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OKLAHOMA GEOLOGY NOTES

OKLAHOMA GEOLOGICAL SURVEY, THE UNIVERSITY OF OKLAHOMA

On the cover—

Photomicrograph of Saddle Mountain Granite

The photomicrograph on the front cover is a crossed-nicols view of the Saddle Mountain granite (specimen W055) from the Wichita Granite Group of Middle Cambrian age (NE¼ SW¼ sec. 1, T. 4 N., R. 15 W.). Photo width approximates 1.7 mm in the thin section. The Saddle Mountain is a fascinating unit because it changes character continuously from an extrusive rock (spherulitic rhyolite) in the north to an intrusive rock (granophyric granite) in the south. This sample has textures appropriate to its transitional character.

Approximately centered in the photomicrograph is a pseudophenocryst of "granophyre," co-precipitated quartz (single crystal) and alkali feldspar (single crystal). The "crystal's" morphology is determined by the alkali feldspar. Several growth stages can be discerned, with the later additions of more quartz and feldspar continuing the interpenetrating web of the two original single crystals. The pseudophenocryst probably grew initially close to the solidus, as the body quenched rapidly, with later growth from surrounding glass (now completely devitrified). Feldspar is at extinction, forming the black areas in the center of the photo, while quartz forms the white areas. Surrounding the pseudophenocryst are other granophyric growths and quartz phenocrysts.

See the article by Myers, Gilbert, and Loiselle in this issue for more information.

M. C. Gilbert

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Short articles on aspects of Oklahoma geology are welcome from contributors. A set of guidelines will be forwarded on request.

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Contents

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GEOCHEMISTRY OF THE CAMBRIAN WICHITA GRANITE GROUP AND REVISIONS OF ITS LITHOSTRATIGRAPHY

J. D. Myers,[1] M. C. Gilbert,[2] and M. C. Loiselle[3]

Abstract—The formations within the Wichita Granite Group are provisionally revised from five units—Mount Scott, Headquarters, Reformatory, Lugert, and Quanah—to a new total of 10, with acceptance of these previously used names: Saddle Mountain, Medicine Park, and Cache in the east, and Cooperton and Long Mountain in the west. Field studies and a detailed consideration of their individual chemical compositions led to this assignment. New bulk-rock analyses, by X-ray fluorescence, including determination of Rb and Sr, when combined with previously completed wet chemical analyses, provide characterization of each unit. Comparison of the newer analyses with the older shows good agreement, so that the total data set can be used with some confidence. Wichita granites can be divided into three chemical classes: Mount Scott, Reformatory, and Mountain Park, with possible significance as to source. All these granites belong to the A type of Loiselle and Wones (1979).

Introduction

The Wichita Mountains of southwestern Oklahoma are the surface expression of a larger basement of intrusive and extrusive, mafic to silicic igneous rocks. The province is anomalous because at least the silicic rocks are Middle Cambrian in age, the youngest basement known between the Appalachians and the Rockies. Within the Wichitas there are three profound unconformities. The oldest truncates the gabbros and is the surface on which the rhyolites poured out and along which the granites intruded. Estimates of the duration of this interval range from 10 m.y. to 900 m.y. The second unconformity truncates the rhyolites and is the surface upon which a discontinuous sedimentary sequence of Upper Cambrian through Mississippian units was deposited. The final major unconformity represents Pennsylvanian uplift, significant erosion exposing units as low as the substrate gabbros, and final covering by Permian sediments eroded from the Ouachita Mountains. Figure 1 is a simplified, diagrammatic picture of the igneous relations in the Wichitas. The earliest unconformity runs approximately through the middle of the figure, separating gabbros from granites and rhyolites, while the second is the land surface. The purpose of

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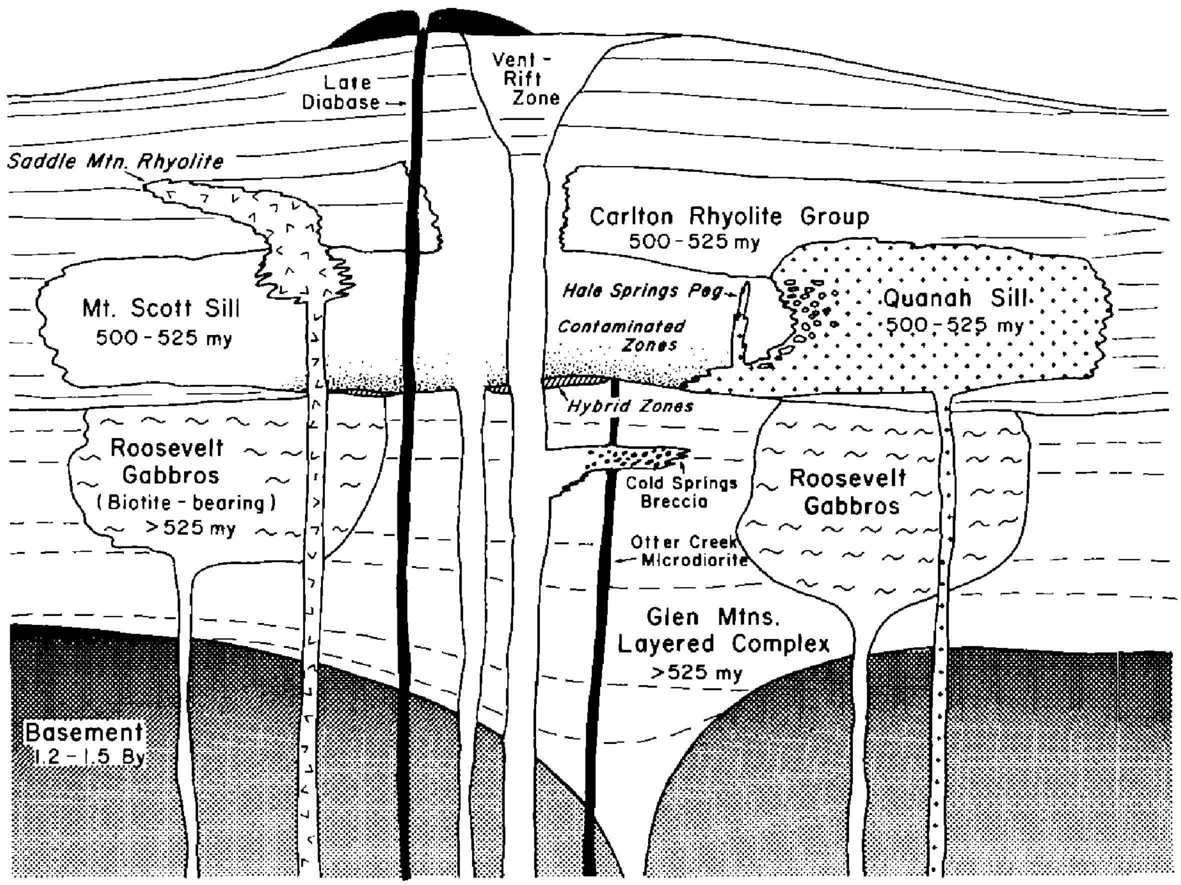

Figure 1. Diagrammatic presentation of igneous relations at close of Middle Cambrian volcanism. Raggedy Mountain Gabbro Group of uncertain age is represented by older Glen Mountains Layered Complex and younger intrusive Roosevelt Gabbros (of which Mount Sheridan Gabbro is a member). These units were beveled by an unconformity onto which Carlton Rhyolite Group lavas were extruded. The same liquid(s) formed granite sills of Wichita Granite Group. Three of these are shown: older Mount Scott Granite; Saddle Mountain Granite with its extrusive "rhyolite" end; and Quanah Granite, also intruding Mount Scott. Hale Springs pegmatite is shown as an offshoot of Quanah into Mount Scott, but pegmatites also cut Sandy Creek Gabbro (Roosevelt Gabbros). Basal Mount Scott commonly has a zone of higher C.I. next to gabbros. Hybrid zones (e.g., leucogranogabbro) always occur along granite–gabbro contact. Diabase dikes cutting granites and rhyolites represent youngest igneous event.

this report is to discuss the chemistry of the Wichita Granite Group, represented in the figure by the Mount Scott and Quanah units, and to note nomenclature existing in the literature found useful in further discriminating the granitic units.

This effort is part of a larger program by Gilbert to compile a new geologic map of the Wichita Mountains for the Oklahoma Geological Survey (OGS). The lithostratigraphy of the major igneous groups was laid out by Ham and others in OGS Bulletin 95 in 1964. Revision of this stratigraphy, with special reference to the mafic rocks of the Raggedy Mountain Gabbro Group, was published recently by Powell and others (1980). The units exposed at the surface are shown in table 1. Because work was in progress at

TABLE 1.—LITHOSTRATIGRAPHIC CLASSIFICATION OF EXPOSED BASEMENT ROCKS OF WICHITA PROVINCE, OKLAHOMA[1]

Age (m.y.)	Group	Formation	Member	General lithology
?		diabase		Fine-grained diabase cutting Wichita Granite Group
514±10?		Cold Springs Breccia		Dark-gray microdiorite blocks in matrix of pink leucogranite; locally medium-gray quartz monzodiorite blocks in light gray granodiorite matrix
525±25	Wichita Granite Group	[2]Quanah Granite Lugert Granite Reformatory Granite Headquarters Granite Mount Scott Granite		Group typified by medium- to fine-grained alkali feldspar granites; granophyric texture sporadically distributed within the group
525±25	Carlton Rhyolite Group			Rhyolitic lavas interbedded with minor tuffs and agglomerates
?		Otter Creek Microdiorite		Fine-grained diorite and quartz diorite
514–527 ± 10			Glen Creek Gabbro	Medium-grained biotite-amphibole-bearing olivine gabbro
500–530 ± 30		Roosevelt Gabbros	Sandy Creek Gabbro	Medium-grained biotite amphibole-bearing gabbro ± olivine
			Mount Sheridan Gabbro	Medium-grained biotite gabbro locally fractionated to ferrogranodiorite

TABLE 1.—*Continued*

	Raggedy Mountain Gabbro Group		M Zone	Anorthosite, anorthositic gabbro, and troctolite with cumulus plagioclase augite, olivine
509–730 1,300–1,500		Glen Mountains Layered Complex	L Zone	Anorthositic gabbro with minor troctolite; coarse-ophitic augite; cumulus plagioclase, and olivine
			K Zone	Alternating bands of anorthosite and troctolite; cumulus plagioclase, olivine
			G Zone	Troctolite and olivine gabbro; medium grained; cumulus plagioclase olivine
?	Tillman Metasedimentary Group	Meers Quartzite		Metaquartzite with microcline and sillimanite; inclusions in rocks of Raggedy Mountain Gabbro Group *and* Wichita Granite Group

[1] Relative ages shown with oldest unit at bottom. Uncertainties in relative and absolute ages are discussed in Powell and others (1980).
[2] Formations of Wichita Granite Group—currently being revised.

the time of this last report, no changes were made in the silicic intrusive rocks of the Wichita Granite Group. The granite lithostratigraphy employed here will be formalized in a later publication.

Besides field relations and petrographic characteristics, the current study includes examination of the chemical composition of the granitic rocks. Owing to limited outcrops and overall gross similarity of many of the granites, chemical data were required to clarify the named units and to aid in understanding granite petrogenesis. These new data, combined with selected older, high-quality analyses, have yielded interesting and useful results. Because the chemical differences between and among the granitic units are small, analyses of high precision are required. Therefore, this report reviews sample selection as well as preparation and analytical procedures. These new analyses were generated by X-ray-fluorescence (XRF) methods.

An additional objective of this report is to compare the new data to older analyses of Wichita granites. The older analyses used for comparison were those: (1) supplied by C. A. Merritt, done by classical wet chemical methods and partly presented in Ham and others (1964), Merritt (1965), and Merritt (1958); (2) retrieved from the files of G. W. Chase, Oklahoma Geological Survey, also done by wet chemical methods and partly represented in the references above; (3) taken from Hamilton (1959), which were done in the laboratories of the U.S. Geological Survey, Denver; (4) provided by Gilbert, which were performed by David Foster in 1978 in the laboratory of the Oklahoma Geological Survey; and (5) taken from a few published sources of the early 1900's. These were utilized because they meet high standards of analysis, were generally well characterized, and could be closely located. Since data on granites and rhyolites from Adams (1977) and Hanson (1977), which were summarized in Hanson and Al-Shaieb (1980), are reconnaissance in nature, they are not used here.

Procedures

Sample selection.—Samples were selected on the basis of three criteria: regional importance, representative character, and freshness. The granitic outcrops of the Wichita Mountains consist of knobs projecting through Permian conglomerates and shales. Consequently, stratigraphic continuity does not exist over most of the region. Attempts to define and map granitic units on petrographic characteristics alone have met with limited success. To aid mapping and petrogenetic study, all major outcrop areas as well as outcrops that have figured prominently in the literature have been sampled. When samples were collected, care was taken to determine the degree of homogeneity of the exposure. Where two or more granitic types were recognizable, material representative of each variant was collected. Although road cuts, quarries, and prospect pits provided excellent opportunities to obtain unweathered samples, the granites are commonly reddish from pervasively disseminated, secondary hematite (Taylor, 1915). Despite this alteration, samples were chosen to minimize recent weathering effects.

Distinctly unusual rock compositions exist in the Wichitas (e.g., Huang, 1955) as well as zones where two clearly different rock chemistries have partially to wholly mixed (e.g., Cold Springs Breccia; see Powell and others, 1980). Many of these special occurrences are found at the regional gabbro–granite contact that crops out along the length of the mountains. Consequently, sampling near this contact and these special rock types must be selective if the primary igneous liquids are to be characterized.

As mentioned earlier, samples also were collected from outcrops that had been sampled and analyzed by earlier workers. Localities chosen for resampling had to meet the following criteria: (1) the locality described in the literature had to be easily identifiable, (2) analyses had to be of high quality, (3) a general petrographic description of the analyzed rock had to be available, and (4) an abundant supply of fresh sample could be collected. Localities meeting these requirements were used to provide comparison between the older analytical data and the new data described here.

