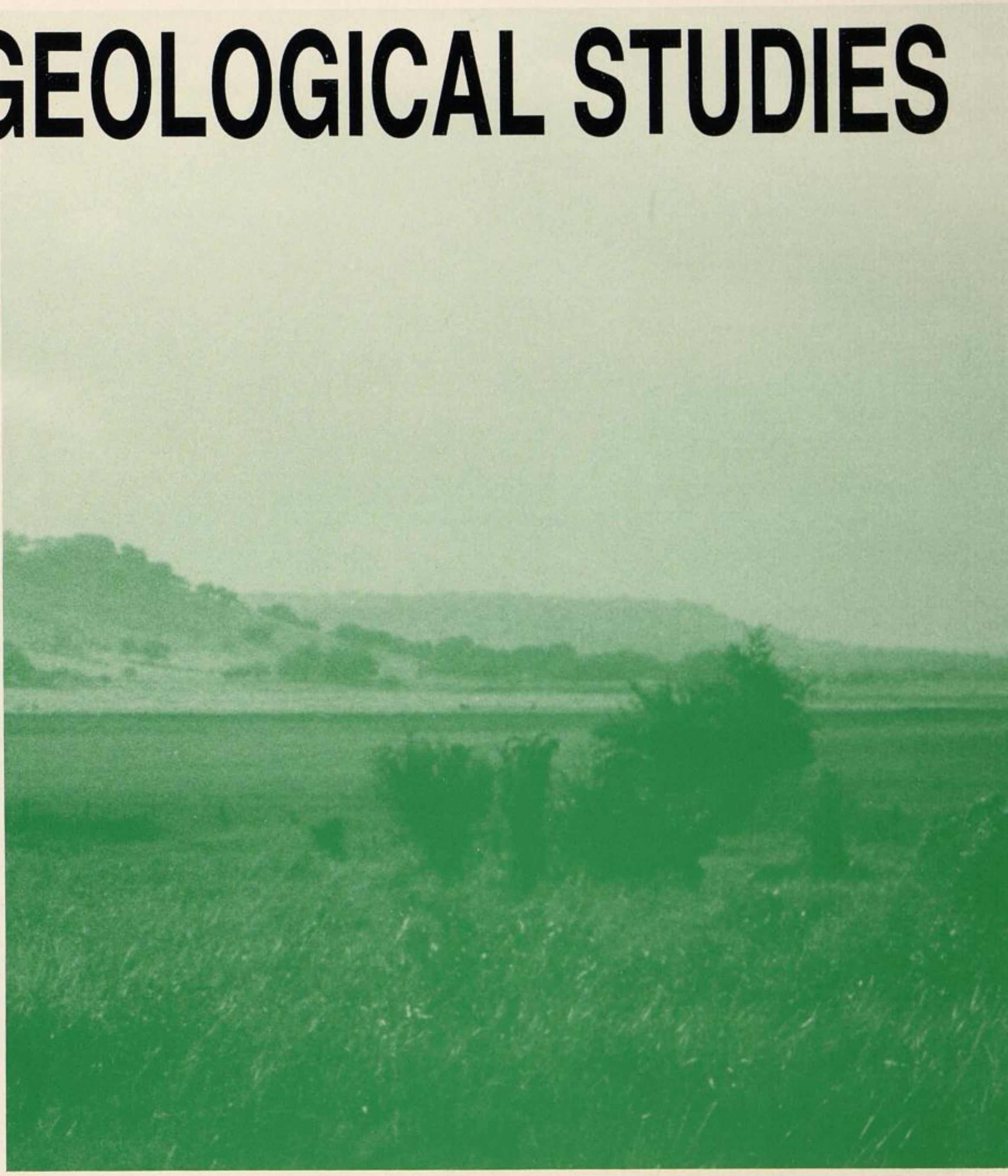
BAYLOR GEOLOGICAL STUDIES



SPRING 1995

Bulletin No. 55

Geomorphic Response to Regional Structure, Lampasas Cut Plain, Central Texas

BRADLEY CLARK PARISH

"Creative thinking is more important than elaborate equipment--"

Frank Carney, Ph.D.
Professor of Geology
Baylor University
1929-1934

Objectives of Geological Training at Baylor

The training of geologists in a university covers but a few years; their educations continue throughout their active lives. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

Cover: The Lampasas Cut Plain, Central Texas.

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Geomorphic Response to Regional Structure, Lampasas Cut Plain, Central Texas

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BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
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Baylor Geological Studies

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*Geomorphic Response to Regional Structure, Lampasas Cut Plain, Central Texas**

Bradley Clark Parish

ABSTRACT

The Lampasas Cut Plain and the Callahan Divide form an ancient landscape within central and north-central Texas. This landscape is characterized by broad lowlands and mesas capped by the Edwards Limestone. Geologic formations play a key role in this landscape. The massive resistant Edwards Limestone forms the "caprock" of the divides in the Cut Plain and Callahan Divide. The Comanche Peak, Walnut, and Paluxy Formations form the catenary slopes extending from the hilltops.

These Fredericksburg formations (Early Cretaceous) were all deposited on a flat Trinity-aged shelf. However, the present configuration of the Edwards Limestone and adjacent formations is that of an eastward, gently sloping surface with local anomalies in the dip rate that resemble "steps". These steps generally trend in a north-south direction and are probably caused by flexures created by deep-seated faulting developed during major subsidence of the East Texas Basin.

A lineament analysis across the study area reveals that two distinct patterns exist: 1) primary lineaments with an azimuth direction of 040°-070°; and 2) secondary lineaments with an azimuth direction of 300°-330°. These lineaments appear to be formed by or related to the margins and axes of major subsurface structural features, the overall structural "grain" of Texas, and the semi-brittle character of the rock.

These lineaments are visible on satellite imagery as surface expressions of regional joint systems. Joint patterns within the study area correspond to the major lineament directions. Therefore, the joints have a strong influence on lineament production.

Within the study area, these lineaments and joints appear to control the following factors: 1) major trunk drainage; 2) the orientation of major valleys; 3) the orientation of scarp faces of Edwards-capped divides; and 4) the geometry and major direction of Edwards-capped divides. Where lineaments do not have a strong influence on drainage, as occurs in areas between major trunk streams drained by minor tributaries, geologic dip controls drainage. Therefore, where lineament zones are present, they control drainage and geomorphic landforms that trend northwest-southeast. Where lineaments (or their influence) are lacking, dip control of drainage exists and is evidenced by the down-dip (west-east) crenulated side of Edwards-capped divides.

INTRODUCTION

PURPOSE

"The Lampasas Cut Plain is the modified northern extension of the great Edwards Plateau. It is a greatly dissected dip plain, now recognized by the general level of its many remnantal summits, which dominate all the country south of the Brazos River, between the Western Cross Timbers and the Balcones Fault Zone...." (Hill, 1901, p. 78). This region of dramatic landscapes has long been of interest, first because it best reveals the stratigraphy of Fredericksburg (Comanchean) rocks, and second because of the beautiful and apparently simple correlations between stratigraphy and landscape.

However, in recent years it has drawn increasing interest because the once "simple and clear" correlations between stratigraphy and landform have been questioned. The landscape of the Cut Plain is apparently far older than previously supposed, with a far more complex history than previously assumed, involving far more controls than once were recognized.

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*A thesis submitted in partial fulfillment for the M.S. degree in Geology, Baylor University, 1992.

Within this complex history, one of the major unanswered questions now involves the role of geologic structure in the evolution of Cut Plain landscapes. Recent reconnaissance studies of structure in the Cut Plain (Parish, 1990, p. 17) indicated far greater complexity than was originally recognized, but the effect of this complexity on landform was not known. Therefore, the purpose of the present investigation is to describe the geologic structure in the Lampasas Cut Plain and to relate this structure to landform and the evolution of landforms in this major geomorphic region.

LOCATION

The area of this study is in central and west-central Texas. The physiographic provinces of major importance are the Lampasas Cut Plain and the Callahan Divide. The Callahan Divide, the Colorado-Brazos River drainage divide, lies west of the Lampasas Cut Plain (Fig. 1). No physiographic "break" separates the Callahan Divide from the Lampasas Cut Plain. However, the eastern Callahan Divide and western margin of the Lampasas Cut Plain are characterized by a significant difference in structural dip and possibly in structural history. The study area covers an area of approximately 17,000 square miles depicted on four sheets of the Texas Geologic Atlas Series: Abilene, Brownwood, Dallas, and Waco (Fig. 2).

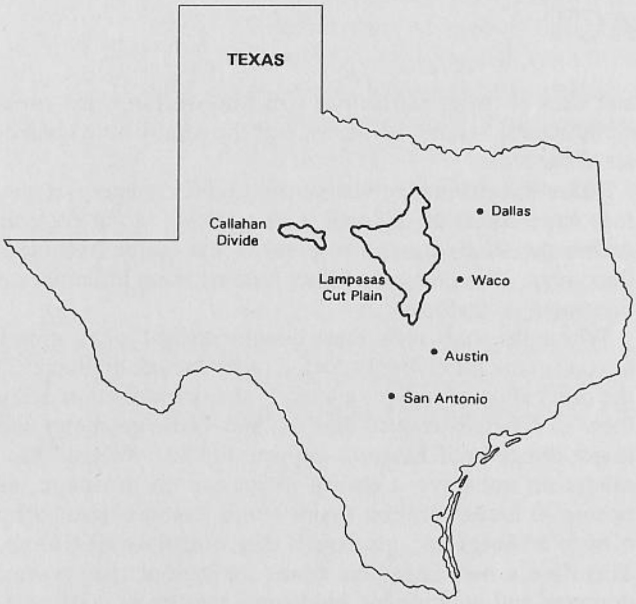

Fig. 1. Map of Texas showing the physiographic provinces of major importance to this study. The Lampasas Cut Plain is characterized by landscapes of broad lowlands separated by mesas capped by the Edwards Limestone. The Callahan Divide contains similar landscapes but is separated from the Cut Plain by differences in structural dip and history.

METHODS

This investigation progressed along five pathways. First, two years of field work concentrated on description of landform and geologic structure in the Lampasas Cut Plain and Callahan Divide (Appendix A). Second, a review of selected literature involved geomorphology, stratigraphy, depositional history, and original configuration and present structure on the Edwards Limestone (Appendix B). Third, 1:24,000 scale United States Geological Survey topographic maps and 1:250,000 scale geologic sheets of the Geologic Atlas of Texas Series were used to establish geology and to aid in selection of field localities. Fourth, surface and subsurface structural maps, cross sections, topographic profiles, and isopach maps were constructed to aid in determining relationships between structure and regional landform. Fifth, landscape was correlated with geologic structure to determine possible structural controls on landscape evolution.

PREVIOUS WORKS

This investigation began with numerous field trips, in which a general interest in this area grew. These were the "previous works," mainly oral, from professors and fellow students, that influenced this study. A second category of previous works deals directly with the Lampasas Cut Plain, its evolution through time, the processes related to this evolution, and the resulting characteristic landforms. A third category includes those works that deal with surface and subsurface geologic features and regions that, in some way, are important to this area of investigation. A final category deals with topics on general geomorphology, landscape evolution, and processes related to structural and lithologic variation.

Together, these four categories provided the background of knowledge necessary for the development and completion of this study. The works from the four categories are listed chronologically in table form in Appendix B. For each cited work, a date, author, title, and a brief discussion of the importance to this study are given.

ACKNOWLEDGMENTS

The first order of thanks goes to the Department of Geology at Baylor. The financial support provided by assistantships and scholarships, which were so kindly given, was an influential factor in the completion of my graduate work and this thesis. Dr. Harold H. Beaver is the driving force behind this support; the care and respect he portrays to each student is greatly appreciated.

The second order of thanks goes to O. T. Hayward, who really taught me the true science of geology. Dr. Hayward suggested this thesis topic to me in the Fall of 1989. Since then he has provided brilliant insight, criticism of ideas, and enthusiasm for some of the questions unanswered before the completion of this thesis. Thanks, O. T., for being such an influential "character" in my educational career and my life.

Thanks are extended to Dr. W. G. Brown for his geological insight and critical review of this thesis, and to Dr. Robert Packard for his thoughts and comments. Several individuals in the professional world are due many thanks: To Tom Fletcher and Andree Griffin of ORYX Energy, for their assistance in the completion of the structural maps; to David Amsbury of NASA, for his thoughts on the configuration and stratigraphy of the Edwards Limestone; to Shirley Baker, who typed the first draft through final revisions.

Sincere thanks go to my parents, Leland and Madeline Parish, and to my in-laws, Kyndall and Wanda Twitty, for their emotional and financial support. Thanks especially go to my dad, who accompanied me during some of the fieldwork. Finally, thanks go to my wife, Debra, whose help with field work and review of this thesis were paramount in its completion. Thanks, Deb, for your love, care, and support.

GEOMORPHIC EVOLUTION OF THE LAMPASAS CUT PLAIN

The Lampasas Cut Plain is a landscape that has undergone extensive episodic evolution throughout geologic time. "Perhaps nowhere in Texas are stratigraphy, structure, and landform more closely interrelated than they are in the Cut Plain" (Hayward and others, 1990, p. 14). In a first glance at landscapes that dominate this region, it appears that stratigraphy and lithology control landforms (Fig. 3). The hard, dense, reefal Edward Limestone caps the characteristic mesas, with marly and chalky Comanche Peak limestones and the fossiliferous Walnut Clay forming the gentle descending slopes and valley floors of the typical Cut Plain view.

A second and closer glance at these landscapes reveals that surficial structure is also a dominant control on landforms. The generally flat-lying sedimentary formations in this region allow widespread development of typical landforms.

