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IGNEOUS GEOLOGY OF THE WICHITA MOUNTAINS AND ECONOMIC GEOLOGY OF PERMIAN ROCKS IN SOUTHWEST OKLAHOMA

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CONTENTS

FIGURES

TABLES

IGNEOUS GEOLOGY OF THE WICHITA MOUNTAINS AND ECONOMIC GEOLOGY OF PERMIAN ROCKS IN SOUTHWEST OKLAHOMA

Kenneth S. Johnson and *Rodger E. Denison*

Part I. Regional Geology

INTRODUCTION

Southwest Oklahoma contains three major geologic and tectonic provinces: the Wichita Mountains, the Anadarko basin, and the Hollis basin (fig. 1).

The rugged outcrops of the Wichita Mountains form the upper surface of a rigid crustal block of Cambrian igneous and metamorphic rocks that are mantled with a veneer of Permian red-bed sediments. A thick section of Late Cambrian to Early Devonian carbonates and Late Devonian to Pennsylvanian clastics, represented in outcrop by steeply dipping Late Cambrian-Ordovician strata on the east and northeast sides of the Wichita Mountains, was almost entirely stripped off the Wichita block during the Pennsylvanian by intensive uplift. The basins adjacent to the Wichitas contain a Late Cambrian-Permian sedimentary column 40,000 feet thick in the Anadarko basin and 10,000 feet thick in the Hollis basin.

Principal studies of the Wichitas include those of Chase and others (1956), Ham and others (1957), Merritt (1958), Ham (1963), Ham and others (1964), and Stone (1967). Additional information on Permian rocks and the economic geology of southwest Oklahoma can be obtained from Scott and Ham (1957), Ham and Curtis (1958), Ham (1960), Jordan and Vosburg (1963), Ham and Johnson (1964), and Johnson (1967, 1969, and 1972).

In preparing this guidebook, Johnson assumed primary responsibility for information and field-trip arrangements covering the Pennsylvanian-Permian geology and the economic geology of southwest Oklahoma. Denison assumed responsibility for the portion on igneous geology and Cambrian-through-Mississippian history of the Wichita

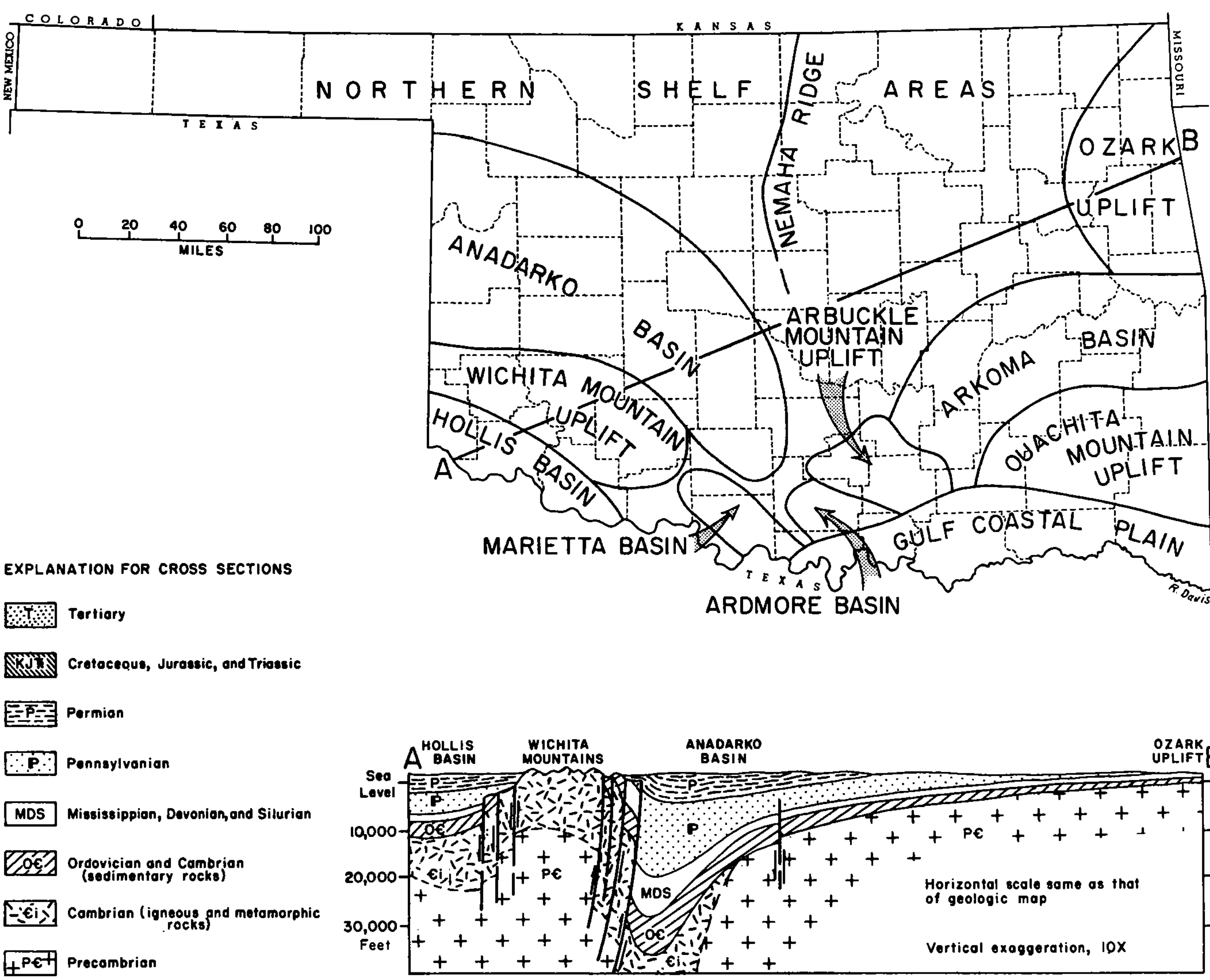


Figure 1. Map and cross section showing major geologic provinces of Oklahoma.

Mountain region. Scofield and Hunter cooperated with Denison in preparing material on the layered basic igneous rocks at Roosevelt (Stop 5), and Brockie worked with Johnson on the Eagle-Picher copper mine at Creta (Stop 10).

Appreciation is expressed to Roy D. Davis for drafting the illustrations and to Rosemary L. Croy and William D. Rose for editing the manuscript and nursing it through publication.

BASEMENT ROCKS AND PRE-PENNSYLVANIAN SEDIMENTARY ROCKS

Overview

The Wichita-Anadarko system is unique in that it is underlain by layered igneous rocks of Cambrian age and has the thickest stratigraphic sequence and the most dramatic structural relief of any area in the stable continental interior. The igneous rocks are overlain by a thick, largely carbonate sequence of Late Cambrian to Mississippian sedimentary rocks which were deformed in a series of episodes during Pennsylvanian time. The mountains were deformed along a general N. 60° W. axis. The basement and massive lower Paleozoic carbonates deformed as a single element, as will be demonstrated on the field-trip stops. The tremendous uplift along the mountain front provided a source for the Pennsylvanian and Early Permian clastics that were dumped northward into the adjacent Anadarko basin.

The mountains remain much as they were in Permian time—now in the process of being exhumed from their blanket of flat-lying Permian red beds. Near the main fault that divides the Wichita and Anadarko segments, the basement is estimated to lie at depths exceeding 40,000 feet, and it may be closer to 50,000 feet, depending upon structural complications. The world's deepest well, the Lone Star Producing Co. 1 Baden Unit, was drilled in the Anadarko basin 6 miles east of Sayre in Beckham County. The well reached a total depth of 30,050 feet in the Viola Limestone (Late Ordovician) before it was abandoned as a dry hole. An estimated 5,000 to 9,000 feet of rocks from the Simpson and Arbuckle Groups underlie the Viola. The Lone Star well was not in the deepest part of the basin and was presumably drilled on a structural high.

The localization of Cambrian igneous activity along an axis that was later a depocenter and a zone of intense compression and failure cannot be accidental, but the exact cause of the localization has not been satisfactorily explained. It undoubtedly occurred in response to deep crustal weaknesses, perhaps a plate boundary suture that was never fully developed. In any case, major localized deformations at an odd angle to continental margins are unusual on the craton, and the Wichita Mountains merit intensive geologic investigation.

Basement Rocks

The three major types of igneous rocks exposed in the core of the Wichita Mountains are gabbro, rhyolite, and granite (fig. 2). Ham and others (1964, plate 4) show the schematic evolution of these units; the rhyolite was extruded over the exposed layered gabbro sequence, and the granites intruded both the rhyolite and the gabbro. The base of the rhyolite was a zone of weakness favored for the injection of granite as sills.

The gabbros present a considerable gravity and magnetic anomaly, which suggests considerable volume. Known as the Raggedy Mountain Gabbro, they form a band at the anticlinal crest of the Wichita uplift, stretching northwest-southeast for about 120 miles. The thickness of the Raggedy Mountain Gabbro is unknown. The maximum drilled thickness is over 8,000 feet, but this is in a structurally complex area; only about 600 feet can be demonstrated to crop out.

The best known outcrop area, in the Raggedy Mountains of Kiowa County, shows the layered structure clearly. The composition is varied, with anorthositic, troctolitic, and diallage gabbro bands mapped. The general composition is plagioclase rich, but—due to erratic mineral distribution and the lack of an exposed chilled margin—the bulk composition is difficult to estimate. Many of the outcrops contain extraordinarily fresh rocks.

The gabbro is inferred to have intruded into a host of metasedimentary rocks under very quiet conditions. It is thought to be comagmatic with a suite of extrusive basalts and spillites found deep in the subsurface. Later, the mass was uplifted and eroded such that the gabbro and a few roof pendants of quartzite were exposed. The rhyolite flows then covered the gabbro, which was not again exposed until the late Paleozoic erosion.

The rhyolite was extruded on a surface of eroded gabbro, basalt flows, metasedimentary rocks, and massive granitic rocks. It is inferred or can be demonstrated to cover approximately 17,000 square miles of southern Oklahoma, even after considerable diminution by erosion prior to deposition of the Reagan Sandstone and erosion during the late Paleozoic. Most of the rhyolite was extruded as welded tuffs, although textural evidence for this exists in only a small percentage of the samples. For the most part, the rhyolites have only been devitrified and deuterically altered. Relict spherulites, perlites, and eutaxitic structures are common but not volumetrically important.

The granites seen in the Wichita Mountains intruded into the active volcanic pile. The granites are highly siliceous, leucocratic, and texturally and mineralogically typical of shallow, epizonal intrusion; many are micrographic granite porphyries. The most conspicuous form of intrusion was as a sill injected at the base of the rhyolite. However, there is ample evidence of irregular intrusions into the volcanic pile, particularly along the axis of the present mountain uplift.

Erosion following the culmination of igneous activity appears to have been minor and probably was most telling on the distal edges of the giant rhyolite pile. The isotopic ages on the siliceous rocks center about 500 to 525 m.y. (Tilton and others, 1962; Ham and others, 1964; Denison and others, 1966; Burke and others, 1969). There is some disagreement about the time scale in the Cambrian, but it seems clear that 10-20 million years is all that could have elapsed between the igneous culmination and the transgression of the sea in Late Cambrian (Franconian) time.

Overlying Sedimentary Rocks

The early and middle Paleozoic rocks overlying the basement rocks in the Wichita Mountains are mostly shallow-water carbonates. Data on thickness and general stratigraphy are shown in figure 3, taken from Chase and others (1956), Brookby (1969), and Barthelman (1969) for the exposed rocks and Takken (1968) for the subsurface. A

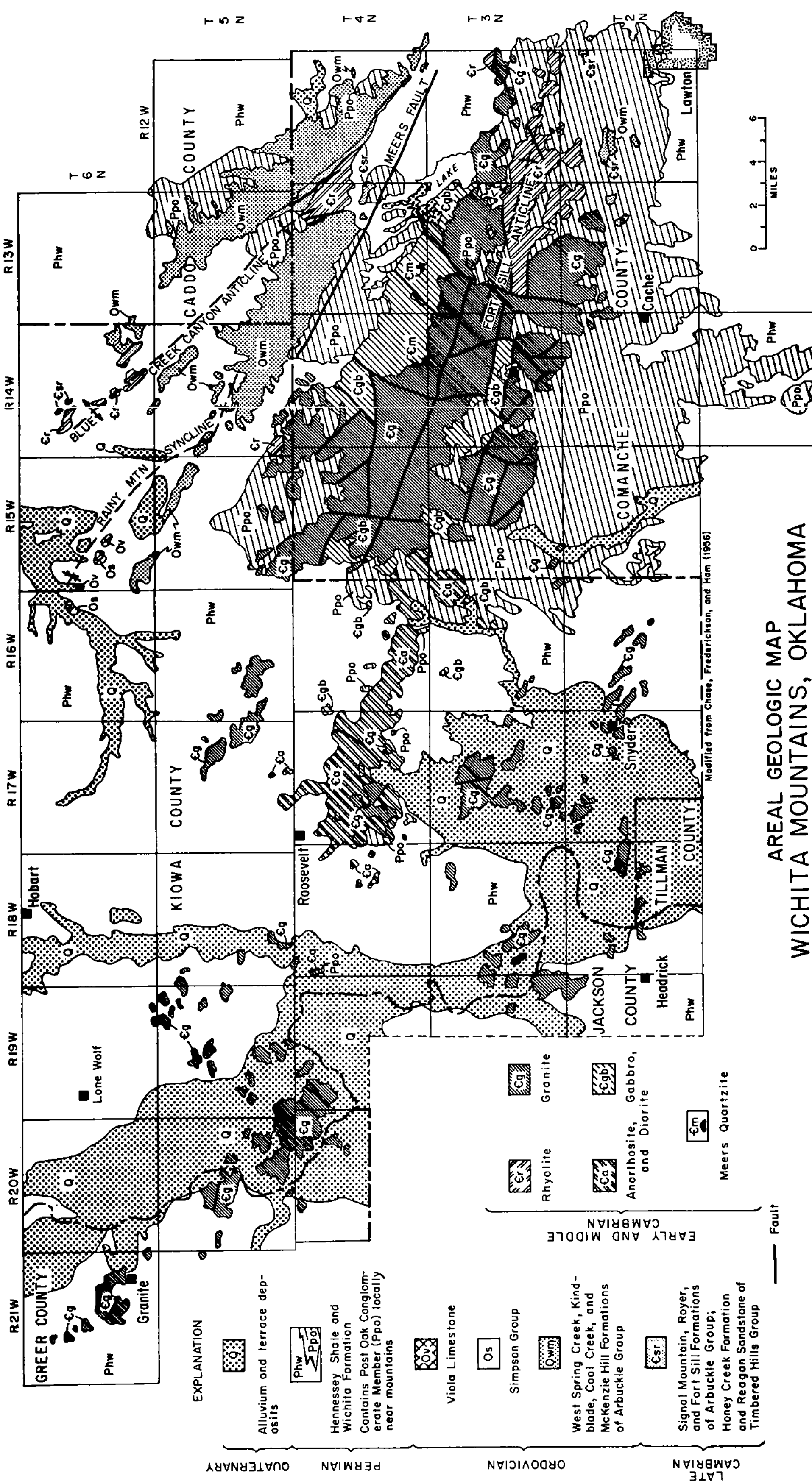


Figure 2. Areal geologic map of Wichita Mountains.

SYSTEM		STRATIGRAPHIC UNITS		APPROXIMATE THICKNESS, IN FEET
MISSISSIPPIAN	not exposed	Springer Formation		1400
		Goddard Formation		600
		"Chester Formation"		2500
		Sycamore Limestone		500
		"Osage Formation"		350
		"Kinderhook Formation"		100
DEV.-SIL.		Woodford Shale		500
			Hunton Group (undifferentiated)	1500
ORDOVICIAN		Sylvan Shale		225
	exposed	Viola Limestone		775
		Bromide Formation	Simpson Group	2300
	not exposed	Tulip Creek Formation		
		McLish Formation		
		Oil Creek Formation		
		Joins Formation		
	exposed	West Spring Creek Formation	Arbuckle Group	6000
		Kindblade Formation		
		Cool Creek Formation		
		McKenzie Hill Formation		
		Signal Mountain Formation		
CAMBRIAN		Royer Dolomite		
		Fort Sill Formation		
		Honey Creek Formation	Timbered Hills Group	80-475
		Reagan Sandstone		
		Carlton Rhyolite		2500-3500

Figure 3. Generalized pre-Pennsylvanian stratigraphic sequence in Wichita Mountain area. Mississippian names in quotations are informal names used for subsurface units.

more complete discussion of relevant Cambrian-Ordovician stratigraphy is found in Ham's (1969) Arbuckle Mountains discussion, which presents a close analogy for the sequence in the Wichitas.

The basal transgressive sequence is the Timbered Hills Group, composed of the Reagan Sandstone and the Honey Creek Formation, a sandy calcarenite. The units are gradational and are Franconian in age. The overlying Fort Sill, Signal Mountain, McKenzie Hill, Cool Creek, Kindblade, and West Spring Creek Formations constitute the Arbuckle Group. Locally, dolomites replace these shallow-water carbonates along stratigraphic horizons; the Royer Dolomite, for instance, replaces the lower part of the Signal Mountain and the upper part of the Fort Sill. The top of the West Spring Creek is not exposed, but measured sections in the Blue Creek Canyon anticline suggest that the total thickness of the Arbuckle Group is near or somewhat less than the 6,700 feet measured in the western Arbuckle Mountains.

The Franconian-Trempealeauan boundary lies within the Fort Sill Formation. The contact between Ordovician and Cambrian strata is about 600 feet above the base of the Signal Mountain. The remainder of the Arbuckle Group is Early Ordovician. Of the overlying pre-Mississippian strata, only parts of the Bromide Formation and the Viola Limestone are exposed. Drilling in the surrounding area shows that units from the Simpson Group are present and that the Hunton Group (Silurian-Devonian) is substantially thicker than in the Arbuckle Mountains.

The post-Arbuckle rocks, particularly those of Silurian-Devonian age, show (where paleontologic data are sufficient), several breaks in sedimentation, although none are characterized by significant angular unconformity.

Mississippian rocks, represented by a series of thick shales and limestones (over 4,000 feet thick in the North Gotebo area), are found only in the subsurface. The nomenclature includes a mixture of names borrowed from the Arbuckle Mountains and several time terms. The Sycamore and Goddard formations correlate with outcrops to the east, whereas time terms such as "Chester," "Osage" and "Kinderhook" are used to designate lithologic intervals. These units have been considerably eroded on the south side of the Mountain View Fault, the main fault separating the Wichita Mountain block from the Anadarko basin.

DESCRIPTION OF THE LAYERED BASIC IGNEOUS ROCKS IN THE RAGGEDY MOUNTAIN GABBRO GROUP[1]

Hugh E. Hunter

The term "Raggedy Mountain Gabbro Group" has been applied to the gabbros and allied basic rocks of the Wichita province. Gabbroic rocks are exposed at several localities in the Wichita Mountains, the largest of which is the Raggedy Mountains, which lie in the central part of the Wichita system (fig. 2). Data from surface mapping and from subsurface studies (Ham and others, 1964) indicate that the gabbroic rocks constitute a stratiform body at least 25 miles wide and 110 miles long, extending along the northwest-trending axis of the Wichita Mountains. Surface mapping in the Raggedy Mountains suggests an exposed thickness of approximately 600 feet. The total thickness of the body is unknown, but one well penetrated slightly more than 8,000 feet of gabbroic rocks that were similar in mineralogical and textural characteristics to those exposed in the Raggedy Mountains without reaching the lower contact.

Detailed mapping of the Raggedy Mountains by Gilbert (1960) and Spencer (1961) and reconnaissance work by Spencer and Hunter in the eastern Wichita Mountains have shown that the gabbroic rocks consist of interlayered anorthosite, gabbro, olivine gabbro, and troctolite. The rocks exhibit features typical of a layered basic intrusive complex.

Dikes and sills of fine to medium-grained olivine gabbro intrude the layered series and are in turn cut by younger dikes and sills of microdiorite. Granite and aplite intrude the basic and intermediate rocks and form locally extensive areas of mixed rock consisting of intrusion breccias and assimilation products.

Minerals of the layered series are plagioclase, monoclinic pyroxene (diallage), olivine, orthorhombic pyroxene

[1]Condensed and reprinted from the field trip guidebook prepared for the 1967 Geological Society of America Annual Meeting,

(hypersthene), titaniferous magnetite, and traces of hornblende and apatite in some specimens. Rhythmic layering is conspicuous in many localities, due to abrupt changes in the proportions of feldspar and ferromagnesian minerals. Layers or bands of anorthosite, gabbro, olivine gabbro, and troctolite, ranging from less than one inch to tens of feet in thickness can be observed in individual outcrops. Igneous lamination, defined by preferred planar orientation of tabular plagioclase crystals, is striking in some outcrops and is present to some degree in all rocks in which the tabular habit of the plagioclase is well developed. Rhythmic layering and igneous lamination have had a marked influence on the topography of the area, and the gabbroic rocks exhibit erosional features generally associated with sedimentary strata.

Four stratigraphic units or zones in the layered series were identified by Gilbert (1960) and renamed, using alphabetical designations, by Spencer (1961). The chief characteristics of rocks of the four zones are as follows.

