The Wichita Mountains In Oklahoma: Their Story Through Time

By
Dr. M. Charles Gilbert

GUIDEBOOK 39

Oklahoma Geological Survey
2014

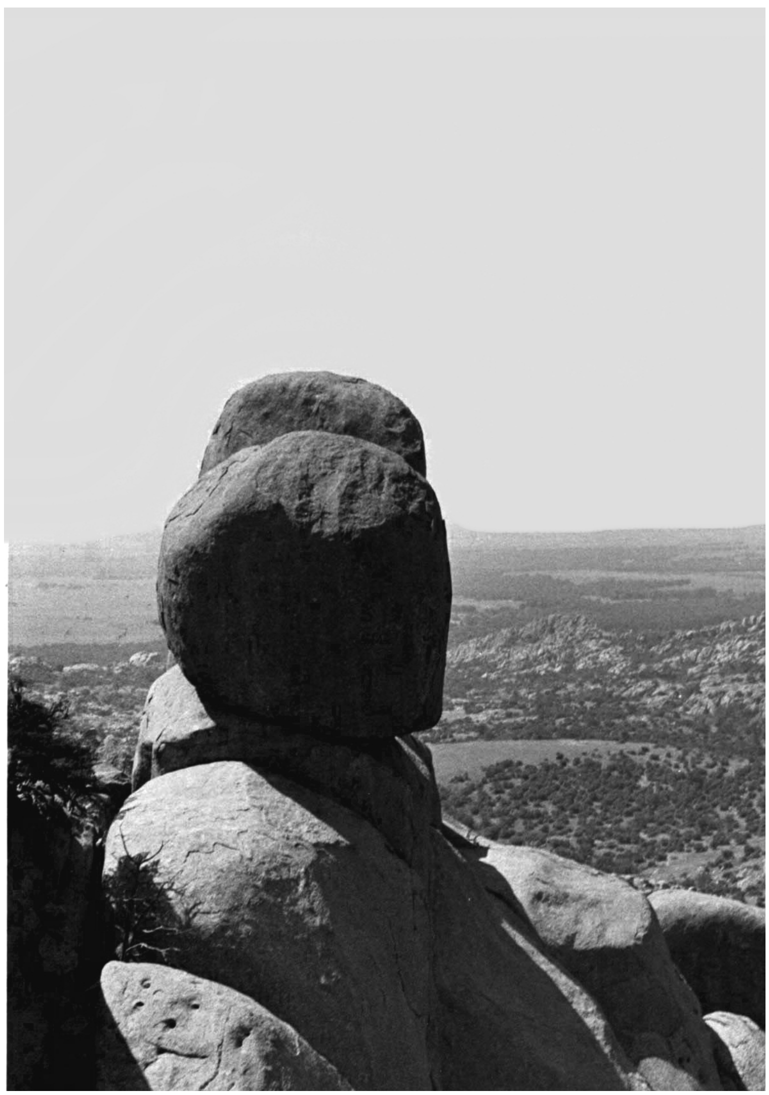
OKLAHOMA GEOLOGICAL SURVEY
Dr. G. Randy Keller, *Director, State Geologist*

GUIDEBOOK 39
ISSN 0160-8746

The Wichita Mountains in Oklahoma: Their Story Through Time

by
Dr. M. Charles Gilbert

ConocoPhillips School of Geology & Geophysics
The Mewbourne College of Earth and Energy
University of Oklahoma



The Oklahoma Geological Survey
The Mewbourne College of Earth and Energy
University of Oklahoma
Norman
2014

Cover Photo: The Wichita Mountains Wildlife Refuge with a foreground of longhorn cattle on a grassland lying on a thin base of Permian Hennessey Shale. In the background are peaks of Mount Scott Granite. Photo by Brian J. Cardott, Oklahoma Geological Survey.

Title Page Photo: Large tors of Quanah Granite at west end of Elk Mountain, looking south-southwest.

This publication is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1981, Section 3310, and Title 74, Oklahoma Statutes 1981, Sections 231-238. It is available on-line and as color photocopies. 500 copies have been prepared for distribution at a cost of $3,900 to the taxpayers of the State of Oklahoma. Copies have been deposited with the Publications Clearinghouse of the Oklahoma Department of Libraries.

Contents

Preface

This geological guide to the Wichita Mountains was developed over a number of years. It was intended to be useful to the general public as well as to beginning geologists (students) and professional geologists. This is an area that can be enticing and welcoming to visitors and explorers. It reveals much of the great 500-million-year-long history of southwestern Oklahoma, with implications for a huge surrounding region. If you were visiting the Wichitas and are curious about the rocks being hiked, about the topography of the mountains being climbed or viewed, about the kind of landscape one is seeing, about how the rocks were formed, or about any other intriguing geologic question, then hopefully this guide will get you started on an understanding of their facinating history and composition. The references listed will enable continued scientific exploration. We are fortunate in this area to have some easily accessible sites where geology explains the beauty of nature and the power of nature's processes.

It has been my pleasure to work in the Wichitas for many years. The support of the Oklahoma Geological Survey, ConocoPhillips School of Geology & Geophysics, both at the University of Oklahoma, and earlier, the Department of Geosciences, Virginia Tech, and Department of Geology & Geophysics, Texas A & M, has been substantial and much appreciated. I have been dependent on colleagues such as R. E. (Tim) Denison, John Hogan, David McConnell, Ben Powell, Jon Price and Nowell Donovan for continuous enlightenment. Ken Johnson provided lots of discussion on the Permian history of the area and Neil Suneson extensively reviewed this guide.

Finally, the composition, layout, and presentation of the guide depended on the skills and expertise of Connie Smith and Jim Anderson, stalwarts of the Oklahoma Geological Survey.

Comments about the effectiveness and clarity of the explanations, and where improvements can be made, are welcome and may be sent to mcgilbert@ou.edu or via post to M. C. Gilbert, Conoco Phillips School of Geology and Geophysics, Mewbourne College of Earth and Energy, 100 E. Boyd, Rm 710, University of Oklahoma, Norman, OK 73019.

KEY TO ABBREVIATIONS USED IN THE GUIDE

Ma	millions of years
USGS	United States Geological Survey
kbar	kilobar
km	kilometer
m	meter
cm	centimeter
in.	inch
ft	feet
mi	mile
An	anorthite content in the plagioclase
Fo	forsterite content in the olivine

View of Mount Scott looking northwest along OK 49 in the Wichita Mountains National Wildlife Refuge west of Medicine Park, Oklahoma. A winding road with an entrance on the south side of Mount Scott leads to an overlook. The elevation at the top is 2,464 ft. (Photo by Brian J. Cardott.)

River of boulders (i.e., large corestones) on the south side of Mount Scott where it is cut by the summit road.

The Wichita Mountains in Oklahoma: Their Story Through Time

Dr. M. Charles Gilbert
ConocoPhillips School of Geology & Geophysics
The Mewbourne College of Earth and Energy
University of Oklahoma

This guide to the Wichita Mountains of Oklahoma will develop the geologic history of this area, give some detailed descriptions of specific places to visit to understand the geology, and list references for further information about the area.

Introduction

The Wichita Mountains area rises up out of the surrounding shales, siltstones, and sandstones, known as the Permian "redbeds." These mountains are older than the redbeds. These topographic forms have a present relief of more than 1,000 ft (300 m), so relative to the low relief of most of southwest Oklahoma, they can be called mountains. What is unusual is that these mountainous forms are geologically old, having been carved around 280–270 million years ago (Ma), and so could be called "fossil" mountains. The Wichita Mountains are a beautiful illustration of a paleotopography, actually one of the best examples in North America. These mountainous forms extend below the redbeds for another 1,500 ft (450 m) or so. Thus their actual erosionally carved relief is about 3,000 ft (900 m), which makes them more impressive. The Wichita Mountains extend from Fort Sill about 70 mi (110 km) to the northwest, slightly beyond the town of Granite, Oklahoma (Figs. 1, 2).

The rocks making up the mountains are much older than the topographic forms. The rocks are of two main types: igneous (formed from melted rocks whose original temperatures were in the range 1,290-2,190° F (700–1,200° C) and sedimentary (formed from marine processes when oceans covered this area). The northern part of the Wichitas is called the Slick Hills and is underlain mostly by the Arbuckle Group, a set of limestones at least 6,000 ft (1850 m) thick in this area. These limestones covered all the igneous rocks (even over the top of Mount Scott) but were eroded off about 310–290 Ma (mostly in the Pennsylvanian). These limestones also crop out prominently along I-35 in the Arbuckle Mountains area. This is a clue to the fact that the

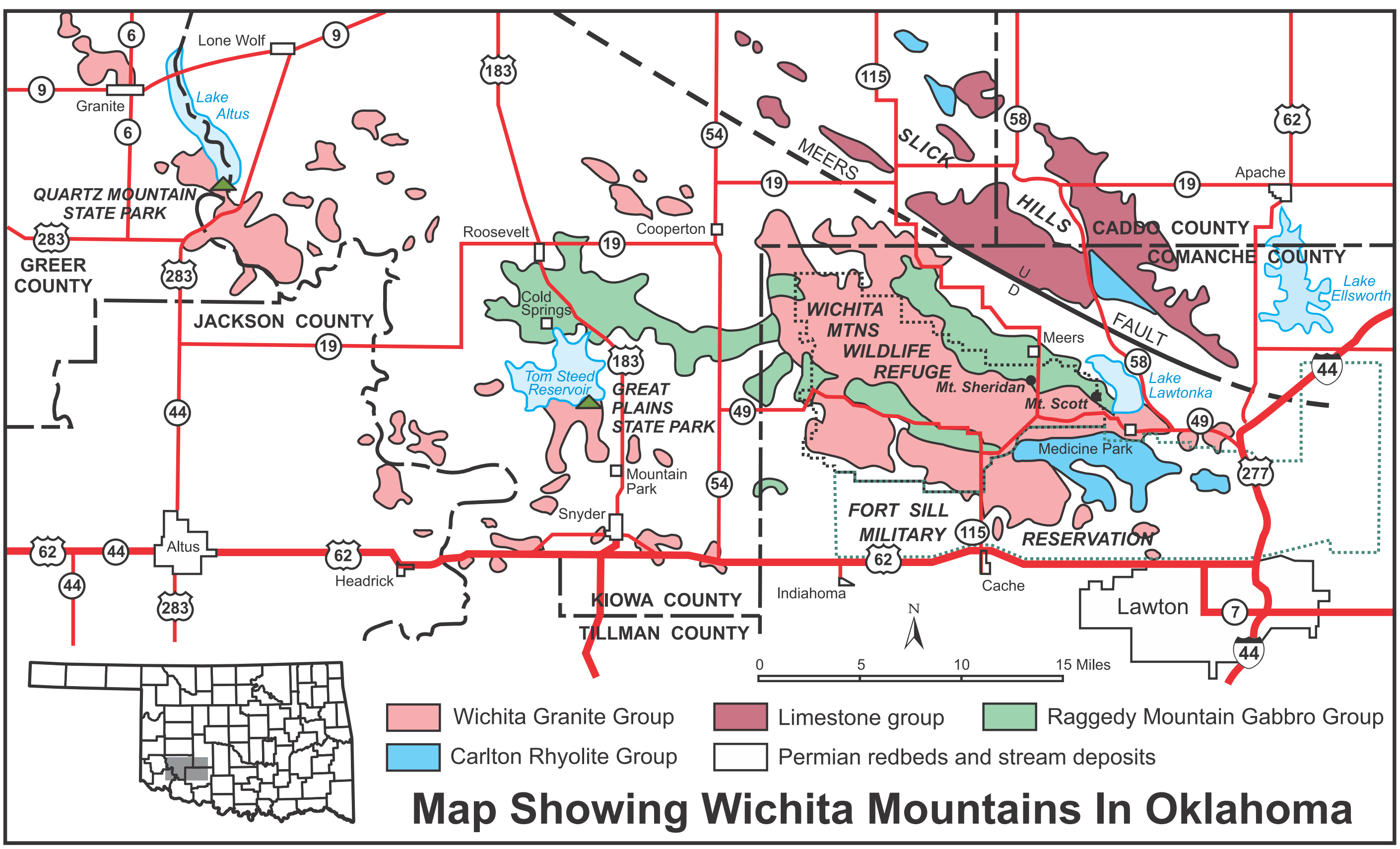


Figure 1. Generalized igneous geology of the Wichita Mountains area.

Arbuckle Group underlies most of Oklahoma. The rest of the Wichitas, the more rugged and higher parts, are underlain by a variety of igneous rocks, which are described below. The igneous rocks were formed in an ancient rift environment similar to that now found in East Africa and in the Rio Grande Rift of New Mexico and Colorado.

Interestingly, the fine-grained clastics forming the redbeds were derived from the east, i.e., from the Ouachita Belt and Ozark Dome areas (Johnson, 1989). The redbeds were formed from mostly stream-borne and shallow-water deltaic marine sediments. They are now exposed throughout almost all of western Oklahoma. To the north of the Wichitas is the Anadarko Basin, the deepest sedimentary basin in North America (~9 mi or ~14 km to basement). It is a compound basin with ~3.5 mi (~6 km) of Cambrian–Mississippian section representing the older "Oklahoma" or "Ancestral Anadarko" basin and a younger foreland basin with ~5.5 mi (~9 km) of Pennsylvanian–Permian section (Gilbert, 1992). The nature of all the subsurface folds and faults (Pennsylvanian) cannot be ascertained directly from surface outcrops because of Permian cover. Source rocks in the basin are sufficient to have generated abundant mobile hydrocarbons, and evidence for hydrocarbons at the surface can be seen throughout the state. Numerous drill holes and abundant geophysical surveys were integrated with the geology mapped in the Wichita Mountains and Arbuckle Mountains to yield a structural and stratigraphic picture of the area. This accepted geological framework allows us to reconstruct the geologic history of Oklahoma (Ham et al., 1964; Johnson, 1989; Campbell, 2007; Keller and Stephenson, 2007).

Wichita Mountains

In the Wichita Mountains area we look at a profound unconformity where Permian strata lie on Cambrian and Ordovician rocks that were exposed during Pennsylvanian uplift and erosion (forming the easternmost Ancestral Rockies). Two classes of rock were exposed in the Pennsylvanian uplift: 1) on the most uplifted crustal block, the Southern Oklahoma Aulacogen basement consisting of Early Cambrian granites, rhyolites, and gabbros; and 2) on adjacent, slightly less uplifted blocks, sandstones and limestones of the Late Cambrian Timbered Hills Group and Cambro-Ordovician Arbuckle Group. The igneous rocks are the uppermost exposures of the Southern Oklahoma Aulacogen, a rift (extensional zone, in principle, like a mid-oceanic rift but cutting continental crust) that propagated from about the vicinity of Dallas northwest through Amarillo to the Uncompahgre Plateau in Colorado (Ham et al., 1964; Keller and Stephenson, 2007 (Fig. 3). This rifted plate was "southern" Laurentia. This rift cut the Mesoproterozoic (~1.4 billion years old) Granite-Rhyolite terrane part of Laurentia. [These older rocks crop out as the eastern Arbuckle basement in south-central Oklahoma.] Igneous rocks filled the rift as extension occurred, thus magmatism and extension were intimately interrelated. The oldest rock types of the rift that are exposed are gabbroic anorthosites of the Glen Mountains Layered Complex and these form the substrate of the exposed stratigraphy. Such rocks can host platinum-group elements as ore deposits, and while prospected, no significant deposits have been discovered. Early Cambrian erosion

Figure 2. Baldy Point, Quartz Mountain State Park.

took off the cover rocks on the Glen Mountains Layered Complex and the uppermost parts of the Glen Mountains Layered Complex. Subsequently, Carlton Rhyolite flowed out on this surface as rifting progressed, and the Wichita Granite Group bodies intruded as A-type sheet granites along the unconformity between the gabbros and the rhyolites (Fig. 4). A more detailed outline of the igneous rock stratigraphy follows the descriptions of the field stops. The large positive gravity anomaly over and along the Wichita Mountains (Fig. 5) tells us that there is little buried granite (silicic rock) in the rift and much more dense basaltic components (i.e., gabbro). G. R. Keller and students have produced the accompanying cross section emphasizing the large amount of gabbro in the rift (Fig. 6; Buckley, 2012). From a regional-scale geological evolution perspective, the Wichitas are the result of a rift (down-dropped block) that produced large volumes of igneous rocks and were later uplifted. This event is globally known as a classic example of tectonic in-

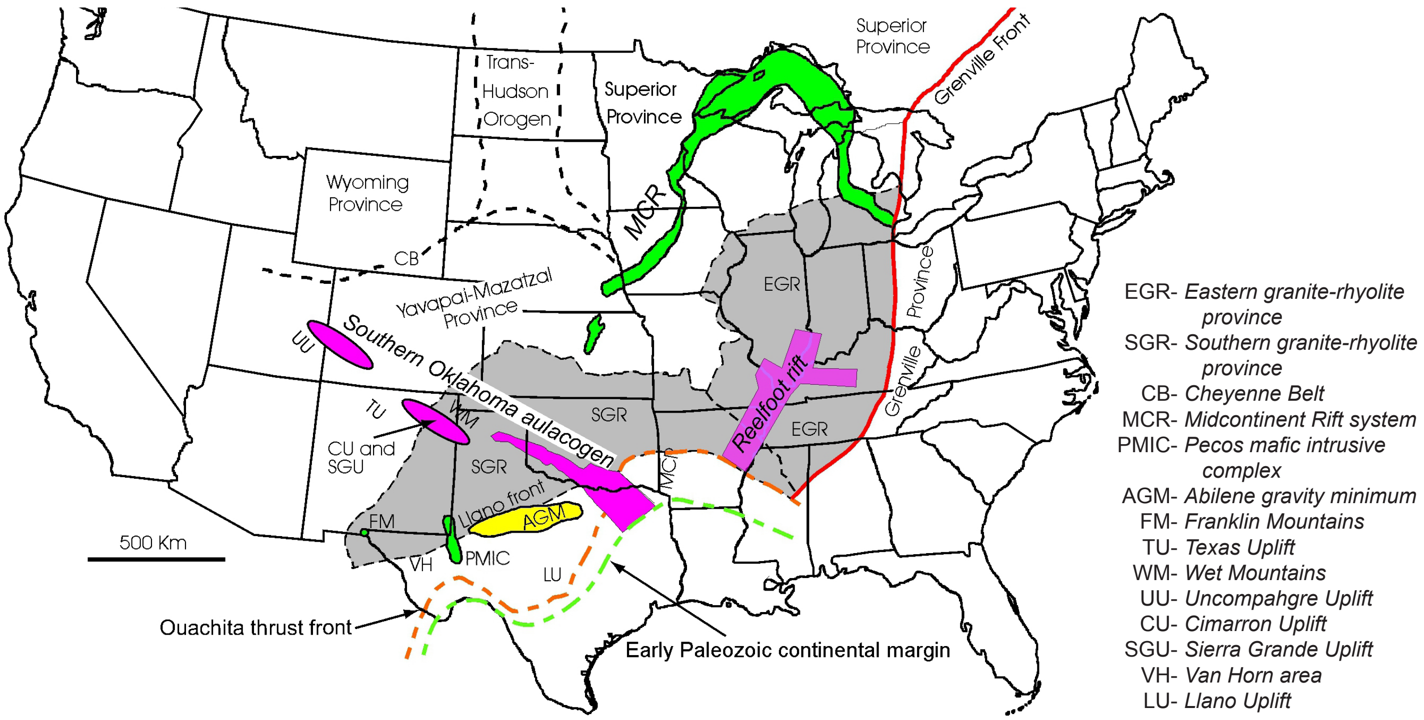


Figure 3. Extent of the Southern Oklahoma Aulacogen. From Keller and Stephenson (2007).