Sample preparation.—Samples ranged in weight from 2 to 40 kg but averaged between 10 and 20 kg. Since crystal sizes were always $\leqslant$1 cm and generally 1–5 mm, this size was adequate to provide a representative sample. The material was broken into fist-sized chunks by sledge, and pieces with weathered surfaces removed. Further sample-size reduction was obtained by passing the rock through a steel-jaw crusher (~1–1½ inches). This coarse material was passed through a ¼-inch screen to remove fines and minimize the possibility of iron contamination. A 100-g split was powdered in a tungsten carbide shatterbox. To eliminate possible contamination, this powder was discarded. A final powder was obtained by grinding 200–500 g of coarse material in the precontaminated shatterbox for 10 to 15 minutes. On other samples checked, more than 98 percent (by weight) of this final powder passed −200 mesh (M. C. Loiselle, oral communication, 1981).

Glass disks for major element analysis (except Na_2O) were prepared following the technique described by Norrish and Hutton (1969) and modified by Harvey and others (1973). (For a detailed description of the procedure, see Loiselle, 1980.) Approximately 1 g of sample was fused with 5 g of spectroflux 105 (a commercial flux described in Harvey and others, 1973) and 0.1 g of $LiNO_3$ (as an oxidant) in platinum crucibles for 10 to 40 minutes. Longer fusion times were required for the more siliceous samples. The molten liquid was cast in a 40-mm aluminum mold. The same procedure was followed for the calibration standards PCC-1, BCR-1, AGV-1, GSP-1, and G-2 (Flanagan, 1976), and a disk of 100 percent spectroscopically pure SiO_2.

Pressed powder pellets for Na_2O and trace-element analysis were made of 3 g of rock powder and 0.3 g of impalpable boric acid (as an internal binder). The powder and boric acid were weighed out, mixed using a diamonite mortar and pestle, and pressed at 10 tons' pressure into a 25-mm pellet with a granular boric-acid backing. The same procedure was followed for standards.

Sample analysis.—Major-element analysis (except for Na_2O) of the fused glass disks followed the procedure for matrix corrections described by Norrish and Hutton (1969) and Harvey and others (1973). By using the same ratio of sample to flux as Norrish and Hutton (1969), matrix-correction factors in Norrish and Chappell (1977) could be used directly. Table 2 lists the operating conditions and estimates of accuracy (obtained from the standard calibration lines) and precision (based on duplicate analyses) for the procedure. Na_2O content was analyzed directly on pressed powders with no matrix corrections applied. Precision and accuracy (both ~3 percent) were within acceptable limits.

Rb and Sr content was analyzed on pressed powders. The 3-g sample size was selected to ensure that the pellet was sufficiently thick to be able to apply matrix-absorption corrections, using the technique of Reynolds (1963).

TABLE 2.—INSTRUMENTAL CONDITIONS AND ESTIMATES OF ACCURACY AND PRECISION FOR MAJOR ELEMENT ANALYSIS

Element	Analyzing crystal	kV	mA	Peak position (2_Θ)	Background offsets (2_Θ)[1]	Estimated accuracy (%)[2]	Estimated precision (%)[3]
SiO_2	PET	50	45	109.21		0.3	0.1
TiO_2	LIF200	40	20	86.14		1.9	±0.01
Al_2O_3	PET	50	45	145.13		0.7	0.5
Fe_2O_3	LIF200	50	20	57.52		1.2	1.0
[6]MnO	LIF200	50	30	62.97		1.9	±0.01
MgO	TLAP	50	45	45.17	+1.9 −1.1	3.6	[5]10–15
CaO	LIF200	40	20	113.09		0.4	1.1
[4]Na_2O	TLAP	50	45	55.10	+1.7 −1.7	3.0	3.0
K_2O	LIF200	40	30	136.69		2.1	0.3
P_2O_5	PET	50	45	89.57	+0.4 −0.5	1.9	±0.01
Sr	LIF200	90	30	*Mo X-ray tube* 25.15	+0.5 −0.5	2.0	2.0
Rb	LIF200	90	30	37.99	+0.7 −1.1	2.0	2.0

K_α lines for all elements used. Flow proportional counter was used for all determinations.

[1] Direct measurements of backgrounds were made for Na_2O, MgO, and P_2O_5. Background corrections for remaining elements were made during reduction of the raw data.

[2] Based on regression of USGS standards PCC-1, BCR-1, AGV-1, GSP-1, and G-2, and a disk of 100 percent spectroscopically pure SiO_2.

[3] Calculated from replicate analyses for SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, and K_α; for TiO_2, MnO, and P_2O_5 at these concentration levels, the precision is ±0.01 weight percent absolute. For Na_2O, see note 4.

[4] Na_2O analyzed on pressed powder pellets with no matrix corrections applied. Estimates of precision and accuracy from independent data (M. C. Loiselle, oral communication, 1981).

[5] Owing to the low concentration and count rate, the precision of the MgO analyses is poor and not well constrained.

[6] With an Al_2O_3 filter between the tube and sample to reduce Cr tube line interference.

Comparison with selected older data.—G. W. Chase, in the early 1950's, and C. A. Merritt, in the late 1950's, had a number of samples chemically analyzed at the then active Rock Analysis Laboratory, University of Minnesota, under the direction of S. S. Goldich. This laboratory was known for the high standards set in silicate-rock analysis. In addition, W. E. Hamilton secured four more analyses in the late 1950's from the U.S. Geological Survey analytical laboratories using rapid-rock methods. Although the samples from which these sets of analyses were obtained are not available, the localities from which the samples came are reasonably well described. Table 3 lists four of our XRF results (SQ, W936C, W743, W9108) alongside four corresponding wet chemical analyses (three of Merritt's, M-1, M-9, M-10; one of Hamilton's, WM-1). Although XRF data are known for precision for many elements over a considerable range of concentrations, extra effort is necessary to ensure accuracy of such data, or at least its comparability with data generated by other means. Thus, the comparison in table 3 serves two purposes: it tests rock homogeneity on the outcrop scale and, if the first is satisfied, ability of the XRF data to report concentrations compatible with the classic methods. Within these constraints, the two data sets are in good agreement.

TABLE 3.—COMPARISON OF ANALYSES

Wichita Granite Group								
Wt%	**SQ+**	**M–1**	**W936C+**	**M–9**	**W743+**	**WM–1**	**W9108+**	**M–10**
SiO_2	72.93	72.78	75.26	76.43	76.78	77.58	76.08	77.64
TiO_2	.41	.45	.15	.15	.13	.14	.13	.10
Al_2O_3	12.26	12.44	11.64	11.82	11.67	11.75	11.25	11.69
Fe_2O_3	3.65	2.31	2.00	1.86	1.71	.90	1.56	.93
FeO	—	1.53	—	.25	—	.07	—	.49
MnO	.07	.09	.03	.02	.00	.01	.03	.02
MgO	.41	.31	.15	.18	.00	.06	.14	.02
CaO	1.19	1.29	.29	.30	.34	.29	.34	.29
Na_2O	4.17	3.81	3.70	3.86	3.70	3.34	3.97	3.71
K_2O	4.31	4.32	4.43	4.67	5.03	5.32	4.67	4.75
P_2O_5	.08	.08	.00	.00	.00	.01	.01	.00
$H_2O(+)$		.16		.11		.20		.03
$H_2O(-)$		.00		.06		.07		.03
CO_2		.06		.12		.03		ND
F		.18						
LOI	.21		.36		.47		.46	

No symbol = wet chemical analysis.
+ = XRF analysis (VPI & SU); all iron is reported as FE_2O_3.
ND = no data.

Discussion of Results and Revised Lithostratigraphy of the Granites

Introduction

The Wichita igneous province, for data reporting and mapping purposes, can be subdivided into eastern and western provinces. Oklahoma Highway 54 is taken as the approximate north–south dividing line. Although the eastern province contains the largest expanse of igneous outcrop, most of the previously existing nomenclature originated in the far western parts of the mountains—e.g., Headquarters, Reformatory, and Lugert, where exposures are more scattered. Only the Quanah of Taylor's (1915) units was defined in the east. Merritt (1965) split the Mount Scott from the Lugert on the basis of comparison of petrographic characteristics between eastern and western outcrops. Other workers (Hoffman, 1930; Green, 1952; Hull, 1951; Hessa, 1964; Polk, 1948) introduced names that have been used informally but have not received wide acceptance. On the basis of these studies—plus Gilbert's new mapping that incorporates the unpublished work of Chase and of R. E. Denison, all for the Oklahoma Geological Survey—new units are being introduced and will be described more fully at a later date. A preliminary outline of these units by province, with a summary of the pertinent chemical data, is given in the brief discussion following (tables 4–7; fig. 2).

Eastern Province

Mount Scott Granite.—In 1965, Merritt formally named the Mount Scott by redesignation of those rocks in the eastern Wichitas formerly called Lugert. Analyses from two locations, one from atop Mount Scott (acquired from Chase) and one from the Ira Smith Quarry along Oklahoma Highway 49, were used in the definition. Texturally, these rocks are quite different; the Mount Scott sample contains approximately 70 percent granophyre, whereas the Ira Smith sample is non-micrographic. Despite this difference, these rocks have similar major-element chemistry. Another sample from Mount Scott (WM9, Hamilton, 1959) as well as one collected west of Mount Sheridan by Iddings (Clarke, 1910; Taylor, 1915) are chemically similar. In addition to sample SQ discussed earlier, we have analyzed five more rocks petrographically identified as the Mount Scott. All of these samples have chemistries similar to that originally defined as the Mount Scott (tables 4, 5). With these new data, we have more closely defined the areal extent of the Mount Scott granite (fig. 2). Although some outcrops have been reassigned, our results confirm Merritt's basic nomenclature.

This unit has two facies: facies A, which is the typical rock of variable granophyre content exposed widely over a distance of 55 km, from near the intersection of Oklahoma Highway 49 and U.S. Highway 177 on the

TABLE 4.—WICHITA GRANITE GROUP, PROVISIONAL LITHOSTRATIGRAPHIC UNITS—EASTERN PROVINCE, WICHITA MOUNTAINS, OKLAHOMA

Formation	Petrography	Type locality or reference	Age relations
Quanah	Facies C—Medium-grained, granophyric, biotite-bearing. Facies B—Fine-grained aplitic phase of A. Facies A—Typical, arfvedsonite-bearing, grain size ~ 10 mm.	Taylor (1915); Chase (1954) and Gilbert (1977–81, unpub.).	Cuts Mount Scott and Cache; youngest in east.
Cache	Granophyric microporphyry, grain size ≤ 1–2 mm, magnetite, very low C.I.	Green (1952) and Gilbert (1977–81, unpub.). See analyses W743, WM-1, tables 3 and 5. E. side of hill 1545′ SW SW SW-7-2N-13W.	Cut by Quanah. Relationship to Mount Scott unclear.
Medicine Park	Granophyric microporphyry, grain size ≤1–2 mm, magnetite, very low C.I., distinct purplish cast, pyroxene-bearing in places.	Denison (1973, 1977, unpub.). Gilbert (1977–81, unpub.). NE-18-3N-12W.	Appears to cut Mount Scott. Relationship to Cache and Quanah unclear.
Saddle Mountain	Gradational from spherulitic-porphyritic to granophyric-porphyritic; hornblende + biotite.	Hoffman (1930); Gilbert (1977–81, unpub.). SW-30-5N-14W to NE-7-4N-14W.	A possible differentiate of Mount Scott. Relations to other units unclear.
Mount Scott	Facies B—microgranite with C.I. as A but no ovoid feldspar; appears to underlie A. Facies A—Typical, variably granophyric porphyry with ovoid feldspar, primary plagioclase, hornblende, ≤2–4 mm, C.I. of 4 to 6.	Merritt (1965); Gilbert (1977–81, unpub.).	Appears to be oldest in east.

TABLE 5.—BULK-ROCK CHEMISTRY–WICHITA GRANITE GROUP—EASTERN PROVINCE, WICHITA MOUNTAINS, OKLAHOMA

Wt (%)	Mount Scott (10)# A	Saddle Mountain (2)	Medicine Park (1)	Cache (2)	Quanah (4) A
SiO_2	72.3 (1.3–.6)+	74.2 (.2)	75.5	77.2 (.4)	76.2 (.9–.5)
TiO_2	.44 (.05–.03)	.41 (.02)	.24	.14 (.01)	.16 (.05–.04)
Al_2O_3	12.3 (.4–.3)	12.6 (.25)	11.7	11.7 (.05)	11.8 (.2–.1)
*Fe_2O_3	3.9 (.4–.3)	3.0 (.25)	2.4	1.3 (.4)	2.4 (.6)
MnO	.08 (.02–.08)	.04 (.01)	.00	.01 (.01)	.02 (.01)
MgO	.31 (.22–.31)	.31 (.06)	.05	.03 (.03)	.03 (.06–.03)
CaO	1.2 (.2–.2)	.76 (.17)	.37	.32 (.03)	.23 (.12–.15)
Na_2O	3.8 (.4–.7)	3.7 (.2)	2.9	3.5 (.2)	4.0 (.4–.6)
K_2O	4.3 (.05–.07)	4.43 (.03)	4.6	5.18 (.15)	4.75 (.3–.4)
P_2O_5	.08 (.06–.02)	.07 (.01)	.01	.01 (.01)	.01 (.01)
H_2O/LOI^x	.34 (.3–.2)	.57 (.03)	.28	.34 (.14)	.56 (1.0–.4)
TOTAL	99.06	100.09	98.05	99.73	100.16
Sr, ppm	91 (9–7) [6]#	ND	35 [1]	7 [1]	9 (4) [2]
Rb, ppm	127 (8–11)	ND	140	231	169 (8)

Number of analyses averaged.

+ Range of values is average; if two values, first is positive variation, second is negative.

* Total Fe as Fe_2O_3.

^{x} H_2O + from the wet chemical analysis has been averaged with "loss on ignition" from the XRF data. These are not strictly comparable.

Analysis list

Mount Scott: SQ, W78, W738, W7248A, W992, W998, C196, M1, WM9, IMS.
Saddle Mountain: W7125, C246.
Medicine Park: W017.
Cache: W743, WM1.
Quanah: W984, W986, C193, C464.

east to the vicinity of Tom Steed Reservoir on the west; and facies B, less typical but underlying facies A in the vicinity of Mount Scott itself. Whether facies B is an early phase of the Mount Scott and later intruded by facies A, or whether B is a younger phase that intruded beneath the main mass (A), is still problematic. It may, in fact, eventually be correlated with some of the other finer grained granites. No chemistry is available for this unit.