M-zone: Predominantly anorthosite; lenses, layers, and irregular areas of gabbro and olivine gabbro; some lenses of troctolite; plagioclase-pyroxene intergrowths have fine ophitic texture.

L-zone: Predominantly anorthosite; irregular areas of diallage gabbro; rare lenses of troctolite; plagioclase-pyroxene intergrowths have coarse ophitic texture.

K-zone: Alternating layers of anorthosite and troctolite; coarse ophitic pyroxene at some horizons; olivine with poikilitically included plagioclase rimmed by spinel-orthopyroxene intergrowths.

G-zone: Medium-grained troctolite with 5 to 15 percent titaniferous magnetite.

Anorthosite is the predominant rock type, but along the southern margin of the Raggedy Mountains and in the area immediately south of Roosevelt, Oklahoma, significant amounts of troctolite and lesser amounts of diallage gabbro and olivine gabbro are interlayered with anorthosite. These rocks have been designated the K-zone. Rocks stratigraphically above the K-zone comprise anorthosite with diallage gabbro and minor olivine gabbro and troctolite. Textural differences in plagioclase-pyroxene intergrowths have been used to subdivide these rocks into the L-zone and the M-zone. These subdivisions show consistent stratigraphic relationships in the western Raggedy Mountains, but the L-zone is not exposed east of sections 19 and 30, T. 4 N., R. 17 W. Troctolite with a high proportion of titaniferous magnetite is exposed at Iron Mountain, a low hill lying on the township line separating T. 4 N., R. 16 W. and T. 4 N., R. 17 W., and has been mapped as the G-zone.

K-ZONE

Rocks of this unit occupy the lowest established stratigraphic position in the layered series. The zone is at least 120 feet thick, but the lower contact has not been observed. The rocks consist primarily of many alternating bands of anorthosite and troctolite with masses of coarse ophitic pyroxene sporadically distributed in the layers. Rhythmic layering is pronounced, and igneous lamination, in which the plane of preferred orientation of tabular plagioclase crystals is parallel to the layers, is evident in most outcrops. Plagioclase (An_{70-75}), olivine (Fo_{65-67}), diallage, and titaniferous magnetite are the principal minerals. Most olivine grains enclose numerous fine laths of randomly oriented plagioclase and are surrounded by partial or complete rims of orthopyroxene and (or) symplectites of black spinel and orthopyroxene.

L-ZONE

This zone consists primarily of anorthosite in which large diallage crystals are irregularly distributed. Locally, the anorthosite grades to diallage gabbro or is interlayered with minor olivine gabbro or troctolite. Rhythmic layering is rare in this zone, but igneous lamination is pronounced in most outcrops. The most striking characteristic of the zone is the presence of ophitic plagioclase-pyroxene intergrowths ranging up to 30 cm in diameter; pyroxene in crystallographically continuous masses encloses numerous plagioclase laths. In grain size, composition, and degree of preferred planar orientation, the enclosed plagioclase is identical with that external to the pyroxene. Plagioclase (An_{70-75}) and diallage are the principal minerals with minor hypersthene, olivine (Fo_{65-67}), and titaniferous magnetite.

M-ZONE

The M-zone is distinguished from the underlying L-zone by finer grain size, greater variety of rock types, and the textural characteristics of plagioclase-pyroxene intergrowths. As in the L-zone, pyroxene crystals are rather large (0.6 to 13 cm in diameter), nearly spherical, and they enclose numerous grains of plagioclase. Plagioclase within the pyroxene is anhedral, randomly oriented, and generally finer grained than that external to the pyroxene. The composition of plagioclase enclosed within pyroxene was compared with that of external plagioclase in 8 specimens; in 6 of these specimens, enclosed plagioclase is more sodic (An_{50-60}) than external plagioclase (An_{70-75}). Olivine (Fo_{65-67}) is more abundant than in the L-zone, generally as fine grains intergrown with plagioclase but also as cores within larger pyroxene grains.

The genetic significance of the different plagioclase-pyroxene intergrowths is not clear. It is evident that the large masses of pyroxene in the L-zone grew as interprecipitate crystals interstitial to feldspars that had attained planar orientation, probably under the influence of gravity. Textures in the M-zone suggest cotectic crystallization of plagioclase and pyroxene.

G-ZONE

Outcrops of this zone are confined to the slopes of Iron Mountain and to small exposures in nearby low areas. The rock is medium-grained troctolite that contains 5 to 15 percent titaniferous magnetite. The principal minerals are plagioclase (An_{70-75}), olivine (Fo_{65-67}), and titaniferous magnetite. The texture is xenomorphic, and olivine grains lack the reaction rims and symplectites that are common in the other zones.

The plagioclase and olivine have approximately the same composition as in the other zones, and the rocks are closely related. A well-defined, linear structural trend extending northwest-southeast lies immediately west of Iron Mountain and may represent a fault trace along which vertical movement has taken place. The stratigraphic position of the G-zone is not established, but the G-zone is tentatively placed below the K-zone.

PETROGRAPHY, MINERALOGY, AND CHEMISTRY OF THE LAYERED BASIC IGNEOUS ROCKS IN THE RAGGEDY MOUNTAIN GABBRO GROUP

Nancy L. Scofield

The material herein is based on a detailed, vertical study of three sections of the layered series, selected to give maximum stratigraphic exposure. This necessarily limits the lateral extent of the study and, therefore, how far these relationships can be extrapolated laterally. Some features listed in Hunter's descriptions were not found in the sections studied and some details uncovered by these sections were not mentioned by Hunter, because of differences in the nature of the two investigations.

The three sections studied are shown on the map in Figure 4. Using Hunter's labeling system, the lower section is in the K-zone; the middle section spans the L-zone and includes part of the K- and M-zones, and the upper section is entirely within the M-zone.

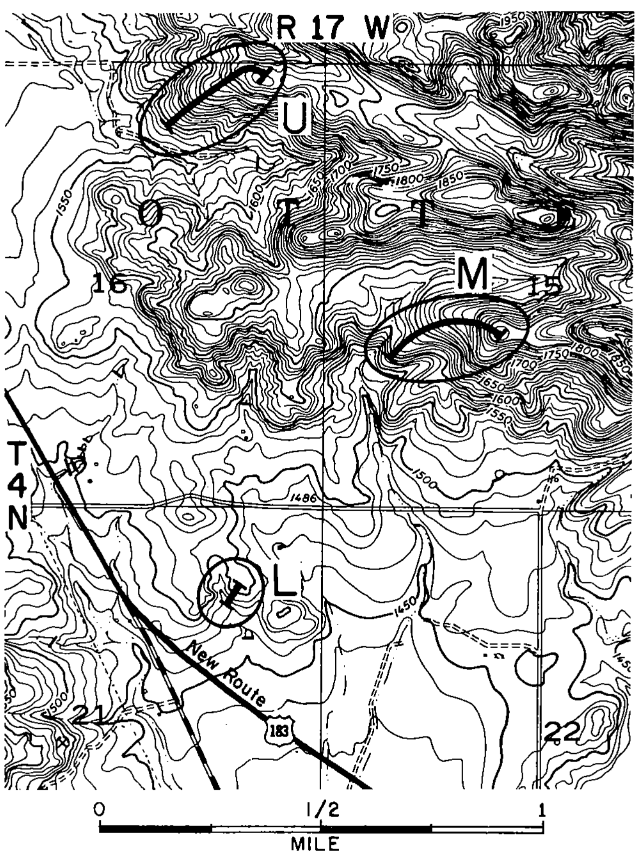


Figure 4. Index map showing location of lower (L), middle (M), and upper (U) measured sections in layered series of Raggedy Mountain Gabbro Group near Roosevelt. Base from U.S. Geological Survey topographic map of Glen Mountains 7½-minute quadrangle.

PETROGRAPHY

Definitions used for rock types are: anorthosite, 90 percent or more plagioclase; olivine-bearing anorthosite, less than 10 percent olivine, less than 5 percent pyroxene, plus plagioclase; troctolite, 10 percent or more olivine, less than 5 percent pyroxene, plus plagioclase; gabbro, 10 percent or more pyroxene, less than 5 percent olivine, plus plagioclase; and olivine gabbro, olivine plus pyroxene exceeds 10 percent, plus plagioclase.

The K-zone in the lower section consists of alternating bands of anorthosite and olivine-bearing anorthosite. This rhythmic layering can be seen in outcrop, and the transitions are abrupt. A similar rhythmic layering, obscured in outcrop but revealed in modal analyses of thin sections, occurs in the K-zone of the middle section. The L-zone in the middle section consists of very pure anorthosite. Other than plagioclase, there is a very low (0-2.3) percentage of interstitial clinopyroxene and a trace to 1.3 percent opaques. The M-zone is olivine gabbro alternating with anorthosite, in another example of rhythmic layering. In the middle section, clinopyroxene crystals are equidimensional, about 2-5 cm in diameter, and give the rock a glomeroporphyritic texture. In the upper section clinopyroxene crystals are elongate, up to 20 cm in length, and widely separated. Because of sporadic large crystals or clusters of crystals, thin sections from the M-zone often show only one or part of one crystal, resulting in modes unrepresentative of the whole rock.

Textures are those of cumulates, ranging from adcumulate anorthosite to heteradcumulate olivine-bearing anorthosite to mesocumulate olivine gabbro. Dominant textural influences are igneous lamination and adcumulus growth in anorthosite and olivine-bearing anorthosite and intercumulus development of large, poikilitic pyroxene in gabbro.

Modes of the different rock types are summarized in Table 1. Vertical variation in the modal analyses delineates the K-, L-, and M-zones and shows the overall dominance and uniformity of anorthosite. Modes of ferromagnesian minerals are low, except for those of some gabbro samples that may not represent the whole rock. Troctolite was not found among the samples studied.

All rocks were remarkably fresh, showing very little alteration.

Table 1.—Modal Analyses of Anorthosite and Gabbro from Raggedy Mountain Gabbro Group[1]

	Pl	Cpx	Opx	Ol	Op
Anorthosite	93-99 0.0-5.7	tr-2.0 0.0-2.3			tr-1.3
Olivine-bearing anorthosite	87-96 0.0-1.1	0.3-1.7 0.0-0.4	0.2-5.3 0.0-0.8	0.6-4.7 0.0-2.6	tr-1.6
Olivine gabbro	44-90 0.0-1.2	1.0-50.0 0.0-0.8	0.0-7.5 0.0-0.8	0.0-1.3 0.0-1.2	tr-4.3
Mean	92.1	5.3	0.8	1.2	0.5

Pl = plagioclase; Cpx = clinopyroxene; Opx = orthopyroxene; Ol = olivine; Op = opaque; tr = trace.

[1]For each rock type, the mode is listed first for the unaltered mineral and then for the altered.

MINERALOGY

Table 2 shows the size ranges of crystals analyzed; the mineral composition is given in Table 3.

Table 2.—Range of Crystal Sizes in Raggedy Mountain Gabbro Group

	Range	Common Range
Pl	0.2-12.0 mm	1.0-5.0 mm
Cpx	3.5 mm-20 cm	
Ol	1.0-5.0 mm	
Op	0.05-5.0 mm	0.05 mm

Pl = plagioclase; Cpx = clinopyroxene; Ol = olivine; Op = opaque.

Table 3.—Range in Composition of Minerals in Raggedy Mountain Gabbro Group

	Range	Common range	No. of samples
Pl	An_{60-83}	An_{76-78}	13
Cpx	$Wo_{45-38}En_{40-37}Fs_{18-23}$		4
Opx	En_{83-80}		6
Ol	Fo_{66-74}		6

Pl = plagioclase; Cpx = clinopyroxene; Opx = orthopyroxene; Ol = olivine.

Plagioclase

There is a wide range in composition from one thin section to another, although the range is somewhat narrower in the anorthosites. This large amount of scatter precludes the detection of cryptic layering by means of plagioclase compositions.

Larger plagioclase crystals tend to be subhedral and elongate; smaller crystals are anhedral and equant, and medium crystals show both modes. The sericite, clay, and calcite show minor alterations, generally restricted to fractures or cleavage but occasionally to grain boundaries. Two sets of rodlike inclusions of unknown composition intersect at acute angles of from 30° to 60°. Twinning is observed according to the albite, Carlsbad, and pericline twin laws. Zoning is not common, but there is some continuous zoning and some discontinuous zoning, usually involving only the edge of the grain. A vermicular form of plagioclase, generally at grain boundaries and making up as much as two percent of some thin sections, is common in the anorthosites. Gradations from physical and optical continuity with the adjacent "normal" plagioclase crystal to optical discontinuity and physical continuity to complete detachment may be found. Igneous lamination is prominent and widespread.

Pyroxene

Clinopyroxene compositions show some iron enrichment and calcium depletion upward through the composite section. Three of the four orthopyroxene compositions determined were En_{83}.

Both clinopyroxene and orthopyroxene range from interstitial to ophitic in habit, indicating intercumulus crystallization around pre-existing plagioclase crystals. Some textures suggest cotectic crystallization of plagioclase and pyroxene as noted by Hunter. In the field, large crystals of clinopyroxene stand out in relief on weathered surfaces. Ophitic development is less common for orthopyroxene than for clinopyroxene. Orthopyroxene occurs as rims on clinopyroxene crystals in some thin sections, but its most common occurrence is as a reaction rim corona or partial corona around olivine. Coronas are 0.25-0.50 mm thick. It is common for the corona to extend the poikilitic habit of the olivine crystal enclosed. Vermicular titaniferous magnetite and ilmenite, 0.01-0.05 mm thick, is intergrown with orthopyroxene in the coronas. The contacts between the opaque minerals and orthopyroxene are sharp.

Orthopyroxene is rarely altered, but clinopyroxene shows minor alteration to green clay, some of which is chlorite. In the interior of some clinopyroxene crystals are some rod- and some blade-shaped inclusions of ilmenite.

Olivine

Three samples from the upper section yielded olivine compositions of Fo_{66}, whereas three samples from the lower and middle sections yielded compositions in the Fo_{70-74} range.

In the field, many surfaces are pitted from the weathering of olivine crystals. Olivine crystals in the K-zone are larger and locally concentrated, in contrast to the smaller and relatively evenly disseminated ones in the M-zone. They are poikilitic to subpoikilitic, enclosing plagioclase crystals about 2 mm long. No plagioclase crystals are included in the center of olivine grains; olivine crystals are interpreted, therefore, as primocrysts that continued to grow poikilitically from intercumulus liquid. Olivine crystals invariably show alteration to a green to yellow-green material, iddingsite, and (or) secondary magnetite.

Opaques

In addition to vermicular magnetite and ilmenite in coronas and ilmenite inclusions in clinopyroxene, ilmenite and magnetite occur separately and together in discrete interstitial grains, usually associated with pyroxene and in large (up to 5.0 mm), poikilitic, intercumulus grains. Some opaques have rims of orthopyroxene. In addition, there are rare, small (0.01 mm) grains of pyrite, some of which are surrounded by pyrrhotite or goethite.

Apatite

Slender, euhedral apatite crystals 0.1 to 0.2 mm long, were observed, but they are rare.

CHEMISTRY

The dominance of anorthosite and paucity of ferromagnesian minerals are reflected in the chemistry of the rocks, as determined by x-ray fluorescence analysis and shown by the average whole-rock analysis in Table 4. Notable are the high Al_2O_3 and CaO values and low Fe_2O_3 (total iron) and MgO values. This analysis closely resembles that of bytownite plus a trace of mafic minerals. The near uniformity is reflected in the narrow range in typical analyses from zones K, L, and M, as shown in Table 4.

Oxides were ploted against elevation for the samples from the middle and upper sections (figs. 5 and 6). In the

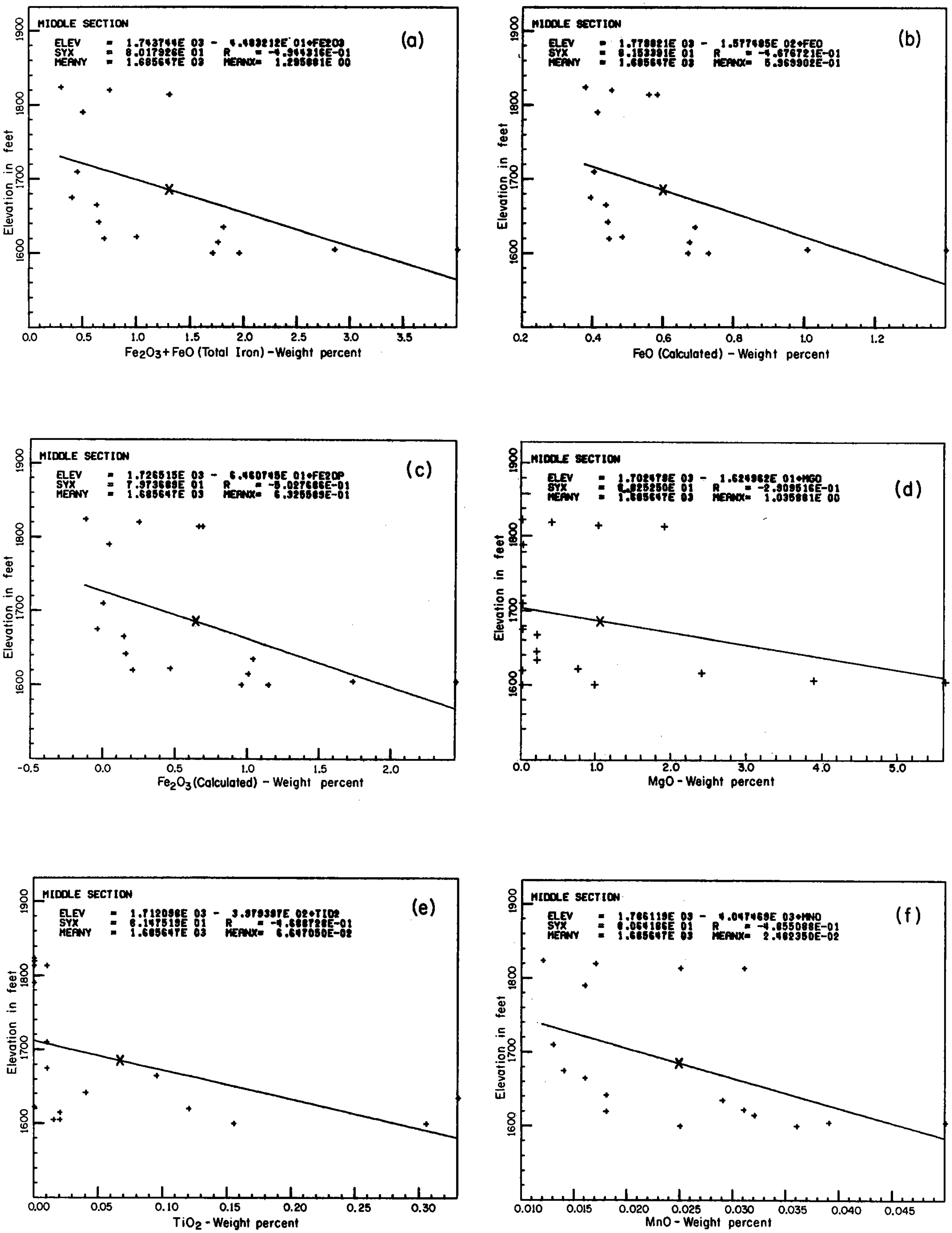


Figure 5. Graphs showing weight percent of various oxides versus elevation for middle measured section (see fig. 4 for location). R = correlation coefficient.

