

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle An Evaluation of the Suitability of ERTS Data for the Purpose of Petroleum Exploration		5. Report Date June 1974	6. Performing Organization Code
7. Author(s) See Front Cover		8. Performing Organization Report No.	
9. Performing Organization Name and Address Eason Oil Company 5225 Shartel Avenue Oklahoma City, Oklahoma 73118		10. Work Unit No.	11. Contract or Grant No. NAS5-21735
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771		13. Type of Report and Period Covered Type III Final Report Jan. 1973 - Jan. 1974	
14. Sponsoring Agency Code			
15. Supplementary Notes ERTS Experiment No. NASA #173			
16. Abstract ERTS-1 data give exploration geologists a new perspective for looking at the earth. The data are excellent for interpreting regional lithologic and structural relationships and quickly directing attention to areas of greatest exploration interest. Information derived from ERTS data useful for petroleum exploration include: linear features, general lithologic distribution, identification of various anomalous features, some details of structures controlling hydrocarbon accumulation, overall structural relationships, and the regional context of the exploration province. Many anomalies (particularly geomorphic anomalies) correlate with known features of petroleum exploration interest. Linears interpreted from the imagery that were checked in the field correlate with fractures. Bands 5 and 7 and color composite imagery acquired during periods of maximum and minimum vegetation vigor are best for geologic interpretation. Preliminary analysis indicates that use of ERTS imagery can substantially reduce the cost of petroleum exploration in relatively unexplored areas.			
17. Key Words (Selected by Author(s)) Geology, Petroleum Exploration, Anadarko Basin		18. Distribution Statement Reproduced by NATIONAL TECHNICAL INFORMATION SERVICE US Department of Commerce Springfield, VA. 22151	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

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PRICES SUBJECT TO CHANGE

AN EVALUATION OF THE SUITABILITY OF ERTS DATA FOR THE  
PURPOSES OF PETROLEUM EXPLORATION

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June 1974  
Final Report

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## I PREFACE

The objective of this experiment is an evaluation of the applicability of Earth Resources Technology Satellite-1 (ERTS-1) data for the purposes of petroleum exploration and a preliminary assessment of the costs of using the data relative to the costs of customary exploration approaches. In particular, we wanted to determine the ability of ERTS data to delineate major structural and lithologic features and to test ERTS as a reconnaissance exploration tool in a geologically well known area (the Anadarko Basin) in order to assess its usefulness in an unknown area.

The experiment involves: interpreting black and white and color composite ERTS imagery in the form of positive and negative transparencies, and positive paper prints at scales ranging from 1:1,000,000 to 1:250,000; testing and evaluating a variety of enhancement procedures - optical, electronic, and digital; comparing the results obtained against published maps and reports, geophysical data, and field work; and evaluating the results in order to determine what useful information can be obtained from the data and what bands, formats, scales and techniques and procedures are best for extracting the information. The work also includes a careful comparison of spring and fall acquired imagery in order to determine the best time of year to acquire imagery for geological interpretation and make a preliminary estimate of the number of times an area should be covered

for optimum interpretation.

Data from Earth Resources Technology Satellite-1 (ERTS-1) are exceedingly useful for petroleum exploration purposes. ERTS data give exploration geologists a new perspective for looking at the earth and reveal new avenues of inquiry. The data are excellent for interpreting regional lithologic and structural relationships and for quickly directing attention to areas of greatest exploration interest.

## II. SUMMARY OF RESULTS

ERTS data are extremely useful for petroleum exploration purposes. The data are excellent for interpreting regional lithologic and structural relationships and quickly directing attention to areas of greatest exploration interest. Perhaps the most important contribution of ERTS is that it provides the exploration geologist a new perspective for looking at the earth and reveals new avenues of inquiry.

We found that most anomalies of various types (particularly the closed geomorphic anomalies) correlate with known features of interest in petroleum exploration.

Many of the linear features interpreted from the imagery correlate with previously mapped fractures and all interpreted linears checked in the field correlate with fractures at the surface. In general, lithologic boundaries inferred from the imagery parallel but do not coincide with mapped boundaries of established stratigraphic units. In some instances interpretation from ERTS imagery actually revises mapping done at much larger scales. Analysis of the lithologic and fracture maps produced from ERTS interpretation focuses attention on some major questions about regional features.

The results of the experiment indicate that bands 5 and 7 and color composites are generally the most useful for geologic interpretation, and that 1:1,000,000 positive transparencies and 1:250,000 paper prints provide the best format for geologic work. However, all bands must

be interpreted in order to extract the maximum amount of information because each band contains some unique information.

Additive color viewing is an easy, flexible, and useful enhancement procedure, but digital processing of the computer compatible tapes (CCT) holds the best potential for enhancement in the future.

Detailed comparisons of all spring and fall acquired imagery (essentially 6 cycles of imagery) indicates that imagery acquired early in a dry fall and late in a wet spring are generally the best for geological interpretation, if one were restricted to using a limited amount of imagery. However, this comparison reveals that each set of imagery over an area contains a significant amount of unique information and optimum interpretation would require examination of imagery acquired over several years.

### III. INTRODUCTION

#### Background

In our original proposal submitted to NASA in April of 1971 we noted that:

"The United States petroleum industry must find some means of arresting the currently deteriorating cost/success ratio of domestic petroleum exploration. The present state-of-the-art of petroleum exploration could be improved by the infusion of new financially efficient exploration procedures, and we believe that orbital imagery may constitute one of these."

The results of this experiment indicate that this intuitive postulate is true, particularly for the less explored areas of this country and relatively unexplored areas abroad.

This need for new, more cost-effective techniques is particularly important. Our original proposal noted:

"Numerous governmental commissions and agencies as well as oil and gas industry associations have recently spotlighted the fact that the nation is now in (and faces in the foreseeable future) an energy shortage of serious dimensions. Salient facts and considerations are:

- \* Gas distribution companies have long lists of customers waiting for new connections;
- \* Many industrial or utility plants face problems of converting from gas to coal or oil with all the attendant pollution and ecological problems;
- \* Importation of crude oil and liquid natural gas is on and will be on the upswing -- the nation is dependent on foreign supply.

- \* Prices for oil and gas at all levels of distribution are rising (both foreign and domestic) thus bringing more fuel to the furnace of inflation;
- \* Domestic inland exploratory spending and drilling activity are at a record low level since World War II;
- \* Domestic oil and gas reserves are declining despite substantial increases in demand; and
- \* The nuclear power industry has not expanded at the rates predicted for earlier forecasts because of public opposition."

The need for increased effectiveness in domestic petroleum exploration was urgent at the time we submitted the proposal and has become even more so consequent to the events of the past year.

A thoughtful appraisal of this situation can only lead to the conclusion that every aspect of new technology applicable to petroleum exploration must be exhaustively tested in order to:

- \* Best utilize technical efforts using customary tools by rapidly focusing exploration attention on the most promising areas;
- \* Reduce the time required to go through the exploration cycle;
- \* Maximize the cost savings in both of these.

#### Objective

As stated in our original proposal the objectives of this experiment are to:

1. Evaluate the ability of ERTS-1 imagery to contribute to an understanding of the geology of the Anadarko Basin-- particularly to contribute to our understanding of the

tectonic history of that basin as it relates to hypotheses for oil and gas exploration; and,

2. Assess the realistic costs for utilization of such data and specifically to assess the incremental value of specialized advanced analytical techniques available to small and middle-sized oil exploration companies.

As work progressed the objectives were broadened and became an effort to determine:

The types and amounts of information of value to petroleum exploration that can be extracted from ERTS data.

The best data products, methods, and techniques to use to extract this information.

The costs of acquiring and using these data for petroleum exploration relative to the costs of obtaining similar information using conventional means.

In particular we wanted to determine the ability of ERTS data to delineate major structural features and to test ERTS as a reconnaissance exploration tool in a geologically well known area in order to assess its usefulness in an unknown area. We did not set out to find oil in the Anadarko Basin, but rather have used it as a geologically well known area with which to test a new exploration tool.

#### General Considerations

The Anadarko Basin lies in western Oklahoma and the Panhandle of Texas. It is an area that has been extensively explored for petroleum for more than 50 years.

In pursuing the experiment we relied primarily on

standard image interpretation techniques, and applied these techniques to black and white and color composite products in transparency and positive print forms. In addition to this work we evaluated several photographic, optical, electronic and computer enhancement techniques.

Throughout the experiment supplementary imagery acted as a cognitive bridge between field work and published data and ERTS-1 imagery and data. This imagery included high altitude black and white multiband, color and color infrared photography, and infrared scanner data supplied by NASA, and side-looking airborne radar (SLAR) provided by the Strategic Air Command.

As noted by many other remote sensing workers, one of the most important lessons learned during this experiment is that optimum exploitation of the space acquired imagery depends upon effectively integrating the space acquired data, aircraft acquired imagery, and ground data (field work, published information and geophysical data). The value of integrating all of these information sources cannot be emphasized too strongly.

From our experiment we have found ERTS-1 data to be an exceedingly valuable tool for obtaining a rapid geologic assessment of large areas. In particular, ERTS data provide a host of information on lithologic distribution and structural features, and quickly draw attention to anomalous features and areas that are of interest from the

standpoint of petroleum exploration. Such features include major fracture trends and several types of anomalies which are discussed below. ERTS data enable one to confirm, refine or modify existing interpretations, and supply a certain amount of new information, particularly about regional relationships. Perhaps most important of all, ERTS gives one a new perspective for looking at the earth and raises many new questions that serve as a basis for additional inquiry. ERTS is not a cure-all find-all, but rather a starting point for regional explorations. In order for information derived from ERTS-1 data to be useful in petroleum exploration, it must be combined with a wide variety of other types of data and included within the structure of a rational exploration strategy.

#### Acknowledgements

We extend our gratitude to NASA for including us in the ERTS-1 Principal Investigator Program and to those individuals who made the program work, particularly Mr. Richard Stonesifer, Mr. Herbert Blodget, Dr. Nicholas Short, and the people of the NASA aircraft program. We thank the many people who have shared their knowledge and experience in the Anadarko Basin with us, including Drs. Mankin, Johnson and Fay, and John Roberts of the Oklahoma Geological Survey, Drs. Myers, Wickham, and Kitts of the School of Geology at the University of Oklahoma, and Bill Jackson and Les Hellen of Eason Oil Company. We are grateful to the many people who

have offered helpful criticism and suggestions during the progress of the experiment. Special thanks go to Louise Skinner and all the people who have typed, retyped and reproduced this and our other reports, and to Don Bernard of Eason Oil Company for his drafting.

#### IV. APPROACH

Members of the study team were generally familiar with published materials on the Anadarko Basin and its hydrocarbon potential. Additional library research was done before arrival of the first ERTS-1 data and later on in the course of the study. The interpretations and analyses of the interpretations were done without direct reference to any surface or subsurface maps or published reports. Such comparisons and checks were made only later in the study.

Our original request included RBV and MSS imagery. Due to early switching and electrical problems on ERTS-1, we have received the MSS coverage only. We used 70 mm. positive and negative transparencies for production of other photographic and enhanced products. 9.5 in. x 9.5 in. transparencies and prints at a 1:1,000,000 scale were interpreted individually and as mosaics. Prints of fall imagery, bands 5 and 7 at 1:250,000 were produced and studied. We created six mosaics; four of fall and two of spring coverage as shown in table 1. Prints at 1:1,000,000 of fall imagery as received from NASA were very dark. We did not print our own. Consequently, the mosaic made from these prints was useful only marginally. Also, we employed tapes of selected scenes, both fall and spring. Complementary imagery employed included high

Scale Season	1:1,000,000	1:250,000
Fall 1972	Color, band 6	Bands 5, 7
Spring 1973	Color band 6	

Table 1. Mosaics of ERTS-1 imagery over the Anadarko Basin.

altitude multiband aerial photographs. This photography was collected and supplied by NASA as an integral part of our ERTS evaluation. It includes five rolls of 70 mm. black and white, color and color-infrared photos, and three rolls of 242 mm. (9.5" X 9.5") color and color-infrared photos. In addition, the RS-7 Thermal Infrared Scanner collected data on the same flight. The Strategic Air Command supplied three short strips of Side-Looking Airborne Radar (SLAR). Location of flight lines and approximate ground coverage of the airborne imagery is shown in figure 1. A complete inventory of imagery received from NASA is included at the end of this report as Appendix A. A description of the enhanced imagery is included in another section of this report ( p.106).

Several types of interpretive maps were made on clear acetate overlays from the imagery, photographs and enhanced images. Initially, these were all done on one overlay with colors used to distinguish one type of interpretation from the other. We soon found that there was such a mass of information derivable from ERTS, that each type of information was best recorded on a separate overlay. Therefore, we produced a set of overlays consisting of inferred lithology, of linear features and of anomalies for bands 5 and 7 and the color composite of each frame.

We say "inferred" lithology because, in general, we cannot recognize tonal or textural differences due directly

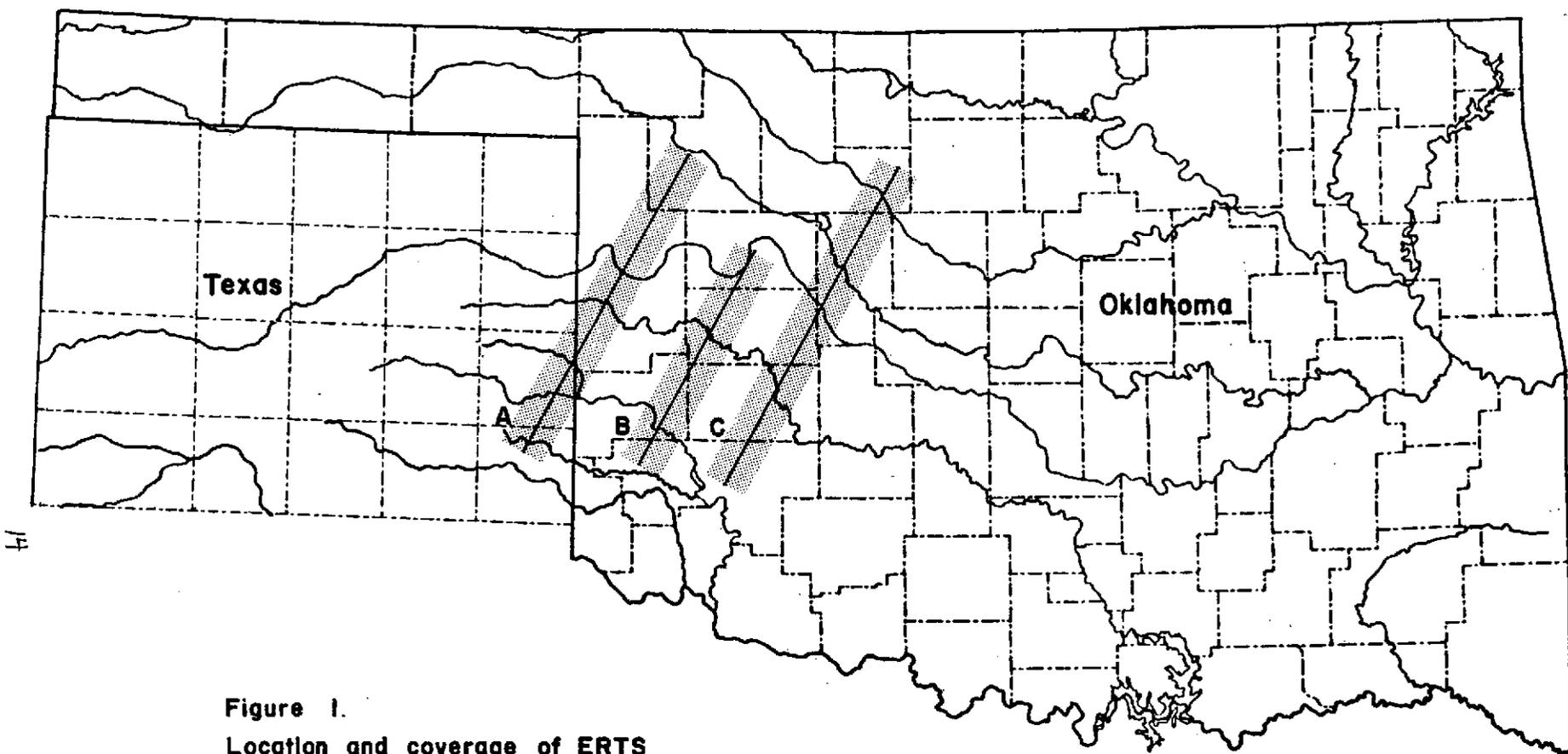


Figure 1.  
 Location and coverage of ERTS  
 underflight photography.

0 40 80 Kilometers  
 0 25 50 Miles

14

to exposed bedrock. What is seen on the imagery are tones, textures, lines or patterns created by differences in distribution and reflectivity of various plant types, both natural and agricultural and of soils and alluvium. Tonal and textural differences may result from topographic effects or contrasts in drainage patterns and densities.

Lithology was interpreted from bands 5 and 7 and from the color composites of every usable scene. Only certain scenes were interpreted for lithology from bands 4 and 6. This same statement holds true for all interpretations. A complete set exists for 5, 7 and color frames. Bands 4 and 6 were interpreted where a refined understanding was desired or when we wished to compare and contrast information and usefulness of all bands.

Linears or linear features include straight segments of streams, alinements of streams, tonal linear anomalies (dark or light zones), topographic alinements, tonal contrasts across a line, linear lithologic contacts, or any combination of these, one in line with the other.

Anomalies are of several kinds and these were interpreted onto acetate overlays as they were noted on the imagery. They were keyed as to their basis on the imagery or their geologic origin where this could reasonably be inferred. Thus, there are tonal and textural anomalies in the imagery. Geomorphic anomalies due to topography or drainage patterns were recorded. There are "hazy"

anomalies which appear as slightly blurred areas. Many of the anomalies are "closed" or roughly circular. Some are due to radial or annular drainage patterns or to tone contrasts. The basis for others is still obscure.

The individual overlays were compiled into regional maps. This resulted in ERTS maps of:

- lithology (Spring and Fall)
- linears 10 km. or longer (Spring and Fall)
- linears 25 km. or longer (Spring and Fall)
- hazy anomalies (all imagery)
- closed anomalies (all imagery)
- miscellaneous anomalies (all imagery)

These regional compilations were used to locate and compare ERTS features with geophysical data, surface and subsurface geological maps and studies of known structures and features of interest in petroleum exploration and with high-altitude multiband photographs. The regional maps were analyzed and interpreted both to evaluate ERTS imagery and for further understanding of information derived from the imagery.

Individual interpretations and regional compilations of this material total 120 overlays. In addition, a number of interpretations were done from the auxiliary photographs, TIR and SLAR imagery. The high altitude photography was particularly valuable as a bridge between the space acquired ERTS imagery and ground features. It provided a means of

understanding the nature and origins of features detected on ERTS images, reducing field checks. The photography is particularly valuable for furthering study of anomalies first noted on ERTS. The photography is also valuable for working in the opposite direction. That is, interesting features or anomalies are frequently noted on the photos and it is desirable either to focus on these at the smaller ERTS scale in order to understand what a particular feature looks like on ERTS or to place them into the regional perspective provided by ERTS. Initially, the photography is also extremely valuable for learning and understanding the kinds and nature of responses seen on ERTS images and in general, becoming familiar with ERTS data.

In summary, small-scale photos and ERTS imagery continually feed back on each other, one serving to focus attention on some part or aspect of the other, continually enriching understanding of both sets of data.

## V. ANADARKO BASIN TEST SITE

### General Description

The Anadarko Basin occupies about 76,800 square kilometers in western Oklahoma and the Panhandle of Texas and is bounded approximately by 34°45' and 37° north latitude and 97°30' and 101°30' west longitude. (figure 2 ) The basin was chosen as a test site because there is a great deal of published information available on the surface and sub-surface geology of the area, there are many structures that act as traps for hydrocarbons, the Anadarko Basin is similar to several other large epicontinental sedimentary basins, Eason's geologists know the area well, and it is convenient to our offices in Oklahoma City.

Climate of the area ranges from moist sub-humid in the north and eastern parts of the area to semi-arid in the western part of the area. Rainfall ranges from one meter per year in the east to less than 40 centimeters per year in the far west. Consequently, native vegetation ranges from scrub oak in the east to short prairie grass and sage in the west.

The entire area is extensively farmed and ranched and most land holdings are divided along township and range survey lines. This imposes a Pervasive north-south and east-west oriented cultural lineation over much of the area. Whereas this cultural lineation breaks up and otherwise obscures many natural boundaries and lineations that

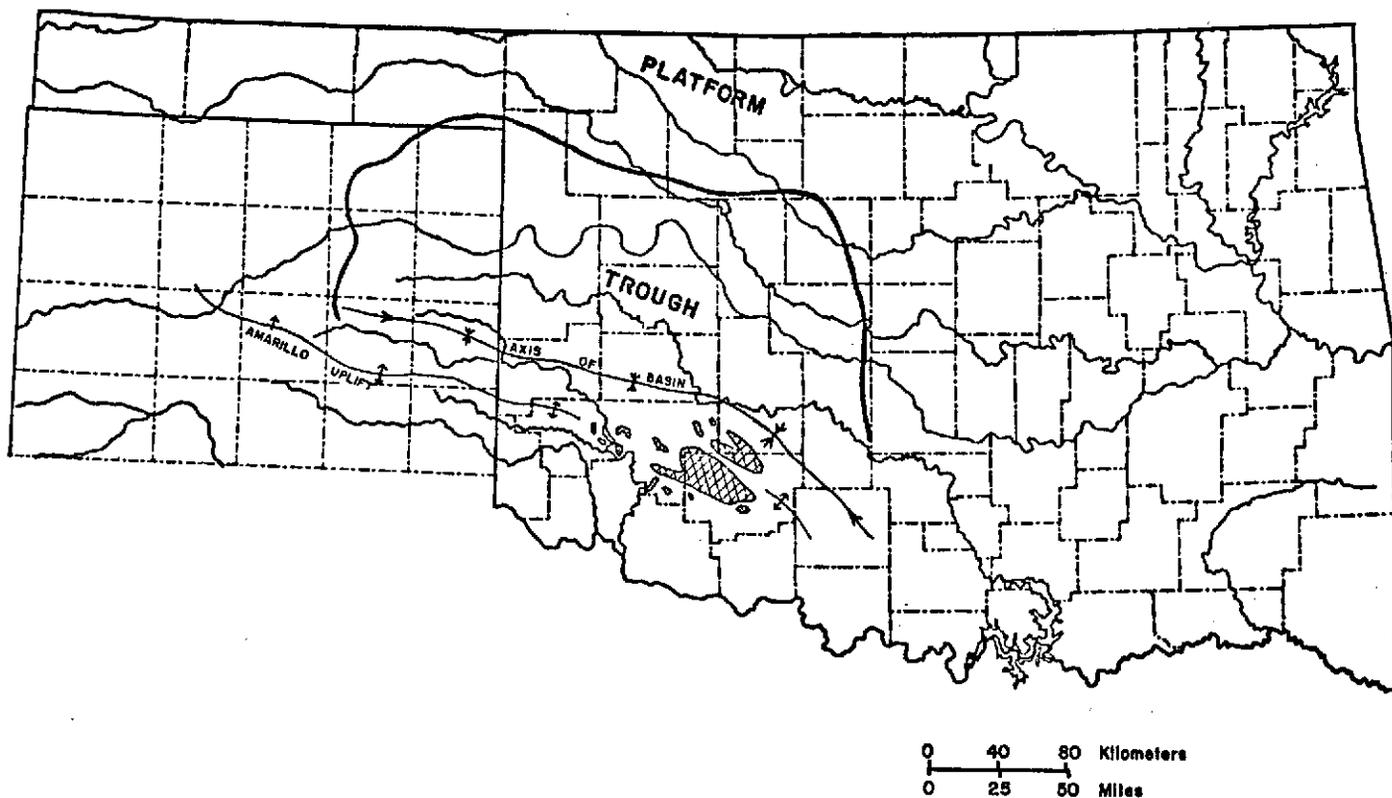


Figure 2. Map showing location of the Anadarko Basin and associated features. Crosshatched area denotes lower Paleozoic sedimentary and crystalline rocks exposed in the Wichita Mountain Uplift.

might ordinarily be visible in the area, constancy of the pattern makes it rather easy to separate man-made linears from natural linears.

A second aspect of the extensive agricultural usage of the area is that the tonal patterns produced by the vegetation are bounded by the cultural linears. Much of what we interpret is, in the final analysis, sensor response to vegetation. Thus at some seasons of the year the cultivated vegetation tends to mask natural boundaries and at other times of the year vegetation serves to accurately mark these boundaries.

In general, changes in topography parallel the changes in climate and vegetation. Altitude of the surface steadily rises from 300 meters in the east to 1,500 meters in the west. Topography of the eastern part of the area is characterized by gently rolling hills with local relief of approximately 60 meters. In the west the topography is characterized by flat undissected uplands and mesas and deep canyons with local relief on the order of 350 meters.

#### Geology

The Anadarko Basin is a large west-northwest trending asymmetric syncline. The south flank of the basin is much steeper than the north flank. For the purposes of this paper it can be defined by the -1000 meter structural contour on the top of the Mississippian rocks. The axis of the basin lies about 40 kilometers north of the Wichita Mountains

which expose early Cambrian crystalline rocks. The basin is filled with approximately 18,000 meters of late Pre-Cambrian and Paleozoic sedimentary and layered volcanic rocks. The western end of the basin is covered by flat-lying late Tertiary continental sedimentary rocks.

Rocks in the basin have undergone several periods of deformation the most severe of which began in early Pennsylvanian time and continued intermittently until early Permian time, producing many structures of importance to geologic exploration. The basin is bounded by the Nemaha Ridge on the east, the Amarillo-Wichita mountain front on the south, the Cimarron uplift on the west end and the Central Kansas uplift on the north.

