Oklahoma GEOLOGY Notes

OKLAHOMA GEOLOGICAL SURVEY VOL. 48, NO. 6 DECEMBER 1988

On the cover—

Cavernous Weathering of Sandstone in the Ouachita Mountains

Pictured is an example of cavernous weathering developed in Pennsylvanian turbidite sandstones of the Ouachita Mountains (field of view ~1 m wide). This photograph was taken looking up from under a ledge of amalgamated medium- to thick-bedded sandstones in the Jackfork Group on Buffalo Mountain in southern Latimer County. This type of weathering is most common in cool, moist areas, generally on north-facing mountain slopes. The activity of surface water (presumably acidic from its interaction with humic material on these slopes) seeping through and dissolving the cement of the sandstone is a likely explanation for this phenomenon. Sandstones in the Jackfork Group are more susceptible to cavernous weathering than other sandstones in the Ouachitas, because of their greater porosity and permeability, features that are undoubtedly of interest to the petroleum industry.

Charles A. Ferguson

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OKLAHOMA GEOLOGICAL SURVEY VOL. 48, NO. 6 DECEMBER 1988

STRUCTURAL STYLE OF THE FRONTAL THRUST BELT OF THE OUACHITA MOUNTAINS, SOUTHERN PITTSBURG COUNTY, OKLAHOMA

William E. Hardie[1]

Abstract

A recent deep gas exploration play in the frontal thrust belt of the Ouachita Mountains of Oklahoma, and an increase in road cuts and well-site clearings, have augmented subsurface and outcrop data to the degree that new interpretations can be made regarding the complex structure of this thrust-faulted terrain. This study examines the nature, origin, and sequence of emplacement of numerous structural features of the Pittsburg Quadrangle, a 60-mi^2 area on the boundary between the Ouachita Mountains and the Arkoma basin, near McAlester, Oklahoma, in southern Pittsburg County.

The major thrusts, from north to south, are (1) the Choctaw, (2) Buck Creek, (3) Katy Club, (4) Pine Mountain, and (5) Ti Valley thrusts. Numerous imbrications occur between these faults, either linking major thrusts or dying out in bedding planes. The structural transition from the Ouachita Mountains into the Arkoma basin is interpreted as an incipient triangle zone. A more mature and deeply eroded triangle zone exists farther south, within the frontal Ouachitas. An area previously interpreted as a "klippe" is reinterpreted here as a gravity slide. Cross sections show minimum cumulative shortening in excess of 15 mi in the thrust sheets north of the Ti Valley fault. With minor exceptions, fault propagation occurred in the direction of regional tectonic transport (northwestward).

Introduction

The structural and stratigraphic complexity of the Ouachita Mountains of southeastern Oklahoma has been the cause of debate among geologists for many years. Perhaps nowhere else is this more evident than in the frontal thrust belt of the Ouachita Mountains, where large displacements on thrust faults and rapid lithologic changes within given units have made accurate correlation from one thrust sheet to the next difficult. Inadequate well control, a lack of road cuts, and lithologic similarity of different formations have caused disagreement with regard to outcrop identification, structural style, amount of fault displacement, and actual existence of certain faults. The result is a mistrust of existing geologic maps and cross sections.

Since the last geologic map of the frontal Ouachitas was published (Hendricks and others, 1947), a deep gas-exploration play and numerous new road cuts and well-site clearings have greatly increased surface and subsurface data. This study examines the nature, origin, and sequence of emplacement of numerous structural features in the Pittsburg Quadrangle, a 60-mi^2 area on the boundary between the Ouachita Mountains and the Arkoma basin, near McAlester, Oklahoma, in southern Pittsburg County (Fig. 1).

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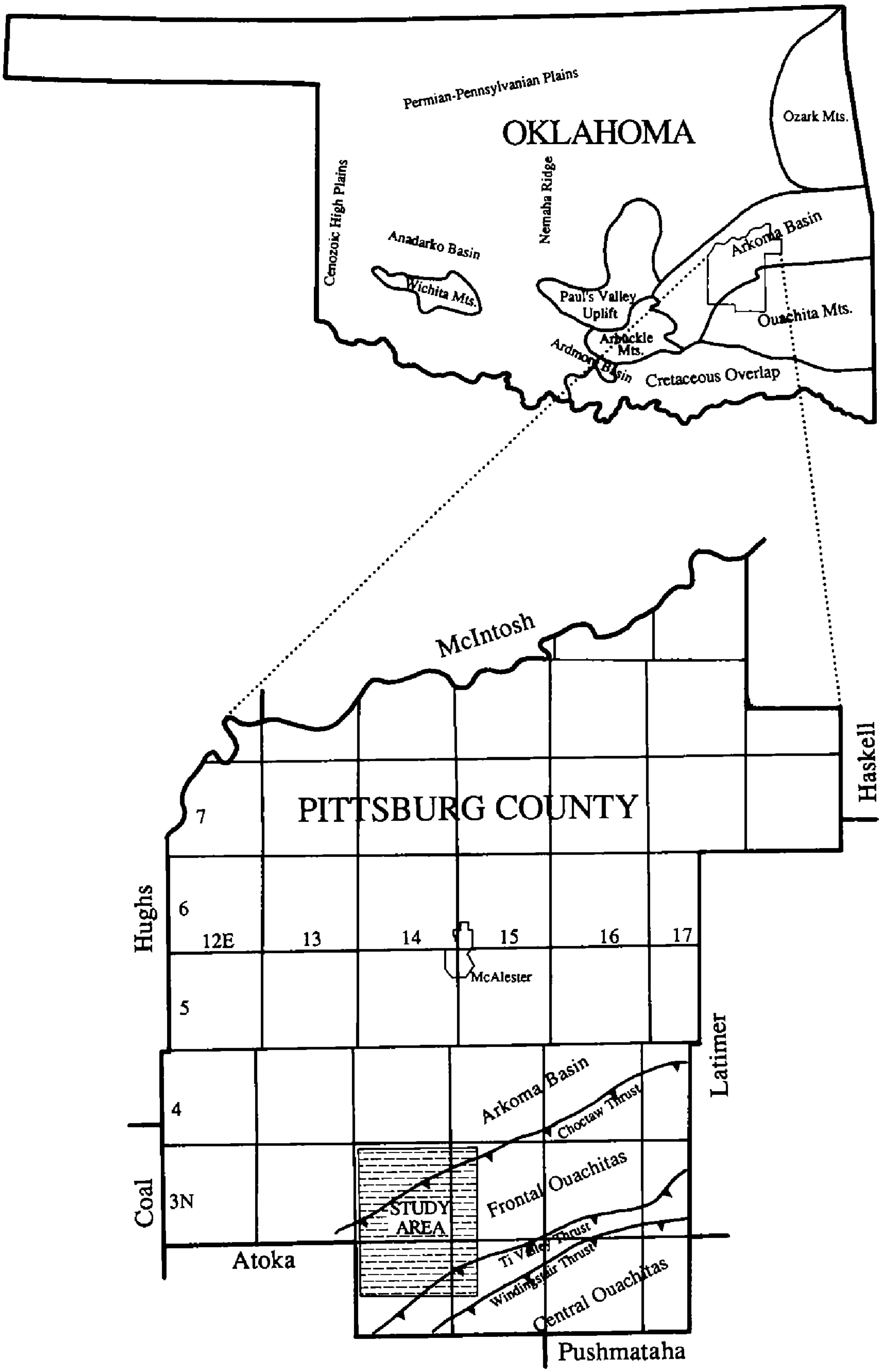

Figure 1. Location of the study area (Pittsburg Quadrangle) and subdivisions of the Ouachita Mountains–Arkoma basin area.

In the study area, the frontal thrust belt consists of a NE-trending band of rocks ranging in age from Late Devonian to Middle Pennsylvanian and includes all rocks lying between the Choctaw and Ti Valley thrusts. Northward, exposed rocks in the much less structurally complex Arkoma basin are restricted to the Middle and Upper Pennsylvanian (Fig. 2). As an active continental margin during the late Paleozoic, the Ouachita Mountains experienced forces of sufficient magnitude to cause overthrusting, bringing into juxtaposition the differing facies of the outer shelf and slope environments, as seen in the Pittsburg Quadrangle.

Methods

After preparing a preliminary geologic map on 1:36,000-scale color aerial photographs, verification and revision were carried out through field mapping. Much more time was spent examining structurally complex areas than in intervening areas where contacts, located in the field, could easily be interpolated by stereoscopic study of the aerial photos. The final map was drawn on a 7.5′, 1:24,000-scale topographic map (Fig. 3). Cross sections were then drawn perpendicular to structural strike, all wells being projected into the line of section along the tectonic "B" axis (Fig. 4). An attempt was made to keep all cross sections in "structural balance." Other data compiled to aid in the interpretation (though not shown here) included structure-contour maps on top of the Wapanucka Formation and on four of the thrust-fault surfaces.

Most workers have recognized the need for further subdivision of the frontal Ouachitas to facilitate detailed explanations of geology. For this study, the structure will be described in terms of thrust sheets. Each thrust sheet is named after the major thrust at its base and includes all strata above that thrust (or southward in map view) to the next major (named) thrust.

With the data available, it was possible to evaluate the nature of the major thrusts, the structural transition from the frontal Ouachitas into the Arkoma basin, and various structures associated with thrust faulting. Most of the terminology used in this study is adapted from the works of Boyer and Elliott (1982), Jones (1982), and Butler (1982).

Structural Analysis

Introduction

The large amount of shale within the frontal thrust belt of the Ouachitas has led some workers to propose variations on the style of deformation ordinarily associated with thrust belts (see "tectonic squeezing" in Rippee, 1982, and Viele, 1973). However, a seismic section shot near the Pittsburg Quadrangle shows reflectors in the Wapanucka which indicate typical thrust-belt geometries, with a sole thrust underlying all thrust imbrications. Electric logs indicate that structurally incompetent shales provide the gliding surface for all major thrusts, and that a large portion of these shales is carried at the base of the allochthonous sheet, rather than being restricted to the top of the footwall. This variation in style is undoubtedly due to the large amount of shales.