The main phase, facies A, is remarkable for its consistent chemistry over the entire region. This is particularly evident in the SiO_2, TiO_2, CaO, and P_2O_5 contents. The Mount Scott is the only Wichita granite whose primary CaO content is greater than 1 wt percent. Petrographically, it is distinguished from the other Wichita granites by: (1) a higher color index (4–6

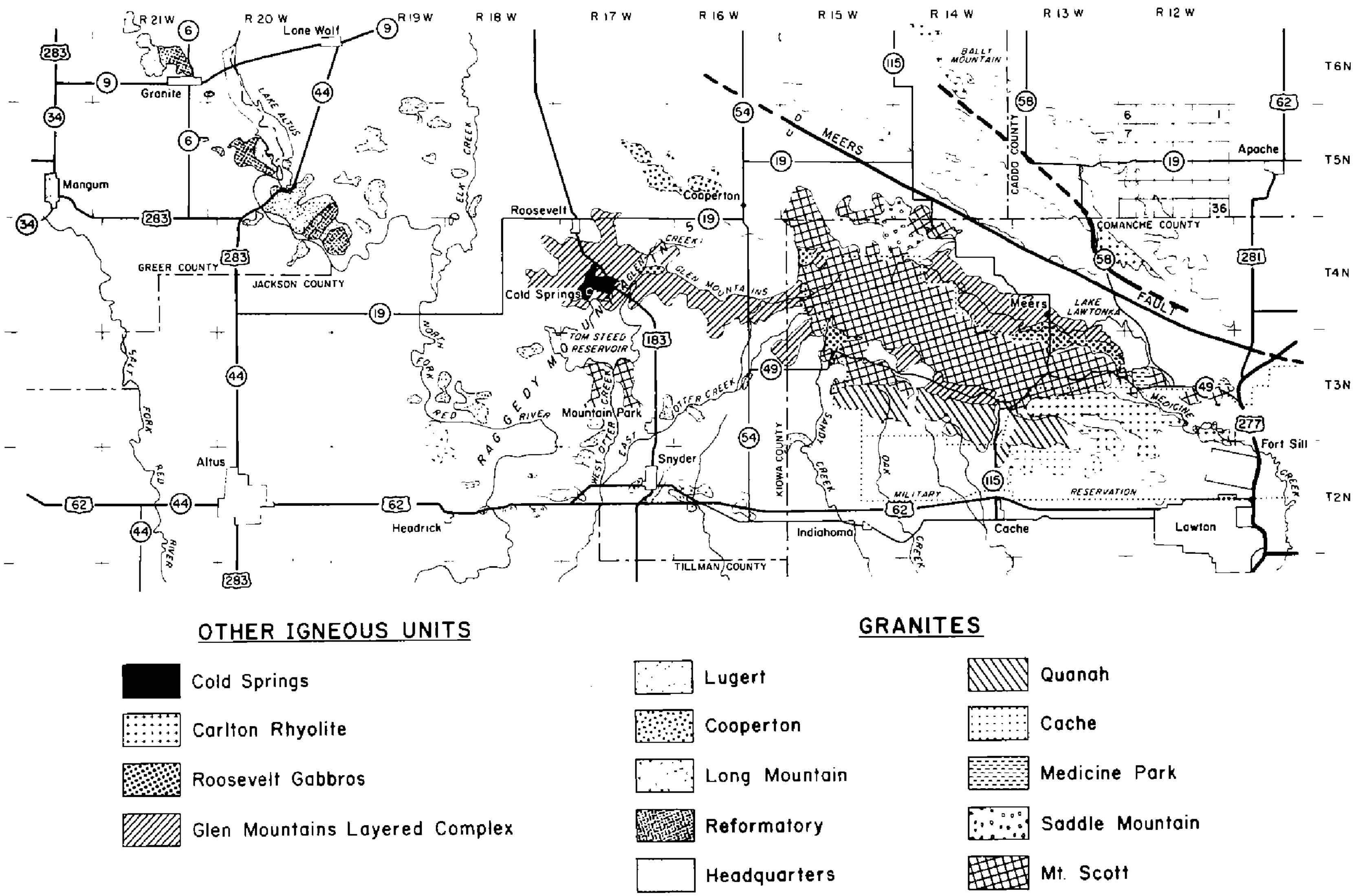

Figure 2. Map showing distribution of igneous units in Wichita Mountains with emphasis on lithostratigraphy of granites.

TABLE 6.—WICHITA GRANITE GROUP–PROVISIONAL LITHOSTRATIGRAPHIC UNITS—WESTERN PROVINCE, WICHITA MOUNTAINS, OKLAHOMA

Formation	Petrography	Type locality or reference	Age relations
Lugert	Facies B—Finer grained, variably granophyric, biotite more common than hornblende. Seems to be older than A. Facies A—Typical. Medium-grained, abundant inclusions ranging from basalt to meta-sedimentary; hornblende.	Merritt (1958); Denison (1977) and Gilbert (1977–81, unpub.).	All workers report it to be youngest granite in the west, but relations with newly defined units unclear.
Cooperton	Granophyric microporphyry with biotite dominant, low C.I.	Hull (1951); Merritt (1965, 1967); Gilbert (1977–81, unpub.).	Occupies isolated outcrops, so relative age not determined. Taylor (1915) originally called it Lugert, Merritt (1965) placed it with Mount Scott, but chemistry and petrography distinct. May be related to Saddle Mountain in eastern province.
Long Mountain	Highly granophyric microporphyry with hornblende dominant, low C.I.	Hessa (1964); Merritt (1965); Denison (1977) and Gilbert (1977–81, unpub.).	Taylor (1915) considered it part of Lugert. Merritt placed it with Mount Scott, but chemistry and petrography different. Cut by Lugert-A.

Reformatory	Facies B—Flat Top granite of Polk (1948). Arfvedsonite + hornblende characteristic. Facies A—Largest grain size of any Wichita granite (10–15 mm). Hornblende + biotite characteristic; non-micrographic. Inclusions of Headquarters common north of Granite.	Taylor (1915); Merritt (1958) and Gilbert (1977–81, unpub.).	Taylor did not recognize B and called it Lugert. Merritt (1958) combined B with Reformatory on the basis of Polk's (1948) work. A and B cut by Lugert.
Headquarters	Fine-grained (2–3 mm) equigranular granite with C.I. of 2–3, biotite-bearing.	Taylor (1915); Merritt (1958); Wasteneys (1962).	Cut by Reformatory. Once considered oldest Wichita granite. Merritt (1967) believed it to be second oldest. However, relations with Cooperton, Long Mountain, and Mount Scott unclear.
Mount Scott	Character as in table 4.	Merritt (1965); Denison (1977) and Gilbert (1977–81, unpub.).	Westernmost verified exposures in vicinity of Tom Steed Reservoir. Lugert and possibly Long Mountain cut Mount Scott.

TABLE 7.—BULK-ROCK CHEMISTRY–WICHITA GRANITE GROUP—WESTERN PROVINCE, WICHITA MOUNTAINS, OKLAHOMA

	Headquarters (2)#	Reformatory		Long Mountain (4)	Cooperton (5)	Lugert	
Wt (%)		A (3)	B (1)			A (6)	B (6)
SiO_2	+76.0 (.3)	74.3 (.2–.1)	75.9	75.0 (1.4–1.0)	75.0 (.5–.4)	73.6 (2.1–1.9)	76.9 (.7–.4)
TiO_2	.19 (.04)	.26 (.03)	.19	.19 (.05–.04)	.24 (.01)	.24 (.10–.08)	.13 (.10–.05)
Al_2O_3	12.4 (.2)	12.7 (.3–.4)	12.7	11.9 (.2–.3)	12.2 (.5–.2)	12.6 (.8–.7)	12.0 (.4–.3)
*Fe_2O_3	1.4 (.04)	2.3 (.1–.2)	1.6	2.3 (.3–.3)	2.3 (.1)	2.5 (1.5–1.1)	1.5 (.5–.25)
MnO	.03 (.0)	.03 (.01)	.02	.03 (.01)	.03 (.01)	.04 (.03–.02)	.02 (.01)
MgO	.21 (.06)	.19 (.13–.19)	.02	.20 (.05)	.10 (.06–.04)	.19 (.13–.11)	.09 (.08–.06)
CaO	.45 (.01)	.47 (.01–.02)	.03	.39 (.12–.10)	.28 (.20)	.39 (.40–.12)	.34 (.17–.23)
Na_2O	3.7 (.1)	4.2 (.4–.2)	4.2	3.7 (.2–.3)	4.3 (.6)	3.6 (.7–.6)	3.8 (.4)
K_2O	4.9 (.1)	5.1 (.2–.1)	4.8	4.6 (.15–.17)	4.32 (.11–.15)	4.9 (.45–.75)	4.9 (.56–.59)
P_2O_5	.03 (.1)	.01 (.01)	.00	.01 (.01)	.02 (.01)	.01 (.03–.01)	.01 (.01)
×H_2O/LOI	.18 (.2)	.33 (.43–.33)	.12	.57 (.45–.46)	.18 (.11–.05)	.44 (.56–.30)	.20 (.19–.17)
TOTAL	99.49	99.89	99.58	98.89	98.97	98.51	99.89
Sr, ppm	#5 [1]	44 [1]	ND	38 (16–26) [3]	52 (7–10) [4]	30 (47–22) [4]	54 (51) [2]
Rb, ppm	195	144	ND	142 (16–23)	115 (13–14)	120 (22–16)	174 (16)

Number of analyses averaged.
+ Represents range of values in average; if two values, first is positive variation, second is negative.
* All Fe as Fe_2O_3.
× H_2O from the classical method has been averaged with "loss on ignition" from XRF data. These are not strictly comparable.

Analysis list

Headquarters: W7140A, M4.
Reformatory: *A*: W7140C, M5, TREF. *B*: M8.
Long Mountain: W936C, W9100, W9102A, M9.
Cooperton: W7132, W09A, W010, W012, CCOOP.
Lugert: *A*: W786, W7136D, W7186A+, W936B, W9101A, M6. *B*: W7136, W7188, C394, M10, WM24A, WM26.

percent); (2) gray, ovoid feldspars; (3) primary plagioclase; and (4) a mafic assemblage of hornblende and oxides.

Saddle Mountain.—This unit is being expanded somewhat beyond the original definition of Hoffman (1930). He applied the name to a peculiar spherulitic porphyry, bearing hornblende as the chief mafic mineral, whose typical outcrop was the W½ sec. 31, T. 5 N., R. 14 W., and sec. 36, T. 5 N., R. 15 W. Most workers have placed this in the Carlton Rhyolite Group. However, this unit can be traced in the field from one with extrusive petrographic characteristics gradually into one with intrusive character very similar to the Mount Scott itself. The analyses of table 5 show a TiO_2 content greater than 0.4 wt percent, also very much like the Mount Scott. Comparison of CaO and P_2O_5 contents among the granites suggests their close tie with the Mount Scott. It appears to be a differentiated arm of the Mount Scott that partially extruded up through the sill roof. It can be mapped as far south as sec. 7, T. 4 N., R. 14 W.

Medicine Park.—Denison (Johnson and Denison, 1973) informally referred to a granite finer grained than the Mount Scott in the Medicine Park area. Earlier mapping of W. E. Ham and Denison in 1959 (R. E. Denison, written communication, 1977) had shown its existence. The unit generally has a distinct purplish cast but a low color index (C.I.). Although the rock is represented only by one new analysis (table 5), it is sufficiently distinctive (the only member of the Wichita Granite Group with more than 1 percent normative corundum) to warrant report. Clear and detailed contact relations with the Mount Scott have not been seen. However, it is interpreted to intrude the Mount Scott, because the latter is commonly highly fractured near the contact.

Cache.—Green (1952) originally called the fine-grained granite in contact with the Quanah around the old Craterville Park area northeast of Cache the Cache granite. This unit did not seem sufficiently distinct to Merritt to warrant special designation. Our new analysis, plus that of Hamilton (1959), and Gilbert's mapping, confirm the Cache as a separate unit from the Mount Scott with which it had previously been lumped. The type area is in secs. 6–9, T. 2 N., R. 14 W., and especially along the approximately north–south Quanah–Cache contact across the hill whose altitude is 1,545 feet, (SE¼SE¼ sec. 12, T. 2 N., R. 14 W.). This is one of the most siliceous of the Wichita granites, also having a very low TiO_2 content and, along with the Medicine Park, having normative *or* exceeding *ab*.

As the Cache only contacts the Quanah, relations with the Mount Scott or the Medicine Park are problematic.

Quanah Granite.—Taylor (1915) was the first to recognize this unit in the southwestern part of the Wichita Mountains Wildlife Refuge. Facies A is the "normal" Quanah referred to in most previously published references. This unit is areally the most extensive and the only one for which we have good chemical data. Petrographically, the Quanah is similar to the Reformatory. Quanah alkali feldspars (~10 mm) are only slightly smaller and lie in a rough approximation to closest packing with the smaller quartz distributed in the interstices. Characteristic mafic phases are an alkali amphibole, generally called riebeckite, but better termed arfvedsonite, and (or) a sodic pyroxene, acmite. The occurrence of albite in this unit was noted by Merritt (1966) rimming the perthitic alkali feldspars. This is clearly subsolidus feldspar unmixing. Interestingly, while others have chosen to focus on the peralkalinity of this unit and to emphasize its differences from other Wichita granites, its fundamental chemistry is the same as most of the others. Its somewhat distinctive mineralogy is determined by the conditions of crystallization rather than chemistry. Over a 17-km exposure, this facies is rather homogeneous, as demonstrated in table 5. Huang (1958) also reported a few fayalite-bearing samples.

Facies B is sporadically distributed along the center trend of the overall outcrop. It may be a quenched, aplitic phase of facies A.

Facies C, where found, is near contacts with the Mount Scott and (or) Glen Mountains Layered Complex. Whether some contamination of the Quanah liquid by these other, preexisting units can account for this facies has not been determined. One analysis of Chase's reported in Ham and others (1964, table 10, GWC428) appears to be either of facies C or a mixed rock and is not included here. Merritt (1967) also chose not to include it in his characterization of the Quanah.

Western Province

Mount Scott.—This sill has the largest known extent of any of the Wichita granites. Facies A has a very distinctive chemistry and petrography, so that its characterization in the eastern province is also applicable in the west, at least as far as the Tom Steed Reservoir area. Facies B has not been identified, as yet, in the west. Contact relations, as first determined by Denison (1959, unpub.) and reported by Merritt (1967), show that the Mount Scott is intruded by at least one facies of the Lugert and probably also by the Long Mountain as well. This establishes the Mount Scott as one of the earlier granites throughout the Wichitas. Clearly, it also has the most distinctive and different chemistry of all the granites noted earlier, being specifically the lowest in SiO_2 content (~72 wt percent), and highest in TiO_2, Fe, MnO, MgO, P_2O_5, and CaO content (tables 5, 7).