#### Stratigraphy and Geologic History

In general terms the layered rocks in the Anadarko Basin can be divided into six major groups. (figure 3 ) The oldest rocks in the basin consist of more than 7,000 meters of late Precambrian and early Cambrian sedimentary and layered igneous rocks. Above the Cambrian series are about 5,000 meters of pre-early Pennsylvanian rocks - - sandstone, shale, and limestone, and approximately 5,000 meters of Pennsylvanian and early Permian clastic rocks that mark a period of rapid subsidence and orogenic deformation. Next higher in the sequence are about 1,000 meters of gently dipping Permian rocks - - mostly red beds and evaporites that accumulated during late gentle basin

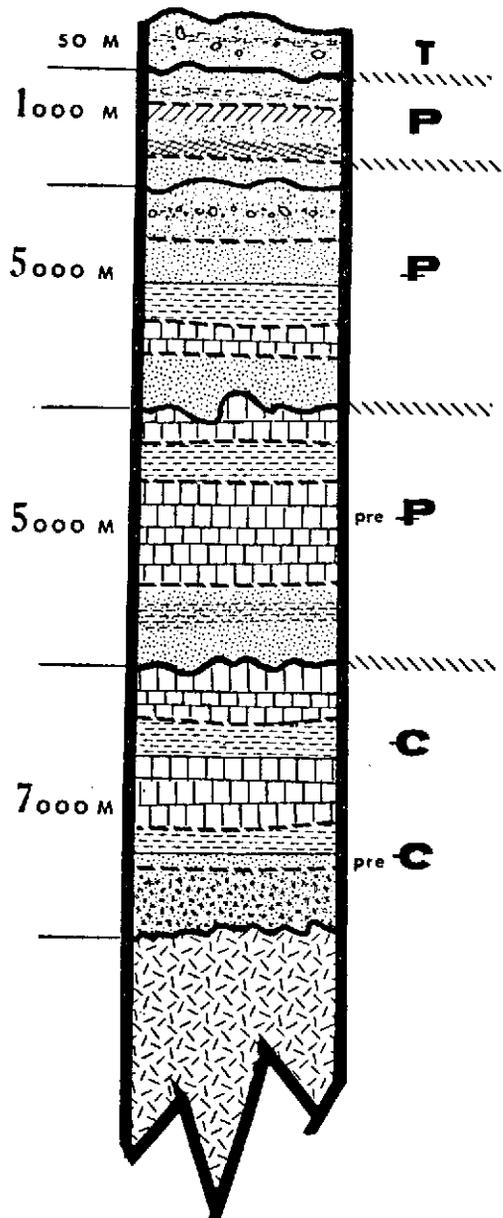


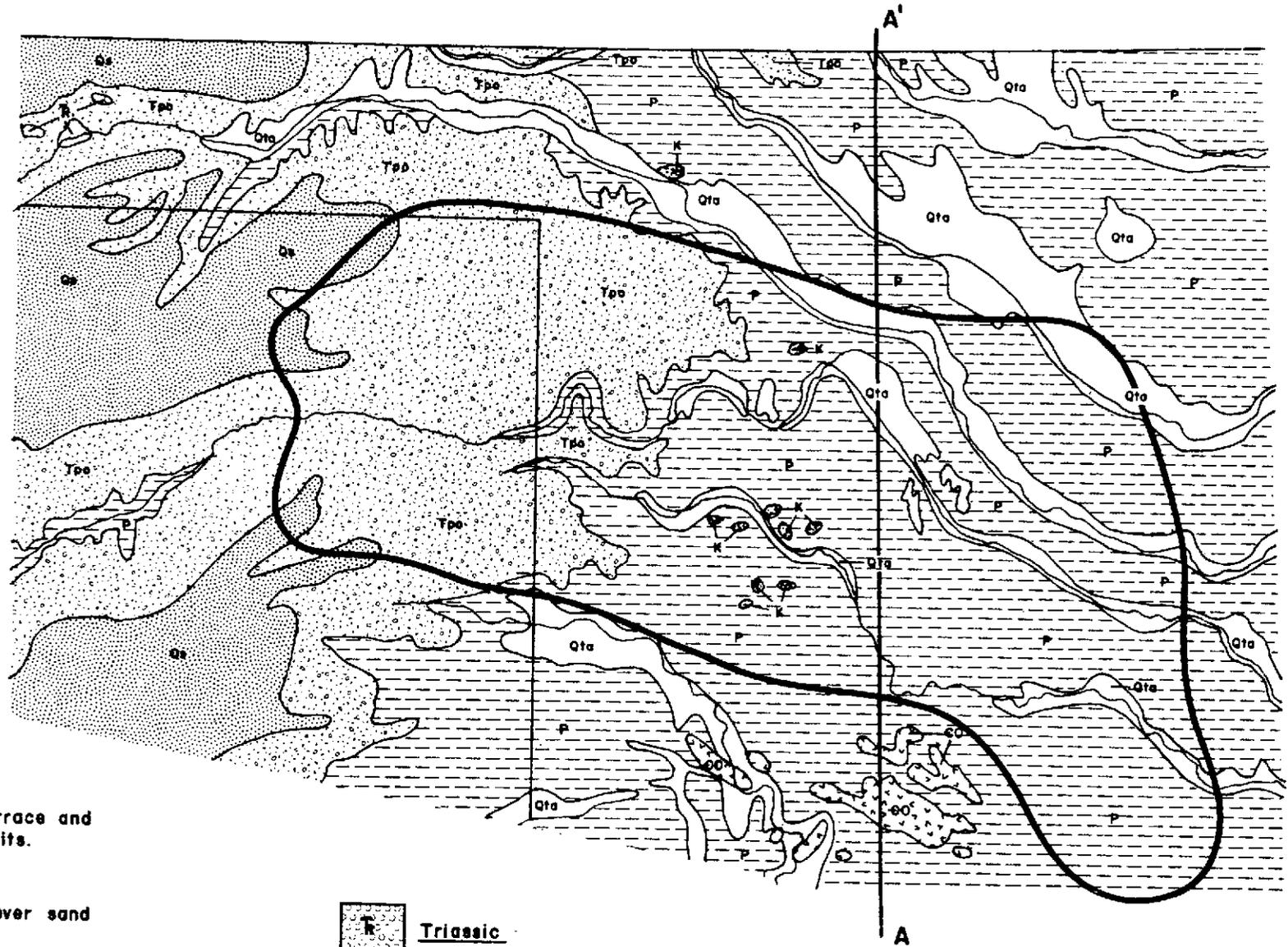
Figure 3. Simplified stratigraphic column for the Anadarko Basin, showing the late Precambrian and Cambrian (pre-C, C) sedimentary and igneous rocks, pre-Pennsylvanian (pre-P) miogeosynclinal rocks, Pennsylvanian (P) clastic sedimentary rocks deposited during orogenic downwarp of the basin and uplift of the Wichita-Amarillo Mountain system, and Permian (P) late stage basin fill composed of red beds and evaporites. A thin cover of Tertiary rocks (T) occurs in the western part of the basin.

subsidence with periods of restricted circulation (marking the end of the evolution of the Anadarko Basin per se.) Tertiary (primarily Pliocene Ogallala) fluvial and deltaic clastic rocks overlie the west end of the basin, and Quaternary deposits occur along the major rivers and as large areas of wind-blown sand on the uplands (figure 4).

Evolution of the Anadarko Basin began in late Cambrian time when seas spread into the mid-continent from the Ouachita trough to the south. In the southern Oklahoma embayment Precambrian clastic rocks were reworked and deposited as the Reagan sandstone.

The embayment axis trended west-northwest from central Oklahoma to the Sierra Grande highland to the west. Several areas of high relief affected sedimentation. Among these were Sierra Grande in the west, Llanoria to the south, and the central Kansas arch on the northeast. By the time of deposition of the Cambrian-Ordovician Arbuckle group the crust in the vicinity of the present Anadarko Basin had developed into a broad sag. Minor structural adjustments caused thinning and local unconformities in units near the margin of the basin. This pattern of deposition continued essentially uninterrupted into mid-Devonian time. As the basin gradually subsided, the sea encroached on wider and wider areas during the deposition of the Simpson, Viola, Sylvan and Hunton formations. Deposition was continuous near the center of the basin but

Figure 4. Generalized Geologic Map Of The Anadarko Basin.



**Qta** Quaternary: terrace and alluvial deposits.

**Qa** Quaternary: cover sand on uplands

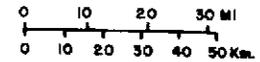
**Tpo** Tertiary: pliocene, Ogallala formation.

**K** Cretaceous

**R** Triassic

**P** Permian: redbeds, undifferentiated.

**eo** Cambrian and Ordovician outcrops of Wichita Mtns.



Scale: 1:2,000,000

(After Branson & Johnson, 1972)

was repeatedly interrupted on shelf areas.

The entire region was uplifted in middle Devonian time. The Hunton formation, a primary target in current deep drilling programs, and all older rocks were bevelled, particularly to the north and northeast exposing Precambrian rocks in places. Wheeler (1955) suggests that by this time the Amarillo-Wichita trend was already a positive feature.

The siliceous shales of the Devonian-Mississippian Woodford Formation accumulated on this irregular surface. Woodford deposition continued into Mississippian times. A thick carbonate section was deposited during the relatively stable Mississippian period. At the end of Mississippian time epierogenic uplift again occurred, seas retreated to the basin deeps, and the top of the Mississippian was eroded. Many features which later became prominent structural features began to develop as gentle folds and local warps.

Springeran deposition was restricted to the deep part of the basin. In the center of the basin deposition was continuous into Morrowan time. Morrowan deposits overlapped Springer deposits toward the edges of the basin.

The Anadarko Basin and the Amarillo-Wichita-Criner Hills uplift as they exist today developed within the large basin in late Morrowan and Atokan time. This tectonic activity known as the Wichita Orogeny raised the Amarillo and Wichita Mountains by high angle faulting and developed a foredeep to the north, creating the strong asymmetry of the Anadarko

Basin. This fault system parallels older structural trends and consists mostly of normal faults (Wroblewski, 1967).

Marine deposition continued in the basin through Atoka and Des Moines time. However, there is a wide spread unconformity at the top of the Atoka and there are local onlap-offlap relationships throughout the Atoka and Des Moines sections on the shelf. Coarse clastic rocks thin northward from the mountains, interfingering and grading into finer grained basin and shelf deposits.

The basin deepened rapidly during the Pennsylvanian period. A new north 30° west trending system of faults formed, cutting older folds and faults (Wroblewski, 1967). These structures formed during a period of down-to-the-basin normal faulting. A third episode of Pennsylvanian tectonic activity produced faults that trend north 45° east. These faults cut other Pennsylvanian faults but may have been active in pre-Pennsylvanian time (Wroblewski, 1967). Both the north 30° west and north 45° east sets of faults are transverse to and apparently unrelated to previously established structural trends.

The importance and persistence of old structures is demonstrated by the Ft. Cobb, Cordell, Sayre and Mobeetie features. These are pre-Mississippian faulted anticlines trending northwest that were again deformed during Pennsylvanian time (Wroblewski, 1967).

Renewed orogeny in late Pennsylvanian time rejuvenated older structures but deformation did not extend as far north into the Anadarko Basin as did earlier activity. Missourian and Virgilian deposition was widespread and continuous with the lower Permian. Clastic rocks consistently grade into finer grained basin deposits to the north. By late Pennsylvanian times all but a few topographically high remnants of earlier tectonic activity had been covered by these deposits.

During Permian time the basin gently subsided. The basin became filled and land locked and great evaporite sequences accumulated.

Triassic and Jurassic deposits consist of isolated evaporites and terrestrial materials that accumulated in an arid upland. Little remains of Cretaceous rocks which may or may not have once covered much of the region. Apparently, the entire area was elevated and tilted to the east during Laramide deformation.

Tertiary activity consisted of minor warping and the accumulation of terrestrial deposits.

Rocks that crop out in the area include Permian red beds and evaporites, Tertiary fluvial and deltaic clastic sedimentary rocks, and Quaternary alluvium along major rivers and the terraces adjacent to the rivers, and large areas of wind borne sand on the uplands.

Most of the structures that trap hydrocarbons were created during the intermittent tectonism that began in earliest Pennsylvanian time and continued into earliest Permian time. Most of the structural traps in the basin are located in the highly deformed frontal zone north of the Wichita-Amarillo Mountain trend (figures 5 and 6).

#### Possible Role of ERTS

Exploration for structurally trapped hydrocarbons in the basin is exceedingly difficult because the important structures are buried by Permian and younger rocks up to 2,000 meters thick that have undergone at most only gentle deformation and for the most part mask the more highly deformed lower Paleozoic rocks. The surface features that reflect the deeply buried structures are extremely subtle and may be masked by much younger structures produced by the solution of Permian evaporite deposits.

Features of interest in petroleum exploration resulting from this complex history that might be detected in ERTS imagery include:

Linear features marking old fracture trends that may have controlled deposition, formation of structural traps or routes of migration for hydrocarbons.

Patterns of lithologic units of the surface that could give clues as to the overall structure of the basin and the existence of hydrocarbon trapping structures.

Closed geomorphic, tonal or textural anomalies that might indicate buried structural features such as fault blocks, domes or anticlines.

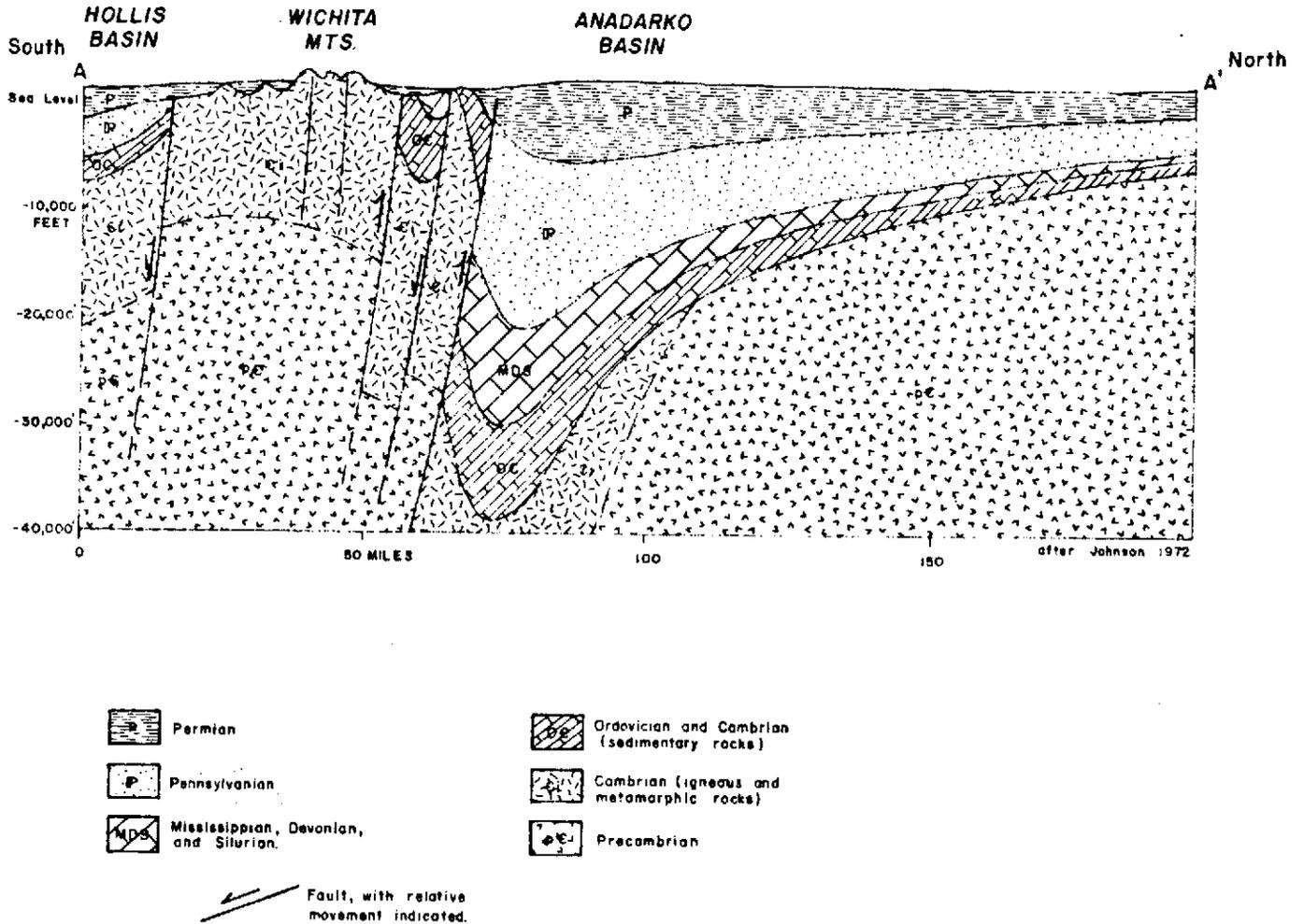
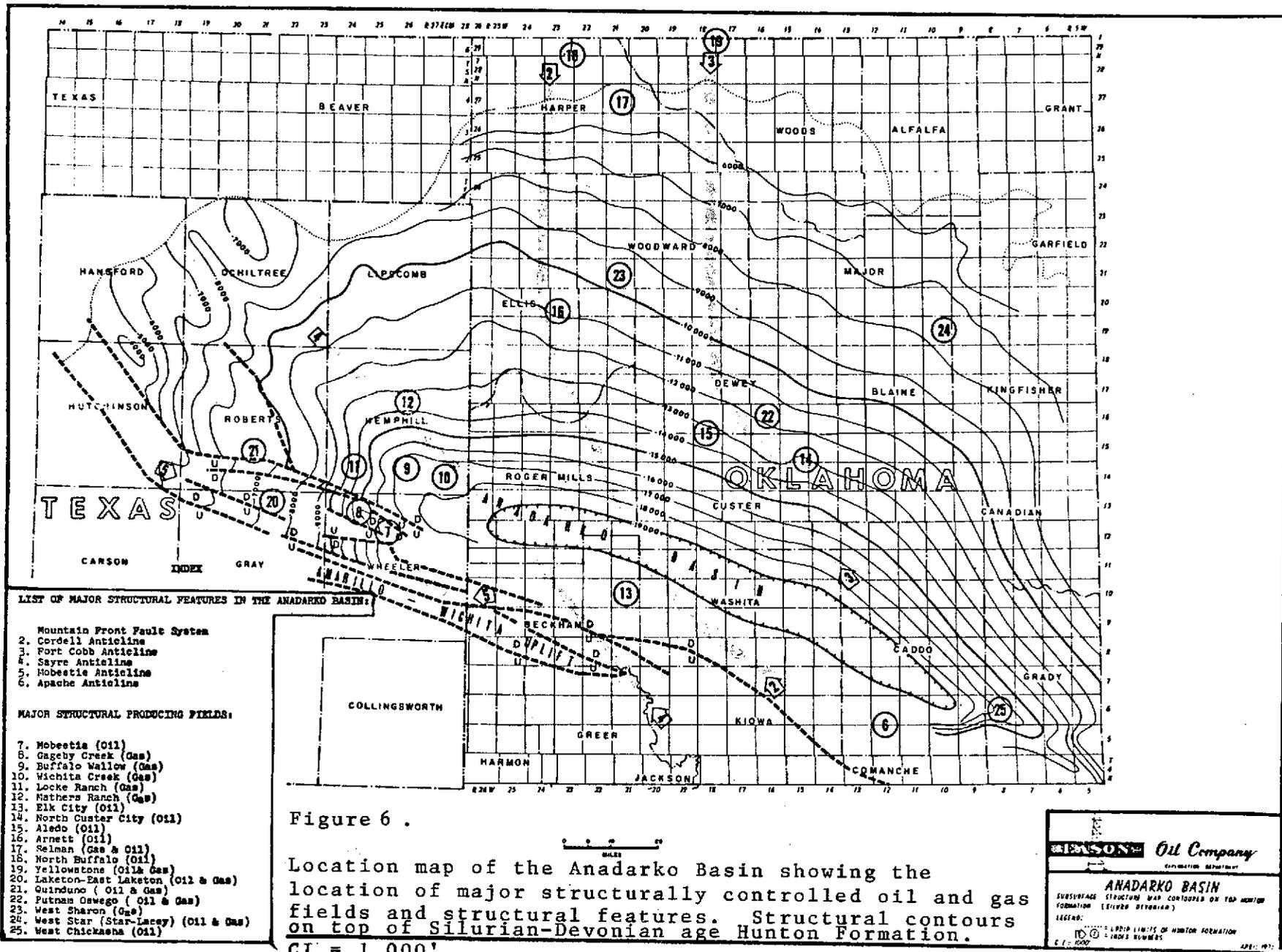


Figure 5. Cross section through the Wichita Mountains and Anadarko Basin showing asymmetry of the basin and the complex frontal structure composed of folds and high angle faults. Line of section shown in figure 4.

30

NOT REPRODUCIBLE



Our hypothesis was that the synoptic view provided by ERTS imagery might allow integration of a sufficient number of these subtle features so, as in effect, to see the deeply buried structures through the overlying rocks (Melton, 1959), (Doeringsfeld, 1964), (Trollinger, 1968).

Intensive petroleum exploration began in the basin in 1917. Traditionally, exploration has concentrated on structures along the south flank of the basin and on shallow stratigraphic traps on the northern shelf of the basin. It is only during the past five years that the deeper parts of the basin have received extensive exploration attention. At present there are more than 75 rigs drilling in the basin for targets that range in depth from several hundred meters to 7,800 meters. Since distribution of the draft of this report, a new drilling record has been set in western Oklahoma. The Lone Star #1 Bertha Rogers, at 9,570 meters (31,441 ft.) is the deepest hole in the world. However, it will have to be plugged back to 4,260 meters. The Rogers exceeds the Lone Star #1 Baden (record holder since 1972) by 410 meters.

## VI. EVALUATION OF THE ERTS IMAGERY

An important step in evaluating the applicability of ERTS imagery to petroleum exploration was to determine which bands, scales and formats of imagery were best for geologic interpretation in the Anadarko Basin, what times of the year were best for acquiring imagery with the maximum amount of interpretable geologic information and what kind of resolution could be expected in the imagery. To do this we carefully compared several different types of interpretations made from prints and transparencies at several scales of all bands and color composites of imagery acquired at several times of the year.

From these comparisons we concluded that if one were constrained to use a limited amount of imagery, by time or funds available, one should use band 5 and 7 and color composites of imagery acquired during periods of maximum or minimum vegetation vigor either in the form of 1:1,000,000 scale transparencies or 1:250,000 paper prints. However, if at all possible, one should interpret all bands of imagery acquired at several different times of year. In fact, in an area like Oklahoma, where the annual climatic cycle is highly variable, one would at least want to examine, if not interpret in detail, imagery acquired over several years time.

### Comparison of Scale and Format

We used prints at a scale of 1:250,000 (1" = 4 mi.) for interpretation and compilation. At this scale, prints of entire ERTS frames are inconvenient to handle, but manageable. Imagery at this scale has several advantages over small scale images. No magnification is needed for most of our purposes and little or no detail is lost in the enlarging process. The 1:250,000 scale permits careful interpretation and precise location of data points and geologic features and resolves features that are ambiguous or difficult to define at smaller scales. It matches the scale of standard 1° x 2° USGS topographic maps. Also, it is convenient for discussion and compilation purposes.

Transparencies of ERTS frames at 1:1,000,000 (1" = 16 mi.) are convenient for handling, storage and study (provided a light table is available). A near-maximum amount of information can be derived from them although moderate magnification (3x to 10x) is frequently required. The same can be said for prints at the same scale except for lighting difficulties. Transparencies eliminate glare and a need for properly positioned overhead lighting and preserve a bit more visual detail. However, prints can be made into mosaics. Mosaics are convenient up to 30 or 35 frames, but at 1:250,000, mosaics of 4 or 6 frames become difficult to display and handle.

We used 70 mm. (1:3,369,000) positive and negative

transparencies mainly for enhancement and/or photographic reproduction. The positives are also occasionally useful for reference and projection in lantern slides.

Interpretation at scales of 1:1,000,000 and at 1:250,000 showed little difference in the amount and kind of information derived from imagery. Tonal and geomorphic anomalies were the same but there were some "new" textural anomalies found at 1:250,000 that had not been noted at 1:1,000,000. The larger scale permits more detailed and precise location of lithologic boundaries than the smaller. We did, however, recognize the same units at both scales.

In mapping linears we noted differences in the number and lengths of linears appearing on imagery of the same frame at these two scales. In one test case (frame 1131-16465) on band 7 we counted 1,557 linears. 186 of these were unique to the larger scale image while 457 were unique to the smaller. On band 5 there were 1,950 linears, 520 unique to the smaller scale, 565 unique to the larger. Although there may be several reasons for varying counts of linears from interpretation to interpretation, these figures demonstrate that a maximum amount of information on linears can be derived by employing at least two different scales.

Interpretation at 1:250,000 consistently produced linears of greater length than did those at 1:1,000,000. The larger scale significantly extended the lengths of

linears previously noted on imagery at 1:1,000,000. Only in a few instances did the smaller scale extend linears from the larger.

In summary, we feel that one scale has no real interpretive advantages over the other. The main advantages are in terms of convenient format for study or display. Certainly both scales add something and both should be used when possible.

Parts of one scene were enlarged to 1:100,000 with little apparent loss of definition. This is probably the working limit for geologic purposes. An entire image enlarged to this scale would be an unwieldy object. Enlargement to this scale should be produced only for areas of special interest.

## Resolution of Imagery

It is difficult to assess apparent resolution of the imagery in the Anadarko Basin because of the variables involved in recognition of different kinds of cultural and geological features and the difficulty in distinguishing recognition from resolution. We might generalize about recognition of non-linear and linear features. Non-linear features include warehouses, ponds, quarries, buttes, fields, woodlots, etc. Ponds as small as one acre (68 meters in diameter) can be recognized on band 7 in high-contrast situations. However, 100 meters seems to be the practical minimum dimension needed for recognition of individual fields, buildings and other features as well as ponds.

Linear features (bedrock joints, roads, creeks, etc.) whose width is much less than 64 meters are easily recognized because of their length, either from their own reflectivities if they stand in strong contrast to their surroundings, or from the difference in reflectivities of areally extensive features on either side. For example, creek beds as narrow as 15 meters can be recognized by topography, shadow, or vegetation contrasts or a combination of these. The length of creeks and their meandering habit distinguish them from hedgerows, or fence rows, for instance. The smallest feature we have noted is in a high contrast

situation on band 7 where two highly reflective bridges cross a lake. One visible bridge has a roadway 8.5 meters wide plus two sidewalks 1 meter each or a total of 10.5 meters (34 ft.). The other bridge has only 7.3 meters (24 ft.) of roadway and no sidewalks, yet is visible on ERTS images. A working limit for recognition of linears by their own reflectivity seems to be 20 meters. Linears of essentially zero width such as fence lines, lithologic contacts or faults are recognized by contrasts in reflectivity on either side of the line.

### Comparison of Bands

One of the first steps in handling and interpreting ERTS-1 imagery was to determine the applicability and utility of each of the four MSS bands to analysis of structural and lithologic features. We concluded that bands 5 and 7 are most useful for initial geologic interpretation. Their utility is optimized when they are used together. Band 4 is the least useful. Bands 6 and 7 contain largely redundant information, yet the minor differences between the two are exceedingly important for geologic interpretation. The subtleties of tonal difference in many instances correspond to differences in lithology or surficial composition. We emphasize that these conclusions are of a general nature only. No study is complete until all four bands have been studied and compared. There are items of information unique to each band.

Another conclusion is that color composites contain the most information of any single product. In addition to tonal variations, there are color differences in the composites which either add information or make interpretation quicker and easier. One drawback is the imperfect registration of bands in making the composites. This causes loss of resolution and detail and renders them less "sharp" than individual black-and-white bands.

