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A petrographic study of igneous rock from three drill holes near the Meers fault, Oklahoma

by

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A PETROGRAPHIC STUDY OF IGNEOUS ROCK FROM THREE DRILL HOLES NEAR THE MEERS FAULT, OKLAHOMA

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INTRODUCTION

In recent years the Meers fault, located in southwestern Oklahoma (fig. 1), has gained the attention of scientists since it was discovered that as much as 5 m of vertical displacement has occurred within the past 3,400 years (Ramelli and Slemmons, 1986; Ramelli and others, 1987; Crone and Luza, 1990; Kelson and Swan, 1990). To learn more about and to further characterize the structural setting of the Meers fault and its history of deformation, in 1988 the Oklahoma State Geological Survey drilled five holes along a southwest-northeast trend perpendicular to the strike of the fault (fig. 2). These drill holes, located in SW¼SW¼ sec. 24, T. 4 N., R. 13 W., Comanche County, Oklahoma, are near trenches excavated in 1985 by Crone and Luza (1986). They established that the last known movement along the Meers fault occurred between 1,200-1,300 years ago (Crone and Luza, 1990). During the drilling program, two of the five holes collapsed and only cores from drill holes MF-2, MF-4, and MF-5 were recovered (K.V. Luza, personal commun., 1991). Drill holes MF-4 and MF-5 are about 200 ft apart and are on the southwest side of the fault. Drill hole MF-2, located about 400 ft northeast from MF-4, was drilled to the northeast of the fault (fig. 2).

This report presents the results of the study of the igneous rock portion of the three completed drill holes. The types of igneous rock and their relative degree and type of alteration were determined. In addition, the types of strain indicators were determined from core samples. It was not possible to determine the amount of apparent displacement across the Meers fault from core samples.

GENERAL GEOLOGIC BACKGROUND

The Meers fault, the southernmost fault within the broader Frontal Wichita fault system (Harlton, 1951, 1963, 1972), bounds the north side of the Wichita Mountains in southwestern Oklahoma (fig. 1). Northeast of the Meers fault and flanking the southwestern edge of the Anadarko basin are the Slick Hills, consisting mostly of folded and fractured Cambrian-Ordovician limestones (Donovan, 1986).

Although historically aseismic (Lawson, 1985; Luza and others, 1987), the Meers fault may have the potential for causing large, damaging earthquakes. A prominent scarp (about 16 miles long) in Quaternary deposits along the Meers fault (first noted by Gilbert, 1983a, b) indicates that the fault may have released large earthquakes in the geologically recent past (Donovan and others, 1983; Ramelli and Slemmons, 1986). Crone and Luza (1986) and Madole (1988) have shown that some of the scarp's relief are the result of oblique, late Holocene surface faulting. This oblique sense of movement consists of left-lateral slip and equal or greater up-to-the north vertical slip (Crone and Luza, 1990). On the basis of the surface-faulting event, Crone and Luza (1990) have calculated a moment magnitude of slightly more than 7 for the Meers fault. This value is similar to that (6.6 to 7.2) determined by Kelson and Swan (1990) for the same area of Meers fault.

IGNEOUS LITHOLOGY

The Wichita Mountains were uplifted during Carboniferous foreland tectonism (Kluth and Coney, 1981; Brewer and others, 1983) and are composed of principally gabbro, granite, and rhyolite. These igneous rocks are late Precambrian-Cambrian intrusions related to the development of a Precambrian-Cambrian aulacogen. The oldest igneous rocks in the Wichita uplift are assigned to the Raggedy Mountain Gabbro Group (Ham and others, 1964) or the Raggedy Mountain Formation of Powell and others (1980) and Powell (1982). The Raggedy Mountain Gabbro Group is divided into the older Glen Mountains Layered Complex and the younger Roosevelt

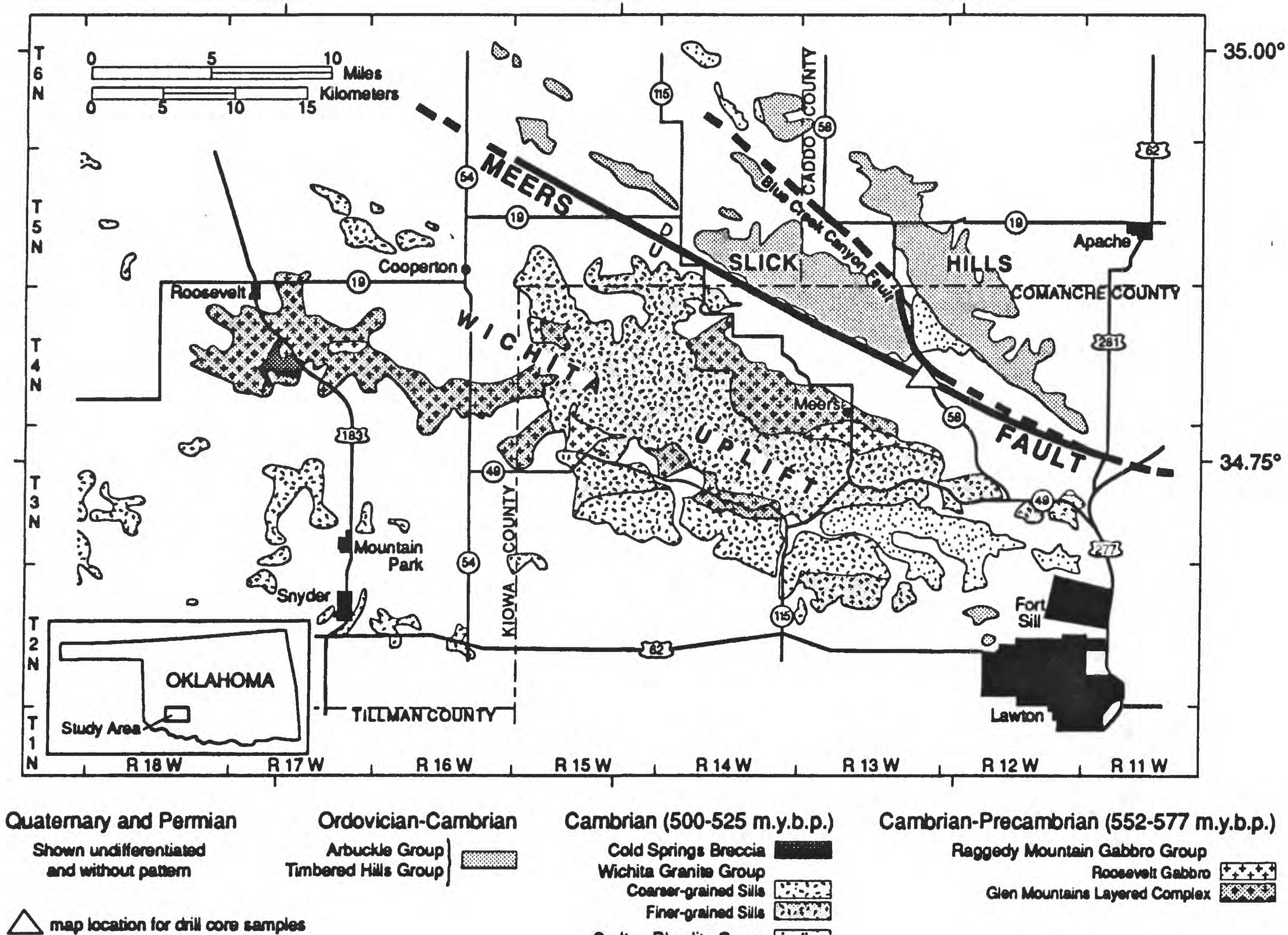


FIGURE 1. Geologic map of the Wichita Mountains, Oklahoma. Open triangle locates drill sites where Route 58 intersects Meers fault. Drill holes completed by the Oklahoma State Geological Survey in 1988 and trenches excavated in 1985 by Crone and Luza (1986). Modified from Powell and others (1980) and Gilbert (1982).