Headquarters Granite.—This granite, occurring around the town of Granite in the far northwestern part of the Wichitas, was named the Headquarters (Taylor, 1915). The granite is characterized by grain sizes of ~3 mm, and biotite plus magnetite as mafic phases. Where porphyritic, the feldspars stand out in relief. Our analysis, plus the only previous analysis of the Headquarters (Wasteneys, 1962), is presented in table 7.

Taylor (1915), Merritt (1958, 1967), and Wasteneys (1962) showed that the Headquarters was intruded by the Reformatory. Many examples of the Headquarters engulfed in the Reformatory have been reported near the contact. However, inclusions of what appear to be Headquarters are found as far to the southeast as Snyder.

Chemically, this unit is interesting for having the highest normative *an* content (~2 percent) outside of the Mount Scott and the Saddle Mountain.

It is also very low in Fe content. These attributes, plus its characteristic biotite and uniform finer grain size, set it off from the other granites.

Reformatory Granite.—This granite, originally named by Taylor (1915), is the coarsest found in the Wichitas (10–15 mm alkali feldspars) and contains numerous, diverse inclusions. The observed inclusions consist of (1) Headquarters Granite, (2) Carlton rhyolite, (3) metasediments, and (4) mafic rocks. Gibson (1981) studied the metasedimentary inclusions from one quarry. The extent of the Reformatory was expanded by Merritt (1958) over that originally shown by Taylor.

We recognize two facies of this formation: facies A, near the town of Granite, is the typical coarse-grained member as defined originally by Taylor (1915); facies B is that rock labeled Flat Top granite by Polk (1948) and placed in the Reformatory by Merritt (1958). Both chemistry and petrography require some separate designation. Facies A is somewhat richer in Fe, Mg, and Ca, while facies B has 0.5 normative corundum. Facies A bears hornblende plus a lesser amount of biotite, while facies B carries alkali amphibole plus hornblende. Because facies A and B are not in contact, relative time relationships are unknown, except that the Lugert cuts both.

Long Mountain.—Hessa (1964) used this name informally for the granite found in and around Long Mountain, 4 miles west of Snyder (sec. 18, T. 2 N., R. 17 W., and sec. 13, T. 2 N., R. 18 W.). This unit is highly granophyric and is clearly cut by another granite, assumed to be the Lugert (e.g., in the Youngman Quarry of Navajoe Mountain), leading Merritt to believe it was actually a variant of the Mount Scott. Chemical analysis now shows this to be incorrect (tables 5, 7). The Long Mountain can be recognized as a petrographic (thus mappable) type extending from near the intersection of U.S. Highway 62 and Oklahoma Highway 54 west to the Navajoe Mountain area. Some aspects are similar to the Cooperton Granite, except that hornblende is typical for the Long Mountain and biotite for the Cooperton.

Cooperton.—Hull (1951) applied this name to granite composing the hills west of Cooperton. Taylor (1915) had placed these rocks with the Lugert, but Merritt (1965) felt they were more similar to the Mount Scott. No contacts between this unit and other granites have yet been identified. Again, both chemistry and petrography require a separate designation. These rocks are typified by biotite, while the Lugert (A) and the Mount Scott both contain hornblende. Four geographically separated XRF analyses gave similar results for SiO_2, Al_2O_3, TiO_2, and Fe_2O_3, but variable results for CaO, Na_2O, and K_2O (table 7).

Lugert Granite.—Taylor (1915) named this granite from outcrops near the original town of Lugert, which is now covered by Lake Altus. With time, this unit has been successively restricted in size. The original Mount Scott Granite was defined essentially as the Lugert east of U.S. Highway 183 (Merritt, 1965). Polk's (1948) Flat Top granite was taken from the former Lugert and added to the Reformatory by Merritt (1958). Merritt's (1958) description of the Lugert in the western Wichitas indicated that it was a heterogeneous unit consisting of a variety of petrographic types. This is best seen in the mafic-phase assemblages: magnetite plus either hornblende or biotite (Merritt, 1958). Our chemical work confirms this heterogeneity and provides a basis for further separation. Two facies are currently recognized: facies A, which is the "normal" Lugert as described by Merritt (1958), and facies B, which is generally the more granophyric but older. Both types can be seen in the road cut south of Quartz Mountain Lodge (SW¼ sec. 15, T. 5 N., R. 20 W.). The chemical variability of facies A is about a factor of two larger than any of the other named units. Mafic and sedimentary inclusions are common, so that differing amounts of mixing may be the cause. Consequently, meaningful characterization of the primary igneous liquid may be precluded.

It is particularly important that local field relations are evaluated when sampling the Lugert. For example, in the Quartz Mountain State Park highway exposure noted above, nominal Lugert contains two granitic facies. A published analysis and an unpublished analysis available for this locality do not agree. Our new analyses (of both facies) indicate that each of the earlier analyses was taken from a different facies.

Other Granitoid Rocks

Not all granitoid rocks of the Wichita Mountains are being included in this discussion of the Wichita Granite Group. Specifically, the following units will be treated separately: (1) Cold Springs Breccia, (2) coarse-grained intermediate rocks of the type called leucogranogabbro, and (3) contaminated rocks of the Wichita Granite Group. Since the purpose of this report is to characterize the pristine granite types, detailed discussion of these rocks is not warranted here. The presence of such rock types requires careful sample selection.

The Cold Springs Breccia was raised to formation rank by Powell and others (1980) and removed from the Wichita Granite Group. Stratigraphically, the breccia intrudes the Raggedy Mountain Gabbro Group and is never in contact with the granites. The Otter Creek Microdiorite is the mafic component of the Cold Springs Breccia (table 1). Compositionally, the breccia varies continuously from the microdiorite (basaltic in composition) to an ill-defined granitic component. This granitic component may or may not be related to the Wichita Granite Group.

Because the intermediate rocks (Huang, 1955) occur along the contact (unconformity) between the Wichita Granite Group and the Raggedy Mountain Gabbro Group, they are probably related to the Wichita Granite Group. Although of limited extent, these rocks can be mapped separately. This unusual group of rocks may be the result of interaction of the high-temperature granitic liquids (Gilbert, 1978) with the gabbroic saprolite along the unconformity. Consequently, their bulk composition is not of a primary igneous origin.

Contaminated rocks are really variants of the intermediate ones, except that they clearly belong to the granites. A number of localities yield outcrops of granitoids with a much higher C.I. and silica contents of around

67 wt percent. This is particularly true of the Mount Scott and Lugert Granites. In all cases, these outcrops can be shown to be near the base of the local granite unit and near the gabbroic substrate. The interpretation seems straightforward that such rocks were not crystallized directly from the primary granitic liquids forming the bulk of the defined units.

Chemical Classes

Myers and Gilbert (1980), in plotting variation diagrams, found that the granitic compositions fell into three natural SiO_2 groupings. These groupings not only are separated by gaps in SiO_2 content but are characterized by consistent internal chemistry and between two groups are offset in some oxide concentrations. Three chemical classes, summarized in table 8, were defined: (1) Mount Scott, (2) Reformatory, and (3) Mountain Park. A direct correlation between mapped unit and class exists for the Mount Scott, but the other classes contain several units mapped as different granite types. The Reformatory class includes facies A of the Reformatory Granite as well as other mapped granite types. The Mountain Park class, named for the small town in the south-central part of the Wichitas, includes granite rocks from such diverse units as the Headquarters and Quanah Granites as defined by earlier workers. These chemical classes are believed to be likely representatives of primary silicate liquids. Interestingly, this clustering can be seen in the earlier, limited data of Ham and others (1964, fig. 11). Comparison of CaO content from these older data with the present data set is shown in figure 3.

Myers and Gilbert (1980) noted a significant geographic control: the Mount Scott class is concentrated in the eastern Wichitas, the Reformatory

TABLE 8.—CHEMICAL SIGNATURE OF GRANITE CLASSES, WICHITA GRANITE GROUP

Oxide wt (%)/Class	Mount Scott	Reformatory	Mountain Park
SiO_2	71.0–73.6	73.8–74.7	75.0–77.6
TiO_2	>0.4	0.2–0.3	.1–.25
Fe_2O_3 (total Fe)	>3.5	1.8–2.7	1.2–2.6
MnO	>.07	0.02–0.05	0.00–0.04
CaO	1.0–1.5	0.3–0.7	0.1–0.6
K_2O	~4.3	4.2–5.3	4.1–5.5
P_2O_5	.08	.00–.02	.00–.01
*Rb (ppm)	127	127	174
Sr (ppm)	91	41	22

*Rb and Sr data revised from Gilbert and Myers (1981).

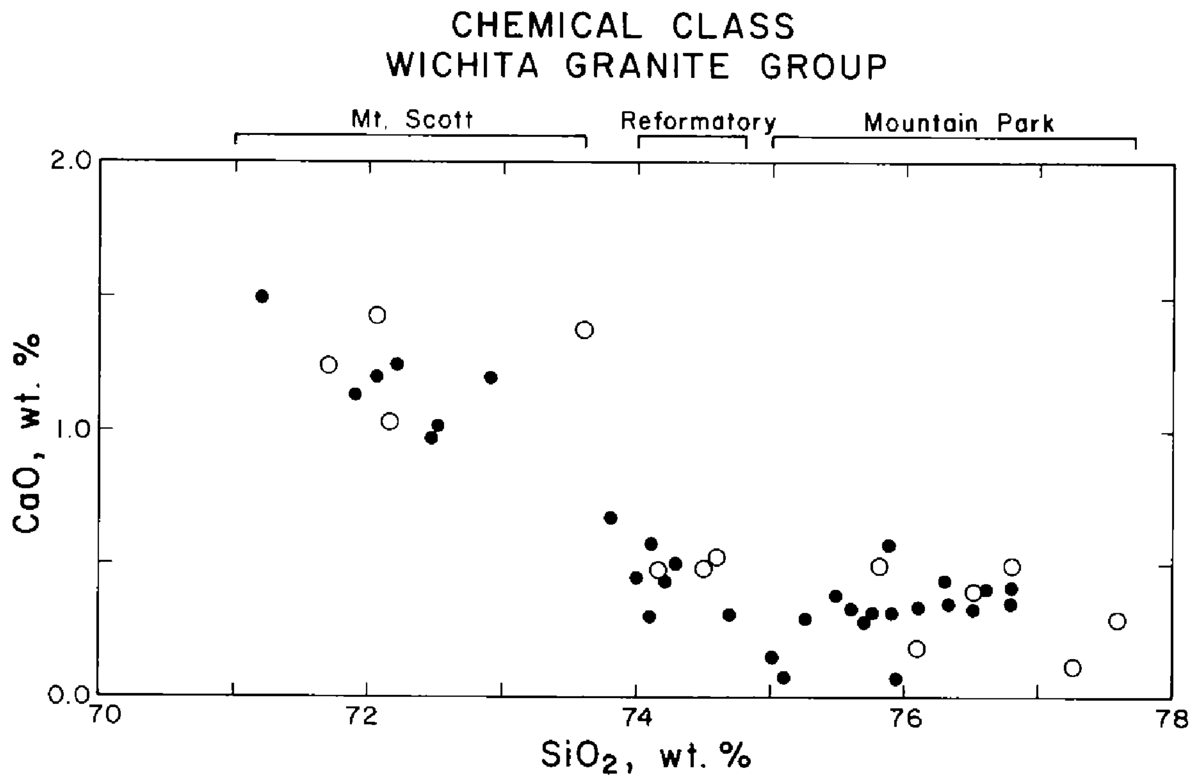

Figure 3. Harker variation diagram of CaO vs. SiO_2, illustrating three chemical classes found in Wichita Granite Group. Solid circles are new XRF analyses discussed in text. Open circles are older, high-quality wet-chemical analyses plotted in OGS Bulletin 95 (Ham and others, 1964, fig. 11).

class in the western, and the Mountain Park class along the whole length of exposures. Since rocks of presumably different relative age are included in these types, the magmatic-source regions must have been tapped periodically during emplacement.

Classification As A-Type Granites

Loiselle and Wones (1979) proposed the addition of A-type granites to the I and S granite-source classification of Chappell and White (1974). A-type granites, which are anhydrous, alkaline, and anorogenic, occur in crustal blocks with prior melting histories and commonly are associated with some form of alkalic basaltic volcanism. The Wichita Granite Group is marked by A-type characteristics (table 9), similar to granites of the Pikes Peak Batholith in Colorado (Barker and others, 1975) and the Wolf River Batholith of Wisconsin (Anderson and Cullers, 1978). The Wichita granites are also chemically and petrographically similar to the St. Francois Mountains granite suite of southeastern Missouri. The Oklahoma rocks are distinguished from these granites by their anomalous age—Middle Cambrian—and the special tectonic setting. Recognition of the Wichita granites

TABLE 9.—CHARACTERISTICS OF A-TYPE GRANITES

Index	Wichita Granite Group*
Low CaO	<0.5; <1.5 wt %
Low Al_2O_3	11.6–13.0 wt %
High Fe/(Fe + Mg)	.92–.98 (by wt)
High K_2O/Na_2O	1.1–1.5 (by wt)
High K_2O	4.2–5.3 wt %
Generally low f_{H_2O}	estimated ≤1 wt % H_2O in magma
High HF/H_2O	F-bearing alkali amphiboles
Enriched incompatible trace elements (REE, except Eu; Zr, Nb, Ta)	negative Eu-anomaly: Zircon-rich pegmatites; Zr, .03 wt %
Low in mafic trace elements (Co; Sc; Cr; Ni)	Co, Sc: <.0005 wt %
Low in "feldspar" trace elements (Ba, Sr, Eu)	Sr: 22–91 ppm
Initial $^{87}Sr/^{86}Sr$ 0.703–0.712	0.707 ± .001 (Johnson and Denison, 1973)

*Most common abundances.

as A-type leads to further intriguing implications to be dealt with more fully in later publications.

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STATISTICS IN OKLAHOMA'S PETROLEUM INDUSTRY, 1980

M. Lynn Prater[1]

Information for some of the figures has been taken from a new source. This has resulted in a few discrepancies that should be noted when using the figures.