We compared the following aspects of the imagery examined: overall contrast; tonal signatures and relative

visibility on each band of common features such as roads, quarries, towns, clouds, snow, native and cultivated vegetation, gross lithologic types, bare soil, shadows, river bottoms, clear and silty water bodies, etc.; scan-line visibility; variations in tone between lines; atmospheric haze; effects of contrast reversals between bands, and effective resolution. Examples of some of the above are:

- \*Healthy plants appear white on band 7, black on band 5.

- \*Water is black and in high contrast to all other features on band 7, while it may be light gray to black on band 5 depending on silt content.

- \*Most standing bodies of water are difficult or impossible to locate on band 4 because the reflectivity of turbid water in this band is very close to that of several types of soils, rocks and plants. This results in overall low contrast.

- \*Cities, large towns and major roads stand out as light areas in a background of medium grays on band 4.

In comparing bands, we found that for the same types of information, contrasts and tonal quality vary from region to region and even within regions. Thus, a statement here that a given band is best for fracture analysis means it is best for this purpose in western Oklahoma and the Texas Panhandle and not necessarily everywhere. The reason for this variation is that overall contrast and tonal signature are determined by the distribution of relative sizes of areas covered by, and degree of intermixing of

areally extensive features (particularly soil and rock types and vegetation types). The distribution and reflectance of these features will vary with climate, season and topography. Thus, the sparse vegetation of western Oklahoma may provide a high contrast situation in band 5 but images in band 5 taken over southeast Oklahoma or southern Missouri may be of very low contrast due to profuse vegetation in those areas.

#### Standing Water:

Lakes and ponds appear black on band 7. Since plants are ubiquitous and on band 7 are white to light gray when healthy, ponded water stands in stark contrast to light background. This makes locating and inventorying water easy and rapid. Moreover, ponds are visible at the limits of resolution of the imagery, namely as small as 34 meters in radius. Band 6 generally reveals standing water quite well but is somewhat more subject to scatter by atmospheric moisture and haze. In some instances, there is less contrast between land and water than in 7, and some small ponds that are quite visible on band 7 are not seen on 6. Band 6 is more sensitive to turbidity in water than is 7 and may show strong plumes of silt when no hint is these is seen on 7.

The tonal qualities of water are quite variable on band 5. Clear water is near black. Silty water may appear medium to dark gray on 5, depending mainly on the silt content and its dispersion in the upper portions of water bodies. Because its tone varies on 5, water may produce a

low or high contrast with adjacent surface materials. In addition, since 5 is generally a high contrast band, many kinds of features show up well and, as a result, water bodies may be lost among many other high contrast features.

Terrestrial water bodies are difficult to locate on band 4 images. Regardless of turbidity, water is seen as middle gray tones similar to the tones of many rock, soil and vegetation types, and shorelines may be impossible to detect. Often a water body can be distinguished from surrounding features only by its "smooth" uniform tone. Subtle tone differences and light shadows may lend a slight texture to the surrounding surfaces.

#### Stream Valleys:

The varying appearances of stream valleys between bands 5 and 7 and in different parts of the study region reinforce the observation that the generalizations made are valid only for the region considered. In some frames, small and intermediate size streams (3 to 70 kilometers long) are seen easily on band 5 in situations where live plants (low reflectivity in this band) are concentrated in the valleys, and slopes and uplands are of high or moderate reflectivity. The valleys then are dark or almost black and stand in marked contrast to some of the slopes and uplands which appear light gray.

On some of these frames in band 7, the plants near the streams are white or at least irregularly bright and higher

surfaces are also moderately bright to medium gray in tone. The resulting contrast is lower than in 5 and opposite in tone. Thus, in some frames both 5 and 7 may be useful for drainage analysis but, when contrast is good in both 5 and 7, band 7 often proves more useful for locating and tracing small streams and valleys. Band 6 is similar to 7.

Short streams are often difficult to see on band 4 because contrast is low. Rugged or badlands topography enhances valleys in this band as it does in all others.

Major streams such as the Red, Washita, Canadian and Cimarron Rivers are markedly different from the small streams because they have large meanders, wide valleys, braided channels and broad expanses of their beds exposed. The beds of the Red, Canadian and Cimarron usually show as continuous bright strings on bands 4 and 5. These river beds contain large expanses of quartz sand which in the field is white to pale yellow to reddish brown to pale red. In band 7, the bed material has a lower reflectivity overall. Band 7 is sensitive to a variety of factors which affect reflectivity and make the beds of these rivers much less distinct than they are on 4 and 5. The freshly washed channel is bright, but moisture and standing water along with some vegetation and surface particle types reduce reflection at points along the stream. The result is a discontinuous or mottled, moderately bright thread on the imagery which is easily lost among surrounding features.

The beds and valleys of the Washita and North Canadian are generally narrower than those of the aforementioned streams. Water is restricted to narrow channels, and trees and shrubs close in the banks. Farming and ranching extend close to the channels. Farming does not reach into the wide, braided beds of the other major streams but is restricted to the adjacent floodplain and, in some instances, to older terraces. White or highly reflective sand is exposed only occasionally because trees and shadows cover portions of the channels and because much of the riverbeds are wet or water-covered. Moreover, the narrow riverbed easily is lost among varied tones produced by the agricultural lands lining the banks. In addition, the vegetation is spotty, being variously dense, scattered or absent. Different reflectivities are also produced by variations in soils and lithology exposed in riverbanks which produces a string of irregular bright and dark features against a "mottled" background. These factors all make it difficult to determine the exact courses of the Washita and North Canadian.

#### Linear Features:

Most of the above discussion on minor streams is applicable to linear features. In fact, fault and joint traces are most frequently revealed by drainage alignments. Linear features in the imagery may include a variety of things: roads, imagery processing effects, scanlines, strike of rock units, drainage alignments, anomalously straight

stretches in streams; lines of vegetation, springs and water bodies; plateau and fault scarps; anomalous alinement of tonal features; even political boundaries where surveying or land use practices change abruptly. As used here the meaning of "linear features" or "linears" is restricted to naturally occurring features that are inferred to be related to fractures in the crust. This excludes all cultural and political effects and artifacts of imagery production and handling. Lineation may refer to joints, faults or an expression of layering, thus is a non-specific term.

An early surprise in viewing ERTS-1 imagery was the discovery of linears of great length that seemed not to have been recorded in the literature. Most of these are subtle alinements not defined by any single major feature. These linears may be 20 to 150 kilometers or more long and be indicated by a subtle alinement of many kinds of features such as vegetation lines; straight streams; abrupt changes of streams from meandering to linear channels; tonal differences in soils, cultivation in elongate fields perhaps influenced by the topography near the linear; and unresolved tonal alinements.

No generalizations can be made about the appearance of such extended linears on various bands. Only a small number appear on all bands. Many are so subtle that a particular linear may be seen on one band, or two, but not on the other bands. Or, they may be so subtle that

they can be seen on a second band only after being "discovered" on a first. Some of these linears are related to the very old, regional tectonic features. Those we have checked in the field are expressed at the surface as joints and faults. That is, they are real and have structural significance.

Most linears, ranging from 3 to 20 or 25 kilometers long, were recognized most easily on band 5 and 7, although large numbers can be recognized on 4 and 6 with more careful study (figure 7). These linears are defined by straight streams, alinement of 2 or more stream valleys, vegetation alinements, by tone difference in surface materials (mainly soil and weathered rock), by anomalous cultivation patterns, and by combinations of these factors. Comparisons of several overlays of linears show that some linears match between the two bands but that the majority are different. That is, although bands 5 and 7 are both excellent for tracing linears, they exhibit different fractures and must be used to complement each other (figure 7). Band 6 is generally as useful as 7 and because of slight differences from 7, it may reveal some linears better than 7. Band 4 also can be used for tracing linears, and these will usually be helpful additions to the other bands. Contrast is lower in 4, but the marked differences in reflectivities of various features from other bands is important. There are linears seen on 4 that cannot be seen on other bands.

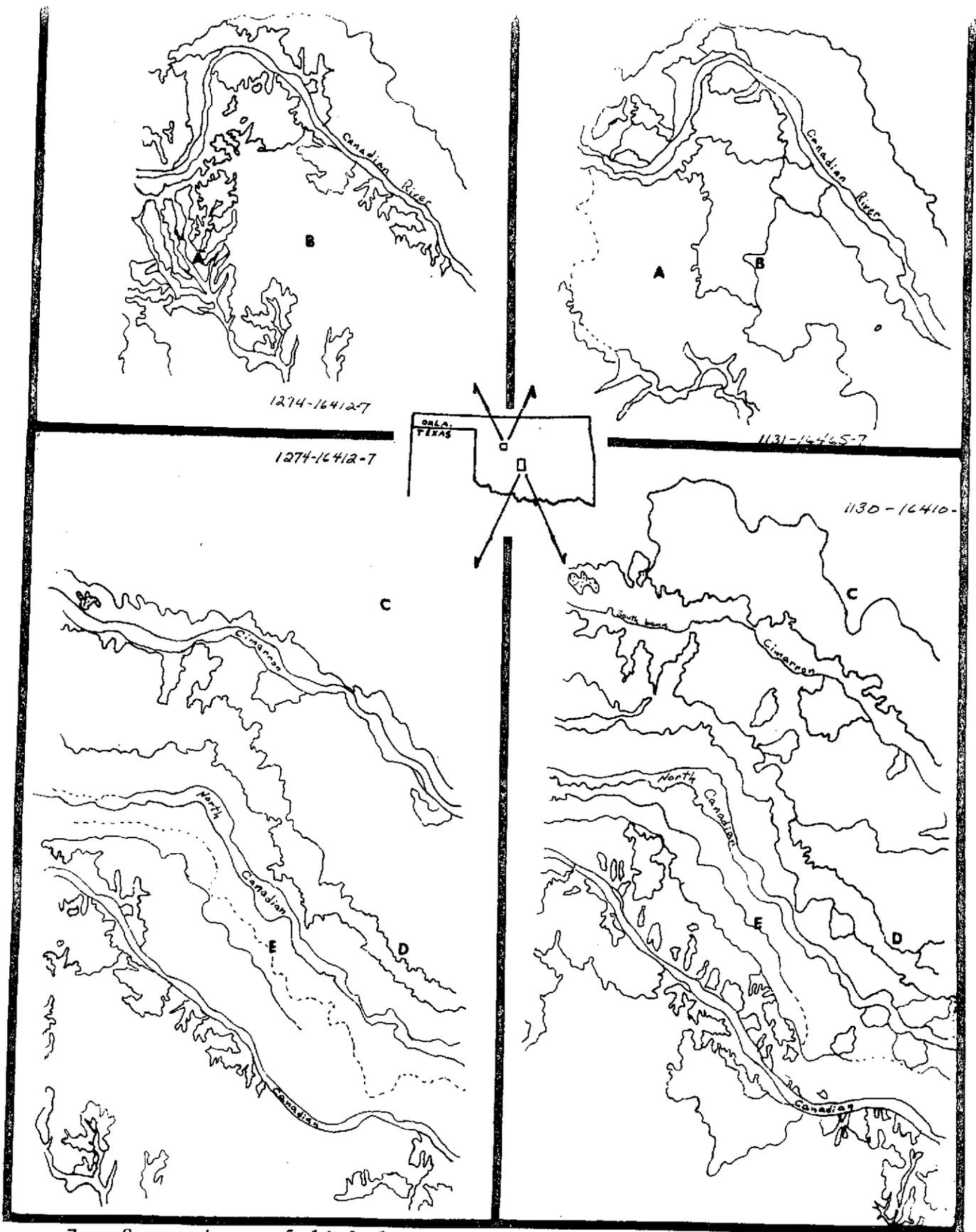


Figure 7. Comparison of lithologic interpretations derived from imagery collected in October, 1972 (left) and in April, 1973 (right). A shows detail obtained in spring which is absent in the fall. B, C and E show boundaries derived from fall imagery which are either indecipherable or only poorly defined in the spring. D shows a contact drawn with more detail and precision in the spring than in the fall. 46

### Lithologic Boundaries:

Agricultural activities affect most of the surface area of the test site. The disturbances caused by man's activities generally obscure geologic features, lithologic boundaries in particular. As a result, no single band can easily be accepted as most useful for purposes of delineating rock units. All bands must be studied, compared, contrasted and the results combined into a reasonable interpretation.

In general, we found it difficult to recognize many mapped lithologic boundaries. The difficulty arises partly because of the effects of agriculture and the fact that on ERTS images most rock units in the area have no readily distinguishable tonal differences from adjacent mapped units. This may in part be because several of the established units are defined on features that do not affect reflectivity, such as fossil evidence. There are many exceptions to this generalization. Many factors aid in distinguishing known units. These same factors can be used to define new "imaged units" or "photolithologic units". Units are easily established when there are contrasts in any or all of the following features: grain size, degree of consolidation, plant growth, agricultural practices, surface effects of ground water, topographic expression (e.g., plateaus, badlands, rolling hills, cliffs, stream density and/or pattern), tone or reflectivity. Such features

may or may not coincide with established rock units. Moreover, their occurrence may be irregular and interrupted. In such cases, either a new set of units, termed here "image units" is established, or disconnected, irregular units are mapped which are difficult to interrelate and analyze.

One example of successful lithologic mapping is the Wellington-Garber contact where a moderate topographic and vegetation contrast occurs. In fact, we were able to re-define the contact and revise existing maps changing the position of the contact 10 to 12 kilometers in some places. Second, the region around and to the west of Elk City, Oklahoma, is a generally flat to rolling surface. It is underlain by Quaternary and Tertiary deposits above gently dipping more dissected Permian strata. Agriculture dominates the flat upland and groundwater and planting practices differ slightly between Quaternary and Tertiary areas. In addition, there is less agriculture and a different topography in the Permian. Generally, it is not possible to distinguish one Permian unit from another.

Several features are used to interpret lithologic boundaries in the imagery; all of them can give ambiguous results. These are tonal and textural clues, created by any or all features such as: stream patterns and density, topographic breaks and shadows, vegetation types and distribution, tones of soil and bedrock, and even the distribution

of farming patterns.

One example is found in southwestern Oklahoma in an area where agriculture is limited to high, flat areas above lower, dissected or badland topography. Most of the high, farmed areas have a high reflectivity on bands 5 and 7 and include Tertiary and Permian units. These bright areas might well be interpreted from band 7 as one unit as is done in the band 7 geologic map west of Elk City (figure 16, p.85). This interpretation is satisfactory if it is understood that the unit is an "image unit" and may bear no relation to established stratigraphic units. If one wishes to map units that can be properly interpreted as rock units or mapped formations, other bands must be studied. Band 5 yields much the same results although subtle differences are apparent within the area. Figure 15, p. 81 combines information from all bands. Compare the Elk City area in this illustration with the same area in figure 16. Band 4 interpretation compares well to a geologic map and clearly distinguishes the Tertiary (light) unit from Permian units which are dark in this band. Band 5 and 7 are generally most useful for study of rock units, but all bands must be examined for a complete analysis. Band 7 on some frames shows more detail than 5 and more units (not necessarily equivalent to mapped rock units) are mapped with more clearly defined boundaries. Conversely, interpretations made from band 5 show fewer units and different units with more generalized

boundaries. At some times of the year, where surface and vegetation contrasts are just right, 5 and 7 are remarkably similar in overall appearance and in much detail. Commonly as noted earlier, a contrast reversal exists between 5 and 7, resulting in a difference in the kind and/or amount of information extractable from the bands.

Native vegetation is sensitive to underlying rock composition, topography and drainage and is often a good indicator of the extent of rock units. This then makes band 5 and 7 particularly useful for mapping rock units, because vegetation is usually dark in 5 and, when healthy, bright in 7. These bands are most useful where plants growing on one unit stand in strong contrast to the soils and rocks of an adjacent unit and where adjacent units support different biotas. For instance, Hennessey and Wellington shales support grasses, shrubs and associated low growing plants with trees near streams and in draws. Thus, these units appear lighter than the associated Garber which supports a tangled growth of scrub oaks and hickories on a well-dissected surface. The contrast between grassland and timber is easily traced. In fact, our interpretation suggests that some parts of the contact between Garber and Wellington should be revised. Native vegetation, like agricultural practices and plant species, is sensitive to factors related to the underlying geology and hydrology. Crops that dominate the agriculture of one

area are only minor crops elsewhere. Farming is limited to relatively flat or rolling areas and is only spotty in more rugged lands. The presence of cultivated areas on a flatland will emphasize the contrast between flat and dissected lands.

Where vegetation is sparse, units (again, not necessarily matching published lithologic units) may often be distinguished by the tone differences seen on different bands. An area of exposed rock might appear all of the same tone on 6 while two shades of gray are distinguishable in the same area on 4.

Textures created by degree of dissection of the surface or by varying resistances of rock layers to erosion are also helpful for interpretation of units. Visibility of textures varies in different bands, and band 4 may be more useful than 5, 6 or 7.

Care must be taken in defining units, especially on the basis of tone. Rocks may appear in various shades of gray for any number of reasons including moisture content, grain size of surface materials, degree of compaction of grains, density and type of vegetation, health of vegetation, lateral variation in atmospheric haze, color and composition of rocks, degree of weathering, slope, and agricultural practices. Likewise, textural differences may provide a convenient basis for defining units, but these units may subdivide or combine mapped formations.

Fresh bedrock and soil exposures generally appear brighter on all bands than do corresponding weathered and plant covered exposures. For example, most new roads are quite conspicuous (on band 4 in particular) as bright lines. Older roads are usually difficult to see. Apparently, weathering and plant growth on the shoulders and adjacent stripped land lowers the reflectivity of these surfaces. Paved surfaces likewise become darker in time. Dunes, quarries and salt seeps all are highly reflective. Active sand dunes are bright on all bands. Their tone on 7 is just discernably brighter than on 5 and 6. They are somewhat less bright on 4. Gypsum quarries show a moderately high reflectivity on bands 5 and 4 and a slightly lower reflectivity on 6 and 7. Areas encrusted by salt such as Salt Creek, Great Salt Plains and several other areas along the Cimarron River, generally are highly reflective in bands 4 and 5 and moderately so in 6 and 7. The presence of detrital material such as clay, mixed with the salt may tend to lower reflectivity in one or more bands. This is apparent in Salt Creek Canyon which is visible but not readily detectable on all bands. Large limestone and sandstone quarries and sand and gravel pits are bright on all bands. Both contrast and reflectivity are lower on 7 than on the other bands. Highest contrast between quarries and background is found in band 4 and is also good in 5. Quarries in granite are generally smaller than those in other types

of rocks. Because they are small their apparent brightness is lower than other fresh rock types. Granite is brightest on bands 4 and 5, less so on 6, and is only moderately bright on 7.

The preceding visual comparisons of the reflectivities of several rock types on the 4 MSS bands do not necessarily indicate that automatic discrimination of gross rock types may be feasible. The apparent reflectivities on the imagery at our disposal are subject to many variations in collection, handling, and processing.

#### Tonal Anomalies:

These are places within areas of more or less uniform tone which exhibit a tone either brighter or darker than that of the surrounding area. The basis for the tonal anomaly may or may not be related to geologic features. For instance, a narrow elongate zone somewhat lighter than nearby surfaces may indicate a linear fracture zone. Other features such as carbon black plants, irrigation districts and unrecognized thin clouds may create similar tonal anomalies. We did not specifically study different types of tonal anomalies and their comparative detectability on various bands.

#### Other Factors Influencing Geologic Interpretation of ERTS-1 Imagery:

Haze and clouds may affect geological interpretation. Clouds and haze are most transparent to the wave lengths of

light recorded by band 7 and least transparent to those recorded by band 4. Cloud shadows are most clearly seen on band 7 and least noticeable on band 4. In general, the presence of clouds and even thin haze or fog can be detected by comparing the apparent area of cloud coverage as seen in band 4 and 5 with cloud shadows seen on bands 6 or 7. One must exercise caution when interpreting features seen through clouds on bands 6 and 7 because thin clouds or haze can alter tone or reduce contrast in such a way as to lead to erroneous conclusions.

Cities, new roads and major roads have moderate to high reflectivity in all bands. They are best detected on band 4 which exhibits a more even, lower overall contrast than the others. Band 5 usually offers the most detail within large cities. Urban areas have lowest contrast with other features on band 7.

Light snow cover often enhances linear features and is an aid for interpretation. Reflectivity is highest on bands 4 and 5, lower on 6 and 7. Thin snow cover or a light "dusting" of snow is seen most easily on band 5.

#### False-Color Composite Imagery:

Color imagery adds the advantage of hue. Because the eye can detect so many subtleties of hue and shade, a great deal more information is available and is more easily extracted than from black and white imagery. In fact, some subtleties supply information which cannot be garnered from

one band alone or even two. As one example, some bright areas on band 7 might easily be interpreted as having a healthy vegetation cover, while a color composite might show these areas are better interpreted as fallow fields with highly reflective sandy soils.

There are a few drawbacks to the use of color images. Bands must be combined in perfect registration which is often impossible. Imperfect registration causes color haloes and loss of sharpness or definition. Also, there are a few subtle features visible only on a single band which may be masked by combination with other bands.

#### Summary:

Color imagery is the most readily useable and contains the greatest amount of information, combining as it does two or more bands. Some details and subtleties are best studied on individual bands. Band 4 has the lowest overall contrast and is most affected by haze. In fact, this band gives an impression of having been fogged. Band 5 and 7 are most useful for geologic uses. They offer highest contrast in areas where there is a variety of vegetation, soil, rock, stream and cultural features. Contrast is lowest where entire regions have a more or less homogeneous plant cover. Band 6 is largely redundant with 7.

### Comparison of Season Coverage

In the Anadarko Basin the primary sensor response is to vegetation while the surfaces of bare rock and soil play the next most important role in creating image responses. Atmospheric conditions particularly affect responses seen on band 4. There is no subsurface information received directly by ERTS. Vegetation, both native and agricultural, vary with climatic and topographic conditions. The Anadarko Basin is located in a climate zone where seasonal changes are strong and both plants and soils contribute significantly to image responses. Thus, differences in imagery collected at different times is substantial. Furthermore, the climatic cycle in this area is highly variable and imagery would have to be collected over a period of several years (5 - 10) to even begin to sample the possible variations. Response in areas drier than the Anadarko Basin depends mainly on soil and rock while moister and warmer areas present mainly vegetation responses to ERTS. Applicability of ERTS data to other basins was not tested by us.

The comparison presented here is based on images acquired from October 25, 1972, through December 2, 1972, and from March 20, 1973, through April 23, 1973. It is drawn from extensive notes made about the imagery during the course of interpretation. We have no summer or winter coverage.

Because vegetation responses play a vital role in the information content of the ERTS imagery of the area, one would need to study imagery from all four seasons in order to evaluate fully ERTS-1 imagery (see figure 8). Indeed, several years' coverage is needed for exhaustive study since seasons are variable, arriving earlier or later one year than the next, varying in calendar length, and being affected by different combinations of climatological factors and extremes.

We concluded that, if we were forced to choose a limited amount of imagery for geological studies, we would choose imagery from an early dry fall and a late wet spring.

In particular, we concluded that a combination of band 5 dry-fall imagery and band 7 wet-spring imagery are the most readily interpretable for our purposes. That is, given a budget short on time and money, the above combination would allow the greatest amount of information to be derived in a minimum of time at lowest cost. Ideally, of course, all bands of every coverage should be studied for optimum information. In practice, however, as the number of bands and coverages increase so do requirements of time and manpower, even considering the synoptic nature of ERTS data.

The choice of combinations was made because not only are spring and fall in contrast to each other, but also the greatest differences between band 5 and band 7 are found

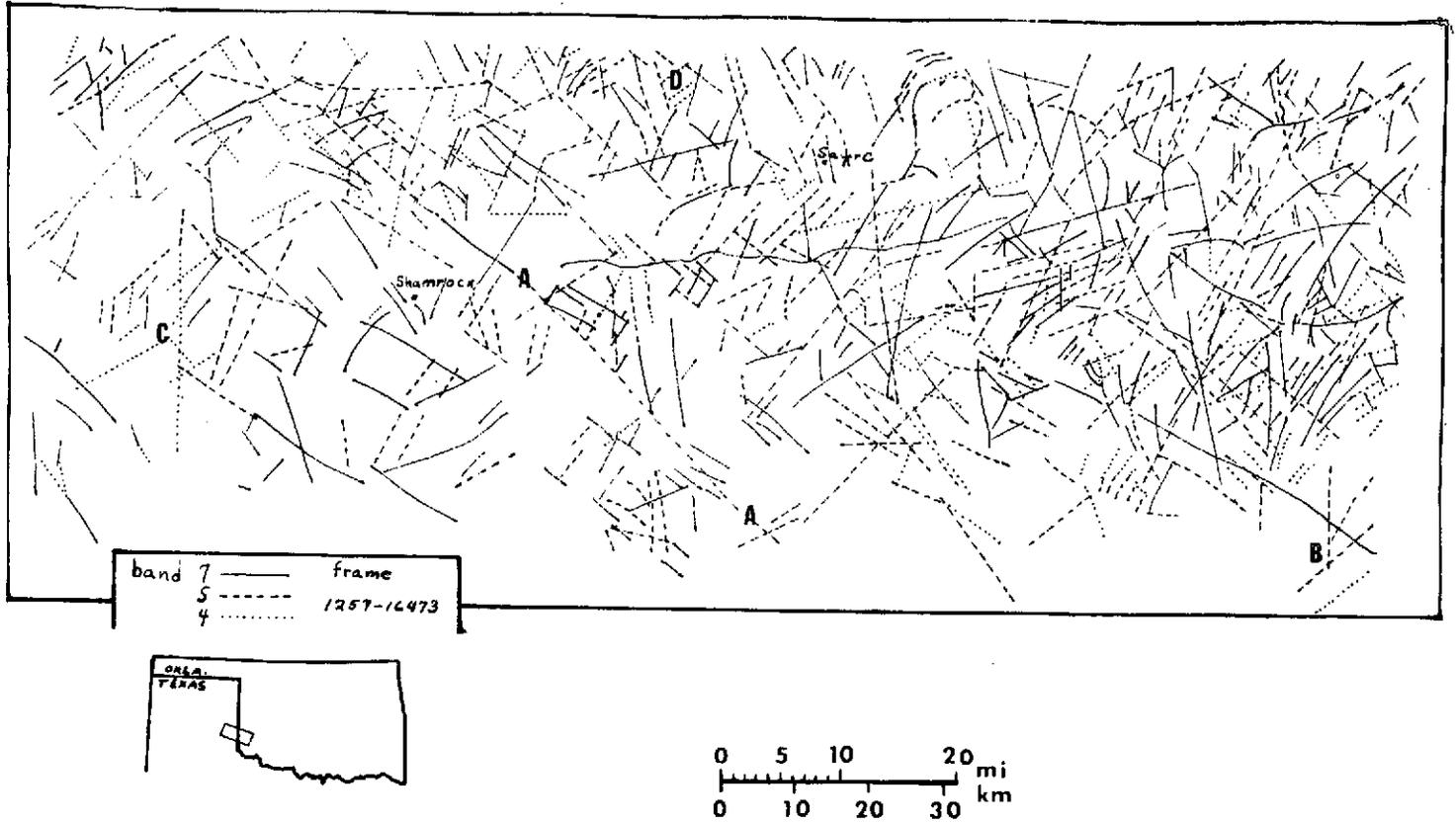


Figure 8. Each ERTS band contains some unique information as shown here. Band 7 linears were compiled for part of one frame. Next, linears were added from band 5 that did not match any from band 7. Examples are A and B. Last, band 4 linears (such as C and D) that matched neither band 7 nor 5 were added.

from one season to the next. A more practical approach is to use both bands 5 and 7 for both seasonal extremes. Addition of bands 4 and 6 will provide the broadest information base possible, but 5 and 7 contain the greatest amount of easily extractable geologic information.