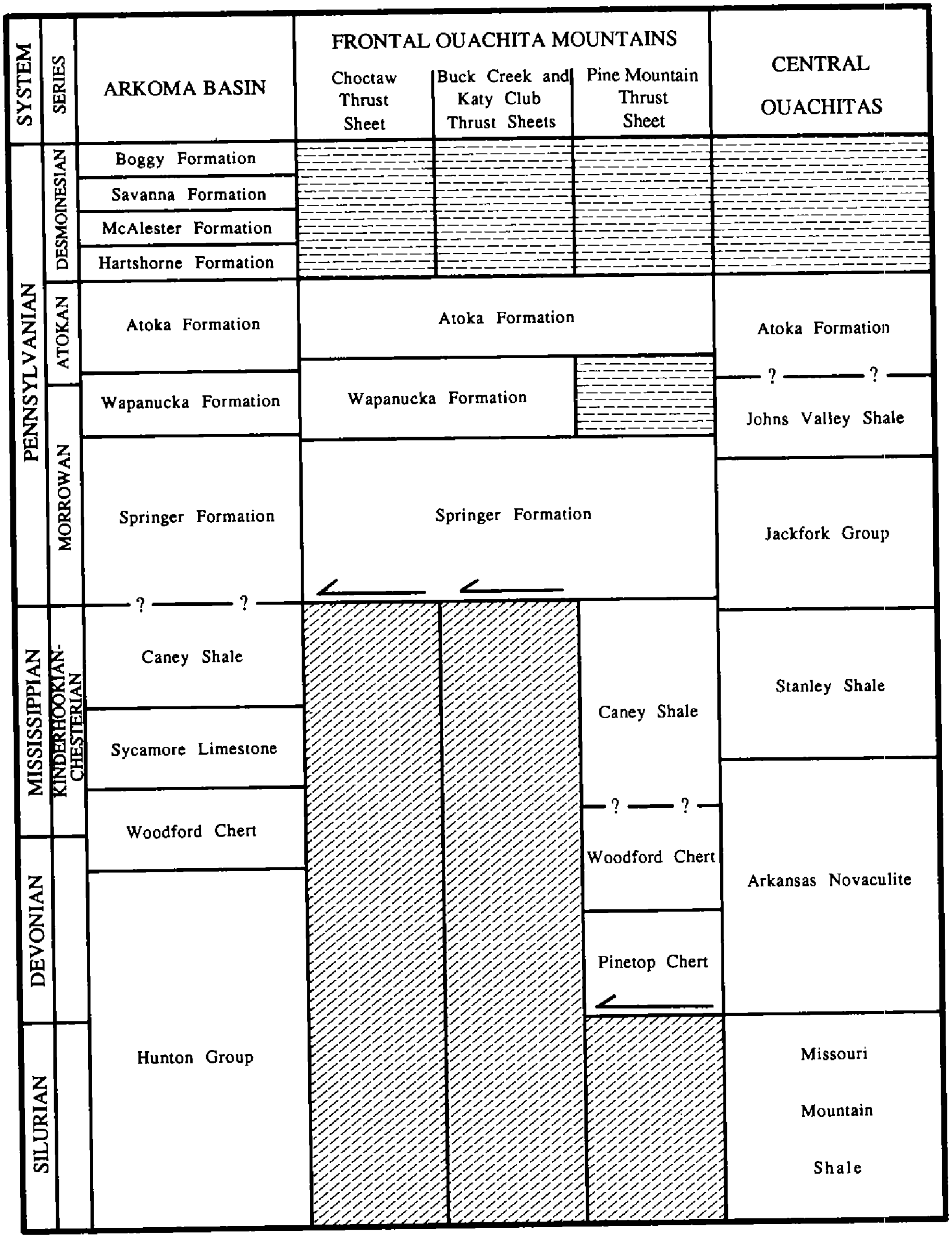

Figure 2. Stratigraphic sequence in the Pittsburg Quadrangle. Horizontally hachured areas indicate nondeposition or strata removed by erosion. Formations above the diagonally hachured areas indicate the oldest strata encountered in individual thrust sheets.

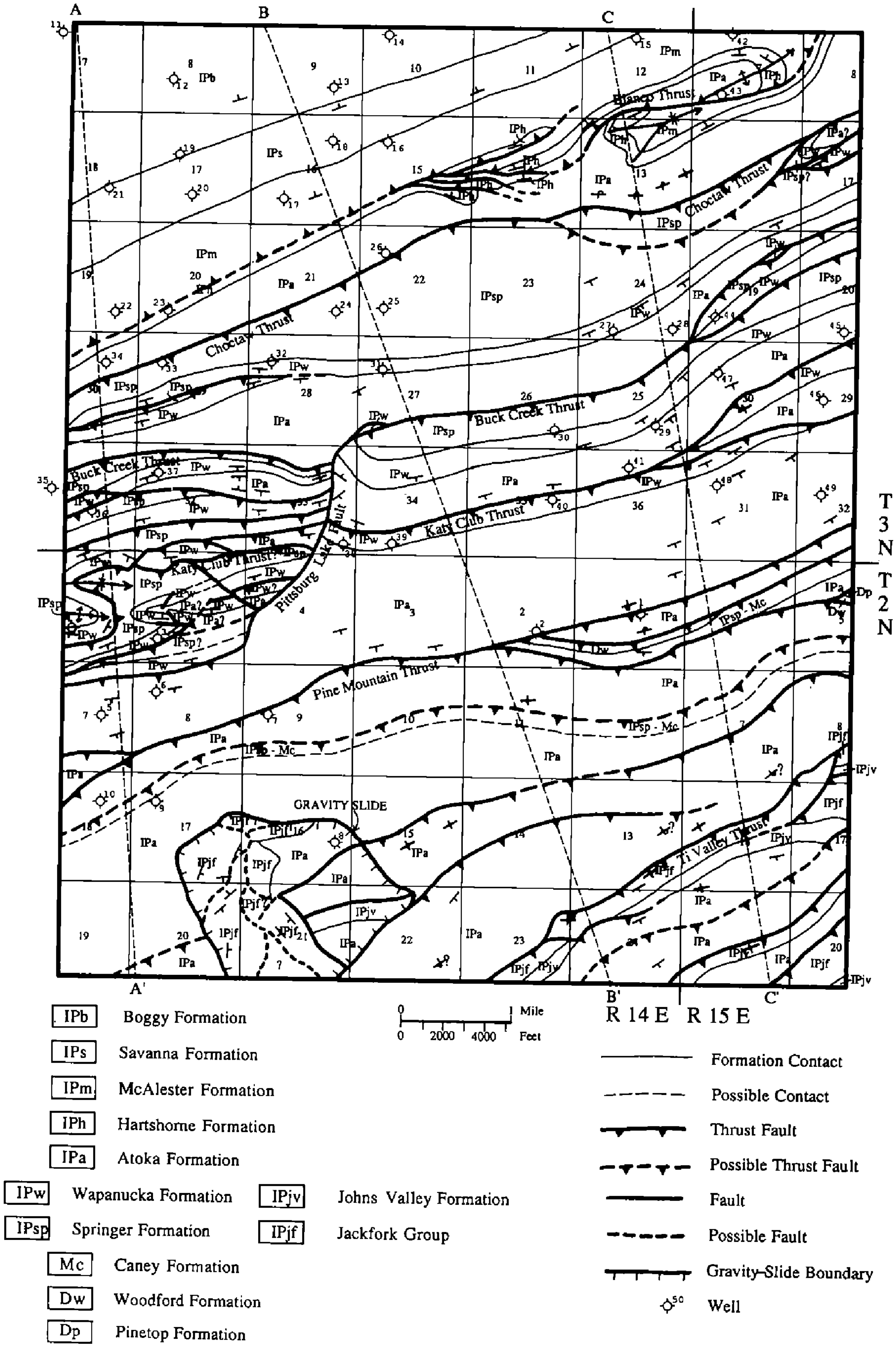

Figure 3. Surface geologic map of the Pittsburg Quadrangle, Oklahoma.