Most of these "first impressions" are probably true. They provide a relatively simple model of the evolution of this region. Conversely, the process effect in the evolution of this region is a very complex one. It appears that over time process dominated stratigraphy in shaping landscapes formed largely by slope retreat (Hayward, 1990, oral communication). Process also seems to best explain the forma-

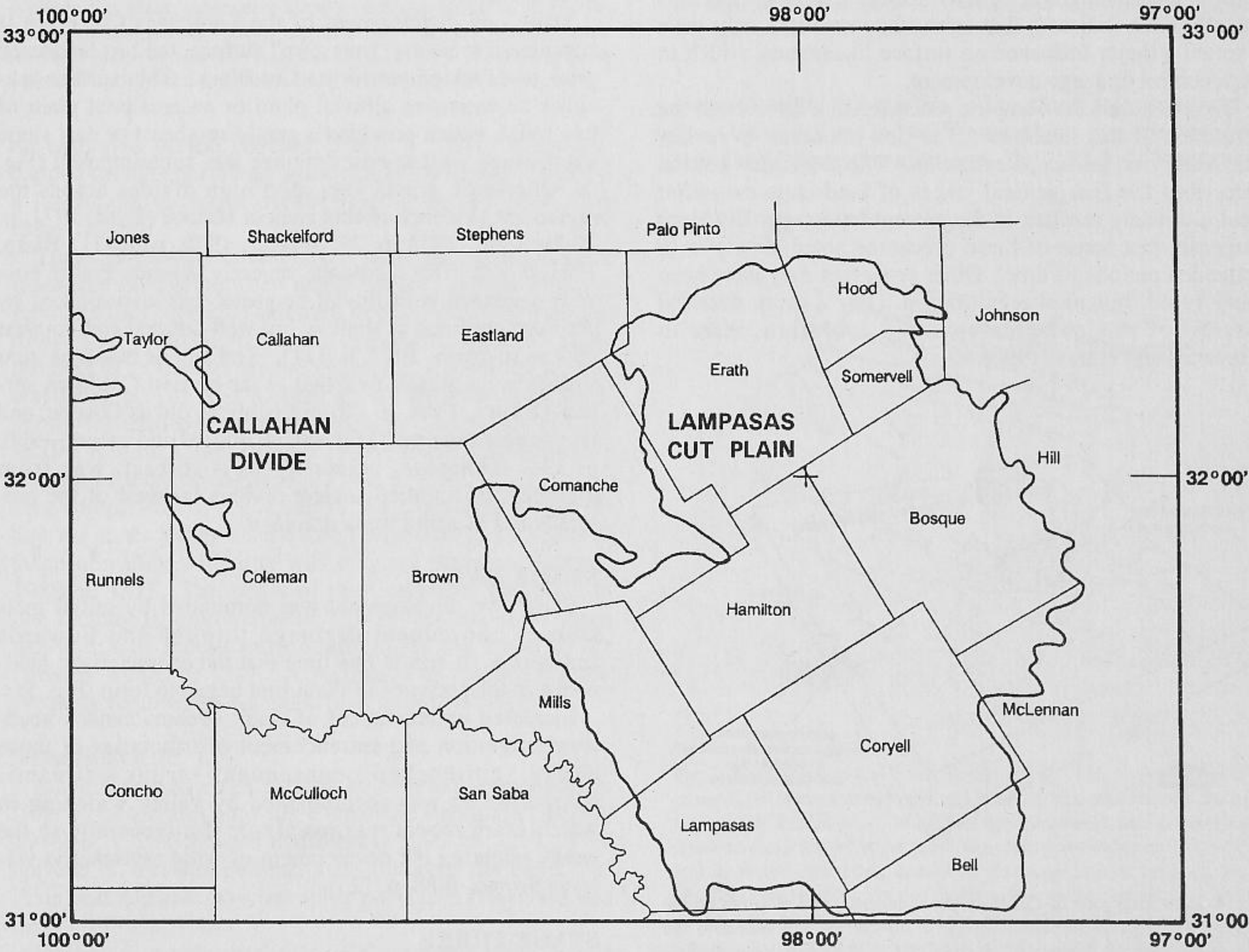

Fig. 2. Index map showing the immediate study area. The area extends from longitudes 97°00′ to 100°00′ West, and from latitudes 31°00′ to 33°00′ North. It covers an area of about 17,000 square miles, shown on two 1x2 degree geologic sheets (Abilene and Brownwood) and the western halves of two others (Dallas and Waco).

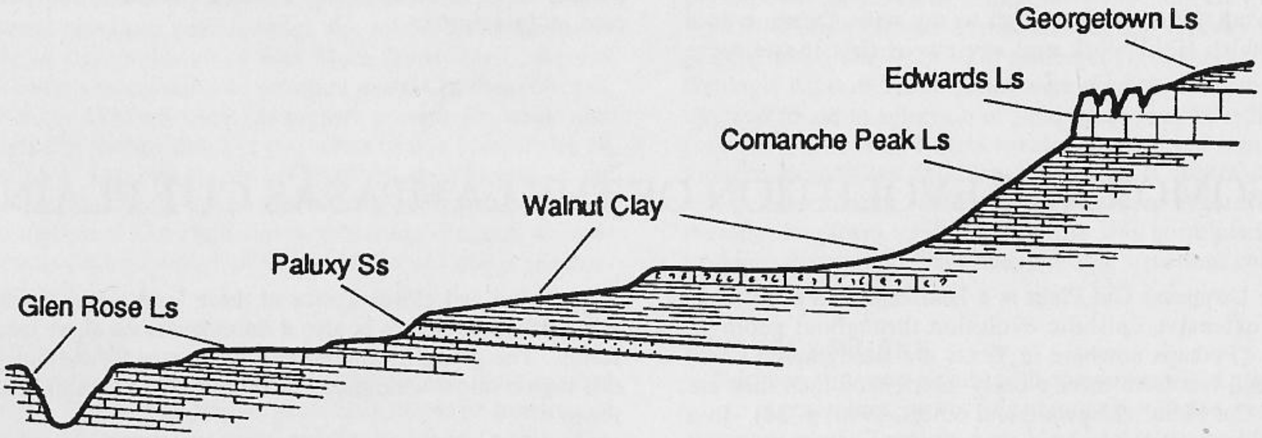

Fig 3. Index section of formations found in the Lampasas Cut Plain. The Georgetown Limestone, a formation of the Washita Group is present on drainage divides east of the Leon River. The Edwards Limestone, the upper unit of the Fredricksburg Group, forms the caprock for the mesas throughout the Cut Plain and the Callahan Divide. The Comanche Peak, Walnut, and Paluxy Formations form the slopes and wide valleys within the Lampasas Cut Plain. The Glen Rose Formation, a competent fossiliferous limestone that forms the Glen Rose Prairie along major trunk drainage, has been deeply entrenched and represents a late stage in Cut Plain development.

tion of pediments and caliche-armored slopes. Yet this investigation indicates that subsurface structure may have exerted a major influence on surface lineaments, which in turn control drainage development.

To understand the complex processes that have led to the evolution of this landscape, it is first important to review the history of landscape evolution. Therefore, this section describes the five general stages of landscape evolution that ultimately resulted in the present landscape. Evidence suggests that some of these processes acted slowly over extended periods of time. Other processes may have been very rapid, but of short duration. For a more detailed review of this complex episodic evolution, refer to Hayward and others (1990).

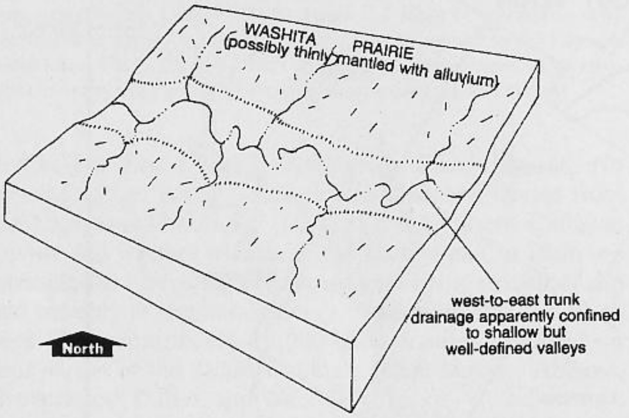

Fig. 4. High Stage one in Cut Plain development. This Washita Prairie surface, which forms the eastern margin of the Cut Plain, is similar to and correlative with the "time zero" surface of Cut Plain development. This erosional surface reflects a time antecedent to initial Cut Plain incision. As ancestral drainage entrenched into the near-flat landscape, the beginning of Cut Plain evolution occurred (Hayward and others, 1990, p. 18; block diagram adapted from Hayward and others, 1990).

STAGE ONE

Stage one development of the Lampasas Cut Plain is considered to be the "time zero" surface, the last landscape prior to development of the Cut Plain. This surface was either an extensive alluvial plain or an erosional plain of low relief, which provided a gentle southeast or east slope upon which west-to-east drainage was superimposed (Fig. 4). Quartzose gravel lags atop high divides across the region are evidence of this ancient surface (Byrd, 1971, p. 22-29; Epps, 1973, p. 29; Walker, 1978, p. 20-21; Tharp, 1987, p. 17). This landscape, an early Washita Prairie possibly veneered with fluvial deposits, was also marked by drainage confined to shallow but well-defined east-to-west valleys (Corwin, 1977, p. 111). The age of this time zero surface is far greater than that of the earliest Cut Plain surface (Brown, 1988, p. 120), possibly as old as Eocene, and no younger than mid-Miocene (Hayward and others, 1990, p. 23). Drainage, primarily west-to-east, was from presently unidentified ancient divides far west of the present heads of major trunk drainage.

STAGE TWO

Stage two development was dominated by initial incision of consequent drainage through the Edwards Limestone. It was at this time that the characteristic landforms of the present Cut Plain first began to form (Fig. 5).

Increased entrenchment of trunk streams caused headward migration and entrenchment of tributaries of these newly entrenched consequent trunk streams. Entrenchment was accompanied by valley widening in which scarp retreat was mainly up dip (generally to the west), initiating the development of wide asymmetric valleys (Brown, 1988, p. 123).

STAGE THREE

The principal landscape modification during stage three was slope retreat by pedimentation. Stage three also marked the end of earliest entrenchment, a time at which trunk drainage reached and maintained grade for

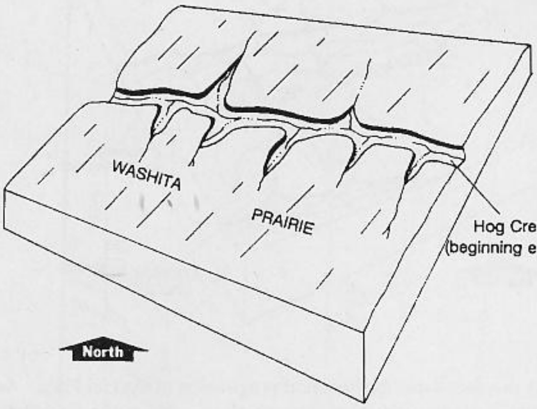

Fig. 5. Stage two in Cut Plain development. At this the earliest stage in Cut Plain evolution, the Washita Prairie covered the area that is now Cut Plain. Initial incision through the Edwards Limestone locked Washita Prairie drainage in place and established the first drainage network of the evolving Cut Plain; subsequent slope retreat was probably very slow. Outside the entrenching valleys, the landscape remained Washita Prairie for a long period of time (Hayward and others, 1990, p. 29; block diagram adapted from Hayward and others, 1990, p. 30).

an extended period (Brown, 1988, p. 128). Edwards-capped divides narrowed while valleys widened, creating a landscape in major aspect similar to the ones seen today (Fig. 6).

Three landforms characterize stage three: 1) narrow mesa-like divides between major streams capped with the Edwards Limestone; 2) catenary slopes extending from the divides and graded to the "intermediate surface" (now referred to as the Comanche Pediplain; Hayward and others, 1990, p. 18); and 3) very broad, slightly undulating, gently inclined pediments (Comanche Pediplain), chiefly in the Walnut Clay, graded to the trunk and tributary streams of stage three (Brown, 1988, p. 128).

A comparison of the width of the Comanche Pediplain and the inner valley of the Leon River suggests that this stage of valley widening was of great duration (Brown, 1988, p. 131). The width of the Comanche Pediplain at one locality is approximately 73,000 feet, about 24 times the width of recent entrenchment by the Leon River (Brown, 1988, p. 131). A pediment of this magnitude probably required an extended time span to develop.

STAGE FOUR

Stage four was characterized by renewed entrenchment (Fig. 7) of streams into the Comanche Pediplain (Brown, 1988, p. 132; Hayward and others, 1990, p. 120). This episode of renewed entrenchment involved the entire Cut Plain and adjacent physiographic provinces (Hayward and others, 1990, p. 120).

Recent entrenchment to form the inner valleys was a complex process involving four episodes of alluviation separated by three episodes of entrenchment on major trunk streams, and alluviation and entrenchment events even on minor tributaries. Alluviation is represented by the "100 foot" terrace of Yarmouthian age, the "60 foot" terrace of Sangamonian age, the "30 foot" terrace of

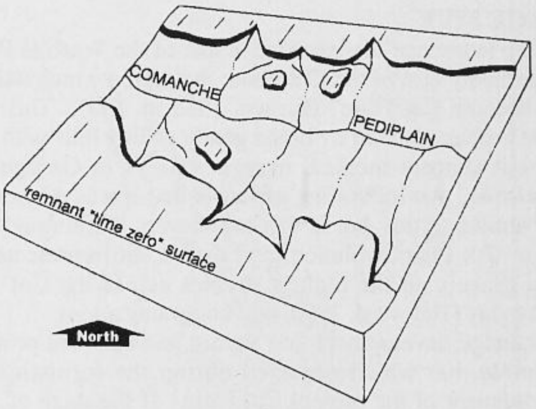

Fig. 6. Stage three in Cut Plain development. After incision through the Edwards and Comanche Peak Limestones, the processes of slope retreat continued as streams approached grade and incision slowed. This stage appears to have continued over a long period of time, as is evidenced by the broad pedimented surfaces (Hayward and others, 1990, p. 35; block diagram adapted from Hayward and others, p. 34).

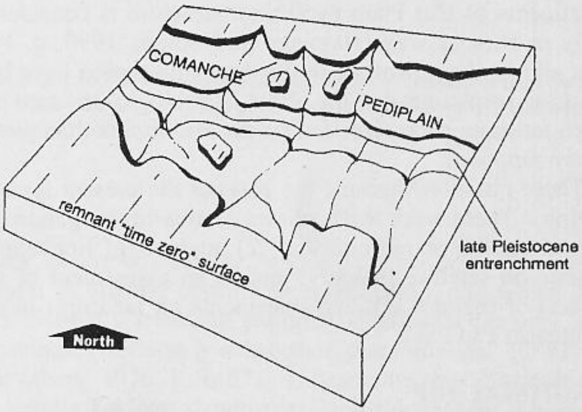

Fig. 7. Stage four in Cut Plain development. This stage is marked by renewed entrenchment by trunk and tributary drainage through the broad Comanche Pediplain. This latest entrenchment was controlled by renewed dissection of major trunk drainage, principally the Brazos River and its major tributaries, caused by a change in base level or climate (Brown, 1988, p. 133). In this diagram we see the characteristic uplands of the Lampasas Cut Plain, and the broad sloping Comanche Pediplain that together formed the stage three landscape, and in the middle ground we see renewed headwater dissection along a minor tributary just beginning to cut away at the older landscape. Similar recent entrenchment has occurred on all streams within the Cut Plain (Hayward and others, 1990, p. 120; block diagram adapted from Hayward and others, 1990, p. 120).