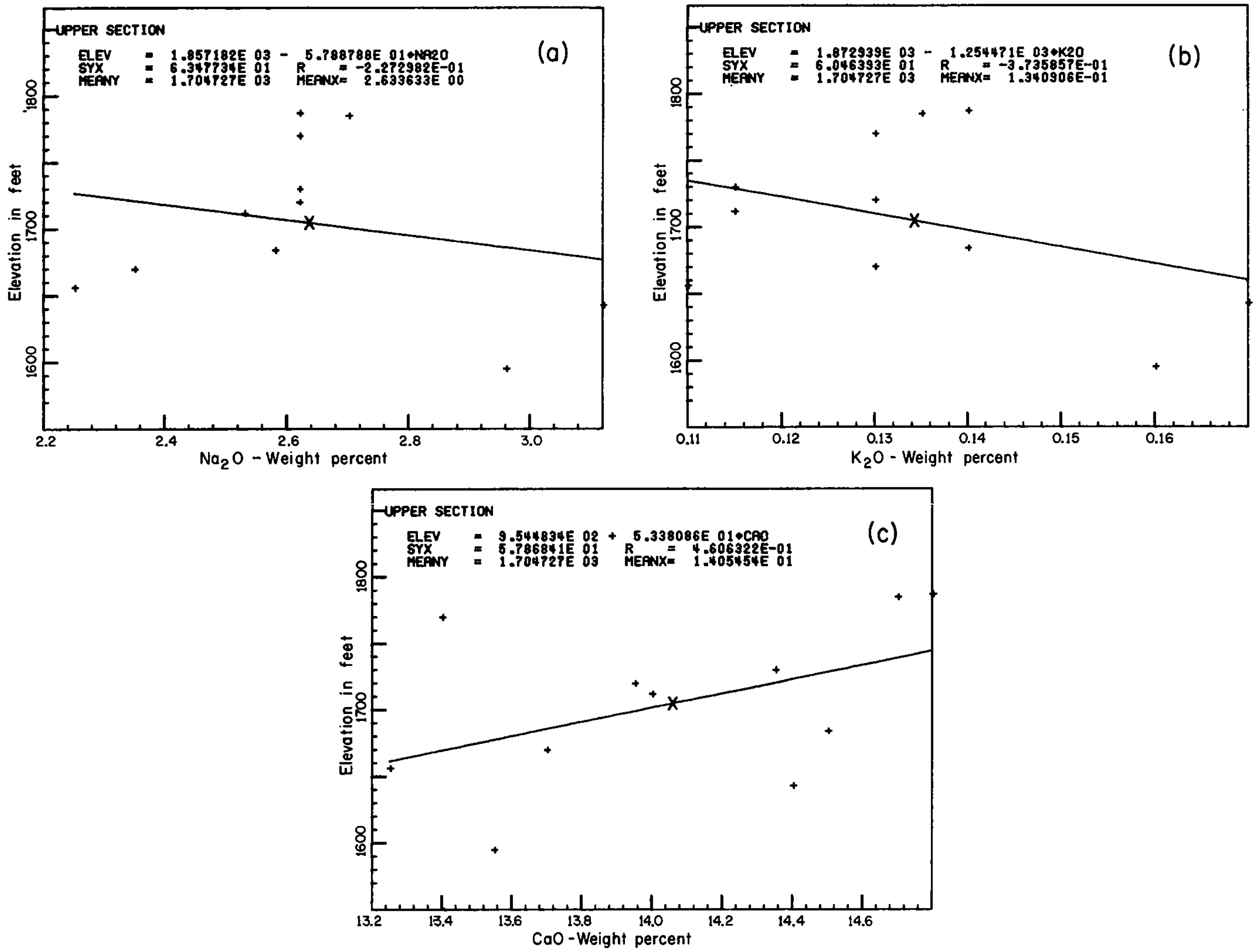


Figure 6. Graphs showing weight percent of various oxides versus elevation for upper measured section (see fig. 4 for location). R = correlation coefficient.

Table 4.—Chemical Analyses of K, L, and M-Zone Rocks

	Mean	K-zone (R1L1[1])	L-zone (R12M1[2])	M-zone (R12U2[3])
SiO_2	47.03	46.58	47.38	47.58
Al_2O_3	31.27	28.50	33.00	31.00
Fe_2O_3	1.70	3.95	0.63	2.45
TiO_2	0.09	0.020	0.095	0.000
MnO	0.03	0.051	0.016	0.045
CaO	14.41	13.20	14.70	13.70
MgO	1.67	4.85	0.20	3.00
K_2O	0.13	0.130	0.170	0.130
Na_2O	2.63	2.40	2.85	2.35
P_2O_5	0.10	0.085	0.010	0.085

[1]Anorthosite.
[2]Olivine-bearing anorthosite.
[3]Olivine gabbro.

middle section, total iron, FEO (calculated), Fe_2O_3 (calculated), TiO_2, and MnO give correlation coefficients at the 95 percent confidence level by "t" statistics. MgO follows FeO and Fe_2O_3 but has a lower correlation coefficient. The sudden increase in these oxides around 1,800 feet marks the entrance of the M-zone at the top of the L-zone. All of these trends are in the direction of decreasing oxide with increasing elevation. In the upper section (fig. 6) the CaO trend gives a 90 percent confidence level. K_2O and Na_2O trends oppose the CaO trend but have lower correlation coefficients. CaO increases and K_2O and Na_2O decrease with elevation. This is suggestive of reverse cryptic layering. Coupled with evidence that the anorthositic rocks occur near the top of the intrusion, the chemical analyses prompted development of a flotation model for the separation of plagioclase.

PENNSYLVANIAN TECTONICS

Tectonic development and structural relief in southwest Oklahoma results mainly from Pennsylvanian uplift of the Wichita block and concurrent sinking of the Anadarko and Hollis basins. Movement was primarily block faulting whereby the Wichita block was thrust upward and northward toward the Anadarko basin; a series of high-angle reverse faults now separate the two provinces (fig. 1).

Pennsylvanian fault movement was clearly an example of basement-rock tectonics and probably occurred along zones of structural weakness that had been intermittently active since Precambrian time.

Uplift took place in the Wichitas during two major periods (Ham and Wilson, 1967, p. 397-398, fig. 12): a Morrowan-Early Atokan stage, during which the Wichita block was raised some 10,000 to 15,000 feet, and an Early to Middle Desmoinesian stage when most of the remaining 15,000 to 20,000 feet of uplift presumably occurred. The surface of the basement rock is as much as 40,000 feet lower along the axis of the Anadarko basin than it is 6 to 10 miles farther south on the Wichita uplift (Ham, Denison, and Merritt, 1964, pl. 2), and probably 30,000 to 35,000 feet of throw occurred during the Pennsylvanian Period.

As the Wichita block was uplifted, it was denuded of about 15,000 feet of pre-Pennsylvanian sediments. Early and middle Paleozoic carbonates were the source of thick limestone conglomerates deposited close to the mountains in Pennsylvanian and earliest Permian time (Chase, 1954; Edwards, 1959). With stripping of the sedimentary rocks in various areas, a flood of arkosic sandstones and granite wash spread far into the Anadarko basin and, to a lesser extent, into the Hollis basin. These Pennsylvanian clastic sediments are as much as 15,000 feet thick in the axial part of the Anadarko basin and about 4,000 feet thick in the Hollis basin.

PERMIAN PALEOGEOGRAPHY AND SEDIMENTATION

With cessation of tectonic uplift of the Wichita block by Early Permian time, southwest Oklahoma received a thick sequence of post-orogenic red-bed clastics and evaporites deposited on the east side of the broad epicontinental sea that covered much of the southwestern United States (fig. 7). Epeirogenic movements caused a slow but continual sinking of the region. The Wichita uplift was a relatively stable crustal block extending westward beneath the sea; it probably formed a shoal or peninsula much of the time and partially separated the inland sea in Oklahoma into the Anadarko basin (north) and Hollis basin (south).

Exposure of the igneous rocks in the Wichitas to Permian erosion is attested by Early Permian limestone conglomerates and granite wash in adjacent basins, as well as by wave-cut grooves, benches, and potholes which are now being exhumed through erosion of Permian sediments.

Permian clastic sediments were derived from the Ouachita province to the southeast and from other land areas in eastern Oklahoma; the Wichita Mountains contributed a lot of detritus in adjacent areas during earliest Permian (Wolfcampian) time, but its role as a source area diminished rapidly during Leonardian time as the granite hills wore down and were covered by a flood of sediment. Late Permian sediments probably covered the highest peaks of the Wichita Mountains. About 7,000 feet of Permian sediments are present along the axis of the Anadarko basin, about 4,000 feet in the Hollis basin and 1,500 to 2,500 feet (increasing westward) overlying the buried part of the Wichita block.

Four major sequences of evaporite rocks are present in the Permian of western Oklahoma (Jordan and Vosburg, 1963). Basically, they comprise interbedded gypsum and (or) anhydrite, salt (in subsurface), reddish-brown shale, and dolomite. They were deposited behind the carbonate banks built up around the Delaware and Midland basins to the southwest (fig. 7). The field trip will examine two of these evaporite units—one in the Cloud Chief Gypsum and the other in the Blaine and the underlying Flowerpot Formations.

Evaporite deposition in the Blaine Formation and associated strata resulted from evaporation of sea water. The cycle of evaporite precipitation begins with formation of 0.5-5.0 feet of dolomite, followed by 5-30 feet of gypsum or anhydrite, and finally 5-30 feet of salt. For a number of reasons, the complete evaporite sequence is not found everywhere within the region: precipitation may have been interrupted locally by an influx of less concentrated water; certain chemicals may have been depleted before precipitation of a particular salt could start; and the more soluble units (salt and sometimes gypsum) were deposited in places but dissolved later. Typically, above each gypsum or salt bed is 2 to 30 feet of red-brown shale that is overlain by 1 to 2 feet of greenish-gray shale. The complete cycle consists of dolomite, gypsum and (or) anhydrite, salt (in subsurface), red-brown shale, and green-gray shale. Ham (1960) attributes this cyclicity to transgression of the sea through periodic eustatic rise of sea level. This caused deposition of gray shale, followed by deposition of carbonates, sulfates, and salt through evaporation of sea water. Subsequent marine regression caused displacement of saline water by brackish water, with the result that red shale was deposited to close the cycle.

The stratigraphic succession of outcropping Permian rocks in southwest Oklahoma is shown in Figure 8. Evaporite units associated with the Blaine Formation grade eastward into shales and then into deltaic and alluvial sandstones. They are overlain by a sequence of red-bed sandstones (Whitehorse Group), then gypsum (lower Cloud Chief), and additional red beds (upper Cloud Chief and younger strata).

Flexing, minor faulting, and gentle folding of Permian rocks resulted from slight adjustments along major pre-Permian tectonic zones (fig. 8, cross section C-D). Assuming original horizontality of the Blaine and younger Permian formations, the central part of the Wichita block has been raised some 2,000 feet higher than the Anadarko basin and 1,000 feet higher than the Hollis basin since Permian time.

Post-Permian history of the region consisted (presum-

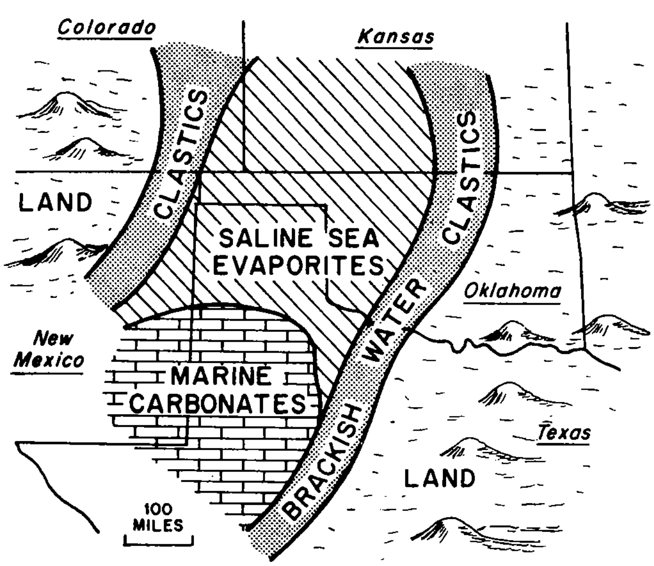


Figure 7. Paleogeography and principal facies in Permian basin of southwestern United States during evaporite deposition in Leonardian and Guadalupean time.

ably) of gentle uplift and nondeposition during Triassic and Jurassic time, followed by extension of shallow Cretaceous seas over all but northeast Oklahoma. Withdrawal of the seas by early Tertiary time set the stage for continuing epeirogenic uplift of the area, and Tertiary and Quaternary erosion once again exposed the Early Paleozoic igneous and sedimentary rocks of the Wichita Mountain block.

ECONOMIC GEOLOGY OF SOUTHWEST OKLAHOMA

Mineral deposits are abundant and diverse in southwest Oklahoma, but many of them have been developed on a limited scale. Major resources examined in this section include gypsum, anhydrite, copper, and salt; other principal resources considered include granite, limestone, dolomite,

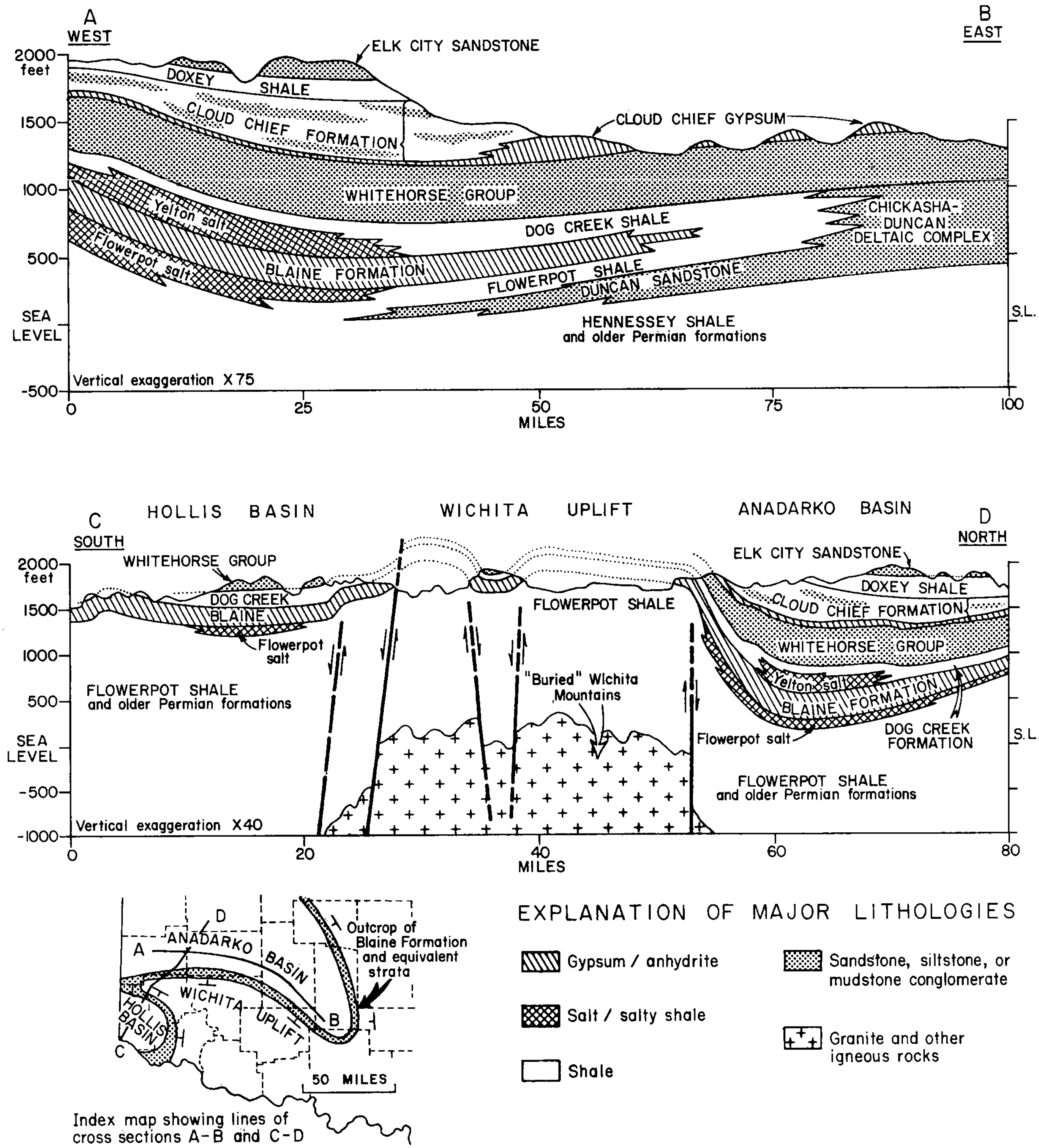


Figure 8. Cross sections along axis of Anadarko basin (top) and across Wichita uplift (bottom) showing stratigraphy and structure of outcropping Permian rocks in southwest Oklahoma (modified from Johnson, 1967, p. 19, 27). Note different scales on cross sections.

shale, sand and gravel, and petroleum (Johnson, 1969). Resources that are in limited quantity or require improved technology for future development include lead, zinc, hematite, titaniferous magnetite, ilmenite, and aluminum resources in the form of anorthosite and clays.

Gypsum and Anhydrite

Large reserves of high-purity Permian gypsum and anhydrite crop out in southwest Oklahoma as part of an area of western Oklahoma recognized for its valuable deposits. Johnson (1972) refers to three major gypsum regions. The southwestern and northwestern gypsum areas, as shown in figure 9, have important gypsum reserves in the Blaine Formation; the reserves in the west-central gypsum region are in the Cloud Chief Formation. Total estimated reserves for the 3 regions are 48 billion short tons, based on surface and near-surface gypsum with a maximum non-gypsum overburden of 30 feet (Johnson, 1972). In 1972, 8 companies quarried 1,178,000 tons of gypsum in the State (U.S. Bureau of Mines, preliminary figures).

The Blaine Formation is 150-200 feet thick in the southwest gypsum region and contains 5 to 8 beds of minable gypsum, each one 10-30 feet thick. The deposits are found on the south side of the Anadarko basin and in the Hollis basin. The gypsum is 95-99 percent pure; calcium and magnesium carbonate commonly constitute 0.5-2.0 percent of the rock, and silica and alumina constitute 0.3-0.8 percent. Disseminated anhydrite in most outcrops and quarries constitutes 0.5-1.5 percent of the rock. Beds of anhydrite are rarely found in outcrop, and in core tests they seldom appear at depths of less than 75-100 feet.

Reserves in the southwest gypsum region are estimated at slightly over 17 billion tons and are greatest in southwestern Beckham County and Harmon County. Up to 75 feet of gypsum can be bench-stripped from beds in those counties without removing more than 3 or 4 thin units of shale and dolomite.

The west-central gypsum region consists of outcrops of the Cloud Chief Gypsum, which is an important resource only in the central part of the Anadarko basin, where there is a single bed of massive sulfate rock 100-120 feet thick (Ham and Curtis, 1958). The top part of the bed is eroded in many places, leaving some 20-75 feet of sulfate rock forming hills in most of the region. The lower part of the sulfate bed, up to 40 feet locally, is anhydrite, and the top 25-70 feet is massive gypsum. Purity in the northern part of the region is generally 90-97 percent and in the central and southern part is 95-98 percent. Calcium and magnesium carbonate typically comprise 1-7 percent of the rock, and silica and alumina make up 0.4-4.0 percent. Reserves are estimated to be just under 14 billion tons in the region, with the majority of the purest stone found in Washita County, where the Cloud Chief Gypsum is at or just below the surface for about 200 square miles.

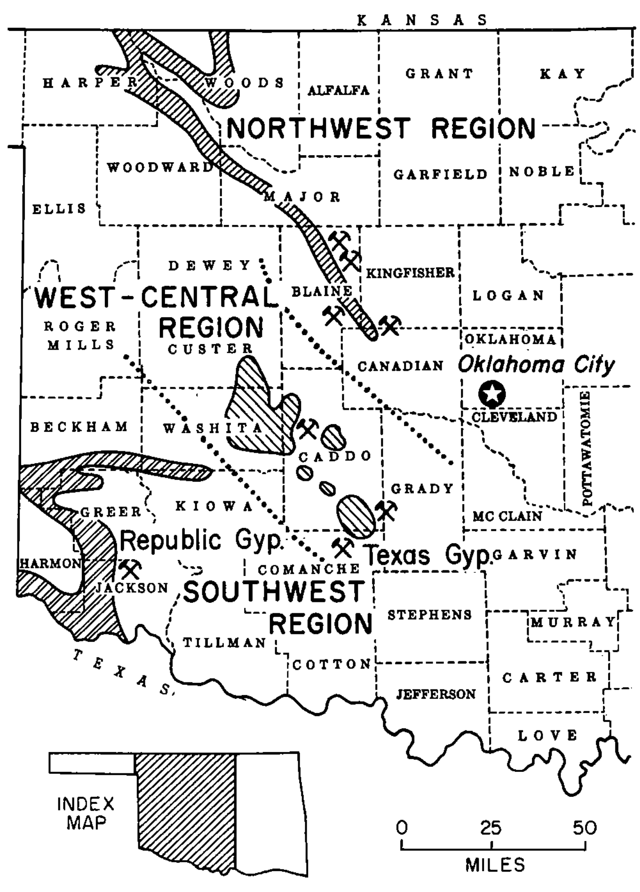


Figure 9. Index map showing regions of major gypsum reserves in western Oklahoma and locations of eight operating gypsum quarries (modified from Johnson, 1972, fig. 3).

Copper

Copper has been reported in Permian sedimentary rocks at many localities in southwestern Oklahoma. In fact, the pattern of occurrence is generally similar throughout western Oklahoma: chalcocite and malachite are the most common minerals, occurring in sandstone and shale as encrustations, impregnations, veinlets, small nodules, and mineralized wood. The few early attempts at mining resulted in failure, owing to the lean grade of ore and the small size of deposits, but a new concept of copper mineralization was introduced in 1962 with discovery of malachite in a persistent 6-inch-thick shale bed along an outcrop distance of 3 miles (Ham and Johnson, 1964). Initially called the "lower copper bed," and with a copper content of 2.6 to 4.5 percent at the outcrop, it was the first United States report of a bedded copper shale in Permian strata.

Eagle-Picher Industries began mining and milling operations at Creta, Oklahoma, in 1965 and shipped the first concentrates by rail to El Paso, Texas, in October 1965. A second copper-shale deposit was discovered about 15 miles to the north, near Mangum, and that deposit (which is similar geologically to the Creta deposit) is being investigated by Lobaris Copper Company. The Mangum deposit is 6 to 18 inches thick, averaging 14 inches, and has an average grade of 1.4 percent copper.

The major copper-shale deposits occur in the brackish-water or shallow-marine facies of the upper Flowerpot (fig. 10). The shoreward equivalents of these strata are now eroded south of the Wichitas, but they probably were deltaic sandstones and mudstone conglomerates similar to those still present in the eastern part of the Anadarko basin (see fig. 8, cross section A-B).