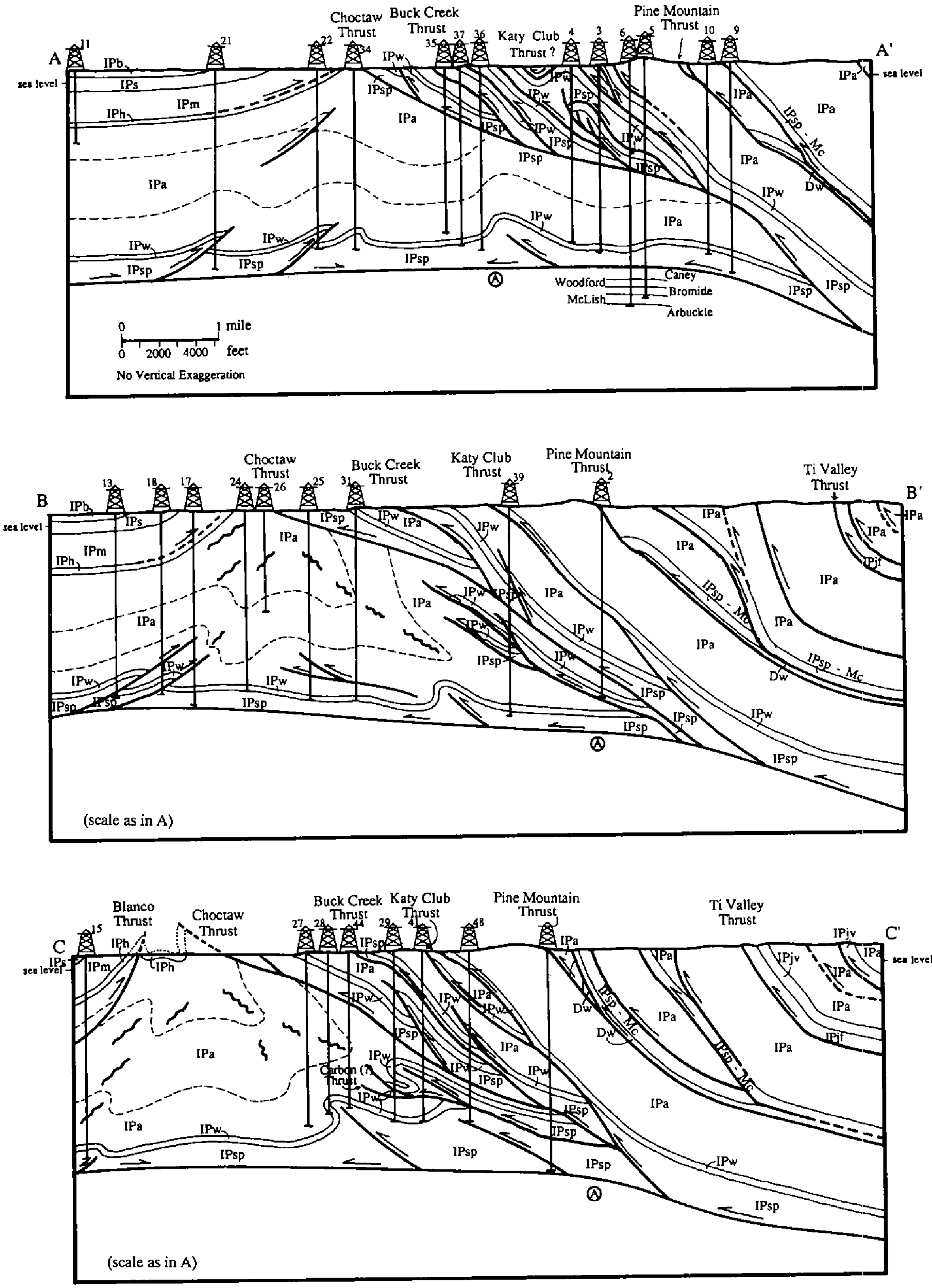

Figure 4. Cross sections.

Tectonic transport was toward the northwest, and total shortening across the quadrangle is calculated at 15.5 mi, about 50% (Table 1). Major thrust faults, from north to south, are (1) the Choctaw, (2) Buck Creek (newly named), (3) Katy Club, (4) Pine Mountain, and (5) Ti Valley thrusts. Between these major thrusts are numerous imbrications, some of which lose displacement or sole out laterally, while others link with major thrusts. Rejoining and connecting splays (Boyer and Elliott, 1982, p. 1198) are often found between imbrications.

TABLE 1.—MINIMUM CUMULATIVE SHORTENING ON INDIVIDUAL THRUST SHEETS WITHIN THE PITTSBURG QUADRANGLE

Thrust Sheet	Minimum Cumulative Shortening
Choctaw Sheet	6,000 ft
Buck Creek Sheet	11,400 ft
Katy Club Sheet	15,400 ft
Pine Mountain Sheet	44,200 ft
Total	15.5 mi

Note: Total shortening includes both shortening within thrust sheets and shortening by stacking of thrust sheets.

Structure Along the Transition from the Frontal Thrust Belt to the Arkoma Basin

The nature of the structural transition from the frontal Ouachitas to the Arkoma basin is not readily apparent from the map view alone. The trace of the Choctaw fault separates N-dipping beds of the Arkoma basin from S-dipping beds of the frontal Ouachitas. Outcrops just south of the Choctaw trace, in a tributary to Brushy Creek (SW¼NW¼ sec. 24, T. 3 N., R. 14 E.), expose tightly crenulated shales and thin sandstone beds of the Springer Formation. In CS½ sec. 13, T. 3 N., R. 14 E. (north of the Choctaw thrust), a resistant sandstone bed in the Atoka, which can be traced to the west for about a mile, becomes overturned and dips S from nearly vertical to 45°, indicating proximity to the footwall cutoff of the Choctaw thrust.

In the northwest corner of the area (secs. 12,13, T. 3 N., R. 14 E.; secs. 7,18, T. 3 N., R. 15 E.), fault drag along the Blanco thrust has folded the beds of the hanging wall into an anticline, and those of the footwall into a syncline. Dips in the Hartshorne Formation on this structure show a NE plunge ~30°. Down-plunge viewing reveals a cross section of a fault–fold interchange. This fault structure and the imbrications in the Hartshorne just to the west (secs. 14,15, T. 3 N., R. 14 E.) can be genetically classified as underthrusts.

A possible rejoining splay (Boyer and Elliott, 1982, p. 1198) in association with a reentrant in the Choctaw fault (sec. 24, T. 3 N., R. 14 E.; sec. 18, T. 3 N., R. 15 E.) could be an eroded "horse" if the splay once rejoined the Choctaw updip.

These features are common in thrusts which put shale on shale (Boyer and Elliott, 1982, p. 1198).

In cross section A–A′ (Fig. 4), the leading-edge thrust for the frontal thrust belt is the Choctaw thrust. At some point between section A–A′ and B–B′, beneath and in front of the Choctaw thrust, a new leading-edge thrust is developed, which in cross section C–C′ cores a recumbent fold. Although this thrust dies out before reaching the surface in the study area, it may correlate with the Carbon thrust in the Wilburton gas field (~15 mi east of the Pittsburg Quadrangle), where it extends into the Arkoma basin and crops out in places (see Berry and Trumbly, 1968).

The structure found below the trace of the Choctaw thrust in the study area resembles that of the foreland margin of the Cordillera in Alberta, Canada, where it is referred to as a "triangle zone" (Jones, 1982). Theoretically, a triangle zone is enclosed by thrusts on all sides (Fig. 5). The "ideal" triangle zone according to Jones (1982, p. 64) is characterized by folded blind thrusts, the anticlinal crests showing lateral migration with depth, all of which are bounded by an upper and lower detachment (Fig. 5). The lower detachment of the triangle zone in this study is represented by the sole thrust in the Springer Formation (labeled "A" on all cross sections), while its flanks (or upper detachment) are delimited by the S-dipping Choctaw and Carbon(?) thrusts of the Ouachita Mountains and a zone of poorly developed, N-dipping underthrusts above and below the Hartshorne Formation in the Arkoma basin. Thus, the structure within the triangle zone consists of a large synclinal fold which becomes more tightly folded up-section, where it develops additional detachments in response to volumetric problems. Based on Jones's definition, the structure in front of the Choctaw thrust and within the Arkoma basin seems to be an incipient triangle zone which becomes better developed toward the east (compare cross section A–A′ with C–C′, Fig. 4). The asymmetric anticlines along both flanks of this triangle zone are the primary drilling targets in the Pittsburg, South Pittsburg, and South Blanco gas fields. Farther east, in the Wilburton gas field, the nature of the deeper part of this triangle zone differs, S-dipping thrusts in the Wapanucka extending much farther into the Arkoma basin, and N-dipping underthrusts being altogether absent (see Berry and Trumbly, 1968, pl. I).

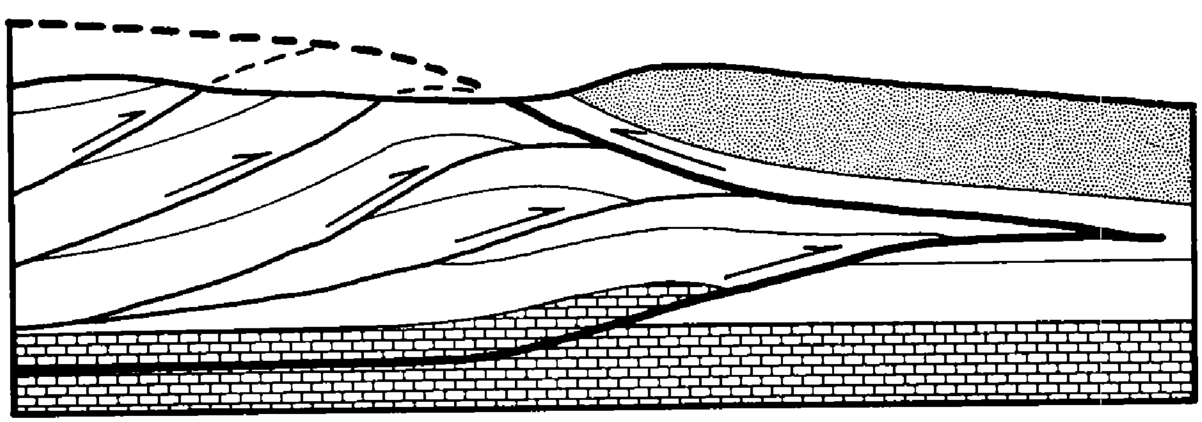

Figure 5. A triangle zone in the foreland of the Cordillera in Alberta, Canada (from Jones, 1982, p. 70).

A second, more mature triangle zone may have existed immediately south of the trace of the Choctaw thrust, its internal structure lying entirely within the Ouachita Mountains (Fig. 6). The upper detachment of an ideal triangle zone "is a horizontal surface that becomes differentially uplifted by thrusting beneath it" (Jones, 1982, p. 70). The upper detachment of this older triangle zone has been eroded away, but would have been an underthrust along a bedding-plane detachment in the Atoka, created by differential movement between younger Atoka rocks and the older rocks of the Ti Valley through Choctaw thrust sheets (Fig. 6A,B). The lower detachment is represented by the Choctaw thrust, which may have joined the upper detachment to form the characteristic wedge of a triangle zone. Development of the younger incipient triangle zone rotated the older one, increasing the original dips on the thrust planes and reactivating movement along them (Fig. 6C).