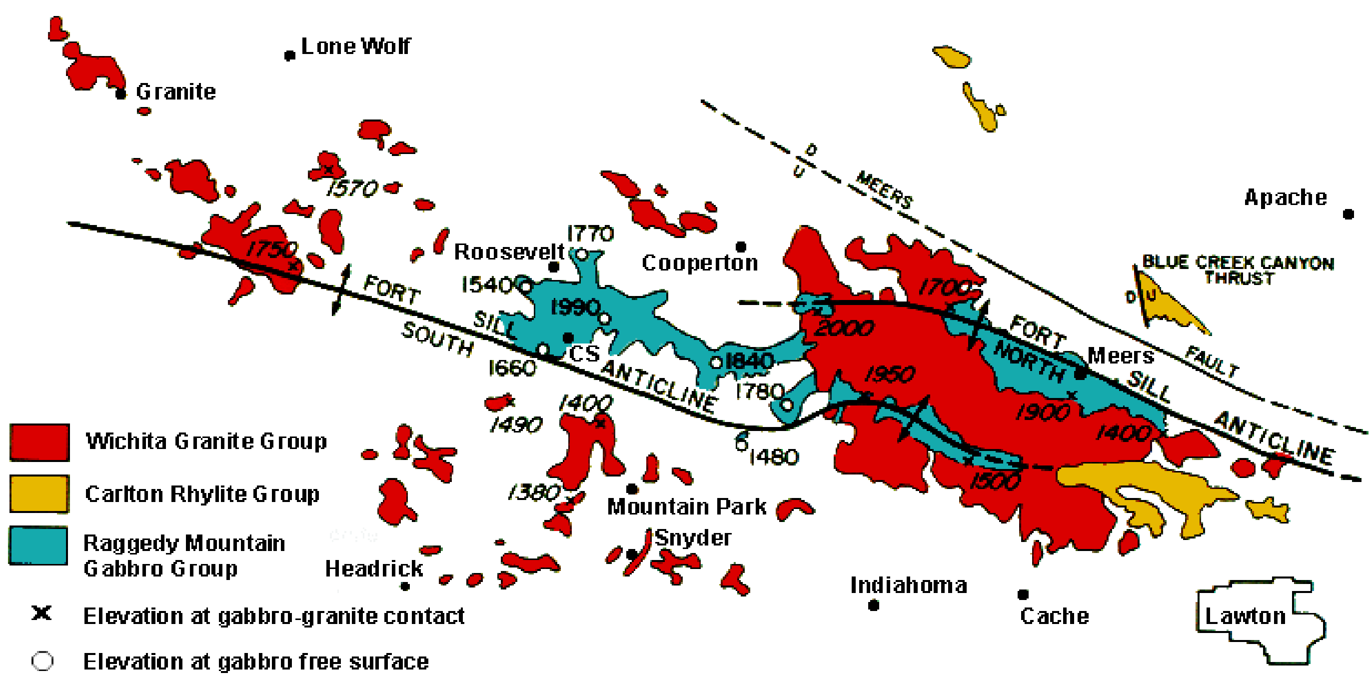


Figure 4. Distribution of the main igneous rock types.

version. The scale of this inversion is demonstrated by an anomaly in the Earth's gravity field. Thanks to seismic surveys and drilling results, we can use gravity measurements to construct deep models of the Earth's structure across this ancient Cambrian rift. The modeling shows that the Wichitas have a huge core of dense igneous rocks resulting in the gravity anomaly which is so big that a person in central Oklahoma who weighs 200 lbs would weigh 200.03 lbs in the valley areas of the Wichitas. Puckett (2011) is documenting significant occurrences of basalt in the subsurface, not previously recognized and studied in the Arbuckle Mountain area as revealed by deep drilling.

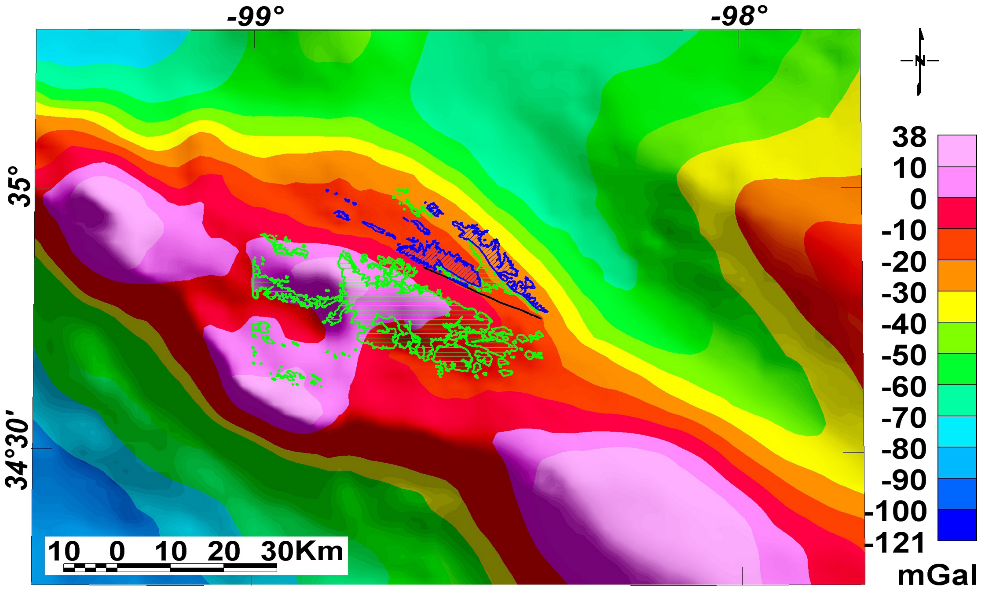


Figure 5. Bouguer gravity map of the Wichita Mountains area. The very large gravity high centered on the uplift indicates that a massive intrusive body is located in the upper crust. The outcrop of the igneous rocks are outlined in green. The carbonate rocks in Slick Hills are outlined in blue. The black line indicates the clearest portion of the scarp of the Meers Fault. (constructed by G. R. Keller and students).

After igneous processes ceased and the crust was no longer extending in the Mid-Cambrian, erosion cut into the igneous sequence. Flooding of the continental surface reached this area in the Late Cambrian depositing a transgressive sequence (Sauk transgression) that begins with the Reagan Sandstone, followed upward by the Honey Creek Formation, and then the Fort Sill Formation, which is in the lower part of the Arbuckle Group (Donovan, 1986). Accumulation of ~3.5 mi (~5 km) of Paleozoic sediments occurred over this area which became the center of the "Old Anadarko" Basin (also called the Oklahoma Basin). This older basin would have looked like the present Williston, Illinois, or Michigan Basins in terms of its sediment thickness and its areal extent (Gilbert, 1992) (Fig. 7).

During the Pennsylvanian, some kind of plate closure occurred against Laurentia as the supercontinent Pangea was being assembled. Part of that event is represented in the extreme deformation of the Ouachita Mountains of southeastern Oklahoma, Arkansas, and the Marathon region of west Texas. The old Anadarko Basin was dismembered by uplifted blocks of the crust, including the core zone of the Southern Oklahoma Aulacogen. These blocks are the easternmost of the Ancestral Rockies. The uplifted blocks were eroded down through the Lower Paleozoic sedimentary sequence and to the rift basement. This denudation developed a low-relief plain near sea level by the beginning of the Permian.

Later, in the Early to Middle Permian, a distinct phase of uplift of at least 0.6 mi (1 km) occurred (Gilbert, 2004). The paleotopography displayed in the Wichitas was carved at that time. However, the regional topographic highs to the east were resulting in streams flowing to the west depositing clastics in very low-relief delta plains. New work of G. S. and M. J. Soreghan of the University of Oklahoma and their students shows a significant part of the Lower Permian here in Oklahoma was wind-deposited (loess). These clastic wedges, commonly mudflats, interfingered with seas that lay to the west (west Texas area).

These seas periodically were cut off from the main oceanic circulation and developed world-class evaporites which today are known from western Oklahoma, western Texas, and southeastern New Mexico (Johnson, 1989). The evaporitic sequences are mostly higher in the Permian section, or, for the same time line, are farther west than the facies seen in central Oklahoma. These Permian clastics buried the eroded topography of the crustal blocks uplifted earlier in the Permian. This required approximately 0.6 mi (1 km) of subsidence for the blocks previously uplifted.

We can be sure that the Permian units buried the Wichita Mountains (the igneous core as well as the Slick Hills) from the work of Kenneth S. Johnson and Nowell Donovan. It is unclear whether Triassic and Jurassic units ever covered the Wichita Mountains. Such units crop out in the far western Oklahoma panhandle and in the Texas panhandle but are not present in western Oklahoma. However, Cretaceous seas did cover this area but much of the direct evidence for these younger stratigraphic units is not available locally. We do know from regional studies that Cretaceous seas invaded and covered most of Olahoma. In fact, there was a Cretaceous seaway that stretched from Texas to the Arctic across North America. Furthermore, the Miocene-Pliocene Ogallala formation which is now being eroded back off of western Oklahoma, may have added to the cover in the Wichita Mountains area.

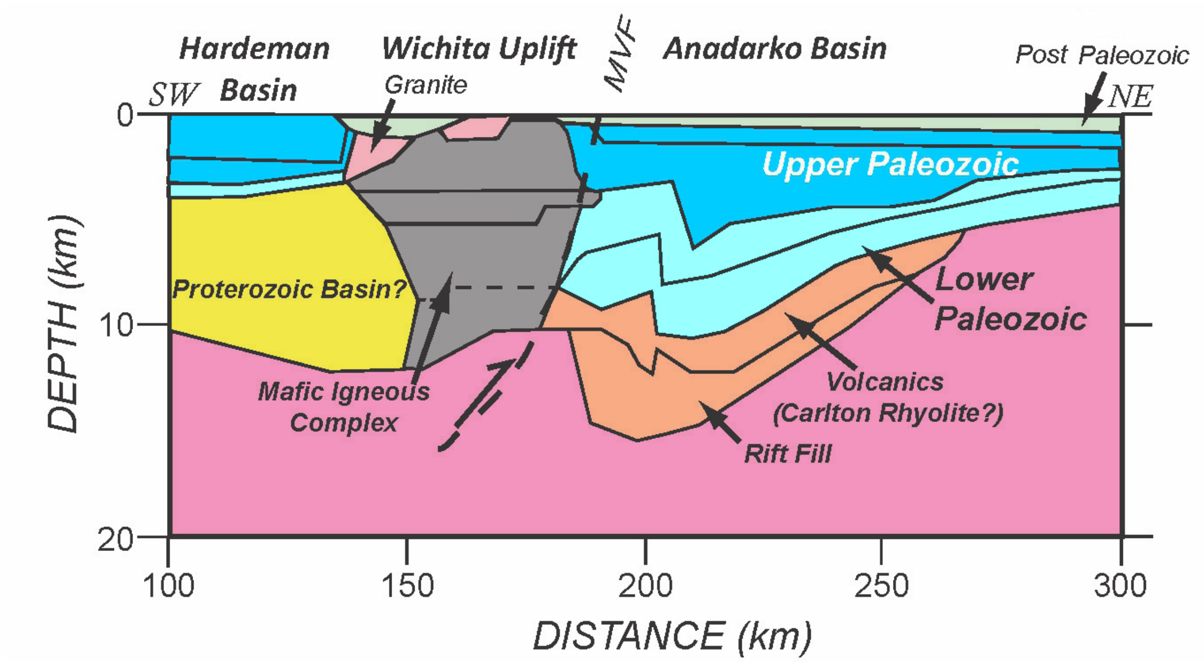


Figure 6. Geophysically based cross section of the Wichita Mountains. *MVF*-Mountain View Fault. (Constructed by G. R. Keller and students.)

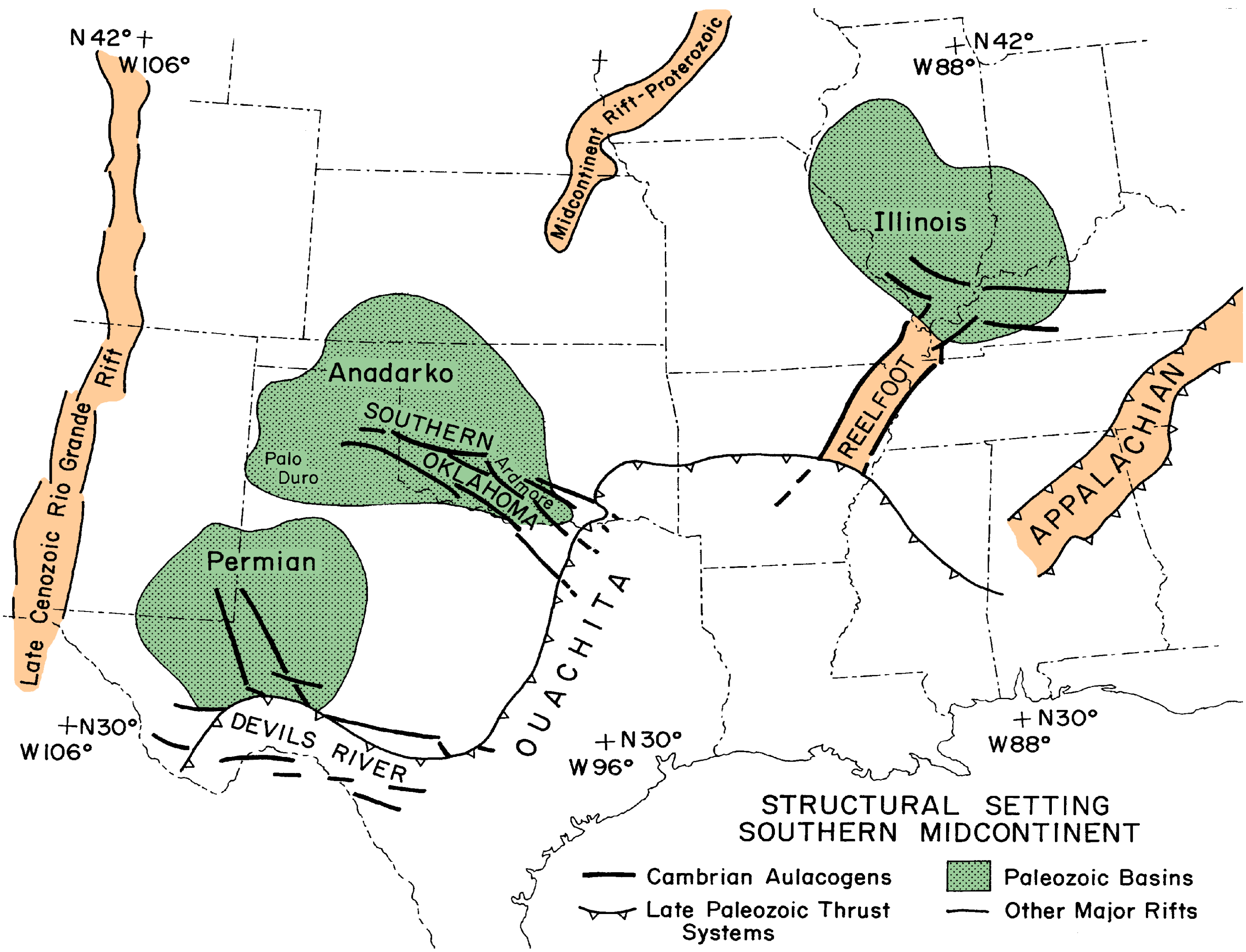


Figure 7. Structural setting of the Southern Midcontinent (from McConnell and Gilbert, 1990).