Analysis shows that band 7 spring imagery has some advantages over fall imagery in the same band. Cultivated areas have a more uniform tone on spring imagery, decreasing cultural effects and increasing perceptibility of lithologic trends which are longer and more continuous than on fall images. These trends are interrupted and/or are interpretable with difficulty in the fall. However, fall imagery is useful for adding detail to gross lithologic units as interpreted from spring coverage. Whereas, spring imagery may mask certain important lithologic boundaries, and fall image interpretation may create a confusing arrangement and large number of units, combining interpretations from the two seasons refines the results with fall detail added to gross spring units.

Stream valleys and badlands stand in strong to moderate contrast with agricultural patterns on spring images. Valleys of most large rivers are especially apparent in the spring probably because of recent high water and the presence of flowing water in the channels. The North Canadian River channel is the main exception to this statement. It is practically indistinguishable on all frames and bands except for spring band 5.

On band 7 spring images where uplands are cultivated and slopes contain little vegetation, uplands are light and bluffs, badlands and valleys are darker. In other areas, well-vegetated (mainly agricultural) stream valleys stand out light against darker hills on the same image.

Comparison of two frames of band 7 taken over the same area in spring (5 April and 23 April) demonstrates the value of using as much seasonal coverage as is practicable. The overall contrast of 23 April is greater than on 5 April. Tonal anomalies such as those near Watonga and Drummond Oklahoma, are more marked. In fact, the later images are superior in all respects to the earlier. Streams, topography and detail within cities are more distinct in the 23 April images.

We conclude that a combination of band 5 fall imagery with band 7 spring imagery is the prime minimum choice of imagery because of the extreme differences between the bands in these seasons. However, we cannot make a clear choice of seasons for band 5 alone. Band 5 images acquired in the two seasons should be studied together since they complement each other, one revealing what the other does not. In other words, trade-offs of types and amounts of information and/or relative ease of interpretation involved in such a choosing do not favor one coverage or the other. They both contain unique and valuable information.

In general, roads, towns, airfields and quarries are more visible on the fall band 5 images (30 November) than on the spring (5 April). There are some exceptions, e.g., detail within many cities is enhanced by spring vegetation, and a few roads and towns stand in higher contrast to surrounding vegetated areas than in the fall.

Topographically and texturally expressed features are better expressed on fall imagery because there is less visual confusion being provided by agricultural patterns, vegetation dominating valleys and a lower sun elevation angle. Bluffs, badlands, stream valleys and certain textural anomalies also appear more clearly on fall imagery.

Rock and soil types all tend to have similar brightness and are relatively difficult to distinguish one from another. Where contrasts do exist, however, they are more easily recognized on fall images, where they are not obscured by vegetation and cultivated patterns. One example is the contrast between Quaternary alluvium and Permian rocks or soils on the north side of the Cimarron River.

Variations in soils, rocks, topography, drainage, availability of groundwater, and farming practices create many contrasts in vegetation on spring images that are not visible in the fall. The vegetation in many places creates continuities within inferred units, while the appearance of the same unit on fall coverage may be interrupted. The reverse is true in some instances. For example, alluvium

along the north side of the Cimarron is easily distinguished by its high reflectivity from Permian units in fall band 5 images. The alluvium cannot be mapped as one widespread unit from spring images.

Major river beds are more easily distinguished in the fall, but visibility varies along the course of the streams. Some stretches of the beds are more easily discerned in one season than in the other.

Lakes are more turbid in the spring than in the fall. Turbidity frequently lowers contrasts between water and surrounding areas, making interpretation more difficult.

In brief, band 5 is best interpreted for two or more seasons because one complements the other.

Band 5 coverage of late spring is more useful than the same coverage earlier in the spring. In comparing coverage from 5 April 1973, with 23 April 1973, we noted lakes were less turbid and stood in higher contrast on 23 April images than on 5 April. Likewise, river beds were brighter and vegetation was more widespread and darker, resulting in higher contrast and greater continuity of units. Images from 23 April contain light-toned anomalies which are more apparent than on earlier images. Details of drainage may be somewhat enhanced by the higher 23 April contrast (between Canton and Waynoka, Oklahoma,) or may be obscured as compared to 5 April by a wider and denser distribution of agricultural areas which may "camouflage" details.

We found imagery in both band 5 and 7 acquired early in a dry fall to be preferable to late wet-fall imagery. For band 5, though overall contrast is higher and atmosphere clearer on 30 November, more detail and continuity can be seen on 25 October imagery. For example, several lithologic contacts are easily distinguished in October which are not visible, or at least are less discernable in November. Some small streams are obscured in November, but major river valleys are more easily detected than in October.

Strong differences appear on band 7 between 25 October and 30 November of the Oklahoma City area. Comparison emphasizes the advantages of using both coverages when practicable. While many details are enhanced on November imagery, several large rock or alluvial units are more distinguishable on October scenes. November scenes are camouflaged by growing agricultural crops (mainly winter wheat) while October scenes have large areas dominated by dead or dormant plants, live plants, fallow fields and exposed soils. Many streams or valleys are obscured in November where both uplands and lowlands are cultivated or where vegetation response is similar in both places. In other places, especially the east side of the frames where uplands are not farmed and are dominated by trees and brush, creeks and lowlands are quite noticeable on November

but obscure or indistinguishable on October. Vegetation contrasts are greater in October and bare rock-(or soil) vegetation contrasts are lowest. November images show bare rock (or soil) is clearly differentiated from vegetated areas.

In addition to the difference noted among the various cycles of imagery, we noted some variations across the area on the same cycle of imagery. We believe these are largely the result of the climatic gradient across the test site.

We made no detailed comparison of seasonal coverage in bands 4 and 6. What study we did on these two bands and on their seasonal differences, quickly lead to the conclusion that coverage acquired in at least two contrasting seasons must be interpreted for optimum results.

## VII. RESULTS

### Linear Features

Evaluating information on linear features interpreted from ERTS data is difficult. We noted literally thousands of linears ranging in length from 2 kilometers to more than 150 kilometers.

Most of the test site is farmed and ranched and surveyed on a one-mile township-range grid. The greatest part of the grid is defined by roads. While the road and field pattern imposes a strong north-south and east-west linear system, the system is generally quite distinct, not easily confused with natural linears. Our rose diagram (figure 9) of directional frequency of linears shows a strong maximum centered approximately on north <sup>40</sup> east. This peak is a legitimate result of our interpretation of linear features. We took care during interpretation on 1:1,000,000 scale imagery to avoid including cultural linears. Frequent checks were performed against topographic and base maps and against ERTS imagery at a 1:250,000 scale. Since compiling these statistics we have re-checked many linears to be sure they are not cultural. Moreover, the peak is just east of north, not directly north. And there is no strong east-west peak which might be expected to accompany a strong north-south trend if the trends resulted from the surveyed grid.

It is difficult or impossible in most instances, to

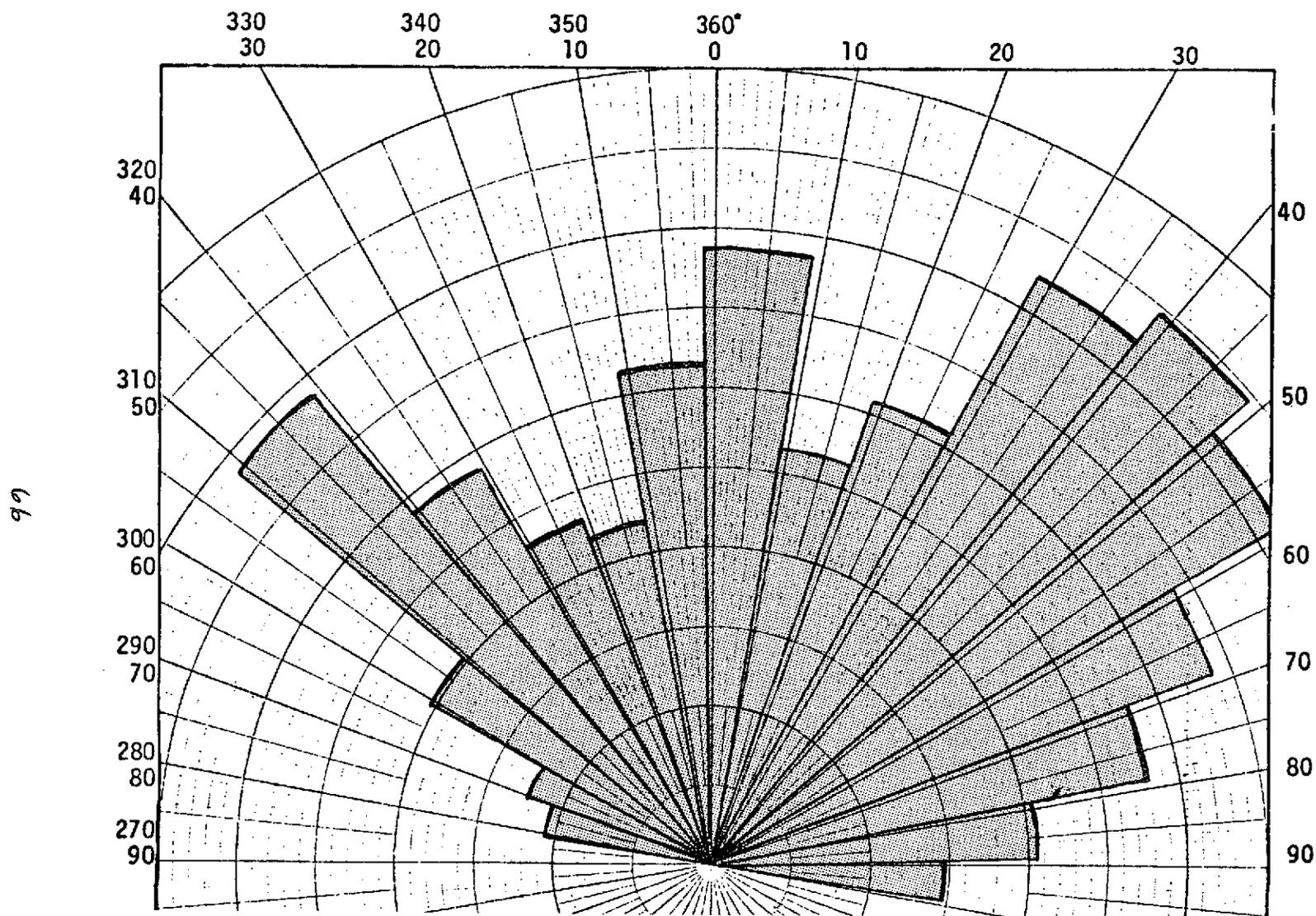


Figure 9.

Azimuths of linears  $\geq 10$  km. in length.  
 Groups =  $10^\circ$ . (Derived from ERTS imagery  
 acquired Fall 1972 and Spring 1973).  
 Total number of Linears: 2,817

distinguish fault related from joint related linears or either of these from stratigraphic linears. It is easier to make distinctions when abundant surface and subsurface data are available, where field checks can be made or where aerial photographs are available.

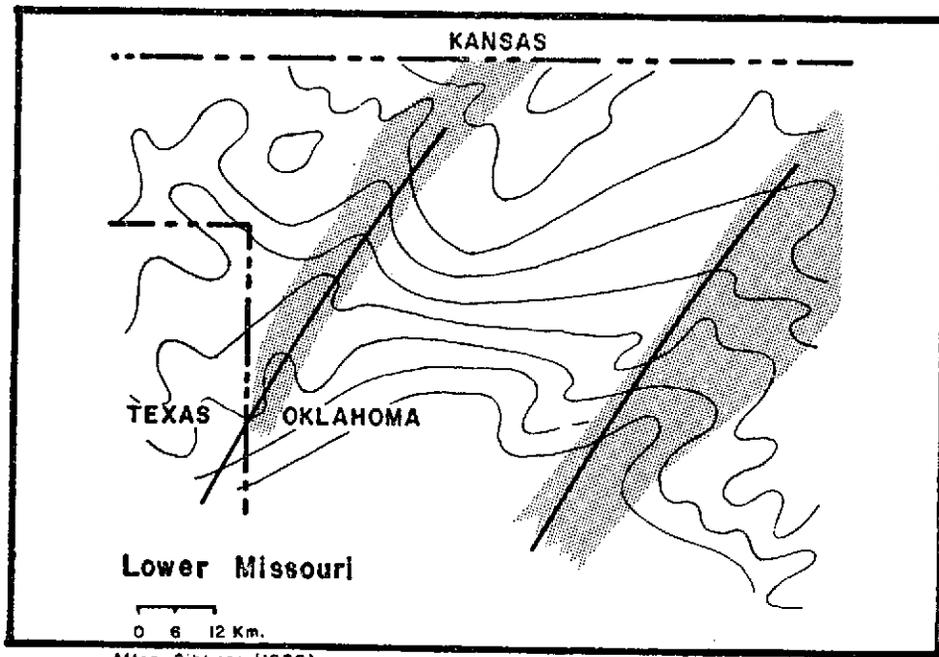
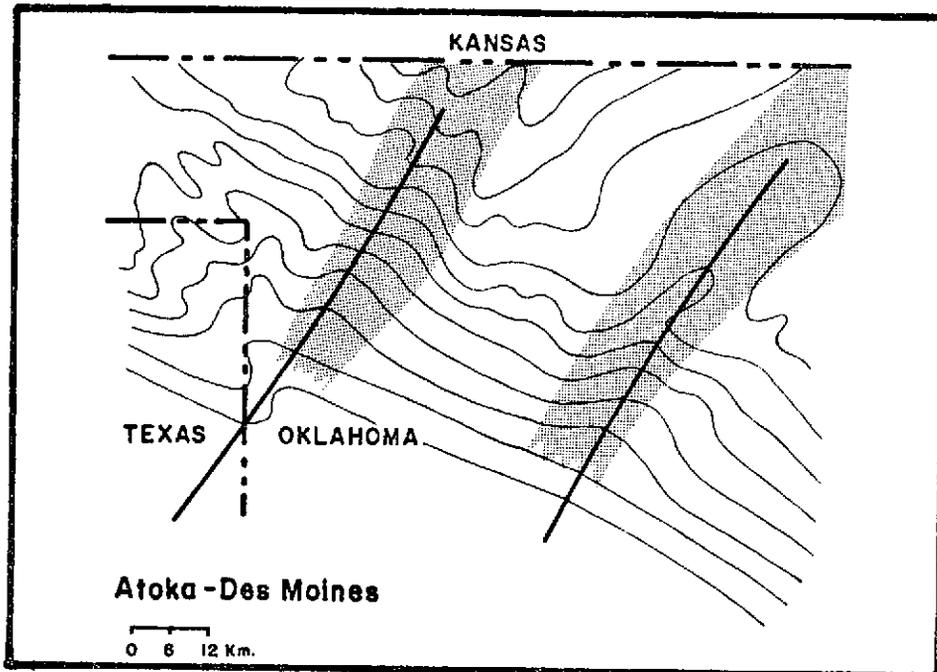
Because of the widespread occurrence of Quaternary surficial materials and lack of aereally extensive outcrops of bedrock over the region, it is generally impossible to tell type, direction and amount of movement involved along interpreted faults. It is possible to formulate generalized hypotheses about the tectonics of the basin and associated Amarillo-Wichita uplift, but not to give even approximate figures on fault movement.

One result of our interpretation of linears is summarized in the rose diagram. The length of the graphs of each subgroup is directly proportional to the number of linears equal to or greater than 10 kilometers in each azimuth group. Inspection shows three maxima. These peaks center near north  $45^{\circ}$  west, north  $4^{\circ}$  east and north  $45^{\circ}$  east. The peaks coincide with the azimuths of linear sets which are quite noticeable upon visual inspection of compilations of linears. In addition, the set centering on north  $83^{\circ}$  west is visually prominent because of the great lengths of some of the linears in this set.

Although the regional sets of linears are easily defined, their significance is not easily determined.

Most linears, including the most prominent sets, seem to be of most significance on a secondary level. That is; there seem to be no characteristics that set "important" linears apart from "trivial" linears. Anyone familiar with the Anadarko Basin could associate certain linears with known subsurface features. It would be desirable to relate linears to potential hydrocarbon traps where little or no subsurface data are available. Our success at this second task has been less than hoped.

There is evidence that at least the regional sets of linears are fault related. Two major linears (figure 10) in northwest Oklahoma trend north 30° east and coincide with linear zones of thickness shown on isochore (thickness) maps compiled by Gibbons (1965). These linears probably represent faults that were active in Pennsylvanian times and affected sedimentation. There are several linears associated with subsurface limits of various evaporite units. One linear trending north 30° east through Texas and Beaver Counties, Oklahoma into the Texas Panhandle coincides with the approximate western limit of some of the Cimarron evaporites. Another linear of this same set runs northeastward from T9N, R26W in Beckham County, Oklahoma into central Roger Mills County. The Yelton salt of Permian age occurs in two locations. One extending from western Beckham County into central Wheeler County, Texas. The other occurs in the northeast quarter of



After Gibbons (1962)

Figure 10. Isochore map of Pennsylvanian sediments in northern Anadarko Basin showing correlations of regional linears (heavy lines), trending N 30 W, with thick strata (patterned areas).

Beckham County and extends into northwest Washita County, Oklahoma. The linear lies between these two salt bodies and within 4 kilometers of the western occurrence. We have field checked this linear and found that one portion of it is occupied by an anomalous straight segment of the Washita River where the river makes an abrupt northeastward turn. The portion of the linear west of Elk City is a zone of anomalous dips (up to  $15^{\circ}$  as compared to regional dips of  $1^{\circ}$  to  $2^{\circ}$  ), subdued topographic lows, and contains native brush and grass instead of agricultural or grazing crops.

One linear trending north  $5^{\circ}$  west appears to be a fault truncating the west end of the main Wichita Mountains near the western border of Commanche County. Other linears coincide with the frontal deformed zone of the Wichitas which form the south flank of the basin. These linears also coincide with producing structures which are part of the frontal zone and they trend about north  $40^{\circ}$  west from near Duncan, Oklahoma to the Alden and Apache fields in T6N, R12W. They can be traced north  $70^{\circ}$  to  $80^{\circ}$  west to the Erick field in Beckham County, Oklahoma.

Another linear that coincides closely with oil and gas fields is parallel to the previously described north  $40^{\circ}$  west linears, and extends from T9N, R15W in southeastern Washita County, Oklahoma into T22N, R26W in northwest Ellis County, Oklahoma. Figure 2 shows that the axis of the

basin changes azimuth in southern Caddo County.

Figure 11 compares our interpreted linears with published known or hypothesized regional faults. The faults appear as interpreted for basement rocks (Ham et al., 1963), surface exposures, well-log and geophysical interpretations (Harlton, 1951, 1963), regional analysis, well-log and geophysical interpretation (Wroblewski, 1967), and several other sources. We interpreted many linears which coincide with and/or extend published faults, including the Stony Point and Blue Creek Canyon faults and extensions of the prominent Meers Valley fault, all in the Wichita Mountains.

The one fault that we felt should most certainly be visible is the Meers Valley fault. We did not map it during our interpretations and can find only the most subtle of linears even when concentrating specifically on the location of this fault.

Although we can confirm or extend many published faults there are two published sets for which we see little or no evidence. These are the north  $60^{\circ}$  west set in western Oklahoma and the north  $45^{\circ}$  west set in the Texas Panhandle. Most of the lengths of these faults are hypothetical extension of faults known in oil fields separated from each other by many miles. They are accepted as valid by only a few geologists familiar with the area.

In summary, there are many instances where ERTS-based

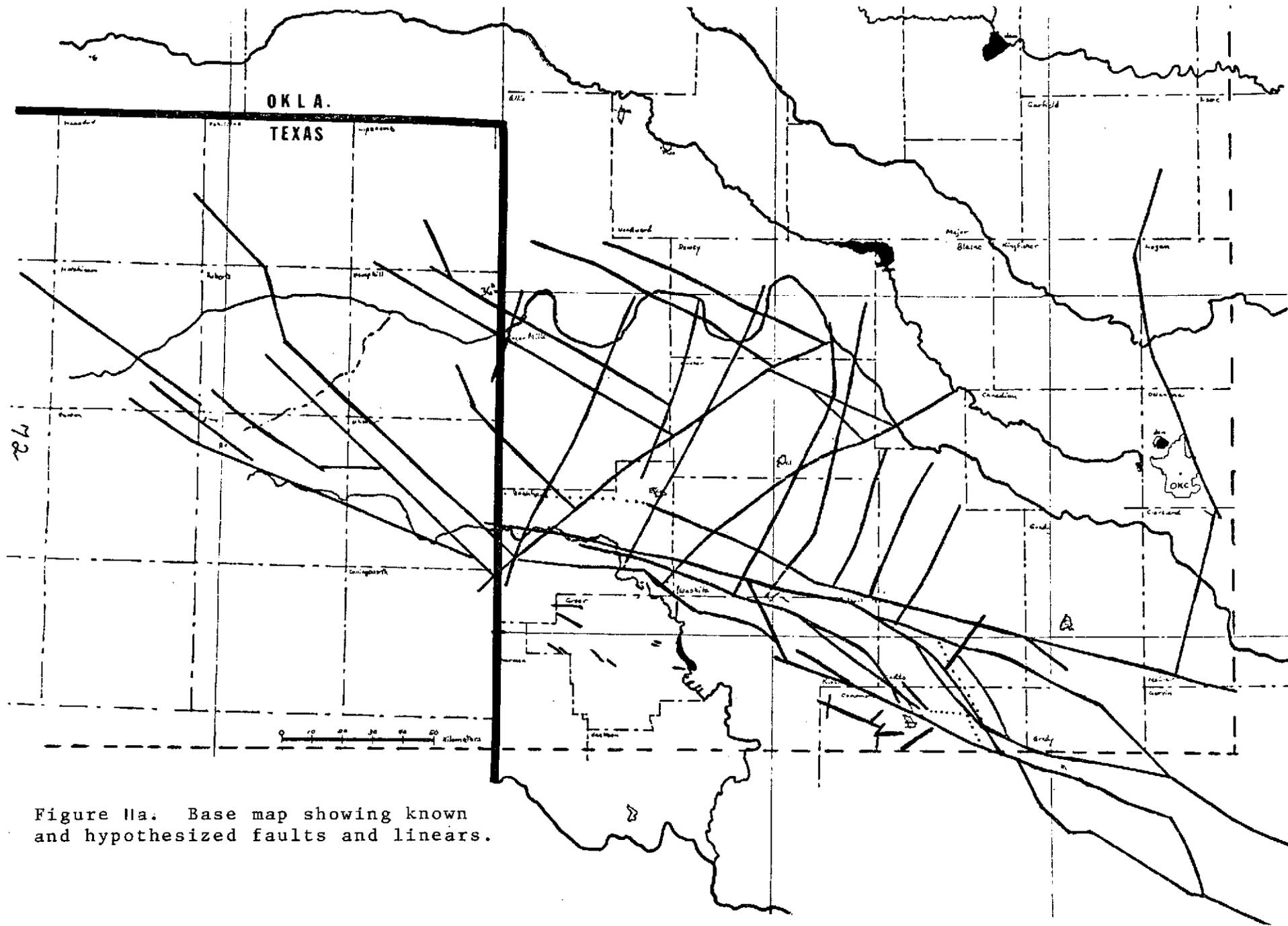


Figure 11a. Base map showing known and hypothesized faults and linears.

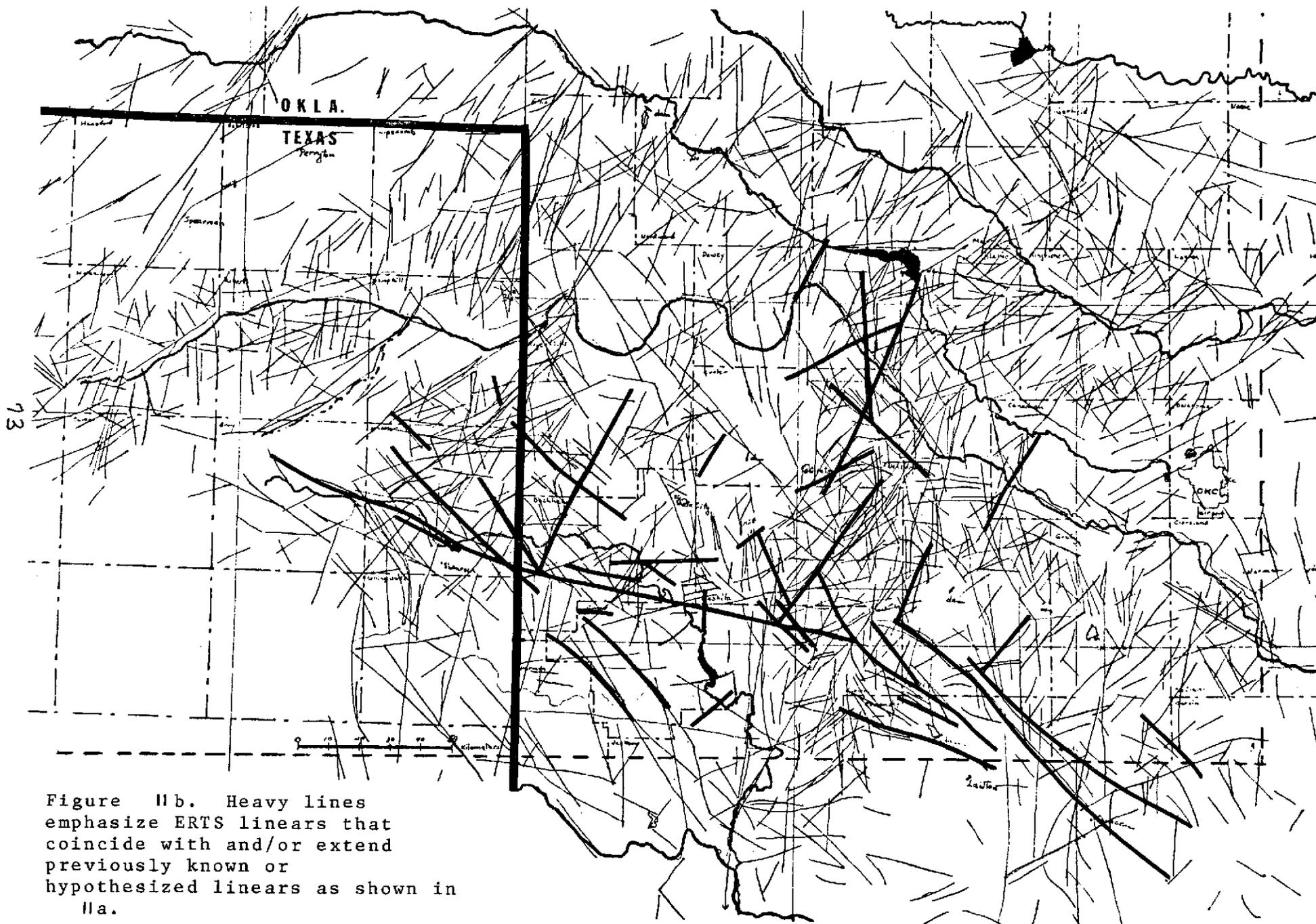


Figure 11b. Heavy lines emphasize ERTS linears that coincide with and/or extend previously known or hypothesized linears as shown in 11a.

linears coincide with known or hypothesized faults and linears compiled from studies of basement rocks, interpretations of specific oil and gas fields and seismic studies, older air photo interpretation and from maps of surface geology. They coincide with the main features of the Anadarko Basin and Wichita Mountains. Many linears or systems of linears were previously unknown or unmapped. They are prominent and of great length. There are a few concentration of linears, for instance, in the region just south of Weatherford, Oklahoma. However, there is little evidence the imagery would set any given linear or set of linears apart from others or which indicate that they hold any particular significance to petroleum geology.

