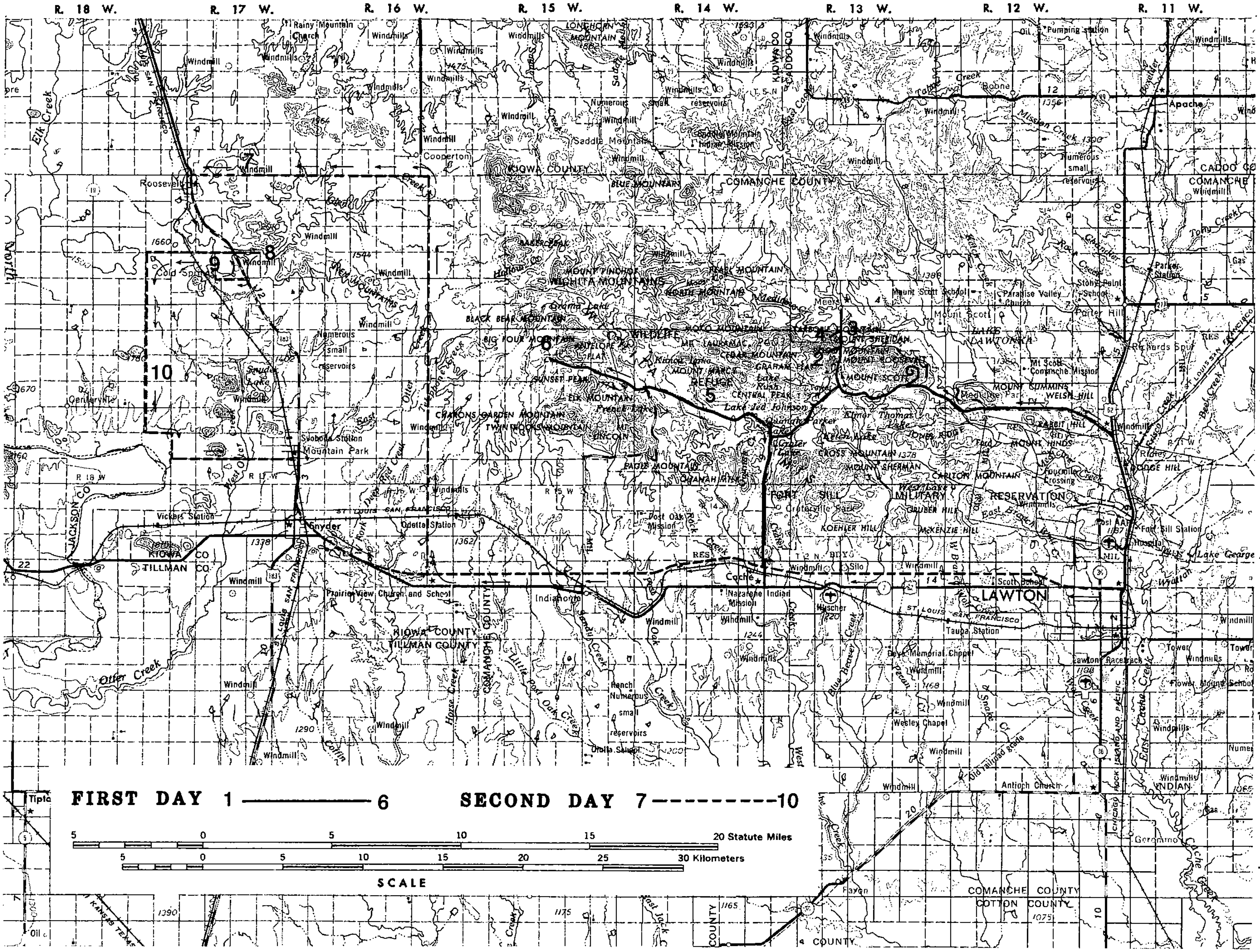

Figure 52. Topographic map of Wichita Mountain area, showing route and stops of field trip. Base from U.S. Geological Survey topographic map of Lawton quadrangle, 1:250,000 series.

ROAD LOG

Log starts and ends at the entrance to the Montego Bay Motel from Gore Boulevard, on the south side of Lawton.