Salt

Bedded salt deposits in Oklahoma are restricted to the western half of the State. In southwest Oklahoma, salt occurs in 3 principal Permian salt sequences, each 100 to

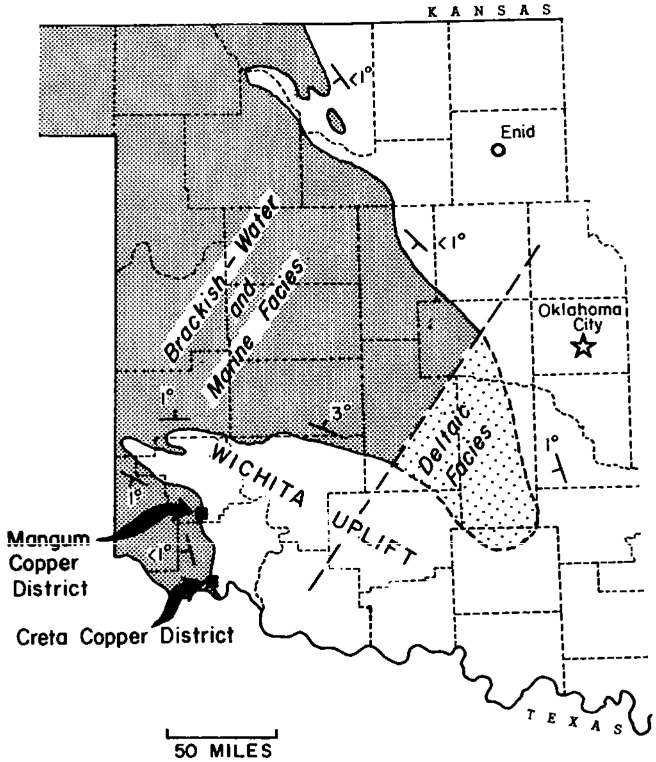


Figure 10. Map of western Oklahoma showing distribution and facies of upper Flowerpot strata. The two principal copper shales at Creta and Mangum are in brackish-water and marine facies.

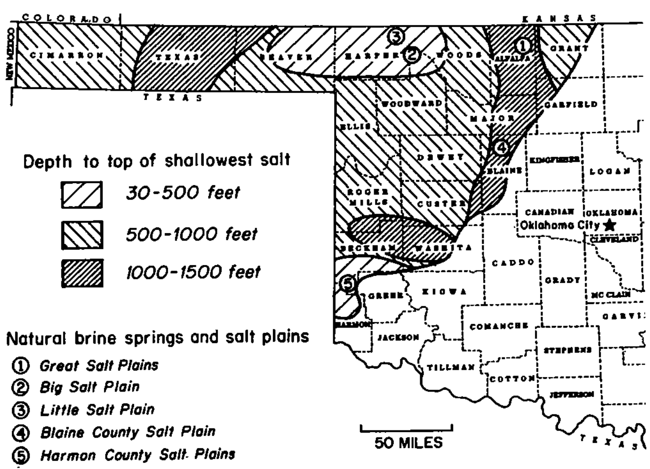


Figure 11. Map of western Oklahoma showing depth from surface to top of shallowest salt unit and distribution of natural brine springs and salt plains (from Johnson, 1972, fig. 8).

1,000 feet thick, in the Wellington (oldest), Cimarron, and Beckham (youngest) evaporites (Jordan and Vosburg, 1963). Individual salt beds are typically 5 to 30 feet thick, and are interbedded with shale and some gypsum. Halite is the only salt known to occur in these beds.

Salt beds are 30 to 3,000 feet below the surface in various parts of the State (fig. 11). Saturated brine is emitted at 5 different areas of salt springs or salt plains, with emissions at each ranging from 150 to 3,000 tons of salt per day (Ward, 1961).

The depth and thickness of salt beds make them suitable for either underground or solution mining, but to date most of the production has been by solar evaporation of brine on the salt plains. Chemical and petrographic data on rock salt are lacking, but analyses of brine and of salt produced from the brine indicate a high purity. Oklahoma's salt reserves (in place) have been estimated at 20 trillion short tons, but the resource is greatly underdeveloped: 3 small companies have a total annual production of about 10,000 tons, which is used primarily in stock feed, water softening, and deicing roads.

Large-scale utilization of brine at salt plains offers an excellent opportunity to combine mineral production with curtailment of an environmental problem. Removing salt from the brine helps to minimize contamination of surface water in such major rivers as the Arkansas, the Cimarron, and the Red. There has been little effort so far on the part of industry and government to explore the possibility of a joint program to eliminate the salt as a pollutant and convert it to a marketable product. The salt plains are ideal sites for the production of salt by solar evaporation. The flat land is readily adaptable for shallow earthen pans, and the windy, dry climate enables an annual production yield estimated at 1,000 tons of salt per acre of salt pan (Johnson, 1970b).

Other Minerals

Granites and other igneous rocks of the Wichita Mountains are produced from a number of quarries for the monument and building trade, and crushed granite is used intermittently for aggregate and rip-rap. Colors are red, pink, gray, and black, and the textures range from fine to coarse crystalline. At present, 5 companies are producing stone from 8 quarries in the Wichita Mountains.

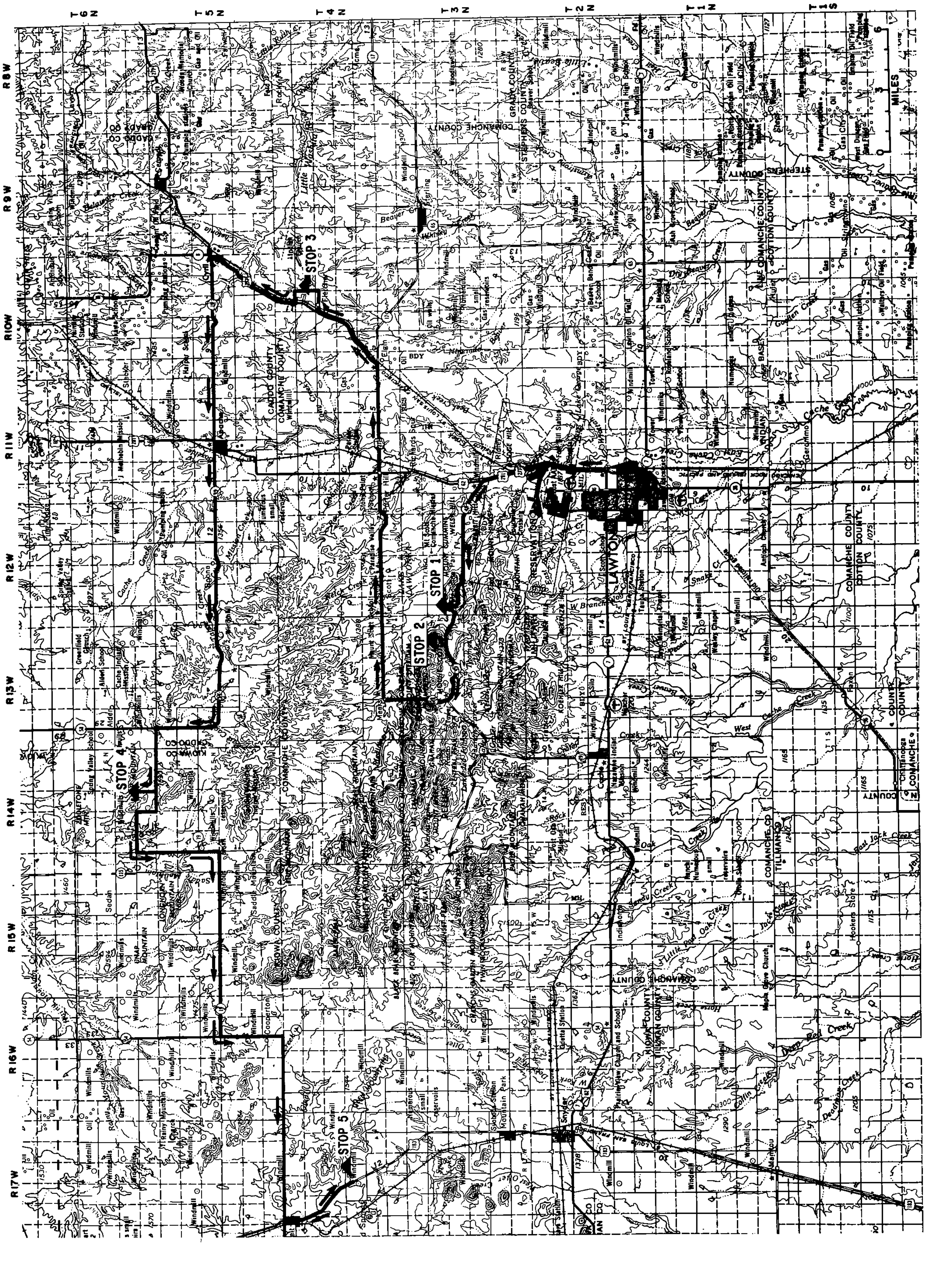
Limestone and dolomite resources exist mainly in the Cambrian-Ordovician carbonate sequence exposed on the northeast flank of the Wichita Mountains. Two major quarries are producing crushed stone, and several other aggregate quarries have been abandoned. Additional resources that have been developed locally are the thin (1 to 9 feet thick) dolomites of the Permian formations.

Shales in the Permian sequence are quarried at several places in southwest Oklahoma for the manufacture of common brick.

A number of pits dug in Quaternary alluvial and terrace deposits are being worked for sand and gravel. Quartzite gravel up to 6 inches in diameter has been washed eastward from the Rocky Mountain region, across the High Plains, and into western Oklahoma.

Oil and gas have been produced from a number of major fields in the Anadarko basin and the Ardmore basin. Other smaller fields are producing in the eastern part of the Hollis basin and from scattered locations on the Wichita block. Most of the fields are structural traps, and production is predominantly from coarse sands and granite wash of Pennsylvanian age.

Metal resources in the Wichitas include small vein deposits of lead and zinc, low-grade Cambrian hematitic sandstone (30 to 35 percent iron oxides), and titaniferous magnetite that is closely associated with the gabbro-anorthosite sequence. Titanium occurs in ilmenite in alluvial sands around the Wichita Mountains, with some of the sands containing 3 to 7 percent ilmenite. The alumina of anorthosites (28 percent Al_2O_3) in the Wichitas, and of kaolin (25 percent Al_2O_3) on the flanks of anorthosite outcrops, must await improved technology or higher aluminum prices before these large resources can be developed.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STOP 5
LAWTON
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STEPHENS COUNTY

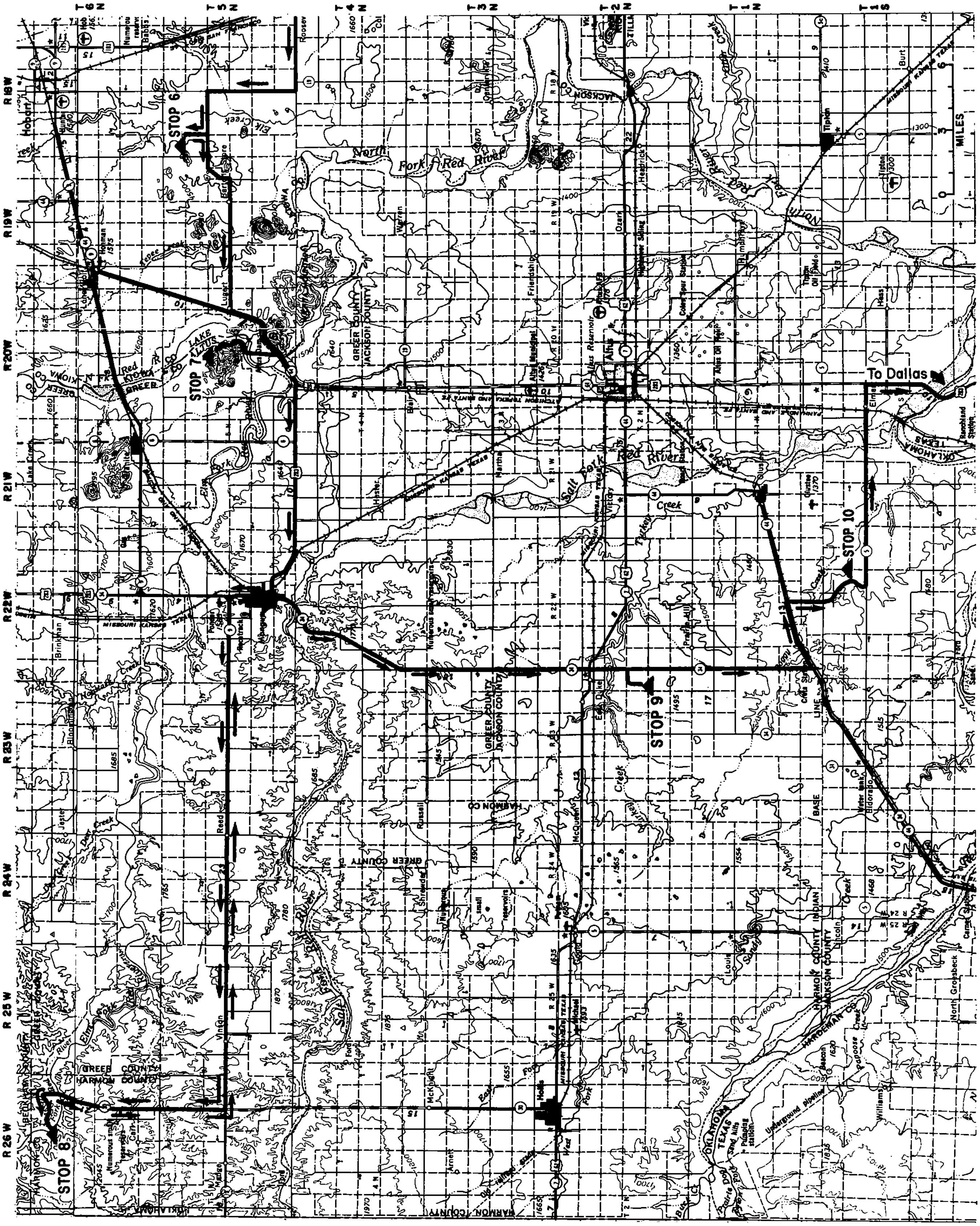

Figure 12. Map of southwest Oklahoma showing route followed on field trip through Wichita Mountains and surrounding area. Top portion is eastern segment of region, and bottom portion, western segment.

This section outlines a 2-day field trip planned to cover some of the principal geologic features of the Wichita Mountains and the economic geology of the Permian rocks of southwest Oklahoma. By driving the 200 miles from Dallas, Texas, to Lawton, Oklahoma, late in the afternoon on Friday, November 9, participants can start early Saturday morning for the nearby Wichita Mountains.

The customary road-log method will not be used on this trip, but a brief summary of major features between stops will be provided. The accompanying Route Map (fig. 12) should be adequate to show the roads we will follow.

The first field day, 6 stops will be covered in 150 miles; the seventh stop will be the lodge at Quartz Mountain State Park, where we will spend the night. The second day, stops 8 through 10 will be covered, a distance of 120 miles, and we will leave the last stop about 1:30 p.m. for the 235-mile drive back to Dallas. We should arrive about 5:30 p.m. (half an hour before the welcoming party starts).

Buffet breakfast and a box lunch will be provided Saturday and Sunday, but the evening meal and liquid refreshments are not provided.

STOP 1. View of Mount Scott from Lake Lawtonka, NE¼NW¼ sec. 18, T. 3 N., R. 12 W., Comanche County.

This stop (fig. 13) is one of the best for pointing out the sill character of granite. Mount Scott rises about 1,100 feet above this location. The lower, densely wooded slope is underlain by rocks of the Raggedy Mountain Gabbro Group (fig. 14). The reddish, lightly wooded upper part is supported by the Mount Scott Granite, the most widespread of several granites in the eastern part of the mountains.

Over 750 feet of the sill is exposed at the top of the mountain. The Carlton Rhyolite was the cover under which the sill was injected. It is exposed to the south of Mount Scott. The rhyolite is intensely silicified and converted to hornfels near the contact. In the Fort Sill area the Carlton shows some flow features in hand specimen, but in thin section all original fabric is seen to have been destroyed during the sill injection. This very low grade, dry metamorphism reduced the groundmass to a fine granoblastic mosaic while leaving the phenocrysts essentially untouched.

The same sequence of granite sills injected above gabbro and below rhyolite can be traced nearly 100 miles along the exposed and buried uplift, mostly to the west. The sequence of micrographic granite injected beneath rhyolite was found in a well just south of the Arbuckle anticline in the western Arbuckle Mountains some 70 miles to the east. It is clear that the relationship here of a granite sill beneath rhyolite is or was characteristic of several thousand square miles in southern Oklahoma.

The rock exposed in the modest roadcut to the east of the pullout is not the same granite that occurs on Mount Scott. This rock is a younger, unnamed granite that characterizes a fairly large area around and east of Medicine Park. The dam on Lake Lawtonka is on a fault, as are most of the dams in the Wichita Mountain area. This practice is almost mandatory, because the streams favor fault zones. We know of no problems caused by building dams on these late Paleozoic (probably Pennsylvanian) faults.

The rock exposed in the roadcut is a delicately micrographic granite containing nearly 98 percent quartz and mesoperthite. Quartz accounts for almost exactly one-third of the rock volume. The granite would lie very close to the tertiary minimum in the system quartz-orthoclase-albite. Free plagioclase is present only in trace amounts. Identifiable feldspar alteration products are minimal, but the perthite contains fine hematite dust and tiny vacuoles which cause a somewhat turbid appearance in thin sections. Iron oxides, in small equidimensional crystals averaging between 0.1 and 0.2 mm in diameter, account for three-quarters of the accessory mineral content. Iron oxides are also found surrounding accessory minerals and replacing them along cracks as a thin veinlet network. Zircon, apatite, fluorite, and sphene are present in small, widely distributed crystals but account for less than half a percent of the rock volume. No primary femic mineral remains in the sample examined. Iron-stained chlorite has replaced the original femic mineral. Elsewhere, this granite contains aegirine-augite, which was probably present here at one time.

The texture of the granite is erratic. It is mildly porphyritic, carrying sparse perthite phenocrysts. Most of the well defined texture is a delicate micrographic quartz-perthite intergrowth. Local coarsenings in the rock are rich in quartz and are apparently incipient microlitic cavities.

STOP 2. Top of Mount Scott, C N½SE¼ sec. 11, T. 3 N., R. 13 W., Comanche County.

The top of Mount Scott is at an elevation of 2,464 feet, a bit more than 1,000 feet above the surrounding Permian red-bed plains (fig. 13). The view from the top is unmatched in western Oklahoma.

To the west, the relationship of granite sill to gabbro is well displayed on Mount Sheridan. The rather uniform height of the tallest peaks is believed to be due to Permian peneplanation. To the south, the low, smooth, treeless hills underlain by Carlton Rhyolite can be seen. Beyond the rhyolite, hills composed of limestone represent the type sections of the Fort Sill, McKenzie Hill, and Signal Mountain Formations of the Arbuckle Group (Late Cambrian and Early Ordovician). Eastward, the granites plunge beneath a cover of Permian red beds (fig. 15). Although the uplift can be traced more than 100 miles to the southeast, the basement never again comes closer than about 5,000 feet to the surface. To the north lies the Blue Creek Canyon anticline. This anticline contains a core of rhyolite and a fault (apparently normal) on the west flank of the core. The smooth hills are underlain by rocks of the Arbuckle Group and are known locally as the Limestone Hills. The type section for the Kindblade Formation (Early Ordovician) of the Arbuckle Group is found in these hills on the Kindblade Ranch. Stop 4 is northwestward along the axis of this anticline.

The road up the mountain is built entirely on Mount Scott Granite. A prominent and apparently stable boulder stream can be seen approximately 3 miles from the entrance. The granite is generally micrographic and porphyritic. There does not appear to be any systematic variation in composition within the sill. Fine-grained ghost xenoliths of more basic composition can be seen in many outcrops. Microlitic cavities are also present locally but generally contain only quartz, feldspar, and epidote.