## Lithologic Mapping

ERTS is useful for inferring lithologic distribution. This statement is true even in the Anadarko Basin, which is an area of low relief and gentle dips. Local relief varies from 30 m. to 150 m. with extremes of 350 m. in Palo Duro Canyon and the Wichita Mountains. Dip of surface rock varies from less than 1 degree over much of the area to 3 to 6 degrees in some areas. Rocks in local highly deformed areas such as the frontal Wichita Mountains may dip 10 or 20 degrees to as much as 60 degrees.

Although relief is low and dips are gentle, we are able to map some lithologic units that correspond to published map units. The correspondence of ERTS-derived units to published units is generally inexact. That is, many ERTS-units combine two or more mapped units or ERTS "lithologic boundaries" may be located slightly to one side or the other of published contacts. ERTS contacts may also extend beyond published contacts or terminate more abruptly. In some instances, contacts seen on ERTS imagery are so distinct and clear we believe that they can be used to revise published information. One example (figure 12) occurs near Guthrie, Oklahoma where it appears that the Wellington-Garber contact lies some 13 km. to the east of where it is shown on published maps. This shift has been confirmed by field work and aerial photo interpretation done by Dr. R. O. Fay (verbal communication 1973) of the Oklahoma Geological Survey.

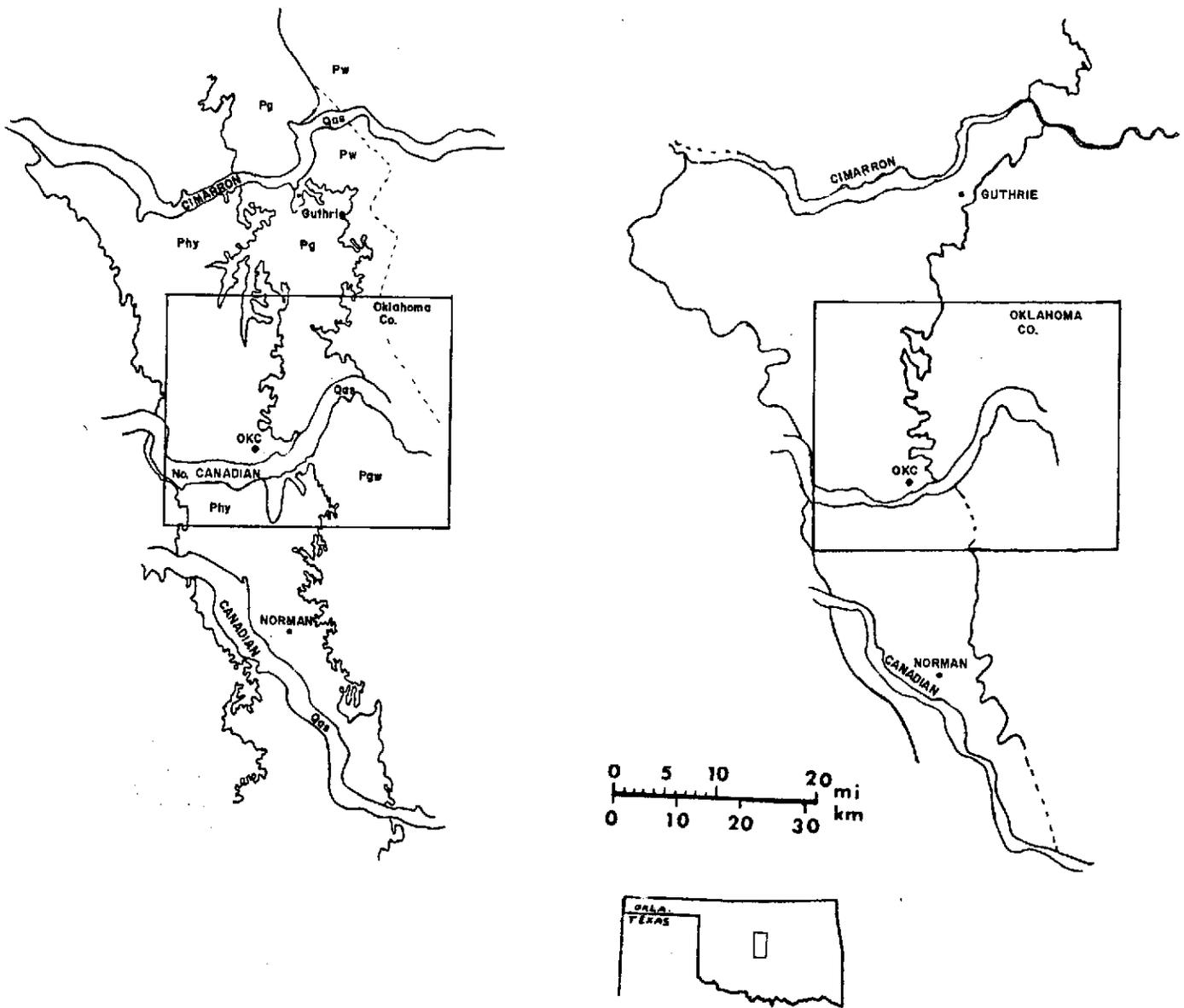


Figure 12.

ERTS interpretation (right) of the contact between Hennessey shale (Phy) and Garber sandstone (Pg) from Norman to northern Oklahoma County matches the contact published on the State Geologic Map (left). From the county line, the contact trends northeasterly until it approximates the Garber-Wellington (Pw) contact as interpreted by R. O. Fay of the Oklahoma Geological Survey (dashed line). The ERTS interpretation may indicate a facies change within the Garber and Wellington which in turn affects groundwater distribution and plant types (Fay, oral communication). Differences between published maps and ERTS-1 maps are important for remapping of formations and for posing questions for further study.

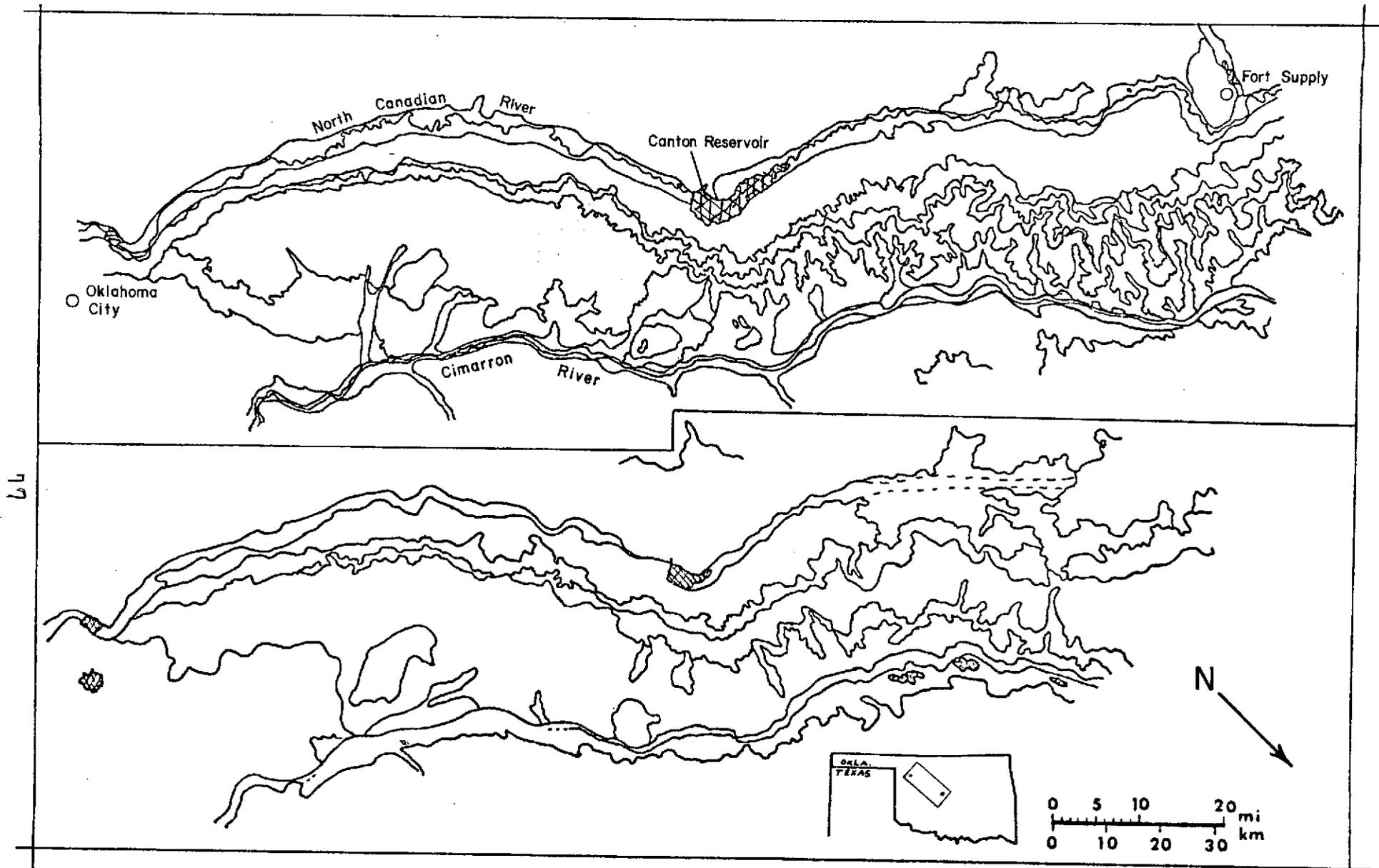


Figure 13. Permian units in the vicinity of Canton Reservoir (center), western Oklahoma. The state geologic map (top) contains more units and contacts are more precisely defined than on the ERTS-derived map (bottom). The same general structure and stratigraphic relationships are apparent on both maps, however. Lakes are shown by a cross hatched pattern.

The lithologic units mapped from ERTS along the divide between the North Canadian and Cimarron Rivers differ greatly from published contacts. Here ERTS units combine two or three published units in places and subdivide these units in other places. Despite the differences as illustrated in figure 13, our interpretation reveals the same gross structure. Strike and apparent dip remain the same. Dissection patterns are the same and changes in strike along the units reveal the same structural features as do published units.

A comparison of ERTS interpretation with published work more detailed than the state geologic map is shown in figure 14. It is apparent that even at the small scale and low resolution of ERTS, a great deal of detailed information is available. Correspondence between published and ERTS-based maps is good. However, on the basis of ERTS data we can not confidently assign given mapped areas to the same units as those appearing in the literature.

Quaternary sand cover in the Texas Panhandle is easily mapped. Moreover, the ERTS mapping coincides precisely (making allowance for ordinary drafting difficulties) with published state maps. The close match is a direct result of strong contrasts between the sand and surrounding or underlying units. The contrasts are due to topography, reflective differences of the mapped units and agricultural practices. The sandy unit is moderately reflective, occupies

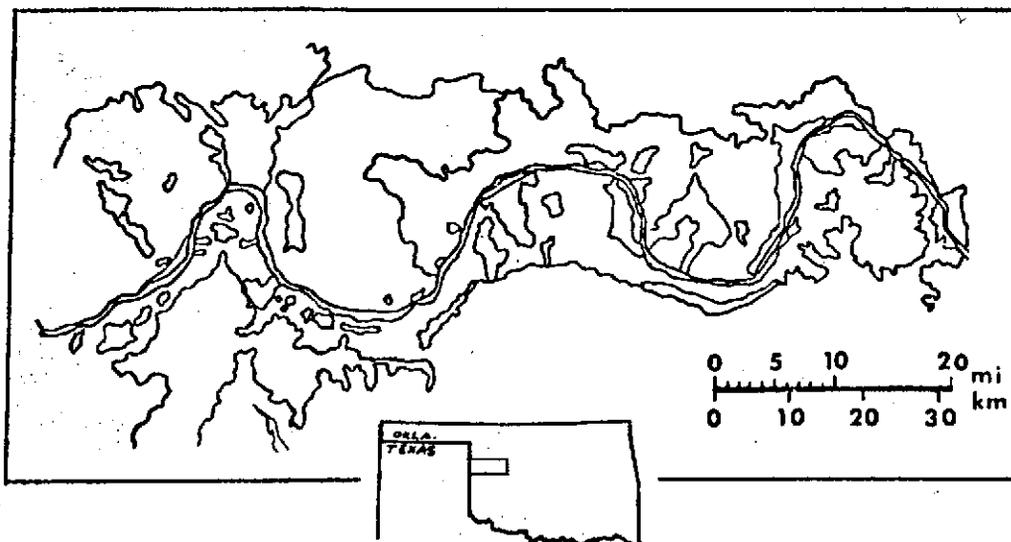
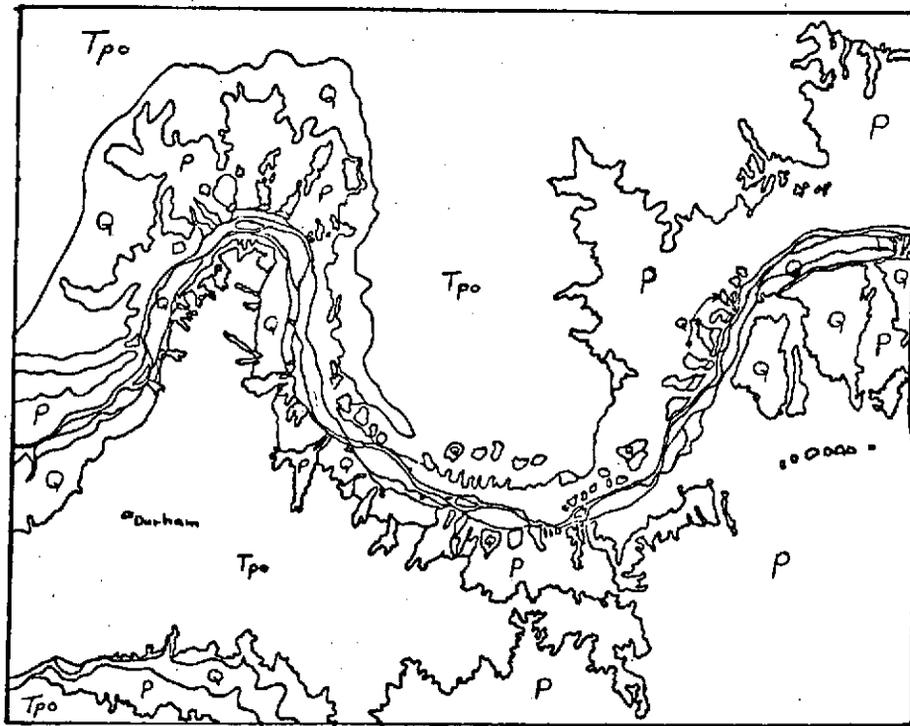


Figure 14

The map at top is derived from two large scale maps, 1:126,000 (Kitts, 1965) and 1:84,000 (Kitts 1959), of Ellis and Roger Mills Counties, Western Oklahoma. The lower map was made from ERTS images at 1:1,000,000 (as shown). While the amount of detail is far greater in the published maps, the ERTS map preserves the main features of the area, even to defining river terraces at some places.

Key: P = Permian, Tpo = Pliocene Ogallala, Q = Quaternary

high, flat areas, is extensively farmed and contains hundreds of small, shallow playa lakes. In contrast is the underlying Pliocene Ogallala formation which has low reflectivity, is dry and dissected, and is used mainly for ranching (figure 15).

Reflective differences of surface materials and vegetation differences enable us to distinguish among several types of surficial Recent or Quaternary deposits. One example is in the Elk City, Oklahoma area (figure 15). On band 5, but not band 7, of full coverage of the area, one can distinguish a 40 square kilometer patch of Quaternary sand from the underlying (and surrounding) soils derived from the Elk City formation. Moreover, both these units are distinguishable from sandy deposits associated with the North Fork Red River just to the south and from Ogallala sediments to the west. Indeed, our ERTS mapping in this area subdivides part of the Ogallala. Based on these observations these units should be restudied to see if reassignment or subdivision of units need be made. It may be that the differences we detect are so subtle that no practical distinction is possible or desirable. On the other hand, the fact that such distinctions can be made from ERTS is important and suggests that ERTS imagery can help provide answers to long standing stratigraphic problems.

Our conclusions on using ERTS imagery for lithologic mapping are summarized on the following page:

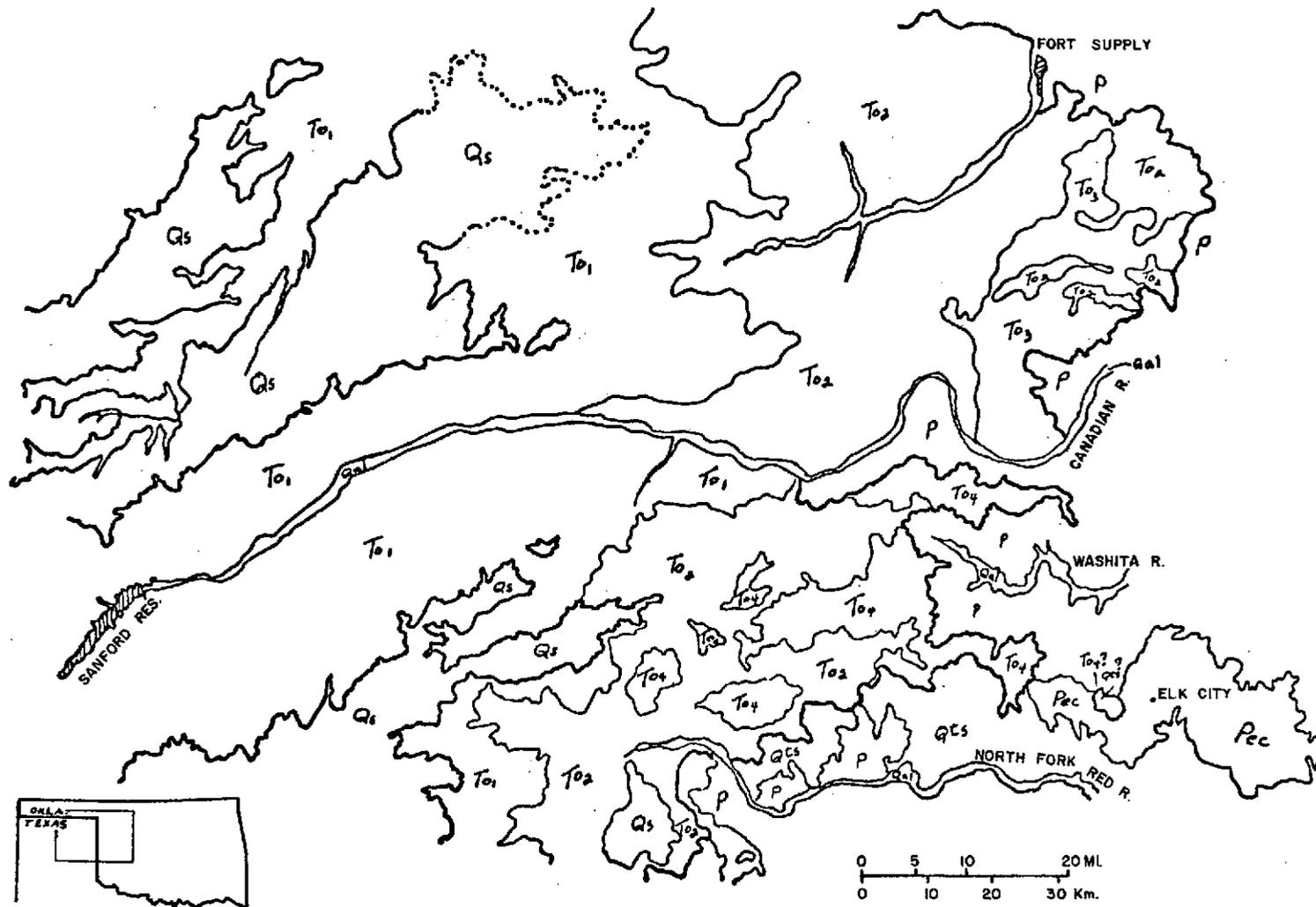


Figure 15. The area shown extends from Sanford Reservoir in Hutchinson County, Texas to Elk City in Beckham County, Oklahoma. Qs, Quaternary cover sand occupies flat topped uplands in Texas. To, Tertiary Ogallala (Pliocene) is actually mapped as four units on ERTS. My subdivisions are shown by subscripts. P = undifferentiated Permian units. Pec = Elk City unit (Permian). A patch of surface material just west of Elk City was mapped as Ogallala from ERTS images, but was originally field mapped as Quaternary sand (Qts). Qal = Quaternary alluvium.

Difficulties and limitations of ERTS for lithologic mapping:

- Many mapped rock units have similar reflectivities and cannot be distinguished from each other on ERTS.
- Large areas are covered by Recent to Quaternary deposits. The total area is somewhat greater than previously mapped. These deposits mask older units.
- Small scale and low resolution limit precision of locating boundaries and identifying small or isolated lithologic features.
- ERTS rock units usually do not coincide exactly with published units. Even the multispectral nature of ERTS data does not permit identification of lithology or rock composition. These parameters can only be inferred crudely from geomorphology, drainage texture, relief, etc.

Value and advantages of ERTS for lithologic mapping.

- Large areas can be mapped quickly.
- Major structural and lithologic features are discernable.
- Existing interpretations of some local areas can be improved.
- Regional relationships among lithologic, structural and geomorphic features can be studied.
- Areas for further study or geophysical work can be located.
- Some units can be subdivided on the basis of their reflectivities.
- Interpretation permits evaluation and revision of published information.
- Low resolution and regional coverage suppress or eliminate a large amount of distracting detail permitting subtle large scale differences to be defined and studied.

### Structural Interpretation of the Geologic Map

Careful study of the geologic maps made of the test site during this experiment demonstrates that using only ERTS images the Anadarko Basin can be defined as a regional feature. (Refer to figure 16 for this discussion).

Interpretation shows that there may be a large basin occupying most of the area. Clearly there is a homoclinal dip to the south and southwest in the northern part of the site, with an uplift on the south which exposes basement rocks. If the area is interpreted as a basin, it is probably asymmetrical with the axis paralleling and just north of the southern uplift. The basin noses (strike of the rocks changes through about  $140^{\circ}$ ) in the southeast part of the study site. The western, broader end of the basin is overlain by younger, essentially horizontal rocks, indicating a probable unconformity.

There is some indication of nosing in the rock pattern mapped in the Duncan area (D). Mapped units in the Permian show a change in strike. The change indicates a synclinal nose (plunging northwest), which is a much sharper nose than appears on the state geologic map.

The inability to distinguish some major mapped rock units points up one of the difficulties encountered in mapping from ERTS imagery. Units are distinguished on the basis of tone, texture, pattern of tones and standard photogeologic inferences. In addition, hue or color is used when mapping from color composite imagery. Factors that can affect the tone, texture, and other visual clues recorded on the imagery include moisture, facies and vegetation changes, differences in climate, topography, slope, and weathering products. Where these factors produce similar photo-responses on adjacent rock units, the units can easily be combined as one image unit. This is the reason El Reno, Hennessey and Wellington rocks may be combined at one place, but distinguishable at another.