Saturday, Feb. 28, 1976

Cumulative mileage	Distance between points	
0.0		Montego Bay Motel, Lawton, Oklahoma. Turn left (west) onto Gore Boulevard.
	0.1	
0.1		Right turn (north) onto U.S. 277-281. Head north through Lawton.
	7.5	
7.6		Take turnoff for SR 49, to Medicine Park and The Holy City.
	0.3	
7.9		Left turn (west) under H. E. Bailey Turnpike.
	1.6	
9.5		Easternmost exposures of Wichita Mountain granites. These outcrops probably correlate with Mount Scott Granite of our first stop (Lugert Granite of Taylor, 1915). Rock consists of 10-percent gray orthoclase phenocrysts 5 mm long in groundmass of graphic quartz and orthoclase.
	3.5	
13.0		Go straight. Good view of Mount Scott along branching road to right.
	1.1	
14.1		State Fish Hatchery, and cross Medicine Creek. This creek drains northern side of Wichita Mountains and contains pebbles of rock types encountered there.
	0.4	
14.5		Mount Scott straight ahead. There are outcrops of granite in all of surrounding hills. Granite characteristically is more resistant to weathering than other igneous rocks of area, and perhaps is more highly jointed. Results are that granite supports all of high topography in region, and in northern areas granite forms much more blocky, angular outcrops than other rocks.
	0.8	
15.3		Go straight. To left is turnoff to Lake Elmer Thomas Dam. Northern dam abutment contains discontinuous basalt dike. Dike terminates near lake's edge; it shows a chilled margin against the granite but is cut by granite dikelets along its full length. The granite is discolored in places near the dike, as if contaminated. This dike almost certainly records an episode of mafic magmatism following the felsic intrusions.
	0.1	
15.4		Enter the Wichita Mountains Wildlife Refuge. Note that the speed limit is 45 mph during the day and 35 at night. This is open range, with longhorn cattle and buffalo quite likely to be on the highway. A driver of a vehicle that hits one of these animals pays a fine based on the gross weight of the animal and the amount of the bid from the local butcher shops for the meat, and loses his driver's license for 6 months. PLEASE DRIVE CAREFULLY.
	1.6	
17.0		Right turn (north) to go up Mount Scott.
	3.0	
20.0		STOP 1. Top of Mount Scott. The purpose of this stop is to get an overview

Cumulative mileage	Distance between points	
		of the geology of the eastern part of the mountains (see detailed description on p. 25). Return to SR 49.
	3.0	
23.0		Right turn (west) on SR 49.
	1.5	
24.5		Most of the road cut is aphanitic felsic material, thought to be hornfelsed Carlton rhyolite. There are extensive exposures of the rhyolite to the south in what is now Fort Sill Military Reservation. The granite is thought to intrude beneath and into the rhyolites. Thus the exposures here constitute the roof of the Mount Scott sill, where it is in contact with the overlying rhyolite. The valley to the south is fault-lined, with the far side granite, and therefore upthrown. The clearest evidence for the intrusive nature of the granite into the rhyolites is from the abundant drill holes into these rocks by various petroleum companies. At the present time the rhyolites to the south, on the military reservation, are inaccessible to civilians for study. Even if permission could be obtained, the presence of live artillery shells on the ground makes the idea of working there very unappetizing.
	0.2	
24.7		The upper part of the road cut is the Permian Post Oak Conglomerate. This coarse-clastic facies formed close to the mountains at the same time as red-shale facies farther away. The shale covers the conglomerate, and apparently covered the mountains entirely sometime during the Permian. Notice the distinctive "cannonballs" of granite. These boulders have been used abundantly in the local architecture, particularly in Medicine Park, the small community we came through shortly before entering the refuge. We will see some examples later this morning.
	1.0	
25.7		Right turn (north) on SR 115, toward Meers. Note that we are on an upland flat. The flat is an exhumed Permian surface, on the top of the Post Oak Conglomerate; it is supported by the granitic rocks around it, whereas the softer shales surrounding the mountains have been eroded below the surface by 50 to 100 feet or more.
	1.8	
27.5		STOP 2. Left turn into a dead-end drive. The purpose of this stop is to examine the vertical variation in the Mount Sheridan Gabbro and look at the contact with the overlying Mount Scott Granite. There is a locked gate here. This part of the refuge is not open to the public. Elk and buffalo roam this country; the remoter parts have nesting eagles. Access is strictly by permission of the refuge manager—trespassers are subject to an automatic $500 fine. We will go through the gate ('76 field trippers have been cleared!) and climb to the top of Little Mount Sheridan (see detailed description on p. 26). Continue northward on SR 115.
	0.1	