The granite was injected under a cover of rhyolite, probably at a depth of less than 1 mile. The present axis of

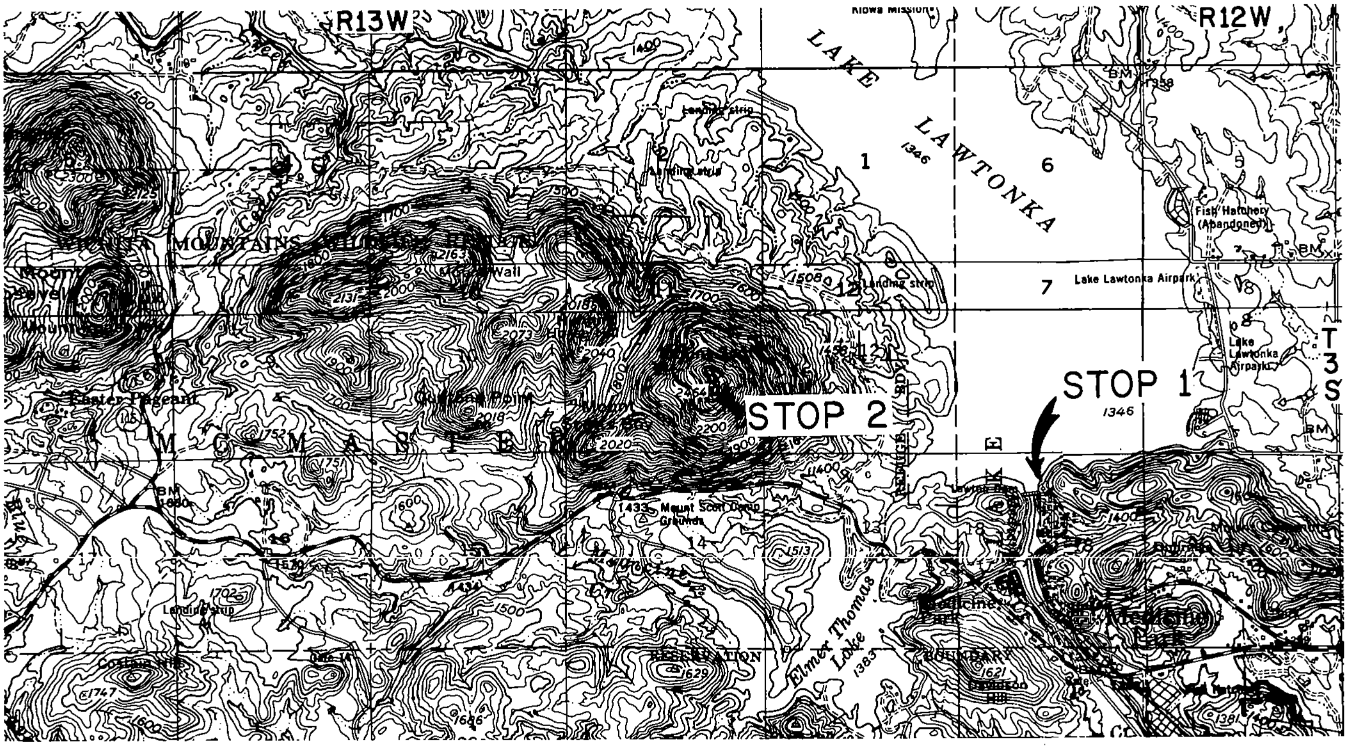

Figure 13. Location map for Stops 1 and 2 in Mount Scott area. Base from U.S. Geological Survey 15-minute topographic-quadrangle series; scale, 1 inch = 1 mile.

Figure 14. View of Mount Scott, looking west from Stop 1 across Lake Lawtonka. Lower wooded slopes represent the Raggedy Mountain Gabbro Group, and upper slopes represent a sill of Mount Scott Granite.

Figure 15. Looking east from Mount Scott at hills of granite near Medicine Park (right) and Lake Lawtonka (left).

the mountain uplift was the axis for the major granitic intrusions during the Cambrian. There does not appear to be much chilling at the margins or chemical differentiation within the sill at this location. The rhyolite and granite are comagmatic, based on geologic and less conclusive isotopic evidence.

The Mount Scott Granite at the top of the mountain is a darker red than the central part of the sill. It shows well defined phenocrysts of perthite and sodic plagioclase set in a generally micrographic groundmass of quartz-mesoperthite. The plagioclase is commonly rimmed by perthite that is in optical continuity with the micrographic perthite. Common hornblende and aegirine-augite are both found as femic minerals. Chlorite is a replacement of aegirine-augite and also occurs in fine masses of vermicular crystals in a late intergranular position. Epidote, sphene, apatite, and zircon are widely distributed accessory minerals. Iron oxides are common as equidimensional crystals and are found with other accessory minerals as clots.

The feldspars are turbid with hematite dust and vacuoles. Modest amounts of clay-sericite alterations and replacement by small epidote granules and chlorite can be found in many feldspar phenocrysts. The quartz and feldspar account for somewhat over 90 percent of the rock, with very nearly one-third of this amount as quartz. This granite has a color index of about 8, which is considerably higher than most granites found in the mountains; the typical granite has a color index of less than 5 and some granites have an index of less than 2.

The granite yields an isotopic age of about 500 m.y. by both K/Ar and Rb/Sr. The enrichment of Sr^{87} is relatively small for Mount Scott Granite samples collected in the eastern part of the mountains and there is little difference in the Rb/Sr ratio. The initial Sr 87/86 ratio is .707± .001.

Merritt (1958, 1965, 1966, and 1967) has provided chemical analyses of several of the Wichita granites as well as a discussion of the distribution of the major mappable units in the Mountains (table 5). Additional chemical data and a general discussion of the basement rocks are found in Ham and others (1964).

Geology between Stops 2 and 3

The drive to Stop 3 crosses the only known area with outcrops of the Precambrian or Early Cambrian Tillman Medasedimentary Group, the Meers Quartzite. It is well exposed 1.5 miles south of Meers, occurring as large xenoliths in the Raggedy Mountain Gabbro (Ham and others, 1964).

Farther along, 9 miles east of Meers and 2 miles west of Porter Hill, we cross a ridge of Ordovician limestones in the Arbuckle Group. The thick carbonate sequence dips steeply to the northeast on the flank of the Blue Creek Canyon anticline. Dolese Brothers Company operates one of the largest crushed-stone plants in the State at this site. The company quarries the Kindblade Limestone for shipment throughout central and western Oklahoma.

Driving from Porter Hill through Elgin to Fletcher, we pass over a homoclinal sequence of Permian red beds—starting with the Hennessey Shale and finishing with the Cloud Chief Gypsum. Strata dip gently to the northeast (the direction we drive) across part of the buried Wichita block and into the Anadarko basin. The dip is less than 1 degree most of the way, but beds are flexed to a "steep" 3 to 4 degrees midway between Elgin and Fletcher, where they overlie the major basement-rock fault zone separating the Wichita block from the Anadarko basin.

STOP 3. Texas Gypsum Company quarry at Fletcher, SW¼NW¼ sec. 11, T. 4 N., R. 10 W., Comanche County.

Texas Gypsum Company, a subsidiary of Temple Industries, Inc., began production of high-purity gypsum at Fletcher, Oklahoma, in September 1962. With increased quarry efficiency, the company has raised annual production to nearly 200,000 tons, making it the second largest gypsum producer in Oklahoma. Crude gypsum is shipped

Table 5.—Chemical and Petrographic Analyses of Mt. Scott Granite (from Merritt, 1965, table 1)

Chemical Analyses	Sample 196	Sample M-1	Norms	Sample 196	Sample M-1	Modes	Sample 196	Sample M-1
SiO_2	72.04	72.78	Quartz	29.96	31.63	Micropegmatite	72.8[1]	--
Al_2O_3	12.70	12.44	Orthoclase	25.12	25.53	Perthite	15.4	59.4
TiO_2	0.47	0.45	Albite	33.00	32.24	Quartz (free)	3.5	29.3
Fe_2O_3	2.49	2.31	Anorthite	4.60	4.09	Plagioclase (free)	2.5 (An_{11})	5.3 (An_8)
FeO	1.57	1.53	Diopside	1.71	0.30	Hornblende	2.1	3.6
MnO	0.09	0.09	Hypersthene	0.38	0.95	Augite	0.6[2]	--
MgO	0.39	0.31	Magnetite	3.61	3.35	Aegerine	--	tr
CaO	1.43	1.29	Ilmenite	0.89	0.85	Riebeckite	--	0.4
Na_2O	3.90	3.81	Fluorite	--	0.35	Chlorite	0.9	--
K_2O	4.25	4.32	Calcite	--	0.14	Epidote	0.1	--
Rb_2O	0.01	0.01	Apatite	0.20	0.19	Magnetite and ilmenite	2.0	1.4
BaO	0.10	0.13				Hematite	--	tr
P_2O_5	0.09	0.08	Differentiation index*	88.08	89.40	Zircon	tr	0.1
H_2O^+	0.32	0.16				Sphene	0.1	0.5
H_2O^-	0.05	0.00				Fluorite	tr	tr
CO_2	n.d.	0.06				Apatite	tr	tr
F	n.d.	0.18				Calcite	tr	--
		99.95						
Less O = F		0.08				Total quartz	29.6	29.3
						Total perthite	62.1	59.4
Total	99.90	99.87				Total feldspar	64.2	64.7

[1] Quartz 26.1%, perthite 46.7%

[2] Altered basic xenolith?

* Sum of normative quartz, orthoclase, and albite (Thornton and Tuttle, 1960).

Sample 196, collected by Gerald W. Chase, is from the top of Mt. Scott (sec. 11, T. 3 N., R. 13 W., Comanche County). The chemical analysis was performed in 1954 by James Markham of the Rock Analysis Laboratory, University of Minnesota.

Sample M-1 was collected by C. A. Merritt and W. E. Ham from the Ira Smith quarry (SW¼SE¼SE¼ sec. 4, T. 3 N., R. 15 W., Comanche County). It was analysed chemically by C. O. Ingamells and Doris Thaemlitz, also of the Rock Analysis Laboratory, in 1959; this analysis was financed by a grant from the University of Oklahoma Alumni Development Fund.

by truck and rail to the company's wallboard plant near Dallas, Texas, and is shipped by rail to its newly opened wallboard plant at Memphis, Tennessee.

Gypsum mined at Fletcher is from a 60-foot-thick massive bed at the base of the Permian Cloud Chief Formation (fig. 16). The deposit is located in Oklahoma's large west-central gypsum region (fig. 9), and is preserved as one of many horizontal outliers along the axis of the Anadarko basin. The top of the gypsum is eroded at all nearby outliers, so the original thickness of the evaporite bed in this area is unknown. Forty miles northwest of Fletcher, where the top of the gypsum is not eroded, the unit is 100 to 120 feet thick (Ham and Curtis, 1958). Remaining reserves on the 80 acres under lease at Fletcher are about 4 million tons of gypsum. Additional resources immediately northeast and southwest will enable expansion of quarry operations in the Fletcher area.

The Cloud Chief Gypsum is white to pinkish-white fine-grained alabaster, with scattered thin selenite veins subparallel to bedding. Single-crystal porphyroblasts of selenite up to 0.5 inch in diameter make up about 5 percent of the rock. The gypsum has formed by anhydrite hydration, but it is not clear whether the anhydrite was primary or was itself derived from an earlier gypsum. A residual lens of light-gray anhydrite 3 to 10 feet thick occurs in the lower part of the deposit.

In this region, the Cloud Chief Gypsum generally contains no shale interbeds, and dolomite is lacking except for finely disseminated grains and a single one-foot-thick bed developed locally at the base. Gypsum grades laterally into red shales and siltstones about 60 miles northwest of Fletcher. The thick, massive, homogeneous, noncyclic sulfate unit appears to have formed in a partly enclosed arm of the sea that was periodically fed with sulfate-rich water (Ham, 1960).

Two composite drill-hole samples provide data on purity of the top two-thirds of the bed (table 6). The top 20 feet of the unit is 97.92 percent pure gypsum, and the middle 20 feet is 96.96 percent pure. Impurities are anhydrite (0.56 and 1.04 percent of the 2 samples) and calcium-magnesium carbonates (0.88 and 1.25 percent). The silica and alumina are probably present in clay minerals, because grains of quartz and feldspar are not visible in thin sections. The small amount of iron probably occurs as hematite and imparts the slight reddish or pink color to the rock. The bottom 20 feet was not sampled but presumably would have a slightly lower purity, perhaps 95 to 96 percent gypsum. Clays and soils that fill solution cavities and crevices cannot be removed completely; thus, feed at the wallboard plants is about 93 percent gypsum.

Gypsum is mined in 2 benches: an upper bench 20 feet thick and a lower bench 35 feet thick, or down to the top of anhydrite where it is present (fig. 17). A system using conveyer belts, a screening station, and crushers was installed early in 1967 to expedite materials handling. The quarry superintendent manages all operations with the help of 2 men; 1 man operates the control tower, and the other works in the quarry and loads the trucks. Mechanization enabled this 3-man crew to produce about 14.2 tons of gypsum per man-hour (t/mh) in 1968, compared to a State-wide average of 6.9 t/mh (Johnson, 1970a).

Assistance and cooperation in gathering information have been provided by Myron Hemmingson, quarry superintendent at Fletcher, and Ted E. Armstrong, president of the company, in Irving, Texas.

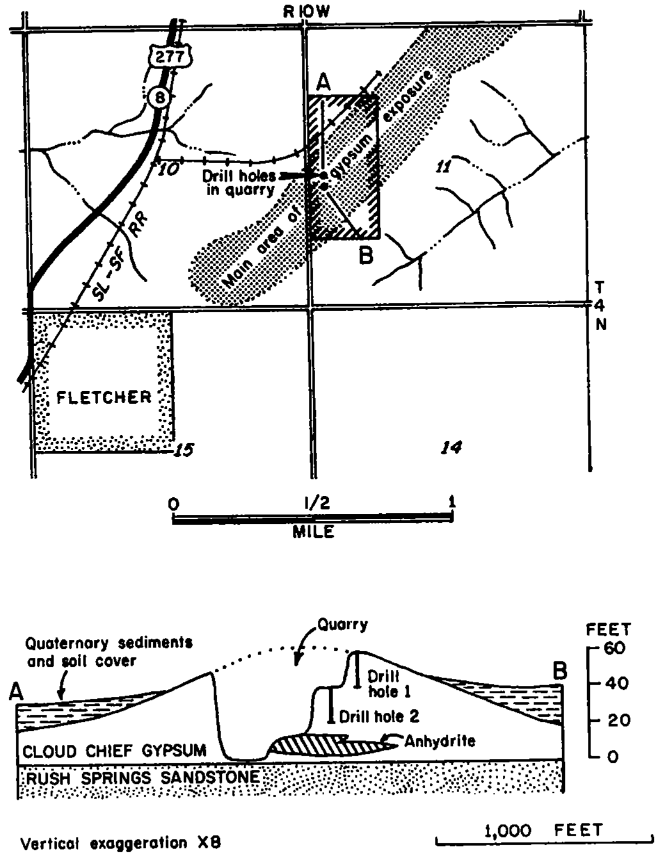

Figure 16. Map of Fletcher area (top), showing main area of gypsum exposure and limits (hachured lines) of Texas Gypsum Company property; schematic cross section (bottom) through main quarry.

Table 6.—Chemical Analyses of Cloud Chief Gypsum from Quarry at Fletcher[1]

	Drill Hole 1 (Upper 20 feet)	Drill Hole 2 (Middle 20 feet)
$CaSO_4 \cdot 2H_2O$ (gypsum)	97.92	96.96
$CaSO_4$ (anhydrite)	0.56	1.04
$CaCO_3$	0.61	0.14
$MgCO_3$	0.27	1.11
SiO_2	0.32	0.59
Al_2O_3	0.19	0.25
Fe_2O_3	0.05	0.04
TOTAL	99.92	100.13

[1]Figures are in weight percent; samples are composites of upper and middle parts of bed from drill holes in open pit; lower 20 feet not sampled. J. A. Schleicher, analyst. Chemical data from Johnson (1965).

Geology between Stops 3 and 4

From Fletcher to Cyril and west of Cyril for about 5 miles, we drive through outliers of the Cloud Chief Gypsum along the axis of the Anadarko basin. Just east of Apache, we move back onto the buried Wichita block, crossing the "steep" (3 to 4 degrees) flexure overlying the basement-rock fault zone.

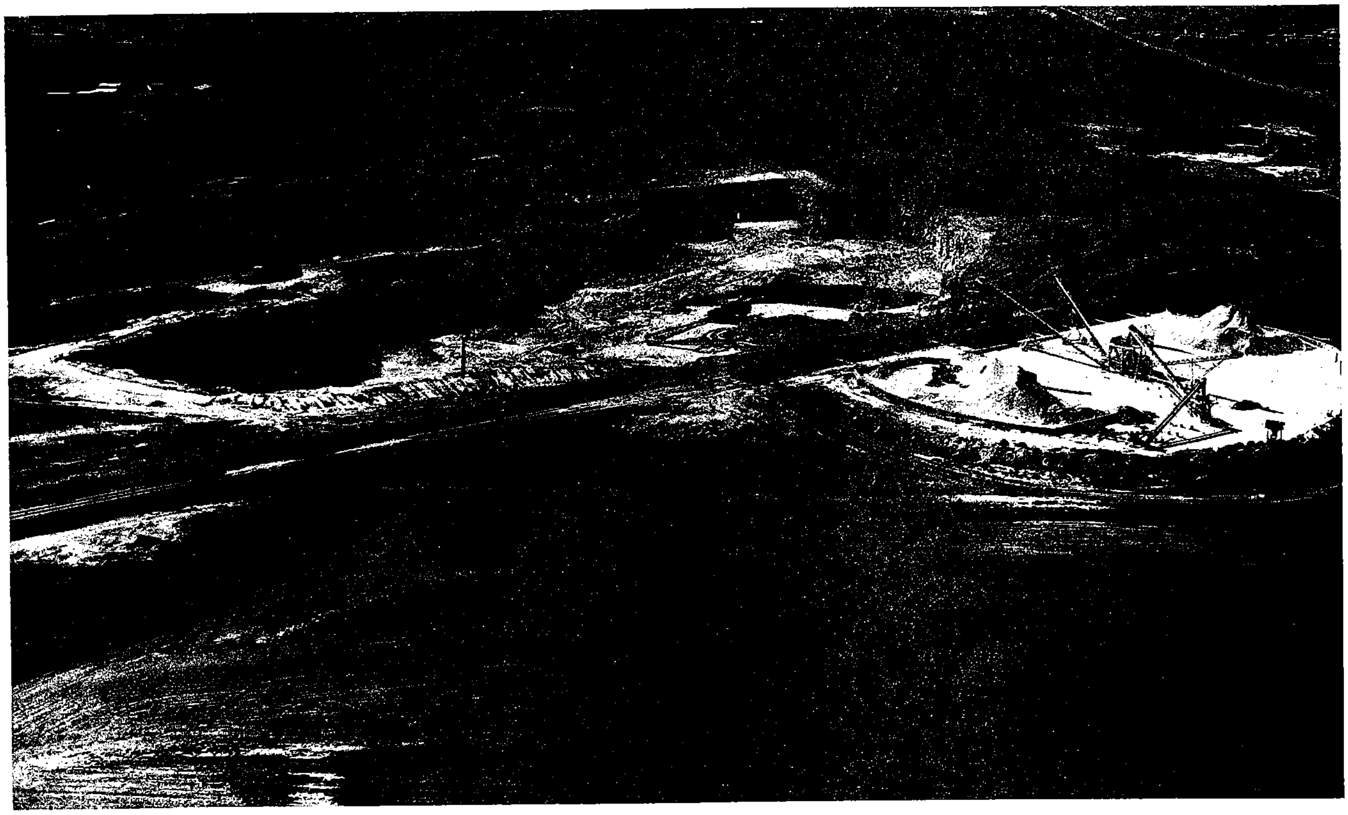

Figure 17. Aerial view of Texas Gypsum Company quarry in massive Cloud Chief Gypsum at Fletcher.

An excellent view of flat-topped Mount Scott and other peaks of the Wichita Mountains is seen to the southwest and south during much of the drive westward from Cyril through Apache. The enormity of tectonic movements of the Wichita and Anadarko provinces is brought home in realizing that the basement rock surface is some 40,000 feet (8 miles) below ground level in the Fletcher-Cyril-Apache area.

Ten miles west of Apache, we pass through the Ordovician limestones of the Arbuckle Group again, dipping northeastward toward the basin off the flank of the Blue Creek Canyon anticline.

In the last mile or two of the approach to Stop 4, we can see the homoclinal dip of a layered sequence of rocks. All of Bally Mountain and the lower part of the mountain to the east (where we will stop) comprise stratified rhyolite flows and tuffs. This volcanic suite is disconformably overlain by Late Cambrian sedimentary rocks.

STOP 4. Rhyolite and sedimentary rocks east of Bally Mountain, W½ sec. 26, T. 6 N., R. 14 W., Kiowa County.

The small rhyolite hill to the east of Bally Mountain (fig. 18) contains exposures that are critical to the understanding of the basement rocks in the Wichita Mountains. A measured section of 650 feet of rhyolite is exposed beneath the Late Cambrian Reagan Sandstone and younger rock on this hill (northeast end of fig. 19).

The outcrop shows clearly the extrusive character of the Carlton Rhyolite and the general conformance of dips between the rhyolite and overlying sedimentary rocks. The Reagan-Carlton contact is a straightforward unconformable relationship, but the general attitude of the beds on either side of the contact is identical. The rhyolite surface at the time of the basal transgression was typically flat. There is, however, a small knob immediately northwest of this hill, which shows that the surface did have some relief. At that place, a small hill of rhyolite was emergent during Reagan time and was finally covered by the Honey Creek Formation (a sandy calcarenite). Overlying the Honey Creek is a very thick sequence (probably 6,000 to 6,500 feet) of shallow water limestones and stratigraphic dolomites from the Arbuckle Group.

