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Post-Carboniferous Tectonics in the Anadarko Basin, Oklahoma: Evidence from Side-Looking Radar Imagery

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ABSTRACT

The Anadarko Basin is a WNW-ESE elongated trough filled with 10+ km of Paleozoic sediments. Most models call for tectonic activity to end in Pennsylvanian times. NASA Shuttle Imaging Radar (SIR-A) has revealed a distinctive and very straight lineament set extending virtually the entire length of the Anadarko Basin. The lineaments cut across the relatively flat-lying Permian units exposed at the surface. The character of these lineaments is seen most obviously as a tonal variation. Between the lineaments there is a more poorly reflecting "gray" zone with better reflectors located south and particularly north of the lineaments. Analysis of stream drainage and topography suggests that the area between the lineaments is low in the west and high in the east. Major streams, including the Washita and Little Washita rivers, appear to be controlled by the location of the lineaments. Subsurface data indicate the lineaments may be the updip expression of a buried major fault system, the Mountain View Fault. This fault is characterized by Harlton (1963) as southerly dipping; recent COCORP data suggest a shallow dip (30-40°). Two principal conclusions arise from this analysis: (1) The complex Mountain View Fault system appears to extend southeast to join the Reagan, Sulphur, and/or Mill Creek Faults of the Arbuckle Mountains, and (2) This fault system has been reactivated in Permian or younger times. We infer that minor reactivation of the Pennsylvanian faults has resulted in a subdued surficial expression of buried structures which largely control the location of several oil fields in the Anadarko Basin.

1. Introduction

The Anadarko Basin of western Oklahoma and the Texas Panhandle records a complex tectonic history that spans the Late Precambrian and the Paleozoic era. This basin is the deepest known in the continental United States, containing at least 11.2 km of Phanerozoic sediments in its deepest parts (Rowland, 1974). It continues to be a productive petroliferous province. Consequently, almost 3,000 papers and abstracts have been published dealing with some aspect of the geology of the Anadarko Basin (McLaughlin, 1984). In spite of this very high level of interest among geologists for reconstructing the sedimentological and structural evolution of the Anadarko Basin, any number of unresolved problems persist. With the development of shuttle-born side looking radar there is a new perspective and scale at which to examine this important province. We report here the principal results of our efforts to use side-looking radar images acquired on the Space Shuttle "Columbia" (the SIR-A experiment) to help unravel the latest stages in the tectonic evolution of the Anadarko Basin.

2. Geologic Setting

The Anadarko Basin is the northwestern part of the deformed Southern Oklahoma Aulacogen (Hoffman, et al., 1974). It is strongly asymmetric, with sediments dipping south at a relatively low angle off the northern shelf area while the deepest part of the basin lies adjacent to or beneath the buried Mountain View Fault on the north side of the Wichita Mountains (Figure 1). The tectonic evolution of this region can be grossly subdivided into four developmental stages. The first was a major episode of rifting accompanied by extensive bimodal igneous activity, including gabbro, granite, and rhyolite. These rocks give radiometric ages in the range 500-600 Ma and are flanked to the north by 1370-1400 Ma gneiss and granite (Ham *et al*., 1964; Bickford and Lewis, 1979) and to the south by rocks of a 7-10 km deep Proterozoic Basin (1200-1400 Ma?; Brewer *et al*., 1981). This stage represents the development of a rift possibly the failed third arm of a triple junction associated with the opening of a Cambrian ocean to the southeast (Burke and Dewey, 1973).

The second stage manifested broad subsidence over the rift as a result of elastic flexure of the cooling lithosphere accompanied by differential subsidence along reactivated faults of the rift (Feinstein, 1981). This interval of subsidence lasted from late Cambrian through the Devonian. Quiet water sedimentation is manifested by up to 3 km of shallow water carbonates, quartz arenites, and shales.

The third stage reflects the severe orogenic disturbances affecting much of the southern mid-continent, possibly resulting from the collision of North America with Gondwanaland (Kluth and Coney, 1981). A series of south-dipping reverse faults on the south side of the Anadarko Basin were developed at this time; these record a cumulative vertical offset of over 10 km (Brewer et al., 1983). Up to 5 km of Pennsylvanian flysch and related sediments were deposited in the Anadarko Basin which persisted as a depocenter through the Pennsylvanian.