Drilling activity in 1980 was the best in the history of the State of Oklahoma (table 1; fig. 1). Exploratory-test completions numbered 508 (up 5 percent), and development-well completions, 9,041 (up 42 percent). The completion-success ratio for both categories increased 41 percent for exploratory and 77 percent for development wells. The average development well in Oklahoma reached 4,498 feet (313 feet shallower than in 1979), whereas the average exploratory test was more than 500 feet deeper (7,886 feet) than in 1979.

Once again, Grady County, with 10 gas and three oil discoveries, had the best exploration record in the State. Pittsburg County, with 10 gas discoveries, was second in exploratory success. Seven counties, which had a total of 24 exploratory wells, had a most remarkable 100-percent exploration success ratio. These counties, with their total oil and gas exploratory

TABLE 1.—DRILLING ACTIVITY IN OKLAHOMA, 1980
(Source: OU Energy Resources Center and *World Oil*, v. 192, no. 3, Feb. 15, 1981)

	1980				1979
	Oil	**Gas**	**Dry**	**Total**	**Total**
All wells					
Number of wells	4,692	2,063	2,286	9,041	6,347
Total footage				42,387,671	31,771,376
Average footage				4,688	5,006
Exploratory wells					
Number of completions	92	114	302	508	484
Percentage of completions				41	37
Total footage				4,006,094	3,567,157
Average footage				7,886	7,370
Development wells					
Number of completions	4,600	1,949	1,984	8,533	5,863
Percentage of completions				77	73
Total footage				38,381,577	28,204,219
Average footage				4,498	4,811

[1] Geologist, Oklahoma Geological Survey.

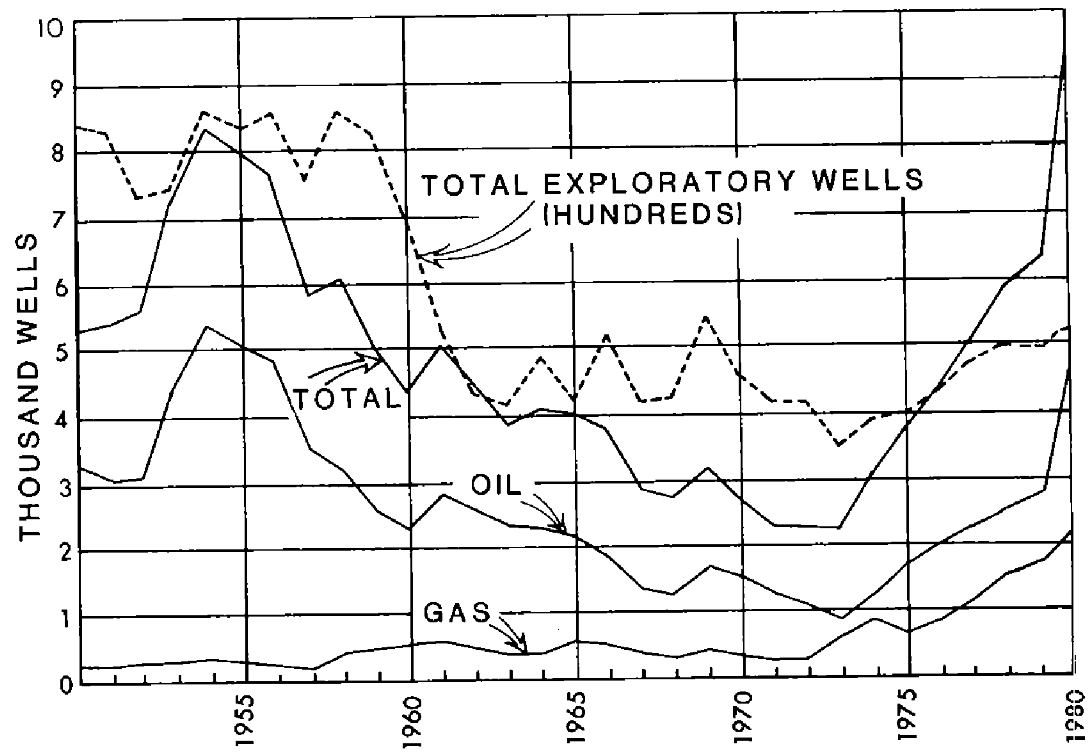

Figure 1. Graph showing total wells drilled, oil wells completed, and gas wells completed in Oklahoma, 1950–80. (Source: OU Energy Resources Center.)

completions, are Blaine (three), Canadian (seven), Craig (one), Hughes (four), Kingfisher (seven), Latimer (one), and Major (one). Canadian County exceeded all other counties in footage drilled, closing the year with a total of 3,631,048 feet (an increase of 1,262,708 feet from 1979). Kingfisher County was second in total footage drilled, with 3,033,754 feet (an amazing increase of 1,727,853 feet). Nine other counties attained totals greater than 1 million feet. As seen in table 2, 10 tests were drilled deeper than 20,000 feet. More than half of the tests (61 percent) were drilled to less than 5,000 feet, and 91 percent penetrated to less than 10,000 feet.

Figure 2 depicts the maximum 1980 drilling depths, by county, for either development or exploratory tests in Oklahoma. The deepest drilling occurred in the west-central part of the State. The shallowest drilling occurred in the northeastern and southeastern corners of the State.

Figure 3 indicates the amount of oil produced in each county of Oklahoma. The south-central part of the State once again produced the greatest amount. Stephens and Carter Counties produced more than 15 million barrels of oil each in 1980.

Figure 4 shows, by county, the distribution of natural-gas production for the State. As in 1979, the Panhandle and the west-central part of Oklahoma produced the most natural gas during 1980. Texas County led the State again, having produced more than 155 billion cubic feet of natural gas.

World Oil (v. 192, no. 3, Feb. 15, 1981) attributed 93 percent of Oklahoma's 1980 wells to independent operators, as compared to 86.6 percent nationwide. Oklahoma was fourth highest in 1980 in independent-operator activity in states averaging more than 2,000 wells.

TABLE 2.—COMPLETION DATA AND DEPTH INFORMATION FOR WELLS DRILLED IN OKLAHOMA DURING 1980
(Source: OU Energy Resources Center)

County	Total Number of wells drilled	Completions Oil	Completions Gas	Percent completions (Oil and Gas)	Number of wells drilled in following total-depth ranges (in feet)[1] 1–5,000	5,000–10,000	10,000–15,000	15,000–20,000	20,000
Adair	1	0	0	0	1	—	—	—	—
Alfalfa	76	45	14	78	10	66	—	—	—
Atoka	3	0	1	33	2	—	1	—	—
Beaver	184	32	93	68	3	179	1	—	—
Beckham	43	2	29	72	10	2	6	24	1
Blaine	89	23	39	70	1	42	45	—	—
Bryan	5	1	1	40	1	4	—	—	—
Caddo	96	19	51	73	21	2	62	9	1
Canadian	372	201	153	95	—	198	171	—	—
Carter	140	109	3	80	73	50	7	1	—
Cherokee	—	—	—	—	—	—	—	—	—
Choctaw	1	0	0	0	1	—	—	—	—
Cimarron	40	9	14	58	28	12	—	—	—
Cleveland	57	31	—	54	—	53	2	—	—
Coal	15	1	3	27	9	6	—	—	—
Comanche	107	70	14	79	103	3	—	—	1
Cotton	51	31	2	65	50	1	—	—	—
Craig	69	9	20	42	69	—	—	—	—
Creek	366	237	30	73	364	—	—	—	—
Custer	61	8	35	70	—	—	49	10	1
Dewey	100	33	40	73	—	57	41	2	—
Ellis	74	9	49	78	—	38	35	1	—
Garfield	302	219	49	89	36	265	—	—	—
Garvin	152	96	11	70	74	66	11	—	—
Grady	139	38	68	76	26	17	81	11	—
Grant	63	15	10	40	27	36	—	—	—
Greer	14	0	0	0	14	—	—	—	—
Harmon	3	0	0	0	1	2	—	—	—
Harper	112	15	46	54	4	107	—	—	—
Haskell	55	0	32	58	9	42	4	—	—
Hughes	167	73	42	69	160	6	—	—	—
Jackson	6	2	0	33	4	2	—	—	—
Jefferson	29	16	1	59	23	6	—	—	—
Johnston	4	0	0	0	4	—	—	—	—
Kay	299	40	207	83	298	1	—	—	—
Kingfisher	365	295	63	98	2	342	18	—	—
Kiowa	41	19	3	54	38	2	—	—	—
Latimer	19	0	9	47	5	5	9	—	—
Le Flore	38	0	25	66	1	30	6	1	—

TABLE 2.—*Continued*

Lincoln	214	94	32	59	172	39	—	—	—
Logan	266	154	22	78	10	212	—	—	—
Love	48	44	1	94	14	28	—	—	—
McClain	56	33	0	59	9	36	9	—	—
McCurtain	—	—	—	—	—	—	—	—	—
McIntosh	84	0	40	48	83	1	—	—	—
Major	230	160	60	96	1	212	15	—	—
Marshall	23	10	5	65	7	14	—	1	—
Mayes	44	19	3	50	44	—	—	—	—
Murray	18	2	0	11	15	3	—	—	—
Muskogee	124	58	18	61	124	—	—	—	—
Noble	179	121	13	75	103	72	—	—	—
Nowata	402	291	79	92	401	—	—	—	—
Okfuskee	144	48	32	56	144	—	—	—	—
Oklahoma	40	13	4	43	—	40	—	—	—
Okmulgee	440	247	90	77	438	—	—	—	—
Osage	750	516	23	72	747	—	—	—	—
Pawnee	172	116	6	71	171	—	—	—	—
Payne	205	155	7	79	170	33	—	—	—
Pittsburg	89	0	60	67	39	41	9	—	—
Pontotoc	185	146	13	86	184	—	—	—	—
Pottawatomie	133	71	4	56	75	55	—	—	—
Pushmataha	1	0	0	0	1	—	—	—	—
Roger Mills	92	3	63	72	—	7	41	43	—
Rogers	163	71	54	77	162	1	—	—	—
Seminole	134	80	8	66	131	3	—	—	—
Sequoyah	11	0	3	27	2	9	—	—	—
Stephens	285	196	23	77	241	41	—	1	—
Texas	122	18	56	61	29	93	—	—	—
Tillman	14	5	0	36	3	11	—	—	—
Tulsa	141	95	16	79	141	—	—	—	—
Wagoner	41	18	3	51	41	—	—	—	—
Washington	265	177	63	91	265	—	—	—	—
Washita	28	2	17	68	—	3	6	12	7
Woods	86	13	36	57	—	84	—	—	—
Woodward	94	17	44	65	—	79	15	—	—
Totals	9,041	4,692	2,063	57.9	5,439	2,759	644	116	11
				(Avg.)	(61%)	(31%)	(7%)	(1%)	(0.15%)

[1]List does not include re-entry wells that have been drilled deeper.

Figure 5 illustrates the historical behavior of exploratory drilling and hydrocarbon wellhead prices in Oklahoma from 1955 through 1980. The drilling and discovery data are expressed as 5-year moving averages. Wellhead prices have been converted to 1967 dollars.

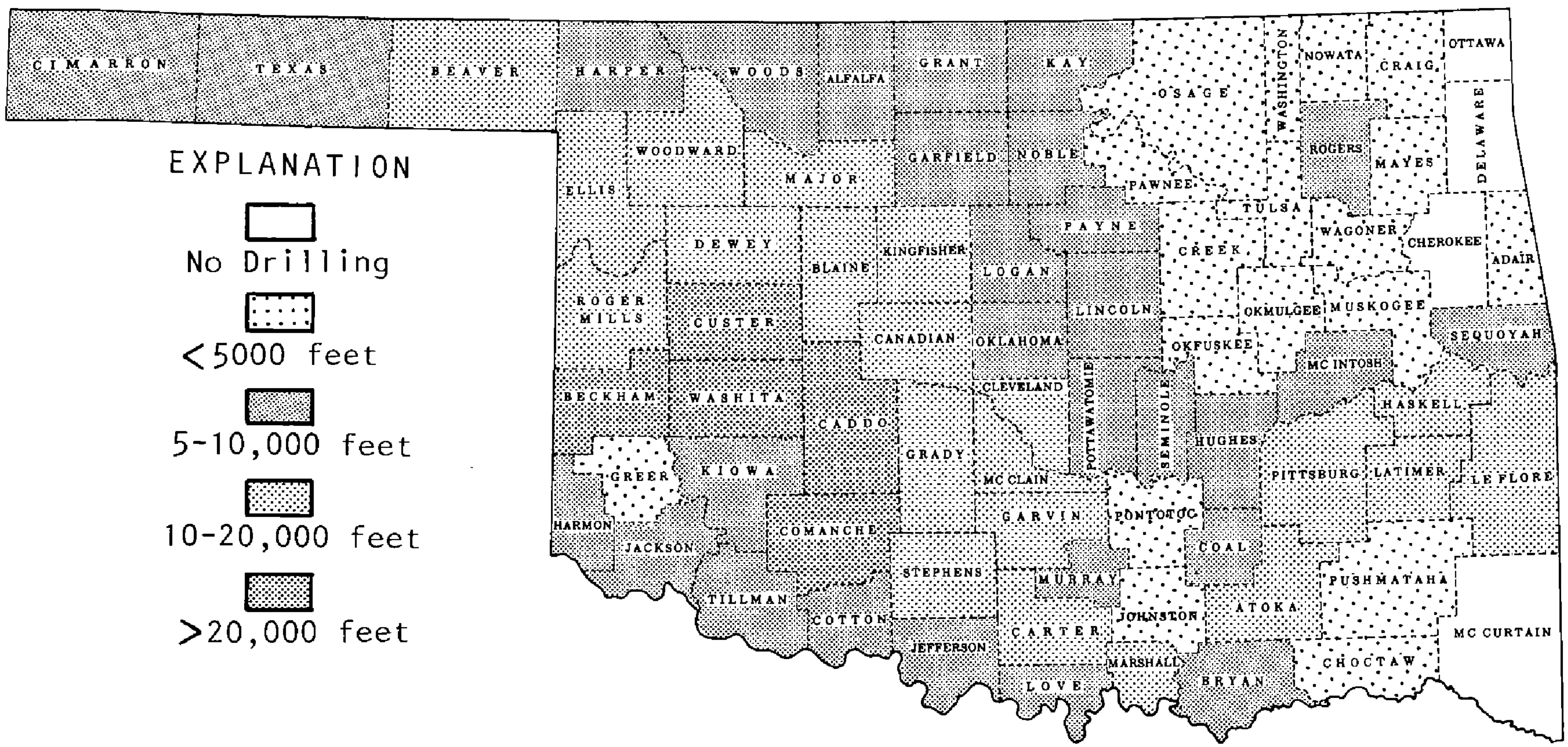

Figure 2. Map of Oklahoma indicating maximum depth range of 1980 development or exploratory drilling. (Source: OU Energy Resources Center.)