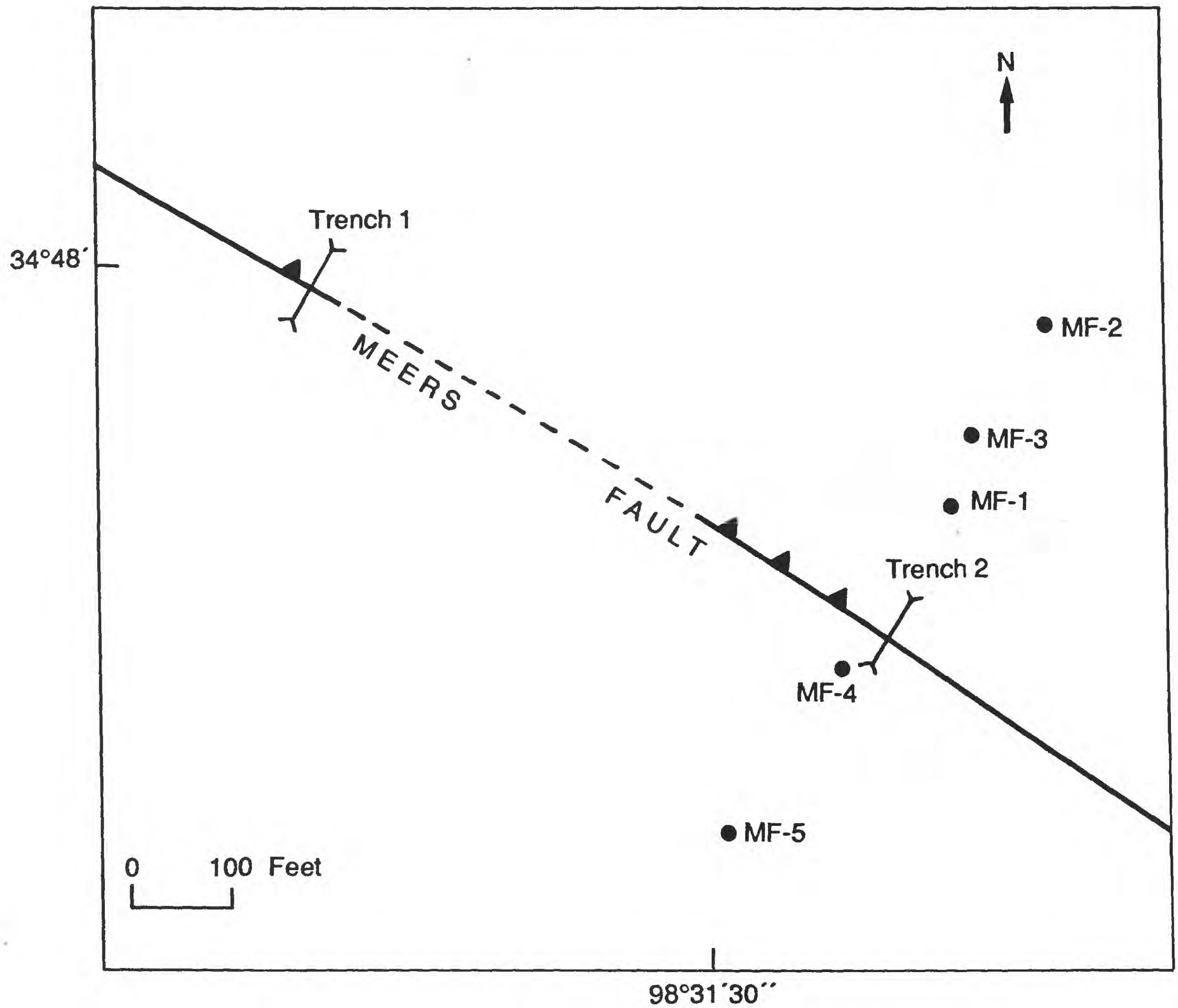


FIGURE 2. Map showing location of drill holes completed in the fall of 1988 by the Oklahoma Geological State Survey with reference to Meers fault (solid line; dashed where inferred) and two trenches excavated in 1985 by Crone and Luza (1986). Teeth indicate separation direction. Modified from K.V. Luza (unpub. data, 1990).

Gabbros. The Glen Mountains Layered Complex (estimated age of 577 m.y.--Sides and Stockton, 1981; Lambert and Unruh, 1986) is subdivided into five zones--G through N (N being the youngest). These zones consist of combinations of and gradations between troctolite, olivine gabbros, anorthositic gabbros, and anorthosites. The overlying Roosevelt Gabbro Formation is divided into the following four gabbro members:

1. Mount Baker (hornblende) Gabbro, a medium- to fine-grained gabbro with hornblende biotite, two pyroxenes, and lacking olivine.
2. Glen Creek Gabbro, medium-grained, biotite-amphibole-bearing olivine gabbro.
3. Sandy Creek Gabbro, a medium-grained, biotite-amphibole-bearing gabbro with or without olivine.
4. Mount Sheridan Gabbro, a medium-grained biotite gabbro, locally fractionated to ferrogranodiorite.

Unconformably overlying the Raggedy Mountain Gabbro Group is the Carlton Rhyolite Group that is described at the Bally Mountain, Blue Creek Canyon, and Fort Sill sections by Ham and others (1964). The Carlton Rhyolite Group is composed of rhyolitic lavas interbedded with minor tuffs and agglomerates that are cogenetic with granite sills of the Wichita Granite Group. The Wichita Granite Group (about 525±25 m.y.; Ham and others, 1964; Gilbert, 1982) cuts and intrudes the older igneous rocks and typically consists of medium- to fine-grained alkali-feldspar granites. Granophyric texture is sporadically distributed within the group (Gilbert, 1982). Granites of the Wichita Granite Group were emplaced as subhorizontal sheets that intruded between the gabbro of the Raggedy Mountain Gabbro Group and the lower part of the rhyolite flows of the Carlton Rhyolite Group. In the area between the Wichita and Arbuckle Mountains, Wichita Granite sills have rhyolite roofs and basalt or graywacke floors (Ham and others, 1964).

The next youngest unit is the Cold Springs Breccia Formation of Powell and others (1980) with a reported age of about 515±10 m.y. (Burke and others, 1969). The breccia is composed of blocks of dark-gray microdiorite in a matrix of light-pink leucogranite.

Basaltic plugs and dikes collectively referred to as the "Late Diabase" (see Powell and others, 1980) are the youngest known igneous intrusions in the Wichita Mountains (Ham and others, 1964; Powell and others, 1980; Gilbert, 1982). Ages for the "Late Diabase" are not known; however, it has been established that these rocks are older than the unconformity separating the lowermost Paleozoic sedimentary rocks from the underlying igneous rocks (Powell and others, 1980).

METHODS

Drill core, supplied for this study by the Oklahoma State Geological Survey, includes all igneous or suspected igneous rocks penetrated in the lower parts of drill holes MF-2, MF-4, and MF-5, and small portions of the overlying sedimentary section (fig. 3). The core was measured in tenths of feet by the Oklahoma State Geological Survey; therefore, these units will be retained for this report. However, measurements of grain size and fracture dimensions in this study will be presented in centimeters and millimeters.

Starting within a portion of the sedimentary units that overlie the igneous rock, 25 samples were collected along the length of each core--one about every 2 ft (where possible). Because of their highly altered and/or fractured condition, some of the igneous rock samples were impregnated with clear epoxy before they were thin sectioned. Half of each thin section was stained for potassium feldspar identification. Classification of the rocks followed the petrographic classification of Williams and others (1982). The Rock Color Chart distributed by the Geological Society of America (Goddard, 1975) is the reference used to define the rock colors. Plagioclase composition was estimated by the Michel-Ley method.

Ultrasonic disaggregation followed by a tap water rinse to remove the clay fraction was used in the method to determine the weight percent of the clay fraction in extremely altered samples. This process removed only a fraction of the clay in these samples. The weight percents determined by this procedure are therefore only minimum values. Clay species was determined by X-ray diffraction of dried, oriented, clay samples having a less than 2 micron size fraction.

Fractures were classified as either microfractures or macrofractures. Microfractures observed in thin section were identified as either transgranular (crossing one or more mineral grains) or intragranular (confined within

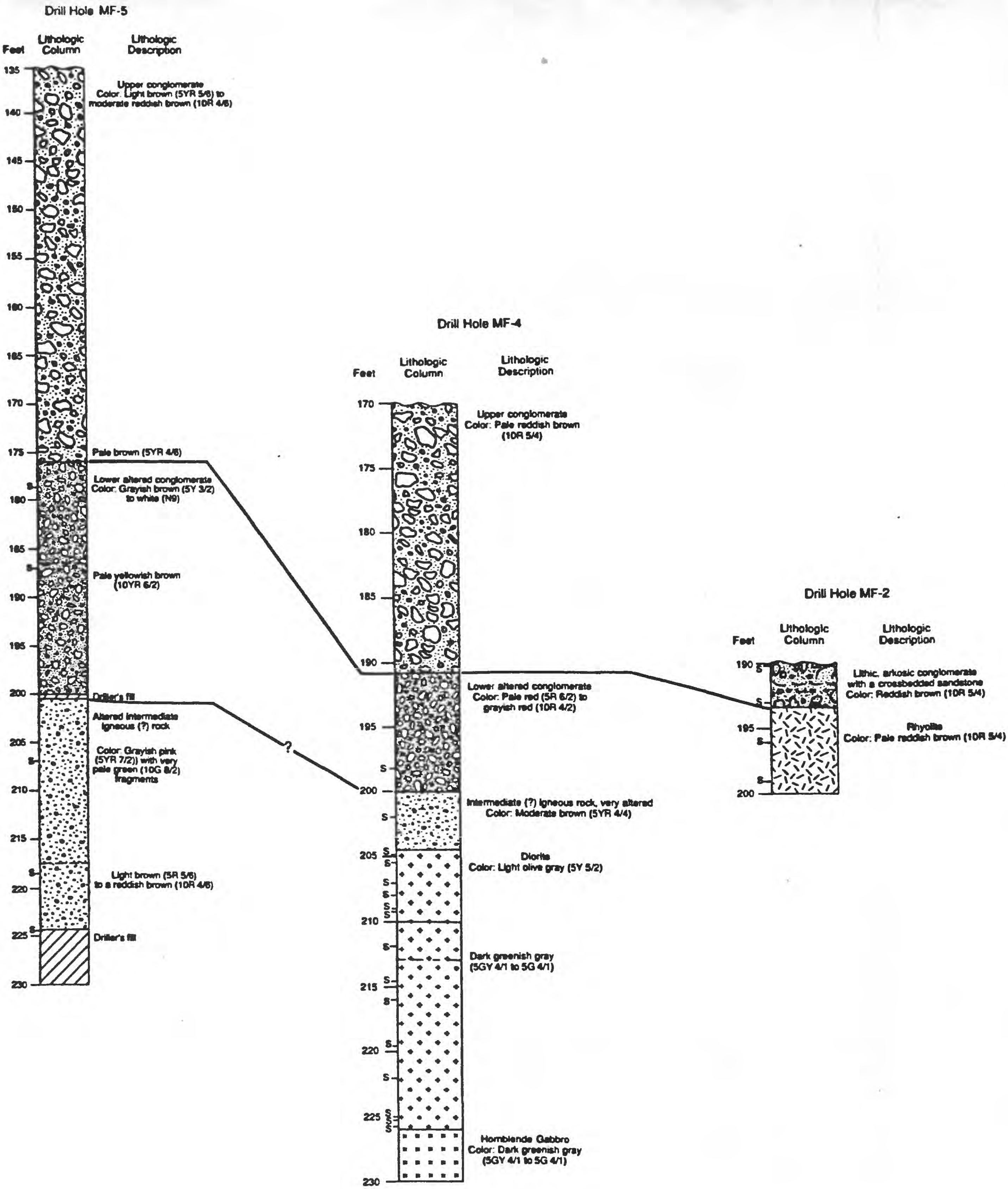


FIGURE 3. Generalized lithologic column (depth in feet) for drill holes MF-2, MF-4, and MF-5. Thin section sample location (S). See figure 2 for drill-hole location.