The fourth and final stage in the evolution of the Anadarko Basin is represented by post-orogenic sediments, principally of Permian age. These can be over 1 km thick and include evaporites, shale, and minor conglomerate (Jordan and Vosburg, 1963). Scattered outcrops of Cretaceous and Tertiary sediments are found in the far western parts of the basin and Quaternary alluvium occupies flood plains. Until recently, orogenic activity was believed to have stopped at the beginning of the Permian. Observations from SIR-A data and the work of Gilbert (1983) and others suggest more recent activity.

3. SIR-A and Airborne Radar Imagery

In November 1981, side-looking radar coverage of the Anadarko Basin was obtained by the Space Shuttle Columbia (Cimino and Elachi, 1982). Briefly, the system employed the L-band (23 cm wavelength) with HH polarization. The look direction of 47.2° off nadir was to the north enabling a swath of about 50 km width to be continuously imaged (Figure 2). Data take 24 B imaged the Anadarko Basin and the Arbuckles along a N60W-S60E axis. Data take 22 imaged the westernmost part of the basin along a N65E-S65W axis (Figures 1 & 2). Subsequently, the region covered by data take 24 B between 99°30' and 96°W was the subject of a September 1983 airborne radar study, using the JPL/NASA L-band synthetic aperture radar (SAR) system aboard the Galileo II, a CV-990 aircraft. Four swaths, each about 14 km wide, were imaged from approximately 35,000 feet with a south-directed look-angle of 15 to 70° (off nadir). Data was correlated optically for the entire study area and a small portion was correlated digitally (Figure 3). The results of these experiments provide the basis for the following discussion.

4. Principal Radar Lineaments of the Anadarko Basin

The principal result of this study is the recognition of three N60W trending lineaments in the Anadarko Basin on the SIR-A images. These lineaments, L_1, L_2, and L_3 (Figure 2) extend from the northwest flank of the Arbuckle Mountains at least as far west as Elk City, Oklahoma, a distance of about 175 km; they may extend into the Texas Panhandle. The lineaments are defined by relative differences in radar backscatter across them. More specifically L_3 is most clearly visible northeast of the Slick Hills (Figure 2). Here L_3 is the boundary between a bright area (strong radar return) to the south and a darker band to the north. L_2 is the most continuous of the three lineaments and is characterized by a brighter return to the north. The dark band between L_3 and L_2 is very distinctive northeast of the Slick Hills (Figure 2). L_1, like L_3, has the darker radar albedo to the north.

In data take 22 the look direction is towards the northwest (Figure 2). Where this crosses data take 24 B the appearance of the three lineaments is less well defined, suggesting that local surface roughness is not a likely explanation. Rather, local slope variations related to northwest trending divides may account for these albedo variations. This proposed slope variation is not a simple relationship. In the west, near Elk City, the drainage patterns indicate that L_1 corresponds to a local high which has a strong reflection from the south dipping slope. This high area gives way to a low area towards the southeast (Figure 2). The Washita River cuts across this lineament .and then follows it from Carnegie to east of Fort Cobb (Figure 2). In this area L_1 loses definition such that L_1 southeast of Anadarko corresponds to an alignment of tributaries of the Washita River and a gradual change in albedo. L_2 appears to be a drainage low in the west near Mountain View (Figure 2). To the southeast L_2 becomes a drainage divide; southeast of Anadarko the south facing slope has a dark radar albedo. L_3 principally follows a drainage low.

The lineaments are also apparent on the airborne SAR data. Digital correlation of radar coverage for a small area southwest of the city of Anadarko is shown in Figure 3. Lineament L_2 is apparent by the backscatter contrast from north to south. The terrain south of L_2 has a higher radar albedo than to the north opposite of the SIR-A. Since the SAR imagery was taken with a south look direction and the SIR-A with a north look direction, this tends to confirm the hypothesis that the lineaments are the result of changes in slope across them.