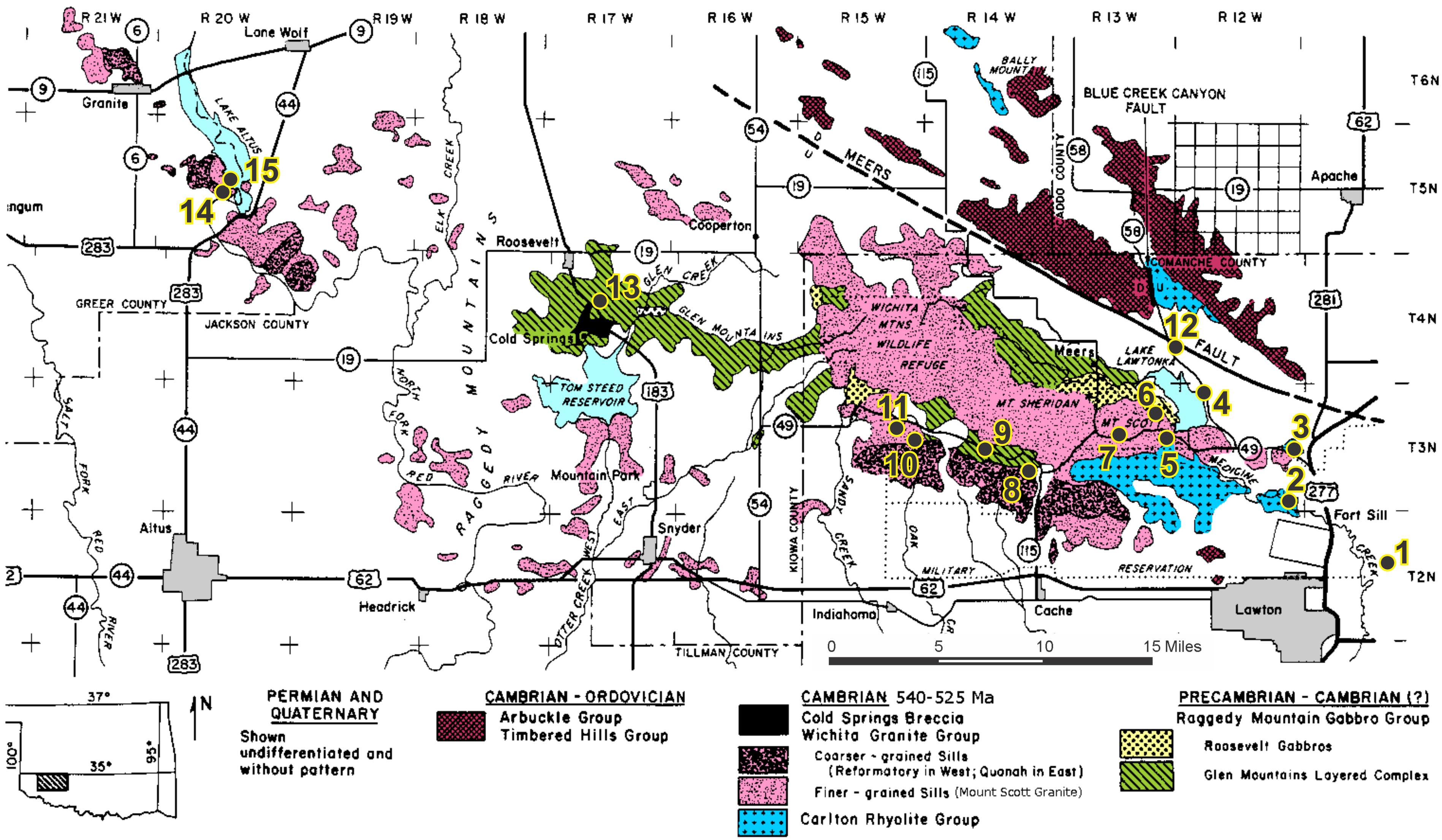


Figure 9. Geological map of the Wichita Mountains. Stops described in the text shown in yellow outline: 12 in the eastern Wichitas, and three in the western Wichitas.

Figure 8. View of Mount Scott from the Medicine Park area. The pronounced tree line on the side of Mount Scott marks the contact of the overlying Mount Scott Granite with the underlying Mount Sheridan Gabbro, one of the Roosevelt Gabbros (Raggedy Mountain Gabbro Group).

STOPS

This guide describes 15 stops in the Wichita Mountains (Fig. 9). These stops cover some of the geological events and rock types discussed above. All of these stops are publicly accessible. Oklahoma Geological Survey 1:100,000 areal geologic maps of the Lawton and Altus quadrangles are available on paper (Stanley and Miller, 2006) or online at http://ogs.ou.edu/geolmapping.php.

Eastern Wichita Mountains

▸ Stop 1: HOLOCENE OIL SEEP: FORT SILL TAR PIT HISTORICAL SITE

Fort Sill Military Reservation, Adams Hill, near Feigel Point on the east range. SE SW NW Sec 15, T 2 N, R 11 W. USGS Topographic Map: Arbuckle Hill.

We are in the Garber-Hennessey. These are the units now being eroded away from the Southern Oklahoma Aulacogen basement seen off to the northwest. [Mount Scott is the highest peak in sight.] Note the seep is on a ridge (topographic high), not in a valley, indicating that the flow path for the oil is not controlled by the present topography, but by the basement (Fig. 10). The sedimentary section here has only about 500 ft (150 m) of Permian (and possibly some Arbuckle Group) on top of basement. Thus the source of the oil must be out in the Anadarko Basin to the northeast and coming up through faults and fractures in this overthrust block. Geochemical characterization by Paul Philp at the University of Oklahoma shows that it is very heavily biodegraded. All of the n-alkanes and isoprenoids have been removed but the more resistant biomarkers, namely steranes and terpenes, are still present. The distribution of the various sterane and terpene biomarkers, typically used for maturity measurements in this oil, suggest that it has been sourced in a deeper part of the basin. Interestingly, Brian Cardott (Oklahoma Geological Survey) also has noted the occurrence of thin layers of coal (24.35% ash; huminite reflectance of 0.28%, suggesting a lignite) which are unusual in the Permian. Finally, fossil vertebrate bones can be seen.

Figure 10. Drainage from oil seep, looking south, on Adams Hill, Fort Sill Military Reservation. STOP 1.

Table 1. List of stops and GPS Locations			
Eastern Wichitas			
Stop 1:	Holocene Oil Seep: Fort Sill Tar Pit Historical Site	559690.97E	3834030.98N
Stop 2:	Carlton Rhyolite at Medicine Bluffs	553550.63E	3838627.86N
Stop 3:	"Fossil" Oil Seep in Mount Scott Granite	553363.34E	3842190.25N
Stop 4:	View of the Granite Gabbro Contact	546686.29E	3846887.39N
Stop 5:	Diabase Dikes and Mount Scott Granite	544583.60E	3843072.93N
Stop 6:	Top of Mount Scott	542846.41E	3844752.75N
Stop 7:	Permian Post Oak Conglomerate (Granite Facies) and Unconformity on Fractured Granite and Rhyolite	539685.35E	3843504.87N
Stop 8:	Quanah Granite	532879.03E	3841193.03N
Stop 9:	Glen Mountians Layered Complex	529946.16E	3842453.99N
Stop 10:	French Lake Dam	527177.07E	3842180.80N
Stop 11:	Tor Topography and Twin Rocks	525075.56E	3844116.38N
Stop 12:	Meers Fault	543949.24E	3850643.75N
Western Wichitas			
Stop 13:	Cold Springs Breccia	500054.11E	3852934.50N
Stop 14:	East End of the South Side of Quartz Mountain	472513.20E	3860952.10N
Stop15:	Ridge Cut on Road to Quartz Mountain Lodge	472392.93E	3861975.47N

Mount Sheridan. (Photo by Brian Cardott)

Table 2. Simplified Stratigraphic Column for Exposed Units in the Wichita Mountains Area

PERMIAN	Whitehorse Group	Rush Springs Formation *(Includes Weatherford Gypsum at top)* Marlow Formation
	El Reno Group	Chickasha Formation *(equivalent to Blaine Gypsum farther west)* Duncan Sandstone
	Hennessey Group	Hennessey Shale Garber Sandstone *(Post Oak Conglomerate interfingers with these units)*
		Pronounced angular unconformity
ORDOVICIAN	Arbuckle Group	West Spring Creek Formation
		Kindblade Formation
		Cool Creek Formation
		McKenzie Hill Formation
		Signal Mountain Formation
		Fort Sill Formation
LATE CAMBRIAN	Timbered Hills Group	Honey Creek Formation
		Reagan Sandstone
		Unconformity *~ 20 million year gap between Reagan and the youngest part of the Wichita Igneous Complex*
EARLY CAMBRIAN	Diabase	*Basaltic dikes of various ages cutting all igneous units*
	Wichita Granite Group	***Eastern Wichitas*** Quanah Granite *(coarse-grained (1–2cm), blocky alkali feldspar, sodic amphibole)* Mount Scott Granite *(fine-grained (<1cm), ovoid alkali feldspar, microrapakivi, granophyric, 534 +/- 1½ Ma)* ***Western Wichitas*** Lugert Granite *(fine- to medium-grained abundant inclusions, amphibole)* Reformatory Granite *(coarse-grained 1–2cm), blocky alkali feldspar, amphibole)*
	Carlton Rhyolite Group	***Geographic stratigraphic sections*** Bally Mountain Blue Creek Canyon Fort Sill
		Unconformity
	Raggedy Mountain Gabbro Group	***Roosevelt Gabbros*** *(primary biotite)* Sandy Creek Gabbro Mt. Sheridan Gabbro ***Glen Mountains Layered Complex*** *(strongly layered anorthosite, cumulus plagioclase and olivine, poikilitic clinopyroxene and magnetite)*

On leaving and retracing the incoming route, note that the valley slope toward Cache Creek is discolored (bleached). Thus, the present oil seep is only part of the hydrocarbon discharge that has gone on here. Methane must also have been leaking to the surface over a considerable area. The area south and east of here contained many shows of petroleum leakage and resulted in the small Lawton oilfield reservoirs that are only a few hundred feet deep (Wegemann and Howell, 1915; Jordan, 1964).

▸ Stop 2: CARLTON RHYOLITE AT MEDICINE BLUFFS

North side of Medicine Creek at Medicine Bluffs, Fort Sill Military Reservation, southwest of Punch Bowl Road, just south of Hand Hill. Sec. 36, T 3 N, R 12 W. USGS Topographic Map: Fort Sill.

Medicine Bluffs is a National Historic Site because of its importance to Native Americans of the plains. Fort Sill now respects and protects this area. The Carlton Rhyolite Group is rhyolitic (72–76 weight % SiO_2) in the Wichita Mountains outcrops (Figs. 4, 11). This is the most extensive Cambrian basement unit in southern Oklahoma (Ham et al., 1964). The group extends in the subsurface west to the Oklahoma–Texas line and east to the western Arbuckles of south-central Oklahoma. It has not yet been further subdivided stratigraphically, but apart from its extrusive character, there are also major basaltic phases in other areas, now being well-documented in the subsurface from well cuttings by Puckett (2011).

The Fort Sill outcrops, which are the largest exposure of the group, contain ~10% pink to red alkali feldspar and ~5 % quartz phenocrysts set in a matrix of recrystallized feldspar + quartz (Fig. 12). The matrix might have once been glassy since the outcrops, while showing layering, tend to be massive. The information monument at the parking site is made from various pieces of the rhyolite and gives one an easy look at the textures, although the text on the sign itself describing the origin of the bluffs in incorrect. Here, one can see crude columnar jointing in the cliff face. A basaltic dike (Diabase) cuts the rhyolite in the eroded notch to the left of the high top ahead to the south. This rhyolite outcrop extends from the bluffs under the parking area and north to Hand Hill. Small sheared basaltic stringers can be seen on the slope below the information monument. While rhyolite can be seen in several areas in the Wichita Mountains Wildlife Refuge, this area is one of the best publicly accessible sites.

The age of the hills is Permian, although the erosional shape may reflect Cambrian rhyolite doming. This can be seen, particularly on the south side of the bluffs, where they are being exposed as the Hennessey Shale/Post Oak Con-

Figure 11. Medicine Bluffs cut in Cambrian Carlton Rhyolite, looking south from Hand Hill area across rhyolite platform. Permian hills exhumed by Medicine Creek as it carved the bluff in the Late Tertiary/Quaternary. STOP 2.

Figure 12. Slab of Carlton Rhyolite displaying alkali feldspar phenocrysts. STOP 2.

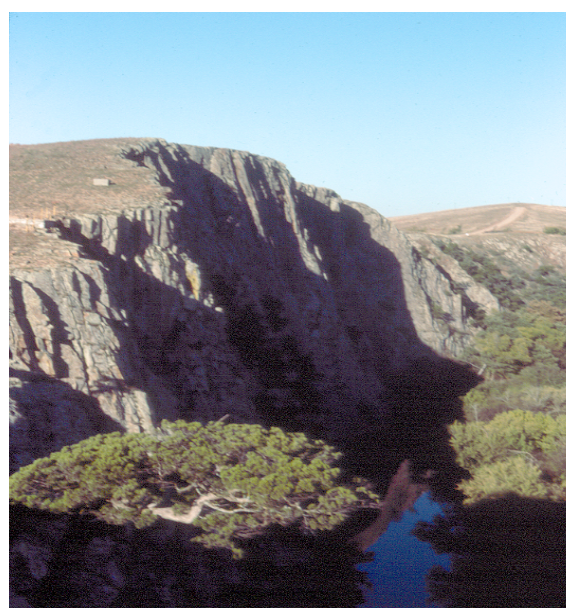


Figure 13: Medicine Bluffs from the crest looking westward, Medicine Creek below. STOP 2.

glomerate is eroded away. However, the age of the cliff is Late Tertiary-Quaternary, showing a nice example of stream superposition by Medicine Creek (Fig. 13).

Figure 14. Fresh road cut in Fall, 2001, along south side of OK 49 displaying asphaltite mass originally filling fracture space in Mount Scott Granite, looking west. STOP 3.

▸Stop 3: "FOSSIL" OIL SEEP IN MOUNT SCOTT GRANITE

South side of OK 49 just 1.5 mi (2.4 km) west of Medicine Park "Y" on the north side of Craig Hill. NE SW NW Sec 24 , T 3 N, R 12 W. USGS Topographic Map: Fort Sill.

This occurrence was unknown until highway lane expansion resulted in additional excavation of Mount Scott Granite in 2001. Interestingly, the roadcut of the older, smaller roadway did not show evidence of the paleo-oil seep, at least by the 1970s. A fracture "pocket" in the wall of the Mount Scott Granite in the new road cut contained a mass of shiny black asphaltite (Fig. 14). The natural fracture network throughout the lower part of the cut of this part of the roadway shows dark, black coatings. Part of this is due to chlorite whose origin is unclear. But it also illustrates the flow path of the hydrocarbons making their way to the surface when this seep was active. Inside these fractured blocks, one can see the more typical red coloring of the granite. One can also see how the dark appearance of the outcrop fades away toward the natural surface indicating the hydrocarbon stain near the ground surface was completely oxidized after the upward flow ceased. These features also would seem to indicate the geologically youthful nature of this seep.

Also interestingly, two diabase dikes were exposed during the road excavation. The dike to the east of the paleoseep area is highly weathered and vertical (Fig. 15), and the dike to the west is larger and sub-horizontal (Fig. 16). Neither of these was known before the road expansion.

Figure 15. Highly weathered vertical Cambrian basaltic dike (Diabase) cutting Mount Scott Granite, east of Fig. 14. STOP 3.

Figure 16. Weathered subhorizontal Cambrian basaltic dike (Diabase) west of Fig. 14. STOP 3.

Figure 17. View of Mount Scott looking west across Lake Lawtonka from OK 58. Note the distinct tree line marking the contact between the Mount Scott Granite above and the Mount Sheridan Gabbro below. The contact can be followed west to Mount Sheridan in the distance. STOP 4.

▸Stop 4: VIEW OF THE GRANITE-GABBRO CONTACT

Along OK 58 ~3 mi (4.8 km) north of its intersection with OK 49. SW Sec 5, T 3 N, R 12 W. USGS Topographic Map: Richards Spur.

Viewing the mountains to the west across Lake Lawtonka, one can see a distinct break in the tree line that runs along the north faces of the peaks from Mount Scott on west across Mount Wall to Mount Sheridan and on to Tarbone Mountain (Fig. 17). This is the contact between the Mount Scott Granite on top and the Mount Sheridan Gabbro below, which is the heavily treed surface (Gilbert and Hogan, 2010). This change in the density of vegetation at a granite-gabbro contact is typical in parts of the Wichitas. Gabbro has much more magnesium and calcium than granite, forms thicker soils, and tends to support more trees. Granite bedrock has trees but more typically they grow best along the major fractures/gullies.

Viewing the peaks south of Medicine Park one can notice the nearer ones are partially tree-covered and are granite (mostly Mount Scott Granite). Farther south on Fort Sill, the knobs are "smooth" and are mostly tree-free. These are underlain by rhyolite (Carlton Rhyolite). Again, a vegetation change with rock type is typical. Although the rhyolite and granite have very similar bulk compositions, and in this sense should support similar vegetation, the rhyolite is much more finely fractured. It may be that rain water drains very quickly through the rhyolite so that the subsurface remains extremely dry and doesn't support trees.

Viewing the ridges to the north, which are now topped by extensive wind-power generators, one can see a distinctly different terrain, again without tree cover: the Slick Hills. These ridges are underlain by limestone (Arbuckle Group mostly) and, while rich in calcium, they do not typically support trees here. Faint, but distinct, lines on the landscape show the individually formed bedded layers ~3.3 ft (~1 m thick) of carbonate. Separating the igneous core of the Wichitas from the Slick Hills, where one is stopping for this view, is the Meers Fault. We are on the most uplifted crustal block of the Ancestral Rockies, which is the core of the Southern Oklahoma Aulacogen, where all the limestone that once covered this uplifted block has been eroded off. The modern Meers Fault crosses the highway a few miles north of us. The Pennsylvanian movement on that fault "dropped" the Slick Hills crustal block down 1.2 mi (2 km), so most of the igneous rocks in the Slick Hills crustal block are still covered up except for some rhyolite outcrops near and along OK 58 and further north in the privately owned Bally Mountain area.