a mineral grain). On the basis of different types of fracture infillings, both types of microfractures were further subdivided. Those fractures apparent on the core surface are referred to as macrofractures. Inclinations of the macrofractures were measured from the vertical axis of the core. Because the cores are unoriented, true strike of these fractures are not known.

ROCK TYPES

The following rock descriptions are summaries of petrographic and X-ray diffraction studies of the different cores. The discussion of the cores starts with the northeasternmost drill hole (fig. 2), MF-2, and proceeds across the Meers fault to the southwesternmost drill hole, MF-5.

Drill Hole MF-2

A conglomeritic/arkosic sandstone and a rhyolite were recovered from drill hole MF-2 (fig. 3). The sandstone, extending from 190.0 to 193.8 ft, is pale reddish brown (10R 5/4), poorly sorted, and consists of kaolinite fragments (as large as granular size), feldspar, quartz, opaque mineral grains, rock fragments, and mud. Average grain size is medium-size sand, with a maximum grain size of 11.4 mm (pebble-size gravel). Rhyolite and granite(?) (fig. 4) were the only rock fragments identified. From 192.5 to 193.8 ft, a gravel/pebble conglomerate appears to grade upward into a finer grained (medium-grained sand with mud matrix), trough crossbedded sandstone (fig. 3). The cross laminae are composed of angular quartz, altered feldspar, and magnetite grains in a white clay matrix. The magnetite grains appear to be concentrated in these laminae. At the top of the crossbedded unit is a sharp contact with a structureless gravel/pebble conglomerate that, in turn, has a sharp, upper contact at 191.2 ft with a structureless, finer grained, arkosic sandstone. The structureless sandstones probably represent debris-flow deposits and the crossbedded sandstone may be a braided-stream or a scour and fill deposit. The kaolinite fragments and oxidized reddish color of the sedimentary rocks attest to subareal weathering.

At 193.8 ft, the sandstone is in sharp contact with a rhyolite, the only igneous rock in drill hole MF-2. Microscopically, the texture of the rhyolite is holocrystalline, inequigranular, porphyritic-aphanitic, spherulitic, lithoidal, and rarely cumulophyric (fig. 5). Phenocrysts are 0.2 to 1.4 mm in width. Spherulites range from about 0.2 to 0.9 mm in diameter. Because the outer portion of the spherulites are difficult to visually differentiate from the groundmass, only the inner reddish core diameters of the spherulites were measured. Phenocrysts comprise 7-26 percent of the rhyolite and include feldspar (5-20 percent; some have poikolitic texture), magnetite (<0.5-3 percent), trace amounts of zircon, and unidentified altered mafic minerals. The groundmass is devitrified and is composed of feldspar, quartz, and magnetite. Void spaces, varying from 1-3 percent, are filled with secondary quartz. This mineralogy and texture is consistent with the rhyolite of the Carlton Rhyolite Group (Ham and others, 1964, p. 53-60).

The rhyolite is altered and intensely oxidized, imparting a pale-reddish-brown (10R 5/4) to the rock. Feldspar phenocrysts are altered to kaolinite and iron oxide; thus, a specific feldspar species was impossible to identify. At 195.0 ft, the mafic minerals have altered to chlorite. The spherulitic and snowflake (lithoidal) texture indicates that the groundmass was originally glass, but it has devitrified, obscuring the original structure and texture of the rock and filling the pore spaces with quartz. After devitrification, the groundmass altered to clay and iron oxides.

The complete alteration of the feldspars to clay (kaolinite?) and iron oxide, the oxidation of the groundmass to a reddish-orange, and the alteration of the mafic minerals to chlorite is characteristic of deuteric alteration. However, because the paleosurface (an unconformable contact between the sandstone and rhyolite at 193.8 ft) is less than 7 ft above the bottom of the drill hole (fig. 3) and because the core is fractured, weathering processes may have also contributed to the alteration of the rhyolite.

Evidence of deformation in the rhyolite observed in thin section includes fractures and undulatory extinction of quartz grains. All fractures appear to have formed after cooling. Perlitic fractures, a result of contraction during cooling, are either not present or are obscured by both the devitrification and alteration. Macrofractures

FIGURE 4. Photomicrograph under cross polarizers of a granitic rock fragment from the upper conglomerate at 193.0 ft in drill hole MF-2. Note granophyric texture. Quartz (Q) and feldspar (K). Magnification: 25x. See figure 3 for sample location.

FIGURE 5. Photomicrograph under plane light of rhyolite from 199.17 ft in drill hole MF-2. Altered feldspar (F). Chlorite (Ch) is formed by alteration of a mafic mineral. Note spherulites (dark colored, radiating masses) and snowflake texture. Magnification: 25x. See figure 3 for sample location.

in the rhyolite core have an average inclination of about 47° from the vertical axis of the core. Microscopically, only two types of intragranular fractures (both less than 0.5 mm wide) were found. These include iron oxide-filled fractures in feldspars and fractured quartz phenocrysts.

Transgranular fractures formed after devitrification include open (unfilled), breccia-filled, iron oxide-filled, quartz-filled, and clay-filled varieties. Unfilled (open) fractures, ranging from 0.05 to 0.3 mm in width, are juxtaposed to earlier filled fractures, and are within a breccia-filled fracture. They also cross all other fractures. In some cases, open fractures at 196.2 and 199.0 ft have iron-oxide coating their walls, suggesting a reopening of older iron oxide-filled fractures. One open fracture narrows from about 0.1 mm to 0.05 mm; the narrower portion of the fracture is filled with iron oxide. It is possible that these open fractures, which are partially filled with iron oxide and/or have walls partially coated with iron oxide, may have developed and/or have been enhanced by removal of all or part of the iron oxide-fill during thin sectioning. Other fractures filled with iron oxide rarely cross phenocrysts.

The majority of silica-filled fractures, varying from less than 0.05 mm to as much as 0.3 mm wide, are mainly present in the groundmass and rarely cross feldspar phenocrysts or spherulites or extend into quartz grains, but they were not found at 199.0 ft. There are also kaolinite-filled fractures, about 0.05 mm in width, at 199.0 ft, as well as a fracture filled with breccia mixed with iron oxide.

The silica-filled fractures are not crossed by or contained within other fractures. It is not known for certain when the silica-filled fractures formed in relationship to other fractures. However, the silica-filled fractures may have formed before devitrification and filled with silica during devitrification. The voids in the rhyolite also filled with silica during devitrification. If true, than the silica-filled fractures may be the oldest of the fractures. The breccia-filled fracture at 199.0 ft is the next oldest because both iron oxide- and clay-filled fractures are found within the breccia fill. Owing to the lack of crosscutting relationships, it is not evident if the clay-filled fractures are younger or older than the iron oxide-filled fractures. Open fractures cross all other fractures, indicating that they are the youngest. With the exception of the breccia-filled fracture, all the fractures described above may have resulted from post-tectonic extension. The older breccia-filled fracture is a result of shear, probably related to a faulting event on the nearby Meers fault.

Drill Hole MF-4

Core from drill hole MF-4 contains two conglomerates, intermediate(?) igneous rock, diorite, and hornblende gabbro (fig. 3). The upper conglomerate is pale reddish brown (10R 5/4) and is matrix supported. It is composed of rounded to angular rhyolite fragments, angular quartz grains, and subangular to angular fine-grained opaque minerals (fig. 6). Grain size ranges from silt-size mud to pebble-size gravel with an average grain size of coarse sand. The contact between the upper conglomerate and a very altered lower conglomerate is at about 190.7 ft and is marked by a sharp change in color from a pale red (5R 6/2) to grayish red (10R 4/2). Above 190.7 ft, the majority of macrofractures in the upper conglomerate are horizontal or form along cobble boundaries, implying a nontectonic origin. In the lower conglomerate, the majority of macrofractures are inclined 47° to 64° from the vertical axis of the core.