Two areas were examined to evaluate the relationship between the lineaments and local geology, including available subsurface information. In the east the three lineaments pass through an important oil field near Cement (Figure 4). In this area, some of the youngest Permian units of the Anadarko Basin are exposed. The lineaments appear to cut across the formation boundaries. There is a suggestion that the shales and gypsum of the Cloud Chief Formation may be localized between L_2 and L_3. Topographically, the lineaments correspond to local drainages (Cross Section A-A', Figure 4). From L_3 to L_2 the elevation increases from approximately 1300 feet (433 m) to greater than 1400 feet (467 m) over a horizontal distance of 4.5 miles (8 km). From L_2 to L_1 the elevation drops slightly, but remains near 1400 feet (467 m). In the subsurface there is approximately 3000 feet (1000 m) of Permian strata covering a folded and faulted Pennsylvanian section (Figure 3). The topographic high associated with L_2 corresponds to a significant fault block (Harlton, 1960). This subsurface structure is a faulted dome which extends for at least two townships in a northwest direction. L_2 follows the axis of this subsurface dome.

In the west near Mountain View, the geological picture is more complex (Figure 5). In the northern portion of the map, flat-lying Permian units are near the axis of the Anadarko Basin. L_1 follows this trend to Elk City where the youngest Permian unit, the Elk City Sandstone, crops out forming a topographic high (Figure 2). In the southern portion of the map, the outcrop pattern suggests inclined units. The Marlow Formation, the Dog Creek Shale, and others form narrow outcrop stripes trending east-west with "V's" indicating a northerly dip. These units vary from the usual 1° dip to as steep as 15-30° (K. Johnson, pers. comm., 1984). Quaternary terrace deposits rest unconformably on these northerly dipping units. The change in orientation of the strata occurs between L_2 and L_3. More significantly, however, is the existence of Permian or younger faults such as the southeast-trending faults on the west side of the map (Figure 5). These faults cut rocks of the Guadalupe Series (Kazanian Age, Late Permian). The topographic profile along B-B' reveals a nearly constant elevation between L_3 and L_2 (slightly less than 1500 feet, 500 m). Between L_2 and L_1 the elevation increases to greater than 1550 feet (510 m) associated with the flat-lying Rush Springs and Cloud Chief Formation. In the subsurface, L_3 corresponds to the southern limit of the complex fault zone associated with the Mountain View Fault (Figure 5). L_2 is just to the north of this subsurface fault. The cross section also illustrates the fact that the early Permian unconformity is cut by one of the faults, although the subsurface location does not correspond well with the mapped surface faults.

5. Discussion

We interpret these lineaments to be the surface expression of minor reactivations of buried major faults in the Anadarko Basin as manifested in minor faults or changes in bedding in the Permian cover. The existence of the buried major fault is well documented from drilling results (Harlton 1960, 1963, 1972) and COCORP seismic profiles (Brewer et al., 1983); structural relief of up to 7 km occurs across these faults (Harlton, 1972). This fault system is complex in plan, but is generally characterized by a series of subparallel high angle reverse faults which trend N70W to N40W across the southern margin of the Anadarko Basin. The Permian cover over these faults is on the order of 0.5 to 1 km thick.

There is some evidence for rejuvenation of these Pennsylvanian faults. The Meers Fault to the south is parallel with the lineaments and has clearly had very recent movement, possibly in the Quaternary (Donovan et al., 1983). West of Mountain View, a system of N70W faults affects the Lower Permian El Reno Group (Carr and Bergman, 1976; Figure 5). Units southwest and southeast of Mountain View are locally faulted and show a steepening of dip to the north, interpreted as flexure or drape folding over units that failed at depth (K. Johnson, pers. comm., 1984). These faults and associated monoclines correspond to the zone between L_3 and L_2 (Figure 5). The connection of these with faults and monoclines to a long lineament trend has escaped notice, possibly because of low relief, relatively incompetent beds, and dense vegetation cover.