Several features in the north indicate the broad outlines of a basin or at least a homoclinal structure. Valleys of the Washita (W), Cimarron (C) and in particular the Canadian (Cn) and North Canadian (N) rivers trace broad arcs from west to east. The assumption might be made that these major streams reflect an adjustment to regional structure, in particular to changes in strike of the underlying rocks and thus partly define the northern reaches of a basin. Supporting this hypothesis are several features. In Oklahoma, north and northeast-facing bluffs and slopes parallel these rivers. Likewise, small streams interpreted as obsequent and resequent flow

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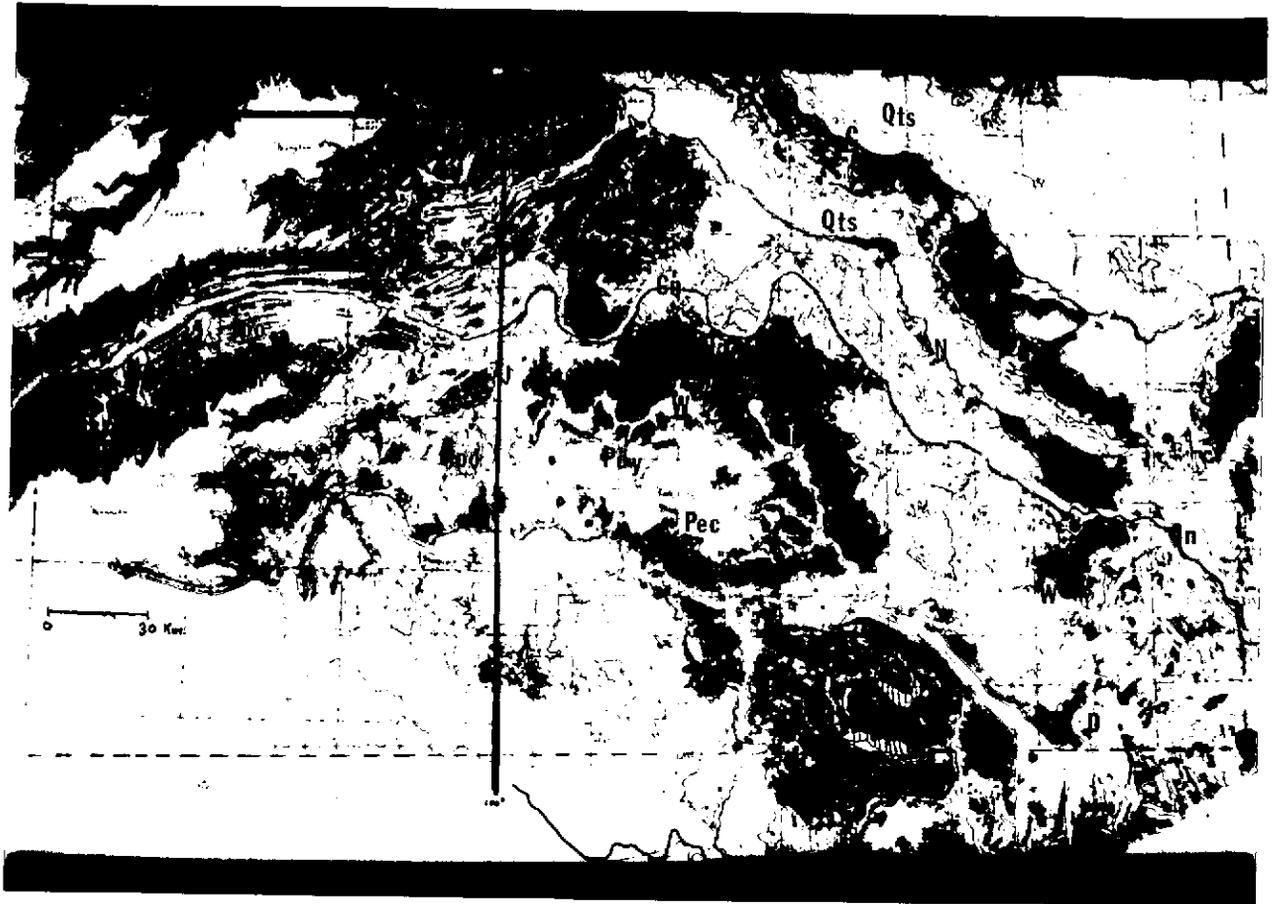


Figure 16. Geologic map derived from ERTS imagery of the Anadarko Basin test site. Key: C = Cimarron River; Qts = alluvial plain; Tpo = horizontal Tertiary sediments; N = North Canadian River; Cn = Canadian River; W = Washita River; Pdy = Doxey Shale; Pec = Elk City member; WM = Wichita Mountains (crystalline); S = sedimentary Wichita Mountains; D = Duncan area.

northeast and southwest, respectively, into the major streams. The bluffs and small streams indicate the underlying rocks dip southwestward on the east, but dip more southerly as one moves west or northwestward along the main rivers. Moreover, the Cimarron and North Canadian have large alluvial plains (Qts) on the northeast indicating the combined effects of several factors. Migration of streams downdip has cut steep slopes on the southwest and left broad plains northeast. Westerly winds have carried material out of the river beds onto their northeast flanks. The major rivers turn eastward at about  $98^{\circ}$  west longitude, (the Washita turns at about  $98^{\circ}30'$  west), indicating a change in structure or a cross-strike course.

Another clue to the synclinal nature of the area can be seen in the rock pattern in the Elk City - Burns Flat area. The Doxey (Pdy) member of the Quartermaster formation crops out continuously on the north, east and south of the Elk City (Pec) member (or Quaternary terrace material covering the Elk City member), forming a southwesterly-directed nose. However, the Quartermaster units at this scale appear to be nearly horizontal or at least of low dip indicating they are little-deformed. They may have been deposited after the greatest subsidence had occurred or they may indicate this is merely a gentle regional downwarp, not a basin which has undergone strong subsidence and deformation.

Some inferred lithologic units indicate the basin is asymmetric. They have a narrower outcrop pattern just north of the Wichitas than they do farther north and east.

To the west of Elk City is a region of horizontal strata (Tpo) which contrasts with the dipping rocks of the basin and overlies the latter with unconformity. It is difficult to determine the dip of the strata exposed in the deeper parts of river valleys in the Oklahoma-Texas Panhandles, but those exposed in the bluffs and slopes appear horizontal. Likewise, the uplands appear topped by flat-lying Quaternary deposits.

Within this region of horizontal strata there is one slight indication of a broad structure. The Canadian River flows within a wide, broadly curved valley flowing northeast in eastern Hutchinson County, Texas, then curving eastward in northern Roberts County and flowing east-southeast in northwestern Hemphill County. The rocks in the area belong to the Tertiary (Pliocene) Ogallala formation. Within the upper part of this formation there are several layers of caliche. An attempt was made to map the caliche since its reflectivity is considerably higher than that of the rest of Ogallala sediments. Mapping the caliche indicates that there is a slight nosing of strata in the Roberts-Hemphill area. The Canadian may breach a slight fold that is asymmetric, the north side having steeper dips.

However, the caliche is irregular in occurrence, appears

to wash out and cover lower slopes in some places, and is difficult to define and trace on the imagery. As a result, the inferred structure may be based upon a fortuitous pattern produced by other conditions. That is, the caliche may occur in a series of localities such that these places form an arcuate pattern. Nonetheless, there is the possibility this broad bend in the Canadian results from a breaching of an anticlinal feature.

In the southern part of the study site there is an uplift of faulted and abundantly jointed rocks. The outcrop of these rocks can be traced from Lawton westward to the area of Mangum, Oklahoma. These outcrops comprise the Wichita Mountains (WM). The strongly jointed rocks can be interpreted from ERTS imagery as exposed basement. There is another large outcrop of rocks (S) north of this main mass of basement rock, which is neither obviously jointed nor layered. The exposure may be interpreted as sedimentary rocks involved and associated with the deformation and uplift of the basement rocks to the south.

There is some evidence on the imagery that the Wichita uplift limits or is involved in the structure of the basin previously described. There is a trend of tonal and linear anomalies extending eastward from the Texas-Oklahoma border near Erick, Oklahoma. It passes just north of the Wichitas and bends around to the southeast at what appears to be the eastern end of the Wichitas near Lawton. Such a trend might be construed as a fault zone forming a

boundary between the basin and the uplift. Another possibility is that this is a zone of steeply dipping beds which are the southern flank of the basin. Thus, analysis of the information interpreted from the ERTS imagery would lead to the correct conclusion that the area is underlain by a large west-northwest trending asymmetrical syncline.

### Recognition of Anomalies

During interpretation of ERTS imagery we identified a variety of different types of anomalies.

We found fewer than 30 anomalies that could be described as tonal and fewer than a dozen textural anomalies. The tonal anomalies are the result of unusual reflectivities possibly produced by peculiar conditions in the rock, soil, plant cover or cultural activity in any given locality (see figure 17).

Where it was possible to identify cultural causes for a tonal anomaly we eliminated it from further study. Preliminary analysis shows a strong correlation between oil fields and tonal anomalies. No attempt was made to relate correlating fields to depth of production or type of trap. This correlation may not necessarily reflect underlying geologic conditions but may be fortuitous or result from the activities of man.

Textural anomalies may be the result of drainage patterns that are more dense than patterns in adjacent areas. They may reflect differences in size and shape of agricultural fields in a cluster, which in turn may reflect anomalous topographic or soil conditions. Other textural anomalies appear as a mottled surface surrounded by a surface of more even overall tone or from indistinct effects which might be described as "grainy" or "jumbled" or "rough" as opposed to adjacent "smooth" or regular surfaces. A preliminary

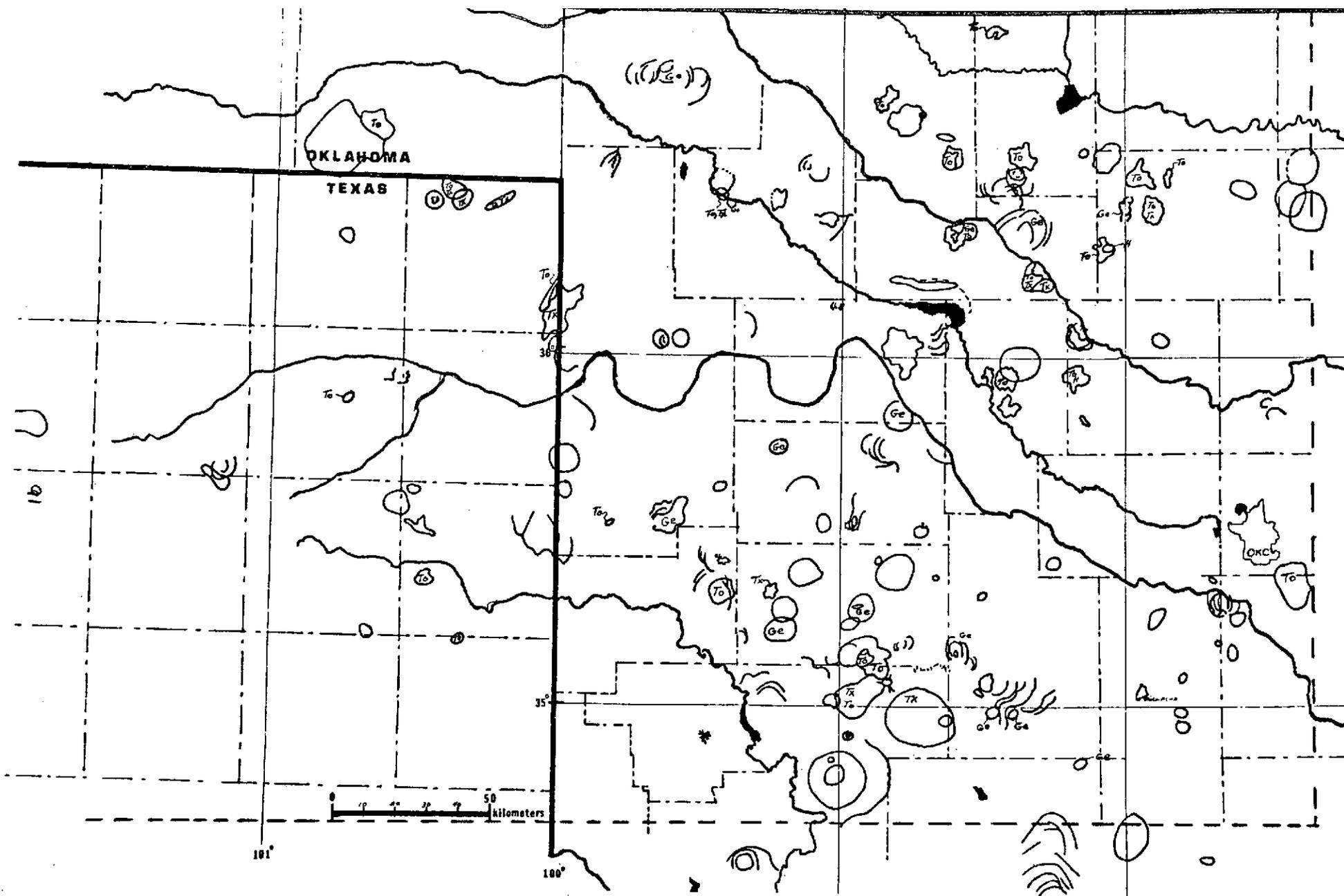


Figure 17. Compilation of several anomaly types. Included are several circular and arcuate anomalies, two hazy anomalies (H), drainage and topographic anomalies, repeated patterns, tonal (To), textural (Tx) and geomorphic anomalies (Ge).

comparison of maps of textural anomalies to an oil and gas field map shows some correlation between fields and anomalies. Textural anomalies need further testing.

We have mapped about 60 "hazy" anomalies (figure 18). "Hazy" areas appear on the imagery as if image detail is lost or the scene has been smudged or partially erased. They are not atmospheric or photographic processing effects. The number of these anomalies varies with changes in season, but many of them persist from season to season. They are more numerous in western portions of the test site than in the east. "Hazy" anomalies are located mostly in areas of Quaternary deposits near major streams and along the eastern thin edge of Tertiary Ogallala sediments. That is, they occur mostly in areas with sandy material at the surface. Some of these anomalies are located on stabilized dunes as indicated by a check of three areas containing "hazy" anomalies. Examples are the large anomaly in the large meander of the Canadian River in Ellis County, Oklahoma, and several others along the north side of the Canadian in Texas. However, the correlation with sandy areas is not entirely consistent. One of the sites checked has no dunes or thick sand deposits. Published maps also show that some "hazy" areas are not on sandy surfaces. "Hazy" anomalies have a high correlation with known producing oil and gas fields. Most of these fields are stratigraphic traps rather than structural traps. We did not check against depth of production. These anomalies may be the result of man's

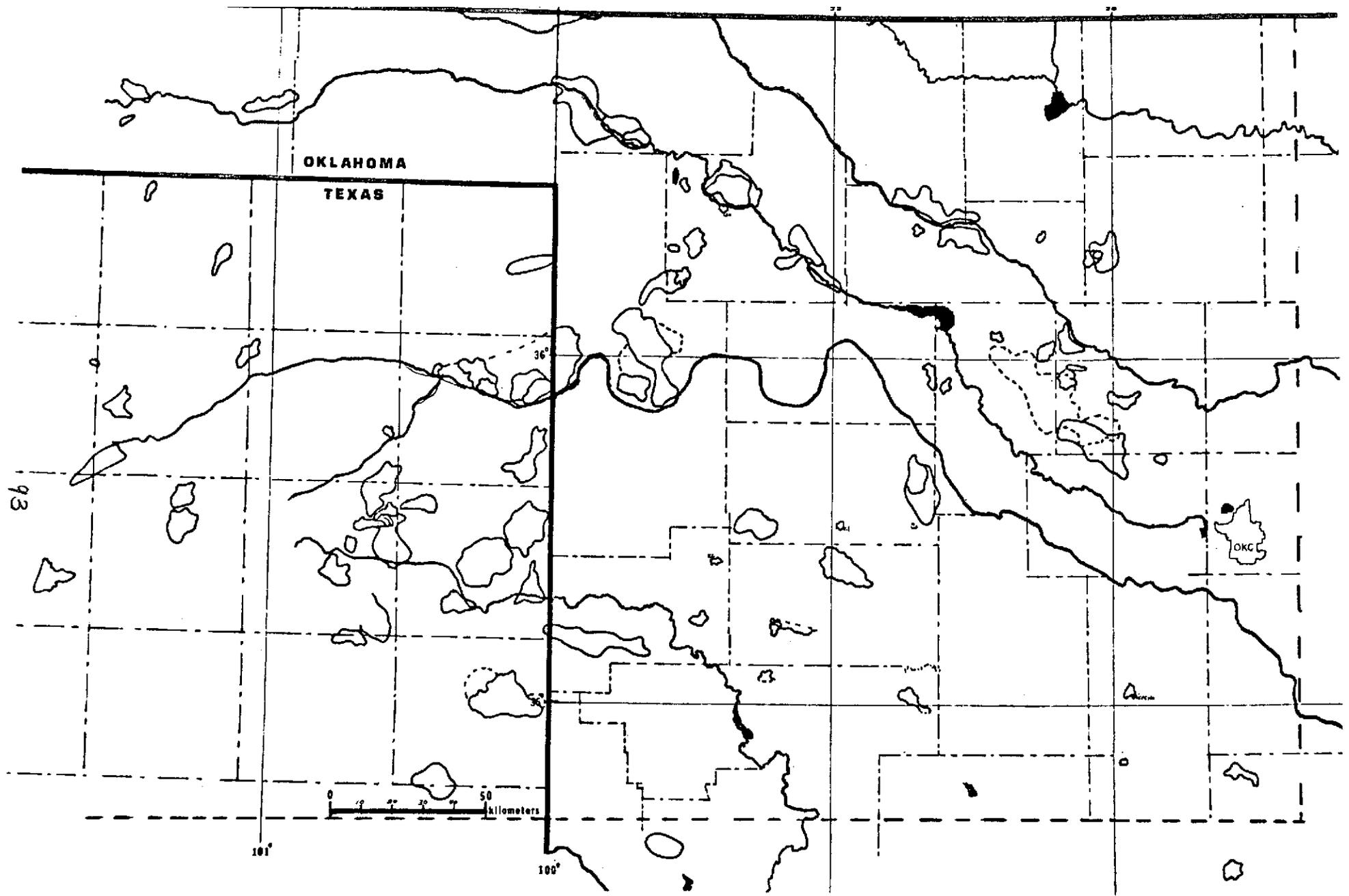


Figure 18. "Hazy" anomalies compiled from fall MSS imagery (1972) and spring imagery (1973). Dashed where limits are uncertain.

activities during oil exploitation, they may reflect the nature of the substrata or may have their origin in some type of geochemical effect caused by hydrocarbons leaking from the reservoir or production equipment. "Hazy" anomalies seem to be unique to ERTS imagery, and are most easily identified on band 4. Moreover, a brief inspection of available SKYLAB S190A photographs did not reveal any "hazy" areas.

The most numerous anomalies (figure 19), are arcuate or near-circular features which we term closed anomalies. Most closed anomalies are geomorphic features such as annular or radial drainage patterns, bends and arcs in stream valleys, circular or arcuate tonal and topographic features, field patterns, etc. We believe closed anomalies hold the most promise for locating potential hydrocarbon reservoirs. Although other anomaly types may have a higher correlation with producing fields of all kinds; closed anomalies show a higher correlation with known subsurface structures and/or structurally controlled hydrocarbon fields.

Other types of anomalies are numerous. We have marked many other localities of interest on the basis of drainage peculiarities, indistinct series of arcuate stream valleys or arcuate linears, topographic peculiarities, and other indistinct but interesting patterns, shapes or concentrations of features. Figure 17 locates some of these anomalies.

The kinds of anomalies discussed above are generally

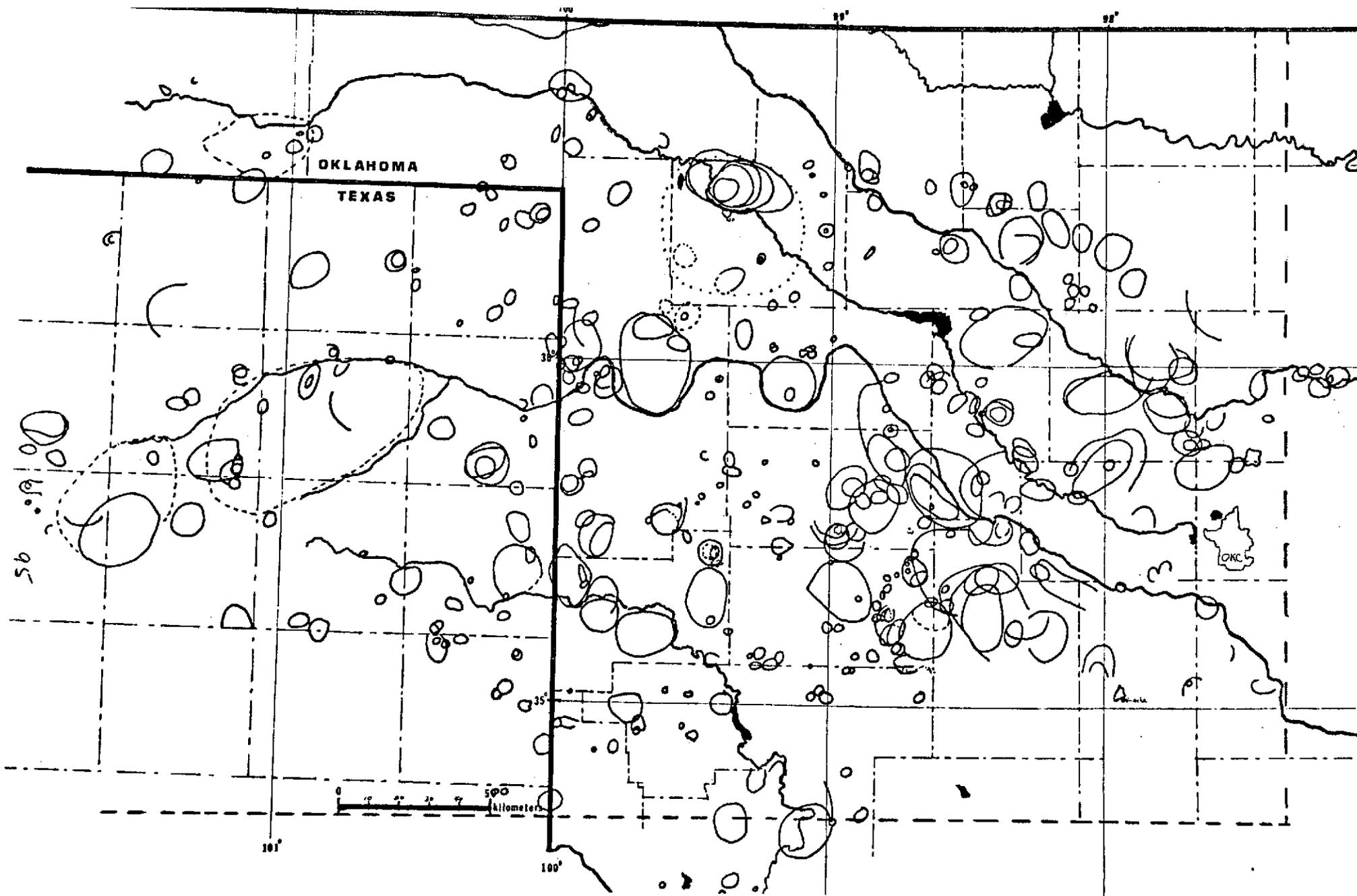


Figure 19. Compilation of circular and arcuate anomalies. Dashed or dotted where boundaries are uncertain.

exclusive. That is, relatively few anomalies of one kind coincide with anomalies of another kind. For instance, only 5 tonal and textural anomalies coincide, and only 22 closed and hazy anomalies coincide. There are more than 250 closed anomalies and about 57 "hazy" anomalies. One method which might be used for locating promising exploration sites is to define sites where two or more anomaly types coincide. On one composite overlay of fall imagery we counted 76 anomalous features. We classified these as geomorphic, tonal and "hazy" areas. Of 76 anomalies, 59 correlate with producing oil and gas fields, 9 are on known but non-producing structures, and the remaining 8 could not be correlated with known features. Twenty-nine geomorphic features are included. Twenty-three correspond with producing areas, 3 with non-productive structures. Three show no correlations. Eight of 12 tonal anomalies correlate with production. One correlates with a known structure and 3 correlate with no known features. Of 35 "hazy" anomalies, 33 correlate with producing fields or drilled structures.

On a more recent compilation, after additional interpretation, 42 of a total of 57 "hazy" areas coincide with producing fields. Six additional areas correlate with known but non-productive structures. Nine have no correlation with known structures.

## Interpretation of Areas of Special Interest

One fruitful method of using ERTS data is to select small areas and concentrate on refining the original interpretation by extracting as much information as possible. We will discuss briefly several sites selected from previous ERTS interpretations, from high altitude photographs and from suggestions by our petroleum geologists.

### Elk City Area:

The entire Elk City area was identified early in our studies as a site of particular interest. We first identified the Elk City Field, South as a closed anomaly. Later study showed that the anomaly resulted from apparent concentric or annular drainage. Several prominent, through-going linears were recorded. Our interpretation is shown in figure 20. Most earlier interpretations (Natural Petroleum Bibliography, 1961), (Lang, 1955) show the Elk City structure as an anticline lying in the axis of the basin. The structure was assumed by some to die out at depth. Wroblewski (1967) suggested that the anticline was bounded along its northeast side by a normal fault trending north 45° west. It was suggested by Harlton (1972) that this fault is part of a regional lineament called the Cordell fault. Scott (1966) published the results of a gravity traverse in which he interpreted the Elk City field as a superficial fold associated with a much larger,

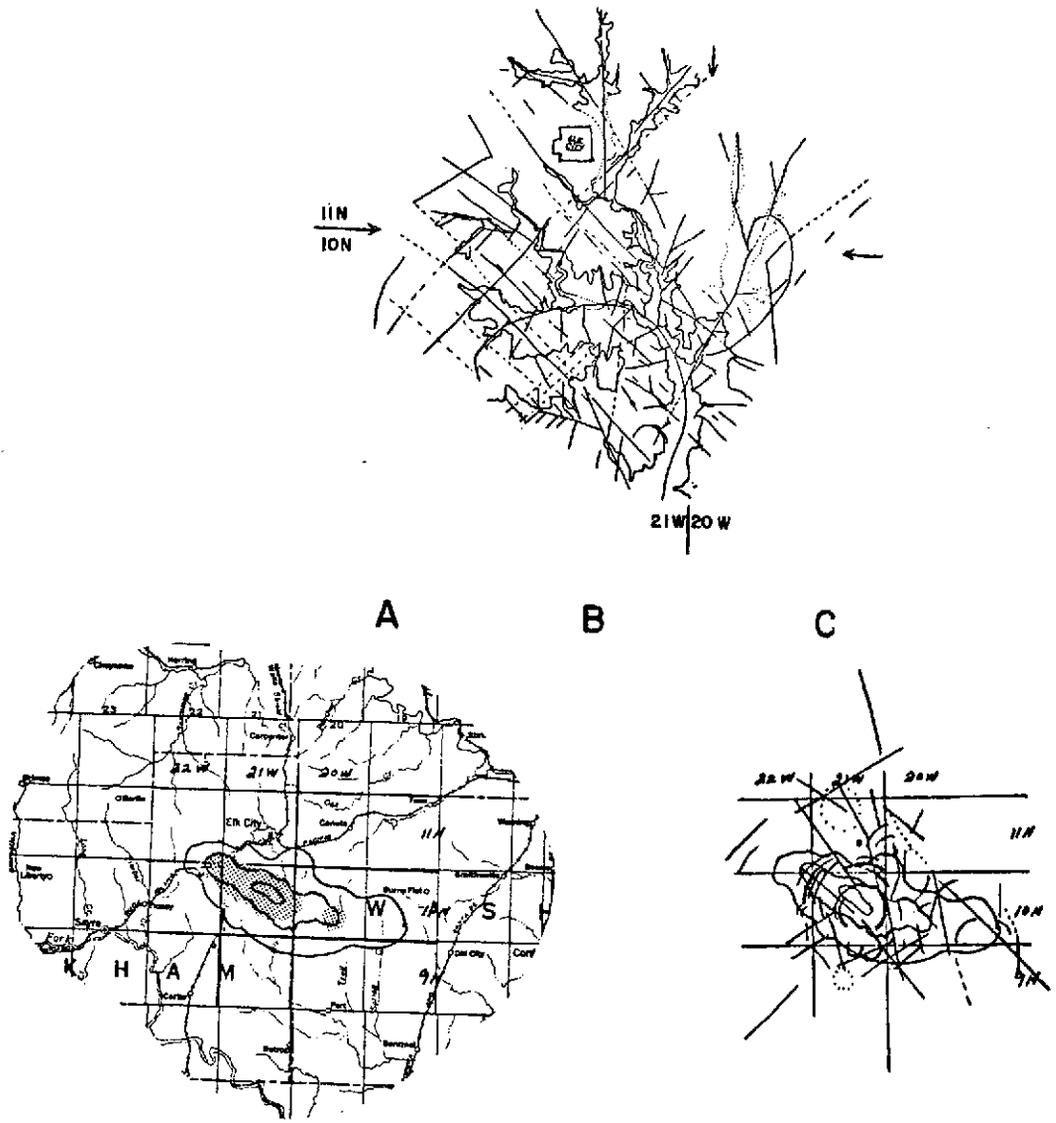


Figure 20. The Elk City structure is shown by subsurface structural contours in (A). Producing areas are shaded. ERTS interpretation of the Elk City anomaly is shown in (C). Both figures are at their original scale of 1:1,000,000. (B) is a reduction of an interpretation done from a color infrared photo at 1:55,000, scale shown is 1:240,000. This interpretation includes lithology. That the ERTS anomaly is a geomorphic feature is apparent from the photo-interpretation.

deeper-seated fault-bounded structure. He places the axis of the deep structure about  $3\frac{1}{4}$  kilometers north of the axis of the Elk City field.