Wisconsinan age, and the present flood plain of Wisconsinan to Recent age (Tharp, 1988, p. 120; Hayward and others, 1990, p. 120).

STAGE FIVE

"The landscape of stage five is that of the Washita Prairie immediately east of the Cut Plain, the region which will one day become Cut Plain" (Brown, 1988, p. 135). This landscape is characterized by broad gently rolling hills with shallow but sharply incised, narrow valleys in Georgetown Limestone. An interesting aspect is that it was a landscape very similar to this, but farther to the west, that formed stage one of Cut Plain evolution, and that is still represented by alien gravels on the highest divides across the Cut Plain even today (Hayward, 1990, oral communication).

Drainage development and stream incision will probably resemble that which occurred during the formation and development of the present Cut Plain. If the stage of slope retreat involves a long time span, as it apparently did in the Cut Plain, divides in the mature Cut Plain will disappear and the Cut Plain will slowly migrate eastward (Brown, 1988, p. 136; Fig. 8).

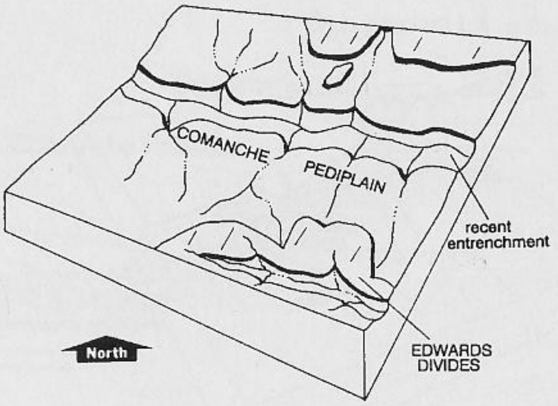

Fig. 8. Block diagram depicting eastward progression of the Cut Plain. As Edwards-capped divides diminish through slope retreat, the Cut Plain landscape moves eastward at the expense of the Washita Prairie to the eastern limit of gentle dip (±25′/mile). The present Washita Prairie probably will someday contain a Cut Plain landscape if erosional and slope retreat processes continue. (Figure adapted from Brown, 1988, p. 138.)

GEOLOGIC STRUCTURE OF THE EDWARDS LIMESTONE IN CENTRAL TEXAS

In the sequence of evolutionary stages in Cut Plain history, no mention has been made of the effects of geologic structure on landform. Even in the far more extensive treatments of Cut Plain evolution, structure is considered only in cursory way (Hayward and others, 1990, p. 14). Yet all who have worked in this beautiful region have had nagging suspicions that the effect of geologic structure has been far more pervasive, and far more complex than previously supposed.

These questions became the basis of the present investigation. There were three phases to this investigation: 1) determination of regional dip; 2) analysis of lineaments visible on satellite imagery; and 3) an assessment of the effects of regional dip and lineaments on landform in the Lampasas Cut Plain.

REGIONAL DIP

Throughout the area of this investigation, the Edwards Limestone (the caprock that armors the divides and mesas that define the Cut Plain) is approximately 15 to 30 feet in thickness. These minor variations in thickness are caused mainly by reef growth and facies changes with the Comanche Peak Limestone (Lozo, 1959, p. 21-22), and even these are insignificant in the overall pattern of Edwards Limestone.

Two differing models of Edwards deposition have been proposed (Amsbury, 1988; Corwin, 1982) but the differing effects of these on structure over the Lampasas Cut Plain are minimal. Therefore, while these are of stratigraphic interest, they are ignored in the following structural interpretations.

The top of the Edwards Limestone is the most easily recognized, the most extensive, and the most reliable structural datum in the region of the Cut Plain. No other unit in the entire Cretaceous section provides the clear lithologic, geophysical, and topographic "signatures" typical of Edwards Limestone across the Trinity Shelf and into the East Texas Basin. For these reasons it was chosen as the structural horizon for this study. The surface on top of the Edwards Limestone can be seen in the topographic expression and determined in the field from topographic maps and from air photos. Although this is sometimes a slightly eroded geomorphic surface rather than a fresh contact, the amount of erosion is so minimal at the topographic break that this method nears the accuracy of traditional methods that transfer outcrop contacts to topographic maps.

The configuration of the Edwards surface at the close of its deposition was that of a regionally near-flat plain with minor local anomalies due to reef growth (Lozo, 1959, p. 22).

From the western margin of the study area along the Callahan Divide to the western margin of the Cut Plain, the average dip of the Edwards is approximately 5 feet per mile. From the western to the eastern margin of the Cut Plain, the average dip of the Edwards is approximately 15 feet per mile. Dip direction is generally east across the study area.

The configuration of the Edwards Limestone across the Cut Plain is that of a homocline with minutely "stepped" monoclines which are caused by local but slight increases in dip. One "step," a zone of increased dip averaging about 18 feet per mile occurs at approximately 98°10′ west

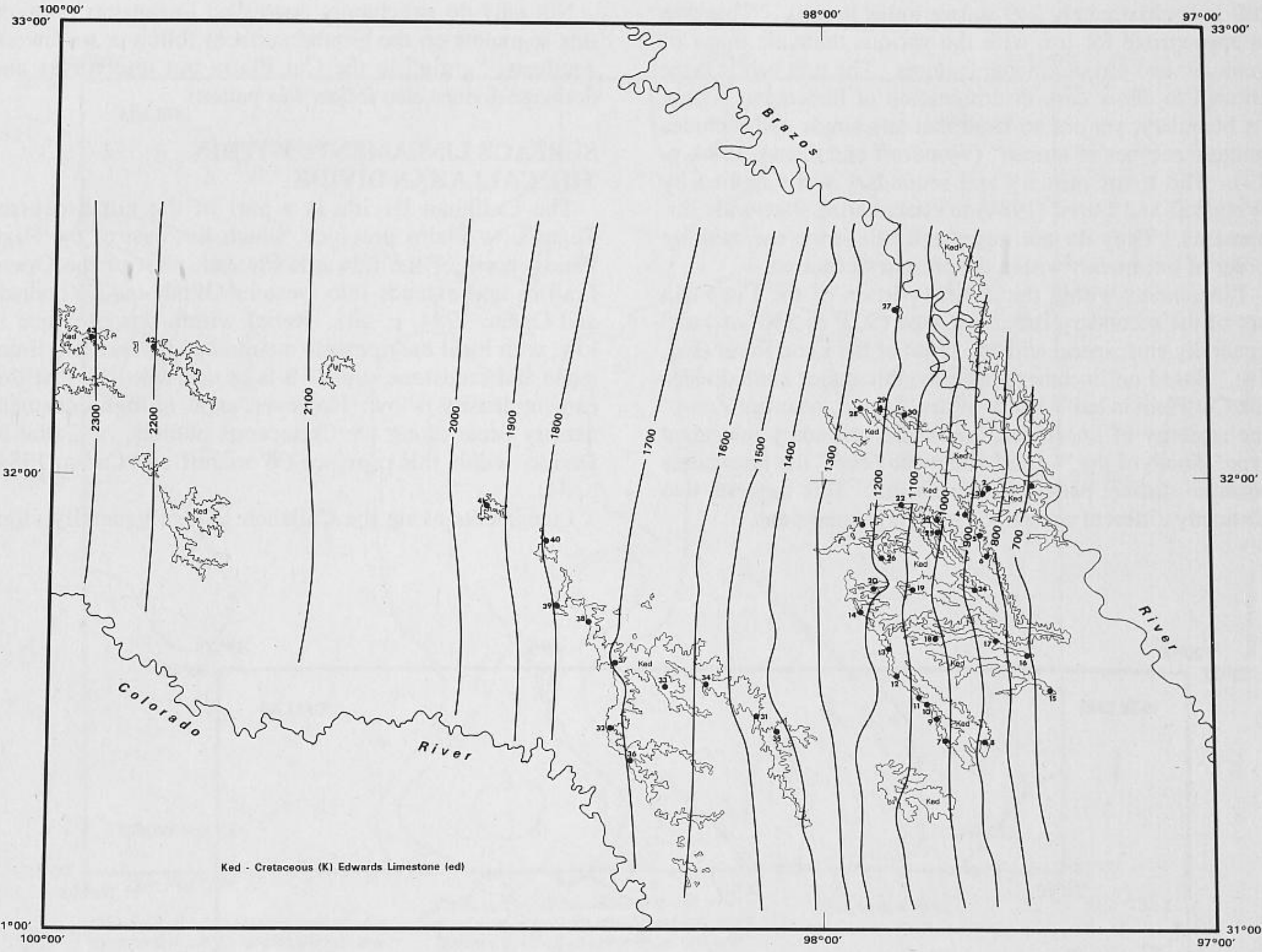

Fig. 9. Projected structural contour surface of the top of the Edwards Limestone (Ked). From 100°00′W to approximately 98°50′W, the dip of the Edwards Limestone averages 5 feet per mile. At 98°50′W, the dip increases to approximately 15 feet per mile. From this point eastward, in local areas, the Edwards Limestone forms a stepped structural pattern with areas of increasing dip rate (as much as 22 feet per mile) interspersed with areas of lower dip rate. This map was computer contoured by SYMPAL.

(Fig. 9.) A second "step," occurring at approximately 97°50′ west, has dip averaging about 22 feet per mile (Fig. 9).

For the purposes of this study, the surface on top of the Edwards Limestone was contoured by SYMPAL, a computer contouring package. A major change in the dip rate is shown at the western margin of the Cut Plain. The most conspicuous change is in the central Cut Plain, where a pronounced north-south trending dip change takes place. This is one of the major lines of inflection change across the region.

SURFACE LINEAMENTS WITHIN THE LAMPASAS CUT PLAIN

Hobbs (1904) introduced the term "lineament" to characterize the spatial relationships of landscape features. He defined lineament in a later publication as "significant lines of landscape which reveal the hidden architecture of the rock basement" (Hobbs, 1912, p. 227). A more recent definition of the term is "a mappable, simple or composite linear feature of a surface, whose parts are aligned in a rectilinear or slightly curvilinear relationship, and which differs distinctly from the patterns of adjacent features and presumably reflects a subsurface phenomenon" (O'Leary and others, 1976, p. 1467). Lineaments may correlate to: 1) known surface structures; 2) surface expressions of known buried structures; 3) surface expressions of either buried or surface structures that were previously unknown; 4) physiographic features that have no known structural affinity; and 5) features of unknown or unclear affinity (Woodruff and Caran, 1984, p. 4). Lineaments can also be represented by straight, parallel interfluves or divides.

Lineament patterns within the Cut Plain are of two orientations: 1) primary lineaments, with an azimuth direction of 040° to 070°; and 2) secondary lineaments, with an azimuth direction of 300° to 330°. These lineament sets were identified through the analysis of band-5 LANDSAT images (Woodruff and Caran, 1984). After the lineaments were plotted on a map of Texas, the state was then divided into 1,190 unit cells at a scale of 1:1,000,000. Each unit cell is approximately 249 square miles in area. "This size is appropriate for use with the various thematic maps of geologic and physiographic features. The unit cell is large enough to allow easy discrimination of lineaments within its boundary, yet not so large that any single cell includes numerous types of terrain" (Woodruff and Caran, 1984, p. 13). The terms primary and secondary were applied by Woodruff and Caran (1984) to characterize state-wide lineaments. They do not necessarily describe the ranking order of lineaments within the present study area.

Lineaments within the central portion of the Cut Plain are of the secondary lineament type (300° to 330° az.) and generally correspond with the trend of the Leon River (Fig. 10). Based on lineament patterns, this major zone divides the Cut Plain in half. North of the "Leon Lineament Zone," the majority of lineaments are of the secondary lineament type. South of the "Leon Lineament Zone," the lineaments form no distinct pattern or correlation. This suggests two distinctly different subsurface structural conditions.

Not only do structurally controlled lineaments (straight line segments on the ground surface) follow a northwest-southeast "grain" in the Cut Plain, but interfluves and drainage divides also follow this pattern.

SURFACE LINEAMENTS WITHIN THE CALLAHAN DIVIDE

The Callahan Divide is a part of the north-central Texas Low Plains province, which lies east of the High Plains, north of the Edwards Plateau, west of the Grand Prairies and extends into western Oklahoma (Woodruff and Caran, 1984, p. 34). Relief within this province is low, with local escarpments maintained by resistant limestone and sandstone strata. It is in this province that lineament density is low. However, areas of high lineament density occur along the Cretaceous outliers, or Callahan Divide, within this province (Woodruff and Caran, 1984, p. 34).