Pittsburg Lake Fault and Surrounding Area

The Pittsburg Lake fault in sec. 4, T. 2 N., R. 14 E., and sec. 33, T. 3 N., R. 14 E., trends NE, nearly perpendicular to tectonic transport. In map view it appears that the Pittsburg Lake fault links the Buck Creek thrust with an unnamed thrust north of the Pine Mountain fault. Structure on the west side of the Pittsburg Lake fault is much more complex than that on the east side, and correlation across the fault is difficult. I feel that the Pittsburg Lake fault represents a transverse ramp which has transferred movement from the Buck Creek fault to the thrust north of the Pine Mountain fault (N¼ of secs. 7,8, T. 2 N., R. 14 E.). It is possible that movement was also transferred to some of the other imbrications on the west side of the Pittsburg Lake fault which "appear" to be truncated by it. Thus, although total "Buck Creek shortening" is equal on both sides of the Pittsburg Lake fault, on the west side it is taken up by two or more thrusts. This scenario would require that the Pittsburg Lake fault have an E-dipping fault plane. Wells drilled just east of the Pittsburg Lake fault (Mackey No. 1 and Little No. 1) encountered numerous repetitions of the Wapanucka Formation at depth (similar to those on the west side of the fault in map view), indicating a 65° E dip on the Pittsburg Lake fault. This conclusion is also supported by the E-plunging syncline in secs. 5 and 6, T. 2 N., R. 14 E., and the apparent offset of the Buck Creek thrust across the Pittsburg Lake fault (in map view). The small "pod" of Wapanucka in the SW¼ sec. 27, T. 2 N., R. 14 E., is most likely a sliver which has been removed from the footwall of the Pittsburg Lake fault at depth (a similar feature is found in the NE¼ sec. 19, T. 3 N., R. 15 E.). Lamerson (1982, p. 289) described such occurrences in the Absaroka thrust system of southeastern Wyoming as "scalloping."

Toward the core of the aforementioned, E-plunging syncline is another, more tightly folded syncline in the Wapanucka (CW½ sec. 5, T. 2 N., R. 14 E.). The fault (Katy Club thrust?) separating the two beds of Wapanucka in each syncline lies at the top of the Wapanucka in the larger (and deeper) syncline. The folding of the thrusted Wapanucka could have been caused by underlying imbrications, which were drilled in the McEntire A-1 and Gladys Rose #1 wells (Fig. 4, cross section A–A′).

There are still many unanswered questions in this area. Did the thrust labeled "Buck Creek" on the west side of the Pittsburg Lake fault develop before or after

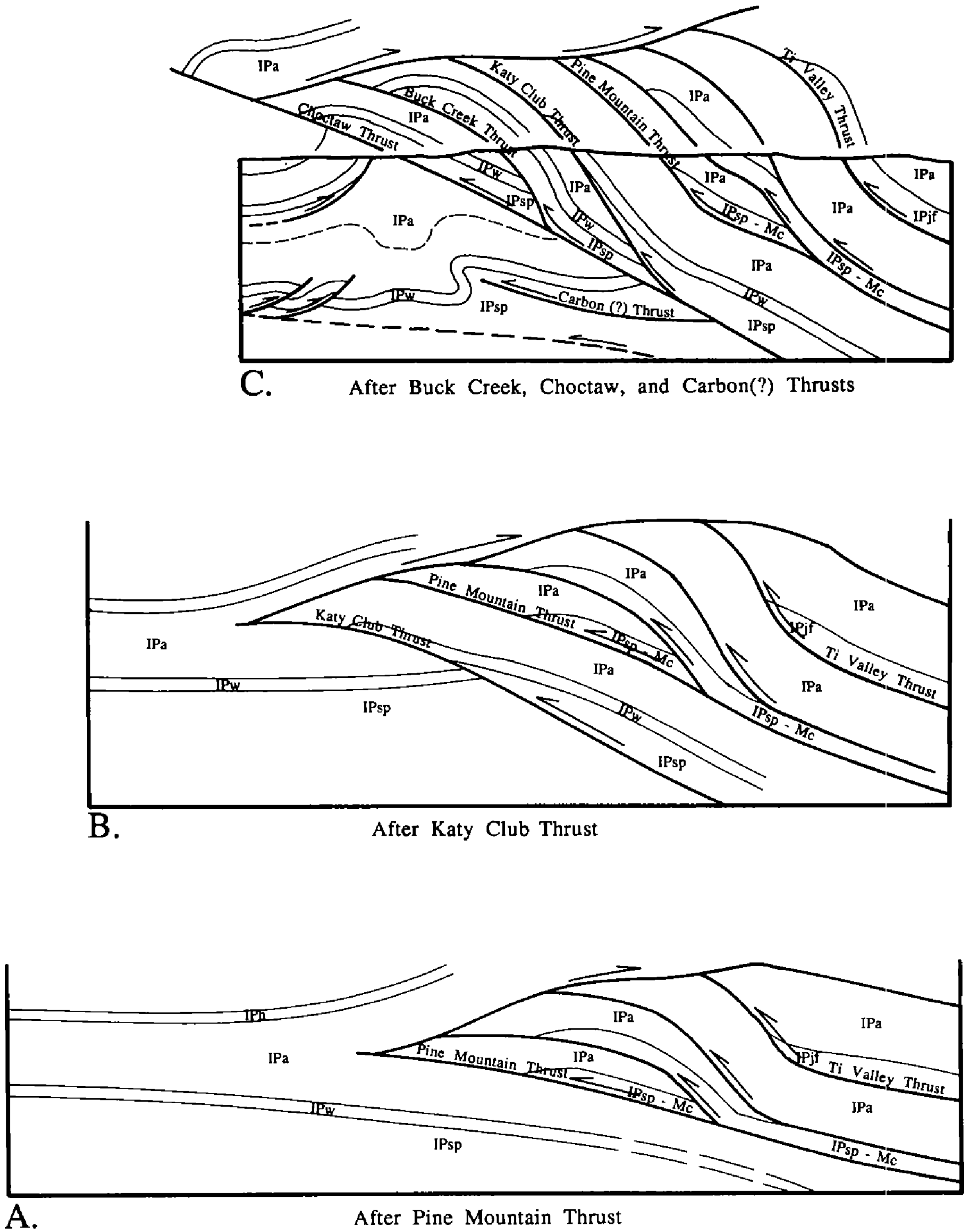

Figure 6. A diagrammatic sequence showing the development of the mature triangle zone within the Ouachita thrust belt and the incipient triangle zone of the Arkoma basin. Diagram C is generalized from cross section B–B′ (Fig. 4). Formation of the incipient triangle zone "bends back" the older thrust sheets, thus reactivating the older thrust surfaces and increasing their original dips.

the Pittsburg Lake fault? Did any of the numerous imbrications on the west side of the Pittsburg Lake fault ever exist on the hanging wall of the Pittsburg Lake fault? If so, they must have been thrust farther than those on the west side, and have since been removed by erosion. If not, then the Pittsburg Lake fault may represent a tear fault which compartmentalizes the Buck Creek thrust sheet and separates equal amounts of shortening on either side. This area has also been mapped by Hendricks and others (1947), Misch and Oles (1958), and Rippee (1982), all three offering interpretations different from those presented here.

Gravity-Slide Area

Perhaps the most enigmatic problem is the area in the southwest quarter of the quadrangle (secs. 15–17,20–22, T. 2 N., R. 14 E.). Hendricks and others (1947) proposed that the rocks of the Jackfork and Johns Valley Formations found here (normally found only south of the Ti Valley thrust) represent a klippe. Others (Misch and Oles, 1957, p. 1903) considered this area a salient of the Ti Valley fault, the western boundary representing a zone of cross faults. The klippe interpretation implies that the Ti Valley thrust has a low angle of dip at the surface and that it approaches a horizontal attitude beneath the area of the "klippe." Nearly all of the Atokan beds (originating in the Pine Mountain thrust sheet) surrounding the "klippe" show steep dips at the surface, and a similar dip likely exists beneath the "klippe." The angular relationship between low dip of the Ti Valley thrust and steep dips in the Atoka beneath suggests that the Ti Valley fault had cut down-section to the north, through at least 10,000 ft of Atoka. Boyer and Elliott (1982, p. 1209) discussed this "decapitation" as a possible alternate method for developing thrust duplexes, but also mentioned that such a structure has not been substantiated.

Dips in the Jackfork Sandstone and Atoka just south of the Ti Valley thrust are all very steep to vertical, which leads to the belief that the Ti Valley thrust also dips steeply within the study area. Irregularities in the trace are small-scale and probably represent actual irregularities in the thrust surface rather than the interaction of a shallow-dipping thrust surface with topography. Neither the klippe interpretation nor the salient interpretation is compatible with the steeply dipping surface outcrop of the Ti Valley thrust, as shown in the cross sections of this study. Since this area represents the only occurrence of the Jackfork and Johns Valley Formations north of the Ti Valley thrust, it seems likely that the rocks did in fact originate in the Ti Valley thrust sheet and were somehow moved to their present location after the emplacement of the Ti Valley thrust. The theory proposed in this study invokes a steeply dipping Ti Valley thrust, the overall structure resembling a hinterland dipping duplex (Boyer and Elliott, 1982, p. 1199–1209). In this model, successive imbrications in the Pine Mountain thrust sheet are developed as progressively younger faults in the direction of transport, subsequent to overthrusting of the Ti Valley thrust sheet. These imbrications are formed by a "progressive collapse of the footwall ramp" (Boyer and Elliott, 1982, p. 1208), and each one eventually links with, and transfers movement to, the overlying Ti Valley thrust (Fig. 7). This model differs from the two aforementioned interpretations in that the Ti Valley thrust is reconstructed at a higher elevation (i.e., it does not underlie the "klippe"), eliminating any down-section movement (decapitation) in the direction