At first appearance, at about 200 ft, the lower conglomerate forms a gradational contact with an altered, brown- (5YR 4/4) colored igneous rock of intermediate(?) composition (a rock that contains about 52-66 percent silica) (fig. 7); this igneous rock extends downward to about 205 ft. All feldspars within the igneous rock are altered to kaolinite, an illitic clay, and carbonate (calcite?). Mafic minerals have altered to calcite(?), chlorite, or biotite. This extreme alteration makes specific mineral identification impossible. However, a few "grains" of magnetite(?) and calcite(?) outline cleavage patterns that suggest that before alteration some of the mafic minerals were amphiboles, probably hornblende. An analysis of two samples collected at 200.8 and 202.8 ft indicates that this material contains more than 59.5 weight percent of a mixture of montmorillonite and kaolinite. After removal of the clay, most of the remaining fragments are moderate brown (5YR 4/4), angular, and range in size from very fine sand to very coarse sand. Some of these brown fragments consist of magnetite(?), hematite, pyrite, and clay; some of these fragments have slickensides; in addition, 15-25 percent of the fragments are calcite. The calcite fragments are either groups of interlocking crystals or single crystals having a crude rhombohedral habit. The calcite fragments are derived from fracture fill of the macrofractures

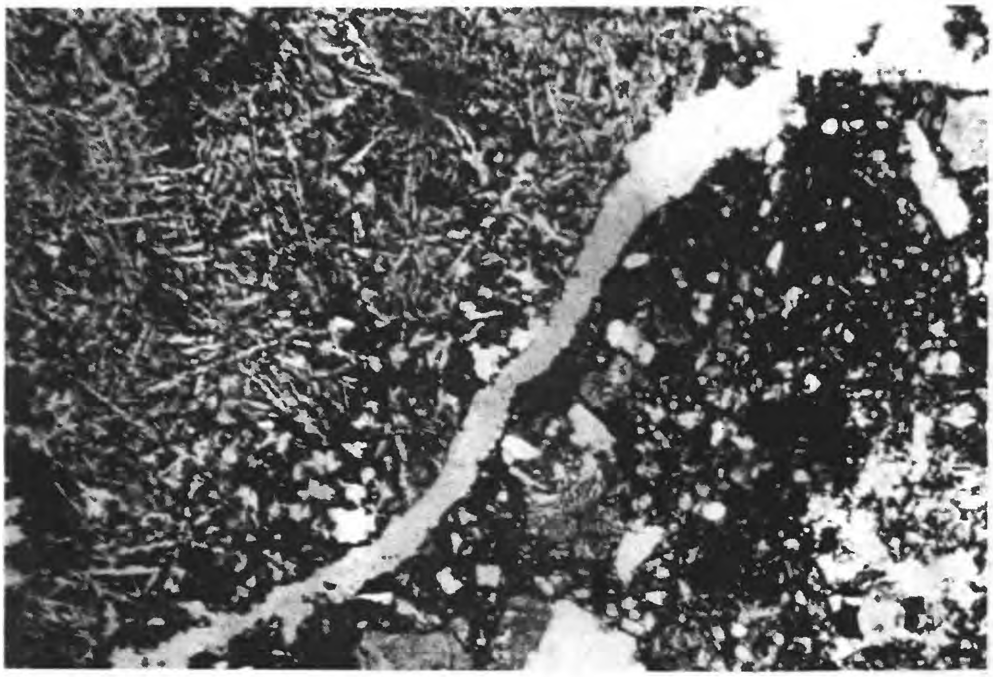


FIGURE 6. Photomicrograph under plane light of upper conglomerate from 175.0 ft in drill hole MF-4. Note rhyolite rock fragment above fracture (center of photo). Magnification: 25x. See figure 3 for sample location.

in the analyzed sample. Most of the alteration in this igneous rock probably resulted from weathering that occurred before and after deposition of the overlying conglomerate.

As observed in thin section, the intermediate igneous(?) rock has two types of transgranular fractures--calcite(?)-filled and unfilled (open) fractures. The calcite(?) fill is not strained, and has a fibrous and/or patchy habit. At 204.5 ft, one fracture is half filled with patchy calcite(?) projecting from one wall toward the fracture's center and a fibrous calcite(?) fill extending from the opposite wall toward the fracture's center; both of these calcite(?) habits are separated by a suture line. Open fractures, 0.1 mm wide, cross calcite(?)-filled fractures at 204.9 ft.

The majority of the mineral grains have intragranular fractures, suggesting that this rock was subjected to greater stress than the rocks in drill hole MF-2. Mineral grains exhibiting similar deformation features in all thin sections include quartz and biotite, the former being fractured and having a high to extreme undulatory extinction and the latter being fractured, and kinked. A few of the altered feldspars have intragranular clay-filled fractures. Some of the altered mafic grains are fractured and filled with magnetite(?). At 204.9 ft, most primary magnetite grains are highly fractured with some fractures filled with calcite(?).

The preceding fracture data indicate that the open fractures are younger than the calcite(?)-filled fractures. Both the intragranular and intergranular fractures filled with various materials may indicate a post-tectonic extensional event; whereas, the kinked and/or fractured biotites and fractured and strained quartz grains suggest an earlier tectonic event.

The contact between the altered, intermediate(?) igneous rock with the underlying diorite is marked by a color change from a moderate brown (5YR 4/4) of the altered intermediate igneous(?) rock to a light olive gray (5Y 5/2) of the diorite. Texture of the diorite (samples from 205.5, 207.0, 208.0, 222.0, and 225.0 ft) is holocrystalline, equigranular, phaneritic, hypidiomorphic-granular, fine to medium grained, and altered to highly altered. The diorite is composed of andesine (45-70 percent) having an An-content of 37-49 percent; potassium feldspar (orthoclase?, <0.05 percent); hornblende (5-40 percent); augite (10-35 percent); quartz (0.05-10 percent); magnetite (10-20 percent); yellow/red biotite (trace to 10 percent); pyrite (0.5 percent); apatite (trace to 0.5 percent), and trace amounts of zircon (fig. 8). At 209.3 ft, the diorite is gabbroic as indicated by the presence of labradorite (An_{69}) with more abundant andesine. A similar diorite, containing 60 percent andesine (An_{33-45}), 15 percent hornblende, 7 percent biotite, 5 percent pyroxene, and 6-9 percent quartz, has been found in both outcrop and in subsurface in southwestern Beckham County (Ham and others, 1964), about 70 miles northwest of the MF drill-hole sites. These diorites are part of the Roosevelt Gabbro Formation of the Raggedy Mountain Group as described by Powell and others (1980) (fig. 1). Diorites in the Arbuckle Mountains differ from the Raggedy Mountain diorites in the Wichita Mountains by their lack of pyroxene and presence of olive-green biotites rather than red-brown biotites (Ham and others, 1964). In this respect, the diorites from drill hole MF-4 are more like to those of the Wichita Mountain area than like the diorites of the Arbuckle Mountains as would be expected by their location.

Most mineral grains in the diorite have been altered. Feldspars have been moderately to highly altered to sericitic and kaolinitic clays and rare calcite(?). Because the composition of plagioclase can change due to alteration, it would be necessary to confirm the optically determined anorthite (An) content of these feldspars by microprobe analysis to confirm the diorite identification. At 222.0 ft, hornblendes are altered to clay and biotite, but at 225.0 ft, only some of the hornblendes are partially to completely altered to biotite. Some of the pyroxenes are moderately altered to either amphibole, chlorite, calcite(?), and/or clay, and some biotites are bleached at this depth. These alteration products probably resulted from deuteric processes.

Deformational features in the diorite include both intragranular and transgranular fractures. Most minerals have intragranular fractures. Quartz grains have slight to high undulatory extinction. Biotites are kinked and feldspars have fractures, less than 0.05 mm wide, filled with clay and calcite(?). Some of these intragranular fractures within magnetite grains are filled with clay. At 204.9 ft, fractures in magnetite are filled with calcite(?). Transgranular, calcite(?)-filled fractures are as wide as 0.5 mm and narrow to less than 0.05 mm. Some fractures are filled with a mixture of clay and some calcite(?) with clay-lined walls. At 225.0 ft, clay-filled fractures, less than 0.05 mm wide, cross iron oxide-filled fractures that are 0.05-0.1 mm wide.