Lineaments along the Callahan Divide generally align

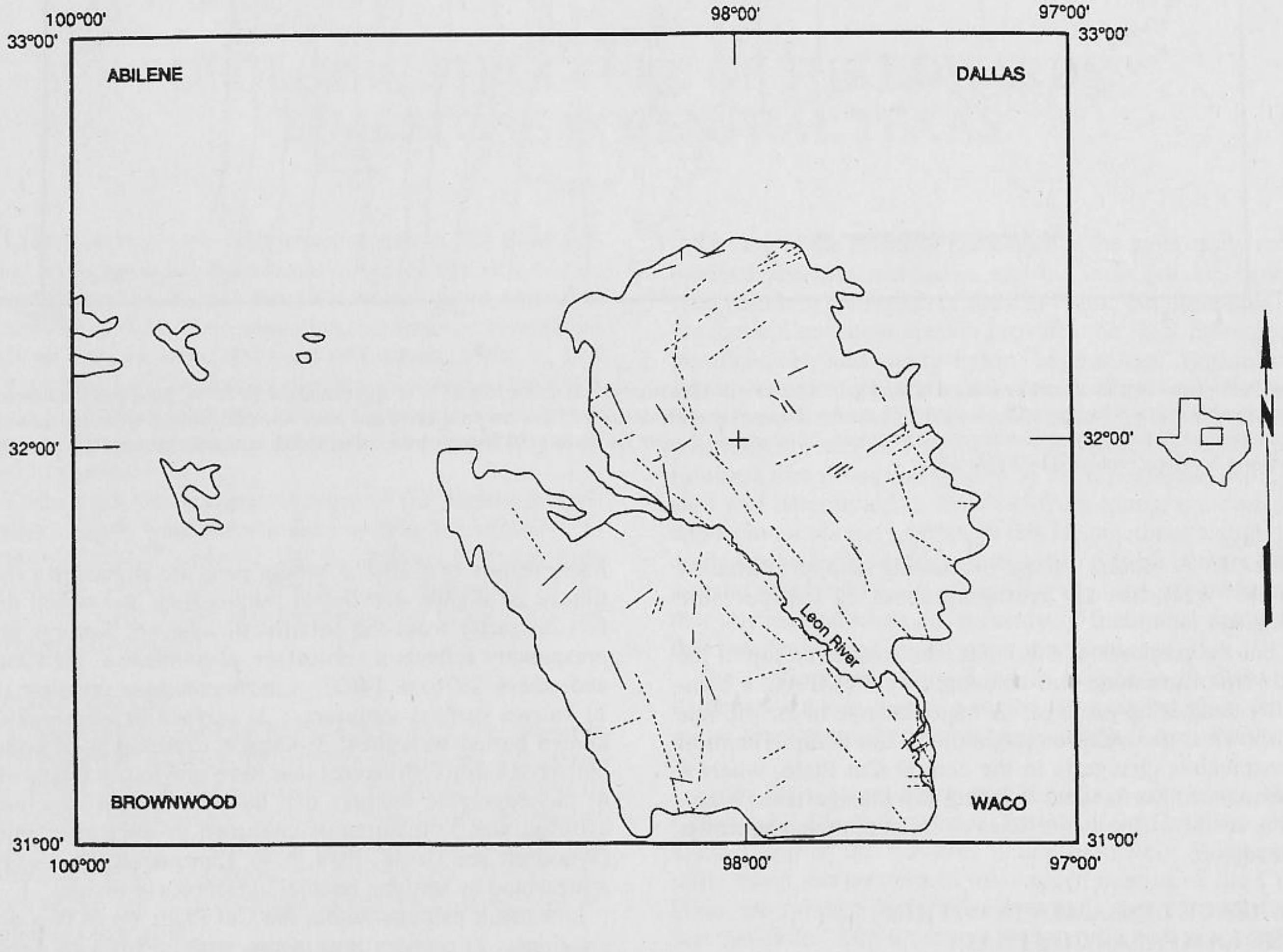

Fig. 10. Lineaments across the Cut Plain from band-5 LANDSAT images (Woodruff and Caran, 1984). Dashed lines are possible lineaments; solid lines are probable lineaments. Lineaments within the Cut Plain occur mainly in two 30° azimuth arcs: 1) primary lineaments, 040° to 070° azimuth, and 2) secondary lineaments, 300° to 330° azimuth. (The terms primary and secondary were defined by Woodruff and Caran, 1984, to describe lineament patterns across Texas. They do not describe ranking order of lineaments in the Cut Plain.) A major lineament zone that loosely parallels the Leon River occurs in the secondary azimuth direction in the central portion of the Cut Plain. This zone appears to divide the Cut Plain into two "lineament regions." North of the Leon River, patterns follow the secondary azimuth direction. South of this zone, no pattern is distinguishable. (Figure adapted from Woodruff and Caran, 1984, Plate I.)

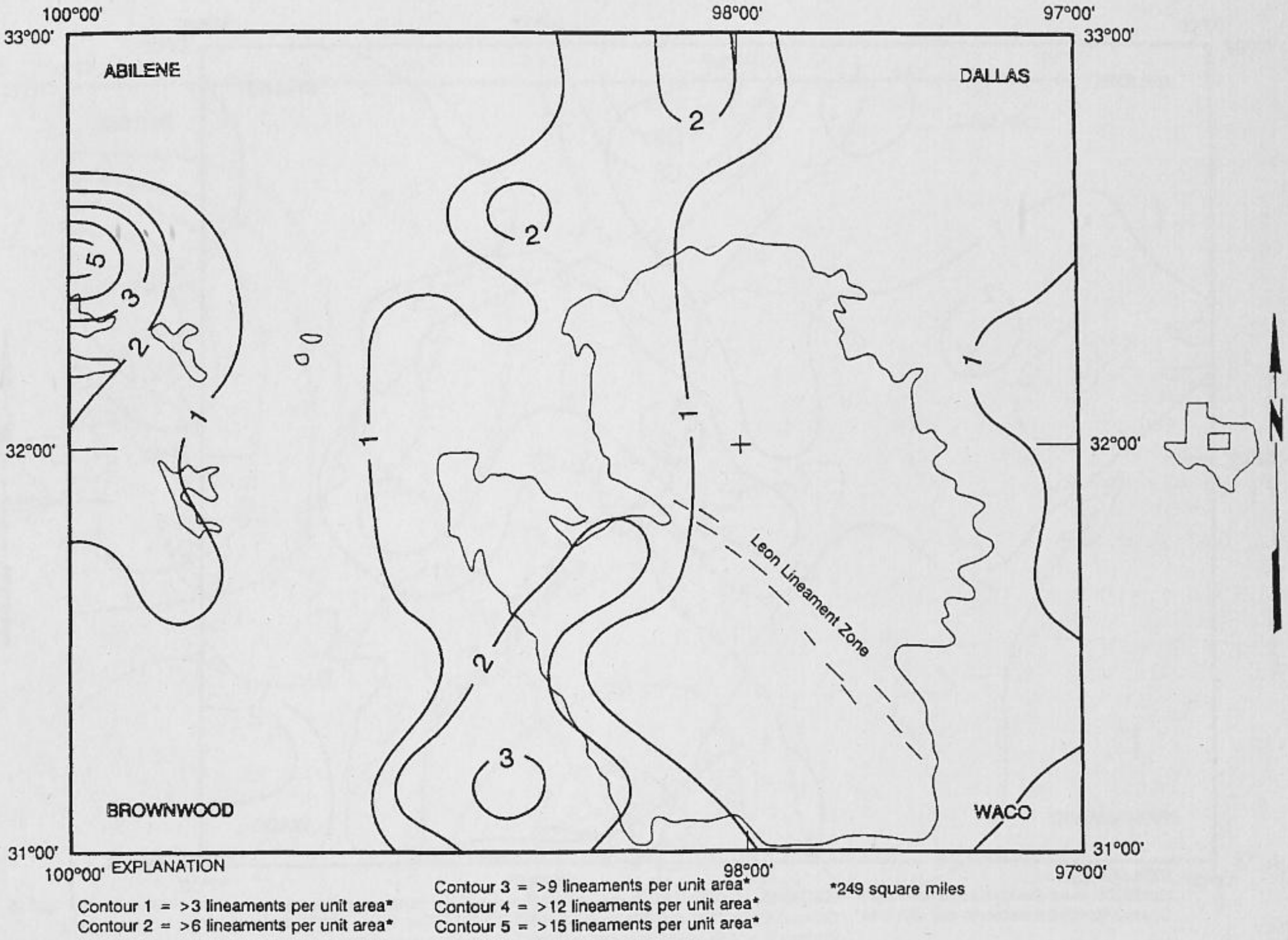

Fig. 11. Density of lineaments in the primary lineament direction (040° to 070°). Two zones of lineaments of this direction exist in the study area: 1) within and including the Callahan Divide; and 2) an area on the western margin of the Cut Plain. The diagram shows that most lineaments within the Callahan Divide are of the primary lineament type. The north-south trending zone at the western margin of the Cut Plain correlates with the subsurface Bend Arch (Woodruff and Caran, 1984, p. 48) and with an increase in dip of the Edwards Limestone into the far western margin of the East Texas Basin. (Figure adapted from Woodruff and Caran, 1984, Plate I.)

with the two prominent lineament directions for Texas. Primary lineaments in the 040° to 070° azimuth range generally align with the overall strike of formations in Texas. Secondary lineaments in the 300° to 330° azimuth range generally align with drainage systems in Texas. Three influential factors may have contributed to high lineament density along the Callahan Divide: 1) the high relief of the Cretaceous outliers that form the divide; 2) lithologic characteristics of the Cretaceous formations; and 3) subsurface structural effects, which may result in enhanced fracture porosity in the Edwards Limestone.

DISTRIBUTION OF LINEAMENTS

Approximately half of the lineaments in the state of Texas lie within the two 30° range of azimuths: 1) from 040° to 070°, which make up 27 percent of the total lineaments, and 2) from 300° to 330°, which make up 22 percent of the total lineaments (Woodruff and Caran, 1984, p. 16). The other 51 percent of lineaments in Texas have orientations outside the two 30° range of azimuth directions.

Within the Lampasas Cut Plain, 37 percent of the total lineaments are of the primary lineament type (040° to 070°) and 49 percent of the total lineaments are of the secondary lineament type (300° to 330°). Therefore, 49 percent of lineaments within the Cut Plain align generally with: 1) the structural grain of Texas; 2) the orientation of interfluves and major drainage divides; and 3) trunk drainage.

On the Callahan Divide, 45 percent of the total lineaments are of the primary lineament type (040° to 070°) and 32 percent are of the secondary lineament type (300° to 330°). This suggests that processes that created lineaments within the Callahan Divide were different from those that created lineaments in the Lampasas Cut Plain. This agrees with the hypothesis that structural form and history within

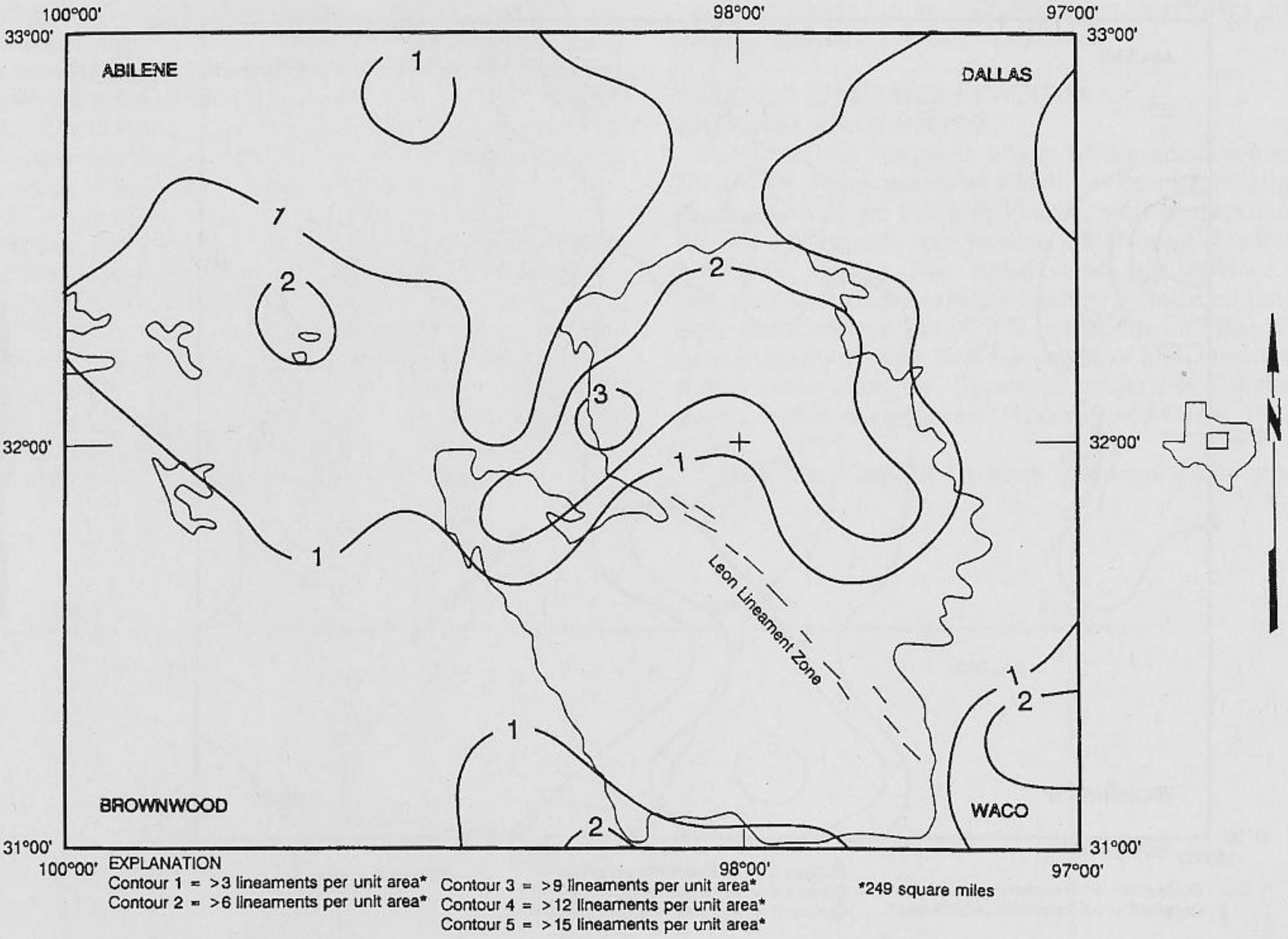

Fig. 12. Density of lineaments in the secondary lineament direction (300° to 330°). The area with the most abundant lineaments within this 30° azimuth range is in the northern portion of the Cut Plain. This area extends from the "Leon Lineament Zone" northward across the northern margin of the study area. Lineaments in this area were apparently created by different mechanisms from those in the remainder of the study area. (Figure adapted from Woodruff and Caran, 1984, Plate I.)

the Callahan Divide and the Lampasas Cut Plain are somewhat different (Hayward, 1990, oral communication).

Two zones of primary lineament orientation exist within the study area: 1) a zone along the Callahan Divide, which contains the highest density of primary lineaments; and 2) a zone that trends north-south at the western margin of the Cut Plain (Fig. 11).

The major portion of secondary lineaments occurs in the northern half of the Lampasas Cut Plain north of the "Leon Lineament Zone" (Fig. 12).

The density of lineaments in the secondary lineament direction suggests that the northern half of the Cut Plain has undergone a somewhat different structural history from that of the remainder of the study area. The density of lineaments in the primary azimuth direction also shows that the Callahan Divide and the area between the Callahan Divide and the Cut Plain have had different structural histories from that of the remainder of the study area. Lineaments in the southern portion of the Cut Plain have orientations outside the two 30° range of azimuth directions suggesting that this southern area may have experienced a structural evolution different from that of the northern Cut Plain.

Lineament intersections are most abundant in three areas: 1) along the Callahan Divide; 2) north of the Lampasas Cut Plain; and 3) southwest of the Lampasas Cut Plain (Fig. 13).

Lineament intersections in the area along the Callahan Divide probably are related to topographic relief, lithology, and structure of the Cretaceous outliers. Slope breaks on the margins of the outliers are areas of high lineament density (Woodruff and Caran, 1984, p. 34). The dense Edwards caprock of the Callahan Divide, when fractured, develops water conduits that magnify the visibility of joint sets. The combination of these physical features with subsurface structure causes high lineament density. Lineaments in the area north of the Cut Plain are controlled by the structure of the Fort Worth Basin, and the area southwest of the Cut Plain is probably controlled by northeasterly trending faults of the Llano Uplift.