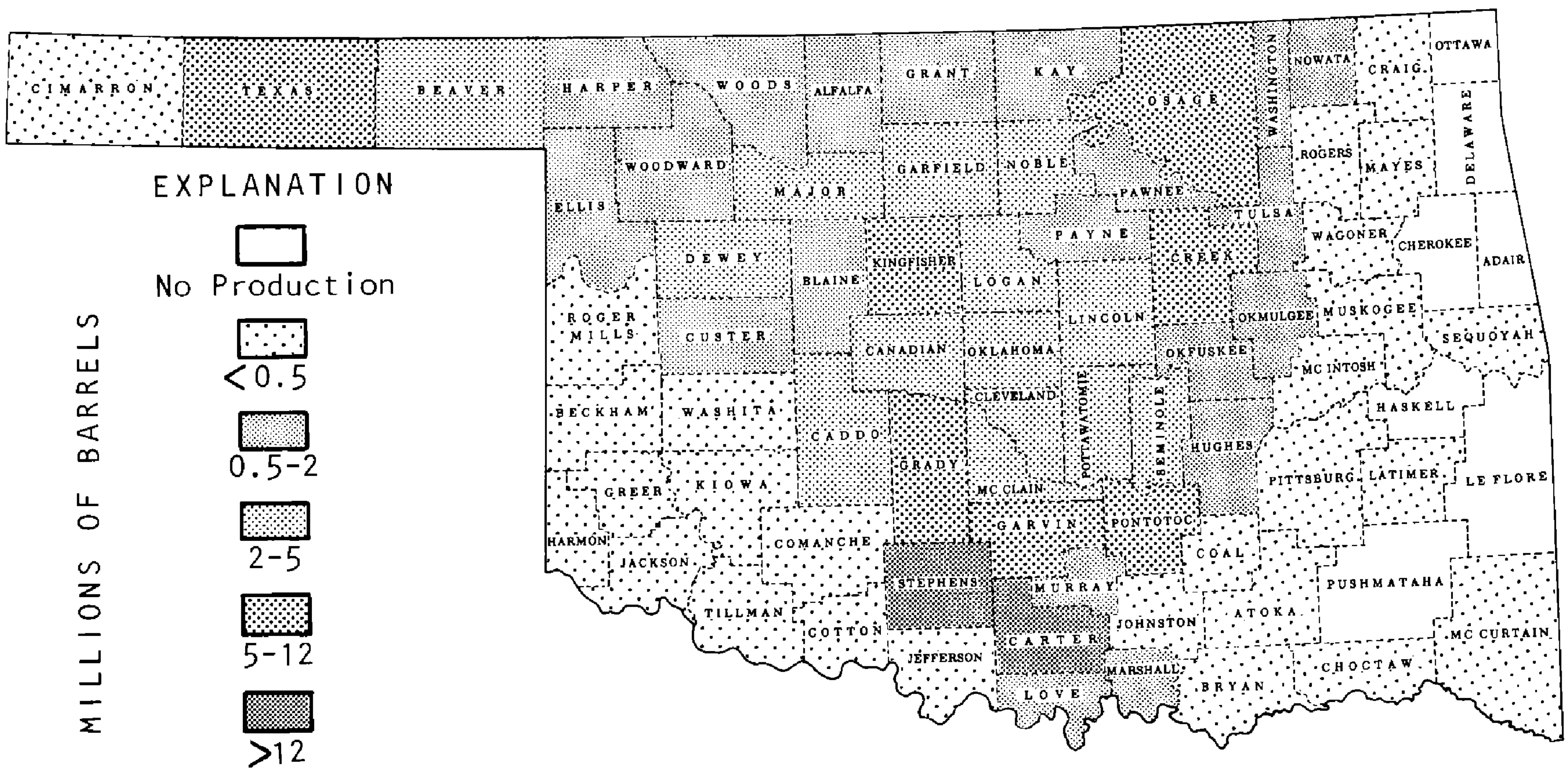

Figure 3. Map of Oklahoma depicting the barrels of oil for each county on which gross production tax was paid in 1980. (Source: Oklahoma Tax Commission.)

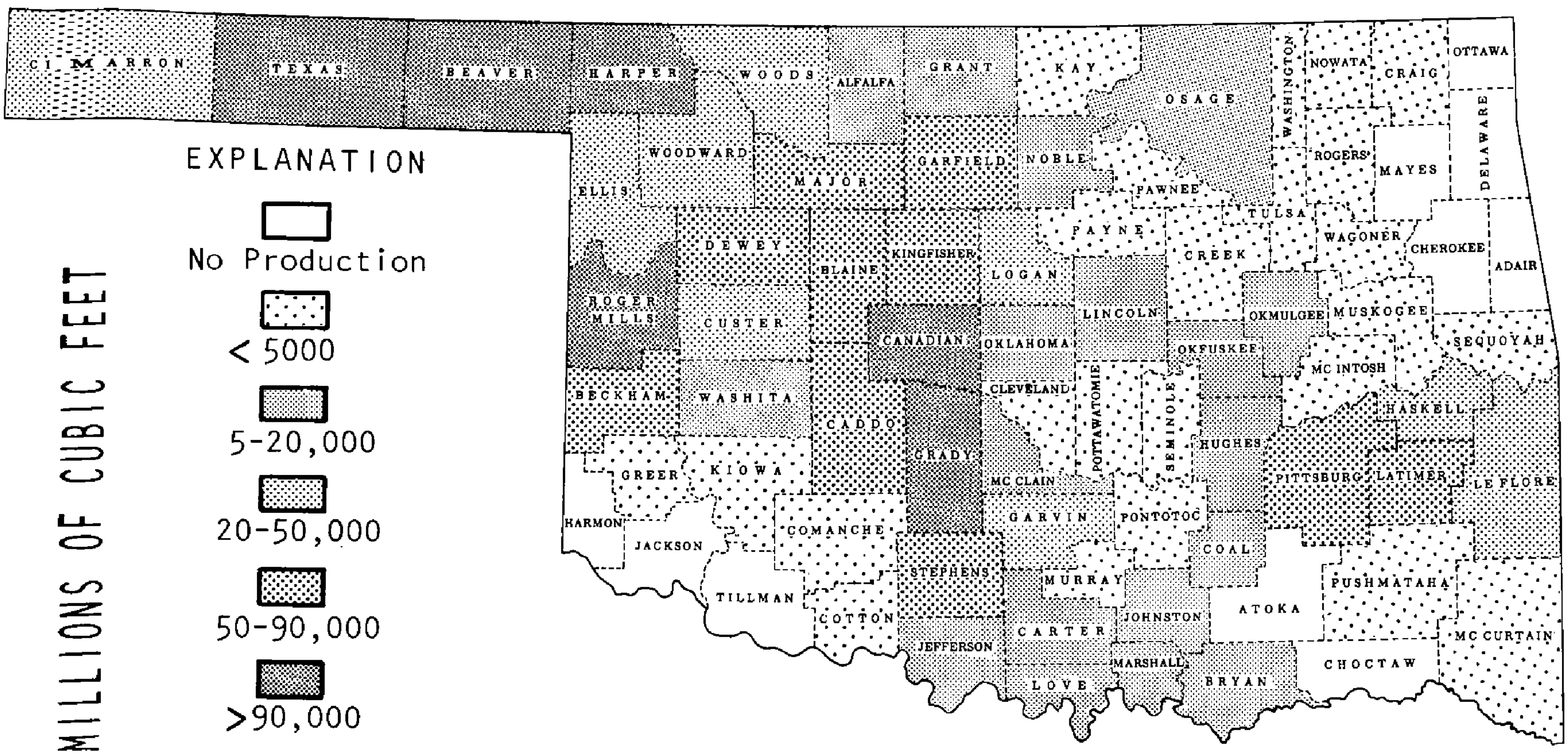

Figure 4. Map of Oklahoma depicting cubic feet of natural and casinghead gas on which gross production tax was paid in 1980. (Source: Oklahoma Tax Commission.)

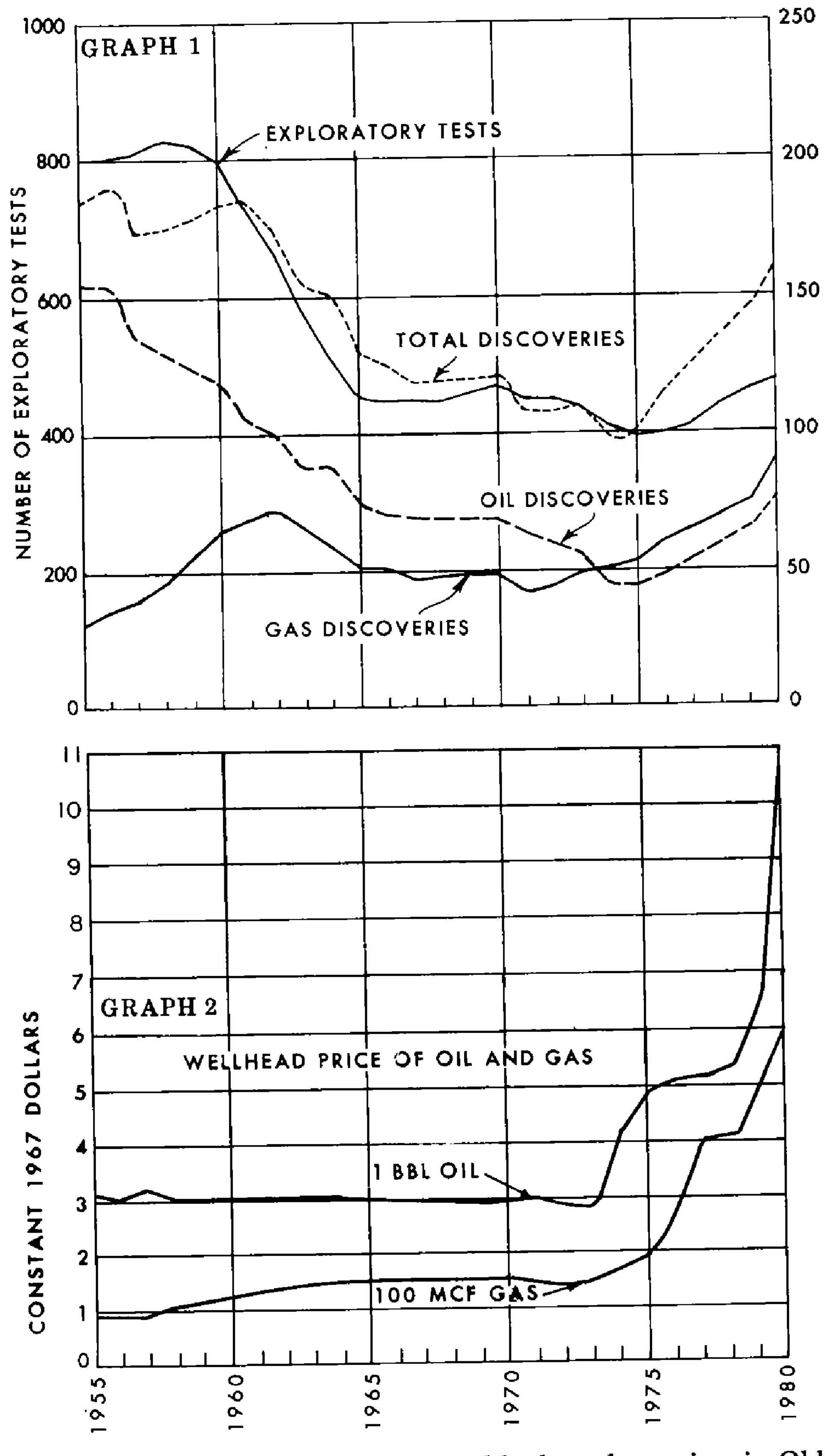

Figure 5. Graphs of exploratory activities and hydrocarbon prices in Oklahoma, 1955–80. Curves in graph 1 are 5-year moving-average trend lines; exploration curve related to scale on left; discovery curves related to scale on right.

The upward trend that was established in 1975 continues with the increases of 1980. The 1980 wellhead price of oil and gas continued the sharp increase that occurred in 1974. As in the five previous years, the trends of exploratory drilling, discoveries, and prices have all been upward.