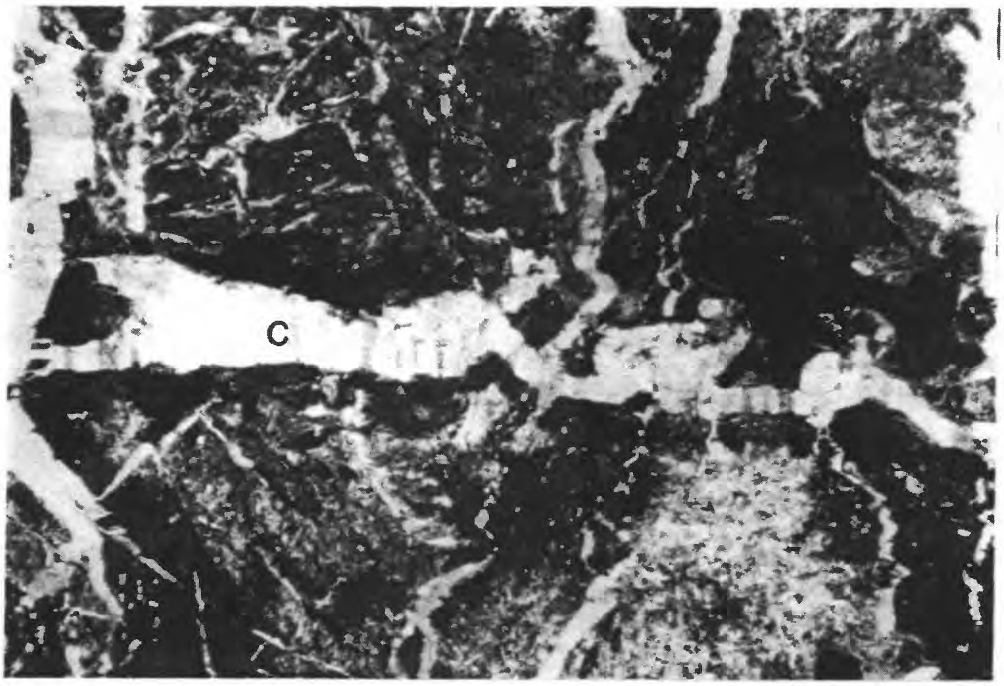
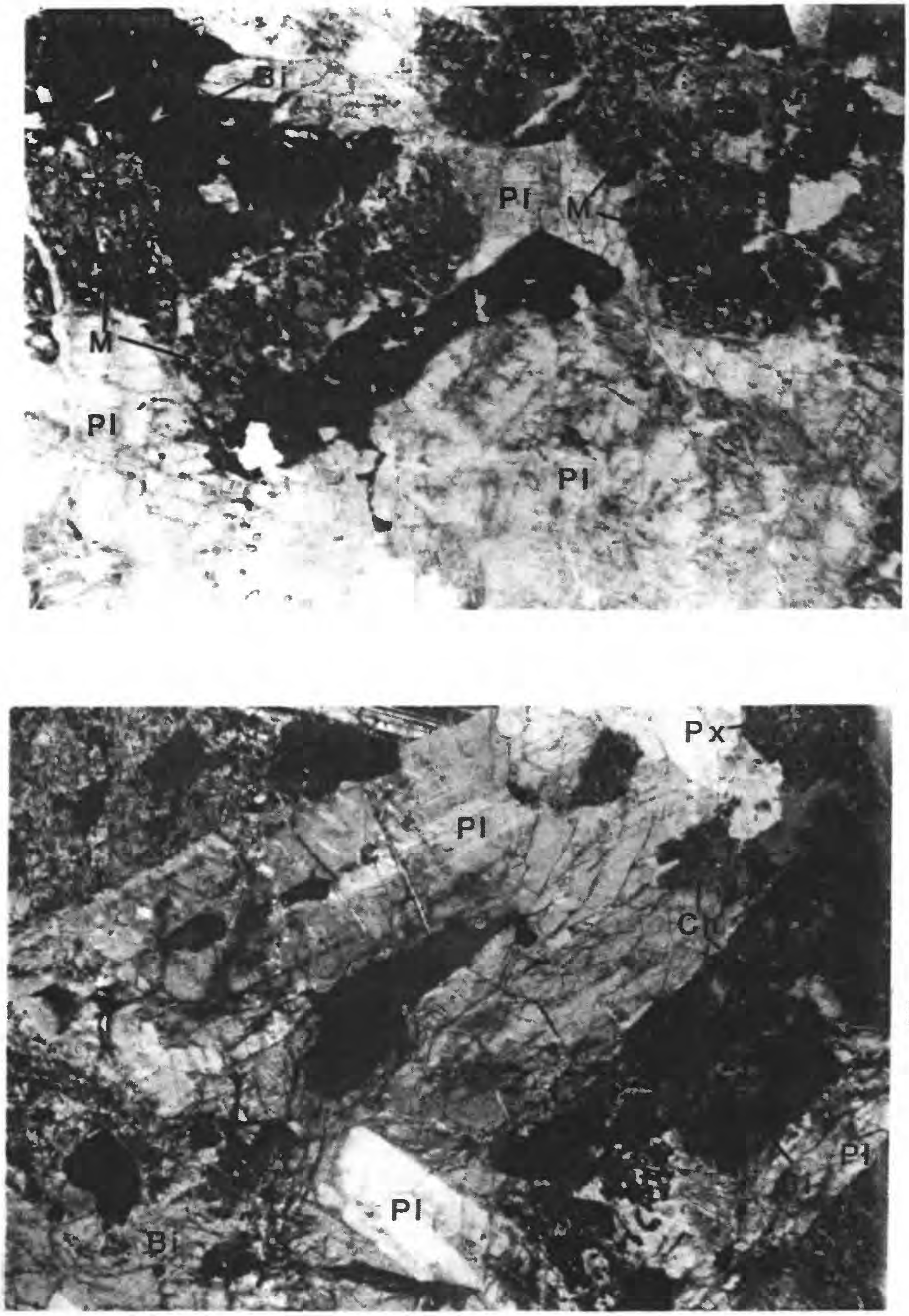


FIGURE 7. Photomicrograph under plane light of an altered igneous rock from 204.9 ft in drill hole MF-4. Fractures are filled with calcite (C). Opaque minerals, dark-colored areas. Altered feldspars, light-colored areas. Magnification: 25x. See figure 3 for sample location.



A

B

FIGURE 8. Two photomicrographs under plane light of diorite from drill hole MF-4. Magnification: 25x. Slightly to moderately altered plagioclase (Pl). Mafic (M) altered to chlorite (Ch) and secondary hornblende. Fractured biotite (Bi). Opaque minerals, dark-colored areas. *A* = sample depth of 208.7 ft and *B* = sample of depth of 225.3 ft. See figure 3 for sample location.

Transgranular, open fractures, less than 0.05 mm wide, are at 207.0 ft and 208.0 ft. At 207.0 ft, these fractures are about 0.05 to 0.2 mm wide. Some narrow to less than 0.05 mm and are filled with clay. Certain open fractures at 225.0 ft are within clay- and iron oxide-filled fractures. Some of the open fracture walls at 225.0 ft are lined or partially lined with iron oxide or clay. Also at 225.0 ft is a breccia-filled fracture, as much as 4.0 mm wide, containing a mixture of altered magnetite grains and clay (fig. 9). This fill mixture appears to exhibit flow structure. Open fractures are within or crosscut to the breccia-filled fracture. Some open fractures separate the breccia fill from the wall of the fracture. Clay-filled fractures, less than 0.05 mm wide, are also in the breccia zone. Macrofractures between 204.9 ft and 208.7 ft have an average angle of about 48° from the vertical axis of the core (Meridee Jones-Cecil and Lee-Ann Bradley, unpub. data, 1990).

From the above data, it appears that the sequence of fracture formation from youngest to oldest is (1) open, (2) either calcite(?) or a calcite(?) and clay mixture fill, (3) clay, (4) iron oxide, and (5) breccia fill. It is not clear if the calcite(?)-filled fractures formed concurrently with the calcite(?) and mixed clay-filled fracture or formed at a different time. Some open fractures have older fill materials that line or partly line fracture walls and indicate that older fractures have reopened. However, the width of some of these open fractures may have resulted from or been enhanced during thin section preparation.

The breccia-filled fracture and kinked biotite grains are probably a result of shear related to faulting. The open fractures and the intragranular filled fractures probably imply a minor extensional event after the shearing event. The majority of the macrofracture angles measured from the vertical axis of the core in this rock are similar to those fracture angles in the overlying lower conglomerate, but they differ from the nearly horizontal fractures of the upper conglomerate. This may indicate an older deformational event that occurred prior to deposition of the upper conglomerate.

The thin-section sample at 226.0 ft is from a hornblende gabbro. The texture of this gabbro is holocrystalline, equigranular, phaneritic, hypidiomorphic-granular, intergranular to slightly subophitic, fine to medium grained, and is altered to very altered (fig. 10). The gabbro consists of labradorite (An_{55}; 40 percent), hornblende (20 percent), magnetite (10 percent), red/yellow biotite (15 percent), quartz (1 percent), pyrite (1 percent), apatite (13 percent), and trace amounts of zircon.

Because of the lack of olivine, the presence of biotite, the high hornblende content (20 percent), the green color of the hornblende, and the fine- to medium-grain size, this gabbro can probably be assigned to the Roosevelt Gabbro Formation described by Powell and others (1980). Indirect evidence to support this conclusion is that members of the Roosevelt Gabbro Formation have been identified in secs. 31 to 36, T. 4 N., R. 13 W., less than 7 miles from the drill sites in sec. 24, T. 4 N., R. 13 W. (fig. 1).

Alteration products in the gabbro are similar to the overlying diorite. Hornblendes are moderately to highly altered to clay and some to chlorite and biotite. Augites are altered to amphiboles, chlorite, and calcite(?) (rare). Plagioclase is slightly to moderately altered to sericite and rare patches of calcite(?). These alteration products are consistent with deuteric alteration.

Deformational features in the gabbro are commonly intragranular; transgranular fractures are rare. Quartz grains exhibit a slight undulatory extinction. The majority of the intragranular fractures are filled with clay; others are filled with calcite(?). The rare calcite(?)-filled fractures, less than 0.05 mm wide, are present within mafic grains. A few calcite(?)-filled fractures are transgranular. Intragranular fractures as much as 0.1 mm wide are filled with unstrained calcite(?). These grains could have been subjected to compressional stress that caused them to fracture. After the compressional event, most of these fractures opened and later were filled with calcite(?) or clay. In the gabbro, the average fracture angles are inclined about 44° from the vertical core axis (Meridee Jones-Cecil and Lee-Ann Bradley, unpub. data, 1990).