We also note that the lineaments L_1, L_2, and L_3 are the on-strike continuation of WNW-ESE trending faults in the Arbuckle Mountains; respectively the Reagan, Mill Creek, and Sulphur Faults. On this basis, we suggest that the lineaments observed on the SIR-A image manifest a fault system extending from the Arbuckles to the Texas Panhandle. This interpretation differs from those of previous investigators, such as Harlton (1963) and Ham et al. (1964), who show no connection between the faults of the Arbuckles and those on the south side of the Anadarko Basin. Intriguingly, Harlton (1972) shows the extension of the Mountain View and Cordell Faults east of 98°E, to within 80 km of the Arbuckle Faults. The subsurface trace of the Cordell Fault corresponds closely with the lineament L_1 and the Mountain View Fault corresponds to L_2. The on strike extension of the Mountain View Fault passes through the Cement Oil Field. The area between L_1 and L_2 is referred to as the Cordell Fold Belt by Harlton (1972). In light of Harlton's (1972) revised interpretation of the subsurface data and our interpretation of the SIR-A imagery, we suggest that Arbuckle and Anadarko Basin faults are colinear and coterminous members of a single, albeit complex, fault system.

The COCORP results suggest that the Mountain View Fault system can be traced to depths as great as 24 km (Brewer, et al., 1983). The proposed length and depth of these faults makes these significant on the continental scale ($\sim$24 km x $\geq$ 175 km). Adjustments in plate motion during the Mesozoic or Tertiary may well be reflected by local adjustments along these preexisting planes of weakness. The length, the relative straightness, and the pattern of local uplift and down dropped sections suggest strike-slip motion. Interpretation of recent movement on the Meers Fault south of the Slick Hills (Figure 2) includes normal (down to the south) and some left lateral separation (Donovan, et al., 1983). The relative importance of strike-slip vs. compressional overthrusting in this region has been explored by others (e.g., Brewer et al., 1983; Tanner, 1967; Walper, 1970; Kluth and Coney, 1981); we will only note that our results support models calling for some late component of fault motion to be strike-slip.

Finally, we note that the SIR-A images may be a valuable tool in petroleum exploration. This region has long been one of the most active and prolific oil producing regions in North America (Evans, 1979). Much of the production comes from structural traps associated with the buried Pennsylvanian faults. The delineation of these traps has been expensive and time consuming. We note that the slight surface expression of these faults observed on the radar images indicates this technique may be of value to the detection of buried faults and thus to the recognition of regional structural features and petroleum structural traps.

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FIGURE CAPTIONS

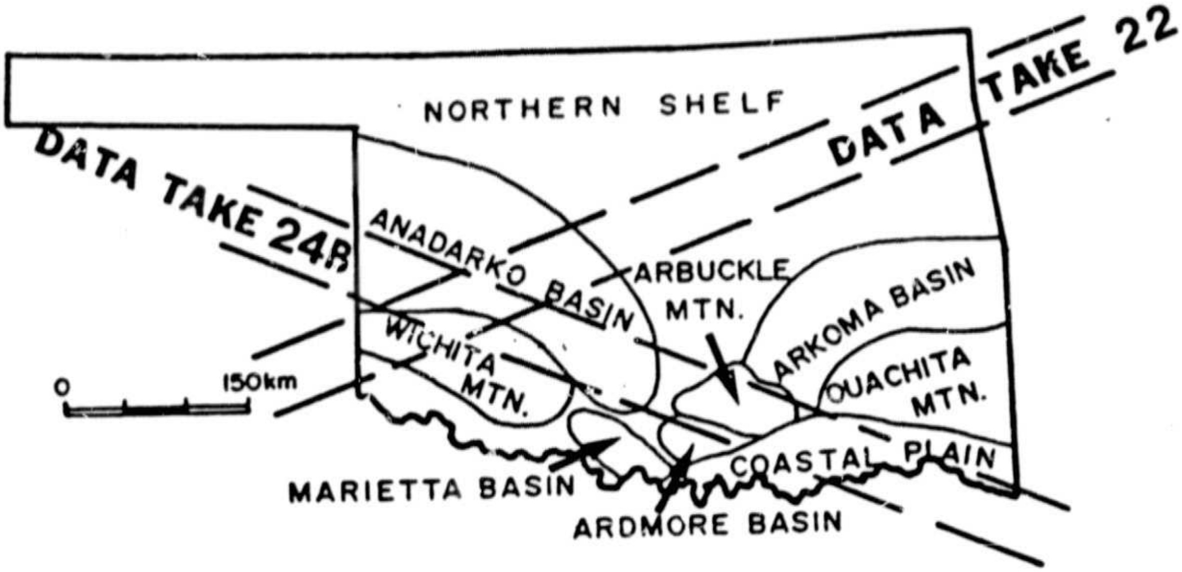
Figure 1. Tectonic elements of Oklahoma and the two flight lines of SIR-A.