▶Stop 5: DIABASE DIKES AND MOUNT SCOTT GRANITE

Quarried area on the north side of the Lake Elmer Thomas Dam, Wichita Mountains Wildlife Refuge. SE Sec 13, T 3 N, R 13 W. USGS Topographic Map: Mount Scott.

This is in a quarried area excavated during the building of the original earth dam in the 1930s (Fig. 18). There are abundant secondary fractures dipping easterly which probably originated during Pennsylvanian deformation. The two main points of this stop are 1) to see the Mount Scott Granite, and 2) to observe the character of Diabase dikes cutting the granite. We will see the Mount Scott Granite again at its type locality on Mount Scott. This is the largest granite of the 11 mapped units (~11 x 34 x 0.3 mi; ~17 x 55 x 0.5 km) in the Wichitas and probably one of the oldest at ~534 Ma. Here typical aspects of the Mount Scott Granite are displayed: 1) ovoid (dark) feldspar phenocryts forming a micro-rapakivi texture, 2) mafic clots, and 3) variably granophyric texture (Fig. 19). The ovoid feldspars suggest magma ponding at ~2 kbar before the near-surface intrusion. Note the granite has been partially melted near the dike and that melt has intruded back into the dike.

The basaltic dikes are composed of calcic plagioclase and clinopyroxene with a diabasic texture and are not distinctly porphyritic. Looking toward the top of the quarry wall, one can see the basalt weathers much more readily than the granite (Fig. 18). Thus, the dikes commonly are poorly exposed at the natural surface. The easternmost dike on the quarry floor (Fig. 20) shows several interesting characteristics: small granitic dikes cross-cutting the basalt, chilling of the basalt dike margins, textural changes in the granite next to the dike, and evidence on its south end of lateral flow (Fig. 21). Jonathan Price (Midwestern State University) produced a simple thermal model of this dike. To develop the features seen, the Mount Scott Granite must have been at least 930° F (500° C) which leads to the interesting conclusion that the dike is only slightly younger than the Mount Scott Granite, and thus its radiometric age would not be distinguishable from that of the Mount Scott Granite. Basaltic diabase dikes commonly cut all the igneous units in the Wichita sequence. For many years this led to the thinking that there was a unit called "Late Diabase." Because the Mount Scott Granite is one of the oldest granites in the Wichitas, the basaltic magmatism must have occurred throughout the period of development of rhyolites and granites. Price et al. (2012) have recently published details on this occurrence and its regional significance.

Figure 18. View of west end of the quarried area at Lake Elmer Thomas Dam where two diabase dikes can be seen cutting Mount Scott Granite. STOP 5.

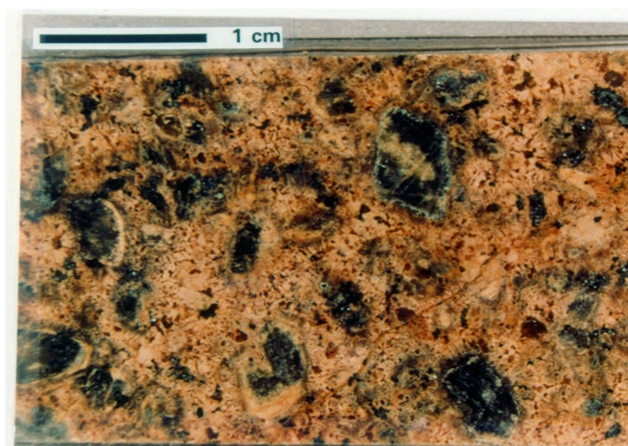


Figure 19. Slab of Mount Scott Granite showing granophyric texture surrounding ovoid and darker feldspar phenocrysts with rapakivi zoning. STOP 5.

Figure 20. Larger east diabase dike showing its two lobes cutting the Mount Scott Granite on the quarry floor. STOP 5.

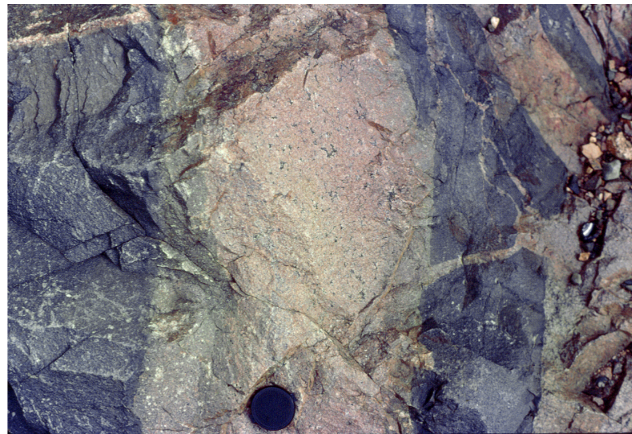


Figure 21. Diabase showing quenching at the dike walls as well as intrusion of the dike by melted Mount Scott Granite. STOP 5.

Figure 22. View westward from the top of Mount Scott toward Mount Sheridan. All the mountains along this line of sight, as far as can be seen, are capped by Mount Scott Granite. The distant tree line on Mount Sheridan traces the granite-gabbro contact. STOP 6.

▸Stop 6: TOP OF MOUNT SCOTT

Wichita Mountains Wildlife Refuge. Sec 11, T 3 N, R 13 W. USGS Topographic Map: Mount Scott.

This topographic feature has an elevation of 2,464 ft (751 m) and a relief of 1,000–1,100 ft (300-335 m). It is the type locality for the Mount Scott Granite which makes up most of the topographic feature and through which the road up Mount Scott is cut. (A gabbroic unit of the Roosevelt Gabbro makes up the lower third of the north face as is well-displayed looking back at Mount Scott from Stop 4). The age of the granite has been determined by the uranium-lead method on zircon at 534 +/- 1.5 Ma (Hogan, Wright, and Gilbert, unpublished). Its sheet form can be viewed easily off to the west, where the base of the granite, against gabbro, may be seen on Mount Sheridan along a distinct tree line sloping to the south (Fig. 22). This sheet granite forms all the peaks that can be seen west-northwest from here as far as one can see.

Calling Mount Scott a "mountain" raises the question of what is a mountain. Is 1,000+ ft (300+ m) of relief enough? Perhaps this is relative, depending on the setting of the relief. What is the age of a mountain? It is not necessarily the age of the rock that makes up the mountain, but the age of the surface that shows the relief. As the Wichitas are clearly exposing a paleotopography, the age of Mount Scott, and the other Wichita Mountains peaks, is the geologic age when the topography was cut. This paleotopography is about 270–280 Ma and has about another 1,500 ft (450 m) of relief that is still buried.

The landscape we view from here also shows strong lithologic control, e.g., the smooth bare hills to the south on Fort Sill are underlain by Carlton Rhyolite, the heavily treed slopes on Mount Sheridan and elsewhere in the Wildlife Refuge are underlain by gabbro, and the low-relief surface farther south, and to the east, surrounding the Wichitas, is underlain by the Hennessey Shale (Fig. 23). The smooth hills to the north, upon which the wind-power generators

Figure 23. View southward from the top of Mount Scott past Lake Elmer Thomas, over the smooth Carlton Rhyolite hills on Fort Sill to the Hennessey Shale beyond. STOP 6.

Figure 24. Aerial view of the south side of Mount Scott. The "River" of boulders can be seen extending up about half the height of the mountain. These spheroidally weathered corestones of the Mount Scott Granite accumulated in a large ravine in the Permian. STOP 6.

are located, are underlain by Arbuckle Group limestones.

We also can see evidence of superposition of Medicine Creek off to the southeast at the Lake Lawtonka Dam site. This shows "modern" stream erosion, wherein a stream cutting down through the softer and less-resistant Permian shales from "above" is trapped between successively exposed, more-resistant and harder granite knobs, and is therefore required to cut the granite to maintain its Late Tertiary course.

The boulder stream, which extends up about half the height of Mount Scott on the south side, and which the road crosses just as it starts up the mountain (Fig. 24), is a valley full of what appear to be toppled tors. These were spheroidally weathered boulders in natural rock columns scattered around the side of Mount Scott. [See also Stops 7 and 11.] They may have been jarred loose from their columns by earthquakes in the Permian while the topography was being carved. These boulder streams are not unusual in the Wichitas, but the one on the side of Mount Scott is one of the larger and most obvious.

▸Stop 7: PERMIAN POST OAK CONGLOMERATE (GRANITE FACIES) AND UNCONFORMITY ON FRACTURED GRANITE, RHYOLITE

Quetone Point, Wichita Mountains Wildlife Refuge off OK 49 extended. SW SE NE Sec 16, T 3 N, R 13 W. USGS Topographic Map: Mount Scott.

Just below the Quetone Point parking area and adjacent to the highway, part of the Post Oak Conglomerate was excavated for road material in the late 1950s–early 1960s along the unconformity surface on top of the granite. Large, rounded granite clasts can be seen in a matrix of sand- and silt-sized material. This is particularly evident viewed from the highway and in the excavated area. The clasts have been transported short distances, and the rounded nature of the clasts is primarily due to spheroidal weathering, not transport. Weathering such as this often occurs when weathering rates are greater than erosion rates and goes on beneath the ground-water table (Fig. 25). Spheroidal weathering typically goes on in fractured feldspar-rich granitoid rocks through the process of hydrolysis, as feldspar + water = clay. Where the fracture network is three-dimensional, various rectangular blocks are formed. Spacing of the fracture planes ultimately controls the size and shape of the resultant corestones. This process accounts for almost all the rounded boulders, of all sizes, in the Wichitas. This rounding of the boulders/clasts is not going on now, rather, went on in the Permian. We know this because the boulders are present in Permian Post Oak Conglomerate here and elsewhere. This process is also responsible for the dramatic tors seen farther west.

The ground surface existing during this weathering episode must have been low-relief and probably also low elevation (near sea level) in the Early Permian (Johnson, 1989). Consequences of this interpretation are that a distinct phase of uplift of ~0.6 mi (~1 km) occurred in the Early Permian, beyond that acquired during the main Pennsylvanian uplift (Fig. 26). Thus, the famous Pennsylvanian Granite Wash in the Anadarko Basin is a true "tectonic" conglomeratic facies, while the unrelated Post Oak Conglomerate represents a somewhat different and smaller tectonic episode.

Finally, an excellent illustration of the paleotopography may be seen to the south across Little Medicine Creek. Tributary gullies cut into granite could not have been formed in the Quaternary because there was an insufficient drainage network to support such erosion (Fig. 27). The Post Oak cover is being removed from this pre-existing topography and uncovering it. Little Medicine Creek canyon, once covered and filled with Post Oak Conglomerate, existed in the Permian and is now being reused (Fig. 28). (See Gilbert (2009) for a more complete discussion.)

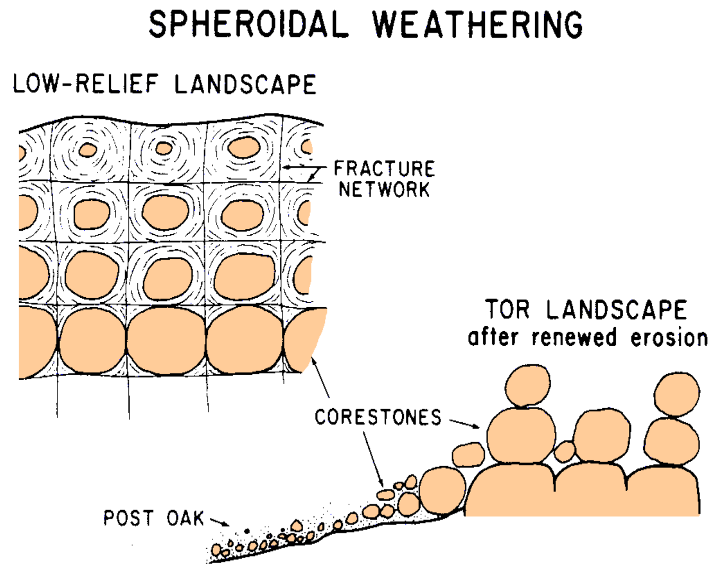


Figure 25: Diagram illustrating how spheroidal weathering in a fractured granite beneath the ground-water table can round granite. Then, later erosion can remove the altered, outer layers, leaving fresher, rounded granite clasts (boulders) of various sizes. This can result in tor topography as illustrated in the Wichitas, and the formation of conglomerate (e.g., Post Oak). STOP 7.

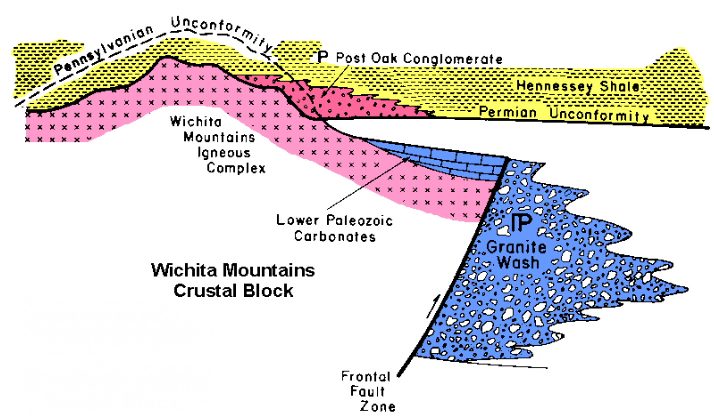


Figure 26. Simplified cross section showing that the Post Oak Conglomerate is a distinct Permian feature unrelated to the older Pennsylvanian Granite Wash of the Anadarko Basin subsurface. STOP 7.

▸Stop 8: QUANAH GRANITE

Parking area at Quanah Parker Lake Dam, Wichita Mountains Wildlife Refuge. SW SE Sec 23, T 3 N, R 14 W. USGS Topographic Map: Quanah Mountain.

This granite typically has blocky alkali feldspar grains about 1 cm in diameter, making it the coarsest-grained of the eastern Wichita granites (Fig. 29). While its color index is quite low, ~5 percent of dark minerals, it is well-known for the occurrence of the sodic amphibole arfvedsonite. Its

Figure 27. View from Quetone Point looking south where a layer of Post Oak Conglomerate is being eroded off exposing a Permian stream channel with its previously formed tributaries cut into granite. The modern Little Medicine Creek now occupies the old channel. STOP 7.

Figure 28. Photograph looking south from Quetone Point on Post Oak Conglomerate and showing the Post Oak Conglomerate layer in the distance. In the foreground, spheroidally weathered clasts of Mount Scott Granite can be seen. These were transported to this location by fluvial means, but most of the rounding is due to Permian weathering. This area around Little Medicine Creek has been stripped of conglomerate by modern erosion. STOP 7.

texture is distinctly different from the Mount Scott Granite so that field mapping is normally quite straightforward. Its texture becomes finer-grained and porphyritic in its border facies against the Mount Scott Granite, showing it is younger than that granite. The Quanah was one of the first Wichita granites to be radiometrically dated at 525 Ma (Tilton et al., 1962). Inclusions of Mount Scott Granite and Carlton Rhyolite in the Quanah Granite are common in places, such as near French Lake (e.g., Stop 10).

From the west side of the dam one can see, on the east wall of the canyon below the dam, fractures and "structures" in the Quanah which can be interpreted as due to magma flow during intrusion. Aplite dikes and pegmatitic veins can be seen on a walk to Little Baldy. These secondary intrusions typically contain annitic biotite and the sodic amphibole arfvedsonite, also called riebeckite. Features such as coarser grain sizes, felsic dikes with arfvedsonite, quenched border facies and inclusions of older rock types point to intrusion with more volatiles, a higher ambient pressure, and lower temperature, when compared to Mount Scott and the earlier granites. From this, we conclude that the Carlton Rhyolite must have been much thicker than it was when the older Mount Scott Granite was intruded (see Hogan et al., 2000).

The name Quanah comes from nearby Quanah Mountain, in turn named for Quanah Parker, the last famous Comanche chief who lived just south of these mountains.

▸Stop 9: GLEN MOUNTAINS LAYERED COMPLEX

Parking area at Panther Creek, Wichita Mountains Wildlife Refuge. NW NE Sec 21, T 3 N, R 14 W. USGS Topographic Map: Quanah Mountain.

The Glen Mountains Layered Complex is the oldest map unit cropping out in the Wichitas. It consists of generally well-layered gabbroic anorthosite. This rock is similar to that found in the Stillwater Complex of Montana and the Bushveld Complex of South Africa. Such rocks are typical source rocks for the platinum-group elements. Presumably we are in the upper half or third of the total complex, which may have 1.9-2.5 mi (3-4 km) of section below us. This anorthositic part is dominated by commonly laminated tabular calcic plagioclase (~An_{60-70}) (Figs. 30 A, B). The plagioclase crystallized early from a magma (a cumulus phase) then sunk (or floated) and was "cemented" together by post-cumulus clinopyroxene, magnetite, and additional plagioclase. It seems possible that those layers with extreme lamination resulted from compaction due to shaking by earthquakes during the rifting process. In some layers, olivine (~Fo_{70}) is also a cumulus phase. Its presence can commonly be detected by the occurrence of pits where the olivine weathered out. The olivine is commonly surrounded by reaction rims of orthopyroxene and magnetite. The Glen Mountains Layered Complex and similar rocks are thought to underlie the granites and rhyolites and form the bulk of the crust beneath this area and along the trend of the Wichita Mountains part of the Southern Oklahoma Aulacogen.

Figure 29: Quanah Granite displaying typical blocky alkali feldspars about 1 cm in diameter. STOP 8.

Figure 30A.