Drill Hole MF-5

Two conglomerates and an underlying breccia are the only rocks in core from drill hole MF-5 (fig. 3). The upper conglomerate, from 135.6 ft down to about 175.8 ft, is matrix supported and is a moderate reddish brown (10R 4/6). It consists of angular to rounded sandstone (light yellow, very fine-size sand to silt-size mud), granite (rare), rhyolite (Carlton Rhyolite Group) rock fragments (as much as 2.0 cm in size), and rounded to

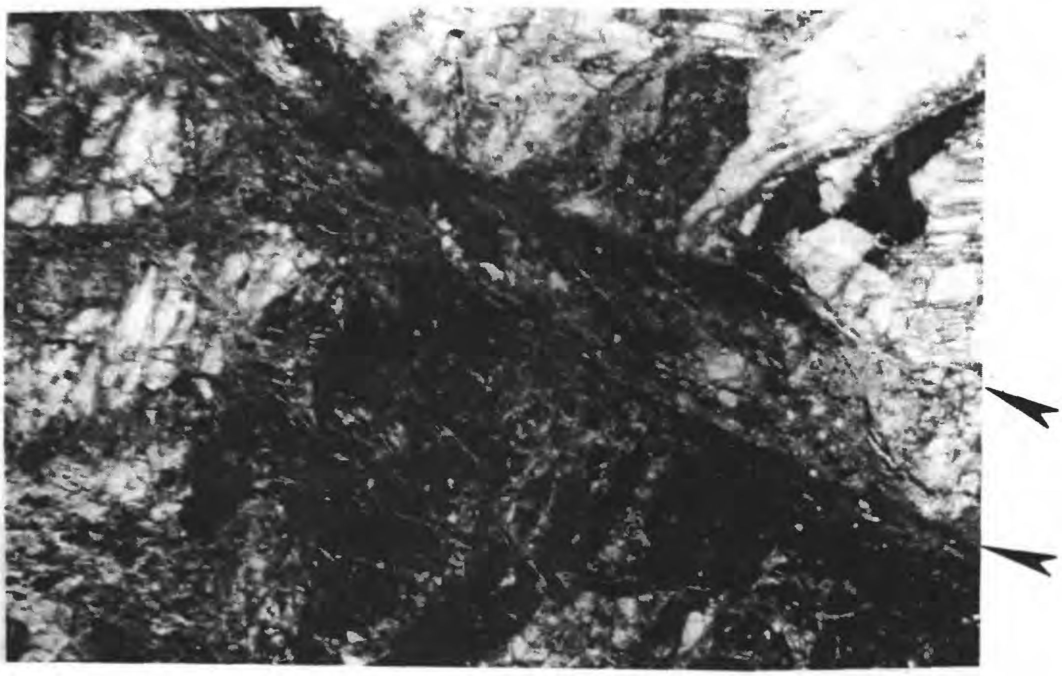


FIGURE 9. Photomicrograph under plane light of diorite from 225.0 ft in drill hole MF-4. Note breccia-filled fracture (arrows) crossing upper right side of photo. Magnification: 25x. See figure 3 for sample location.

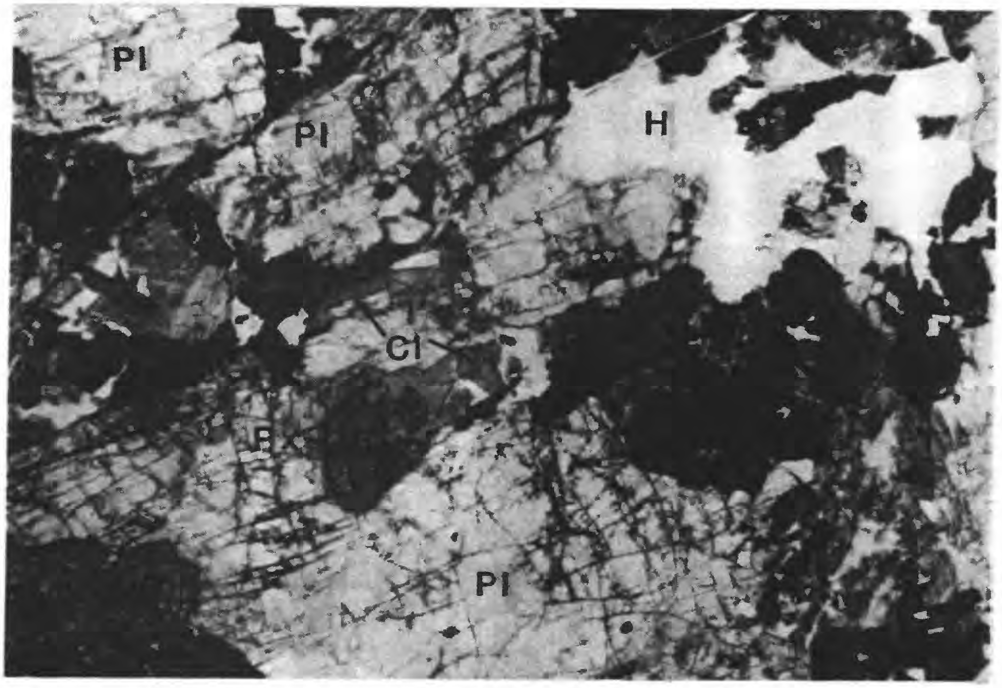


FIGURE 10. Photomicrograph under plane light of hornblende gabbro from 226.0 ft in drill hole MF-4. Plagioclase (Pl) moderately altered to clay. Pyroxene (Px) altered to iron oxides, secondary biotite, and chlorite. Opaque minerals, dark areas. Void, white area. Magnification: 25x. See figure 3 for sample location.

angular, silt size to medium-sand size quartz grains all in a clay-to-silt size matrix. From about 175.8 ft to 200.0 ft is a very altered lower conglomerate(?) (fig. 11) having numerous slickensides and a waxy texture. This material ranges in color from a grayish brown (5YR 3/2) to a pale yellowish brown (10YR 6/2) and contains angular to subangular rock fragments at about 179.8 ft. Rock fragments include rhyolite and granite. An ultrasonically disaggregated sample from 179.8 ft contains 18.4 weight percent of montmorillonite and kaolinite (probably derived mainly from the clay matrix) and 81.6 weight percent of altered rock fragments. Some of the remaining wet rock fragments were squeezed between fingers and found to contain more clay, perhaps twice as much, than implied by the clay values determined from ultrasonic disaggregation. This indicates that clay percentages obtained from ultrasonic disaggregation represent only a minimum clay content for these samples. The remaining rock fragments are angular and are either pale purple (5Y/R 6/2) or grayish orange (10YR 7/4) to a moderate brown (5Y/R 4/4). The fragments vary from very fine sand to very fine gravel size and most appear to be slickensided.

In the upper conglomerate from 135.6 to 175.8 ft, the majority of fractures present are nearly horizontal; whereas, the attitude of the fractures in the lower and very altered conglomerate vary from 22° to 52° from the vertical core axis. Horizontal fractures in the upper conglomerate probably formed during drilling or during the packaging of the core.

Between 200.0 and 200.5 ft is a mixture of loose, pebble-sized rhyolite and limestone fragments that are matrix free. Because these rock fragments are not in a clay matrix, they are believed to be contaminants introduced during drilling. From 200.5 ft down to about 224.3 ft (fig. 3) is very altered and fractured material, having a very waxy texture. Megascopically, this material is very fractured and sheared and is dominantly grayish orange pink (5YR 7/2) with scattered very pale green (10G 8/2) and white-colored angular fragments. These fragments appear to be rock fragments; however, upon closer examination, they are clay clasts (altered igneous(?) rock fragments) that have been brecciated and set in a clay matrix/cement. The pale green material is a mixture of kaolinite and montmorillonite. The green color is probably due to Fe^{2+} content, indicating a local reducing environment. A sample from 202.8 ft, ultrasonically disaggregated, contained 15.6 weight-percent of montmorillonite and kaolinite and 84.4 weight-percent of altered rock fragments, but thin section inspection indicates a much higher clay content (see below). The rock fragments are either pale purple (5P 6/2) or pale yellowish brown (10YR 6/2). The purple material appears to coat the yellowish-brown material. All fragments are angular and vary in size from very fine sand to very fine gravel. Some fragments appear to have slickensides and to contain magnetite(?) grains. Another disaggregated sample from 218.6 ft contained 28.4 weight percent of montmorillonite and kaolinite. Below this material and extending to the bottom of the drill hole at 230.0 ft is a mixture of sand, rock fragments, silt, mud, and some grass cuttings, inferred to be drilling mud.

The breccia below the lower conglomerate was examined in three thin sections of samples from 206.8, 218.4, and 224.5 ft (fig. 12). Examination of the thin sections indicates that some of this material may have been a type of intermediate igneous(?) rock or derived from an igneous rock, but due to extreme alteration, it is impossible to determine a specific rock type. The clay content in these samples range from 65- to about 83-volume-percent, values much higher than the weight percentages determined from ultrasonic disaggregation. I speculate that the ultrasonic-disaggregation values cited above may be low because the breccia was compacted during a deformational event(s), thus making ultrasonic disaggregation very difficult. Other minerals in the three thin sections include altered mafic minerals (10-25 percent), quartz (0.5-1.0 percent), and magnetite (1 to 3 percent). Pyrite (less than 1 percent) is present only at 224.5 ft. In thin section, extremely altered feldspars(?) are assumed to be present because calcite(?) "needles" appear to delineate former feldspar cleavage planes. Because the feldspars are so extensively altered to a mixture of kaolinite, sericite(?), and montmorillonite, their crystal boundaries cannot be distinguished from the clay matrix. Mafic grains are altered to clay and iron oxides. Magnetite is oxidized in all samples. Oxidation is very extensive at 176.8 ft. All grains are "floating" in a clay matrix including the clay fragments (fig. 12).