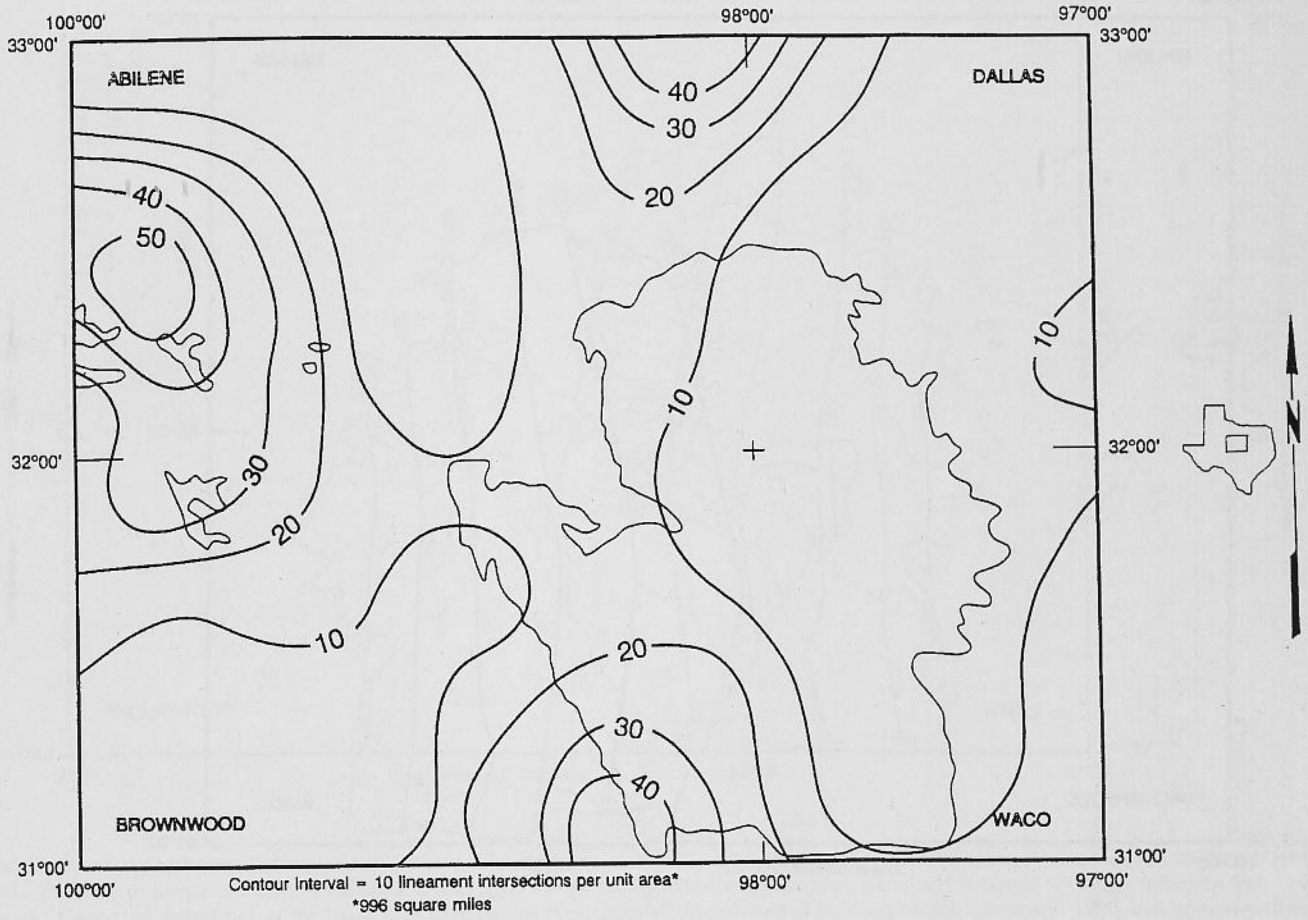

Fig. 13. Density of lineament intersections within the study area. Three areas of marked lineament intersections exist: 1) the area along the Callahan Divide; 2) an area north of the Cut Plain; and 3) an area southwest of the Cut Plain. The area along the Callahan Divide correlates with the topographic breaks on the Edwards-capped mesas. The area north of the Cut Plain is controlled by structure in the Fort Worth Basin. The area southwest of the Cut Plain apparently correlates with the Llano Uplift. (Figure adapted from Woodruff and Caran, 1984, Plate I.)

RELATIONSHIPS BETWEEN DIP AND LINEAMENTS, CENTRAL TEXAS

Surface expression of subsurface structural features is suggested from an analysis of lineaments. Some buried geologic features are expressed in a subtle way by lineaments visible at the earth's surface, for lineaments tend to parallel the structural "grain" within a physiographic region (Woodruff and Caran, 1984, p. 6). "Grain is a generalized expression of physiographic orientation, which is at least in part controlled by geologic structures. Lineaments are components, and hence expressions, of this grain. Physiography is the broad-scale lay of the land. It is chiefly a result of interactions among surface geology, topography, and drainage. These three factors are, in turn, surface manifestations of several other controlling factors including structural setting..." (Woodruff and Caran, 1984, p. 21). This suggests that surficial features such as geology, topography, and drainage, combined with surface lineaments, may be surface expressions of subsurface structural features. Therefore, the purpose of this section is to describe the effects of subsurface geologic structure on structural dip, drainage orientation, and lineament direction and density.

STRUCTURE IN THE LAMPASAS CUT PLAIN

STRUCTURAL DIP

Lineaments within the Cut Plain were originally believed to correlate to or parallel the conspicuous "steps" that occur

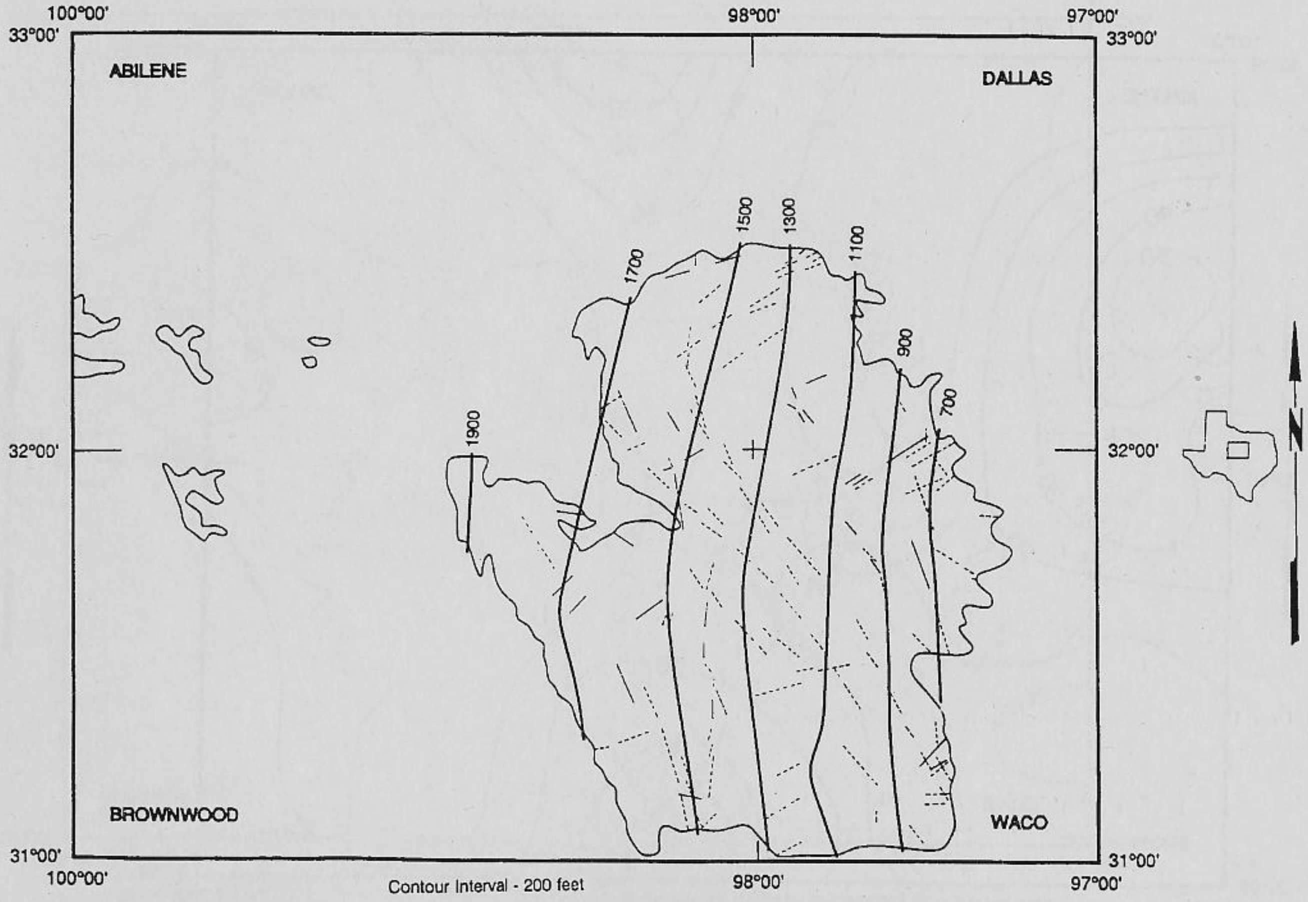

Fig. 14. Lineaments in the Cut Plain and the structural contours of the Edwards Limestone. Lineament patterns in the Cut Plain show little relation to the eastward dip of the Edwards. "Steps" in the Edwards structure are apparently surface expressions of deep-seated faulting created during subsidence stages of the East Texas Basin.

in the regional structure of the Edwards Limestone. However, an overlay of the lineaments within the Cut Plain with the structural dip of the Edwards (Fig. 14) reveals that these two features are in no way correlative.

It appears that these two features formed independently of each other. The "steps" are either the result of deep-seated faults that were activated during subsidence of the East Texas Basin (Hayward, 1990, oral communication) or the result of differential compaction in Cretaceous rocks over the ancient landscape of the sub-Cretaceous Wichita Paleoplain. Deep-seated faulting is suggested by the fact that the "steps" trend in a north-south direction, generally parallel to the trend of faulting along the Balcones and Luling-Mexia Fault Zones. Other lineaments within the Cut Plain are apparently the result of other subsurface structural features, discussed in a later section.

ORIENTATION OF TRUNK DRAINAGE

The orientation of the Brazos, Leon, and Lampasas Rivers is in a northwest-southeast direction. In the Cut Plain, this direction is at a marked angle to structural dip (Hayward and others, 1990, p. 45; Fig. 15). It is generally believed that if this drainage originated as consequent drainage, then it must have resulted from one of several causes: 1) different geologic structure (hence topographic configuration) at the inception of this original drainage; 2) the establishment of trunk drainage on higher units, now removed, in which a northward-thickening wedge of overlying sediment provided the gradient along which consequent drainage developed (Montgomery, 1986, p. 48); or 3) the effects of Tertiary reactivation of deep-seated Paleozoic faults (Amsbury, 1990, oral communication).

The results of the current study suggest that trunk drainage direction is most likely inherited from northwest-southeast trending lineaments. Along smaller tributaries, where drainage is not controlled by lineaments, the drainage direction is from west to east, down-dip. Lineaments on an erosional surface provide pathways of less resistance to erosion through enhancement of fracture porosity.

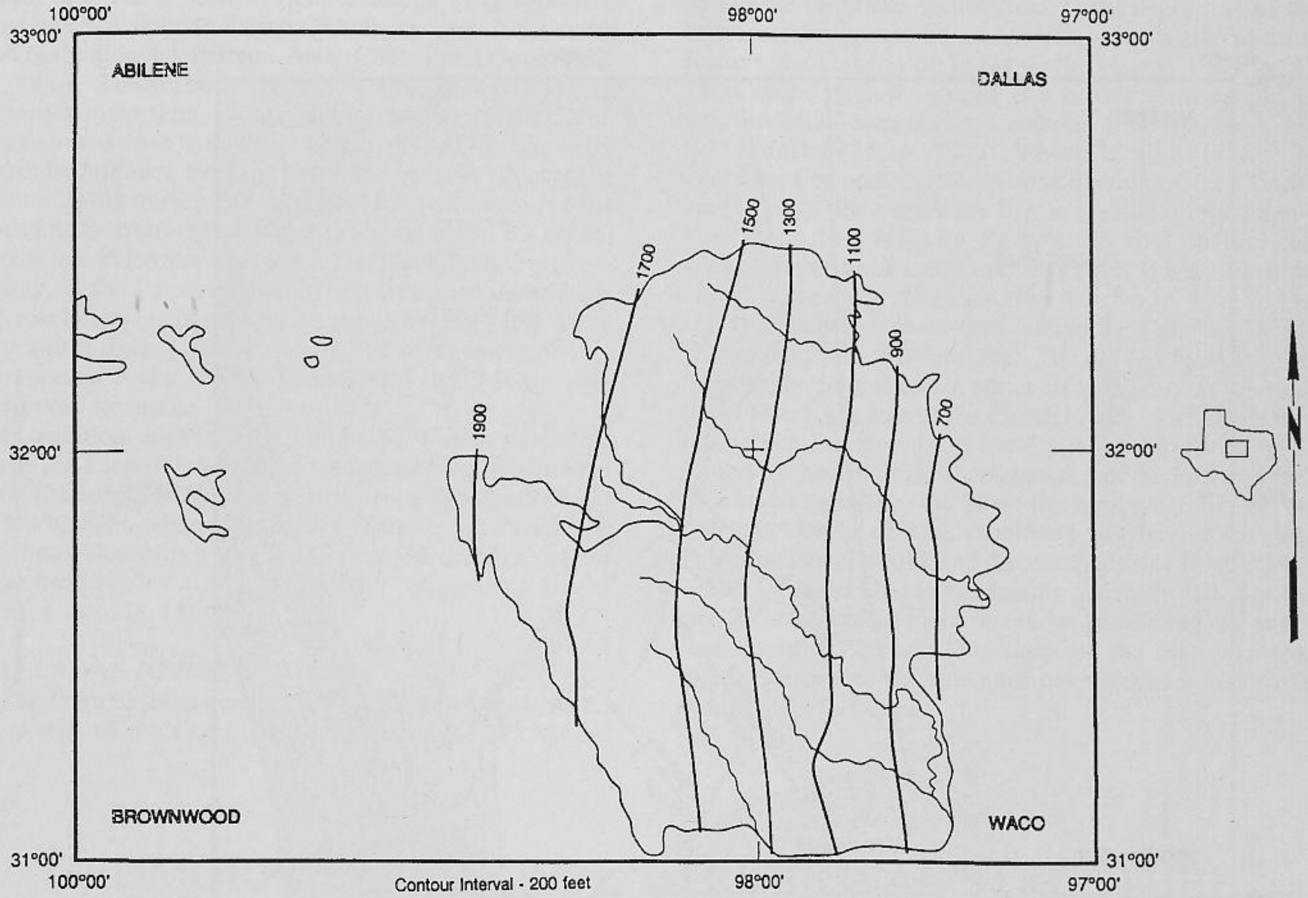

Fig. 15. Overlay of consequent drainage on the Edwards Limestone structural surface. Dip direction is generally due east and consequent drainage is southeast. Therefore, consequent drainage trends at a marked angle to regional dip. Dip direction and rate are related to subsidence stages within the East Texas Basin. Continued subsidence of the basin may have caused "reactivation" of deep-seated Paleozoic faults (Amsbury, 1990, oral communication). Consequent drainage within the Cut Plain is most likely controlled by lineament zones. Where no influential lineament trends exist, smaller tributary drainage is from west to east, down-dip.