Figures 6 and 7 reflect a new source for reserve information. Previously,

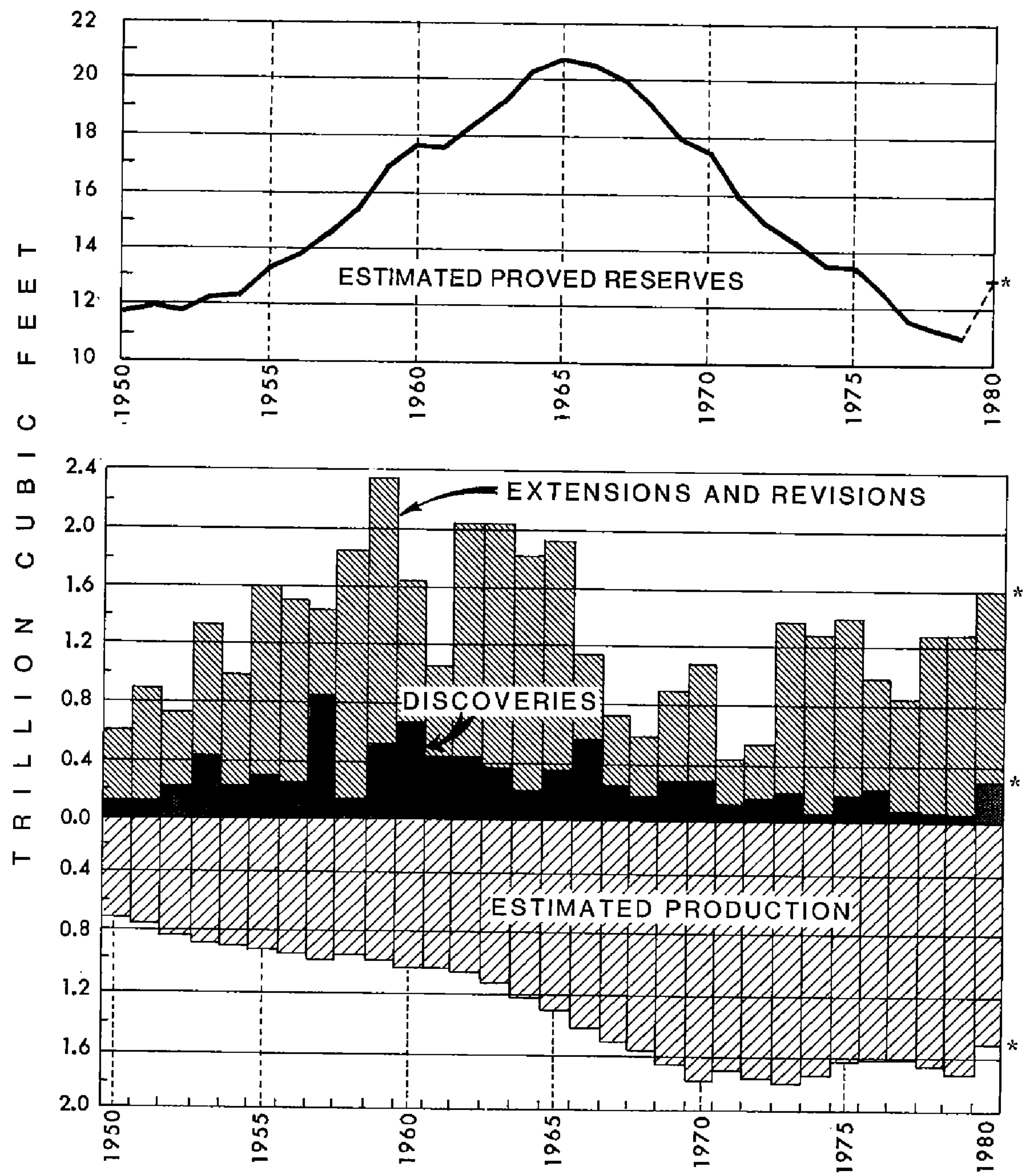

Figure 6. Graph showing statistics for estimated proved natural-gas reserves in Oklahoma, 1950–80. (Source: U.S. Department of Energy, annual reports.)

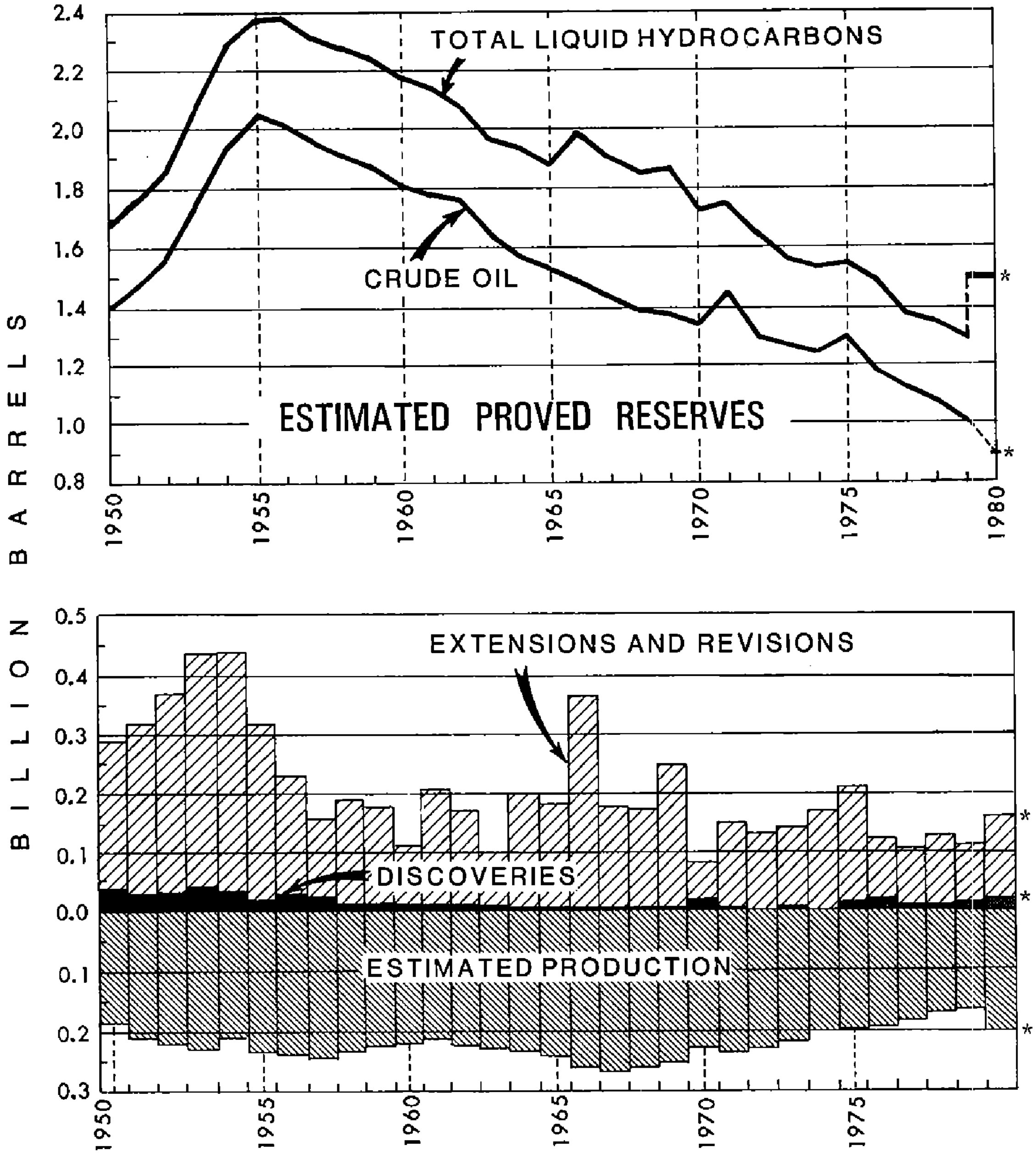

Figure 7. Graph showing statistics for estimated proved total liquid-hydrocarbon reserves in Oklahoma, 1950–80. (Source: U.S. Department of Energy, annual reports.)

the data came from the American Petroleum Institute's and the American Gas Association's *Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas in the United States and Canada*. The U.S. Department of Energy now publishes this information in its *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids 1980 Annual Report*. Since several differences exist in the reports, no comparison of 1980's data with previous years will be attempted. The information from 1979 to 1980 in total liquid hydrocarbons (fig. 7) does show less of a decrease than in previous years.

The historical listing of Oklahoma's annual production and marketing value of hydrocarbons from 1955 through 1980 is given in table 3. The for-

TABLE 3.—CUMULATIVE (THROUGH 1955) AND YEARLY (1956–80) MARKETED PRODUCTION AND VALUE OF PETROLEUM, NATURAL GAS, AND LIQUEFIED NATURAL GAS IN OKLAHOMA[1]

	Petroleum		Natural gas		Liquefied natural gas[2]	
Year through	Volume (1,000 bbls)	Value ($1,000)	Volume (MMcf)	Value ($1,000)	Volume (1,000 bbls)	Value ($1,000)
1955	7,230,010	11,443,269	12,977,332	1,378,370	430,806	1,010,826
1956	215,862	600,096	678,603	54,288	25,454	49,970
1957	214,661	650,423	719,794	59,743	24,947	47,153
1958	200,699	594,069	696,504	70,347	26,141	51,851
1959	198,090	578,423	811,508	81,151	26,767	56,513
1960	192,913	563,306	824,266	98,088	30,816	65,483
1961	193,081	561,866	892,697	108,016	31,865	63,499
1962	202,732	591,977	1,060,717	135,772	33,136	60,987
1963	201,962	587,709	1,233,883	160,405	32,532	64,112
1964	202,524	587,320	1,323,390	166,747	34,163	62,066
1965	203,441	587,944	1,320,995	182,297	34,876	66,769
1966	224,839	654,281	1,351,225	189,172	36,771	80,046
1967	230,749	676,095	1,412,952	202,052	37,489	85,122
1968	223,623	668,202	1,390,884	197,506	39,402	78,349
1969	224,729	701,155	1,523,715	223,128	41,925	73,334
1970	223,574	712,419	1,594,943	248,811	42,842	92,908
1971	213,312	725,610	1,684,260	273,945	41,727	97,588
1972	207,633	709,033	1,806,887	294,523	41,707	99,810
1973	191,204	723,273	1,770,980	334,110	43,718	144,334
1974	177,785	1,277,076	1,638,492	458,904	43,812	251,099
1975	163,123	1,389,164	1,605,410	513,731	40,025	203,535
1976	161,426	1,484,297	1,726,513	866,710	42,514	254,018
1977	151,390	1,504,817	1,824,710	1,452,683	42,350	317,625
1978	150,456	1,640,595	1,773,582	1,599,771	44,369	488,059(e)
1979	143,641	2,158,526	1,845,389	2,062,868	50,752	762,662(e)
1980	150,140	4,110,515	1,902,157	2,856,467	70,000	1,917,000(e)
Totals	12,093,599	36,481,460	47,391,788	14,269,605	1,390,906	6,544,718

[1]Oklahoma Tax Commission.

[2]Preliminary figures for 1980 from U.S. Department of Energy.

(e) = estimated.

mat of this listing conforms to data categories provided by the U.S. Department of Energy.

Table 4 explains in some detail the State's 1980 production and marketing activities. The production of total hydrocarbons increased, as did the marketed value of products. Crude-oil prices for the year averaged $27.38 per barrel (up from $15.03 per barrel in 1979). In 1980, 1,958 producing wells were added, although the average daily production per well dropped from 5.2 to 5.1 barrels.

Table 5 lists 10 of the giant fields in Oklahoma (a giant field is one that has more than 100 million barrels of estimated recoverable oil or equivalent gas). Total oil production for 1980 was 56,541,000 barrels from these giant fields. This was a 19-percent increase from the 47,504,000 barrels of oil produced in 1979.

In 1980, Oklahoma again ranked third in natural-gas and fifth in crude-oil production.

TABLE 4.—HYDROCARBON PRODUCTION IN OKLAHOMA

	1979	1980
Crude oil and lease condensate		
Total annual production (1,000 bbls)[1]	144,623	150,140
Value ($1,000)[1]	2,158,526	4,110,515
Cumulative production 1891–1980 (1,000 bbls)	11,943,459	12,093,599
Daily production (bbls)[2]	396,220	403,500
Total number of producing wells[2]	76,505	78,463
Daily average per well (bbls)[2]	5.2	5.1
Oil wells on artificial lift (estimated)[2]	72,160	74,131
Natural gas		
Total annual marketed production (MMcf)[1]	1,845,389	1,902,157
Value ($1,000)[1]	2,062,868	2,856,467
Total number of gas or gas-condensate wells[2]	14,062	15,245
Natural-gas liquids		
Total annual marketed production (1,000 bbls)[2]	50,752	70,000
Value ($1,000)	762,662(e)	1,917,000(e)

[1]Oklahoma Tax Commission.
[2]*World Oil*, v. 192, no. 3, Feb. 15, 1981.
(e) = estimated.

TABLE 5.—GIANT OIL FIELDS OF OKLAHOMA, 1980
(Source: *Oil & Gas Journal*, v. 79, no. 4, Jan. 26, 1981)

Field	1980 production (1,000 bbls)	Cumulative production (1,000 bbls)	Estimated reserves[1] (1,000 bbls)	Number of wells
Burbank	2,398	520,223	22,180	1,032
Eola–Robberson	1,837	122,606	17,369	546
Fitts	3,902	167,921	20,310	632
Golden Trend	3,988	423,007	41,006	1,081
Healdton	2,458	324,552	25,336	1,396
Hewitt	3,162	251,146	35,074	1,251
Oklahoma City	7,096	737,927	10,841	213
Postle	2,758	92,789	27,044	331
Sho-Vel-Tum	21,472	1,164,601	165,399	8,499
Sooner Trend	7,470	236,088	59,000	4,005
Totals	56,541	4,040,860	423,559	18,986

[1]Percentage of remaining reserves (est.): 9.94 percent.

MARKEY NAMED DIRECTOR OF NEW LIAISON OFFICE

Robert L. Markey is one of thirteen career federal employees who have been chosen to head the state liaison offices under the reorganized U.S. Office of Surface Mining (OSM), James R. Harris, OSM's director, has announced.

Markey will head the Tulsa office that will cover the states of Oklahoma, Texas, Louisiana, and Arkansas.

Harris said that each liaison office will be established once that individual state attains primacy on the regulation of coal mining. The first offices to open will be in Albuquerque, New Mexico, Casper, Wyoming, Charleston, West Virginia, Kansas City, Missouri, and Tulsa, Oklahoma. These offices are expected to be in operation before the first of the year.

Harris has also named Richard E. Dawes as deputy director of the Technical Center that will also serve states and Indian tribes west of the Mississippi River. Dawes began his career with the U.S. Bureau of Mines in 1962, and has been OSM's assistant regional director for technical services and research in Kansas City, Missouri, since November 1978.

Under OSM's reorganization plan, the technical centers will provide support services now located in the five regional offices. The new structure will enable OSM to give the technical support necessary to assist the states, thereby eliminating the duplication of services now rendered in each regional office.

ROSE ELECTED TO AESE POST

At the annual meeting of the Association of Earth Science Editors, held in Denver October 4–7, president Michael Latremouille announced that William D. Rose has been elected vice-president and president-elect of the association for the coming year and that Orrin H. Pilkey would begin his first year of a 3-year term as a newly elected member of the board of directors.

Rose, geologist/editor for the Oklahoma Geological Survey, is a charter member of AESE and served as secretary-treasurer from 1968 to 1971. Pilkey is on the geology faculty of Duke University and is also editor of the *Journal of Sedimentary Petrology,* a quarterly published by the Society of Economic Paleontologists and Mineralogists.

Also, Latremouille presented the AESE Award for Outstanding Editorial or Publishing Contributions to Robert L. Bates, vice-president and president-elect of the association and professor emeritus of geology at Ohio State University.