Cumulative mileage	Distance between points	
27.6		North entrance to the Wichita Mountains Wildlife Refuge.
	1.8	
29.4		Meers. We will have lunch at this little country store. Meers was originally a mining town (if you can call the multiple but fruitless adits in these hills "mines"). Located within the boundaries of the refuge, the town was moved outside the refuge boundary after the designation of the refuge; the new location was to the south of the present location of the store. The town died a slow death owing to the lack of evidence for gold in them thar hills. An entrepreneur moved the post office for a second time, to its present location, where it lives partly on a fascinated clientele who come out periodically from Lawton to have lunch, and partly on the tourist trade (it was written up in the AAA bulletin, summer 1975). After lunch, we will start retracing our steps by returning south toward the refuge.
	0.5	
29.9		STOP 3. Prehnitized layered anorthosite. This is one of Walter Huang's favorite stops, described in his field guide; the rock compositions are given in his petrology text. The purpose of the stop is to examine some of the layered anorthosites (see detailed description, p. 26). After this stop we will continue south.
	0.1	
30.0		Right turn (west) through a gate, immediately followed by a left turn through another gate. We are now on private property, owned by one of the local ranchers. Although the rancher has been extremely courteous, and very generous of access by geologists, continued access will only be assured by mutual respect. Please make sure that you close the gates behind you, and do not chase the cattle.
	0.9	
30.9		STOP 4. This is a quarry operated by the Rock of Ages Stone Company. It is in the Mount Sheridan Gabbro. The purpose of the stop is to get a good look at fresh gabbro, and to discuss the relationships between the massive biotite gabbro and the layered anorthosites of the Raggedy Mountain Gabbro Group. Return to the road after this stop.
	0.8	
31.7		Meers quartzite. The crest of the hill, including road cuts on SR 115, is composed of clastic sedimentary rocks, primarily quartz sandstones with some interlayered shales, now metamorphosed by the surrounding gabbro. The Meers Quartzite occurs as small pods in the gabbro and granite. Two large xenoliths occur, one here and one to the west at the base of Tarbone Mountain. This material is thought to be the only traces of the country rock for the mafic intrusions exposed at the surface. In the subsurface the Tillman Metasedimentary Group is considered the country rock for the intrusive rocks; thus, the Meers Quartzite is thought to be small pieces of the Tillman. The rocks consist of well-preserved quartz sand grains, with a matrix of microcline and smaller amounts of biotite and sillimanite.
	0.1	

Cumulative mileage	Distance between points	
31.8		Right turn (south), after coming back out through the two gates. Note that immediately we cross over a small rise, the continuation of the xenolith of Meers Quartzite.
	0.2	
32.0		Medicine Creek crossing.
	0.1	
32.1		Notice the basaltic dike cutting the Mount Sheridan Gabbro in the road cut. This dike forms a slight ridge in the topography, and can be traced for several hundred meters to the east.
	0.9	
33.0		Reenter the Wichita Mountains Wildlife Refuge through the north entrance.
	1.9	
34.9		Right turn (west) on SR 49. To the northwest, almost totally hidden in a low valley, is The Holy City. This is the site of a massive Easter pageant, with sometimes 100,000 to 200,000 people attending. If you plan to return to the Wichitas someday for geological purposes, avoid the Easter season.
	3.3	
38.2		Sulphur Flat Prairie Dog Town on the right. We are now in the central valley of the refuge, with granitic ranges to the north (Mount Scott or Lugert Granite) and south (Quanah Granite). Although this immediate area is also floored by granite, we shall soon be on a gabbro floor, which constitutes most of the interior of the refuge. Here again, the susceptibility to weathering of the gabbro relative to the granite shows up.
	0.1	
38.3		Bear right (north) at the Y in the road, toward Quanah Parker Visitor Center.
	1.0	
39.3		Quanah Parker Visitor Center is on the left. The center is a modest, but nicely done, introduction to the natural history of the refuge.
	2.2	
41.5		STOP 5. Turn left into the parking lot for Burford Lake Camp Site. We will cross over the road and look at the boulders piled up on the north side. Although they are not strictly in place, they are representative of rocks nearby which are in place. The purpose of the stop is to examine the most pronounced igneous lamination exposed in the layered-series rocks. Similar rocks crop out on the north side of the Wichita Mountains, but lamination this pronounced is rare in the western region, in the Glen Mountains. Continue westward after this stop.
	1.6	
43.1		Exhibition pasture on the right. You may well have already seen the longhorns, but Old Red, the longest horned steer on the refuge, is housed in this pasture. The wapiti (elk) are normally a very shy animal. They are abundant in the northern, restricted part of the refuge, but are almost never seen by the public there. This exhibition pasture has several individuals in it close to the road. You may have to look carefully, though. If they lie down in the grass, they disappear completely.
	1.1	