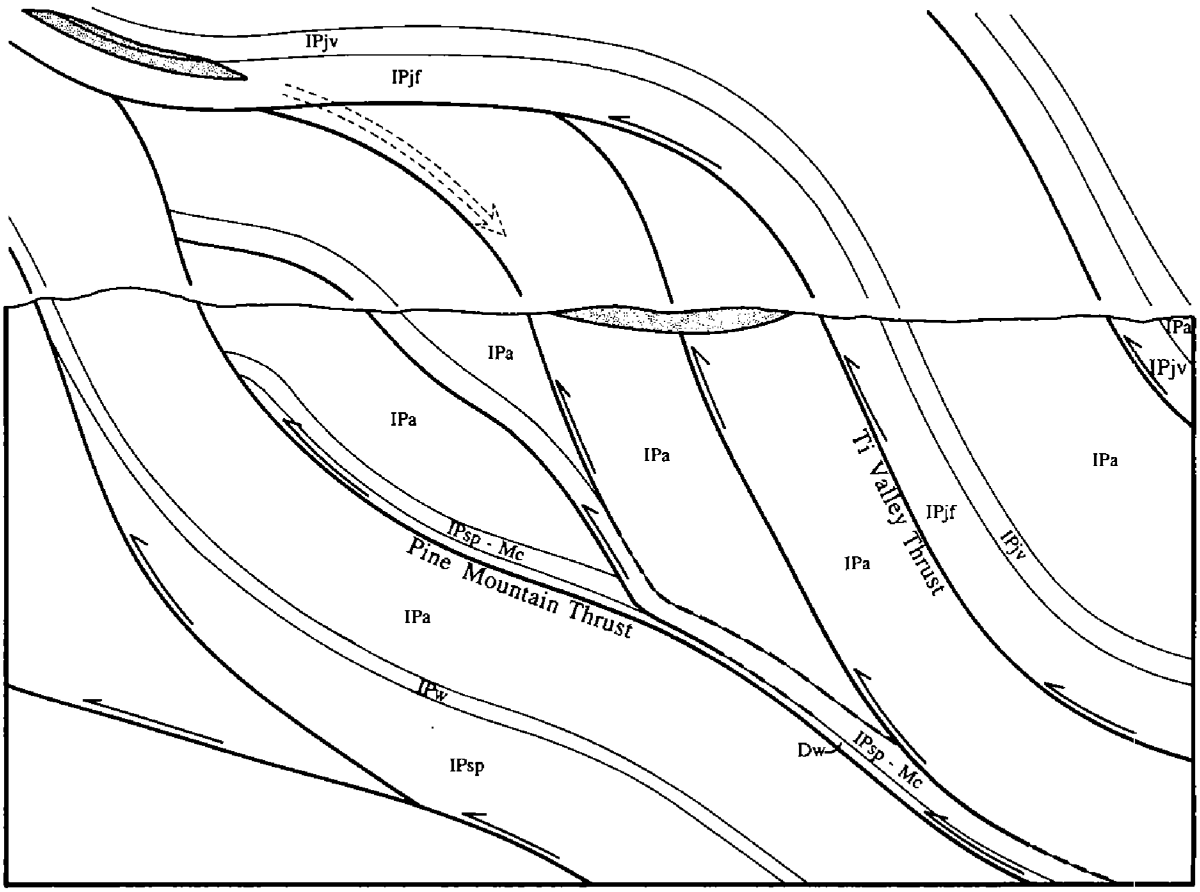

Figure 7. Interpretation of structure in the southwest quarter of the study area, invoking a duplex arrangement of imbrication and later gravity sliding (along the path of the large arrow).

of transport. Subsequent emplacement of the Johns Valley, Jackfork, and Atoka beds (from the Ti Valley thrust sheet) directly on rocks of the Pine Mountain thrust sheet could have resulted from gravity sliding. In this case, the more-resistant rocks of the Ti Valley thrust sheet slid into the topographically lower area, characterized by the deeply eroded Atoka shales of the Pine Mountain thrust sheet (Fig. 7). The resulting structure should be labeled as a gravity slide, and not as a klippe.

Sequence of Development

Although a few minor imbrications seem to have developed in a hindward propagation sequence, all major thrusts developed by forward propagation (Fig. 8). Indicators of a forward-developing sequence of propagation found in the area include (1) a folded thrust, (2) linking imbrications, and (3) near-vertical major thrust planes. In Figure 4 (cross section A–A'), an imbrication in the Buck Creek thrust sheet is shown as having folded an overlying Wapanucka bed and an additional (Katy Club?) thrust. This structure is visible on the geologic map in secs.

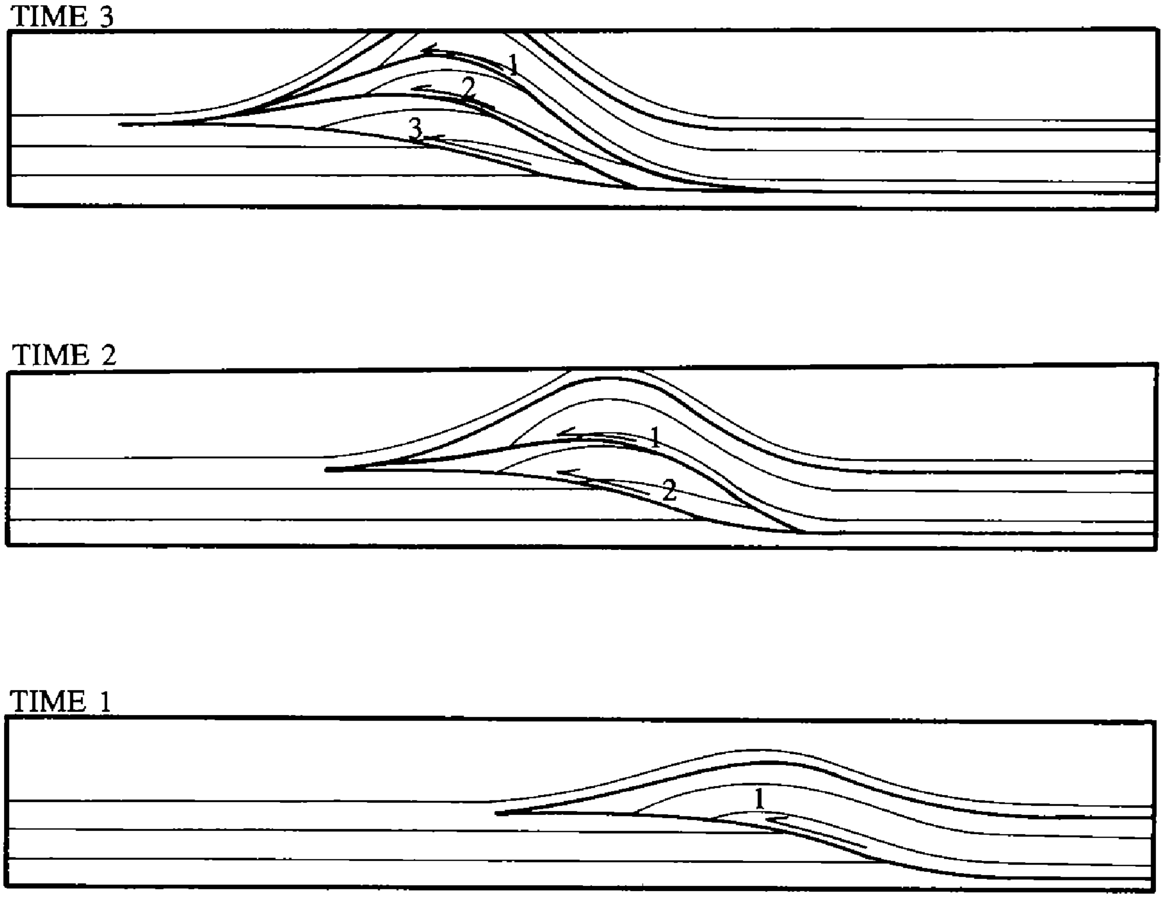

Figure 8. Diagrammatic representation of a forward thrust propagation sequence, in which progressive collapse of the footwall causes a stacking of thrust sheets and a steepening of dips on older fault planes (from Jones, 1982, p. 70).

5 and 6, T. 2 N., R. 14 E. As previously mentioned, the numerous imbrications in the Pine Mountain thrust sheet are interpreted as having transferred movement to, and reactivated portions of, the older Ti Valley thrust (see Fig. 7). Thus, these linking imbrications provide interaction from one major thrust sheet to the overlying (and older) thrust sheet.

The most convincing evidence for forward thrust propagation also involves interaction between thrust sheets. Because all previous thrusts are carried along passively, each additional thrust rotates all overlying structure, making the dips of thrust planes steeper than they were when active (Fig. 8). In the Pittburg Quadrangle, dips of beds and thrust surfaces increase toward the south, from 35° at the Choctaw thrust to near vertical at the Ti Valley thrust. Unfortunately, no definite cross-cutting relationships were found which would confirm such a sequence. Nonetheless, it is my contention that the Ti Valley thrust is the oldest major thrust in the study area, and that major thrusts become progressively younger to the north.

Conclusions

1. Major thrusts in the area trend NE. From north to south, they are the Choctaw, Buck Creek, Katy Club, Pine Mountain, and Ti Valley thrusts.
2. Total minimum cumulative shortening within the Pittsburg Quadrangle is 15.5 mi.
3. The transition from the frontal Ouachitas into the Arkoma basin is here interpreted as an incipient triangle zone, with a more mature and deeply eroded triangle zone farther south, within the frontal Ouachita Mountains.
4. The Pittsburg Lake fault is interpreted as a transverse ramp which links the eastern portion of the Buck Creek thrust with a higher unnamed thrust, north of the Pine Mountain thrust.
5. The area previously interpreted as a klippe has been reinterpreted as a gravity slide from the Ti Valley thrust sheet, which was emplaced on an eroded thrust duplex in the Pine Mountain thrust sheet.
6. Major thrusts developed sequentially, becoming younger in the direction of tectonic transport.