Perhaps Bob Bates is best known for a column he has written since 1955 for *Geotimes,* the American Geological Institute's monthly periodical, but at least as important as this column are his major contributions in other areas

View at Stop 4 of the AESE field trip in the greater Denver area. Ripple-marked sandstone bed in the Laramie Formation (Upper Cretaceous), as seen in the area of the old Eagle Mine, where the Laramie coal was worked underground at a shallow depth prior to 1937. This area, southeast of Boulder near Marshall, is marked by roof-collapse features, strikingly visible from the air, that depict clearly the pattern of the mining method used, the room-and-pillar method.

of earth science, specifically in editing, publishing research, and teaching.

Bates' *Geotimes* column assumed its present form about 1966, when it became known as "The Geologic Column." Peter N. Webb, Bates' colleague at Ohio State, said that this column "has become the geologic communicator's conscience through its humorous and invariably readable comments on the use or misuse of the English language by geologists, engineers, and governmental agencies. There is no doubt but that 'The Geologic Column' is the most widely read part of *Geotimes*, and probably the most widely read of any contribution to the geologic literature."

The overall theme of this year's AESE meeting, communicating better with a larger public, was faced directly by James F. Davis, state geologist of California, in his keynote address to the participants. He said that scientific communication to the public will have to be greatly improved and expanded to address the four most pressing problems to be dealt with during the remainder of this century: (1) radioactive-waste disposal, (2) the development of mineral resources with respect to increasing economic and environmental constraints, (3) expansion of nuclear-energy facilities, and (4) the related question of public safety.

The 300-member AESE was established in 1967 to improve communication, foster education, and promote effective publication in the earth sciences. For its membership the group draws mainly from the North American continent, although several persons from the continents of South America, Europe, Asia, and Australia also are members.

OKLAHOMA ABSTRACTS

AAPG-SEPM-EMD Annual Meeting
San Francisco, California, May 31–June 3, 1981

The following abstracts are reprinted from the May 1981 issue, v. 65, no. 5, of the *Bulletin* of The American Association of Petroleum Geologists. Page numbers are given in brackets below each abstract. Permission of the authors and of Myron K. Horn, AAPG editor, to reproduce the abstracts is gratefully acknowledged.

OKLAHOMA ABSTRACTS is intended to present abstracts of recent unpublished papers relating to the geology of Oklahoma and adjacent areas of interest. The editors are therefore interested in obtaining abstracts of formally presented or approved documents, such as dissertations, theses, and papers presented at professional meetings, that have not yet been published.

Oil Recovery from Aquifer Beneath Refinery

JONATHAN P. SNELL, The University of Oklahoma, Norman, OK

The Sun Oil Co. refinery on the Arkansas River in Tulsa, Oklahoma, is underlain by a pool of hydrocarbons up to 6 ft (2 m) thick that is floating on the ground water and has an estimated volume of over 600,000 bbl. These oils have an API gravity range of 20 to 60°. The source is thought to be leaks and spills during the 50+ years of refinery operation.

An active recovery system is now in operation using a two-pump-per-well system in which one pump removes water, creating a cone of depression which brings the floating hydrocarbons to the well. From there it is removed by the second pump.

This paper describes the alluvial aquifer, oil detection techniques, recovery methods, and the flow of oil and water through the alluvium. [1016]

Deltaic Cherokee Sandstones of Central Oklahoma

MICHAEL USSEGLIO, The University of Oklahoma, Norman, OK

Exploration for delta reservoir sandstones on the Mid-Continent craton can be enhanced by a better understanding of facies character, depositional environments/processes, and factors that controlled their distribution. Appreciation of the dynamic nature of deltaic sedimentation permits the geologist to predict more precisely the stratigraphic relations and sandstone geometry. It also enables the explorationist to predict areas or trends that may previously have been overlooked.

A detailed, subsurface stratigraphic study of the Cherokee sandstones (early Desmoinesian) in central Oklahoma (including parts of Lincoln, Logan, Oklahoma, Cleveland, and Pottawatomie Counties) gives insight into the processes of deltaic sedimentation which should provide help in local exploration and development operations, and in regional exploration in similar rocks encountered throughout the world. Interpretations will be based on core analyses, examination of well cuttings, study of regional and detailed stratigraphic cross sections, and analysis of structure, paleotopographic/paleodrainage, paleogeologic (subcrop), and isolith maps of several key horizons. [1016]

The University of Oklahoma

Calcareous Foraminifers and Algae from the Type Morrowan (Lower Pennsylvanian) Region of Northwestern Arkansas and Northeastern Oklahoma

JOHN R. GROVES, Department of Geology, the University of Iowa, Iowa City, IA 52242

Type Morrowan (Lower Pennsylvanian) calcareous foraminifers and algae, here described in detail for the first time, provide a basis for recog-

nizing the Mississippian–Pennsylvanian boundary in the type Morrowan region. Type Morrowan rocks are distinguished from underlying late Chesterian strata (Pitkin Formation) by the presence of the foraminifers *Millerella pressa, M. marblensis, Monotaxinoides transitorius, Planoendothyra spirilliniformis,* and *P. evoluta* and the algae *Cuniephycus texana* and Genus A species A n. gen. n. sp. Of these taxa, *Millerella pressa, M. marblensis,* and *Monotaxinoides transitorius* may prove to be reliable indices at the Mississippian–Pennsylvanian boundary across North America.

Analysis of the stratigraphic distribution of foraminifers within the type Morrowan demonstrates that an informal, local two-fold chronostratigraphic subdivision of the Morrowan Series is possible based on the appearance of *Hemigordius harltoni* in the upper Brentwood Limestone Member of the Bloyd Formation at the base of the Brewer Bend Limestone Member of the Sausbee Formation in northwestern Arkansas and northeastern Oklahoma, respectively. The appearance of *H. harltoni* closely coincides with the base of the *Idiognathodus sinuosus* Conodont Zone, and falls within the *Branneroceras branneri* Ammonoid Zone and the *Plicochonetes? arkansanus* Brachiopod Zone.

The primitive fusulinids *Eoschubertella, Pseudostaffella* and *Profusulinella* were not recovered from type Morrowan rocks. Thus, there is no local evidence supporting a Morrowan age for any portion of the ranges of those taxa. Use of the appearances of *Eoschubertella* and *Pseudostaffella* by many workers to indicate the base of the Atokan Series is consistent with present knowledge of the type Morrowan foraminiferal succession.

AAPG Research Conference on Temperature Environment of Oil and Gas
Santa Fe, New Mexico, September 13–17, 1981

The following abstract is reprinted from the July 1981 issue, v. 65, no. 7, of the *Bulletin* of The American Association of Petroleum Geologists. The page number is given in brackets below the abstract. Permission of the author and of Myron K. Horn, AAPG editor, to reproduce the abstract is gratefully acknowledged.

Stability of Natural Gas at High Temperatures in Deep Subsurface

COLIN BARKER and MARWIN K. KEMP, University of Tulsa, Tulsa, OK

The components of natural gas are reactive in the deep subsurface and may not survive under all conditions. The stability of natural gas in reservoirs of various lithologies is studied using a combined theoretical and experimental approach.

A computer program uses real gas data to calculate equilibrium in multicomponent (up to 50), multiphase (up to 30) systems simulating subsurface

conditions to 12 km. This program predicts the stability of hydrocarbons in sandstone reservoirs by first considering clean sands and then sequentially adding feldspars and clays, carbonate cements, and iron oxides. All equilibrium compositions have been computed for low, average, and high geothermal gradients; hydrostatic and lithostatic pressures; and with and without graphite. Graphite is present when deep gases are generated by the cracking of oil but is absent in reservoirs originally filled with dry gas. Similar calculations have also been made for limestone and dolomite reservoirs with various combinations of clays, iron minerals, anhydrite, and sulfur, again with and without graphite. Natural gas shows considerable stability in sandstone reservoirs under most conditions, but its concentration in deep carbonates is more variable and tends to a hydrogen sulfide–carbon dioxide mixture except when an appreciable concentration of iron is present. Hydrogen is present at the 1 to 2 percent level for most lithologies.

A multicolumn gas chromatograph is used to analyze inorganic and organic gases released by crushing rock samples in a Teflon ball-mill. Samples from deep wells in the Anadarko basin and southern Louisiana have been analyzed and the gas compositions compared with those predicted from the computer program. [1359]

OGS ISSUES GEOLOGIC MAP OF SOUTHWEST DAVIS ZINC FIELD

A *Geologic Map of Southwest Davis Zinc Field, Arbuckle Mountains, Oklahoma*, compiled by Robert O. Fay, has been released by the Oklahoma Geological Survey.

The Southwest Davis Zinc Field is located in south-central Oklahoma at the northern and eastern edges of the West Timbered Hills in Murray County. The main ore bodies are in the Lower Ordovician Butterly Dolomite and the Upper Cambrian Royer Dolomite—two formations of the Arbuckle Group—and most of the mines are along the Washita Valley Fault Zone on the north flank of the Arbuckles. Principal minerals are sphalerite (zinc sulfide) and smithsonite (zinc carbonate). Some lead, iron, copper, and cadmium minerals are associated. The ore bodies occur as disseminated deposits or as veins.

The large (3.5- × 4-foot), colorful geologic map was printed at a scale of 1:7920 (8 inches = 1 mile) over a topographic base and covers an area of almost 23 square miles. The descriptive color-coded geologic section ranges from rocks of Middle Cambrian age through Late Pennsylvanian, with Quaternary alluvium following the streams.

Fay compiled his map from William E. Ham's original geologic mapping of the area. Many stratigraphic, lithologic, and paleontologic notations from Ham's field notes have been incorporated in the map.

Included with the map is a 16-page illustrated booklet, also prepared by Fay, in which he discusses the geology of the mineralized area, the mineralogy of the ores, and chemical analyses of ore samples. Several mines and prospect pits are described in detail.

Fay, an authority on the history of mining exploration and operations in Oklahoma, has incorporated many interesting background facts on the development of the ore bodies, plus a biography of Gertrude Sober Field, "Queen of the Arbuckles," a 1933 OU geology graduate who discovered the zinc deposits in 1909. He has included several historic photos.

Oklahoma Geological Survey Map GM-20 (with booklet) can be obtained from the Survey at the address given inside the front cover of this issue. The price is $7.

OGS RELEASES BIBLIOGRAPHY

The Oklahoma Geological Survey has published a two-volume annotated bibliography of more than 5,000 references to all phases of Oklahoma geology, with entries covering the years 1955 through 1979. The publication should prove valuable to those seeking information on the geology of Oklahoma and Oklahoma's earth resources. Interrelated disciplines are included.

Since 1956, a geological bibliography—indexed since 1958—has been issued annually in *Oklahoma Geology Notes*, or in its predecessor *The Hopper*, as an auxiliary source of information for researchers, students, industry personnel, and others who are concerned with developments in the resources and production of mineral commodities or in Oklahoma's geology or physical environment. Entries have been assembled from local, national, and international publications and include, for recent years, abstracts, unpublished theses and dissertations, and open-file reports. Each bibliography lists material issued during the preceding year.

The present set was compiled by Elizabeth A. Ham, associate editor for the Survey, and Christine D. Gay, former Survey proofreader. The compilation incorporates the past bibliographies into two convenient, spiral-bound volumes on a year-to-year basis.

Indexing, focused toward the user seeking specific information, has become increasingly detailed and is organized by localities, time periods, mineral resources, and geological provinces, as well as by subdisciplines of the geological sciences, such as stratigraphy, structural geology, environmental geology, sedimentology, paleontology, geophysics, and hydrology.

The two-volume set, *Combined Bibliographies of Oklahoma Geology*, covering the period 1955–79, was issued as Special Publication 81-5. It can be obtained from the Oklahoma Geological Survey at the address given inside the front cover. The publication, available only as a set, is priced at $8.

OGS GEOLOGISTS ATTEND ANNUAL GSA MEETINGS

Six Oklahoma Geological Survey staff members recently attended the annual convention of The Geological Society of America (GSA) and its divisions in Cincinnati, Ohio.

Representing the Survey at the meetings were Charles J. Mankin, director; Kenneth S. Johnson, associate director; Thomas W. Amsden, biostratigrapher and lithostratigrapher; Samuel A. Friedman, senior coal geologist; Salman Bloch, uranium and base-metals geologist; and Brian J. Cardott, organic petrographer.

Mankin served as master of ceremonies for the annual convention banquet and also attended a breakfast business meeting of the Association of American State Geologists. He reports that specific questions addressed at the breakfast meeting included development of cooperative agreements between the U.S. Geological Survey and State surveys when working in areas of mutual interest.

In addition, Mankin met at the convention with representatives of the American Geological Institute to discuss publication of "Compte Rendu," the proceedings volumes of the Ninth International Congress of Carboniferous Stratigraphy and Geology. He served as a member of the national organizing committee for the congress, which met in 1979 in Urbana, Illinois, and he has been instrumental in securing publication funding.

Mankin also met with representatives of the National Academy of Sciences' Continental Scientific Drilling Committee.

Johnson participated in a field trip that covered the hydrogeology and karst development in the Mammoth Cave area and examined related pollution problems in central Kentucky. He explained that conditions encountered in Kentucky "relate to potential problems that may arise in Oklahoma's limestone and gypsum terrain."

Johnson also presented a report on plans and programs for the 1982 meeting of the South-Central Section of GSA, which will be held in Norman March 29–30.

Amsden delivered a paper at the meeting during a short course offered by the Paleontological Society, which met in conjunction with GSA. He presented an expanded version of his paper, "Biostratigraphic and Paleoenvironmental Relations: A Late Silurian Example," at a colloquium at Oklahoma State University November 12.

Amsden joined in a field trip taken to examine the stratigraphy and paleoecology of the Cincinnatian Series (Upper Ordovician) in the vicinity of Cincinnati. The trip covered rocks of the same geologic age as rocks he has studied intensively in Oklahoma.

Friedman, former chairman of GSA's Coal Geology Division and current chairman of the division's publication committee, presented a report on publication of nine articles on estimation of coal resources in the United States and the techniques of estimating, exploring for, recovering, and managing these resources. He also proposed the scheduling of a conference to discuss the establishment of uniform standards on coal resources.

Friedman was appointed a delegate to the convention committee of The American Association of Petroleum Geologists by the councilors of AAPG's Energy Minerals Division, who held their mid-year meeting at the GSA convention.

Cardott, who has been conducting investigations in coal petrology for the Survey, attended symposia and technical sessions and participated in the luncheon meeting of the Coal Geology Division. He conferred with representatives of microscope manufacturers on equipment, and with coal petrologists on laboratory techniques.

Bloch attended technical sessions.

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