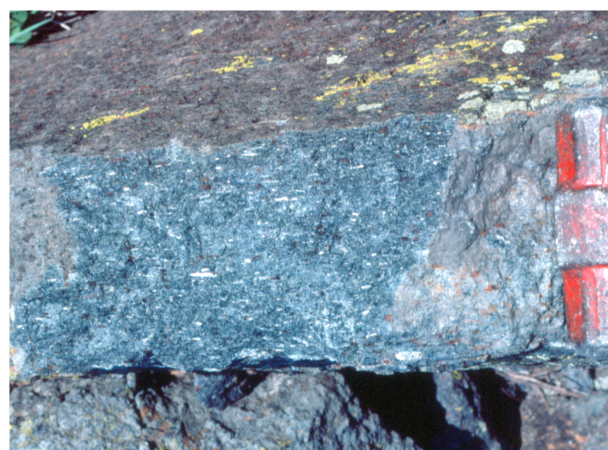


Figure 30B.

Figures 30A and B. Photos of broken Glen Mountains Layered Complex anorthosite with strong cumulus plagioclase lamination. The plagioclase here (mostly labradorite) are tabular shaped where the edges of the tablets show the strong alignment over layers with thicknesses of centimeter to meter scale. Note also how the lamination can control the shape of later fractured blocks of the gabbro. STOP 9.

▸Stop 10: FRENCH LAKE DAM

Transitional Quanah Granite Intrusive into Glen Mountains Layered Complex, French Lake Area. NW Sec 20, T 3 N, R 14 W. USGS Topographic Map: Quanah Mountain.

Start at the parking lot for French Lake and cross the small footbridge on the east side which leads into the Dog Run Hollow Trail System. Follow the trail to the left (north) along the arm of the lake. The importance of this stop is in seeing textural changes in the Quanah Granite which reflects its intrusive history: the granite is finer-grained than at Stop 8, showing that it cooled against pre-existing rock units, and that the granite encloses a variety of xenoliths (inclusions or enclaves). These xenoliths include Mount Scott Granite, Carlton Rhyolite, and rarely gabbro, demonstrating two important facts: the Quanah is younger than these other rock types and that Quanah intruded against these pre-existing rock units. At the dam site and below its north side, the contact between the Quanah and the Glen Mountains Layered Complex (gabbro), where the granite intruded against the gabbro, is well-displayed. This means that the Mount Scott Granite, which is not here now, was once overhead and has been eroded back off to the north.

Just after crossing the bridge and moving north, climb up a few feet on the Quanah Granite outcrop to observe a small, subhorizontal, aplitic dike (fine-grained granite) about 1 ft (0.3 m) thick cutting the Quanah. Along the upper contact of the dike is a vuggy quartz zone which shows vapor saturation at the end stages of granite crystallization. Proceeding farther north, and just before the trail turns back to the east along the lake shore, good exposures of rhyolite and Mount Scott Granite xenoliths may be seen.

Below the dam on the north side is a great exposure of Quanah Granite and its contact with the Glen Mountains Layered Complex (gabbro) (Fig. 31). The contact zone is partially eroded out, but granite dikes can be seen cutting the pre-existing gabbro, demonstrating the age relationships and that this is not a fault contact, but an intrusive contact (Fig. 32). The Quanah here has a myriad of xenoliths, interesting textural variations, and aplite dikes, all typical of an intrusive contact zone.

Finally, farther to the north away from West Cache Creek and the lake, Permian Post Oak Conglomerate is well displayed deposited on the gabbro. This conglomerate unit can be followed to the north where it forms a ridge over which the main east-west Refuge highway (OK 49 extended) passes. The conglomerate used to cover this whole area but was eroded off in the late Tertiary and Quaternary. The Refuge Interior Lowland, mostly underlain by gabbro and conglomerate, was a valley in the Permian.

Figure 31. View looking north across the face of French Lake Dam on West Cache Creek. The ridge beyond the trees is Permian Post Oak Conglomerate lying on Glen Mountains Layered Complex. Quanah Granite forms the base of the dam. STOP 10.

Figure 32. View looking east from French Lake Dam along the contact between the Glen Mountains Layered Complex on the left (north side) and the Quanah Granite on the right (south side) on the north side of West Cache Creek. STOP 10.

▸Stop 11: TOR TOPOGRAPHY AND TWIN ROCKS

Viewed from OK 49 just west past Headquarters and the Sunset Picnic turnoffs. Twin Rocks in Charons Garden. NW NE Sec 13, T 3 N, R 15 W. USGS Topographic Map: Quanah Mountain.

Moving west, OK 49 climbs up a hill just west past the Sunset Picnic area turnoff. From the top of the hill looking southwest, one can see Twin Rocks, a classic tor topographic feature (Fig. 33). Tors are natural rock columns, pedestals, and piers that project up from the surroundings. The process of spheroidal weathering is responsible for forming the rounded shapes and boulders so charactoristic of the granites of the Wichitas (see also Stops 6 and 7). The mountainous terrain to the south, especially the boulder field atop and on the southwest side of Elk Mountain, the Mount Lincoln area, and all the Charons Garden area, dis-

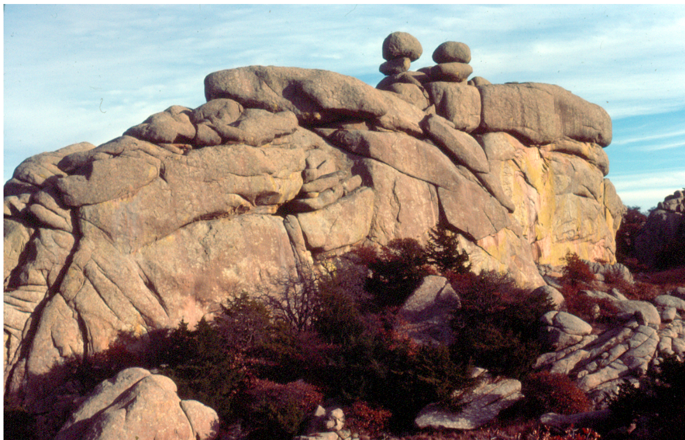


Figure 33. Twin Rocks, Charons Garden area, Quanah Granite. Twin Rocks can be viewed from the east-west cross Refuge highway (OK 49 extended) just west of the Sunset Picnic area turnoff. This is a classic example of tors and tor topography. STOP 11.

plays well the effects of spheroidal weathering. This region of the Refuge is underlain by the coarse-grained Quanah Granite. This granite has widely spaced fractures and thus generates large rounded boulders. These topographic forms were carved in the Early Permian and then buried and preserved in later Permian sediments. This paleotopography is now in the process of being uncovered and displayed.

▸Stop 12: MEERS FAULT

At the east-west section line crossing OK 58, 1 mi (1.6 km) north of Ann's Café and 1 mi north of the east-west Meers Road. Sec. 24-25 line, T 4 N, R 13 W. USGS Topographic Map: Meers.

This ~19-mi (~30-km)-long Holocene fault is unusual because it appears to follow a Pennsylvanian–Permian predecessor. In the Pennsylvanian, the Meers Fault (Fig. 34) was ***down*** to the north with about 1.2+ mi (2+ km) of throw, thus placing the Arbuckle Group rocks of the Slick Hills in their present structural position. However, about 1,100 years ago, movement occurred which could have generated a magnitude-seven earthquake. Holocene topography was offset 9–16 ft (3–5 m) ***vertically up*** to the north and with about the same offset horizontally (left-lateral), forming a scarp that can be traced for more than 30 km (Fig. 34).

Here the Meers Fault cuts the Hennessey Shale and the

Figure 34. Aerial view of the west-northwest-striking Meers Fault cutting across the limestone facies of the Post Oak Conglomerate in the Slick Hills. North side (upper right) is up. Good views available on Google Earth. STOP 12.

Figure 35. View looking west-northwest along the Meers Fault scarp on the Kimbell Ranch. Scarp runs along the straight tree line ahead marking the site of a new stream channel formed about 1,100–1,200 years ago where the scarp blocked drainage to the pre-faulted stream already existing on the right. STOP 12.

Holocene scarp is not so noticeable (unless you are looking for it) but is close to its maximum offset. Standing at this intersection and looking west-northwest, one can see on the skyline the V-shaped notch where the fault crosses the ridge.

Several rather dramatic topographic effects of the faulting can be seen in places. Where the fault cuts more erosionally resistant bedrock (e.g., Post Oak Conglomerate-limestone facies) one can see a more distinct scarp. Locally this scarp interrupted small stream drainages creating ponding at these interruptions and leading to the development of a new 1,100-year-old stream locally parallel to the scarp (Fig. 35). And, somewhat more rarely, individually sheared limestone clasts can be found. This fault scarp and the associated topographic effects are equivalent to what is seen in the settings of modern faulting in the western U.S. In fact, this is the best fault scarp to be seen east of the Rocky Mountains, and it came as a surprise to the neotectonic community when its nature was fully appreciated in the 1980s. (See Madole (1986) and Crone and Luza (1986) for details on the faulting effects.)

Figure 36. View looking northward where a Kimbell Ranch road climbs up and over, and crosses the Meers Fault scarp. STOP 12.

The Famous Gold Rush in the Wichitas

Between 1901 and 1907 the Wichita Mountains and surrounding communities were a hotbed of activity as a gold rush swept through the area. Prospectors, miners, entrepreneurs and scam artists poured in staking claims, sinking mine shafts, setting up mining camps and assay houses and hawking worthless claims to unsuspecting victims. Much of the activity centered on land that was at that time a National Forest.

Only small amounts of copper, lead and silver were found, and the fortune-seekers soon moved on to follow new reports of riches and easy fortunes elsewhere. It turns out that during the gold fever of that time the U.S. Geological Survey analyzed 71 samples from the mines and found that they revealed a "uniform absence of even a trace of gold."

To this day, one can see on a hillside a "mine dump" formed of rocks that came from one of the many mines that are the result of long-forgotten hopes and dreams. See Gilbert and Powell (1988) for location of an old smelter foundation.

From time to time, the Oklahoma Geological Survey still receives inquiries about gold in the Wichitas. To date, nothing containing significant amounts of gold have ever been reported nor are they expected.

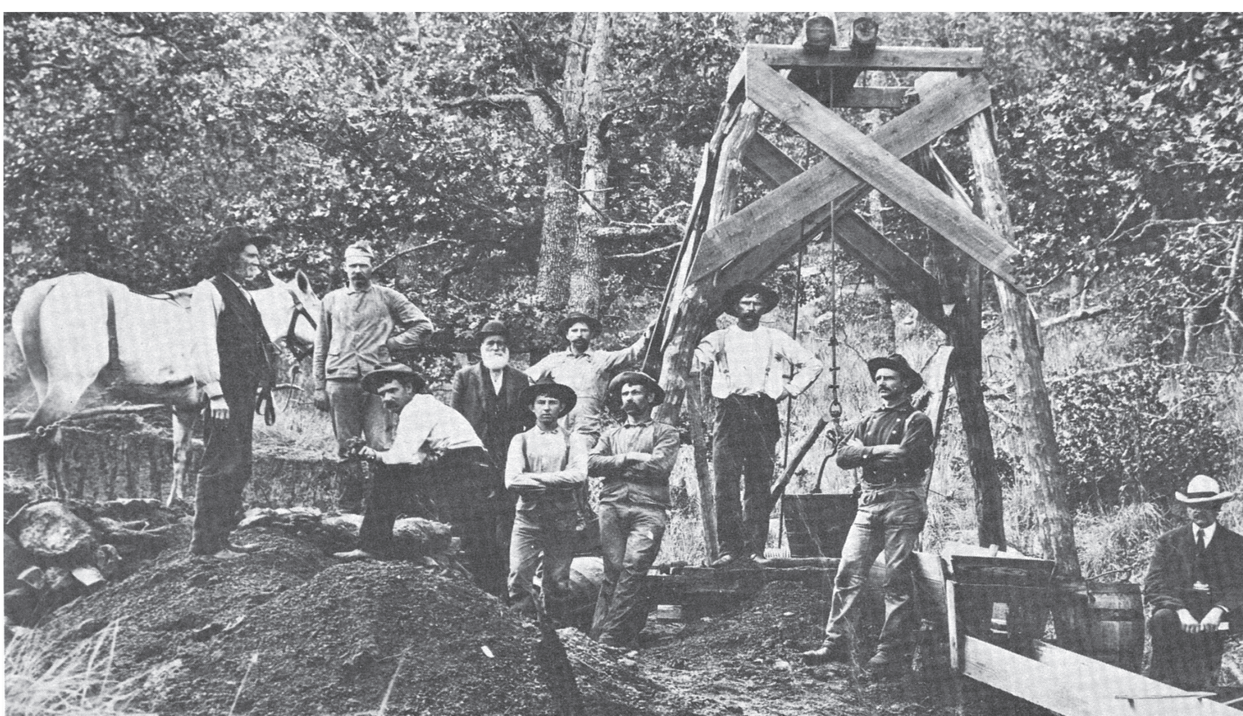
Between 1901 and 1907 more than twenty-five hundred shafts were sunk in the Wichita Mountains. Most were crowned with horse-powered hoists and shaft houses, such as this one near Snyder. Photo courtesy of the Western History Collections, University of Oklahoma.)

For more information see:

Wichita Mountains: Oklahoma Historical Sociey's Encyclopedia of Oklahoma History and Culture. http://digital.library.okstate.edu/encyclopedia/entries/w/wi002.html

Plazak, Dan, 2006, A Hole in the Ground With a Liar at the Top: Fraud and Deceit in the Golden Age of American Mining: The University of Utah Press, Salt Lake City, Utah, 374p

Wilson, Steve, 1989, Oklahoma Treasures and Treasure Tales: University of Oklahoma Press, Norman, Oklahoma, 344p.



Campbell Mine at the north base of Mount Scott in the Wichitas was sunk sixty-five feet deep with a thirty-foot tunnel. Photo courtesy of Western History Collections, University of Oklahoma.)

Western Wichita Mountains

THE ROOSEVELT AREA

Between the eastern end of the Wichitas (Stops 1-12), and the far western end (Stops 14-15) is a distinct area around the town of Roosevelt and around nearby Lake Tom Steed (Great Plains State Park). This area is well known for the largest outcrops of the Glen Mountains Layered Complex. This unit takes its name from the Glen Mountains local range prominent in this area. The range also includes several of the Roosevelt Gabbros and the petrologically fascinating mixed rock unit, the Cold Springs Breccia, described at Stop 13.

▸Stop 13: COLD SPRINGS BRECCIA

Excavated area along east side US 183, ~ 2.5 mi (~4.0 km) south of Roosevelt, Oklahoma. NW SW Sec 16,T 4 N, R 17 W. USGS Topographic Map: Glen Mountains.

This outcrop (Fig. 37 on page 24-25) has been described recently by Pritchett and Ambuehl (2013) because it is easily accessible due to new highway construction. The chemistry and interpretation of the Cold Springs as a unit has been discussed by Vidrine and Fernandez (1986). The Cold Springs cuts the Raggedy Mountain Gabbro Group and is cut by diabase dikes and granitic dikes, leaving its age relative to some of the other igneous units of the Wichita Mountains area problematic (Fig. 38).

Figure 38. This is figure 5 of Pritchett and Ambuehl (2013), showing later cross-cutting granitic dikes. Note the differential weathering of the intermediate and mafic rock compared to the granitic dike at the top of the photo. STOP 13.

This is an interesting igneous mixed rock assemblage known for some time (Taylor, 1915; Walper, 1949). It was given the lithodemic designation Cold Springs breccia by Powell et al. (1980). The black basaltic unit of the breccia was separately named by them Otter Creek Microdiorite because of its dominant mineralogy —plagioclase + amphibole —rather than the typical basalt mineralogy of plagioclase + pyroxene. The significance of this is that the Otter Creek magma was water-rich compared to almost all other Wichita mafic rocks. The Roosevelt Gabbros were also hydrous but not to the extent of the Otter Creek. Certainly the most widespread basaltic dikes in the Wichitas are what we call Diabase. This unit is anhydrous. Thus, it seemed necessary to Powell et al. (1980) to separately name the Otter Creek.

In the Cold Springs there are all gradations of mineralogy, composition, texture, and boundaries/contacts between the basalt and granite end members (Fig. 39). Thus, the question of the origin of this unit arises: In what way did at least two different magmas interact and in what sequence? Did two magmas (or more) intrude together, or was a basaltic one

Figure 39. A variety of contact relations between Otter Creek and an intermediate liquid. STOP 13.

first, then intruded by a silicic one; or was a silicic one first, then intruded by a basaltic one? Certainly, in a loose sense, a lot of magma mixing and interaction has occurred. The problem is keeping track of the heat balances involved in melting, crystallization, and reaction. A "granitic" composition melt would have a solidus of about 1,290-1,600°F (700–900°C) while a basaltic one would have a solidus of 1,830-1,920° F (1,000–1,050°C), where anhydrous, and 1,560-1,740°F (850–950°C), where water-rich (at the presumably relatively low pressure emplacement of the Cold Springs).

Some quarrying was done in the first half of the 20th century, west of this highway, as Cold Springs granite. This was in very limited areas where somewhat more uniform and larger masses of intermediate granodioritic-dioritic compositions could locally be quarried, yielding a "gray granite" (Fig. 40). An interesting example of spheroidal weathering is also on display along the roadcut (Fig. 41).

Figure 37. This panorama (above and next page) is figure 1 of Pritchett and Ambuehl (2013), which shows most of the length of the Cold Springs Breccia outcrop provided by new highway construction. STOP 13.

The intermediate compositions surrounding some of the already rounded, fine-grained, more mafic globes are weathered, leaving these essentially unweathered globes to appear suspended in a weathered matrix. It is an illustration of the more rapid weathering of coarser-grained masses compared to adjacent or included finer-grained masses noted in Stop 13.

Figure 40. The man is standing near the contact between the more texturally uniform Cold Springs below, which had been quarried, and the more compositionally and texturally varied Cold Springs above. STOP 13.

Figure 41. A roadcut illustrating differential weathering related to grain size but opposite what might have been expected based on bulk rock chemistry. STOP 13.