Another feature that may play a factor in the evolution of northwest-southeast drainage orientation is the presence of a major topographic salient bounded on the south by the Rio Grande and on the north by a broad zone extending from Palo Duro Canyon southeastward along the narrow Colorado/Brazos divide at the southern edge of the Cut Plain (Woodruff and Caran, 1984, p. 26). This salient and the embayment that lies to the north have had marked effects on drainage development for river systems from the Brazos River southward. "The Brazos and Colorado systems show evidence of migration of the trunk streams off the topographic salient and into the embayment. This is especially true of the Colorado River: all except one of its major tributaries west of the Balcones Escarpment enter the trunk stem from the west" (Woodruff and Caran, 1984, p. 26-27). This pattern is also partly true for the Brazos River system. However, river systems that feed the Brazos, such as within the Cut Plain, still parallel the general southeast trend of the Brazos. These topographic factors have played a role in the establishment of northeast-trending drainage systems for parts of the Colorado River system (Concho, San Saba, Llano, and Pedernales Rivers) west of the Cut Plain into the vast embayment. These northeast-trending drainage features have led to the perception of lineaments that parallel the drainage orientation (Woodruff and Caran, 1984, p. 27). The Cut Plain lies in the embayment region and is characterized by southeast drainage patterns parallel with lineaments.

SUBSURFACE GEOLOGIC STRUCTURE

The regional dip of the Edwards Limestone changes abruptly along a north-south trend at the western margin of the Cut Plain. At this line, the dip increases from 5 feet per mile to approximately 15 feet per mile. This zone also marks the location of the north-south trending Bend Arch of the subsurface (Fig. 16). West of the Bend Arch, Paleozoic rocks dip westward into the Midland Basin; east of the Bend Arch, strata dip to the east, into the Fort Worth Basin. This zone also marks a change in drainage patterns within the Brazos River system. East of the Bend Arch within the Cut Plain, drainage flows to the southeast. West of the Bend Arch, tributary drainage trends northeast (Woodruff and Caran, 1984, p. 35; Barker, 1988, p. 57). Geophysical data also indicate a "discontinuity" in the basement along this trend (Watkins, 1961, p. 87). The southeastward direction of the Colorado/Brazos divide east

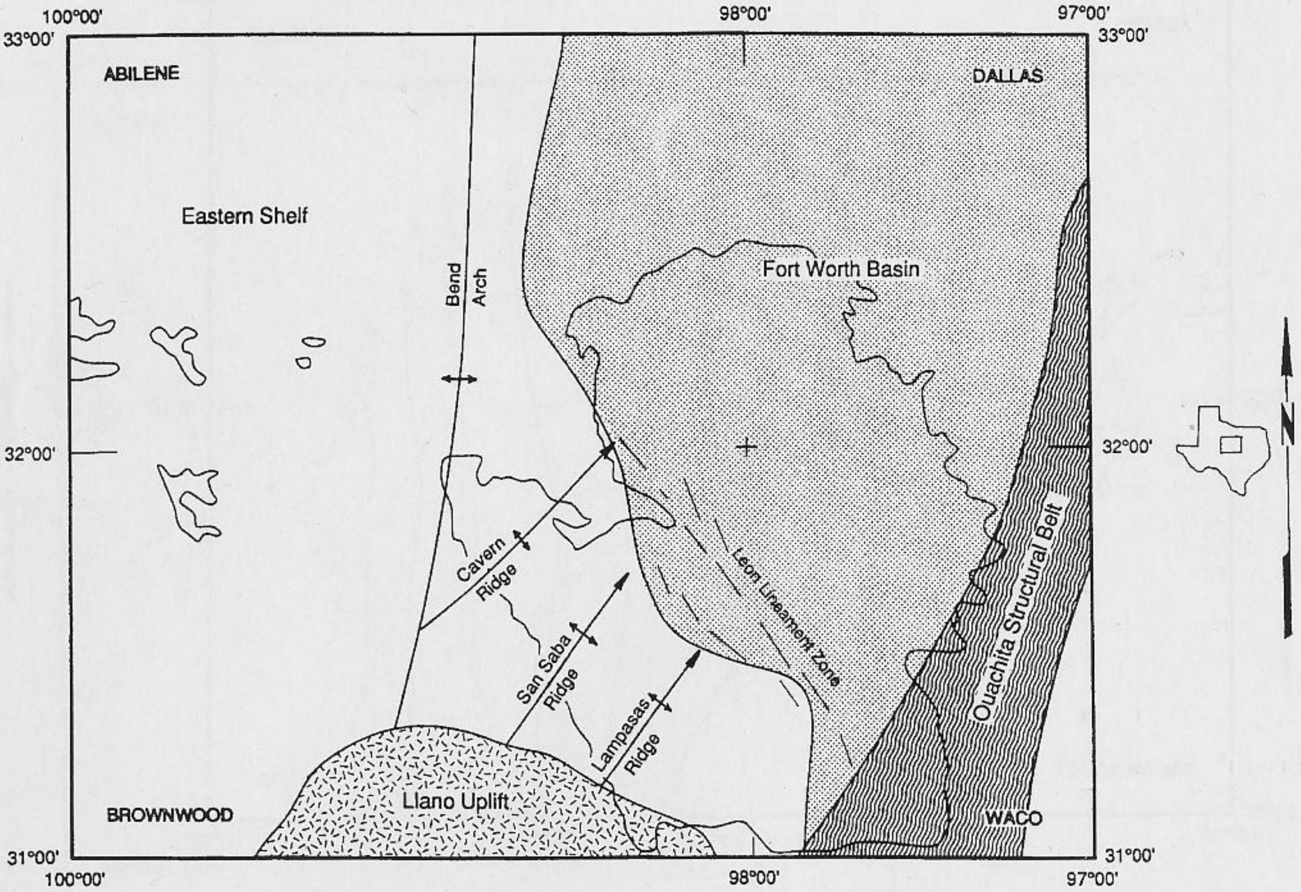

Fig. 16. Correlation of the "Leon Lineament Zone" with the western margin of the pre-Cretaceous Fort Worth Basin. The Fort Worth Basin margin is marked in the subsurface by the northeastward margin of the Llano Uplift, which acted as a foreland buttress during the westward encroachment of the Ouachita overthrust belt (Flawn, 1961, p. 130). It appears that the "Leon Lineament Zone" is a regional, surface indication of the western margin of the Fort Worth Basin. The "Leon Lineament Zone" also marks the subsurface distal ends of positive structural features: 1) Cavern Ridge; 2) San Saba Ridge; and 3) Lampasas Ridge. Within this area, lineaments mark the margins and axes of major subsurface pre-Cretaceous structural features (adapted from Flawn, 1961, and Woodruff and Caran, 1984).

of the Bend Arch "probably aligns with the strike of possible basement faulting along the northern edge of the Llano Uplift. North of this line Watkins' geophysical data indicate an overriding of the craton by a salient of the Ouachita overthrust zone" (Woodruff and Caran, 1984, p. 35). It is therefore suggested that the subsurface Bend Arch has exercised a significant influence on the dip of the Edwards Limestone at the western margin of the Cut Plain.

A correlation exists between the location of the major lineament zone (referred to as the "Leon Lineament Zone") and the western margin of the Fort Worth Basin (Fig. 16). Lineaments also coincide with the margins and axes of major subsurface structural features beneath the Cut Plain. Therefore, it appears that this western margin of the Fort Worth Basin was the primary localizing influence on the "Leon Lineament Zone." This zone also shows a strong influence on orientation of the Leon River drainage system. Lineaments may also correlate with the strike of strata that dip into the Fort Worth Basin.

Also, north of the "Leon Lineament Zone," lineaments that trend northeast may correlate with possible subsurface faults in Paleozoic rocks within the Fort Worth Basin. This western margin of the Fort Worth Basin seems to correlate remarkably well with a cross-strike discontinuity between the Llano basement massif and the Ouachita overthrust belt (Woodruff and Caran, 1984, p. 37).

The "Leon Lineament Zone" also marks the distal ends of three subsurface Paleozoic structural arches that extend from the Llano Uplift: 1) Cavern Ridge; 2) San Saba Ridge; and 3) Lampasas Ridge. These ridges were created by block faulting related to the westward encroachment of the Ouachita fold belt in Pennsylvanian/Permian time, so either these structures were reactivated in the post-Edwards interval or their contribution was entirely passive.

The Llano Uplift, a positive feature, acted as a foreland buttress during the late Paleozoic deformation of the Ouachita overthrust belt (Flawn, 1961, p. 130). The Llano

Uplift began as a positive element during early Paleozoic time and was uplifted during Ordovician time as the south end of the Concho or Texas Arch (Cheney and Goss, 1952, p. 2244, 2262-2263; Adams, 1954, p. 4). During Pennsylvanian time, block faulting and westward tilting began in response to tectonic activity of the Ouachita overthrust belt (Flawn, 1961, p. 143). The buttress effect of the Llano Uplift during the westward encroachment of the Ouachita overthrust belt had a profound effect on central Texas late Paleozoic structure. The block-faulted western margin of the Paleozoic Fort Worth Basin, created by this encroachment, is paralleled on the surface by the "Leon Lineament Zone," though, of course, these lineaments in Cretaceous rocks are not products of the much-earlier Paleozoic thrusting.

In addition, northeast-trending fault blocks extending from the Llano Uplift developed during Pennsylvanian time (Flawn, 1961, p. 143). These led to the development of topographic ridges (San Saba, Cavern, Lampasas) on the Wichita Paleoplain which are terminated along the northwest-trending "Leon Lineament Zone" (Caran and others, 1981, p. 66; Fig. 11).

CALLAHAN DIVIDE

The Fredricksburg section of the Callahan Divide varies from that of the Cut Plain by 1) major facies changes within the carbonate section, and 2) the deposition of the carbonate sediments on an ancient, structurally positive feature, the Concho or Texas Arch (Moore, 1969, p. 9). The Concho Arch developed as a broad, southeast-plunging, low-relief arch during Cambrian time (Nicholas and Rozendal, 1975, p. 198). There is no evidence of Cretaceous or post-Cretaceous reactivation of the Concho Arch, nor is there evidence that it created a topographic "welt" on the Wichita Paleoplain that influenced Comanchean sedimentation. However, it may have an effect on lineament formation (Fig. 10).

It is evident that lineaments within the Callahan Divide are not related to structural dip. The dip (≈5 feet per mile) is probably controlled by minor irregularities in the relatively broad, flat area of the Concho Arch. The abundance of surface lineaments in the Callahan Divide may be caused by the lithologic characteristics of the Edwards rudist mound complex, the great topographic relief of the Callahan Divide, and the underlying structure of the early Paleozoic Concho Arch and the late Paleozoic Bend Arch.

The Callahan Divide lineaments generally fall into the two 30° range of azimuth directions paralleling the structural grain of Texas. This supports the inference that regional structural patterns must have played a major role in lineament formation.

GEOMORPHIC RESPONSE TO REGIONAL STRUCTURE

The analysis of lineaments indicates that landforms and drainage within the Cut Plain and the Callahan Divide are in some ways controlled by structure. Within the study area, lineaments provide a window to dimly view subsurface structural controls. Joint patterns on the Edwards Limestone fall within the two 30° range of azimuth directions that define approximately 75 percent of lineaments within the Cut Plain (Fig. 10). Stream and divide orientations and linear dip anomalies tend to follow this same pattern, indicating that landscape reflects the same lineament directions. These parallels are too numerous to be happenstance, though the actual coupling mechanism is not understood.

LINEAMENT CONTROL OF DRAINAGE

Lineaments visible on LANDSAT imagery of the Lampasas Cut Plain tend to parallel joint sets visible in the Glen Rose and Edwards Formations on the surface. Joints parallel to major lineaments may have resulted from lineament development or may have aided lineament development. Joint orientations parallel major lineament trends, as do orientations of streams, valleys, and Edwards-capped divides within the Cut Plain. "Joints influence physiographic features because they represent surfaces of decreased resistance along which surficial processes of weathering and erosion can act more effectively" (Finley and Gustavson, 1981, p. 24).

Joint control of drainage is best developed where streams flow on jointed bedrock, such as the Edwards and Glen Rose Limestone. However, there is also evidence to support the belief in joint control of linear drainage where streams flow on the Walnut Clay (Fig. 17). This latter relationship strongly resembles that of the High Plains of Texas where "joint control" of drainage is expressed in poorly unconsolidated Ogallala sediments (Finley and Gustavson, 1981, p. 27). As within the Cut Plain, a high percentage of lineaments on the High Plains are oriented in the 300° to 320° direction (NNW-SSE) while the mean surface gradient is from 90° to 140° (E-ESE) (Finley and Gustavson, 1981, p. 27). Lineaments, as expressions of joints, apparently control drainage despite land surface or structural dip directions.