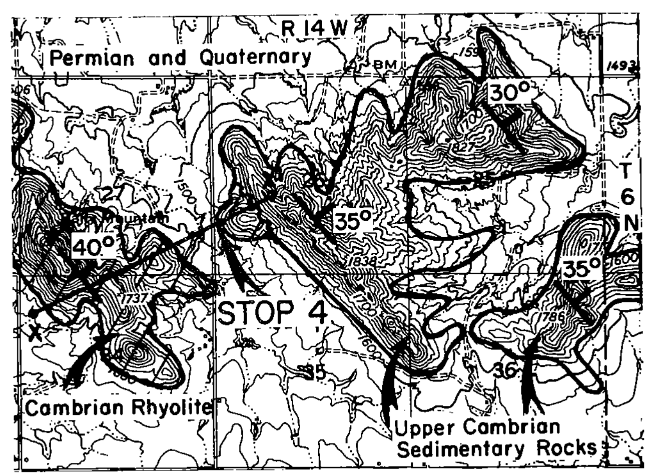

Figure 18. Location map for Stop 4, 1 mile east of Bally Mountain. Base from U.S. Geological Survey 15-minute topographic-quadrangle series; scale, 1 inch = 1 mile. Cross section X-X¹ shown in figure 19.

The rhyolite on the hill includes welded tuffs and strongly flow-banded layers (figs. 20 and 21). These present among the best exposures of basement rocks over an estimated 17,000 square miles in southern Oklahoma. Based on a well (the Stanolind No. 1 Perdasopfy) drilled 15 miles southeast of this stop, the rhyolite in this area is

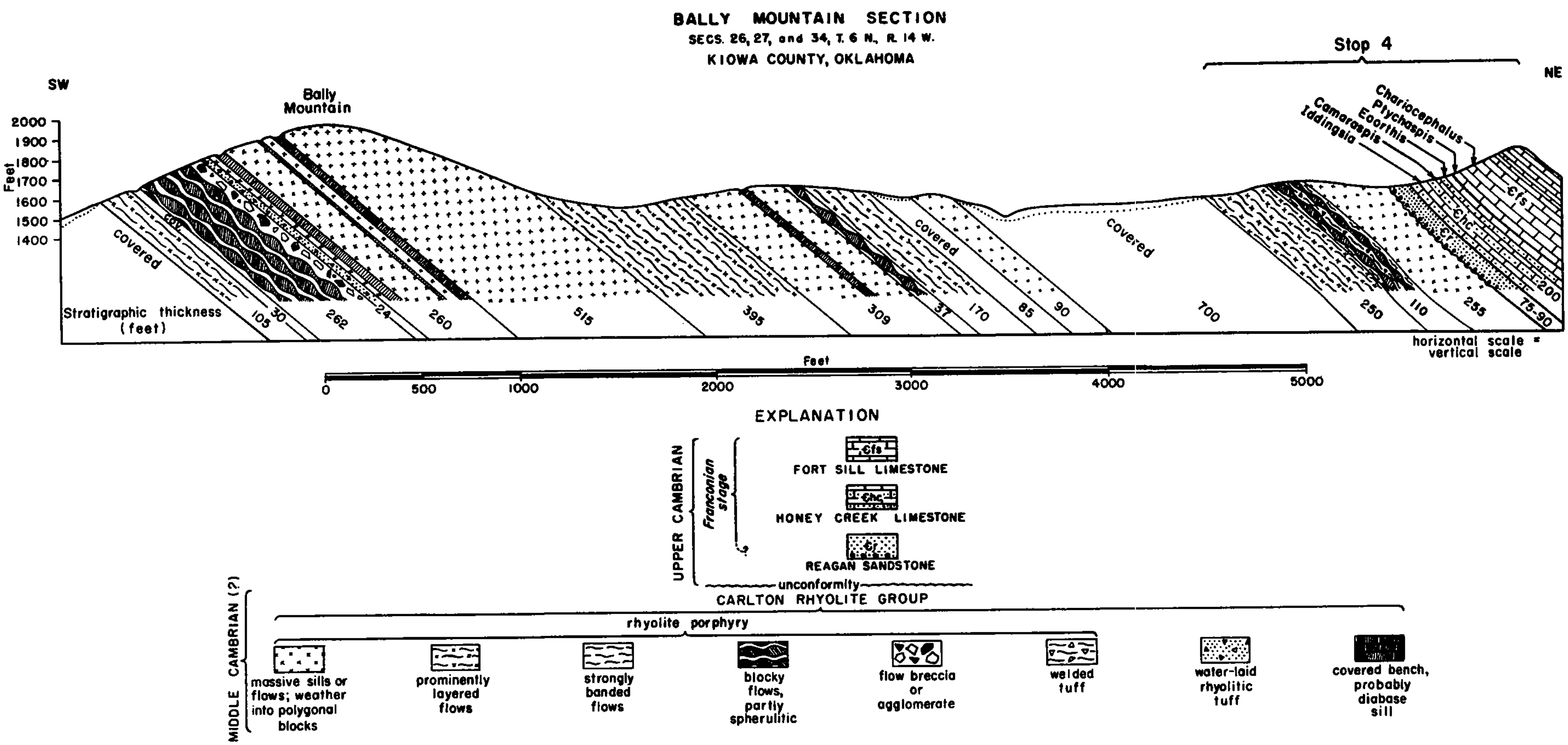

Figure 19. Measured section of Carlton Rhyolite Group at Bally Mountain (modified from Ham and others, 1964, fig. 4). Rocks examined at Stop 4 include upper part of sedimentary-rock sequence (right side of section).

Figure 20. Bed of strongly flow-banded rhyolite in upper part of Carlton Rhyolite Group exposed on Bally Mountain. View is toward northwest; Zodletone Mountain is on horizon at left.

Figure 21. Detail of flow-banded rhyolite in figure 20, showing parallel and contorted flow banding.

underlain by a sill of micrographic granite. The granite is in turn underlain by a sequence of basalts and spillites (see Ham and others, 1964, plate 3). Gabbroic rocks like those seen at Mount Scott have been replaced in the stratiform sequence by the basic extrusives. The schematic evolution shown by Ham and others (1964, plate 4) attributes this to a pre-rhyolite fault, between Mount Scott and this site, that uplifted the present mountains and removed the basalts before the rhyolite was extruded.

Widess and Taylor (1959) show parallel layered reflections approximately 20,000 feet below the basement surface. They are basaltic flows and associated sedimentary rocks, presumably, and are thought to be late Precambrian and Early Cambrian on the basis of speculative reasoning.

Geology between Stops 4 and 5

After rejoining State Highway 19, the next 9 miles are traveled between hills and peaks of granite on the south and limestone on the north. The rugged topography of granite shows up clearly in this area, as does the striking alignment of vegetation along easily weathered faults and joint zones. Another major limestone quarry is visible 3 miles north of the road at Unap Mountain, where Dolese Brothers Company is producing stone from the Kindblade Formation for shipment throughout western Oklahoma.

Dikes and deeply weathered gabbro and anorthosite are well exposed in roadcuts just east of Roosevelt. The high degree and great depth of alteration indicates that this is a residual weathering zone, where the weathering occurred during Permian time and the ancient surface is now being exhumed.

STOP 5. Rhythmic layering of troctolite and anorthosite at Roosevelt, C NE¼ sec. 21, T. 4 N., R. 17 W., Kiowa County.

Rodger E. Denison and *Nancy L. Scofield*

The rocks exposed on the low ridge about 400 meters south of the section-line road are of the K (lowest) zone of figure 4. Layering within the zone strikes east-west and dips gently to the north. The prominent layering and differential erosion causes the outcrop to assume a sedimentary appearance from a distance (fig. 22). The layering is caused by variations in the plagioclase and olivine content and lamination of tabular plagioclase crystals. Clots of coarse diallage occur in the anorthositic layers.

Rotan (1960) mapped eight units at this locality. In ascending stratigraphic order they are: troctolite 1, troctolite 2, and anorthositic gabbro 1, thin interlayered troctolite and anorthositic gabbro, anorthositic gabbro 2, olivine gabbro 1, anorthositic gabbro 3, and olivine gabbro 2.

The hills to the north are the main part of the Raggedy Mountains. There the upper units, M and L, are exposed. The units were originally defined by Spencer (1961) and Gilbert (1960). They chose letters near the middle of the alphabet to designate the units, hopeful that the sequence could be extended above and below that already found. Thus far this has not been possible.

A more complete discussion of the geology of this stop and the surrounding area appears earlier in this report in the sections on layered basic igneous rocks in the Raggedy Mountain Gabbro Group.

Geology between Stops 5 and 6

Not much to see, better catch a short nap.

STOP 6. Potholes and wave-cut grooves in Granite, near C NE¼NW¼ sec. 7, T. 5 N., R. 18 W., Kiowa County.

Potholes and wave-cut grooves in the Lugert Granite are exceptionally well developed in the western part of the Wichita Mountains (fig. 23). The potholes are shallow, circular depressions a few feet in diameter, presumably formed by the eddying of sand and stones on the granite floor of the sea during Permian time (Ham and others, 1957, p. 24). These and other erosion features of the region are now being exhumed by removal of the overlying Permian shales (fig. 24).

Permian sediments draped across hills at this site dip at an angle of 4° to 7° away from the granite, whereas farther from the hills the dip decreases to 1° to 3° (fig. 23). The sediments were probably nearly horizontal when laid down on the sea floor, and thus the steeper dip adjacent to the hills results from differential compaction and greater settling of the thicker sedimentary sequence away from the hills.

Geology between Stops 6 and 7

Driving amongst the isolated sharp hills and peaks that rise 200 to 700 feet above the Permian red-bed plain provides an impression of how these same peaks once stood as islands rising out of the Permian sea. Smooth, nearly vertical wave-cut surfaces or grooves can be traced several

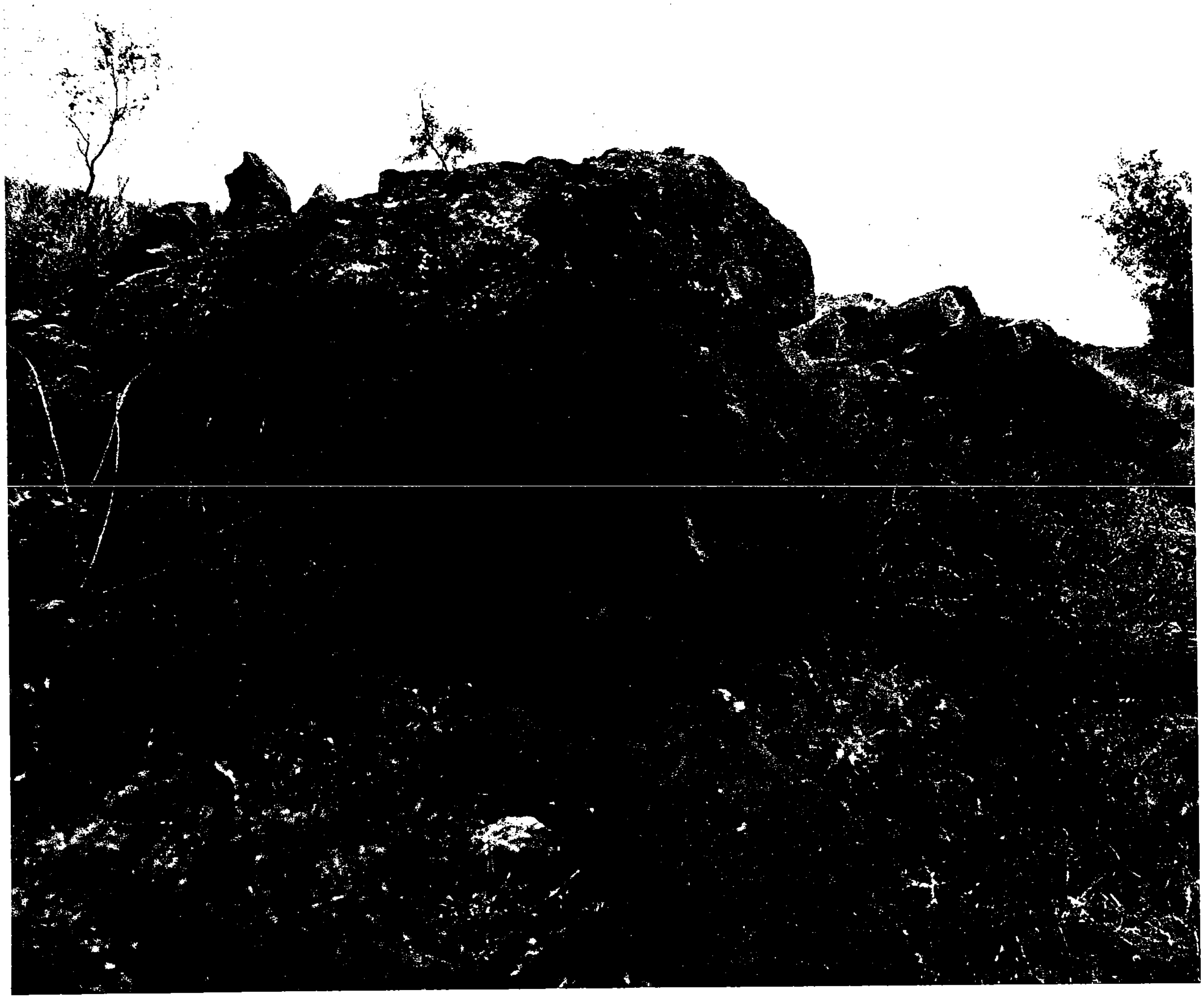

Figure 22. Layered anorthosite and troctolite in K-zone; dip 15° toward north (left) at Stop 5 near Roosevelt.

hundred feet horizontally around the lower part of some granite hills. The lower grooves on the hills are now being uncovered by erosion of Permian shales, whereas the higher ones, more than 50 to 75 feet above the plain, have generally been destroyed. A good example of these grooves is seen on the small hill in NE¼ sec. 14, T. 5 N., R. 19 W.

After reaching Lugert and driving several miles south on State Highway 44, we see Lake Altus, which backs up behind Altus dam, built by the U.S. Bureau of Reclamation in 1948 (fig. 25). The purpose of the project was to provide water for irrigation and municipal water supply and to aid in flood control on the North Fork of the Red River.

On the top or flanks of high granite mountains south of Lugert are flat surfaces, normally 50 to 300 feet wide, that may be remnants of Permian wave-cut platforms. The elevation of the most conspicuous platform is 2,130 to 2,150 feet above sea level.

STOP 7. Quartz Mountain State Park (overnight lodging arranged), mostly in sections 15, 16, 21, and 22, T. 5 N., R. 20 W., Greer County.

The hills around Quartz Mountain are underlain by several granites. The relief is considerably lower than in the eastern part of the Mountains. The hills are being exhumed from their cover of Permian red beds and show a variety of wave-cut grooves and other features from the Permian seas. None are quite as well developed as those at Stop 6.

The oldest granite in this immediate area is the Reformatory Granite, a relatively coarse-grained leucocratic quartz-perthite rock (table 7). It was named for outcrops about 4 miles northwest of here, at the State Reformatory, where inmates literally made little ones out of big ones in days gone by. This granite is cut by two finer-grained granites. The older of the two is probably equivalent to the Mount Scott Granite of the eastern Mountains. The younger is the Lugert Granite, probably the most common granite in the western Mountains. This is a generally leucocratic even-grained rock favored by tombstone makers.

The Reformatory Granite is evidently an irregular pluton intruding the Headquarters Granite near the town of Granite about 6 miles northwest of this stop. It offers quite a contrast to the sill injection that is common in the eastern Mountains.

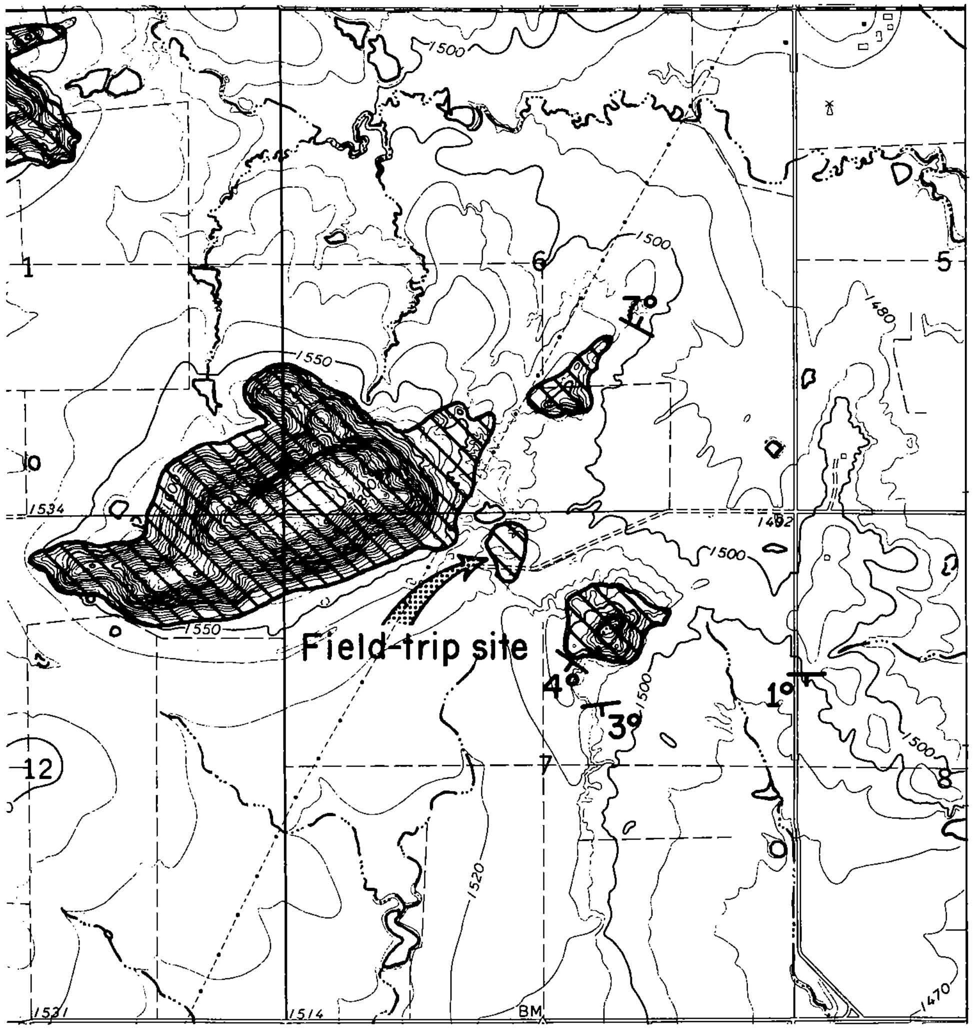

Figure 23. Location map for Stop 6 in T. 5 N., R. 18 W. Base from U.S. Geological Survey 7½-minute topographic-quadrangle series; scale, 1 inch = 2,000 feet. Dip of Permian sediments decreases away from hills of granite (diagonal lines).

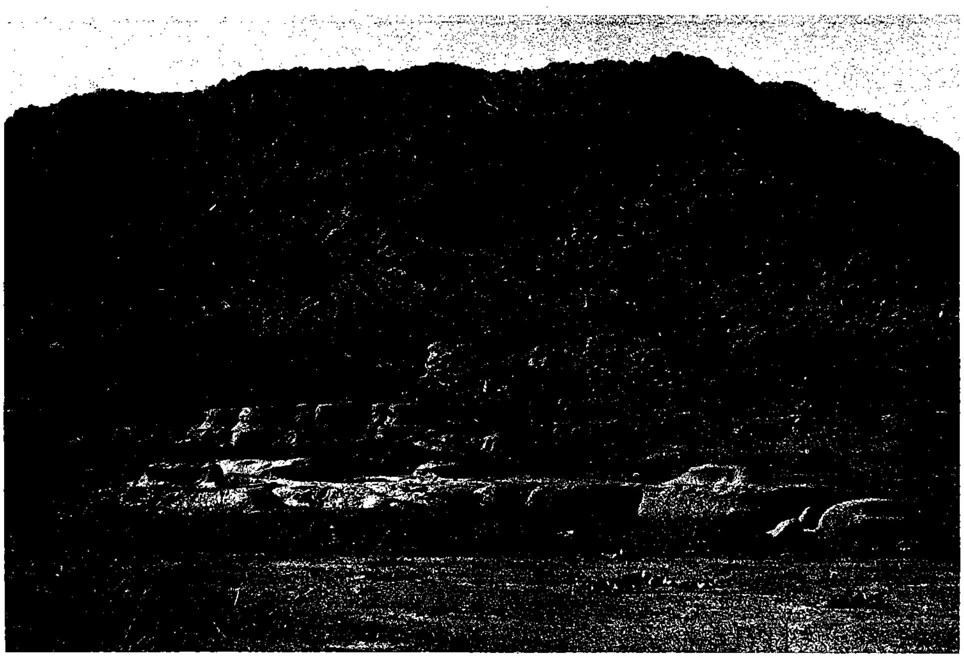

Figure 24. Potholes and wave-cut grooves on Lugert Granite. Formed and then buried in Permian time, they are now being exhumed by erosion of overlying shales.