Qualitatively, intragranular fractures in these samples appear to be more prevalent than in samples from the other drill holes. Only quartz and magnetite grains commonly have intragranular fractures. The majority of the feldspars are too altered to recognize intragranular fracturing. However, some clay-filled fractures are intragranular within feldspar(?) outlines at 218.4 ft. Quartz grains at 206.8, 218.4, and 224.5 ft have a high to

FIGURE 11. Photomicrograph under cross polarizers of lower conglomerate from 176.8 ft in drill hole MF-5. Note altered mineral grain(?) in upper left. All other material is clay. Fractures are unfilled (dark areas) or clay filled (light-colored areas). Magnification: 25x. See figure 3 for sample location.

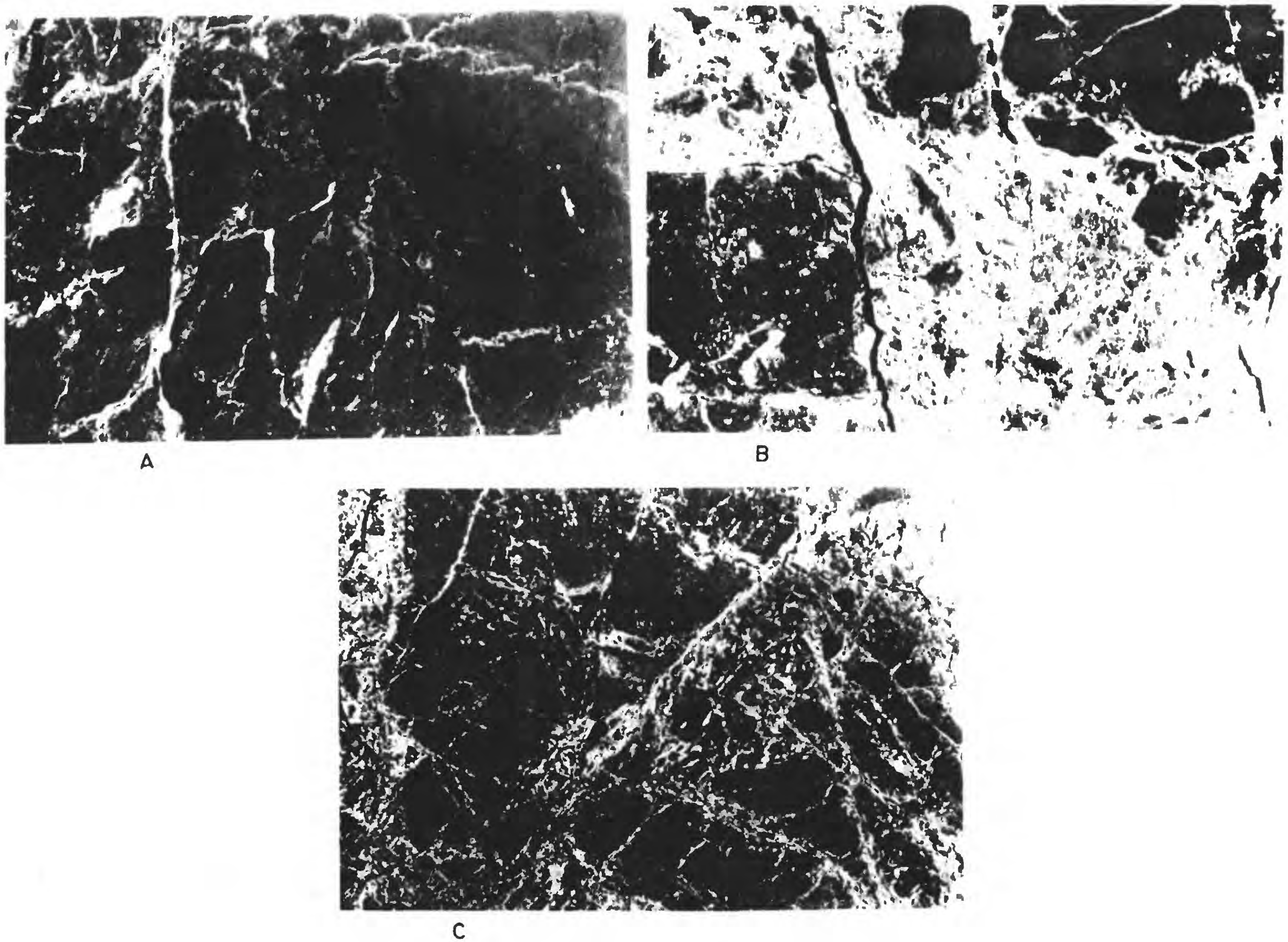


FIGURE 12. Photomicrographs under cross polarizers of altered breccia from 206.8 ft (a), 218.4 ft (b), and 224.5 ft (c) in drill hole MF-5. Magnification: 25x. (a) Note fractured opaque minerals (dark areas) in clay (light-colored areas). (b) Altered opaques in upper right and altered mafic in lower left of photo. The light-colored clay fills a shear fracture. Unfilled fractures are dark areas. (c) Outlines of two altered and fractured minerals. All fractures are clay filled. See figure 3 for sample locations.

extreme undulatory extinction indicating that they have been strained. All quartz and magnetite grains are fractured and are round to angular.

Transgranular fractures found in thin section include open (unfilled), iron oxide-filled, clay-filled, and breccia-filled types. Open fractures, varying from 1.0 to less than 0.05 mm wide, cross the iron oxide-filled fractures at 186.4-200 ft and the clay-filled fractures at 224.5 ft. Open fractures are also found along the center of some clay-filled fractures at 206.8 and 218.4 ft and in breccia-filled fractures at 206.8 and 218.4 ft. Most open fractures are transgranular at 206.8 ft and a few outline or partially outline mineral grains as if the clay matrix surrounding the mineral grains were pulled away from these grains, possibly during drying of the core.

Iron oxide-filled transgranular fractures at 218.4 and at 224.5 ft vary from less than 0.05 mm to as much as 0.5 mm in width. Some altered mineral grains at 218.4 ft also contain iron oxide-filled fractures. Clay-filled fractures at 206.8 and 218.4 ft vary from less than 0.05 mm to as much as 0.05 mm in width. Also present are breccia-filled fractures, as wide as 1.0 mm, containing a mixture of sheared and nonsheared opaque minerals (magnetite?), clay, and mineral fragments all floating within a matrix composed of iron oxide and clay. Megascopically, the breccia fractures, which are several centimeters wide, and other fractures are about 25° off vertical core axis.

Because they cross or are within all other fractures, the open fractures are the youngest. Owing to the lack of crosscutting relationships, the relative age of the other fractures is not known. The breccia-filled fractures indicate a shearing event; the remaining fractures imply extension following shearing.

On the basis of the above data, the core from 200.0 to about 224.5 ft is believed to be a highly altered, fault breccia with an overlying slickensided, brecciated, and highly altered conglomerate(?) (from 175.8 to 200.0 ft). This lower conglomerate(?), in turn, is also capped by a fractured and highly oxidized lithic, matrix-supported, upper conglomerate. If my identifications are correct, the fault breccia may indicate a nearby fault; the core was also subjected to intensive alteration due to weathering that resulted in a clay content that exceeds 60 percent by volume and is composed of montmorillonite and kaolinite. The lower conglomerate(?) covered the fault breccia in drill hole MF-5 and the altered igneous(?) rock in drill hole MF-4.

DISCUSSION AND CONCLUSIONS

Correlations

With the exception of the conglomerates, the rocks identified in this study cannot be correlated from one drill hole to the next, because each drill hole penetrates a different rock type or a rock that is too altered to specifically identify. The conglomerate unit that can be correlated among all three drill holes is the upper oxidized conglomerate that has a high rhyolite-fragment content. A lower, highly altered and slickensided conglomerate is present only in core from drill holes MF-4 and MF-5. These conglomerates may be equivalent to the Permian Post Oak Conglomerate of the Hennessey Group (fig. 13) that is present along the Meers fault and adjacent areas (Chase, 1954).

The rhyolite in core from drill hole MF-2 and present as round to angular fragments in the upper conglomerate in the other drill holes is part of the Carlton Rhyolite Group. Because of the extreme devitrification, it is not possible to relate the rhyolite to a specific section described by Ham and others (1964). The diorite and hornblende gabbro in core from drill hole MF-4 are believed to be a part of the Roosevelt Gabbros of the Raggedy Mountain Gabbro Group. It was not possible to determine whether the diorite was differentiated from the gabbro during cooling.