Figure 2. SIR-A Data Takes 22 and 24 B with sketch showing principal drainages, the three lineaments observed in Data Take 24 B, towns and mountains. The shaded areas indicate positive drainage areas. The diagonal lines mark the overlap between data takes.

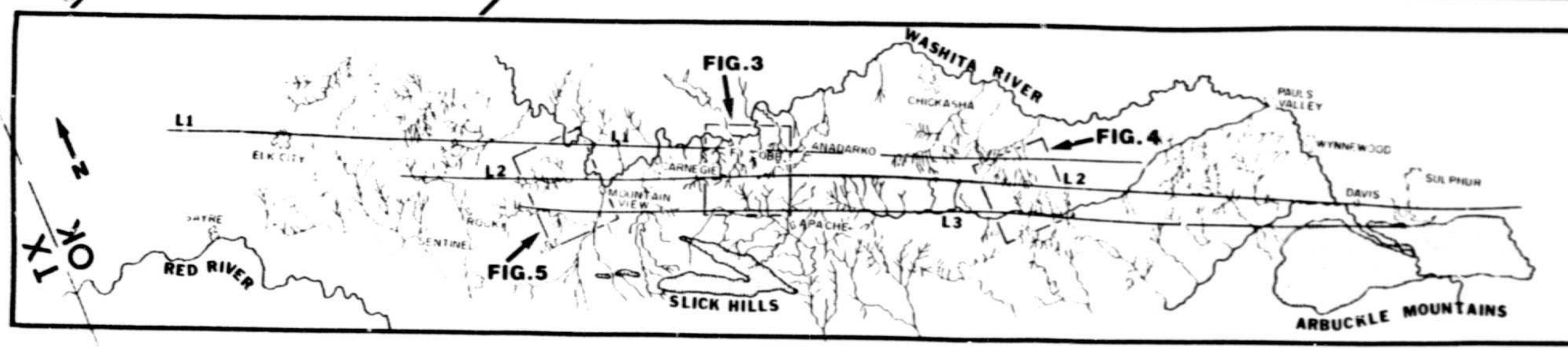
Figure 3. Digitally correlated SAR data for an area southwest of Anadarko (V-V polarization).

Figure 4. The Cement Area of Oklahoma. Geologic map is after Havens, 1977. Topographic profile A-A' from existing topographic maps. Subsurface structure along a portion of A-A' after Harlton (1960).