Cumulative mileage	Distance between points	
44.2		Go straight. The refuge headquarters is off to the left. This is also an exit from the refuge. The road passes through the Quanah Granite in areas of lovely exfoliation jointing and large, smooth, rounded boulders–classic granite weathering.
48.0	3.8	Exit the Wichita Mountains Wildlife Refuge via the western entrance.
48.4	0.4	Entrance to the Ira B. Smith Granite Quarry. We will park a little farther on.
48.5	0.1	STOP 6. Park in the drive on the right, where it says "No parking for hunters." We will walk back along the road we came on, then up the dirt road into the quarry. The purpose of this stop is to examine fresh samples of the Mount Scott (Lugert) Granite. There is a second quarry below this one (to the west). If you climb the spoils pile, go very carefully–some of the large blocks are not stable, and may roll down the slope. After this stop, we will return through the refuge to the Montego Bay Motel.
58.6	10.1	Go straight. This is the Y intersection at the Prairie Dog Town. We will continue south at this intersection to Cache.
63.7	5.1	Turn left (east) on U.S. 62, to Lawton.
74.5	10.8	Blinking red light at intersection with the Cache highway–entrance into Lawton. Continue onward.
78.0	3.5	Turn right (south), onto U.S. 277-281. Right after the turn onto the entry ramp, stay left, to get onto the highway.
79.1	1.1	Take exit ramp for Gore Boulevard.
79.4	0.3	Left turn on Gore Boulevard, east over the freeway.
79.6	0.2	Entrance to home-away-from-home.

END OF FIRST DAY

Sunday, Feb. 29, 1976

Cumulative mileage	Distance between points	
0.0		Montego Bay Motel, Lawton, Oklahoma. Turn left onto Gore Boulevard.
0.1	0.1	Right turn (north) onto U.S. 277-281.
1.1	1.0	Left turn (west), on U.S. 62, the Cache highway.
4.0	2.9	Bear right (do not follow the Cache highway here). So far, we are retracing last night's steps.
5.0	1.0	The low hills on the right in the foreground are limestone.
15.6	10.6	Cache. Go straight on through.
29.2	13.6	Right turn (north) on SR 54.
37.2	8.0	Road to west entrance of the Wichita Mountains Wildlife Refuge.
40.9	3.7	Climb up to a low rise. This is the eastern end of the Raggedy Mountains. The best known exposures of the layered anorthosites of the Raggedy Mountain Gabbro Group occur west of here in the higher parts of these hills. Here the hills are composed of anorthosite, with scattered large oikocrysts of pyroxene and magnetite. To the right are the hills that form the western margin of the Wichita Mountains Wildlife Refuge. These hills are entirely granite. The entire area visible to the east is part of the restricted area we entered near Meers yesterday.
45.4	4.5	Left turn (west) onto SR 19, toward Roosevelt.
53.0	7.6	STOP 7. Stop in the obvious road cut. The purpose of this stop is to examine the well-developed layering of the anorthosite, and to see the diabase and aplite dikes which intrude the layered series. Continue westward toward Roosevelt.
53.7	0.7	Road cut with extremely fresh anorthosite.
54.5	0.8	Left turn (south) on U.S. 183 in Roosevelt.
56.2	1.7	Boulders by the side of the road are out of place but show some of the large poikilitc pyroxene crystals. These crystals reach 15 cm across and can be seen by the reflections of the sun. Detailed work in these rocks on cloudy days is difficult and on rainy days is a total loss.
57.8	1.6	We are now crossing the Glen Mountains. The hills to the left contain the thickest and most continuous sequences of layered anorthosites yet found in this area.
58.3	0.5	Turn left (east) on a section-line road marked by some rock pillars. All of the land to either side of this road is privately owned, and should be entered only after contacting the owners. Such permission has been obtained for the '76 field trippers.
59.4	1.1	STOP 8. Please park in such a way that neither the road nor the gates are obstructed. At this stop we will spend some time climbing the slope to the north. We will examine some of the various textures of the layered anorthosites in the process: we will also examine the intrusion breccia of the intrusive group. Return to the highway, U.S. 183.
60.5	1.1	Turn left (south) on U.S. 183.
61.1	0.6	Turn right (west), to get onto the old highway. A new reservoir has just been built to the south and covers part of the old highway–thus the new highway. Continue south on the old highway.
61.4	0.3	Turn right (west) on dirt road.
62.3	0.9	Turn right (north).
62.7	0.4	STOP 9. The Cold Springs Granite Company Quarry. This area is the subject of a thesis in 1950 by Jack Walper of Texas Christian University. We will return the way we came to the new U.S. 183.