QUARTZ MOUNTAIN STATE PARK

Quartz Mountain is near the western end of the Wichita Mountains. Just a few miles to the north beyond Granite, Oklahoma, the last outcrops of igneous rock disappear beneath the Permian Hennessey Shale. The "mountain range" extends west-northwest in the subsurface toward Amarillo. Two geologic processes are at work in the disappearance of the mountains: the absolute elevations of the eroded tops of the old peaks are getting lower, and the elevation of the surrounding plains is getting higher as one moves west. Elevation of the plains around Fort Sill is near 1,100 ft (335 m) and around Granite is 1,600 ft (490 m) so that the baselevel shaly environment through which the peaks project is 500 ft (150 m) higher than it was around Fort Sill at the eastern

end of the mountains.

It is worth noting again that one is viewing a "fossil" topography being exhumed by present-day erosion (Fig. 42). Seeing older topographic forms being displayed so clearly at the Earth's surface is relatively rare as most Earth topography is geologically young (usually having been carved in about the last 20 Ma). Wichita Mountains topography formed in the Early Permian (~280–270 Ma) and was then buried by fine sediments (Hennessey Shale at the present level of exposure) in a delta-plain environment, with the sediments derived from the east (Ouachita Mountains and Ozark Plateau regions). There are some weathering/erosional features in the park that, in the first half of the 1900s, were described to the action of "waves" in the Permian sea.

Although there was a sea not far away, the sediments that directly enclose the mountains are largely fluvial and deltaic. It is much more reasonable to view these weathering features as related to ground-water sapping in the Permian sediments when the sediment level was somewhere above the present stratigraphic level. This could have occurred during the covering (depositional) stage or during an unroofing stage in later time.

One can view the contact relations between the Reformatory Granite and the Lugert Granite on the south side of Quartz Mountain. This affords the opportunity to see some of the results of processes that go on when 1,470°+ F (800°+ C) silicic magmas intrude pre-existing rock. One can also see the effects of magma becoming saturated in a volatile constituent (water), leading to the formation of miarolitic cavities.

Figure 42. Baldy Point, Quartz Mountain State Park. This projection of paleotopography, carved in Reformatory Granite, sticks up through Permian Hennessey Shale.

▸Stop 14: EAST END OF THE SOUTH SIDE OF QUARTZ MOUNTAIN

Park at the Nature Center or the New Horizon Trail Head, Quartz Mountain State Park. NE SW Sec 22, T 5 N, R 20 W. USGS Topographic Map: Lake Altus.

.

Go north across the small gully to the base of the mountain slope. This location is geologically important because an interesting local igneous history can be worked out by eye from the textural relations in the rocks. Here, we can see the contact between the later Lugert Granite and the earlier Reformatory Granite and the relations seem to tell a rather complicated story.

First, however, before going farther west, look directly at the immediate rock face. You see a very "holey" surface (Fig. 43). These are large miarolitic cavities, essentially gas bubbles formed in the liquid magma as H_2O exsolved from the rock melt. This commonly occurs as magma comes near the Earth's surface because the solubility of H_2O is a function of pressure and the pressure is falling as the magma rises toward the surface and is intruded into the upper crust. Clearly the gas did not escape here because the vesicles are not deformed by compaction. All this is going on as the magma crystallizes to granite somewhere around 1,470° F (800° C). There are also pegmatitic pods (masses of coarser feldspar and quartz) in the granite, compatible with the water coming out of solution in the cavities.

Farther up the slope there are some weathering/erosional sculptures, features that look like someone took a huge knife or spatula and carved slices across the granite face forming a scalloped surface. These, along with some related horizontal notches and ridges, were once attributed to Permian wave action. Most modern observers think we are looking at ground-water solution effects formed when the mountains were covered with shale. This could have been in the later Permian as the mountains were being buried, or in the Tertiary as they were being uncovered.

From this outcrop area west, magnificent examples of a medium-grained but coarser Lugert Granite magma phase invading and dismembering a finer Lugert Granite phase can be seen (Fig. 44 A, B). As the finer granite is more resistant to weathering than the coarser, the finer xenoliths tend to stand up and stick out of the rock surface. Once your eye is attuned to these features, it is impressive to pick a spot on a small knob and view the surroundings. Some of the inclusions are as big as RVs. If one keeps moving west along the south side of Quartz Mountain, you will eventually come to a contact where the coarse Lugert is against a much coarser unit, the Reformatory (Fig. 45).

What is fascinating is that the Reformatory fines toward this contact. What does this show? It shows that an unknown unit existed here when the Reformatory was

Figure 43. View northward of an internal contact of Lugert Granite mass full of miarolitic cavities against less evolved Lugert. STOP 14.

originally intruded against which it cooled. That was before the fine Lugert intruded. But let us review this scenario. The fine Lugert intruded against the previously quenched Reformatory about at the current Reformatory-Lugert contact. How do we know this? Because the textures of the fine-grained inclusions of early Lugert themselves fine as one traces these inclusions closer to the contact. Finally, the coarser-grained Lugert phase intrudes, breaking up the finer phase, and itself not fining against the Reformatory. It is likely that the coarser Lugert intruded just after the finer Lugert. Perhaps the Reformatory itself was still hot.

What was the original rock against which the Reformatory first intruded? It might have been rhyolite. An interesting question for you. The Reformatory has been dated by John Hogan at about 530 Ma.

▸Stop 15: RIDGE CUT ON ROAD TO QUARTZ MOUNTAIN LODGE

Deep road cut in the southwest-northeast ridge that ends on the northeast as Twin Peaks, Quartz Mountain State Park. SE SW Sec 15, T 5 N, R 20 W. USGS Topographic Map: Lake Altus.

This road cut is wide enough to park and observe some interesting features: 1) two phases of the Lugert Granite—one, fine-grained, porphyritic, granophyric, and early; the other, medium-grained, non-granophyric, inclusion-rich, and later; 2) several types of xenoliths (sedimentary and mafic); and 3) locally pervasively fractured granite with some possible fault gouge.

Along the northeast side of the road cut, there is a steeply

Figure 44 A. Looking westward where early finer-textured Lugert blocks have been stoped (now xenoliths) by later coarser-textured Lugert. The finer-textured Lugert is more resistant to weathering and consequently sticks up denoting various sizes and shapes of stoped blocks. STOP 14.

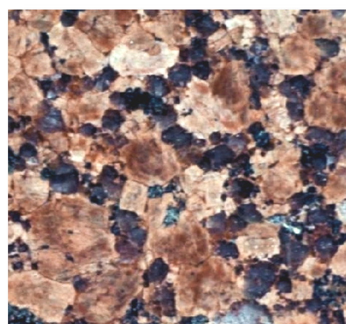


Figure 45 (left). Reformatory Granite displaying typical blocky alkali feldspars 1-2 cm in diameter. This is the coarsest granite in the Wichitas and it has been widely used in Oklahoma for monuments. STOP 14.

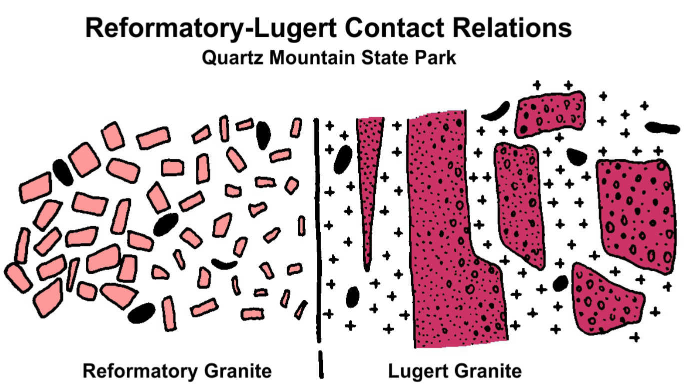


Figure 44 B. Older fine Lugert has quenched against a pre-existing boundary. The older Reformatory is quenched against the fine Lugert. The slightly later and somewhat coarser Lugert then intruded. STOP 14.

dipping contact between the finer phase of the Lugert and the coarser, which strikes approximately parallel to the road cut. As the contact surface and the cut face are nearly parallel, they intersect each other many times. The inclusions in the coarser phase are abundant but erratically distributed. The mafic ones are less numerous and range in size from 0.8-3.1 in. (2-8 cm), while the sedimentary ones are more abundant and range from 0.8-12 in. (2-30 cm). Particularly around the southeast entrance area to the road cut many nice examples of fine-granite xenoliths surrounded by coarser granite may be seen. In places, small quartz veins can be found in fine-granite xenoliths which end at the contact with the coarser granite.

Outline of the Igneous Stratigraphy

INTRODUCTION

Codification of the igneous rock units in Wichita Mountains' exposures was done by Powell et al. (1980) and modified by Myers et al. (1981), partly based on the earlier work of Ham et al. (1964) and Merritt (1958, 1965, 1967) (see Table 3). Granite units have been further modified (Price, 1998) and a different, more modern, organizational system has been used on limited areal sections of the gabbros (Cooper et al., 1986: Cooper, 1991). Basically, the gabbroic rocks are generally older and underlie the granites (Fig. 46). Rhyolites are thought to lie unconformably on gabbros and be intruded by granites along that unconformity (Ham et al., 1964). The igneous rock systems are totally within and a part of the Cambrian Southern Oklahoma Aulacogen, a classic rift bimodal system, and, in effect, define its extent. Hogan and Gilbert (1998) have argued that the whole igneous system in the Wichita Mountains exposures is a shallowly emplaced anorthosite-mangerite-charnockite-granite complex.

THE MAFIC ROCKS

Mafic rock units are tholeiitic and consist of two kinds of gabbroic bodies known collectively as the Raggedy Mountain Gabbro Group and of basaltic dikes (Diabase) which intruded throughout the period of granitic magmatism. The oldest and most widespread of the gabbros, also the oldest igneous rock unit in the Wichitas, is the Glen Mountains Layered Complex (Fig. 47). From textural and mineralogic evidence this body was shallowly emplaced, i.e., near the surface. The uppermost section was eroded away in the Early Cambrian before significant silicic magmas rose. What is exposed of the Glen Mountains Layered Complex is an anorthositic section representing the middle to upper sections of a typical layered complex with notable phase and cryptic layering, perhaps 0.6-1.2 mi (1-2 km) thick. Thus, there should be 1.9-3.1 mi (3-5 km) of buried section, presumably including some more ultramafic layers. This would be consistent with the prominent positive gravity anomaly present over the rift.

The other, younger gabbroic unit in the group is the Roosevelt Gabbros which are a series of five biotite and amphibole-bearing bodies, all hydrous in nature. While geochemistry demonstrates their primary mantle-derived character,

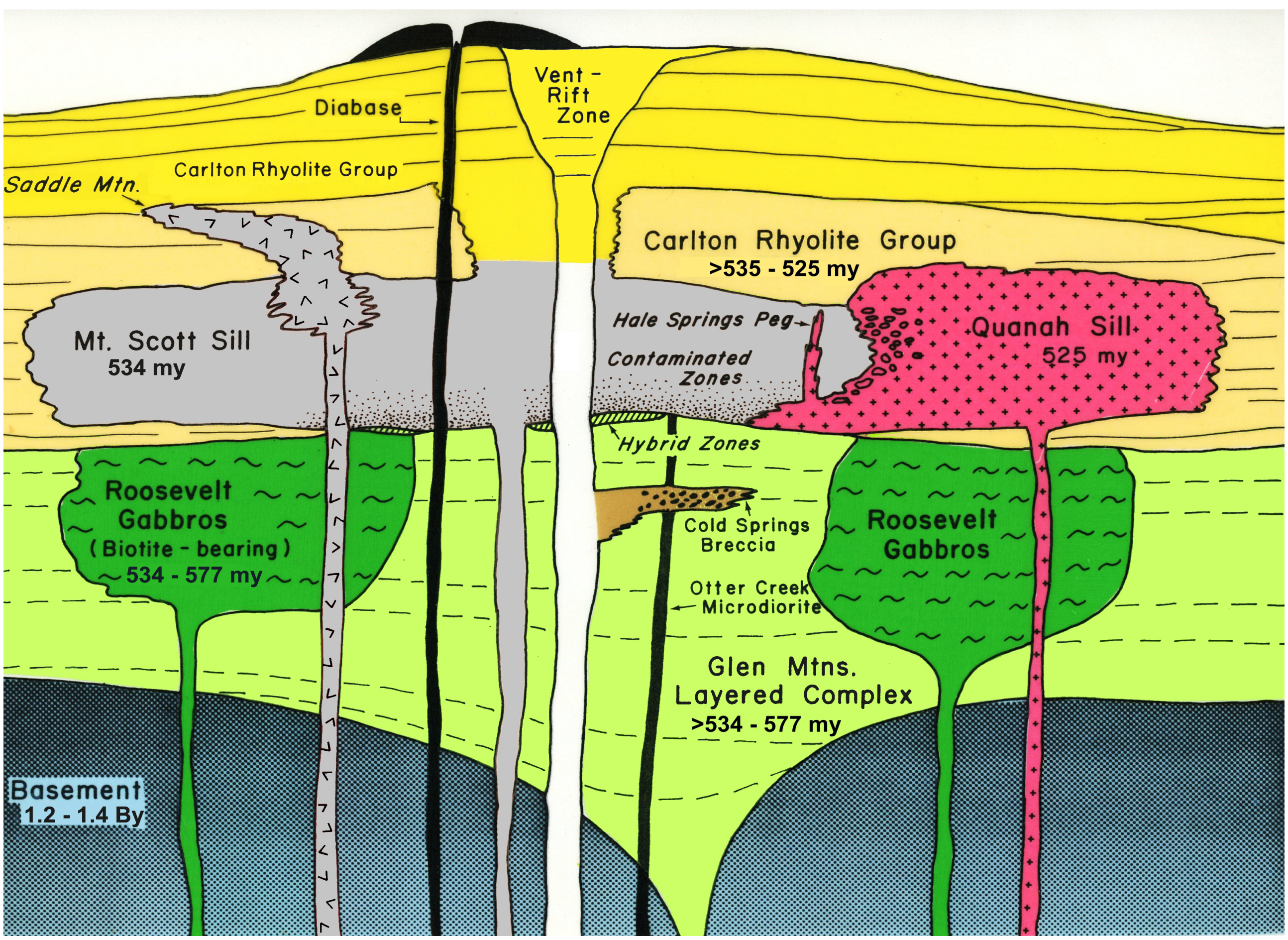


Figure 46. Simplified cross-section of the igneous stratigraphy letting Mount Scott Granite and Quanah Granite represent all the granites, showing rhyolites buildling up over the time of rifting and granite emplacement. No structure (e.g., faulting) is shown, and the only erosion occurs on the Raggedy Mountain Gabbro Group before the silicic volcanic rocks start accumulating.

Table 3. Igneous Stratigraphy of the Wichita Mountains
All units are early Cambrian, but some relative ages are not known

Diabase	Basaltic dike series that cuts all the units below but whose ages apparently span the igneous sequence	
Cold Springs Breccia And Otter Creek Microdiorite	Fine-grained diorite mixed with leucogranite	
Wichita Granite Group*	**Eastern Wichita Mountains** Quanah Granite–C Cache Granite–F Saddle Mountain–F Mount Scott Granite–F Rush Lake Granite-F Medicine Park Granite – F	**Western Wichita Mountains** Lugert Granite – F Reformatory Granite – C Long Mountain Granite – F Coopertown Granite – F Headquarters Granite – F
Carlton Rhyolite Group (thought to span the granite ages)	**Geographic Sections** Bally Mountain Blue Creek Canyon Fort Sill	
Raggedy Mountain Gabbro Group (oldest of the outcropping igneous units)	**Roosevelt Gabbros** Iron Mountain Gabbro Mt. Baker Gabbro Glen Creek Gabbro Sandy Creek Gabbro Mt. Sheridan Gabbro **Glen Mountains Layered Complex**	

**C = relatively coarse-grained granite <1/2 cm; F = relatively fine-grained, <1/2 cm. Based on discussion in Hogan et al. (2000).*

it also demonstrates they are not derived directly from the Glen Mountains Layered Complex. The largest is the Mount Sheridan Gabbro which has been the most studied and is easiest to see along OK 115 where it crosses Medicine Creek. Although these bodies clearly intrude the Glen Mountains Layered Complex, there is ambiguity about the age of the Roosevelt Gabbros compared to some of the granites (see Gilbert and Hogan, 2010).

The Diabase was discussed by Merritt (1958) and Ham et al. (1964) as a somewhat separate lithologic unit and it was utilized in Gilbert and Donovan (1982) and Gilbert (1986) as Late Diabase for the same reasons. These are basaltic dikes with diabasic texture. The designation "late" was based on observations that such dikes were commonly the last igneous activity noted in most descriptions of other igneous rock units. More detailed work now shows that diabase dikes were probably intruded at all stages of igneous activity, thus "late" should be dropped (Price et al., 2012). Trace-element patterns of the Diabase are similar to those for the Roosevelt Gabbros (Gilbert and Hughes, 1986). Also see new work by Hanson et al. (2012).

THE SILICIC ROCKS

Carlton Rhyolite Group was the name given by Ham et al. (1964) to all the Cambrian rhyolites related to the Southern Oklahoma Aulacogen, including those originally known as Colbert Porphyry in the Arbuckles. Because no more detailed stratigraphic breakdown has been made since, the rhyolites have been discussed based on three areas of outcrop: Fort Sill (the biggest), Blue Creek Canyon and Bally Mountain in the Slick Hills. More detailed work is being done on the Wichita Mountains outcrops by R. E. Hanson, Texas Christian University (Hanson et al., 2012). Typically the rhyolites have 10–20% phenocrysts with alkali feldspar being more dominant than quartz.