Provenance and depositional environment

The source of the granite and rhyolite fragments in the upper conglomerate in core from all three drill holes is not known because flow indicators in the conglomerate are not well defined. The rhyolite fragments could have been derived from a rhyolite outcrop 6 miles south of the study site and/or from another rhyolite outcrop 2 miles north of the study area. A granite that crops out 6 miles south of the study site may be the

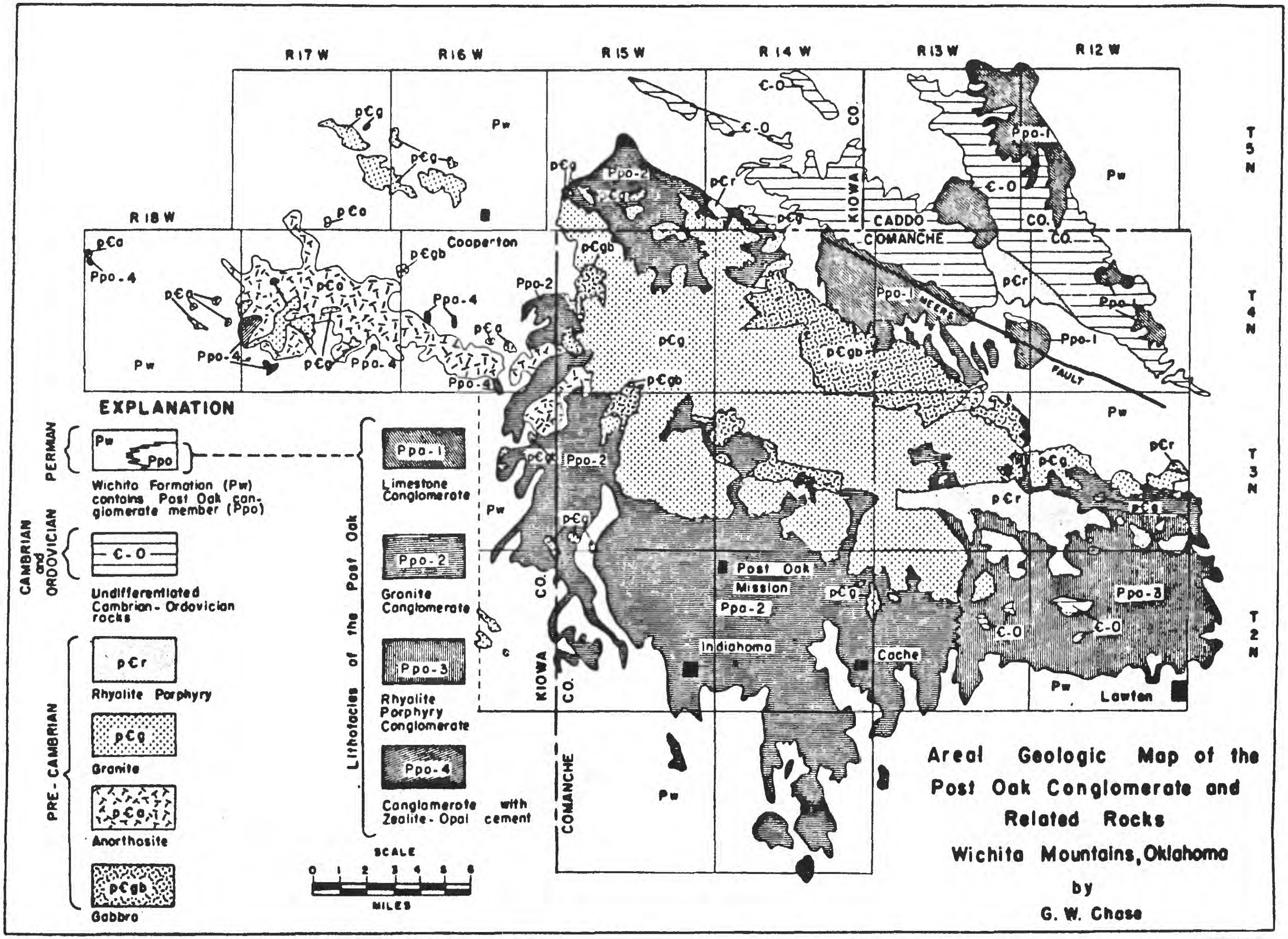


FIGURE 13. Geologic map showing distribution of the Post Oak Formation relative to other rock units of the Wichita Mountains, Oklahoma (after Chase, 1954).

source of the granite fragments (fig. 1). Comparison of the present basal elevation of the upper conglomerate among the drill holes cannot help to determine the location of the source area because faulting may have changed the original slope direction along which deposition took place. In drill hole MF-2, the upper conglomerate contains massive, structureless sandstones and a gravel/pebble conglomerate that grades upward into a finer grained, trough-crossbedded sandstone. The structureless sandstones may be debris-flow deposits, and the crossbedded sandstone indicates a braided(?) stream or a scour and fill deposit. The immature and poorly sorted sediment, the braided stream or scour and fill deposit, and the debris-flow(?) deposits suggest that the upper conglomerate encountered in the three drill holes may have been deposited in an alluvial fan. The kaolinite fragments, oxidized reddish color of the rock, and the altered granite and feldspar fragments indicate subareal weathering, perhaps in a semiarid to humid environment.

A color and textural change marks the contact between the upper and lower conglomerates in core from drill holes MF-4 and MF-5. The lower conglomerate also differs from the upper conglomerate by being more altered and fractured, indicating an earlier depositional event that covered altered igneous(?) rock in drill hole MF-4 and very altered breccia material in drill hole MF-5. The flow direction for the lower conglomerate is not known. The depositional setting for the lower conglomerate is probably similar to that described for the upper conglomerate. The lower conglomerate is not apparent in the core from drill hole MF-2, suggesting that either this conglomerate was not deposited that far north or, more likely, that it was eroded prior to deposition of the upper conglomerate.

Deformation

After deposition and lithification, the lower conglomerate was fractured. The fractures have angles from the vertical core axis (average about 40°) similar to those developed in the underlying breccia material in core from drill hole MF-5 and in the underlying rock in core from drill hole MF-4. The upper conglomerate lacks these steeper dipping fractures. I believe that the steeper dipping fractures in the lower conglomerate indicate that deformation occurred prior to the deposition or lithification of the upper conglomerate. Both the lower and upper conglomerate suggest that two different uplift events occurred in their source area.

Underlying the lower conglomerate in core from drill hole MF-5 is a fault breccia. This rock has a greater number of fractured mineral grains and shear fractures and is more weathered (indicated by the high volume percentage of clay products) than the rocks in the other drill holes. These characteristics suggest that drill hole MF-5 is near or within a fault or fault zone southwest of the Meers fault. In a study conducted in California, Biegal and Chester (1991) found that intragranular fracturing and clay alteration in a granodiorite and amphibolite increased towards the North Branch of the San Gabriel Fault. The findings of Biegal and Chester (1991) may explain why there appears to be a relatively higher number of intragranular fractures and more clay alteration products in the core from drill hole MF-5 than in the other drill holes. The presence of a secondary fault near the Meers fault agrees with the findings of two seismic-reflection studies--one by Harding (1985) a few miles southwest from this study site, and another by Miller and others (1990) less than 150 ft from the drill sites. Both studies found subsurface faults adjacent to the Meers fault. The diorite and gabbro core from drill hole MF-5 suggest that a block of igneous rock is present between the Meers fault and the fault near drill hole MF-5.

The three drill holes have four similar types of fractures in common. In approximate order from oldest to youngest, they are (1) breccia-filled fractures, (2) clay-filled fractures, (3) iron-filled fractures, and (4) open (unfilled) fractures. These different fractures indicate that at least four events of deformation occurred in the past. The breccia-filled fractures may be evidence of an early shearing event associated with faulting, followed by at least three post-tectonic extensional events as suggested by both intragranular and transgranular open and filled fractures.

Suggested further work

This study could not determine the amount of separation across the Meers fault. Additional drill holes are needed between drill hole MF-2 and the Meers fault to reveal the amount of separation along the Meers fault. A deeper drill hole near drill hole MF-2 is needed to determine the thickness of the rhyolite and the type of rock beneath the rhyolite. This information, combined with the data from drill hole MF-4, would give a better understanding of the structural relation and related magmatic intrusions that have occurred during and after the development of the southern Oklahoma aulacogen. In addition, verification of the petrographic classification of the igneous rock in core from drill hole MF-4 by microprobe analysis would strengthen the findings of this study.

SUMMARY

The important results of this study identify an igneous rock of intermediate(?) composition probably of the Roosevelt Gabbro Group, a rhyolite of the Carlton Rhyolite Group, and a diorite and gabbro of the Roosevelt Gabbro Group in core from three different drill holes adjacent to the Meers fault. These rocks cannot be correlated among the drill holes because of the degree of alteration and/or because each of the core contain different kinds of igneous rocks. Based on the relatively higher amount and degree of intragranular fracturing, shearing, and alteration of the core in drill hole MF-5 compared to core of the other drill holes, it is believed that a subsurface fault is present near drill hole MF-5. This fault may mark the southern boundary of a block of igneous rock that is bounded on the north by the Meers fault.

The fracture study indicates that four types of fractures are common to core of the three drill holes. An early faulting event(s) followed by at least three post-tectonic extension events are suggested by the types of intragranular and transgranular open and filled fractures.

It is not possible to determine the amount of separation across the Meers fault based on information from the cores of the drill holes. Additional drill holes are recommended to determine amount of separation, to establish correlation of the igneous rocks found in the different drill holes, and to provide a better understanding of the tectonic history of the Meers fault.

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