Cumulative mileage	Distance between points	
	1.6	
64.3		Turn left (north) on U.S. 183.
	0.6	
64.9		Turn left (west) on the section-line road that we followed eastward earlier.
	3.5	
68.4		Turn left (south) on a section-line road. Ahead is Twin Mountain, the subject of the last stop of the field trip.
	4.0	
72.4		STOP 10. This is another of Huang's stops. We will examine the leucogranogabbro and look at relationships between it, the nearby red Lugert Granite, and the dikes in the area. Continue southward to the next major east-west section-line road. Take this road east (left) to U.S. 183. Right turn (south) on U.S. 183, toward Snyder. We may have to jog several times to get to the highway. The hills are composed of the typical red Lugert Granite. The spar pole from a quarry at the eastern end can easily be seen, although this quarry is no longer operating. Near the crest of the hill is an operating quarry, producing polished red granite for building facings, tombstones, etc.
		Enter Snyder.
	1.1	
		Left turn (east) on U.S. 62B.
	3.0	
		Left turn (east) on U.S. 62.
	26.9	
		Lawton.

REFERENCES CITED

Biggar, G. M., 1974, Phase equilibrium studies of the chilled margins of some layered intrusions: Contrib. Mineral. Petrol., v. 46, p. 159-167.

Bowen, N. L., 1928, The evolution of the igneous rocks: Princeton Univ. Press, 334 p.

Burke, Kevin, and **Dewey, J. F.**, 1973, Plume-generated triple junctions: key indicators in applying plate tectonics to old rocks: Jour. Geology, v. 81, p. 406-433.

Burke, W. H., **Otto, J. B.**, and **Denison, R. E.**, 1969, Potassium–argon dating of basaltic rocks: Jour. Geophys. Research, v. 74, p. 1082-1086.

Chase, G. W., **Frederickson, E. A.**, and **Ham, W. E.**, 1956, Resume of the geology of the Wichita Mountains, Oklahoma, *in* Petroleum geology of southern Oklahoma–a symposium; sponsored by the Ardmore Geological Society: Am. Assoc. Petroleum Geologists, v. 1, p. 36-55.

Clark, S. P., Jr. (ed.), 1966, Handbook of physical constants [revised edition]: Geol. Soc. America Mem. 97, 587 p. (Originally published in 1942.)

Flawn, P. T., 1956, Basement rocks of Texas and southeast New Mexico: Texas Univ. Pub. 5605, 261 p.

Gilbert, M. C., 1960, The geology of the western Glen Mountains, Oklahoma: Oklahoma Univ. unpub. M.S. thesis, 48 p.

Hales, A. L., and **Herrin, Eugene**, 1972, Travel times of seismic waves, *in* Robertson, E. C. (ed.), The nature of the solid earth: New York, McGraw-Hill Book Co., p. 172-215.

Ham, W. E., **Denison, R. E.**, and **Merritt, C. A.**, 1964, Basement rocks and structural evolution of southern Oklahoma: Oklahoma Geol. Survey Bull. 95, 302 p.

Hoffman, Paul, **Dewey, J. F.**, and **Burke, Kevin**, 1974, Aulacogens and their genetic relation to geosynclines, with a Proterozoic example from Great Slave Lake, Canada, *in* Dott, R. H., Jr., and Shaver, R. H. (eds.), Modern and ancient geosynclinal sedimentation (Kay volume): Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 19, p. 38-55.

Huang, W. T., 1955, Occurrences of leucogranogabbro and associated igneous rocks in the Wichita Mountains, Oklahoma: Am. Jour. Sci., v. 253, p. 341-357.

____ 1962, Precambrian igneous rocks of the Wichita Mountains, Oklahoma: Texas Christian Univ. and Baylor Geol. Soc. Field Trip Guidebook, 27 p.