Our ERTS interpretation located a closed anomaly directly over the center of production of the field. The most prominent linears trend north  $45^\circ$  west and north  $40^\circ$  west, bounding the center of the structure. The linear trending north  $45^\circ$  west through the southeast part of the area may represent a fault bounding the deep structure along its northeast side. One linear running about north  $10^\circ$  west intersects the east end of the Elk City structure where its axis shifts to an easterly direction at the township line between 20W and 21W.

#### Woodward Area:

The subsurface geology of the Woodward area is less complicated than that of the Elk City area and the fields of the Wichita frontal zone (Weinkauf, 1968), (Forgotson, 1969).

This area was selected for further study for three reasons. We had noted several strong linears on high-altitude infrared photographs of the area, there are several closed and "hazy" anomalies here and the Morrowan rocks (lower Pennsylvanian) include a prominent channel sand body (shaded area in figure 21) at about 2,480 meters below the surface.

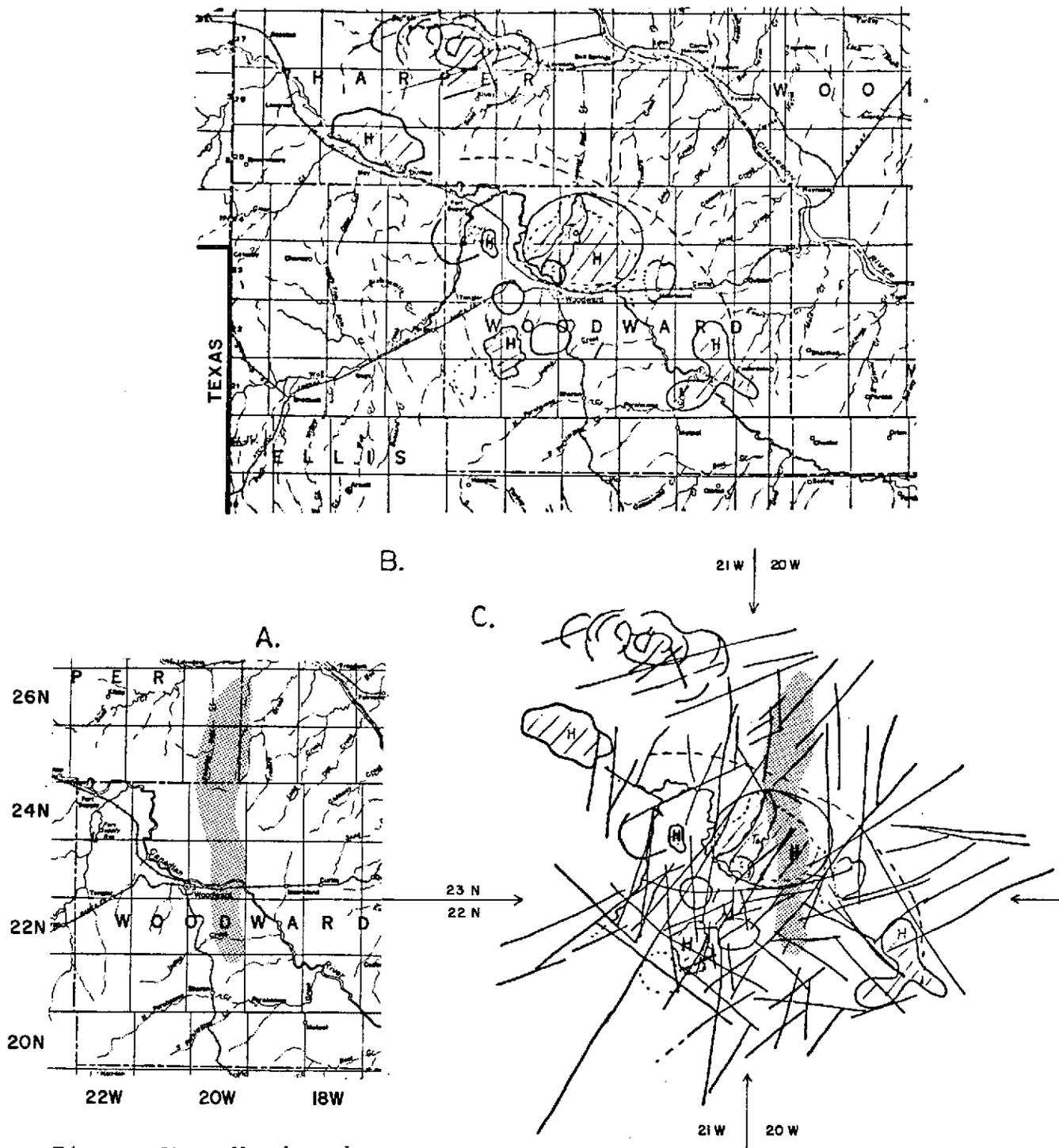


Figure 21. Woodward area.

(A) locates a subsurface channel sand body (Morrowan, Pennsylvanian).

(B) shows a variety of anomalies interpreted from ERTS, including: H=hazy, To=tonal, and several closed and arcuate anomalies.

(C) combines ERTS linears with the anomalies. There is no evidence at the surface of the channel or of structures controlling the location of the channel, with the possible exception of the north-south trending linears. Scale = 1:1,000,000.

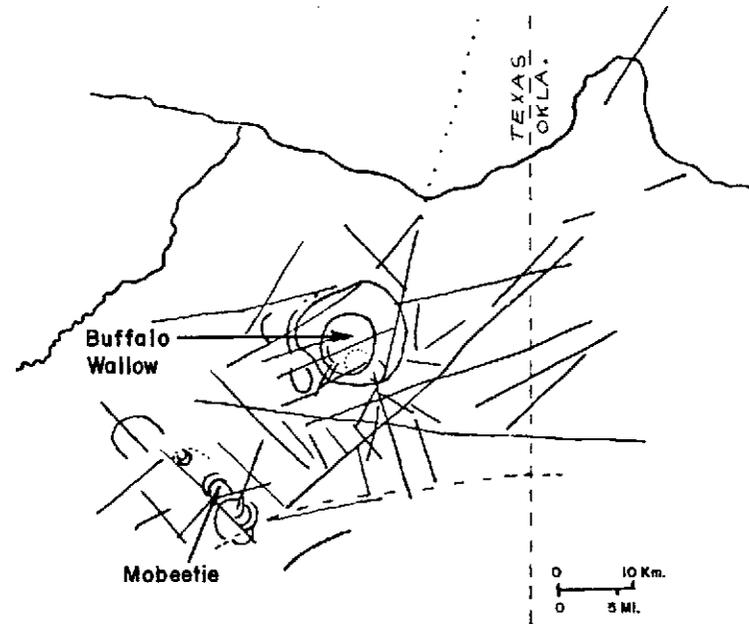
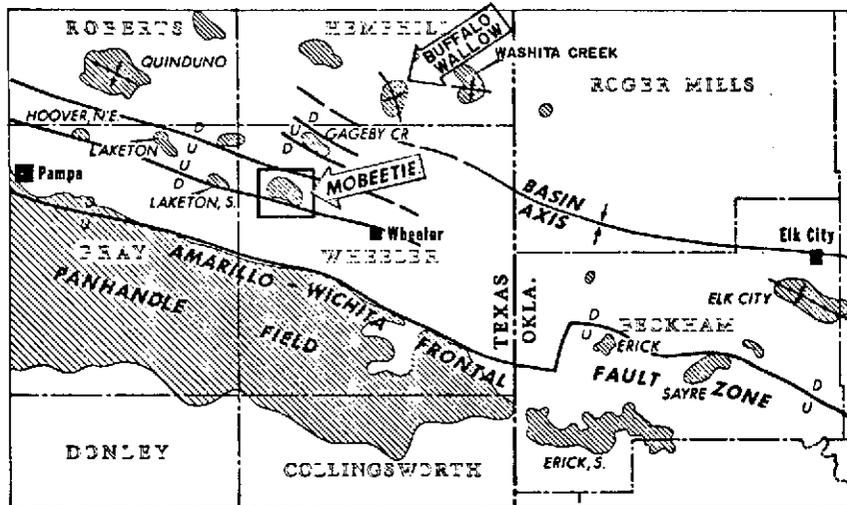
We found no evidence of the channel expressed at the surface. There is a set of linears trending about north-south which might be interpreted as flanking structures of the channel. A large closed anomaly and a "hazy" anomaly coincide with the north Woodward field. A linear trending about north 40° east flanks the northwest side of the West Sharon field. It coincides with and extends a linear seen on the high altitude photos and with a fault appearing in various interpretations of the West Sharon field.

#### Buffalo Wallow Field:

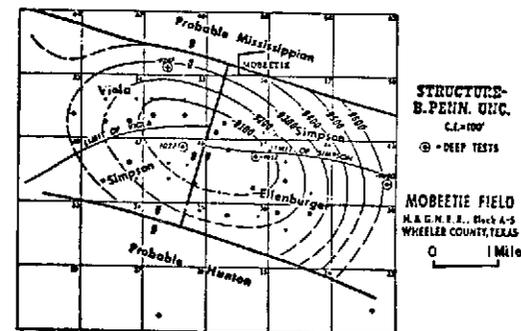
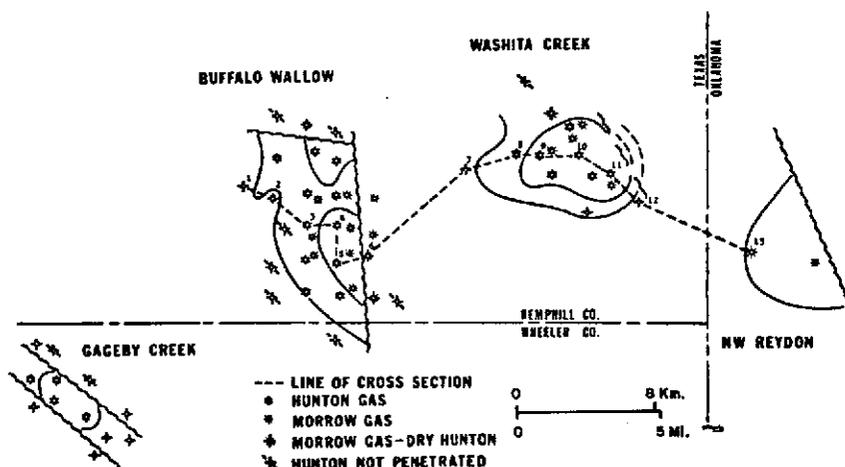
This area was chosen for further study because it was first noted as a closed anomaly on ERTS imagery (figure 22). The center of the anomaly is a nearly perfect circular pattern of fields which also appears as a light-toned anomaly on spring images and coincides exactly with the center of production in the field, Tutten (1972) and others interpret the deep structure (below the Morrow or deeper than 2800 m.) as an anticline closed by normal faults on the north and east. Although our anomaly exactly coincides with the field and although the anomaly is bounded by prominent linears, none of the linears exactly coincides with interpreted faults.

#### Mobeetie Field:

This field, like the Elk City and the Buffalo Wallow fields, was chosen on the basis of an ERTS anomaly. The anomaly is not as prominent as those associated with the



A B  
C D



102

Figure 22. Buffalo Wallow and Mobeetie fields. (A) Tectonic setting of the fields (Sahl, 1970). (B) ERTS interpretations at 1:1,000,000 of Buffalo Wallow and Mobeetie anomalies. (C) Interpretation of Buffalo Wallow structure by Tutton (1973). (D) Mobeetie structure according to Sahl (1970). The ERTS closed anomalies coincide exactly with their respective fields. ERTS linears may reveal undiscovered aspects of the fault control of the fields.

other two fields. Our interpretation (figure 22) closely matches published interpretations (Sahl, 1970), (Wroblewski, 1967). We find a partially closed anomaly, flanked by linears trending north  $45^{\circ}$  west, overlying the buried structure.

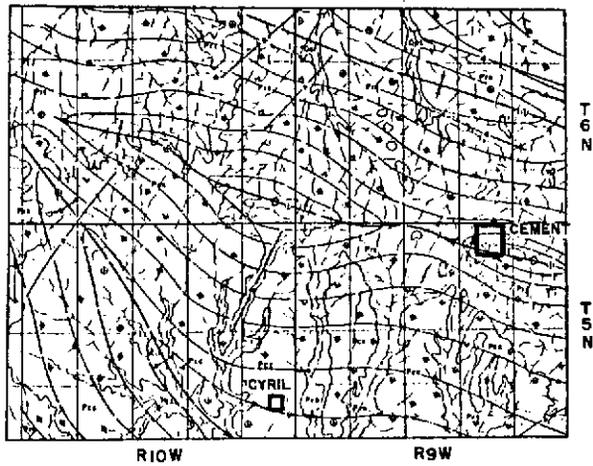
Published analyses describe Mobeetie as an anticline flanked by high angle faults; i.e., a horst. Interpretations of strike of the faults vary from north  $45^{\circ}$  west to north  $70^{\circ}$  west.

#### Cement-Chickasha Area:

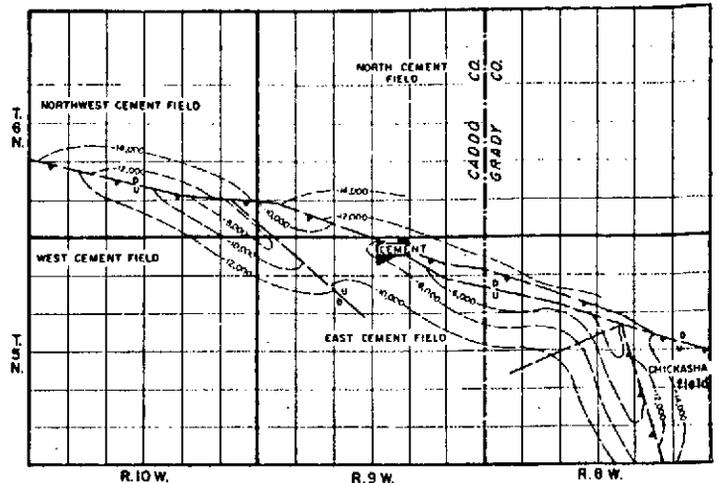
One of the most perplexing areas has been the strongly folded and faulted Cement and Chickasha fields. These fields were mapped at the surface in 1916 (Withrow, 1967), from aerial photographs (Trollinger, 1968) and from drilling data (Herrman, 1961). Although the structures controlling these two fields are fairly prominent at the surface, we found nothing to attract our attention to the area, nor were we able to map the structures when studying the ERTS imagery specifically for this purpose. Refer to figure 23.

The surficial rock units we mapped correspond closely with the units of the Cement-Chickasha area as compiled on the state geologic map at 1:500,000 scale. They include the Cloud Chief and Rush Springs formations of Permian age and Quaternary sand associated with the Washita River.

We mapped three closed anomalies, none of which coincides with major structural features in the subsurface.



A  
C



B  
D

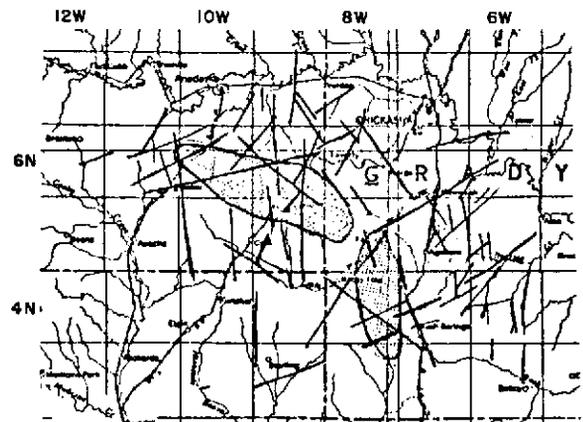
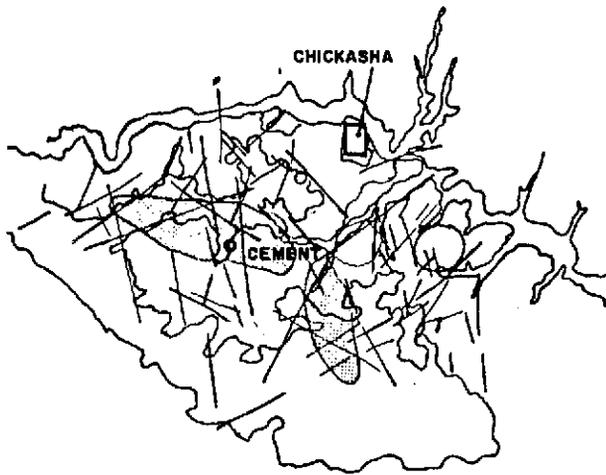


Figure 23. Cement-Chickasha area.

(A) is a published airphoto interpretation of the structure of the Cement area (Trollinger, 1968).

(B) is an interpretation of subsurface structure, after Herrman (1961).

(C) shows an ERTS interpretation of the area. Lithology closely matches the state geologic map. The linears for the most part match joint patterns but not faults. Note two closed anomalies. The Cement and Chickasha fields are shown by the shaded areas. Scale = 1:1,000,000

(D) shows only ERTS linears. Scale = 1:1,000,000

None is prominent enough to draw specific attention to the area.

Two linears parallel but do not coincide precisely with deep faults associated with the structures. One linear runs north-northwest along the east side of the Chickasha field. The other runs northwest through the north side of the Cement field. There are two other sets of linears which may reflect subsurface conditions. The north trending set probably is a result of a joint pattern, based on our field checks. The northeastward set may represent crossfaulting at depth (Trollinger, 1968).

## Enhancement Procedures

We tested several enhancement procedures in order to evaluate the contribution of enhancement to image interpretation for geologic exploration purposes. Enhancement included photographic techniques, color additive viewing, electronic density slicing and edge enhancement, and various digital operations. From our work, which was not exhaustive, we drew the following conclusions (these apply only in the Anadarko Basin, we have not tested them elsewhere):

- \* Electronic edge enhancement and density slicing helped little.
- \* Photographic techniques are cheap, simple, and can be quite useful. Techniques used included high contrast printing, gray scale adjustment, and film sandwiches.
- \* Color additive viewing is flexible and is useful for enhancing specific features such as linears, closed anomalies, and lithologic boundaries.
- \* Digital processes offer the greatest range of possibilities but must be "fine tuned" for each area. Unless a completely interactive system is available this can be a long process. Techniques that seem to be the most useful are density slicing, gray scale adjustment and ratio operations.
- \* Several types of enhancement (photographic, additive color viewing, etc.,) should be tried in any operational program once areas of interest are defined.

We found no enhancement procedure we felt was worth applying to the area as a whole. However, we are convinced that as digital image processing procedures continue to develop and be adjusted to specific environments several

types of digital preprocessing will become standard before any interpretation begins.

Using August 1972 imagery we made a preliminary test of electronic density-slicing and edge enhancement using an I<sup>2</sup>S Digicol. In the Anadarko Basin these procedures did little to aid interpretation. The area tested lies in the south central part of the Basin - an area that is extensively farmed. The problem was that these procedures either emphasized the boundaries between fields or differences in the contents of fields, masking inferred lithologic and structural features. Both of these effects would be desirable for conducting a crop inventory, but do not help geologic interpretation.

It is possible that these techniques would be useful for detecting differences in surface material, lithologic boundaries and linear features in other parts of the area that are less extensively farmed.

Photographic techniques included high contrast printing, gray scale adjustment and film sandwich techniques. By making new negatives from the extremely dark positive transparencies and printing these on high contrast paper we were able to make interpretable 1:250,000 enlargements of the otherwise unusable fall imagery. We found that high contrast paper improved the usefulness of greatly enlarged images.

We attempted to produce a useful edge enhancement using film sandwich (positive and negative of band 7 images).

However, no matter which way the transparencies were offset the technique tended to enhance section line roads rather than natural linears. We did not test this procedure throughout the Basin and, as with the electronic enhancement techniques, the procedure may be useful in areas with less cultural noise.

One technique we did not try, that could be helpful, based on work with the Addcol is differencing bands. A particularly useful combination uses the positive of band 6 or 7 and the negative of the other to produce a new image. The lighter the area the greater the differences. When attempted on the additive color viewer this technique enhanced some inferred lithologic contacts.

An I<sup>2</sup>S Mini-Addcol was used to make a large number of color composite images. Several dozen of these were recorded using a Pentax 35 mm. single lense reflex camera loaded with Ektacolor Professional color film (ASA 100). A limited number of 9" x 9" color composite images were made using a film back built for the Addcol by I<sup>2</sup>S.

This technique has the great advantage that the interpreter can adjust the machine to enhance various features and can immediately see the results without having to wait for photo or computer processing. If a desirable combination is found, it can be recorded on film with reasonable fidelity using relatively simple equipment. We found that the 9" x 9" images produced have nearly the resolution of standard color composites.

In addition to producing color composites the viewer can be used to produce a type of differenced image by using the positive of one band and the negative of another. Edge enhancements can be made by using the positive and negative of the same band and putting the two images slightly out of registration. Figure 24 is a copy of a 9" x 9" image made by illuminating a band 6 negative transparency with green light and a band 7 positive transparency with red light and offsetting the two images approximately 0.5 mm. to the northeast. The result brings out subtle differences in inferred lithology and enhances northwest trending features. At the same time it suppresses northeast trending linears.

Other additive color products selectively enhanced one or several features. Figure 25 is a copy of a band 5, 6, and 7 composite, which emphasizes hazy anomalies. This composite is good for detecting other types of closed anomalies and linear features. Figure 26 is a copy of a composite that brings out a strong linear feature that went undetected until the scene was viewed on the Addcol.

We found additive color viewing to be a very useful technique. However, a particular combination of bands, filters, and light intensities which is successful for one scene must be adjusted for all other scenes and for the same scene acquired at a different time of year.

Various types of digital processing were attempted on a test area just south of the Canadian River in the

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Figure 24. Color composite produced on I<sup>2</sup>S additive color viewer using a negative of band 6 (green) and a positive of band 7 (red) and offset to enhance linear features.

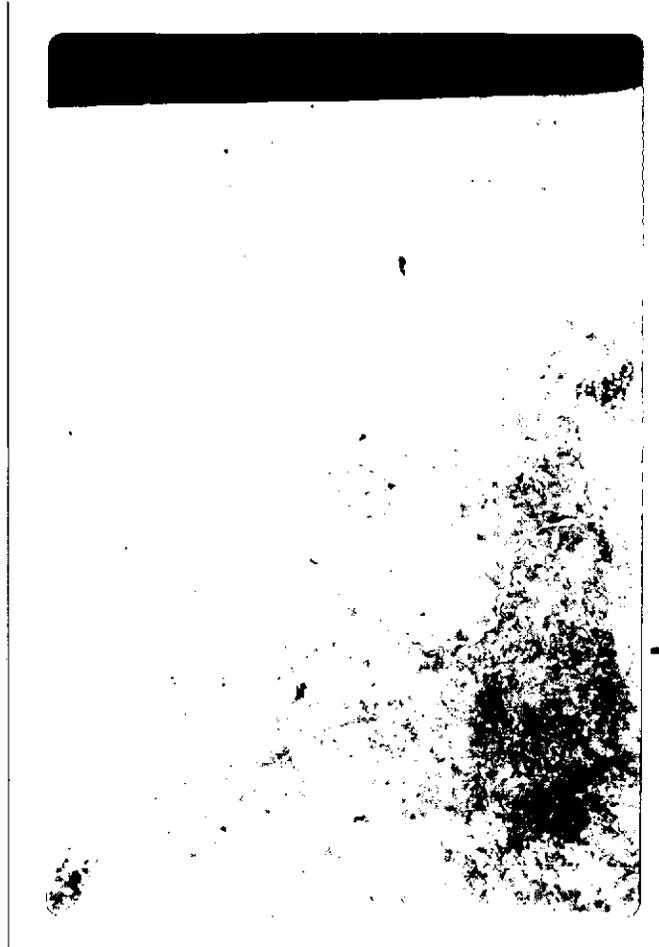


Figure 25. Copy of a false-color composite of bands 5, 6 and 7. This composite emphasizes "hazy" anomalies and linears.

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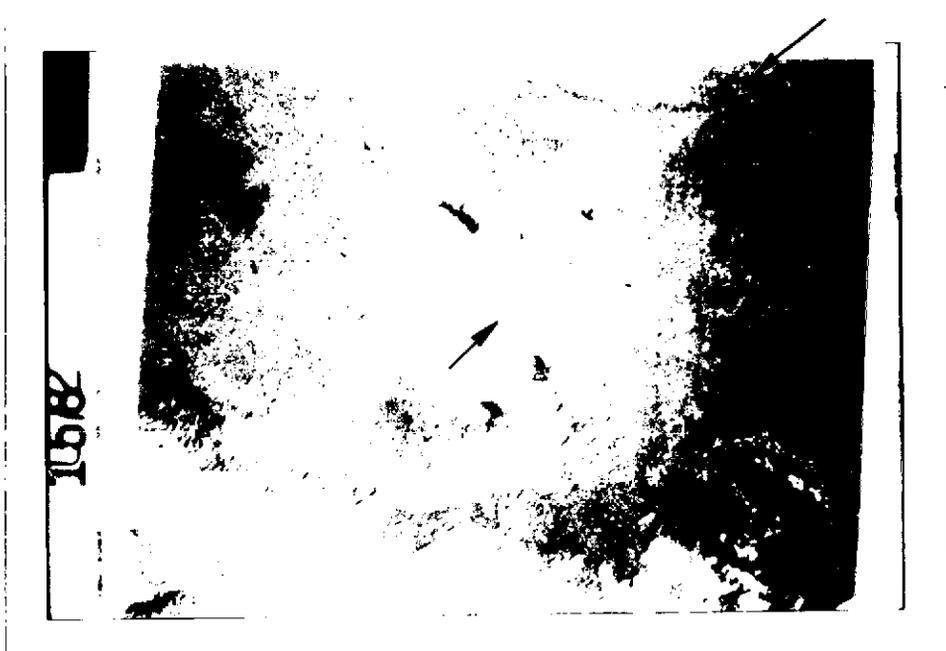


Figure 26. A false color composite was made and photographed, combining a blue filter with band 7, red with 4 and "white" light with the negative of 6. A previously undetected linear is disclosed as indicated by the arrows.

vicinity of the Aledo field. We did not exhaustively test digital processing. We wanted to assess the value of various types of processing in terms of their inclusion in an operational program without attempting to develop the optimum set of processes for the Anadarko Basin. The processes used included gray scale adjustment (histogram equalization), density slicing and stretching and ratioing. Most of the results were out put as histograms and shade prints.