The rhyolites occur as flows and in some cases as ash-flow tuffs although no caldera structures have been identi-

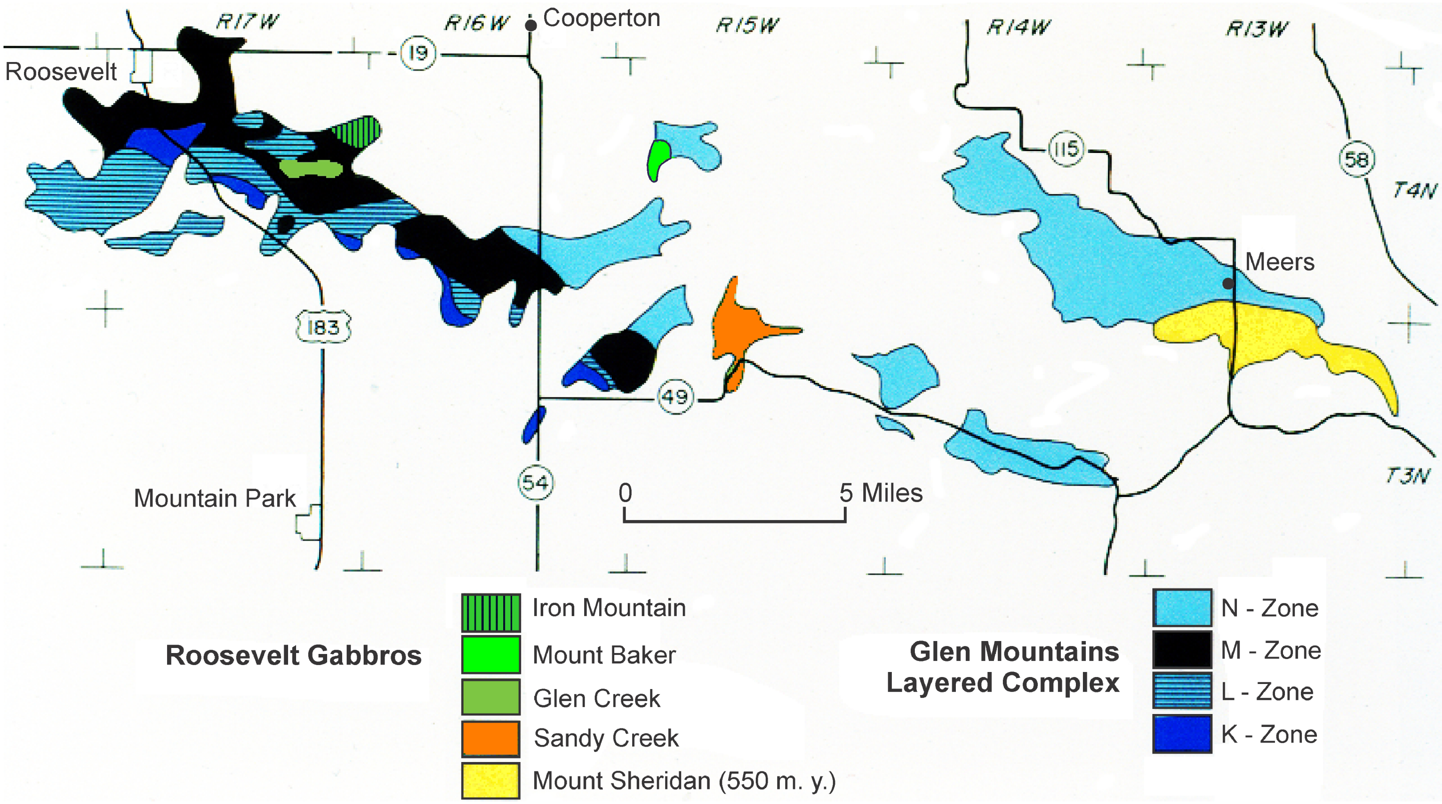


Figure 47. Raggedy Mountain Gabbro Group distribution. Uses an older nomenclature for the member units of the Glen Mountains Layered Complex. The Roosevelt Gabbros cut the Glen Mountains Layered Complex but with problematic ages relative to that of the Mount Scott Granite.

fied. Most seem to be aerially deposited. Rhyolite dikes are known to cut the granite and this observation was used by Ham et al. (1964) to argue that rhyolite units span the ages of granite emplacement.

The Wichita Granite Group now includes 11 recognized units, with Mount Scott Granite being the largest in outcrop area and best studied and dated (e.g., Price, 1998) (Fig. 48). All the granites are sheet-form and seem to be intruded along the same "stratigraphic" horizon—above the gabbros and into and below the rhyolites —though at different depths, but all relatively shallow. They are all A-type, high-silica, metaluminous, alkali-feldspar leucogranites. They are both hypersolvus and subsolvus. Color index is commonly 5% or less. Mafic phases are principally amphibole, biotite, and iron-titanium oxides. Amphibole is ferro-edenitic with sodic forms typical in the Quanah, and the biotite is annitic. Both have high Fe / Fe + Mg and significant fluorine. The sheet form is pronounced and is supported both by field observations and gravity anomaly arguments. This form is compatible with their rift (extensional) setting and contrasts with the more bulbous shapes found in subduction zone (compressional) settings (Fig. 49).

Texturally, the granites can be divided into two classes: finer-grained (<½ cm) and coarser-grained (1–2 cm)(Hogan et al., 2000). Many of the finer-grained granites have distinctive granophyric textures. The two coarser-grained granites are the Quanah Granite (525 Ma) in the eastern Wichitas, and the Reformatory Granite (530 Ma) in the west. [The Reformatory has been quarried for monument stone for more than 100 years and has been used extensively throughout Oklahoma.] These have been taken to be the younger granites from field observations and limited age dating, implying intrusion under a thicker section of rhyolite. Mount Scott Granite is an example of the finer-grained granites and one of the older (534 Ma). It also has a distinctive texture defined by dark ovoid alkali feldspar phenocrysts with rapakivi zoning. Price et al. (1996) suggested that these crystals started to nucleate, grow, and react at depths of 4-5 mi (7-8 km) as magma was rising to emplacement level. Estimates of crystallization temperatures for the granites have ranged from over 1,650° F (900° C) based on whole-rock phase chemistry and zircon geochemistry to ~1,380° F (~750° C) based on mineralogical and other geochemical indicators. Most of the granite magmas were relatively dry (relatively low H_2O, high fluorine) with an fO_2 near fayalite-magnetite-quartz (Price et al., 1999). A new study by Morgan and London (2012)

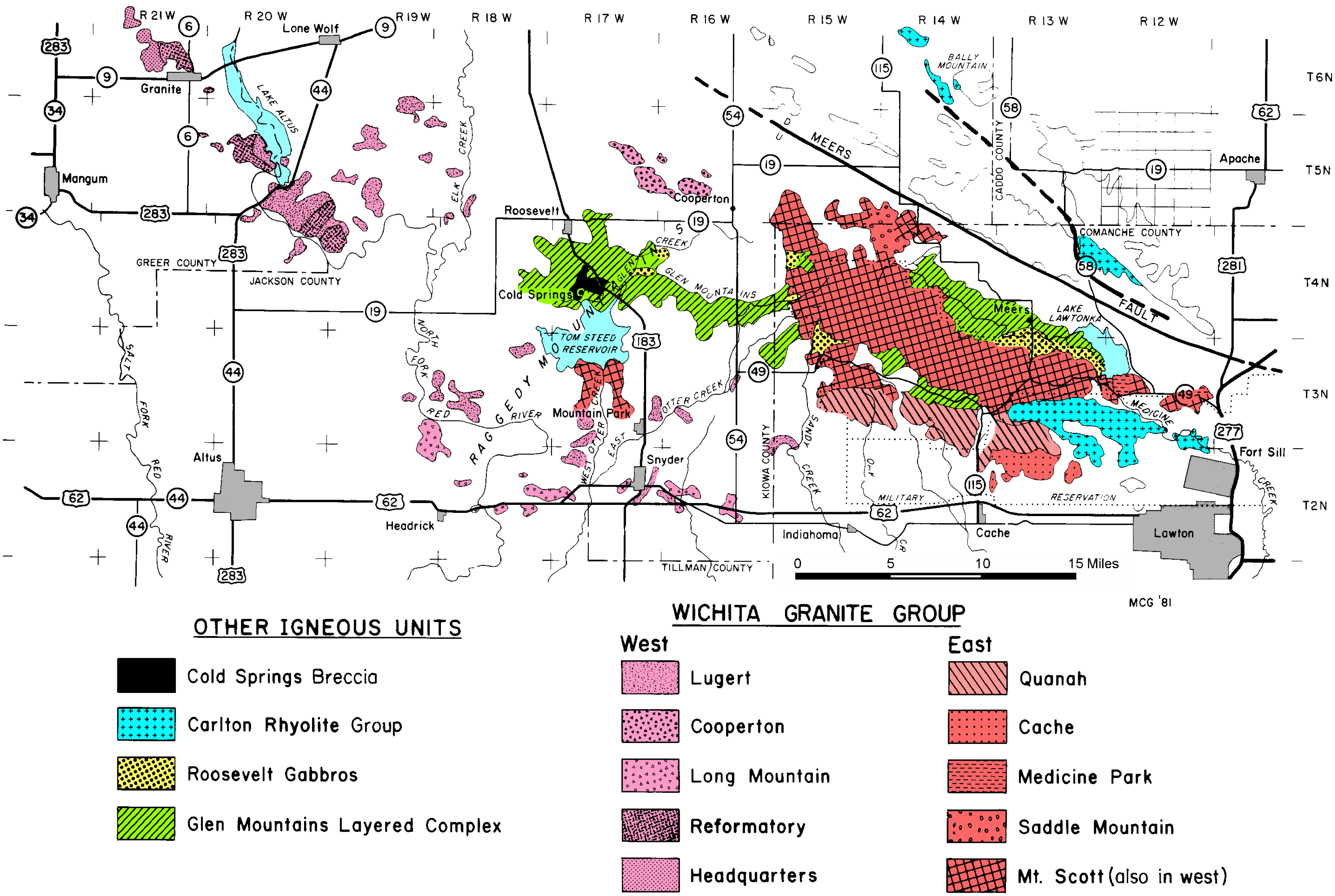


Figure 48. Wichita Granite Group distribution. The outcrop area of the Rush Lake Granite is too small to show on this map.

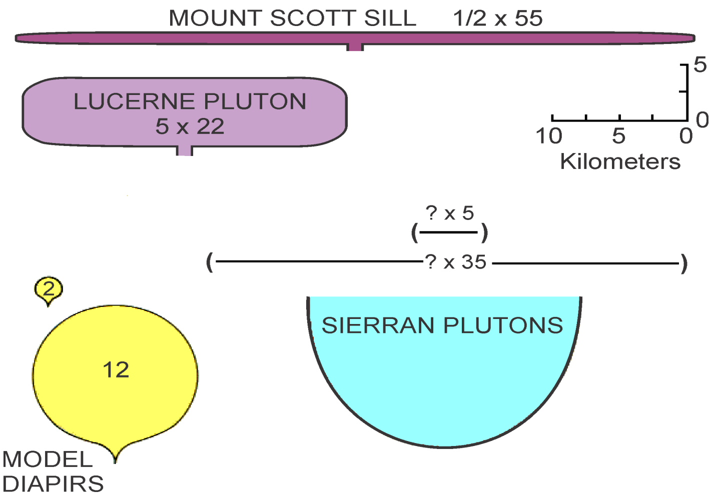


Figure 49. Comparison of shapes of sheet granites like Mount Scottt, formed in an external (rift) environment, with those formed in compressional (?) environments such as the Lucerne Pluton in Maine, the plutons of the Sierra Nevada, with suggested model diapirs of rising granitic magmas.

on the fine-grained Long Mountain Granite discusses how granophyre can form.

THE MIXED ROCKS

There are two mixed rock units in the Wichita Mountains. One is the Cold Springs Breccia found near Roosevelt and best exposed south of Roosevelt in old quarries, along railroad cuts near Lake Tom Steed, and along US 183 (Pritchett and Ambuehl, 2013). Stop 13 is an easily accessible exposure of this unit. This unit consists of two intermixed igneous end-member units: basalt (Otter Creek Microdiorite) and granite (Powell et al., 1980). All compositional and mineralogic gradations between fine-grained granite and basalt exist. This unit intrudes Glen Mountains Layered Complex and Roosevelt Gabbro and is cut by Diabase (see Powell and Gilbert, Stop 1, 1982). Vidrine and Fernandez (1986) have discussed and modeled this unit. The second is leucogranogabbro (Huang (1955) in only local and scattered occurrences. Gilbert and Donovan (1982) pointed out that this odd lithology seems to be found along or near a granite-gabbro contact and might be interpreted as forming where silicic magmas came in contact with saprolitic soils formed on Glen Mountains Layered Complex gabbro following its original unroofing in the Cambrian. This latter rock type can be seen easily only on private land.

Summary

The Wichita Mountains igneous area in southwestern Oklahoma is the major outcrop of the Cambrian Southern Oklahoma Aulacogen. Cambrian outcrops in southern Colorado and gravity data have outlined the extent of this rift from about Dallas out to the Uncompahgre Plateau of southwest Colorado giving it a length of 930-1,240 mi (1,500–2,000) km) (Larson et al., 1985; Keller and Stephenson, 2007; Soreghan et al., 2012). The gravity anomaly in the Wichita Mountains area reflect the larger amount of mafic igneous rock in this part of the Southern Oklahoma Aulocogen. Also, the igneous character of the more western scattered outcrops is more alkalic and more ultramafic as might be expected in the developing and leading front of a rift system as it migrates across an extending continental crust.

The information and comments in this guidebook can be documented from the included list of references. Many key field observations are located in publicly accessible sites in the Wichita Mountains Wildlife Refuge, Great Plains State Park, including the areas around Lake Tom Steed, and Quartz Mountain State Park. Other points of interest are located on private land where the owner's permission for access is required. Note that the Wichita Mountains Wildlife Refuge is a federal unit of the Fish and Wildlife Division of the U.S. Department of the Interior and collecting or defacement of any natural object is not permitted without specific authorization.

Substantial new work on the igneous rocks of the Wichitas is now available from the Oklahoma Geological Survey in Guidebook 38 (Suneson, 2014). This reference includes data and interpretations relevant to both the Arbuckle and Wichita Mountains area.

Mount Marcy looking north from Burford Lake.
(Photo by Jim Anderson.)

Corestone of leucogranogabbro being uncovered from its spheroidally weathered sheath.

Post Oak outcrop north of French Lake.

References

Buckley, A. (Rondot), 2012, An integrated geophysical analysis of crustal structure in the Wichita Uplift region of southern Oklahoma: Shale Shaker, v. 62, p. 432–452.

Campbell, J.A., 2007, Understanding the structure of the Wichita Uplift, southern Oklahoma: Shale Shaker, v. 58, p. 87–97.

Cooper, R.W., 1991, Geology, geochemistry, and platinum-group-element mineralization of the Cambrian Glen Mountains Layered Complex and associated rocks, southwestern Oklahoma: Oklahoma Geological Survey Circular 92, p. 98–108.

Cooper, R.W., Gilbert, M.C., and Powell, BN., 1986, Stop 1, Traverse across the Glen Mountains Layered Complex and into the Glen Creek Gabbro: Oklahoma Geological Survey Guidebook 23, p. 138–148.

Crone, A.J., and Luza, K.V., 1986, Holocene deformation associated with the Meers Fault, southwestern Oklahoma: Oklahoma Geological Survey Guidebook 24, p. 68–74.

Donovan, R.N., 1986, The Slick Hills of southwestern Oklahoma: Oklahoma Geological Survey Guidebook 24, 112p.

Gilbert, M.C., and Denison, R.E., 1993, Late Proterozoic to Early Cambrian basement of Oklahoma, in Reed, J.C., Jr., Bickford, M.E., Houston, R.S., Link, P.K., Rankin, D.W., Sims, P.K., and Van Schmus, W.R., eds., Precambrian: Conterminous U.S.: Geological Society of America, The Geology of North America, v. C-2, p 303-314.

Gilbert, M.C., and Denison, R.E., 1999, Exposed basement rock of Oklahoma: Geology and economic use, in Johnson, K.S., ed., Proceedings of the 34th Forum on the Geology of Industrial Minerals, 1998: Oklahoma Geological Survey Circular 102, p. 25–36.

Gilbert, M.C., and Donovan, R.N., 1982, Geology of the Eastern Wichita Mountains, southwestern Oklahoma: Oklahoma Geological Survey Guidebook 21, 160p.

Gilbert, M.C., and Hogan, J.P., 2010, Our favorite outcrop: The striking but enigmatic granite-gabbro contact of the Wichita Mountains igneous province: Shale Shaker, v. 61, p. 130–134.

Gilbert, M.C., and Hughes, S.S., 1986, Partial chemical characterization of Cambrian basaltic liquids of the Southern Oklahoma Aulacogen: Oklahoma Geological Survey Guidebook 23, p. 73–79.

Gilbert, M.C., and Powell, B.N., 1988, Igneous geology of the Wichita Mountains, southwestern Okla-homa, in Hayward, O.T., ed., Centennial Field Guide, Volume 4, South-Central Section: Geological Society of America, p. 109-126.

Gilbert, M.C., 1986, Petrology of the Cambrian Wichita Mountains Igneous Suite: Oklahoma Geological Survey Guidebook 23, 188p.

Gilbert, M.C., 1992, Speculations on the origin of the Anadarko Basin: in Mason, R., ed., Proceedings of the Seventh International Conference on Basement Tectonics: Kingston, Ontario, Kluwer Academic, p. 195-208.

Gilbert, M.C., 2004, Final movements associated with late Ancestral Rockies deformation: Geological Society of America Abstracts with Programs, v. 36, no. 5, p. 509.

Gilbert, M.C., 2009, The Wichita Mountains of Oklahoma, formation of tor topography, and the Permian Post Oak Conglomerate: Shale Shaker, v. 59, p. 137–143.

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

Hanson, R.E., Puckett, R.E., Jr., Keller, G.R., Brueseke, M.E., Bulen, C.L., Mertzman, S.A., Finegan, S.A., and McCleery, D.A., 2013, Intraplate magmatism related to opening of the southern Iapetus Ocean: Cambrian Wichita igneous province in the Southern Oklahoma rift zone: Lithos, v. 174, p. 57-70.