Huang, W. T., and **Merritt, C. A.**, 1954, Petrography of the troctolite of the Wichita Mountains, Oklahoma: Am. Mineralogist, v. 39, p. 549-565.

Hunter, H. E., 1967, Raggedy Mountain Gabbro Group, *in* Stone, G. T. (ed.), The structure and igneous rocks of the Wichita Mountains, Oklahoma: Geol. Soc. America, South-Central Sec., 1st Ann. Mtg., Field Trip Guidebook, p. 34-41.

____ 1970, Raggedy Mountain Gabbro Group, *4th part of* The structure and igneous rocks of the Wichita Mountains, Oklahoma: Compass, v. 48, p. 27-31.

____ 1973, Description of the layered basic igneous rocks in the Raggedy Mountain Gabbro Group, *in* Johnson, K. S., and Denison, R. E., Igneous geology of the Wichita Mountains and economic geology of Permian rocks in southwest Oklahoma: Oklahoma Geol. Survey, Guidebook for GSA Field Trip No. 6 (1973 Ann. Mtg.), p. 4-5.

Irvine, T. N., 1974, Petrology of the Duke Island ultramafic complex, southeastern Alaska: Geol. Soc. America Mem. 138, 240 p.

Irving, E., and **Park, J. K.**, 1972, Hairpins and superintervals: Canadian Jour. Earth Sci., v. 9, p. 1318-1324.

Johnson, K. S., 1974 [1975], Islands in the sea–geology of the Wichitas: Great Plains Jour., v. 14, no. 1, p. 33-55.

Johnson, K. S., and **Denison, R. E.**, 1973, Igneous geology of the Wichita Mountains and economic geology of Permian rocks in southwest Oklahoma: Oklahoma Geol. Survey, Guidebook for GSA Field Trip No. 6 (1973 Ann. Mtg.), 33 p.

Jones, V. L., and **Lyons, P. L.**, 1964, Vertical-intensity magnetic map of Oklahoma: Oklahoma Geol. Survey Map GM-6, scale 1:750,000, text.

Karns, A. W. W., 1961, Ophitic pyroxene from the Raggedy Mountains area, Wichita Mountains, Oklahoma: Oklahoma Univ. unpub. M.S. thesis, 68 p.

Ku, C. C., **Sun, Stanley**, **Soffel, Heinrich**, and **Scharon, LeRoy**, 1967, Paleomagnetism of the basement rocks, Wichita Mountains, Oklahoma: Jour. Geophys. Research, v. 72, p. 731-737.

Kuno, Hisashi, 1950, Petrology of Hakone Volcano and the adjacent areas, Japan: Geol. Soc. America Bull., v. 61, p. 957-1020.

Lyons, P. L., 1964, Bouguer gravity-anomaly map of Oklahoma: Oklahoma Geol. Survey Map GM-7, scale 1:750,000, text.

Merritt, C. A., 1965, Mt. Scott Granite, Wichita Mountains, Oklahoma: Oklahoma Geology Notes, v. 25, p. 263-272.

____ 1967a, Names and relative ages of granites and rhyolites in the Wichita Mountains, Oklahoma: Oklahoma Geology Notes, v. 27, p. 45-53.

____ 1967b, Mt. Scott Granite, *in* Stone, G. T. (ed.), The structure and igneous rocks of the Wichita Mountains, Oklahoma: Geol. Soc. America, South-Central Sec., 1st Ann. Mtg., Field Trip Guidebook, p. 22-23.

Mitchell, B. J., and Landisman, M., 1970, Interpretation of a crustal section across Oklahoma: Geol. Soc. America Bull., v. 81, p. 2647-2656.

Muehlberger, W. R., Hedge, C. E., Denison, R. E., and Marvin, R. F., 1966, Geochronology of the midcontinent region, United States–Pt. 3, Southern area: Jour. Geophys. Research, v. 71, p. 5409-5426.

Muir, I. D., and Tilley, C. E., 1957, The picrite-basalts of Kilauea, *pt. 1 of* Contributions to the petrology of Hawaiian basalts: Am. Jour. Sci., v. 255, p. 241-253.

Phelps, D. W., 1975, Phase chemistry of the Layered Series, Raggedy Mountain Gabbro Group, Oklahoma: Rice Univ. unpub. M.A. thesis, 122 p.