From this work we conclude that any major operational use of ERTS data for petroleum exploration should consider inclusion of digital processing in the form of gray scale adjustment for at least one band and ratioing of bands 6 and 7 would probably provide the most generally useful products. Such a program might involve a considerable amount of "fine tuning" of the programs to the particular areas. The above conclusion is based not only on our work, but work by Bernstein (1973), Goetz et al. (1973), and Vincent (1973).

We found that gray scale adjustment programs (histogram equalizations) made many linear features stand out and seemed to make lithologic differences more obvious. However, it also made field boundaries and roads more obvious (figures 27 and 28).

A ratio of band 6 to band 7 produced a map in which differences between agricultural fields almost disappeared, greatly reducing the cultural noise in the scene. However,



Figure 27. Example of a band 5 digital density stretch (histogram equalization) printed on a Litton printer. Fine details such as roads, taxi strips at Clinton-Sherman Air Base and lithologic units along the Canadian River are enhanced.

PHOTOGRAPH NOT REPRODUCIBLE



Figure 28. An example of a band 7 density stretch. It is more difficult to distinguish individual Permian rock units and cultural features in this image than it is in figure 27. However, Quaternary units are enhanced.

differences among some surficial materials also seemed to be reduced. Nevertheless, based on our limited work and the reports by Vincent (1973) and Goetz (1973) we are convinced these problems could be overcome with further adjustment and testing.

In summary, an operational program should employ digital processing to enhance selected areas of particular interest, at least. It seems that as more programs are developed and costs drop one should consider applying at least a gray scale adjustment operation to the entire area of interest.

## VIII. ROLE OF ERTS-1 DATA IN EXPLORATION STRATEGY

ERTS-1 data are extremely useful during the initial phases of petroleum exploration, and can make significant contributions later in the exploration process. Our work convinces us that by studying ERTS data one can gain an understanding of regional lithologic and structural relationships and rapidly focus attention on areas of exploration interest, even in an area that is as complex and difficult from the standpoint of surface exploration as the Anadarko Basin. Once specific areas of interest are identified one can derive significant detailed information by detailed interpretation of these areas on ERTS imagery. We believe that ERTS imagery will be most important in the exploration of poorly known areas rather than in highly developed exploration provinces such as the Anadarko Basin.

Aspects of ERTS interpretation that are important in the regional analysis phase of exploration are: mapping inferred lithology and major structural features, such as the axes of large synclines and anticlines, mapping of major fracture systems (if they can be separated from other linears) and mapping of closed anomalies recognized on the basis of tone, texture, geomorphology or inferred structure. Interpretation of this type can be used to postulate the geologic framework of the region and to focus attention on specific areas. An interpretation of

linear features may contribute to overall understanding at this point, but we found it helped little. This preliminary interpretation should be done "blind", that is, without extensive reference to known or published data. Available data should be used to refine and modify the preliminary ERTS interpretation and analysis and to arrive at a regional synthesis of the geology.

Once this preliminary synthesis is complete, areas chosen as interesting or anomalous can be examined in greater detail in order to extract as much information as possible. It is at this level of study that interpretations of linears become important because the linears may coincide with or define alignments of anomalies or may contribute to a greater understanding of specific anomalies. In explored petroleum provinces features identified as being of interest in petroleum exploration should be carefully examined on the ERTS imagery to see if it is possible to extract additional information or discern regional relationships. These interpretations and analyses can be used to plan regional reconnaissance, geological and geophysical programs, and to begin planning more detailed programs for specific anomalies. Any anomalies identified in the ERTS imagery almost certainly would be checked on normal air photographs before undertaking a seismic survey over them.

In addition to providing the interpretive base for planning regional surveys, ERTS imagery is an excellent map

for planning logistics, overflights, the location of operations bases, etc.

Because of small scale and low resolution ERTS interpretation can contribute relatively little during the detailed phases of exploration. In some instances it could help in choosing a well site (e.g., locating a well on the side of a river near access roads instead of the other side). There may be a few instances where ERTS might be useful in actual selection of a location (e.g., extension of known fracture porosity, extension of known fields, etc.), but these situations are expected to be rare. In all instances one would want to obtain confirmation with the more customary exploration tools.

It is necessary, at all levels of ERTS interpretation, to continuously integrate ERTS imagery, aircraft acquired imagery, and ground data. This integration enables the interpreter to fully understand the information content of ERTS imagery, to form a geological synthesis and propose the most reasonable hypotheses.

ERTS provides a means of quickly understanding the geology of an exploration province and it rapidly focuses attention on features that may be of exploration interest. We believe these two advantages will be the main contributions ERTS can make to a petroleum exploration program. These types of information can greatly reduce the amount of reconnaissance geological and geophysical work necessary

and result in a great saving of time and of man power.

## IX. PROGRAM COSTS AND BENEFITS

The cost of this experiment is easy to calculate. The cost of obtaining similar or equivalent information by more customary means is difficult to estimate principally because there are a variety of options and hence prices available for obtaining reconnaissance data. Moreover, the types of data obtained by the two approaches are not precisely comparable.

An oil company can obtain regional geophysical and geological data in any one of several ways. It can:

1. Pay for the survey itself and have the data on a proprietary basis - very expensive.
2. Join a "group shoot" and pay for and obtain the data jointly with several other companies - less expensive.
3. Wait until after reconnaissance surveys are run and then obtain the data essentially second hand when it has been released by the group who paid for the survey - least expensive and least timely.

The second problem of estimating costs is that the types of information obtained by ERTS and customary reconnaissance techniques essentially are not comparable. ERTS interpretation for instance, provides much more information on closed anomalies and linears (inferred to reflect fracture patterns) than customary methods.

On the other hand, reconnaissance geologic field work and seismic and aeromagnetic surveys provide a great deal more detailed and quantitative data than is obtainable from ERTS. One method of dealing with this problem is to attempt to estimate the costs of arriving at a particular common point in an exploration program with ERTS and without ERTS. The common point we have tentatively chosen for this comparison is the point at which one would begin detailed surface mapping and begin to plan detailed seismic surveys and geochemical surveys (if indicated).

The ERTS program in order to be comparable to the conventional program would have to include the cost of air photo interpretation, reconnaissance geology, and seismic work over anomalies identified in the ERTS imagery. For instance, we found approximately 70 anomalies with an average radius of 8 kilometers and a total area of about 14,000 square kilometers. On the basis of air photo interpretation and field work one might choose 30 of these on which to acquire seismic information. Acquisition of a cross pattern of seismic information (lines) over these anomalies would require about 900 line kilometers of seismic work. The cost of the ERTS data are assumed to be small and are included in the cost of the interpretation.

Using a customary approach to regional exploration probably would entail acquiring an air photo interpretation and reconnaissance seismic coverage over the entire area. A reconnaissance seismic survey would require about 4,600

line kilometers of shooting (covering the 80,000 square kilometers area on a 30 x 40 kilometer grid). One probably would want to obtain a standard airphoto interpretation of the entire area. Anomalies located with regional seismic work and airphoto interpretations would be covered with a cross pattern of seismic lines. For purposes of comparison we assume that about the same number of anomalies would be examined in both programs. This would require an additional 900 line kilometers of seismic survey.

Both the conventional and ERTS exploration programs probably would include reconnaissance aeromagnetic surveys and regional gravity surveys of the entire area. However, it is probable that the ERTS interpretation could reduce the amount of gravity data required. Both programs would include a review of available geologic information.

In the conventional survey the reconnaissance seismic and airphoto interpretation would probably be acquired on a non-exclusive basis. In the ERTS program the air photo interpretation would probably be acquired on an exclusive basis so as not to reveal one's intentions. In both surveys the seismic work over anomalies would almost certainly be acquired on an exclusive basis. Under this set of assumptions (probable mode) the conventional program would cost about 1.6 million dollars and the ERTS program would cost approximately 1.1 million dollars. The ERTS program would represent approximately a 30% savings over the conventional program.

Expenses involved in this comparison between a conventional exploration program and an ERTS-based program are summarized in the following table.

<u>A. Conventional Program</u>			
	<u>Non-Exclusive</u>	<u>Exclusive</u>	<u>Probable Mode of Acquisition</u>
Reconnaissance Seismic Survey (4600 Kilometers)	\$400,000*	\$5,060,000	\$ 400,000
Air Photo Interpretation (80,000 Square Kilometers)	64,000*	160,000	64,000
Reconnaissance Surface Geology	200,000	200,000*	200,000
Seismic Survey Across Anomalies (900 Kilometers)	76,000	990,000*	990,000
<b>TOTAL</b>	<b>\$740,000</b>	<b>\$6,410,000</b>	<b>\$1,664,000</b>
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<u>B. ERTS Program</u>			
	<u>Non-Exclusive</u>	<u>Exclusive</u>	<u>Probable Mode of Acquisition</u>
ERTS Interpretation Including Comparison to Air Photos	\$ 25,000	\$ 25,000*	\$ 25,000
Seismic Survey Across Anomalies (900 Kilometers)	76,000	990,000*	990,000
Air Photo Interpretation of Anomalies (14,000 Square Kilometers)	11,200	28,000*	28,000
Reconnaissance Surface Geology Over Anomalies (14,000 Square Kilometers)	35,000	35,000*	35,000
<b>TOTAL</b>	<b>\$147,000</b>	<b>\$1,078,000</b>	<b>\$1,078,000</b>
*Indicates probable mode of acquiring the data.			

Table 2. Comparison of cost of a regional exploration program:  
A. Using conventional methods, B. Using ERTS data.

The above represents only one of many possible permutations and combinations of ways in which the data in each program could be acquired or exactly what data will be

acquired. This last factor depends on the area to be studied and the experience of the exploration group conducting the study. For instance, it is unlikely that all of the anomalies found in either program would be covered by seismic lines. A company could very well choose to examine only part of a basin in detail based on preliminary seismic work conducted in either program. Thus the prices of the two approaches may be nearly the same at one extreme. At the other extreme, the conventional approach would cost almost twice as much as the ERTS approach. The costs of both programs are most sensitive to the amount of seismic data acquired and to the basis on which it is acquired.

The costs of individual elements of the program can also vary considerably. For example, field geology in all but the most straight forward well-developed area (good roads) would certainly cost considerably more. The same is true of seismic surveys. Because the conventional program includes a larger proportion of both these elements, it is probable that, under most circumstances, the cost ratios will be even more in favor of the ERTS approach than is indicated here.

Under almost any set of assumptions the ERTS program could be executed much more quickly than the conventional program resulting in a considerable saving of time and technical manpower. The magnitude or dollar value of this type of savings is almost impossible to estimate.

X. APPENDICES

APPENDIX A (Cont.)

ERTS-1 MSS Frame I.D.	Center Point		9.5"X9.5"		70 mm.		Color		Tape	Date Acquired	Comments
	North Lat.	West Long.	Prt. 4567	+Trn 4567	Neg. 4567	Pos. 4567	P	I			
1240-16523	39 29'	100 28'	xxxx	xxxx	xxxx	xxxx			x	20Mar73	Excellent - air clear, some snow
1240-16525	36 03'	100 55'	xxxx	xxxx	xxxx	xxxx			x	"	" " " "
1240-16532	34 39'	101 21'	xxxx	xxxx	xxxx	xxxx	x	x	x	"	" " " "
1241-16581	37 30'	101 54'	xxxx	xxxx	xxxx	xxxx				21Mar73	West of study site.
1241-16584	36 04'	102 21'	xxxx	xxxx	xxxx	xxxx				"	" " " "
1241-16590	34 39'	102 48'	xxxx	xxxx	xxxx	xxxx				"	" " " "
1255-16354	36 04'	96 41'	xxxx	xxxx	xxxx	xxxx				4Apr73	East of study site.
1255-16361	34 38'	97 07'	xxxx	xxxx	xxxx	xxxx				"	" " " "
1256-16410	37 30'	97 38'	xxxx	xxxx	xxxx	xxxx	x	x	x	5Apr73	Excellent, no clouds, air clear
1256-16412	36 05'	98 06'	xxxx	xxxx	xxxx	xxxx	x	x	x	"	" " " "
1256-16415	34 39'	98 33'	xxxx	xxxx	xxxx	xxxx	x	x	x	"	" " " "
1257-16464	37 32'	99 05'	xxxx	xxxx	xxxx	xxxx	x	x	x	6Apr73	" " " "
1257-16471	36 07'	99 32'	xxxx	xxxx	xxxx	xxxx	x	x	x	"	" " " "
1257-16473	34 41'	99 59'	xxxx	xxxx	xxxx	xxxx	x	x	x	"	" " " "
1273-16354	36 10'	96 39'	xxxx	xxxx	xxxx	xxxx				22Apr73	.60% Clouds south ½.
1273-16360	34 44'	97 07'	xxxx	xxxx	xxxx	xxxx				"	East of area - scattered clouds
1274-16405	37 37'	97 35'	xxxx	xxxx	xxxx	xxxx	x	x	x	23Apr73	" " " " - cloudy.
1274-16412	36 10'	98 03'	xxxx	xxxx	xxxx	xxxx			x	"	Excellent
1274-16414	34 44'	99 30'	xxxx	xxxx	xxxx	xxxx			x	"	"
1275-16473	34 43'	100 00'	xxxx	xxxx	xxxx	xxxx				24Apr73	Cloudy

Continued

APPENDIX A  
Imagery Supplied by NASA

ERTS-1 MSS Frame I.D.	Center Point		9.5"X9.5"		70 mm.		Color		Tape	Date Acquired	Comments
	North Lat.	West Long.	Prt. 4567	+Trn 4567	Neg. 4567	Pos. 4567	P	T			
1004-16403	34 49'	98 16'	xx		x	x				27July72	Cloudy
1007-16572	35 42'	102 14'	xxxx		xxxx	xx x				30July72	West of site
1077-16461	36 03'	99 13'	xxxx	xxxx	xxxx	xxxx				80Oct72	Good - 5% clouds in N.
1077-16463	34 38'	99 41'	xxxx	xxxx	xxxx	xxxx				"	Good - clear
1094-16404	35 56'	97 53'	xxxx	xxxx	xxxx	xxxx				25Oct72	Good - 15% clouds in N.
1094-16411	34 31'	98 16'	xxxx	xxxx	xxxx	xxxx			x	"	Fair - scattered clouds
1095-16460	37 37'	98 86'		xxxx	xxxx	xxxx				26Oct72	Cloudy
1097-16582	34 28'	102 42'	xxxx	xxxx	xxxx	xxxx				28Oct72	Good - west of site
1111-16351	35 51'	96 33'		xxxx	xxxx	xxxx				11Nov72	East of site - cloudy
1111-16354	34 25'	97 00'		xxxx	xxxx	xxxx				"	" " " "
1114-16523	36 00'	100 48'	xxxx	xxxx	xxxx	xxxx				14Nov72	Good - clouds east 1/2
1114-16525	34 34'	101 15'	xxxx	xxxx	xxxx	xxxx				"	" " " "
1130-16404	37 23'	97 28'	xxxx	xxxx	xxxx	xxxx	x	x		30Nov72	Good - clear
1130-16410	35 57'	97 55'	xxxx	xxxx	xxxx	xxxx				"	"
1130-16413	34 31'	98 22'	xxxx	xxxx	xxxx	xxxx	x	x		"	" - 15% clouds in SE only
1131-16462	37 24'	98 54'	xxxx	xxxx	xxxx	xxxx	x	x	x	1Dec72	" - clear
1131-16465	35 58'	99 22'	xxxx	xxxx	xxxx	xxxx	x	x	x	"	"
1131-16471	34 33'	99 49'	xxxx	xxxx	xxxx	xxxx	x	x	x	"	" - clear, 5% snow in NW
1132-16521	37 22'	100 21'	xxxx	xxxx	xxxx	xxxx	x	x		2Dec72	" - " 30% " " SW
1132-16523	35 56'	100 48'	xxxx	xxxx	xxxx	xxxx	x	x		"	" - " 50% " " NW
1132-16530	34 30'	101 15'	xxxx	xxxx	xxxx	xxxx				"	"
1220-16405	37 26'	97 33'	xxxx		xxxx	xxxx				28Feb73	Cloudy
1221-16473	34 36'	99 55'	xxxx		xxxx	xxx				1Mar73	Cloudy
1222-16531	34 36'	101 20'	xxxx		xxxx	xxxx				2Mar73	SW of area
1223-16590	34 37'	102 46'	xxxx		xxxx	xxxx				3Mar73	West of area
1237-16354	36 01'	96 39'	xxxx	xxxx	xxxx	xxxx				17Mar73	Excellent - east of area
1237-16360	34 34'	97 06'	xxxx	xxxx	xxxx	xxxx			x	"	" " " "
1238-16410	37 26'	97 37'	xxxx		xxxx	xxxx				18Mar73	Fair - scattered clouds
1238-16412	36 00'	98 04'	xxxx		xxxx	xxxx				"	"
1238-16415	34 35'	98 31'	xxxx		xxxx	xxxx				"	"

Continued

APPENDIX A (Cont.)

NASA Aerial Photography

70 mm.	B/W	TIR Scanner
240 mm.	Color I-R	1:110,000
240 mm.	Color I-R	1:55,000
240 mm.	Color	1:110,000
70 mm.	Color	
70 mm.	Color I-R	
70 mm.	B/W Pan	
70 mm.	B/W I-R	
70 mm.	B/W Green	

APPENDIX B

ERTS Data Problems

The NDPF photographic products used in this study were generally of high quality. They were clean and scratchless, well-exposed and of even focus throughout. Notable exceptions to this statement are listed below:

SCENE ID	BAND	FORMAT	COMMENT
1130-16404 1130-16410 1130-16413	All	70mm.	Reticulated negatives
1130-16404 thru 16413 1131-16462 thru 16471 1132-16521 thru 16530	All	9"x9"Prints	Very dark, almost black
Various color composites	N.A.	9"x9"Prints and transparencies	Several scratches, several color stains, several with slight mis-registration of bands.
1131-16471	All	9"x9"Prints and transparencies	Longitude digits scrambled.
Various scenes	6 Esp.	All	Scattered parts of some scan lines scrambled.
Various scenes	All	N.A.	Some scenes deleted entirely from catalogue. Center point coordinates differ between catalogue and image legend.

In addition, there are two problems which persist throughout the imagery. These are mislocation of latitude and longitude tick marks and scale problems. Tickmarks for latitude and longitude are consistently in error when judged by existing topographic and base maps. The errors range up to 4 kilometers in any direction and are not appreciably better on Fall 1972 or Spring 1973 images. Tickmarks locating lines of latitude and longitude within one kilometer at 1:1,000,000 would be satisfactory for our purposes. One scene was even found to have the tick marks rotated slightly so that lines of equal latitudes run slightly north of east. Consequently, whenever necessary, we had to determine exact lines of latitude and longitude for ourselves. We simply cannot assume the correctness of the lines as located by tick marks. Scale problems were serious only when making and using regional maps. Existing U.S.G.S. base maps are of a scale slightly smaller than 1:1,000,000 while the scale of the images is slightly greater than this. Mismatch in scale between images and maps is about 5 kilometers across the study site (350 km.)

APPENDIX C

ERTS Descriptor Forms

**ERTS IMAGE DESCRIPTOR FORM**

(See Instructions on Back)

DATE February 2, 1974

PRINCIPAL INVESTIGATOR Dr. Robert J. Collins

GSFC PR -043

ORGANIZATION Eason Oil Company

**NDPF USE ONLY**

D \_\_\_\_\_  
 N \_\_\_\_\_  
 ID \_\_\_\_\_

	PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
1a.	1077-16463-M				oil field, basement rock, alluvial terrace, lineament, aquifer, lake, alluvium, (Red River, Okla.-Texas), agriculture, braided stream, erosion
1b.	1077-16461-M				lineament, lake, dune, clouds, airfield, (Elk City, Okla.), (Canadian River, Okla.), basin, barbed tributary, alluvial terrace, erosion, oil field, meander, highway, agriculture, pipeline, irrigation, (Woodward, Oklahoma)
2	1094-16404-M				lake, braided stream, Oklahoma City, dam, salt flat, erosion, alluvial terrace, barbed tributary, Cimarron River, Okla.), (Canadian River, Okla.), lineament, oil field, meander, quarry, airfield, channelized stream, urban area, highway.

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO      ERTS USER SERVICES  
 CODE 563  
 BLDG 23 ROOM E413  
 NASA GSFC  
 GREENBELT, MD. 20771  
 301-982-5406

# ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

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PRINCIPAL INVESTIGATOR \_\_\_\_\_

GSFC \_\_\_\_\_

ORGANIZATION \_\_\_\_\_

**NDPF USE ONLY**

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N \_\_\_\_\_

ID \_\_\_\_\_

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
3 1094-16411-M				bedrock, basement rock, (Wichita Mts., Okla.), (Red River, Okla.-Tex.), braided stream, lineament, lake, meanders, alluvium, oil field, (Norman, Okla.), clouds, aquifer, fault, joint, airfield, highway, urban area, quarry
4 1114-16523-M				(Canadian River, Texas), lake, oil refinery, oil field, erosion, (Pampa, Texas), clouds, agriculture, irrigation, Ogallala formation, playa lake, lineament, plateau, dam, (Borger, Texas)
51 1114-16525-M				erosion, (Palo-Duro Canyon, Texas), agri- culture, alluvium, entrenched stream, lineament, (Amarillo, Texas), playa lake

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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	PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
6	1130-16404-M				lake, (Arkansas River, Kansas), salt flat, lineament, (Wichita, Kansas)
7	1130-16410-M				lake, braided stream, Oklahoma City, dam, salt flat, erosion, alluvial terrace, barbed tributary, (Cimarron River, Okla.), (Canadian River, Okla.), lineament, oil field, meander, quarry, airfield, channelized stream, urban area, highway
8	1130-16413-M				bedrock, basement rock, (Wichita Mts., Okla.), (Red River Okla.-Tex.), braided stream, lineament, lake, meanders, alluvium, oil field, (Lawton, Okla.), aquifer, fault, joint, wild-life refuge, airfield, (Fort Sill, Okla.), highway, urban area, quarry

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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	PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
9	1131-16462-M				lake, salt flat, dune, (Cimarron River, Okla-Kansas) lineament, agriculture
10	1131-16465-M				lineament, lake, dune, snow, airfield, (Elk City, Okla.), (Canadian River, Okla.), basin, barbed tributary, alluvial terrace, erosion, oil field, meander, highway, agriculture, pipeline, irrigation, (Woodward, Oklahoma)
11	1131-16471-M				oil field, basement rock, alluvial terrace, lineament, aquifer, lake, alluvium, (Red River, Okla., -Texas), agriculture, braided stream, erosion

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
12	1132-16523-M			plateau, lake, sand dune, snow, refinery, highway, lineament, dam, agriculture, playa lake, (Canadian River, Tex.-Okla.), oil field, irrigation, (Pampa, Tex.), (Borger, Tex.), (Sh amrock, Tex.), Ogallala formation
13	1132-16530-M			erosion, (Palo-Duro Canyon, Tex.), agriculture, alluvium, entrenched stream, lineament, (Amarillo, Tex.), playa lake
14	1221-16473-M			(Red River, Okla.-Tex), lake, agriculture, wildlife refuge, clouds
15	1237-16354-M			(OKC, Okla.), (Tulsa, Okla.), (No. Canadian R., Okla.), (Cimmaron R., Okla.), (Arkansas R., Okla.), lake, Deep Fork R.
16	1237-16360-M			(Lake Texhoma, Okla., -Tex.), (Arbuckle Mts., Okla.), lake, (Norman, Okla.), (Red River, Okla., -Tex), bedrock, (Cont.)

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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	PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
16	1237-16360-M <i>cont'd</i> ,				anticline, fault, lineament, silt
17	1240-16525-M				plateau, lake, sand dune, refinery, high- way, lineament, dam, agriculture, playa lake, (Canadian River, Tex.- Okla.), oil field, irrigation, (Pampa, Tex.), (Borger, Tex.), (Shamrock, Tex.), Ogal- lala formation
18	1240-16532-M				erosion, (Palo-Duro Canyon, Texas), agri- culture, alluvium, entrenched stream, lineament, (Amarillo, Texas.), playa lake
19	1255-16361-M				(Lake Texhoma, Okla.- Tex.), (Arbuckle Mts., Okla.), lake, (Norman, Okla.), (Red River, Okla.- Tex.), bedrock, anti- cline, fault, linea- ment, silt

**\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).**

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ID \_\_\_\_\_

	PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
20	1256-16412-M				lake, braided stream, Oklahoma City, dam, salt flat, dune, erosion, alluvial terrace, barbed tributary, (Cimarron R., Okla.), (Canadian R., Okla.), lineament, oil field, meander, quarry, airfield, channelized stream, urban area, highway
21	1256-16415-M				bedrock, basement rock, (Wichita Mts., Okla.), (Red River, Okla.-Tex.), braided stream, lineament, lake, meanders, alluvium, oil field, (Lawton, Okla.), aquifer, fault, joint, wild-life refuge, airfield, (Fort Sill, Okla.), highway, urban area, quarry
22a	1257-16471-M				lineament, lake, dune, airfield, (Elk City, Okla.), (Canadian R., Okla.), basin, barbed tributary, alluvial terrace, erosion, (Cont)

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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ID \_\_\_\_\_

	PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
22a	1257-16471-M				oil field, meander, highway, agriculture, pipeline, irrigation, (Woodward, Okla.)
22b	1257-16473-M				oil field, basement rock, alluvial terrace, lineament, aquifer, lake, clouds, alluvium, (Red River, Okla.-Tex.), agriculture, braided stream, erosion
22c	1274-16412-M				lake, braided stream, Oklahoma City, dam, salt flat, dune, erosion, alluvial terrace, barbed tributary, (Cimarron R., Okla.), (Canadian R., Okla.), lineament, oil field, meander, quarry, airfield, channelized stream, urban area, highway
23	1274-16414-M				bedrock, basement rock, (Wichita Mts., Okla.), braided stream, lineament, lake, meanders, alluvium, oil field, aquifer, fault, joint, (cont.)

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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ID	_____

	PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
23	1274-16414-M				wildlife refuge, airfield, highway, urban area.

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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APPENDIX D  
Acronyms

CCT Computer Compatible Tapes  
EOC Eason Oil Company  
IR Infrared  
MSS MultiSpectral Scanner  
NASA National Aeronautics and Space Administration  
NDPF NASA Data Processing Facility  
OGS Oklahoma Geological Survey  
RBV Return Beam Vidicon  
SAC Strategic Air Command  
SLAR Side Looking Airborne Radar  
TIR Thermal Infrared

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