Hogan, J.P., and Gilbert, M.C., 1998, The Southern Oklahoma Aulacogen: a Cambrian analog for Mid-Proterozoic AMCG (anorthosite-mangerite-charnockite-granite) complexes?: in Hogan, J.P. and Gil-bert, M.C., eds., Central North America and Other Regions: Proceedings of the Twelfth International Conference on Basement Tectonics: Dordrecht, Netherlands/Boston, Kluwer, p. 39-78.

Hogan, J.P., Price, J.D., and Gilbert, M.C., 1998, Magma traps and driving pressure: Consequences for pluton shape and emplacement in an extensional regime: Journal of Structural Geology, v. 20, p. 1155–1168.

Hogan, J.P., Gilbert, M.C., and Price, J.D., 2000, Crystallization of fine- and coarse-grained A-type gran-ite sheets of the southern Oklahoma Aulacogen, U.S.A.: Transactions of the Royal Society of Edin-burgh, Earth Sciences, v. 91, p. 139–150.

Huang, W.T., 1955, Occurrences of leucogranogabbro and associated igneous rocks in the Wichita Mountains, Oklahoma: American Journal of Science, v. 253, p. 341–357.

Johnson, K.S., 1989, Geologic evolution of the Anadarko Basin: in Johnson, K.S., ed., Anadarko Basin Symposium, 1988: Oklahoma Geological Survey Circular 90, p. 3–12.

Jordan, L., 1964, Petroleum-impregnated rocks and asphaltite deposits of Oklahoma: Oklahoma Geological Survey Map GM-8, scale 1:750,000.

Keller, G.R., and Stephenson, R.A., 2007, The Southern Oklahoma and Dneiper-Donets Aulacogens: A comparative analysis: in Hatcher, R.D., Jr., Carlson, M.P., McBride, J.H., and Martinez-Catalan, R., eds., The 4D Framework of Continental Crust: Geological Society of America Memoir 200, p. 127-143.

Larson, E.E., Patterson, P.E., Curtis, G., Drake, R., and Mutschler, F.E., 1985, Petrologic, paleomagnetic, and structural evidence of a Paleozoic rift system in Oklahoma, New Mexico, Colorado, and Utah: Geological Society of America Bulletin, v. 96, p. 1364–1372.

Madole, R.F., 1986, The Meers Fault: Quaternary stratigraphy and evidence for Late Holocene movement: Oklahoma Geological Survey Guidebook 24, p. 55–67.

McConnell, D.A., and Gilbert, M.C., 1990, Cambrian extensional tectonics and magmatism within the Southern Oklahoma Aulocogen: Tectonophysics, v. 174, p. 147-157.

Merritt, C.A., 1958, Igneous geology of the Lake Altus area, Oklahoma: Oklahoma Geological Survey Bulletin 76, 70p.

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

Merritt, C.A., 1967, Names and relative ages of granites and rhyolites in the Wichita Mountains, Oklahoma: Oklahoma Geology Notes, v. 27, p. 45–53.

Morgan, G.B., VI, and London, D., 2012, Process of granophyre crystallization in the Long Mountain Granite, southern Oklahoma: Geological Society of America Bulletin, v. 124, p. 1251–1261.

Myers, J.D., Gilbert, M.C., and Loiselle, M.C., 1981, Geochemistry of the Cambrian Wichita Granite Group and revisions of its lithostratigraphy: Oklahoma Geology Notes, v. 41, p. 172–195.

Powell, B.N., and Gilbert, M.C., 1982, Stop 1—Reid's Pit: Oklahoma Geological Survey Guidebook 21, p. 79-96.

Powell, B.N., Gilbert, M.C., and Fischer, J.F., 1980, Lithostratigraphic classification of basement rocks of the Wichita Province, Oklahoma: Geological Society of America Bulletin, v. 91, p. 509–514 (pt.1); p. 1875–1994 (pt.2).

Price, J.D., 1998, Petrology of the Mount Scott Granite [Ph.D. dissertation]: Norman, Oklahoma, University of Oklahoma, 240p.

Price, J.D., Hogan, J.P., and Gilbert, M.C., 1996, Rapakivi texture in the Mount Scott Granite, Wichita Mountains, Oklahoma: European Journal of Mineralogy, v. 8, p. 435–451.

Price, J.D., Gilbert, M.C., and Hogan, J.P., 2012, Regional significance of diabase dikes in the Mount Scott Granite as exposed at Lake Elmer Thomas Dam: Shale Shaker, v. 62, 456–474.

Price, J.D., Hogan, J.P., Gilbert, M.C., London, D., and Morgan, G.B., VI, 1999, Experimental study of titanite-fluorite equilibria in the A-type Mount Scott Granite: Implications for assessing F contents of felsic magma: Geology, v. 27, 951–954.

Pritchett, B.N., and Ambuehl, D.S., 2013, Our favorite outcrop: Cold Springs Breccia; Shale Shaker, v. 63, p. 316-321.

Puckett, R.E., Jr., 2011, A thick sequence of rift-related basalts in the Arbuckle Mountains, Oklahoma, as revealed by deep drilling: Shale Shaker, v. 61, p. 207–217.

Soreghan, G.S., Keller, G.R., Gilbert, M.C., Chase, C.G., and Sweet, D.E., 2012, Load-induced subsi-dence of the Ancestral Rocky Mountains; Geosphere, v. 8, p. 654–668.

Stanley, T.M., and Miller, G.W., 2006, Geologic map of the Lawton 30′ x 60′ Quadrangle, Caddo, Comanche, Cotton, Grady, Kiowa, Stephens, and Tillman Counties, Oklahoma: Oklahoma Geological Survey Map OGQ-63, scale 1:100,000.

Suneson, Neil H., 2014, ed., Igneous and tectonic history of the Southern Oklahoma Aulacogen: Oklahoma Geological Survey Guidebook 38, in press.

Taylor, C.H., 1915, Granites of Oklahoma: Oklahoma Geological Survey Bulletin 20, 110p.

Tilton, G.R., Wetherill, G.W., and Davis, G.L., 1962, Mineral ages from the Wichita and Arbuckle Mountains, Oklahoma, and the St. Francois Mountains, Missouri: Journal of Geophysical Research, v. 67, p. 4011-4019.

Vidrine, D.M., and Fernandez, L.A., 1986 (A), Stop 2—Geochemistry and petrology of the Cold Springs Breccia, Wichita Mountains, Oklahoma: Oklahoma Geological Survey Guidebook 23, p. 86-106.

Vidrine, D.M., and Fernandez, L.A., 1986 (B), Stop 2—Cold Springs Breccia: Oklahoma Geological Survey Guidebook 23, p. 149-158.

Walper, J.L., 1949, Igneous rocks of the Cold Springs area, Wichita Mountains, Oklahoma [M.S. thesis]: Norman, Oklahoma, University of Oklahoma, 71p.

Wegemann, C.H., and Howell, R.W., 1915, The Lawton oil and gas field Oklahoma: U. S. Geological Survey Bulletin 621-G, p. 71–85.

Wilson, S., 1976, Oklahoma Treasures and Treasure Tales: Norman, Oklahoma, University of Oklahoma Press, 325p.

IDENTIFICATION OF THE MINERALS AND ROCKS IN THE WICHITA MOUNTAINS

(After David London)

Quartz [SiO_2]

1. appearance: translucent, gray to milky, glassy to greasy luster
2. hardness: [7] will scratch glass, harder than a knife blade
3. cleavage: rarely observed
4. fracture: conchoidal

Feldspars [$CaAl_2Si_2O_8$—$NaAlSi_3O_8$—$KAlSi_3O_8$]

1. appearance: white, gray, beige, red, pearly to glassy luster, chalky if weathered
2. hardness: [6] harder than a knife blade
3. cleavage: two good cleavage ~94° to each other, two poor cleavage planes, recognized for having "blocky" cleavage
4. fracture: conchoidal
5. There are two distinct chemical series: 1) *plagioclase* is Ca to Na-rich and is white to gray. In the Glen Mountains Layered Complex and Roosevelt Gabbro, it is uncommonly dark; 2) *alkali-feldspar* is K to Na-rich and generally reddish pink to beige because of oxidized Fe. All feldspars in Wichita granites are of this type. In the field, a hand lens aids in distinguishing. Plagioclase shows a series of fine, parallel striations. Alkali feldspars show a wormy irregular intergrowth of translucent and opaque patches called *perthite*.

Pyroxene and Amphibole [chemically complex silicates rich in Fe and Mg]

1. appearance: green to brownish black, glassy to pearly luster
2. hardness: [5-6] about the same hardness as a knife blade
3. cleavage: good prismatic, pyroxene cleavage planes intersect at ~87° and 93°; amphibole cleavages intersect at ~56° and 124°; use to distinguish
4. fracture: subconchoidal to uneven
5. Besides biotite and magnetite, the principal dark minerals in igneous rock. Pyroxene is dominantly in the gabbros as augite [$Ca(Mg,Fe)Si_2O_6$]; amphibole can be in both gabbros and granites. In the Quanah Granite, the sodic amphibole, riebeckite/arfvedsonite occurs [$Na_2Fe^{2+}{}_3Fe^{3+}{}_2Si_8O_{22}(OH,F)_2$]

Biotite [$K(Fe,Mg)_3AlSi_3O_{10}(OH,F)_2$]

1. appearance: shiny, black crystals
2. hardness: [2 ½-3] easily scratched by a knife$_3$
3. cleavage: one perfect plane, a mica that easily split into thin sheets or flakes

Magnetite [Fe_3O_4]

1. appearance: shiny black crystals, opaque metallic luster
2. hardness: [~6] may scratch a knife
3. cleavage: none
4. fracture: subconchoidal to uneven
5. magnetite grains are attracted to a magnet and can be magnetic themselves

---

MAJOR IGNEOUS ROCK TYPES

<u>Granite</u> – alkali feldspar (60%), quartz (35%), biotite, amphibole, magnetite (5%)
(<u>rhyolite</u> – fine-grained granite; feldspar and quartz phenocrysts set in fine-grained, unidentifiable matrix)

<u>Gabbro</u> – plagioclase (60-90%), pyroxene (10-40%), magnetite (~5%), some units have ~5% olivine (Mg_2SiO_4) which weathers leaving pits in the rock. Trace biotite only in Roosevelt Gabbro
(<u>diabase</u> or basalt – fine-grained gabbro; only plagioclase recognizable in hand lens)

GENERALIZED GEOLOGIC TIME SCALE OF OKLAHOMA

Era	Period		Epoch	Age, Ma*	Description
CENOZOIC	Quaternary		Holocene	.01	*Ongoing modern erosion forms most of Oklahoma landscape. Rio Grande Rift has provided current elevation slope for the last ~20 Ma.*
			Pleistocene	2.6	
	"Tertiary"	Neogene	Pliocene		
			Miocene	23.0	
		Paleogene	Oligocene		
			Eocene		
			Paleocene	66.0	
MESOZOIC	Cretaceous			145.0	*Last major sea invasion ~100 Ma from Gulf to Arctic covered state - mostly eroded off now.*
	Jurassic			201.0	*Only far western panhandle has evidence of these ages.*
	Triassic			252.0	
PALEOZOIC	Permian			299.0	*Surface of western Oklahoma dominated by Permian. Sea retreat left layers of gypsum, salt, and mud.*
	Carboniferous	Pennsylvanian		323.0	*Uplift of Wichitas, Arbuckles, and Ouachitas. Formed Anadarko Basin and subsurface Granite Wash.*
		Mississippian		359.0	
	Devonian			419.0	
	Silurian			444.0	*Sea covered much of the state for 150-200 Ma making many carbonates including Arbuckle Group which forms most of Slick Hills.*
	Ordovician			485.0	
	Cambrian			541.0	*Laurentian plate rifted ~580-520 Ma forming the Wichita Mountains igneous rocks.*
PRECAMBRIAN				~1400.0	*Oldest rock in Oklahoma, part of the Laurentian plate. Underlies most of the state but outcrops as Arbuckle basement near Tishomingo.*
				4600.0	*Earth formed as planetary body.*

*Isotopic ages in millions of years for the beginning of geologic intervals.
From the Geological Society of America, version 4, 2013.

Glossary

Selected terms that might help in understanding parts of the text, or figure captions, are given here. Some of the igneous rock and mineral names are described in the chart in the back of the Guide. The Glossary of Geology, a publication of the American Geosciences Institue (AGI), can be consulted for all geologic terms.

Alkali – Used to describe compositions rich in K (potassium) and Na (sodium).

Anadarko Basin – The thick sedimentary section lying north of the Wichitas and including most of western Oklahoma. This is a compound basin with the basement at 40,000 ft (12,200 m) at its deepest.

Anorthosite – A gabbroic rock consisting of more than 80-90% plagioclase.

Aplite – A finely textured granitic dike commonly cutting its coarser-textured granitic host.

Ash-flow tuff – Rock layer formed from an explosive silicic eruptive event.

Asphaltite – A solid hydrocarbon formed from pre-existing natural organic liquids.

Aulacogen – A rift zone that propagates into a continent from its edge. The Russians, who invented the term, felt such a zone would be deformed in later geologic history, as has happened in the Wichitas.

Basement – The region of igneous and metamorphic rocks which underlies all sedimentary units in Oklahoma. The basement in Oklahoma ranges in age from about 1.4 billion years to about 530 million years. In some regions, as the Wichitas, it is exposed.

Biodegraded – breakdown/alteration of organic matter by living organisms.

Biomarkers – Organic compounds in rocks which geochemists use to trace the origin of petroleum.

Border facies – Textural and mineralogic aspects of an igneous body characteristic of its border/margin.

Breccia – Agglomerated rock of angular particles.

Caldera – The typically large crater associated with rhyolitic eruptions forming ash-flow tuffs.

Clast – An individual rock/mineral fragment making up many sedimentary rocks.

Color index – The percentage of dark minerals in an igneous rock. In granites, this commonly includes biotite, amphibole (hornblende), magnetite.

Cumulus - The first (early) mineral(s) crystallizing from magma forming an igneous rock. [post-cumulus–mineral(s) or processes occurring after the early crystallizing mineral(s).]

Diabasic – Texture dominated by lath-shaped plagioclase crystals in a basalt.

Diapir – Buoyant mass rising through the crust.

Dike – Igneous rock sheet that cuts across internal host rock layering, commonly at high angles to the horizontal; contrast with sill.

Granophyric – Delicate intergrowths of alkali feldspar and quartz.

Laurentia – North America's ancestral continental plate existing in the late Precambrian.

Left-lateral – A fault that, when looking along it, the left side shows displacement towards you.

Limestone – A sedimentary rock formed from the calcareous shells of marine organisms. Here it signifies the previous existence of oceanic water.

Lithodemic – Stratigraphy (names) of mapped igneous rock units.

Mafic – Rock with 48 to 55 wt% SiO_2, dominated by minerals plagioclase and pyroxene.

Ouachita Mountains – Mountainous area of southeastern Oklahoma underlain by highly deformed (folded and faulted) sedimentary rocks.

Ozark Dome – The rugged area of southern Missouri, northeastern Oklahoma, and northwestern Arkansas.

Pangea – Supercontinent existing during the Pennsylvanian-Permian-Triassic. It was an assembly of most previously existing continental plates, including Laurentia. The Jurassic breakup of Pangea led to our present continental masses.

Pegmatitic – Coarse-grained mass occurring in an igneous host rock, commonly with host rock plus more exotic minerals.

Phenocryst – Coarser crystal set in a finer-grained matrix. An early formed crystal. [see porphyritic].

Porphyritic – Texture of coarser crystals (phenocrysts) set in a finer-grained groundmass.

Rapakivi – A Finnish term for alkali feldspar crystals displaying compositional zoning from cores to more Na-rich rims. Commonly clearly shown in coarse crystals but in fine crystals can be called microrapakivi.

Redbeds – Distinctly reddish Permian silts and shales of western Oklahoma. Color is due to finely disseminated hematite.

Sapping – Weathering and erosion along an horizon in a rock wall.

Saprolite – typically clay-rich highly weathered granite/ metamorphic rock.

Silicic – Rock with 65-75 wt % SiO2, dominated by minerals alkali feldspar and quartz.

Sill – Igneous rock unit that intrudes parallel to the host rock internal layering; contrast with dike.

Slick Hills – The long ridges north of the igneous part of the Wichitas (north of Meers Valley) underlain by limestone. Now mostly covered by wind farms.

Solidus – The temperature at which an igneous rock begins to melt or at which crystallizing magmas are totally solid.

Solvus – Phase boundary in temperature space between two limited solid solutions. Hypersolvus signifies a higher temperature than the solvus where only one phase can stably crystallize. Subsolvus signifies a temperature where two phases, two limited solid solutions, can coexist, such as a K-rich feldspar and a Na-rich feldspar.

Stoped – During an igneous intrusion where pieces of the host rock being intruded are encapsulated in the intruding magma.

Tholeiite – Basalt dominated by plagioclase and pyroxene

Tor – A column of rounded rock masses which can result from erosion of spheroidally weathered granite.

Transgression – Oceanic flooding of the continent commonly resulting in a sandstone as the first sedimentary rock layer formed.

Ultramafic – Rock rich in olivine and pyroxene whose bulk composition is less than 45 wt % SiO_2.

Uranium-lead method – A mineral dating method utilizing the radioactive decay of Uranium-235 and Uranium-238 to lead isotopes. The mineral commonly used is zircon.

Unconformity – A break in the stratigraphic record that signifies missing time.

Xenolith = inclusion = enclave – Name for a piece of pre-existing rock found in a magmatic body.

Looking north from Mt. Scott showing the wind farm on the Slick Hills. (Photo by Brian J. Cardott.)

OKLAHOMA GEOLOGICAL SURVEY
1908