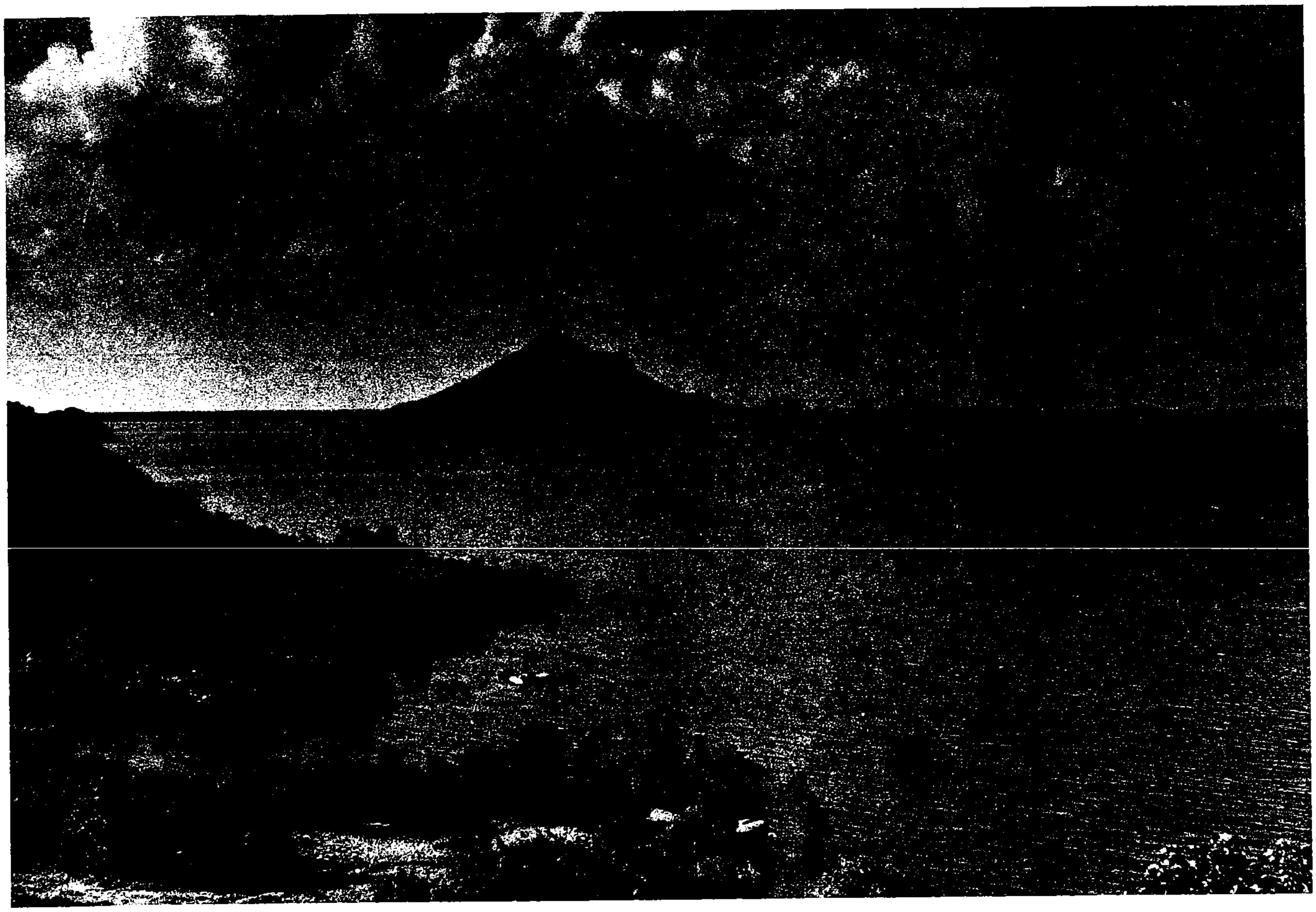

Figure 25. View of Hicks Mountain on Lake Altus. Looking north from State Highway 44 at base of King Mountain.

Geology between Stops 7 and 8

Our drive west from Quartz Mountain is along the plunge of the Wichita block, and only a few peaks of granite protrude above the red-bed plain. As we approach Mangum, we can see—to the southwest—the horizontal benches formed by resistant dolomite and gypsum beds of the Blaine Formation.

Between Mangum and Reed, the once-thick gypsums of the Blaine Formation are largely dissolved and the red beds are mantled by terrace deposits.

On State Highway 30, going north, we descend to the Elm Fork of the Red River and cross a homoclinal sequence of red beds dipping south off the Wichita uplift and into the Hollis basin. Just before reaching the bridge, we pass through gypsum beds (as much as 30 feet thick) from the Blaine Formation (see cross section in Stop 8).

STOP 8. Harmon County Salt Plains, south of Erick, parts of secs. 3, 4, 10, and 11, T. 6. N., R. 26 W., Harmon County.

High-purity salt (halite) is produced by solar evaporation of saturated brines at the Kiser and Chaney Salt Plains in northern Harmon County. About 200 tons of salt is emitted daily at each salt plain (Ward, 1961) from natural brine springs that issue from the Flowerpot Shale in the bottom of small canyons adjacent to the Elm Fork of the Red River (fig. 26). Two companies have constructed evaporating pans and are beginning to produce commercial salt; Western Salt Company is working the Chaney Salt Plain, and Acme Salt Company is working the Kiser Salt Plain.

Resistant gypsum and dolomite beds of the Blaine Formation cap the hills and bluffs in the area, whereas some 80 feet of reddish-brown Flowerpot Shale is exposed in the scarp face below the Blaine (fig. 27). The upper part of the Flowerpot Formation contains as much as 200 feet of interbedded salt and shale in subsurface several miles to the south, but in this area most of the salt is dissolved by ground water and some of the brine is escaping at the salt plains. Key gypsum beds cropping out in the area include the Haystack Bed at the base of the Blaine and the Kiser and Chaney Beds in the upper Flowerpot. The Kiser-Chaney interval embraces the copper shales being mined 30 to 40 miles to the southeast.

Both companies pump saturated brine from artesian wells drilled 30 to 40 feet deep into natural cavities in salt layers (fig. 27). The brine wells generally produce at a rate of 80 to 100 gpm, although the potential is greater. Brine is pumped through 6-inch plastic pipe to flat-bottomed earthen pans. As water evaporates, the brine becomes supersaturated and salt settles on the bottom of the pans. Brine is added every few days.

Harvesting is done with a front-end loader when the salt crust is about 8 inches thick. Only 2 to 3 inches of salt is removed at a time, leaving about 6 inches of salt permanently in place to provide a firm base and to prevent mixing salt with underlying sand. Washed salt produced here is

Table 7.—Chemical Analyses of Granites in Western Part of Wichita Mountains[1]

	Reformatory Granite[2]	Lugert Granite[3]
SiO_2	74.46	74.59
Al_2O_3	12.78	12.90
TiO_2	.23	.22
Fe_2O_3	1.17	.86
FeO	.90	.84
MnO	.04	.04
MgO	.24	.21
CaO	.48	.53
Na_2O	4.01	3.89
K_2O	5.03	5.17
Rb_2O	.02	.02
BaO	.02	.05
P_2O_5	.02	.00
H_2O^+	.24	.14
H_2O^-	.06	.10
Total	99.70	99.56

[1]From Ham, Denison, and Merritt (1964, table 18). Analyst, C. O. Ingamells and Doris Thaemlitz, 1959, University of Minnesota Rock Analysis Laboratory.

[2]Old quarry at Granite, SE¼SE¼SE¼SE¼ sec. 22, T. 6 N., R. 21 W., Greer County.

[3]Outcrop at Quartz Mountain Lodge, NE¼SE¼SW¼ sec. 15, T. 5 N., R. 20 W., Greer County.

used mainly in stock feed and as a water softener. Customers come from a large area of southwestern Oklahoma and Texas.

Brine samples from both companies' production wells are saturated with respect to salt, and the specific gravity is 1.203-1.209 (table 8). Na + Cl is 325 to 334 grams per liter, or about 99 percent of total dissolved solids (TDS) in the brine. Brine samples taken from surface springs are not as pure (Na + Cl is only 97 to 98 percent of TDS), because additional $CaSO_4$ is dissolved by the brine at and near the land surface.

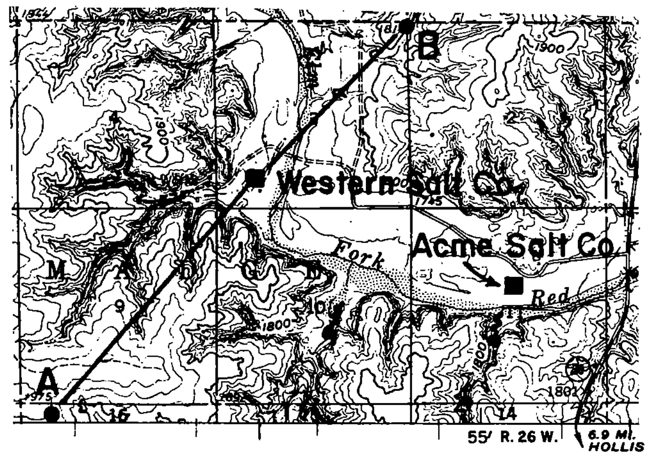

Figure 26. Topographic map showing location of 3 natural brine springs and the 2 solar-salt plants operating in T. 6 N., R. 26 W. Base from U.S. Geological Survey 15-minute topographic-quadrangle series; scale, 1 inch = 1 mile. Cross section A-B shown in figure 27.

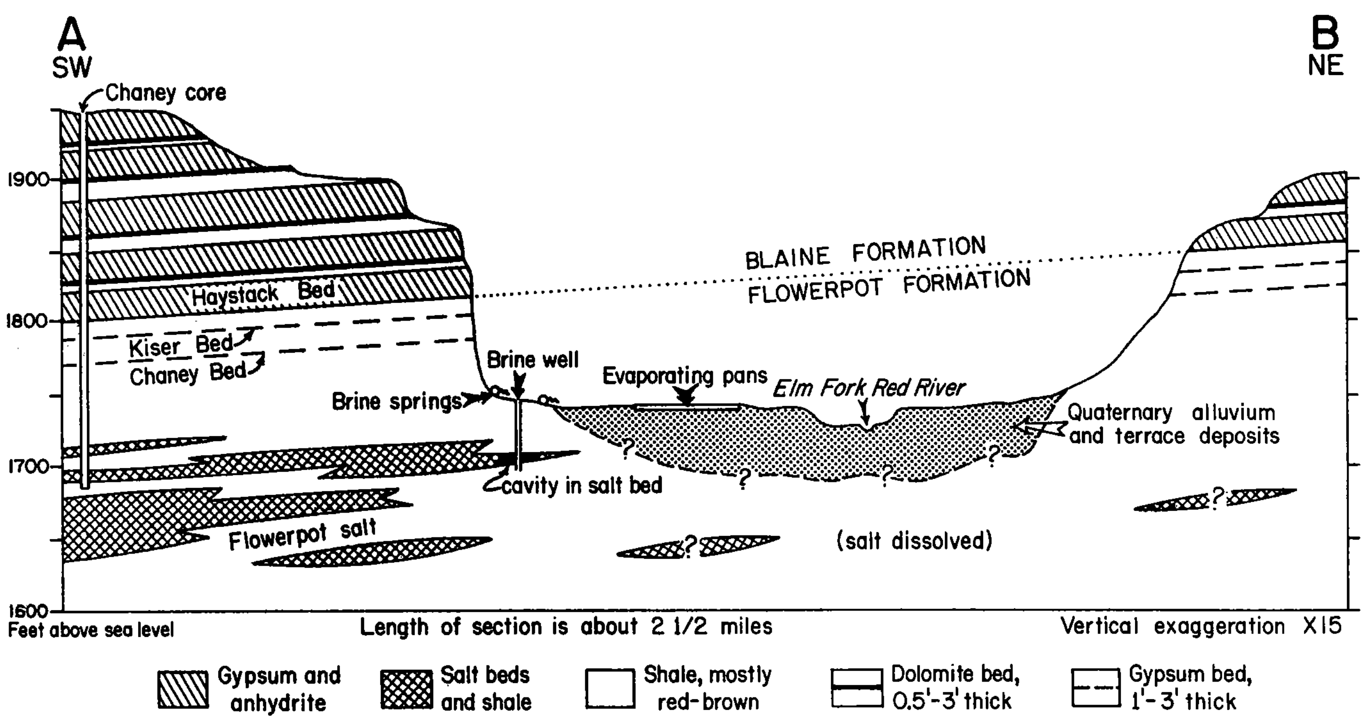

Figure 27. Generalized cross section through salt plain and solar-salt plant adjacent to Elm Fork of Red River. See figure 26 for location of cross section.

Solar salt produced from the brines is more than 99 percent pure NaCl (table 8), and the chief impurities are Ca and SO_4, occurring mainly as gypsum and wind-blown dust.

I estimate, based on climatologic data, that the average annual production in the area is about 1,000 tons of salt per acre of evaporating pan. Excess evaporation over precipitation is 40 inches per year, but since the evaporation rate of saturated brine is only 70 to 80 percent that of fresh water, I feel that the average annual net evaporation is probably 28 inches of brine. Saturated brine contains 430 tons of salt per acre-foot, so 28 inches of brine evaporated in one year would yield 1,000 tons of salt per acre. Climatologic data and potential production here are similar to that reported on Big Salt Plains in northwest Oklahoma (Johnson, 1970b).

Table 8.—Chemical Analyses of Solar Salt and Brine from Harmon County Salt Plains[1]

	Evaporated Salt		Natural Brine	
	Acme Salt Co.[2]	Western Salt Co.[2]	Acme Salt Co.	Western Salt Co.
pH			6.9	6.8
Sp. Grav.			1.203	1.209
	Weight Percent (Dry Basis)		Grams/Liter	
Ca	.120	.134	.338	.379
SO_4	.355	.270	.759	.656
Mg	.040	.043	.384	.400
CO_3	.010	.013		
HCO_3			.220	.120
K	.068	.077	.295	.292
Li	----	----	.002	.003
Fe_2O_3	.001	----	----	----
Al_2O_3[3]	.006	.008	----	----
Acid Insol.[4]	.148	.008	----	----
		Calculated Components		
$CaSO_4$	.384	.382	.904	.930
$CaCO_3$	.017	.022		
$Ca(HCO_3)_2$			.290	.160
$MgSO_4$	.105		.152	
$MgCl_2$	.076	.172	1.411	1.599
$CaCl_2$		.036		.180
KCl	.130	.147	.562	.557
R_2O_3	.007	.008		
Acid Insol.[4]	.148	.008		
Total	.867	.775	3.319	3.426
Dissolved Solids			328.660[5]	337.069[6]
NaCl (by diff.)	99.133	99.225	325.341	333.643

[1] Samples collected July 11, 1973; David A. Foster, analyst. Emission and atomic absorption spectroscopy used in analysis of Mg, K, and Li; other elements by standard wet chemical methods.

[2] Chemical data are average of separate analyses of 3 samples collected from 3 different solar ponds. Samples washed slightly in ponds.

[3] $Al_2O_3 = R_2O_3 - Fe_2O_3$.

[4] Acid insolubles are predominantly wind-blown dust, and are mostly quartz (SiO_2).

[5] Equivalent to 273.2 g/kg, or 27.32% by weight.

[6] Equivalent to 278.8 g/kg, or 27.88% by weight.

Both companies began operations in 1970-71 and are, therefore, just starting production. They each have about 6 acres of evaporating pans (fig. 28), and plan to increase their acreage in the near future. Western plans to pipeline its brine 6 miles east to a new location where large pans and a salt plant are to be built.

Assistance and information were provided by Jack Speed and Jim Shaver of Western Salt Company and by Bill Flowers and his sons Ivan, William, and Charles of Acme Salt Company.

Geology between Stops 8 and 9

The trip to Republic Gypsum Company begins with retracing our route to Mangum. South of Mangum the highway ascends the benched escarpment formed by resistant dolomite and gypsum beds of the Blaine Formation. In this area, most of the Blaine gypsums are abnormally thin or absent at the outcrop due to solution by ground water.

The rest of the route is along the Blaine Formation, but along much of the route the gypsum beds are dissolved and the bedrock is mantled by terrace deposits and soil. Surficial studies around Duke are disappointing in terms of gypsum resources, but drilling beneath the soil veneer reveals several thick minable beds with a gypsum to shale ratio of 1:1.

STOP 9. Republic Gypsum Company quarry at Duke, W½ sec. 24, T. 2 N., R. 23 W., Jackson County.

The Blaine Formation of southwest Oklahoma consists of laterally persistent interbeds of gypsum, dolomite, and shale, and the formation has an aggregate thickness of 200 feet. Nine widespread gypsum layers are typically 10 to 30 feet thick; they are underlain by light-gray dolomites 0.5 to 5.0 feet thick and are overlain by red-brown shales 3 to 30 feet thick. Gypsum purity in the region is high, averaging about 96.5 percent, with principal impurities being carbonates (1.8 percent) and anhydrite (1.5 percent).

The three gypsum beds worked by Republic Gypsum Company at Duke are in the upper part of the Blaine Formation, in the Van Vacter Member (fig. 29). Gypsum beds in the Van Vacter Member are numbered consecutively upward, and thus the mined units are beds 1, 2, and 4 (bed 3 is thin or absent in the Duke area). Bed 1, which is 9 feet thick, is overlain successively by 9 feet of shale, 18 feet of gypsum (bed 2), 9 feet of shale, and 9 feet of gypsum (bed 4). Most of the mining has been done in the thick bed, 2, which is 17 to 21 feet thick in most of southwest Oklahoma.

All three beds are white, fine- to medium-crystalline gypsum. Anhydrite lenses are not present in the mining area, and in general are not present at any place in the region where the gypsum beds are less than 100 feet below ground level. Where the beds are more than 200 feet below the surface, they are mostly anhydrite, indicating that the gypsum at Duke has been derived by hydration of anhydrite.

Overlying each gypsum is a sequence of reddish-brown blocky shale that is itself overlain by a greenish-gray shale about 1.0 foot thick. Above each gray shale is a greenish-gray to brownish-gray dolomite bed 0.4 to 1.0 foot thick, thus exposing a nearly complete evaporite cycle of dolomite, gypsum, red-brown shale, and green-gray shale (if halite had been deposited above gypsum beds in the region,

Figure 28. View of solar-salt evaporating pans of Western Salt Company. Six ponds in center total about 6 acres, with potential average yield of 6,000 tons of salt per year. Looking northeast from top of bluff.

it has dissolved without leaving a trace). The dolomites are variously pelletoidal, oolitic, or microgranular in different parts of the region, and small (0.5 inch long) pelecypod shells are locally abundant.

Each of the gypsum beds contains locally irregular clay-filled solution cavities and sinkholes, and the base of each bed is somewhat uneven, due to solution. This is particularly true for bed 2. The discovery of partial remains of a Columbian elephant (with a possible age range of 10,000 to 50,000 years ago) in a debris-filled sinkhole that cuts bed 2 indicates that at least some of the cavern development and filling occurred in the Late Pleistocene.

Beds 1, 2, and 4 are high-purity gypsum ranging from 96.2 to 98.1 percent gypsum (table 9). Principal impurities are disseminated crystals of anhydrite and calcium-magnesium carbonates. Plant feed now is a blend of stone from beds 1 and 2 (only a small amount of bed 4 is used), but the purity is diluted to about 92 percent by accidental inclusion of clay and soil that fill solution cavities.

Table 9.—Chemical Analysis of Blaine Gypsum Beds Mined by Republic Gypsum Company at Duke[1]

	Bed 1 (9 feet thick)	Bed 2 (18 feet thick)	Bed 4 (9 feet thick)
$CaSO_4 \cdot 2H_2O$ (gypsum)	96.24	97.01	98.11
$CaSO_4$ (anhydrite)	0.78	1.21	0.19
$CaCO_3$	1.50	0.91	0.91
$MgCO_3$	1.02	0.61	0.56
SiO_2	0.33	0.09	0.13
Al_2O_3	0.11	0.06	0.07
Fe_2O_3	0.03	0.02	0.03
TOTAL	100.01	99.91	100.00

[1]Channel samples of beds 2 and 4 collected from open pit; figures are in weight percent; continuous sample of bed 1 from core drilled 2 miles north of mine. J. A. Schleicher, analyst.

The quarry was opened in bed 2 (fig. 30) after removing 3 to 10 feet of overburden with a scraper. As the pit was enlarged, a small amount of bed 4 was worked in a bench-stripping operation, and eventually the pit was dug deeper to develop bed 1 (fig. 31). An average 1:1 ratio of gypsum to shale is anticipated for most of the 440 acres of company-owned land. Original reserves reported by the company were 12.5 million tons of gypsum (Johnson, 1964). Stone is trucked 2 miles to the plant at Duke, where it is crushed, dried, ground, and calcined for the manufacture of wallboard at a rate of 150 million square feet per year.

Republic Gypsum Company is Oklahoma's third-largest producer of gypsum and second-largest producer of wallboard. Since opening its plant in 1964, the company has steadily increased gypsum production and presently accounts for about 15 percent of the State's annual output. Its annual production has ranged from 120,000 to 166,000 tons of gypsum.

Assistance in gathering information has been provided by Jerry Nielson, plant manager of Republic Gypsum Company at Duke.

Geology between Stops 9 and 10

All but the last 4 miles are traveled along the strike of the Blaine Formation. Again, most of the gypsum has been dissolved, but the dolomites and shales are well exposed. Strata dip gently to the west across the Hollis basin at an angle of about 20 feet per mile.

The last 4 miles in the approach to Eagle-Picher property crosses poorly exposed upper Flowerpot shales.