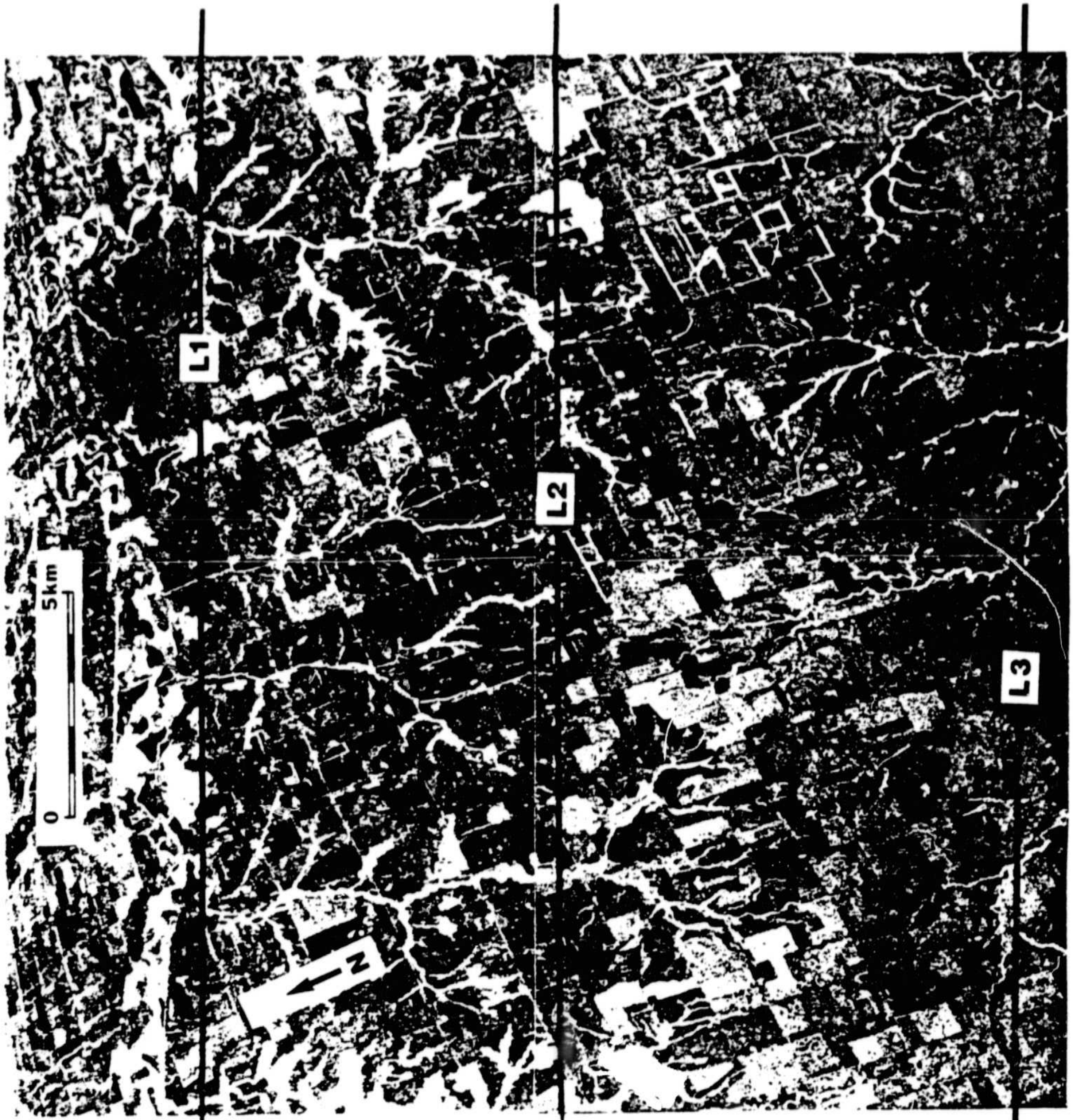
Figure 5. The Mountain View Area of Oklahoma. Geologic map is after Carr and Bergman, 1976. Topographic profile B-B' from existing topographic maps. Subsurface structure along a portion of B-B' after Harlton (1963).