The modes of formation of joints in the study area are unknown. However, several mechanisms have been suggested. One is that joints result from regional compressive or tensile stresses developed during uplift (Price, 1966, p. 82). In the Cut Plain, stresses of this origin include the uplift of the Central Texas Craton, subsidence of the East Texas Basin and, for Paleozoic rocks, the compressive stresses of the Ouachita overthrust during westward encroachment. Jointing may accompany formation of regional flexures (Hobbs and others, 1976, p. 320) that propagate upward through an extensive stratigraphic section. In the region of the Cut Plain, deep-seated faulting generated or reactivated during subsidence of the East Texas Basin may have been such a mechanism. North-

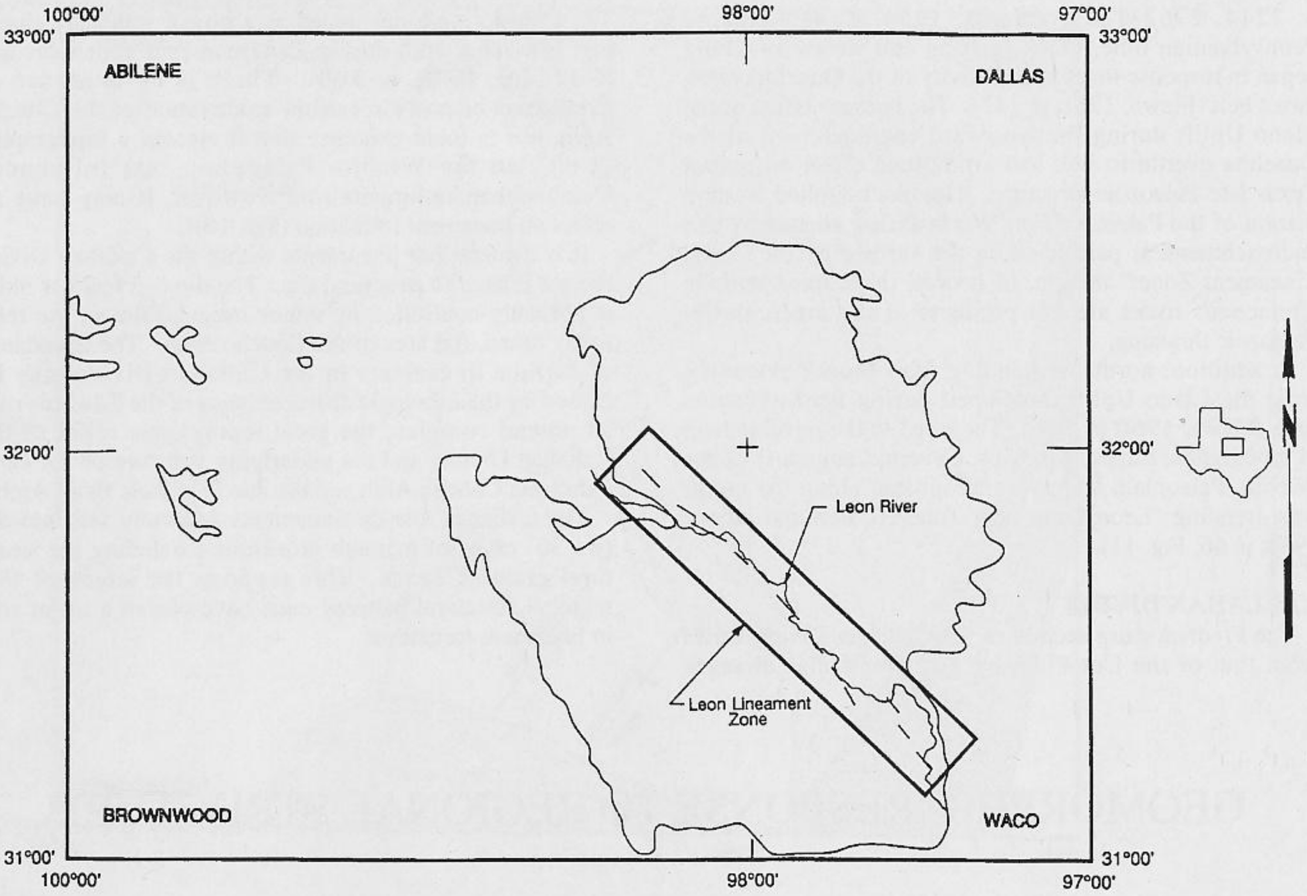

Fig. 17. The "Leon Lineament Zone" and the Leon River. Joint control of drainage is most evident where streams flow on hard bedrock. Within the Cut Plain, joints tend to parallel lineament trends. Northwest-southeast joints appear to have controlled drainage orientation of the Leon River. Even where the Leon River flows on Walnut Clay, joints are a major factor in drainage direction.

south oriented flexures (Fig. 9) in the Cut Plain, and the conspicuous "steps" in the dip of the Edwards Limestone suggest possible connections with subsidence of the East Texas Basin or reactivation of deeper faulting. Regional structures—the Trinity Shelf and East Texas Basin—are clearly evident, and the timing of basin subsidence is "right" to have directly influenced Cretaceous rocks. Furthermore, possible basement-related fault systems of similar orientation (Balcones System) in rocks of Cretaceous age exist, and there is clear evidence of Late Cretaceous-Early Tertiary extensional forces of the right orientation to encourage such faulting.

DIP CONTROL OF DRAINAGE

Dip control of stream orientation in the Cut Plain occurs principally on tributary drainage, as along the divide between the North Bosque and Leon Rivers in northeast Coryell County, southwest Bosque County, and northwest McLennan County (Fig. 18). Neils Creek, Hog Creek, and the Middle Bosque River all trend west-to-east, down-dip, suggesting that lineament or joint control is most effective on larger, low-gradient streams and less effective on smaller, high-gradient streams, where dip becomes the controlling factor. However, there are exceptions. Coryell Creek, as the other tributary drainage in this area, should trend west-to-east, down-dip. However, Coryell Creek flows at a marked angle to regional dip, apparently controlled by lineaments or joints, as is its parent stream, the Leon River. Perhaps where lineament zones are present they provide a least-resistance drainage pathway and therefore control drainage orientation. Where lineament zones are lacking, dip exerts the dominant control on drainage orientation. Thus it may be that the concentration of lineaments of common orientation in lineament zones is the factor that ultimately decides drainage direction.

DIVIDE GEOMETRY

Lineaments apparently control drainage and valley orientation in the Lampasas Cut Plain, leading to lineament control of divides as well. In eastern Mills County and western Hamilton County, lineament-related drainage orientation is naturally paralleled by similar divide orientation (Fig. 19). In this area, lineament control occurs in the two major lineament ranges of azimuths within the Cut Plain.

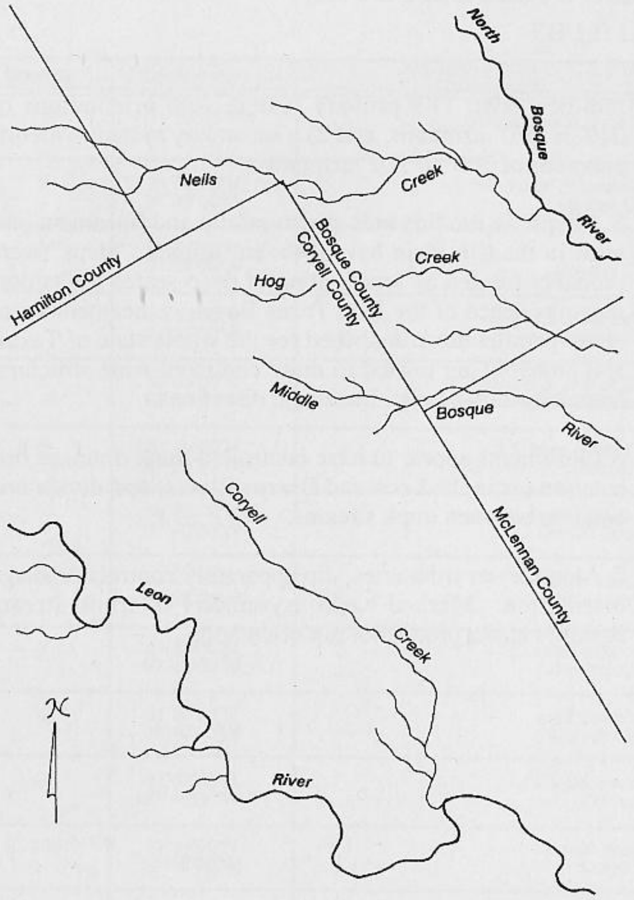

Fig. 18. Map showing dip control of tributary drainage. In the upland areas between the Leon and North Bosque Rivers, Neils Creek, Hog Creek, and the Middle Bosque River all trend west-to-east, down-dip. This suggests that tributary drainage is controlled by dip rather than by other factors. Coryell Creek trends northwest-southeast possibly controlled by the "Leon Lineament Zone." (Figure adapted from Bureau of Economic Geology, 1979, Geologic Atlas of Texas, Waco Sheet.)

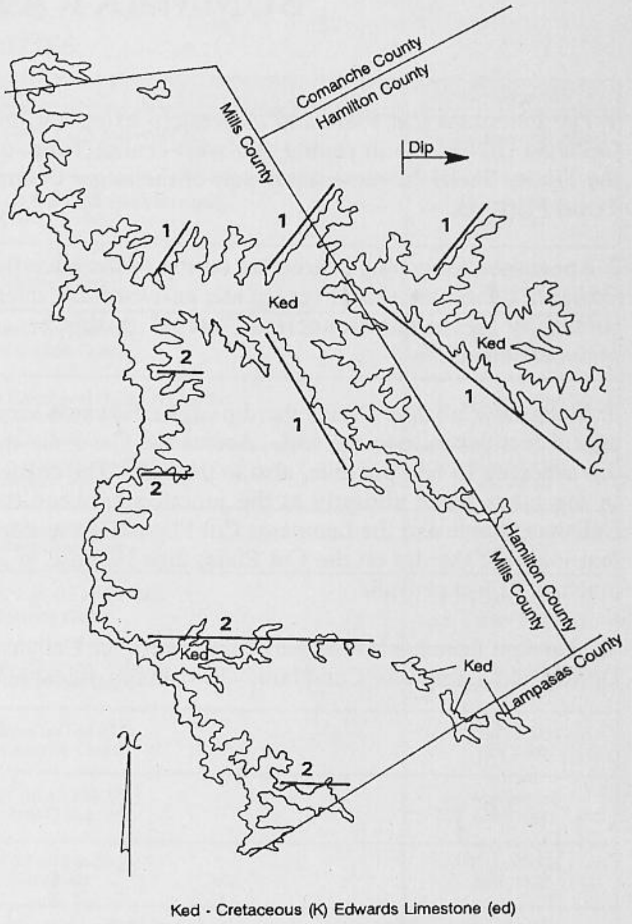

Fig. 19. Map showing apparent lineament control of drainage and divide orientation. Two controls appear to relate to divide orientation: 1) lineaments and joints within the two 30° azimuth directions appear to control the orientation of the up-dip margins of divides (number 1 on map); and 2) dip apparently controls the development of the down-dip crenulated side of divides (number 2 on map). These two aspects of divide physiography are evident throughout the study area. (Figure adapted from Bureau of Economic Geology, 1986, Geologic Atlas of Texas, Brownwood Sheet.)

Those with a primary lineament direction (040° to 070°) occur along the north side of the divide that separates Cowhouse Creek from Bennett Creek. Those with a secondary lineament direction (300° to 330°), occur on the western scarp face of divides separating Bennett Creek, the Lampasas River, and Cowhouse Creek.

Another factor affecting divide geometry is dip-controlled drainage. This is evidenced by the deeply embayed, down-dip divide margin. This drainage pattern is probably the result of dip-controlled overland flow, or the product of groundwater flow, also dip-controlled, which "saps" the base of the Edwards leading to headward migration along localized pathways.

In the Lampasas Cut Plain lineaments of the secondary (300° to 330°) lineament direction are more abundant; they more strongly influence divide configuration than do lineaments of the primary (040° to 070°) lineament direction. Regional dip plays the dominant role in drainage orientation principally in its effect on tributary orientation.

SUMMARY AND CONCLUSIONS

1. The Lampasas Cut Plain and its western extension, the Callahan Divide, are in central and west-central Texas on the Trinity Shelf, the most stable part of the larger Central Texas Platform.

2. An analysis of geologic structure on top of the once-flat Edwards Limestone shows very gentle eastward dip, interrupted by steepened monoclinal "steps" in this broad regional homocline.

3. Along the Callahan Divide the dip of the Edwards averages 5 feet per mile to the east. Across the Cut Plain the dip averages 15 feet per mile, also to the east. The change in dip takes place abruptly at the junction between the Callahan Divide and the Lampasas Cut Plain. On the steps that interrupt the dip on the Cut Plain, dips increase to as much as 22 feet per mile.

4. Abundant lineaments also mark the areas of the Callahan Divide and Lampasas Cut Plain. Two major lineament families exist: 1) a primary system with orientations of 040° to 070° azimuths; and 2) a secondary system with orientations of 300° to 330° azimuths.

5. "Steps" in the Edwards structural dip and lineament patterns in the Cut Plain have different origins. "Steps" were probably formed by reactivation of deep-seated faults during subsidence of the East Texas Basin. Lineaments generally parallel those described for the whole state of Texas, and probably are related to more continent-wide structural features which parallel lineament directions.

6. Lineaments appear to have controlled trunk drainage orientation (as in the Leon and Brazos Rivers) and divide orientation between trunk streams.

7. Along lesser tributaries, dip apparently controls drainage orientation. Marked basin asymmetry of trunk stream basins is also a product of dip orientation.