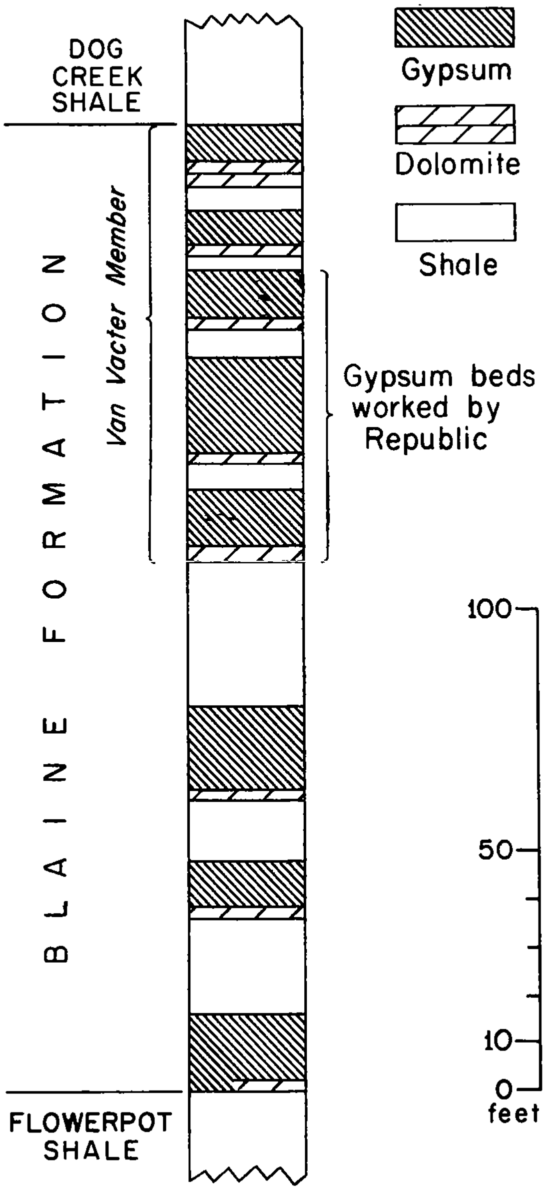

Figure 29. Columnar section of Blaine Formation in southwest Oklahoma, showing stratigraphic position of three high-purity gypsum beds being worked by Republic Gypsum Company.

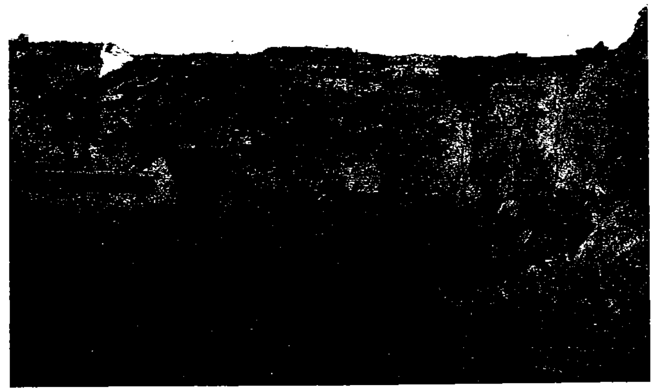

Figure 30. Massive 18-foot-thick gypsum (bed 2) mined by Republic Gypsum Company.

STOP 10. Eagle-Picher Industries, Inc.'s copper mine at Creta, secs. 3, 4, 9, 10, 15, and 16, T. 1 S., R. 22 W., Jackson County.

Kenneth S. Johnson and *Douglas C. Brockie*

Copper mineralization in the Creta area was first detected because of malachite stain on outcrops in a stream bank adjacent to a section-line road. Outcrop mapping, sampling, and analyses established that a 6-inch-thick copper-bearing shale was present for 3 miles along the outcrop, and that the grade ranged from 2.6 to 4.5 percent copper (Ham and Johnson, 1964). Subsequent core drilling and exploration by Eagle-Picher Industries, Inc., established that chalcocite is the primary ore mineral and that an ore body averaging 2.30 percent copper, undiluted, could be mined by strip-mining methods. Initially called the "lower copper bed," the ore bed is now informally named the Prewitt copper shale after the principal owner of the deposit (Johnson and Ham, in preparation).

The Prewitt copper shale is about 40 feet below the top of the Permian Flowerpot Formation and is 8 feet below the thin but persistent Marty (formerly called "Kiser") Dolomite (figs. 32 and 33). An "upper copper shale," just 5 feet above the Prewitt bed, is thinner (1 to 4 inches thick) but is lower in grade and appears to be economically minable only in the extreme northern part of the reserve area.

The Prewitt bed is a medium-gray silty shale and mudstone containing chalcocite as the primary ore mineral and malachite and other oxidized copper minerals at and near the outcrop. It ranges in thickness from 3 to 12 inches, averaging about 7 inches. The present reserve area extends about 3 miles north-south and 1.5-2.0 miles east-west (fig. 34). Increasing depth of overburden becomes a limiting factor along the western edge of the reserve area. As much as 60 feet of overburden has been removed in places. Present reserves call for the removal of as much as 100 feet of overburden in places. Depending upon the price of copper and other economic factors, drilling results indicate that potential ore areas extend as far south from the present reserve area as Red River. Mineralized shale with some economic potential underlies an area of some 12 square miles.

The grade of the Prewitt bed in the mined sulfide zone averages about 2.0 percent copper and ranges from about 0.5 percent to as much as 4.5 percent copper. Other metals, present only in low concentrations (Lockwood, 1972, appendix 6), include lead (10-50 ppm), silver (10-50 ppm), cobalt (10-50 ppm), nickel (30-60 ppm), uranium (50-100 ppm), vanadium (75-150 ppm), and zinc (150-400 ppm). Only copper is recovered in the mining and milling process, but a small amount of silver is recovered from the concentrates at the smelter. Some gypsum in the overburden is crushed and used as road-surfacing material.

The ore bed consists of two different basic lithologies: the upper 4 to 5 inches is laminated, and thereby differs petrologically from other gray shales in the Flowerpot, whereas the lower 3 to 4 inches is blocky shale and generally resembles other gray shales in the Flowerpot. Silt laminae in the upper part of the bed commonly are 0.1 to 0.2 mm thick and constitute 10 to 20 percent of the unit.

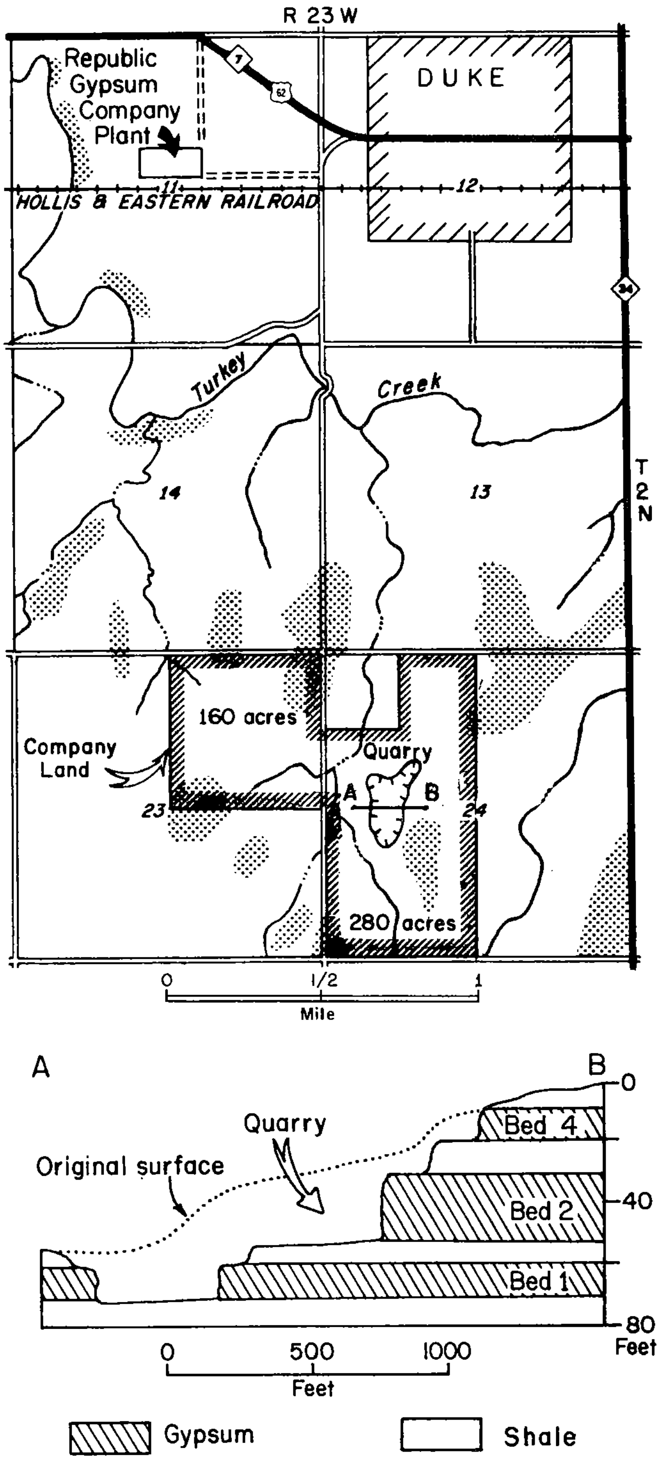

Figure 31. Map of Duke area (top) showing location of Republic Gypsum Company's main quarry and wallboard plant. Exposures of Blaine gypsum indicated by stippling. Below is schematic cross section through main quarry.

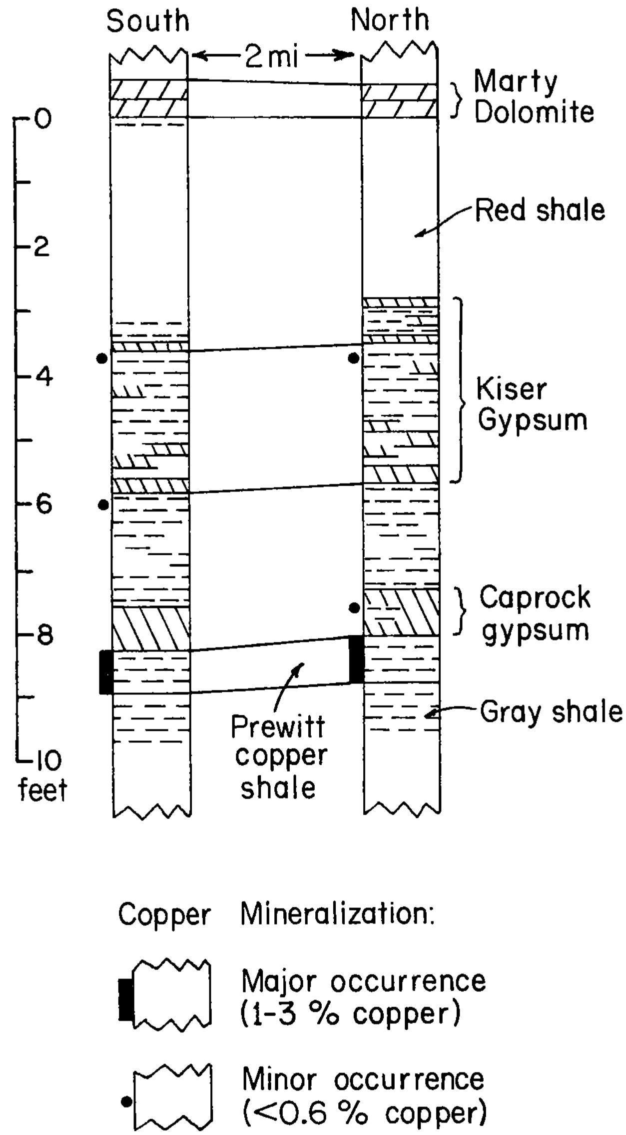

Figure 32. Detailed stratigraphic sections from Eagle-Picher Industries' north and south pits at the Creta copper mine.

Thin-section study reveals that the ore bed consists mostly of microcrystalline clay minerals. Quartz grains, chiefly 10 to 40 microns in diameter, make up 10 to 20 percent of most of the samples. Much of the quartz floats in a clay matrix. According to Lockwood (1972, appendix 5), the laminated and blocky parts of the ore contain an average of the following mineral components: quartz (17 percent in laminated shale and 26 percent in blocky shale), gypsum (28 and 3 percent), illite (45 and 63 percent), chlorite (5 and 6 percent), and chalcocite (4 and 2 percent).

Copper minerals in the Creta deposit are chalcocite (Cu_2S), malachite ($CuCO_3 \cdot Cu(OH)_2$), and brochantite ($CuSO_4 \cdot 3Cu(OH)_2$). Chalcocite, the primary ore mineral, occurs mainly as small grains (commonly 2 to 20 microns) disseminated in the shale. Grains are also concentrated in some silt laminae in the upper part of the bed, and they also are concentrated in thin veins and fill small vugs in the blocky part of the bed. As seen in thin section, many of the grains have a cubiform outline and presumably are pseudomorphs after pyrite. Malachite and brochantite are oxidation products found on the outcrop and where the overburden is less than 10 feet: malachite occurs as films and granules, and brochantite occurs with malachite in nodules locally present on the outcrop.

Strata dip gently westward at 10 to 20 feet per mile, and there are no structural features in the area believed to be related to the ore body. Furthermore, there is no evidence of igneous or hydrothermal activity anywhere in the area after deposition of the Flowerpot Formation. The host shales apparently were deposited in a brackish-water or shallow-marine environment, and syngenetic or early diage-

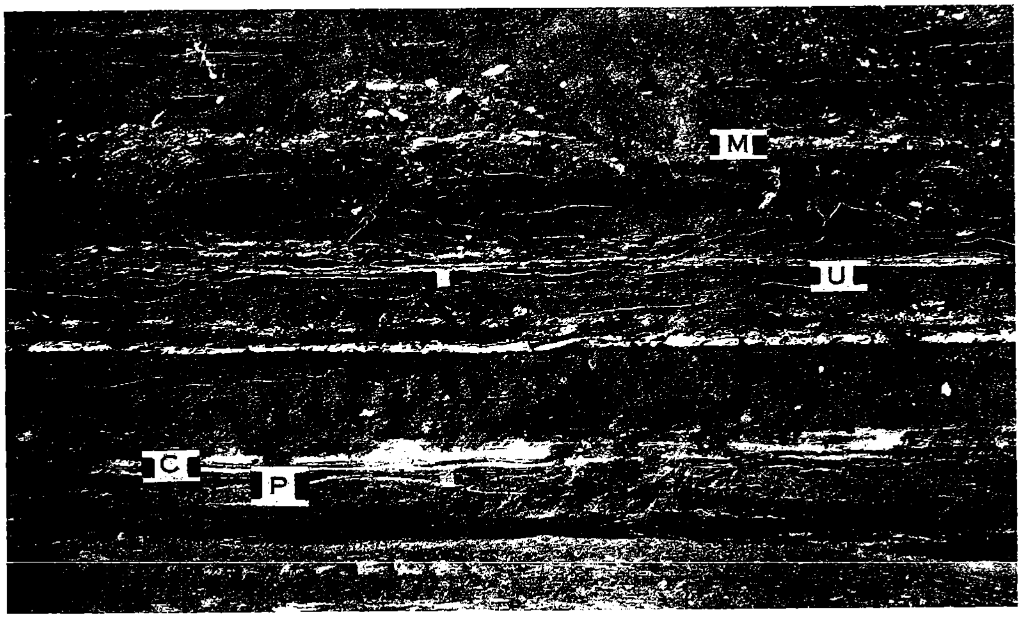

Figure 33. View of lower part of highwall in north pit, showing Prewitt copper shale (P), caprock gypsum (C), "upper copper shale" (U), and Marty Dolomite (M).

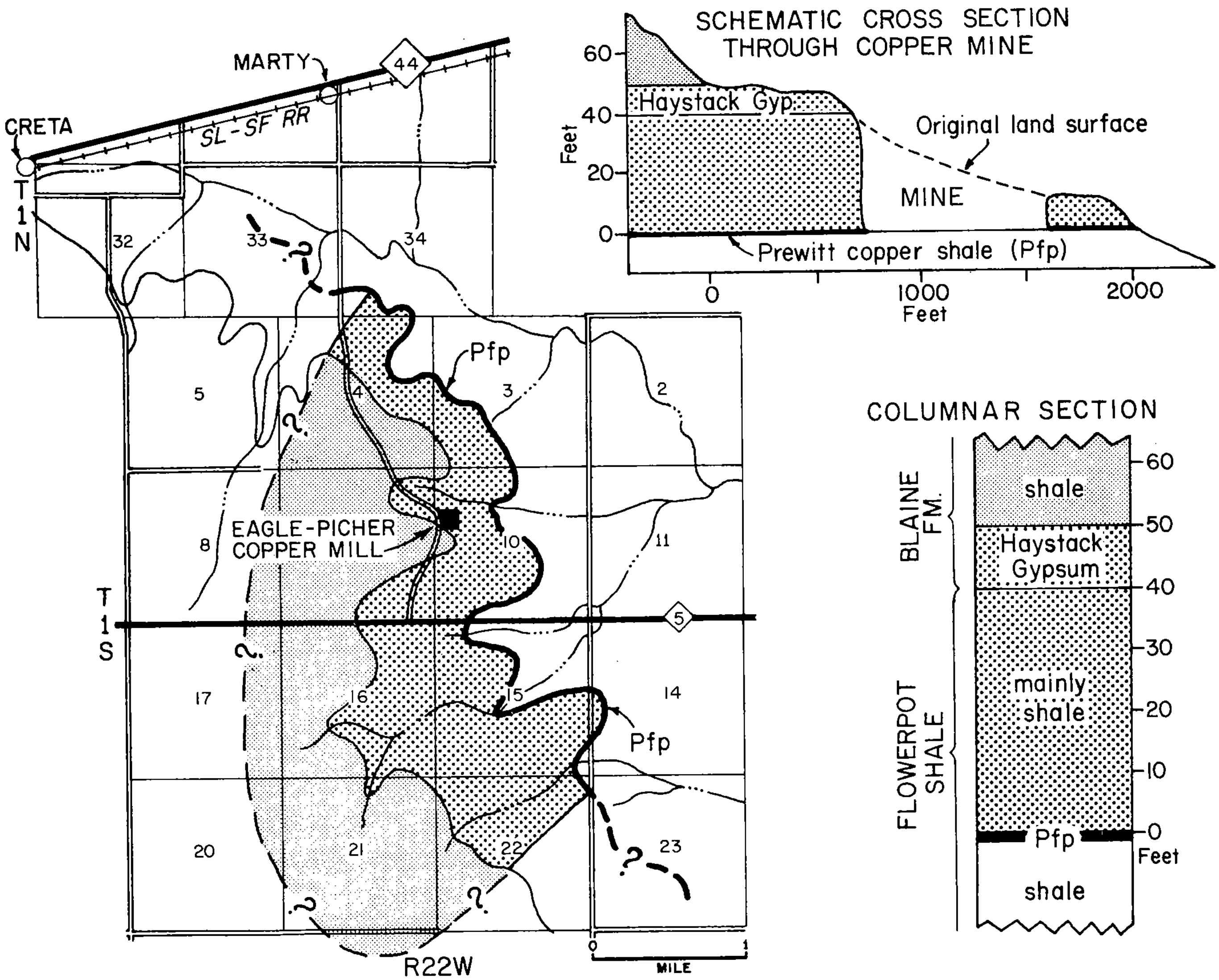

Figure 34. Schematic map, cross section, and columnar section showing principal features of Prewitt copper shale and overlying rock units in Eagle-Picher Industries' mine at Creta. Map shows areas where ore bed has shale and gypsum overburden of 0-50 feet (dense stipple) and greater than 50 feet (light stipple).

netic copper mineralization may have occurred by replacement of pyrite.

Overburden, ranging from 10 to 60 feet thick, is drilled and blasted using ammonium nitrate and then is removed by three draglines with 13-, 13-, and 26-cubic-yard buckets (fig. 35). This stripping removes the overburden from the surface to the top of the "cap gyp" which is 0.5-1.0 foot of massive rock gypsum immediately above the ore bed. Bulldozers rip and front-end loaders then remove the cap gypsum in large slabs, thereby exposing the top of the ore. The ore bed is then drilled and sampled to establish the precise thickness of minable shale. The copper shale is planed off at a minus-2-inch size by a modified form of pulvimixer which can be adjusted to make a precise depth of cut.

The 1,000-ton-per-day mill is designed to recover sulfide minerals and a portion of the nonsulfide minerals by flotation. Ore entering the mill passes through a jaw-crusher and hammer mill and then is ground in ball mills to minus-325 mesh. Flotation reagents are added and the slurry goes through rougher and cleaner flotation cells. About 90 percent of the chalcocite is recovered, and concentrates—containing about 45 percent copper—are trucked 3 miles and loaded into open gondolas for rail shipment to a smelter in El Paso, Texas.

SNOOZE · E · E · E · E · E · E · E · E · E · E · E · E · E · E · E · E · E · E · TIME

It's a long ride to Dallas, so break out the beer or take a long nap.

Figure 35. Oblique aerial photograph of Eagle-Picher Industries' copper-shale strip mine at Creta. Highwall here is 40 feet high and is capped by wide bench of Haystack Gypsum (white).

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