Phinney, W. C., 1972, Northwestern part of Duluth Complex, *in* Sims, P. K., and Morey, G. B. (eds.), Geology of Minnesota: a centennial volume: Minnesota Geol. Survey, p. 335-345.

Powell, B. N., and Phelps, D. W. (in preparation), Mineral chemistry of igneous cumulates of the Wichita Magmatic Province, Oklahoma: implications regarding the tectonic evolution of the southern midcontinent.

Pruatt, M. A., 1975, The Southern Oklahoma Aulacogen: a geophysical and geological investigation: Oklahoma Univ. M.S. thesis, 59 p.

Roggenthen, William, Napoleone, Giovanni, Fischer, J. F., and Fischer, A. G. (in press), Paleomagnetism and age of Wichita Mountain basement [abs.]: Geol. Soc. America, South-Central Sec., 10th Ann. Mtg., Abstracts with Programs.

Rotan, P. M., 1960, Preferred orientation of plagioclase in basic rocks, Raggedy Mountains, southwestern Oklahoma: Oklahoma Univ. unpub. M.S. thesis, 62 p.

Scofield, Nancy, 1973, Petrography, mineralogy, and chemistry of the layered basic igneous rocks in the Raggedy Mountain Gabbro Group, *in* Johnson, K. S., and Denison, R. E., Igneous geology of the Wichita Mountains and economic geology of Permian rocks in southwest Oklahoma: Oklahoma Geol. Survey, Guidebook for GSA Field Trip No. 6 (1973 Ann. Mtg.), p. 6-9.

_____ 1975, Layered series of the Wichita Complex, Oklahoma: Geol. Soc. America Bull., v. 86, p. 732-736.

Shatski, N. S., 1946, The Great Donets Basin and the Wichita System. Comparative tectonics of ancient platforms: SSSR, Akad. Nauk. Izv., Geol. ser., no. 6, p. 57-90.

Snyder, G. L., 1959, Geology of Little Sitkin Island, Alaska: U.S. Geol. Survey Bull. 1028-H, p. 169-210.

Spall, Henry, 1970, Paleomagnetism of basement granites in southern Oklahoma: final report: Oklahoma Geology Notes, v. 30, p. 136-150.

Spencer, A. B., 1961, Geology of the basic rocks of the eastern portion of the Raggedy Mountains, southwestern Oklahoma: Oklahoma Univ. unpub. M.S. thesis, 46 p.

Stone, G. T. (ed.), 1967, The structure and igneous rocks of the Wichita Mountains, Oklahoma: Geol. Soc. America, South-Central Sec., 1st Ann. Mtg., Field Trip Guidebook, 46 p.

Talwani, Manik, Worzel, J. L., and Landisman, M. G., 1959, Rapid gravity computations for two-dimensional bodies with application to the Mendocino submarine fracture zone [Pacific Ocean]: Jour. Geophys. Research, v. 64, p. 49-59.

Taylor, C. H., 1915, Granites of Oklahoma: Oklahoma Geol. Survey Bull. 20, 108 p.

Thornton, E. C., 1975, Anorthosite-gabbro-granophyre relationships, Mount Sheridan area, Oklahoma: Rice Univ. unpub. M.A. thesis, 65 p.

Vincenz, S. A., Yaskawa, K., and Ade-Hall, J. M., 1975, Origin of magnetization of Wichita Mountains granites, Oklahoma: Geophys. Jour. Royal Astron. Soc., v. 42, p. 21-48.

Wager, L. R., 1963, The mechanism of adcumulus growth in the layered series of the Skaergaard intrusion, *in* Symposium on layered intrusions–Internat. Mineralog. Assoc., 3d Gen. Mtg., Washington, D. C., 1962: Mineral. Soc. America Spec. Paper 1, p. 1-9.

Wager, L. R., and Brown, G. M., 1967, Layered igneous rocks: San Francisco, W. H. Freeman and Co., 588 p.

Walper, J. L., 1951, Assimilation in the Cold Springs area of the Wichita Mountains igneous complex, Oklahoma: Am. Jour. Sci., v. 249, p. 47-65.

Wasserburg, G. J., Wetherill, G. W., Silver, L. T., and Flawn, P. T., 1962, A study of the ages of the Precambrian of Texas: Jour. Geophys. Research, v. 67, p. 4021-4047.

Widess, M. B., and Taylor, G. L., 1959, Seismic reflections from layering within the pre-Cambrian basement complex, Oklahoma: Geophysics, v. 24, p. 417-425.