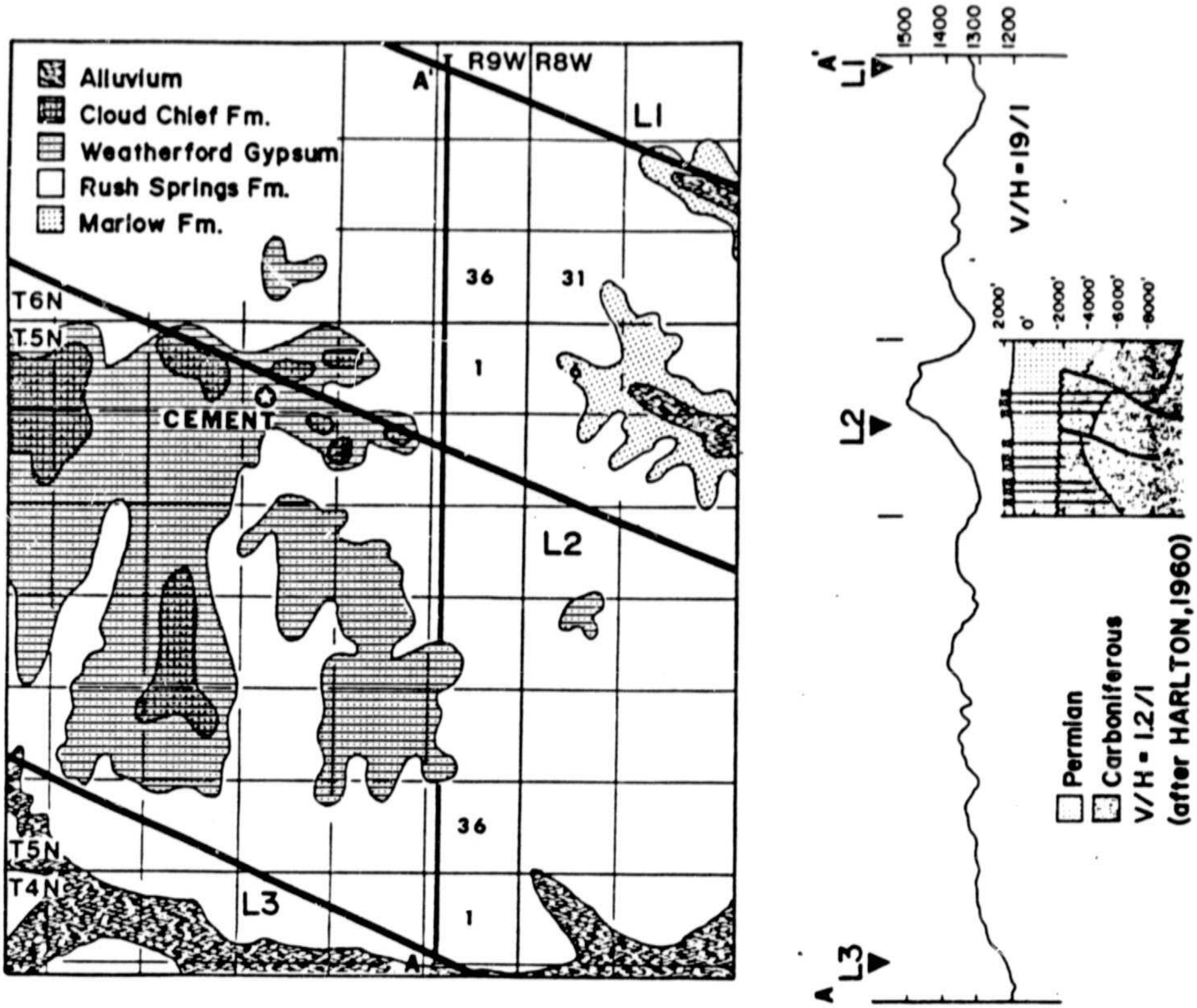

NORTHERN SHELF
DATA TAKE 22
DATA TAKE 24B
ANADARKO BASIN
ARBUCKLE MTN.
ARKOMA BASIN
WICHITA MTN.
OUACHITA MTN.
0
150km
COASTAL PLAIN
MARIETTA BASIN
ARDMORE BASIN