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Appendix: List of Wells

Well No. and Name	Company	Location
1. Ella Mae No. 1	TXO	sec. 1, T. 2 N., R. 14 E.
2. Alice No. 1	?	sec. 2, T. 2 N., R. 14 E.
3. Gladys Rose No. 1	TXO	sec. 5, T. 2 N., R. 14 E.
4. McEntire A-1	TXO	sec. 6, T. 2 N., R. 14 E.
5. Blue Creek 1-7	Hamilton Bros.	sec. 7, T. 2 N., R. 14 E.
6. Blue Creek 1-8	Hamilton Bros.	sec. 8, T. 2 N., R. 14 E.
7. Hoehman No. 1	TXO	sec. 9, T. 2 N., R. 14 E.
8. Hoehman No. 1	Southwest Expl.	sec. 16, T. 2 N., R. 14 E.
9. Ruby A-1	TXO	sec. 17, T. 2 N., R. 14 E.
10. Neal F-1	TXO	sec. 18, T. 2 N., R. 14 E.
11. Ward F-1	Texas Oil & Gas	sec. 7, T. 3 N., R. 14 E.
12. Biggers A-1	TXO	sec. 8, T. 3 N., R. 14 E.
13. Echelle No. 1-9	Seneca Oil	sec. 9, T. 3 N., R. 14 E.
14. Kathyrn No. 1	Cotton Petrol.	sec. 10, T. 3 N., R. 14 E.
15. Sweetin No. 1	Hamilton Bros.	sec. 12, T. 3 N., R. 14 E.
16. Hopper No. 1	Cotton Petrol.	sec. 15, T. 3 N., R. 14 E.
17. Hodgens No. 1	Cotton Petrol.	sec. 16, T. 3 N., R. 14 E.
18. Hopper No. 1	Continental Oil	sec. 16, T. 3 N., R. 14 E.
19. Stroehmer No. 1	Amax Petrol.	sec. 17, T. 3 N., R. 14 E.
20. Stroehmer No. 1	Cotton Petrol.	sec. 17, T. 3 N., R. 14 E.
21. Buela Mae No. 1	Cotton Petrol.	sec. 18, T. 3 N., R. 14 E.
22. Dobbs No. 1	Samson Res.	sec. 19, T. 3 N., R. 14 E.
23. Pittsburg No. 2	Samson Res.	sec. 20, T. 3 N., R. 14 E.
24. Hopper No. 1	Samson Res.	sec. 21, T. 3 N., R. 14 E.
25. Sherrill No. 1	Samson Res.	sec. 22, T. 3 N., R. 14 E.
26. Sherrill No. 1	Amax Petrol.	sec. 22, T. 3 N., R. 14 E.
27. Lee No. 1	Samson Res.	sec. 24, T. 3 N., R. 14 E.
28. Eunice No. 1	TXO	sec. 24, T. 3 N., R. 14 E.
29. Hopper No. 1	Hamilton Bros.	sec. 25, T. 3 N., R. 14 E.
30. Kinnikin No. 1	Samson Res.	sec. 26, T. 3 N., R. 14 E.
31. Fontana No. 1	Samson Res.	sec. 27, T. 3 N., R. 14 E.
32. Sullivan No. 1	Samson Res.	sec. 28, T. 3 N., R. 14 E.
33. Don Scott No. 1-29	Hamilton Bros.	sec. 29, T. 3 N., R. 14 E.
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42. Williams No. 1	Seneca Oil	sec. 7, T. 3 N., R. 15 E.
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45. Iverson No. 1	Samson Res.	sec. 20, T. 3 N., R. 15 E.
46. Indian Nat. No. 1-29	Hamilton Bros.	sec. 29, T. 3 N., R. 15 E.
47. Indian Nat. No. 1-30	Hamilton Bros.	sec. 30, T. 3 N., R. 15 E.
48. Wilkinson No. 1-31	Samson Res.	sec. 31, T. 3 N., R. 15 E.
49. Griffin B-1	TXO	sec. 32, T. 3 N., R. 14 E.

GSA SOUTH-CENTRAL SECTION MEETING
Arlington, Texas, March 12–14, 1989

Sponsored by the Department of Geology of the University of Texas at Arlington, the 23rd Annual Meeting of the Geological Society of America South-Central Section will feature the following meetings and field trips.

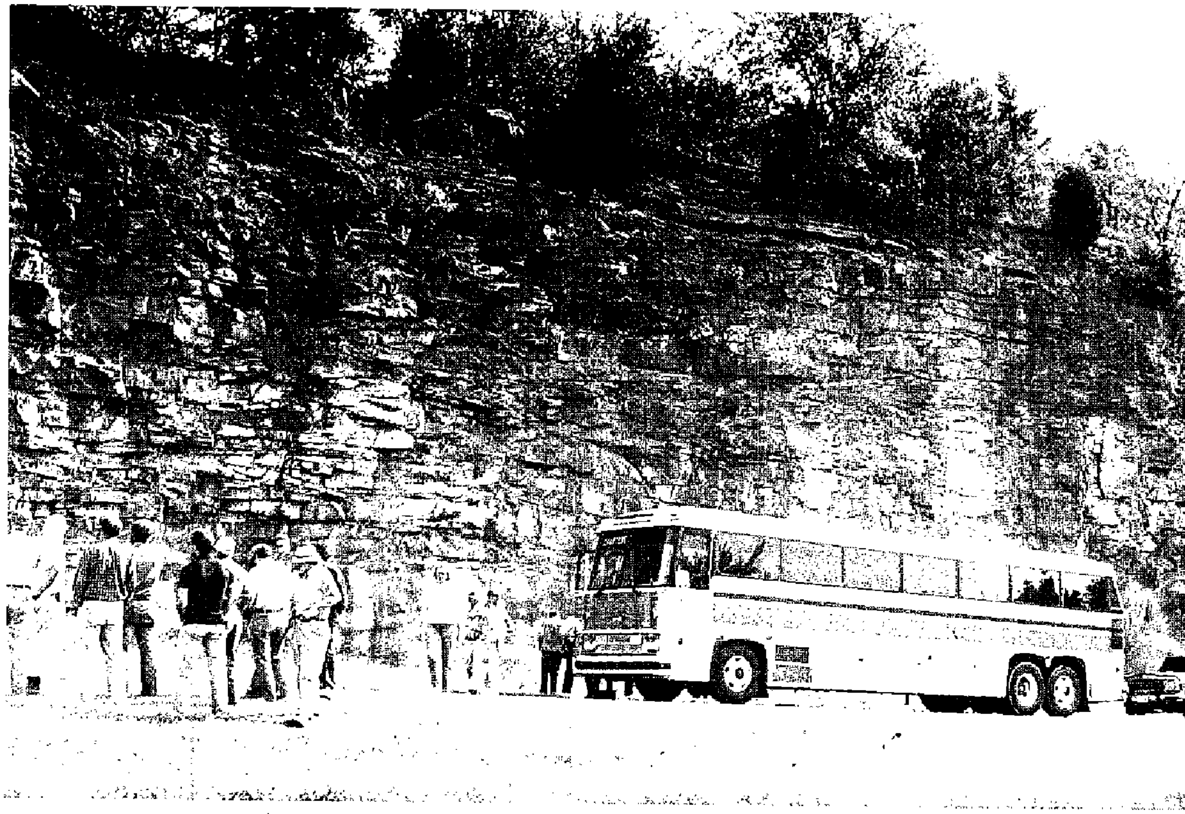
Symposia

Intraplate and Alkaline Magmatism
The Caribbean–North American Plate Boundary: Terranes and Tectonics
Secondary Magnetic Minerals and Their Implications for Exploration and Paleomagnetism
Archaeological Geology of the Southern Midcontinent
Stratigraphy, Sedimentology, and Paleontology of Upper Cretaceous and Lower Tertiary (Paleogene) Rocks in Trans-Pecos Texas
Midcontinent Middle and Upper Pennsylvanian Chronostratigraphy, Biostratigraphy, and Paleoecology

Field Trips

Stratigraphic and Structural Overview of Upper Cretaceous Rocks Exposed in the Waxahachie Vicinity, Northeast Texas
Middle and Late Pennsylvanian Chronostratigraphic Boundaries in North-Central Texas: Glacial Eustatic Events, Biostratigraphy, and Paleoecology
Clastic-Carbonate Shoreline Depositional Environments of the Glen Rose Formation (Lower Cretaceous) in North-Central Texas
Archaeological Geology in the Upper Trinity Basin

For further information about the meeting, contact C. I. Smith, Dept. of Geology, University of Texas, P.O. Box 19049, Arlington, TX 76019; (817) 273-2987. The pre-registration deadline is February 9.



Stop 2 on field trip, Bartlesville–Bluejacket Sandstone at Eufaula Dam.

ARKOMA BASIN, FRONTAL OUACHITAS FOCUS OF NEW OGS GUIDEBOOK

Shelf-to-Basin Geology and Resources of Pennsylvanian Strata in the Arkoma Basin and Frontal Ouachita Mountains of Oklahoma is the title of Oklahoma Geological Survey Guidebook 25, a recently published collection of six topical papers, a cross section, and seven stop descriptions. The guidebook was edited by Kenneth S. Johnson, OGS associate director, and was prepared for a field trip following the 25th annual national meeting of the American Institute of Professional Geologists in Tulsa during September.

Contributors to the guidebook are Charles A. Ferguson, LeRoy A. Hemish, Kenneth S. Johnson, and Neil H. Suneson of the Oklahoma Geological Survey; Glenn S. Visher of Geological Services and Ventures, Tulsa; and W. David Wylie, consulting geologist, Oklahoma City.

From the editor's preface (paraphrased in part):

> This guidebook presents new and recently updated information on the geology and mineral resources of Pennsylvanian strata in parts of eastern Oklahoma. The data are presented along a north–south transect that starts in the Muskogee area on the north, and extends southward through the Arkoma basin and into the frontal belt of the Ouachita Mountains south of Wilburton and Hartshorne. Emphasis of the trip

is on the shelf-to-basin changes that occur within selected Pennsylvanian units, on energy resources in the region, and on the sedimentation, stratigraphy, and tectonics of the Ouachita frontal belt.

Most of the data presented here by Oklahoma Geological Survey staff members result from a cooperative geologic mapping (COGEOMAP) program that the OGS has been conducting within the U.S. Geological Survey and the Arkansas Geological Commission. This COGEOMAP program, which began in 1985, has been highly successful in focusing interest and personnel on detailed geologic mapping in the Ouachita Mountains of Oklahoma and Arkansas. The OGS effort in this program involves geologic mapping of 7.5′ quadrangles along the frontal belt of the Ouachitas eastward from Hartshorne to the Arkansas state line, and mapping just north of the Choctaw fault in the Arkoma basin, where structural features are related to Ouachita Mountains tectonics. The data presented by Visher and Wylie represent an overview of the geologic setting that partly controls hydrocarbon occurrences in the Arkoma basin—a major gas province.