APPENDIX A

FIELD LOCALITIES

Locality	Coordinates	Location	Significance
1	31°58"15"N 97°28'00"W	.8 miles north of junction with HWY 1713 and HWY 56; Bosque County; Allen Bend Quad	Top of Edwards (Ked) elev 700
2	31°58'15"N 97°33"00"W	.5 miles east of junction of road on FM 1713 (tank on right); Bosque County; Pilot Knob Quad	Top of Ked elev 840
3	31°57'00"N 97°34'00"W	.3 miles north of Times Branch; Bosque County; Pilot Knob Quad	Top of Ked elev 845
4	31°55'30"N 97°37'00"W	2.8 miles east of Meridian on HWY 22; Bosque County; Pilot Knob Quad	Top of Ked elev 920
5	31°53'00"N 97°34'30"W	2.3 miles due east of BM at Gulf Coast and Santa Fe RR on unmarked county road; Bosque County; Pilot Knob Quad	Top of Ked elev 860
6	31°49'00"N 97°33'00"W	2.1 miles east of FM 1991 on county road 3221; Bosque County; Clifton Quad	Top of Ked elev 840
7	31°23'00"N 97°40'30"W	Locality at US HWY 84 at South Mountain; Coryell County; Gatesville East Quad	Top of Ked elev 1020
8	31°23'15"N 97°37'00"W	1.4 miles east of FM 1829 on US HWY 84; Coryell County; Oglesby Quad	Top of Ked elev 870
9	31°28'00"N 97°42'00"W	2.3 miles east of Gatesville prison on FM 929; Coryell County; Gatesville East Quad	Top of Ked elev 1045
10	31°37'00"N 98°40'00"W	east divide of Leon River on FM 215; Coryell County; Turnersville Quad	Top of Ked elev 1085
11	31°32'00"N 97°45'00"W	1.4 miles north of HWY 36 on FM 182; Coryell County; Ater Quad	Top of Ked elev 1090
12	31°34'00"N 97°48'00"W	1.0 mile north of HWY 63 on FM 2955; Coryell County; Ater Quad	Top of Ked elev 1135
13	31°40'00"N 98°52'00"W	2.6 miles east-northeast of Jonesboro on FM 217; Coryell County; German Vally Quad	Top of Ked elev 1163
14	31°41'00"N 97°53'00"W	1.2 miles north-northwest of VABM Scoggins triangulation station on unnamed county road; Hamilton County; Cutoff Mountain Quad	Top of Ked elev 1223
15	31°32'30"N 97°24'30"W	2 miles east of Crawford on FM 185; McLennan County; Crawford Quad	Top of Ked elev 640
16	31°36'30"N 97°27'30"W	3.4 miles south of Valley Mills on FM 317; McLennan County; Crawford Quad	Top of Ked elev 710
17	31°39'00"N 97°33'30"W	2.7 miles east of Mosheim on FM 217; Bosque County; Mosheim Quad	Top of Ked elev 840
18	31°39'00"N 97°42'15"W	1 mile southwest of Hurst Spring, on FM 182; Coryell County; Hurst Spring Quad	Top of Ked elev 1040
19	31°46'00"N 97°47'00"W	3 miles east of Cranfills Gap on unnamed county road on Rogstad Mountain; Bosque County; Cranfils Gap Quad	Top of Ked elev 1080
20	31°46'00"N 97°53'15"W	3.2 miles west of Cranfils Gap on FM 22; Hamilton County; Fairy Quad	Top of Ked elev 1210
21	31°54'15"N 97°53'30"W	6 miles south of Iredell on FM 1238; Bosque County; Spring Creek Gap Quad	Top of Ked elev 1240
22	31°55'30"N 97°47'30"W	2.8 miles northeast of Spring Creek Church on county road; Bosque County; Iredell Quad	Top of Ked elev 1120
23	31°55'45"N 97°41'45"W	1 mile west of junction of HWY 6 on county road; Bosque County; Meridian Quad	Top of Ked elev 1020
24	31°46'00"N 97°36'00"W	1.75 miles west of Clifton on FM 219; Bosque County; Clifton Quad	Top of Ked elev 880
25	31°51'00"N 97°43'00"W	5 miles southwest of Meridian on FM 22; Bosque County; Sugarloaf Mountain Quad	Top of Ked elev 1020
26	31°51'00"N 97°49'30"W	5 miles north of Cranfils Gap on county road on Spencer Mountain; Bosque County; Cranfils Gap Quad	Top of Ked elev 1160

Locality	Coordinates	Location	Significance
27	32°22'45"N 97°47'45"W	1.5 miles east-northeast of Brushy, on private property; Hood County; Granbury Quad	Top of Ked elev 1210
28	32°10'05°"N 97°53'00"W	10.5 miles west-southwest of Glen Rose on HWY 67 at roadside park; Somervell County; Chalk Mountain Quad	Top of Ked elev 1280
29	32°10'00"N 97°52'00"W	1.25 miles south of Nancy Smith Cemetary on unnamed county road; Somervell County; Glen Rose West Quad	Top of Ked elev 1240
30	32°09'30"N 97°47'30"W	1.5 miles south of Ward Branch Cemetary on Somervell County road 2009; Somervell County; Glen Rose West Quad	Top of Ked elev 1150
31	31°28'00"N 98°10'00"W	1.65 miles west of Evant on U.S. HWY 84; Hamilton County; Evant Quad	Top of Ked elev 1445
32	31°27'30"N 98°35'00"W	.5 miles east of junction of U.S. HWY 84 and Business 84; Mills County; Goldthwaite Quad	Top of Ked elev 1735
33	31°32'30"N 98°25'00"W	1.8 miles northeast of Bennet Church on FM 2005; Mills County; Caradan Quad	Top of Ked elev 1670
34	31°33'00"N 98°18'00"W	2 miles east of McGirk Cemetary on unnumbered county road; Hamilton County; Pecan Wells Quad	Top of Ked elev 1580
35	31°26'30"N 98°07'00"W	2.2 miles southeast of Evant on FM 183; Coryell County; Pearl Quad	Top of Ked elev 1445
36	31°20'30"N 98°29'45"W	7 miles southeast of Goldthwaite at Castor Siding on county road 162; Mills County; Goldthwaite Quad	Top of Ked elev 1700
37	31°35'00"N 98°33'00"W	12 miles north of Goldthwaite on HWY 16; Mills County; Mullin (1:52,500) Quad	Top of Ked elev 1700
38	31°40'00"N 98°38'00"W	3.5 miles east of Democrat community on FM 218; Mills County;	Top of Ked elev 1780
39	31°42'00"N 98°42'00"W	2 miles northwest of Comanche, Brown, and Mills County triple junction; Brown County	Top of Ked elev 1800
40	31°49'00"N 98°42'00"W	5.5 miles due east of Blanket on unmarked county road; Comanche County; Mercers Gap Quad	Top of Ked elev 1790
41	31°56'00"N 98°52'00"W	4 miles south of May on unmarked county road on top of Hog Mountain; Brown County; Star Mountain Quad	Top of Ked elev 1940
42	32°15'00"N 99°45'00"W	private road 1 mile east of HWY 83-84, 9 miles south of HWY 84 Loop 322 junction; Taylor County	Top of Ked elev 2200
43	32°18'00"N 99°50'00"W	on HWY 277, 5 miles south-southwest of View; Taylor County	Top of Ked elev 2300
44	32°20'00"N 100°10'00"W	Hwy 89 at junction of HWY 126; Taylor County	Top of Ked elev 2500

APPENDIX B

PREVIOUS WORKS

Chronological Listing of Previous Works in the Lampasas Cut Plain and Callahan Divide

Date	Author	Title	Significance
1901	Hill, R.T.	Geography and geology of the Black and Grand Prairies, Texas	Detailed description of the Black and Grand Prairies. First description of the Lampasas Cut Plain within the Grand Prairies.
1904	Hobbs, W.H.	Lineaments of the Atlantic border region	First introduction of the term "lineament" which characterizes the spatial relationships of crests of ridges, drainage lines, coast lines, and formation line boundaries.
1912	Hobbs, W.H.	Earth features and their meaning	Redefined the term "lineament" to include ravines, valleys, and visible lines of fracture and fault breccia zones.
1952	Cheney, M.G. and L.F. Goss	Tectonics of Central Texas	Description of the subsurface Texas or Concho Arch of Central Texas and its relationship with the Llano Uplift.
1954	Adams, J.E.	Mid-Paleozoic paleography of Central Texas	Described the Mid-Paleozoic ancient structural surface within the region of the Texas or Concho Arch and the Llano Uplift.
1959	Lozo, F. E. (Ed.)	Stratigraphic relations of the Edwards Limestone and associated formations in north-central Texas	Detailed lithologic and stratigraphic description of the Edwards Limestone within the study area.
1961	Flawn, P.T., A. Goldstein, P.B. King, and C.E. Weaver	The Ouachita System	Described the entire Ouachita System from development through deformational stages and discussed its subsurface affect on Central Texas structure.
1961	Watkins, J.S.	Gravity and magnetism of the Oauchita structural belt in Central Texas	Provided geophysical data to describe the subsurface geometry of the Oauchita structural belt and its structural nature.
1966	Price, N.J.	Fault and joint developed in brittle and semi-brittle rock	Described the structural and tectonic stresses that are believed to produce faults and joints.
1969	Moore, C.H., Jr.	Stratigraphic framework, lower Cretaceous, west-central Texas	Described the geologic complexes within the Lampasas Cut Plain, Callahan Divide, and the Edwards Plateau.
1971	Byrd, C.L.	Origin and history of the Uvalde gravels of central Texas.	Provided evidence to support the theory that the "time zero" surface of Cut Plain development was a broad alluvial plain.
1973	Epps, L.W.	A geologic history of the Brazos River.	Described the history of the Brazos River through time. Described multiple terraces of the Brazos and its base level changes.
1975	Nicholas, R.L. and R.A. Rozendal	Subsurface positive elements within Ouachita foldbelt in Texas and their relationship to Paleozoic cratonic margin	Described two positive subsurface features (Devils River and Waco Uplifts) within the Ouachita fold belt and discussed the nature of foreland basins such as the Strawn or Fort Worth Basin.

Date	Author	Title	Significance
1976	Hobbs, B.E., W.D. Means, and P.F. Williams	An outline of structural geology	Described the nature of joint systems and subsurface structural features that may produce joints.
1976	O'Leary, D.W., J.D. Friedman, and H.A. Pohn	Lineament, linear, lineation—some proposed new standards for old terms	Provided chronological listing of the definition of the term lineament. Determined first recognition of the term.
1977	Corwin, R.V.	The geomorphic evolution of the Washita Prairie, Central Texas	Described the general characteristics of the Washita Prairie, Lampasas Cut Plain, and the pre-Cretaceous surface.
1978	Walker, J.R.	Geomorphic evolution of the Southern High Plains	Related history of Southern High Plains to that of Central Texas trunk drainage.
1979	Bureau of Economic Geology	Geologic Atlas of Texas, Waco Sheet	Map of geology and stream drainage in area of this study.
1981	Caran, S.C., C.M. Woodruff, and E.J. Thompson	Lineament analysis and inference of geologic structure—examples from the Balcones/ Ouachita trend of Texas	Detailed lineament study along the Balcones and Ouachita trend and probable surface-subsurface relationships.
1981	Finley, F.J. and T.C. Gustavson	Lineament analysis based on LANDSAT imagery, Texas panhandle	Described subsurface effects on lineament formation and related geomorphic features to lineaments.
1982	Corwin, L.W.	Stratigraphy of Fredricksburg rocks north of the Colorado River, Texas	Developed depositional models of Fredricksburg rocks north of Colorado River.
1984	Woodruff, C.M. and S.C. Caran	Lineaments of Texas—possible surface expressions of deep-seated phenomena	Particularly useful study describing the lineaments of Texas and possible subsurface controls. Provided maps of Texas that detail surface lineaments.
1986	Bureau of Economic Geology	Geologic Atlas of Texas, Brownwood Sheet	Map of geology and stream drainage in area of this study.
1986	Montgomery, J.A.	The geomorphic evolution of the Taylor Black Prairie between the Trinity and Colorado Rivers, Central Texas	Explained southeast direction of original consequent drainage within the Cut Plain.
1988	Amsbury, D.L.	Depositional history of Fredricksburg division (Middle/Upper Algian, Cretaceous) of north-central Texas in terms of shallowing-upward sequences	Developed depositional model of Edwards Limestone in north-central Texas, including the area of this investigation.
1988	Barker, C.	The retreating Cretaceous margin, north-central Texas	Related stream drainage patterns east and west of the Cretaceous margin in north-central Texas to retreat of the Cretaceous margin.

Date	Author	Title	Significance
1988	Brown, T.E.	Relationship between basin parameters and landform configuration, Lampasas Cut Plain, Central Texas	Described two types of basin (I and II) and related their formation to the history of Cut Plain evolution.
1988	Tharp, T.L.	Aspects of Leon River drainage history with implications to other Central Texas streams	Related the drainage history to terrace levels and stream behavior of the Leon River.
1989	Parish, B.C.	Geomorphic response to regional structure, Lampasas Cut Plain, Central Texas	Reconnaissance of role of structure in landform development in the Cut Plain.
1990	Hayward, O.T., P.M. Allen, and D.L. Amsbury	The Lampasas Cut Plain —evidence for the cyclic evolution of a regional landform, Central Texas	Historic study describing the geomorphic evolution and processes on the formation of the Lampasas Cut Plain.

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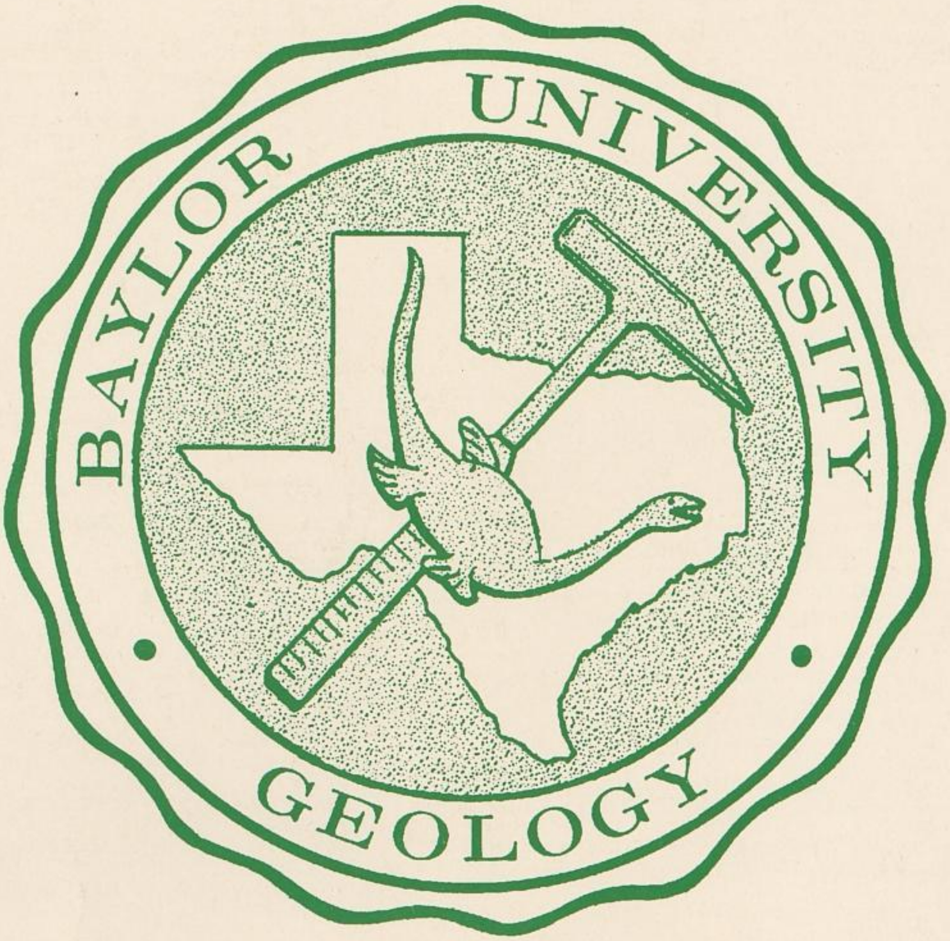
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