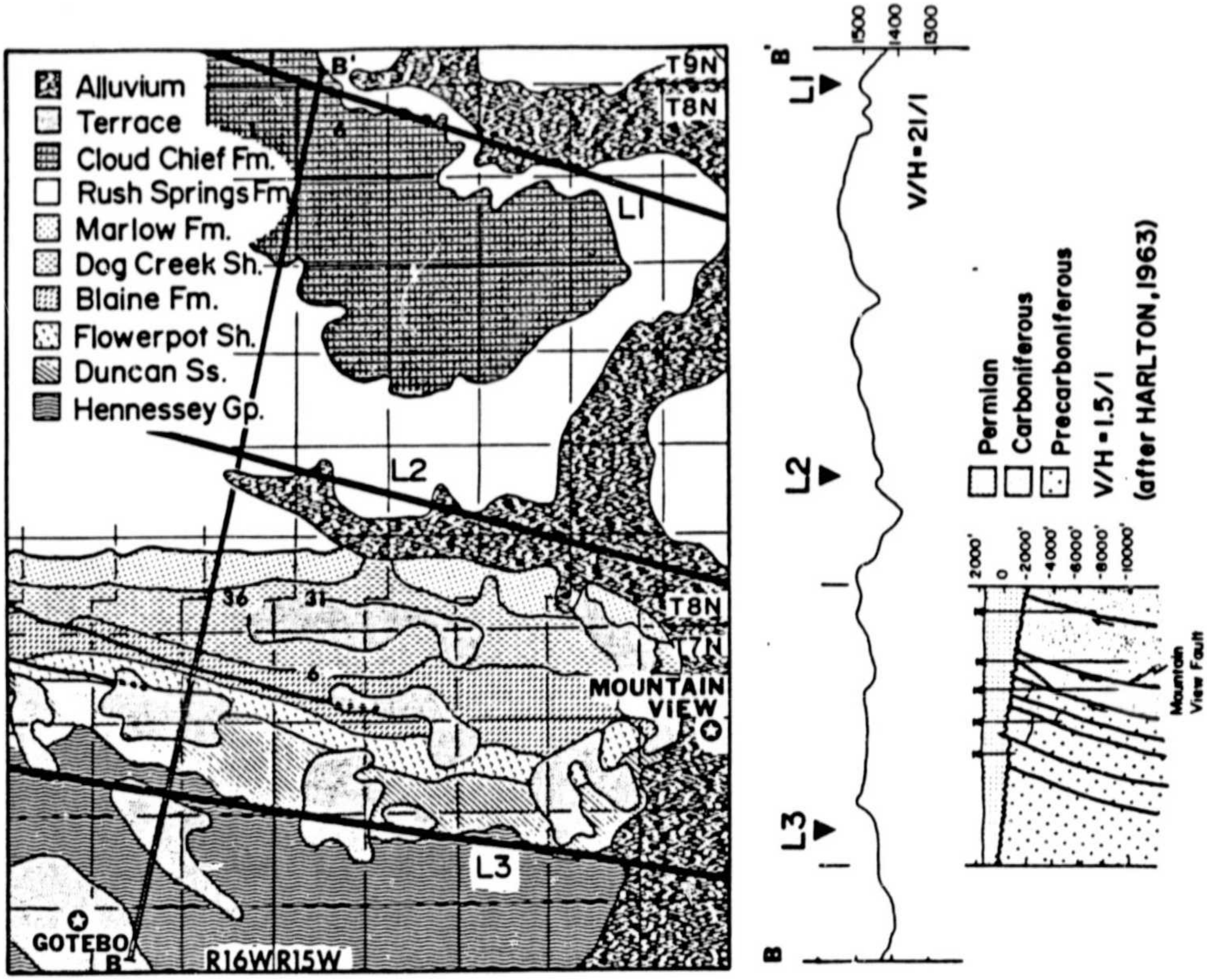
SIR-A DATA TAKE 24B



DATA TAKE 22


L1
L2
L3
0
5km
N


Alluvium
Cloud Chief Fm.
Weatherford Gypsum
Rush Springs Fm.
Marlow Fm.
R9W
R8W
A'
L1
36
31
T6N
T5N
1
6
CEMENT
L2
36
T5N
T4N
L3
1
A
1500
1400
1300
1200
V/H = 19/1
2000'
0'
-2000'
-4000'
-6000'
-8000'
Permian
Carboniferous
V/H = 1.2/1
(after HARLTON, 1960)


Alluvium
Terrace
Cloud Chief Fm.
Rush Springs Fm.
Marlow Fm.
Dog Creek Sh.
Blaine Fm.
Flowerpot Sh.
Duncan Ss.
Hennessey Gp.
B'
T9N
T8N
L1
L2
36
31
6
T8N
T7N
MOUNTAIN
VIEW
L3
GOTEBO
B
R16W R15W
B'
1500
1400
1300
V/H = 21/1
L1
L2
L3
B
Permian
Carboniferous
Precarboniferous
V/H = 1.5/1
(after HARLTON, 1963)
2000'
0
-2000'
-4000'
-6000'
-8000'
-10000'
Mountain View Fault