Guidebook 25 can be purchased over the counter or postpaid by mail from the Oklahoma Geological Survey at the address given inside the front cover of this issue. The price is $13.

NOTES ON NEW PUBLICATIONS

Water Resources Data—Oklahoma, Water Year 1986

Records on surface water in Oklahoma are contained in this 316-page report by L. D. Hauth, J. K. Kurklin, and D. M. Walters. Specifically, it includes (1) discharge records for 126 streamflow-gaging stations and three partial-record or miscellaneous streamflow stations, (2) stage and content records for 29 lakes and reservoirs, and (3) water-quality records for 40 streamflow-gaging stations and three lakes.

Order USGS Water-Data Report OK-86-1 from: U.S. Dept. of Commerce, National Technical Information Service, 5285 Port Royal, Springfield, VA 22161. Specify NTIS number PB88-241-583. The price is $32.95 plus $3 to cover postage and handling.

GeoRef Serials List and KWOC Index

The 1988 edition of the *GeoRef Serials List and KWOC Index* includes more than 10,000 earth-science serials that have been cited in the GeoRef data base since 1967. The Serials List is arranged alphabetically by title and provides the complete title, abbreviated title, CODEN or ISSN (or both), and country of publication for each entry. The KWOC (key words out of context) Index enables a user to identify a serial quickly by any significant word in the title.

Order from: American Geological Institute, Customer Service Dept., 4220 King St., Alexandria, VA 22302. The price for a 2,185-page paper copy is $95; a set of microfiche is $35.

Presentation of Martin Van Couvering Memorial Award to Charles Mankin (right) by AIPG President Sam Evans.

OGS DIRECTOR HONORED AT AIPG NATIONAL MEETING

The American Institute of Professional Geologists Martin Van Couvering Memorial Award for 1988 was presented to Dr. Charles J. Mankin, director of the Oklahoma Geological Survey, for his long and continued support and service to the Institute. The award was given at the AIPG Silver Anniversary Annual Meeting, hosted by the Oklahoma Section, held September 28–October 1, 1988, in Tulsa.

From its beginning in 1963, the American Institute of Professional Geologists has had a history of effective and outstanding service to the profession of geology. Currently there are four honors bestowed by the Institute on those highly motivated geologists contributing to the profession, the Institute, the public, and government. The Martin Van Couvering Memorial Award, established by the Executive Committee in 1979 in posthumous honor of the first president of the Institute, is one of these honors. This prestigious award is bestowed on those individuals who have made outstanding contributions of time and service to the Institute, its committees, and special projects. Dr. Mankin was recognized for his representation on several important national committees, councils, and panels. In addition, he was cited for his contributions to the status of AIPG through his service at a national level to other professional and technical organizations in geology.

Total attendance at the Annual Meeting was 140, with 23 states and the District of Columbia represented. Staff members of the Oklahoma Geological Survey attending the meeting included Betty Bellis, Jim Chaplin, Joy Hampton, Kenneth Johnson, and Michelle Summers.

Robert S. Kerr III, Lieutenant Governor of Oklahoma, gave the welcoming address preceding the technical sessions. Technical sessions covered many aspects of the geological profession, including the history of AIPG, coal mining in the Midcontinent, non-fuel mineral resources of Oklahoma, history of geology, ground water, injection wells, overview of natural gas in the United States, on-site burial of oily wastes, professional liabilities and ethics, and new developments in horizontal drilling for petroleum, ground water, mining, and environmental monitoring.

Dr. Harrison H. Schmitt, geologist, astronaut, and former U.S. Senator, was the the featured speaker at a noon luncheon. He discussed the Apollo 17 lunar flight, gave a geological field evaluation of the moon's surface, and addressed the moon's potential as a future supplier of energy resources (especially helium-3 for nuclear fusion) to the Earth.

A geological field trip to the Ouachita Mountains structural complex was led by Neil Suneson and LeRoy Hemish of the Oklahoma Geological Survey; Glenn Visher, Geological Services and Ventures, Tulsa; and W. David Wylie, consulting geologist, Oklahoma City. Stops were made along the way in the gas- and coal-producing Arkoma basin. Emphasis of the trip was on shelf-to-basin changes that occur within selected Pennsylvanian units, on energy resources in the region, and on the sedimentation, stratigraphy, and tectonics of the Ouachita frontal belt.

Jim Chaplin

OGS TO HOST CAMBRIAN–ORDOVICIAN SYMPOSIUM IN AUTUMN 1989

The Oklahoma Geological Survey will sponsor a symposium on the Late Cambrian–Ordovician geology of the southern Midcontinent, to be held October 18–19, 1989, in Norman, Oklahoma.

Topics to be covered include sedimentology, diagenesis, petroleum occurrence and exploration, other mineral resources, geologic history, and other subjects important to understanding the geology of Late Cambrian and Ordovician rocks of the region. Researchers who are doing exploration in the southern Midcontinent or conducting studies on any of these topics are invited to participate.

For further information about this symposium, contact Kenneth S. Johnson, Oklahoma Geological Survey, 830 Van Vleet Oval, Room 163, Norman, OK 73019; (405) 325-3031. A preliminary title for papers should be submitted by March 1; abstract deadline is June 1, 1989.

KERR-McGEE PLEDGES $2 MILLION TO OU AND OSU

To commemorate the centennials of the University of Oklahoma and Oklahoma State University, a $1-million gift has been pledged to each school by Kerr-McGee Corp.

An initial gift of $300,000 was presented Sept. 19 to OU interim President David Swank by Kerr-McGee President Jere W. McKenny. Kerr-McGee will complete the $1-million gift with $100,000 annual contributions over the next seven years.

The gift immediately will provide six $4,000 endowed scholarships and establish two professorships, one each in petroleum engineering and geology.

"Kerr-McGee's generous gift challenges the University of Oklahoma to continue its pursuit of academic excellence and addresses two of our top priorities—retaining academically gifted students and providing eminent professors to educate them," Swank said. "This gift makes possible the immediate presentation of six Kerr-McGee scholarships to OU students with a proven record of academic achievement. In addition, the Kerr-McGee Centennial Professorships will support OU's goal of offering the highest quality education in the classroom," he added.

Increasing the number of endowed scholarships and professorships is a goal of OU's $100-million Centennial Campaign, which has at its foundation the pursuit of excellence. The University will celebrate its 100th anniversary Dec. 19, 1990.

"I hope that the presentations made today by Kerr-McGee will be but one of many investments by other businesses in our state," McKenny said. "Not only the University, but Oklahoma business will benefit from continuing to ensure excellence in education."

The Kerr-McGee gift of $1-million to Oklahoma State University will endow chairs and professorships in the schools of chemical engineering and accounting. Frank A. McPherson, Kerr-McGee's chairman and chief executive officer, presented the award to OSU President John R. Campbell. OSU will celebrate its centennial Dec. 25, 1990.

"As OSU prepares to enter its second century of education and service to the State and nation, it is paramount that we continue building our academic programs through both public and private support. We're very grateful for this gift and hope that others will follow Kerr-McGee's lead and make an investment in educational excellence for Oklahoma," Campbell said.

In making the presentation, McPherson stated, "Nothing is more critical to the future of Oklahoma and to the quality of life in this state than excellence in education. We must do everything we can to ensure that young people in Oklahoma are provided with the highest quality education available in our country."

KERR McGEE

OKLAHOMA ABSTRACTS

The Oklahoma Geological Survey thanks the American Quaternary Association, the Geological Society of America, and the authors for permission to reprint the following abstracts of interest to Oklahoma geologists.

Origin and Implications of the Terminal Rancholabrean-Age Lower Domebo Member, Western Oklahoma

G. ROBERT BRAKENRIDGE, Dept. of Geography, Dartmouth College, Hanover, NH; and JACK L. HOFMAN, Oklahoma Archaeological Survey, University of Oklahoma, Norman, OK

The lower Member of the Domebo Formation (LMDF) as defined by Albritton (1966:11–13), consists of dark gray silty clay grading downward into brown silty sands and a basal gravel. The LMDF is exposed along cutbanks at the floor of the 33 m deep Domebo Canyon type locality and also in several similar canyons (Hofman, 1988). The Domebo type section yielded mammoth remains and associated Clovis projectile points, and is one of few well studied Clovis kill-butchery sites in the United States. Radiocarbon dates of circa 11,200 B.P. on bone organics and humic acids, of 10,123 and 11,045 on wood, and of 9,400 on organic sediments were obtained from the original exposure. Dates ranging from 9220 to 9780 have been obtained from tree stumps and of 9335 to 9645 on charcoal from exposures of the LMDF at other canyons (Nials, 1977; Hofman, 1988). Dates on the Upper Member of the Domebo Formation are of late Holocene age (Ferring and Hall, 1987).

Because the LMDF gravel rests directly on Permian (Rush Springs) sandstone, one interpretation has been that erosion immediately preceded LMDF deposition. Late Pleistocene cutting was followed by LMDF accretion and burial and preservation of Rancholabrean fauna and Paleoindian artifacts. However, radiocarbon dates are not available for the basal portions of the LMDF, and additional studies may yet document pre-Lower Domebo Quaternary sediments along these canyon floors. A late Pleistocene erosional event may have occurred, but this is not compelled by available evidence.

Initial work is to test alternative hypotheses for canyon morphogenesis and ensuing late Quaternary sedimentation. Important in canyon development was spring sapping and progressive retreat of the Permian sandstone headwalls, but canyon ages and rates of headwall retreat are unknown. In this regard, the LMDF and datable archaeological materials serve as useful markers. The oldest pre-Lower Domebo sediments may be preserved in the downstream canyon locations, whereas the headward reaches may be post-Lower Domebo in age. Study of the chronology and processes of canyon headward growth will aid placing the Lower Domebo Member in an improved geochronological and geomorphological framework.

Reprinted as published in American Quaternary Association *Program and Abstracts of the 10th Biennial Meeting,* 1988, p. 110.

Geochemistry of the Freshwater/Brine Transition Zone that Surrounds the Ozark Plateaus, Oklahoma, Kansas, Missouri, and Arkansas

GREGORY P. ADAMS and SCOTT C. CHRISTENSON, U.S. Geological Survey, Water Resources Division, 615 Dean A. McGee, Rm. 621, Oklahoma City, OK 73102

In the western part of the Ozark Plateaus physiographic province (northern Arkansas, southeastern Kansas, southern Missouri, and northeastern Oklahoma), geohydrologic units consisting of geologic formations of Cambrian, Ordovician, and Mississippian age contain a predominant calcium magnesium bicarbonate type freshwater with a dissolved-solids concentration less than 1,000 milligrams per liter. West of the Ozark Plateaus in central and western Kansas and Oklahoma, the same geohydrologic units contain a sodium chloride type brine with a dissolved-solids concentration greater than 250,000 milligrams per liter. Between the freshwater and brine zone is a volume of aquifer defined as the freshwater/brine transition zone. Within this zone in eastern Kansas and Oklahoma, the water type changes from calcium magnesium bicarbonate, to mixed cation bicarbonate, to sodium bicarbonate, to sodium chloride water; with an abrupt change in dissolved-solids concentration.

In the freshwater zone, ground water flows outward from a southwest trending topographic high. The major-element chemistry as explained by speciation and mass-balance calculation indicates the following processes: Dissolution of aquifer-matrix minerals towards equilibrium, ion-exchange, hydrolysis of albite, and mixing with unflushed saline water. In the brine zone, flow is generally eastward as inferred from solute-transport modeling. Geochemical data indicate that the origin of the brine is ancient evaporated seawater. In the transition zone, plausible mass-balance models indicate the following processes: Mixing of calcium magnesium bicarbonate water with a sodium bicarbonate water and a sodium chloride brine, calcite precipitation, and gypsum dissolution. The sodium bicarbonate water probably enters the ground-water system as leakage from shallow ground water.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 89.

Geohydrology of the Freshwater/Brine Transition Zone that Surrounds the Ozark Plateaus, Oklahoma, Kansas, Missouri, and Arkansas

SCOTT C. CHRISTENSON and GREGORY P. ADAMS, U.S. Geological Survey, Water Resources Division, 615 Dean A. McGee, Rm. 621, Oklahoma City, OK 73102

In parts of northeastern Oklahoma, southeastern Kansas, northern Arkansas, and southern Missouri, aquifers consisting of Cambrian–Ordovician- and Mississippian-age strata contain freshwater that has dissolved-solids concentrations of less than 1,000 milligrams per liter. In central and western Oklahoma, and central and western Kansas, the same aquifers contain brine with dissolved-solids

concentrations that exceed 250,000 milligrams per liter. Between the freshwater and brine zones of the aquifers, a zone exists that is referred to as the freshwater/brine transition zone. This zone is characterized by abrupt changes in concentrations of dissolved ions.

In the freshwater zone, ground water flows radially outward from a southwest-trending topographic high. In the brine zone, flow is inferred to be generally eastward, based on the configuration of the potentiometric surface in the overlying unconfined aquifer and on solute-transport modeling. The solute gradients in the transition zone are caused by dilution of the eastward-moving brine by freshwater from the overlying unconfined aquifer, as indicated by solute-transport modeling. The solute-transport model also indicates that ground-water velocities within the brine zone are extremely slow, resulting in residence times for the brine that probably exceed 100 million years. The brine is probably ancient sea water, as indicated by geochemical evidence, which is compatible with the long residence times indicated by the solute-transport modeling.

Reprinted as published in the Geological Society of America South-Central Section *Abstracts with Programs, 1988*, v. 20, no. 2, p. 94.

Mt. Blanco Revisited: Soil-Geomorphic Implications for the Ages of the Upper Cenozoic Blanco and Blackwater Draw Formations

VANCE T. HOLLIDAY, Dept. of Geography, University of Wisconsin, Madison, WI 53706

Mt. Blanco, on the eastern edge of the Southern High Plains of Texas, contains stratigraphic features significant in interpreting the late Cenozoic history of the region and the vertebrate paleontology of the Great Plains; however, the stratigraphic relations are confused in the literature or are unreported. Mt. Blanco is the type locality for the Blanco Formation and the Blanco Local Fauna, which occurs throughout North America and is the type fauna for the Blancan Land Mammal Age in North America. Here also occur exposures of the Blackwater Draw Formation, an extensive ($\sim$120,000 km^2) eolian sheet that is the surficial cover of the region and contains the 1.4 Ma Guaje Ash and several buried soils. A reexamination of the section shows that (1) Blackwater Draw Formation, an eolian deposit, contains three well-expressed buried soils (5 *YR* hues, argillic horizons >1 m thick, Stages III and IV calcic horizons) and the similar regional surface soil (Paleustalf); (2) the Guaje Ash is within the lower Blackwater Draw Formation but is separated from the Blanco Formation, a lacustrine unit, by about 1 m of sediment, including the lowest buried soil; and (3) the lowest buried soil shows a Stage IV calcrete formed at the top of the Blanco Formation and the base of the Blackwater Draw Formation and probably took about 200 ka to form. These new data suggest that deposition of the type Blanco sediments may have ended by about 1.6 Ma or earlier. Since that time, the Blackwater Draw Formation has accumulated episodically; periods of nondeposition are characterized by landscape stability and pedogenesis.

Reprinted as published in *Geology*, v. 16, p. 505.

Pt-Group Metal Anomalies in the Lower Mississippian of Southern Oklahoma

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Four iridium (Pt-group elements) abundance anomalies have been found within a stratigraphic span of 3 m in the Lower Mississippian of Oklahoma. In ascending order, the first anomalies occur at the top of the Woodford Shale: Ir = 0.25 ppb, Pt = 48 ppb, Os = 7.5 ppb, and Au = 18 ppb. The anomalies occur just below a redox boundary and we suspect that the enriched elements were precipitated from sea water that contacted the organic- and sulfide-rich black shale. Two more anomalies occur in the Welden Limestone, the lower one weak and the upper one strong (Ir = 0.42 ppb, Pt = 50 ppb, Os = 0.075 ppb, and Au = 0.14 ppb). The excess Ir and Pt (also Co, As, and Ni) might have been enriched from sea water by bacteria at these two horizons. A 70-cm-thick interval of excess heavy siderophiles occurs in the overlying Caney Shale; the interval contains the following peak concentrations: Ir = 0.56 ppb, Pt = 150 ppb, Os = 0.51 ppb, Co = 725 ppm, and Ni = 1450 ppm. These elements vary in proportion to the Al (clay) content and we suspect that they were carried in with detrital material from erosion of ultramafic source rocks. We found no evidence of microspherules or shocked-mineral grains in any of these anomaly zones.

Reprinted as published in *Geology*, v. 16, p. 627.

Episodic Potassic Diagenesis of Ordovician Tuffs in the Mississippi Valley Area

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Cambrian–Ordovician strata of the Mississippi Valley have been extensively modified by potassic diagenesis. Ordovician vitric tuffs are altered to K-feldspar and illite-rich, mixed-layer illite–smectite (I/S), both of which have been dated by K/Ar. Rb/Sr dates for K-feldspar support its reliability as a K/Ar clock, despite a dislocation density of 10^9–10^{10} cm^{-2}. Age data document three Paleozoic episodes of potassic diagenesis, which have mean ages of 396 Ma (Early Devonian) for K-feldspar of the upper Mississippi Valley (UMV), 362 Ma (Late Devonian) for I/S of the UMV, and 265 Ma (Permian) for I/S of Missouri.

Devonian dates from the UMV correspond to times of widespread epeirogeny in the U.S. midcontinent, and diagenetic episodes are attributed to regional flow of basinal brines caused by groundwater recharge on uplifted arches. Potassium for K-feldspar may have come from the Michigan basin, and K for illite may have

come from the east-central Iowa basin. K-feldspar and I/S of the UMV are in oxygen-isotopic disequilibrium, indicating that the K-feldspar crystallized from fluid that was either warmer or had lower $\delta^{18}O$ values than that of the I/S. Permian illitization apparently records northward movement of warm saline fluid as a result of the Ouachita orogeny.

Reprinted as published in *Geology*, v. 16, p. 743.

Granite Platforms of the Western Wichita Mountains, Oklahoma: Pediment Outliers of the Southern High Plains

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Hills of Cambrian granite rise up to 900 ft above the adjacent Permian red bed plains in the Lake Altus area of the western Wichita Mountains, Oklahoma. The crests of the highest hills (Flat Top, King, Soldier, and Tepee Mountains) are distinctly beveled at an elevation of 2,100–2,150 ft, 600 ft above the level of the plains. The platform on Flat Top Mountain is a discontinuous surface up to 7,000 ft across. The platforms on the other three mountains are situated below central peaks, and have radial outward dips of 2–10° and widths up to 800 ft. They are widest and least steep on the western and southern sides of the mountains. The Lake Altus platforms have been previously interpreted as Permian wave-cut features that were exhumed by late Cenozoic erosion of the overlying marine red bed sediments.

The present study reinterprets these platforms as late Pliocene–early Pleistocene pediments cut to the level of the southeasterly sloping Southern High Plains surface (the Llano Estacado) which formerly existed in the Lake Altus area. This surface was created by the Late Miocene–early Pliocene alluvial deposition of the Ogallala Fm. The eastern edge of the surface was eroded back to its present position in the Texas Panhandle (110 miles west of the Lake Altus area) by early Kansan time. Evidence for the new interpretation is as follows: (1) studies of modern coasts show that waves are incapable of cutting shore platforms in granite; (2) the platforms closely resemble modern granite pediments; (3) the platforms are best developed on the western and southern hillsides, and facing the Llano Estacado; and (4) an east–west topographic profile shows that the platforms lie at precisely the elevation predicted by an eastward linear projection of the Llano Estacado.

The granite platforms of the Lake Altus area are pediment outliers of the Southern High Plains, and thus are congeners of and correlative with the late Tertiary "Subsummit Pediplains" of the Rocky Mountains.

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