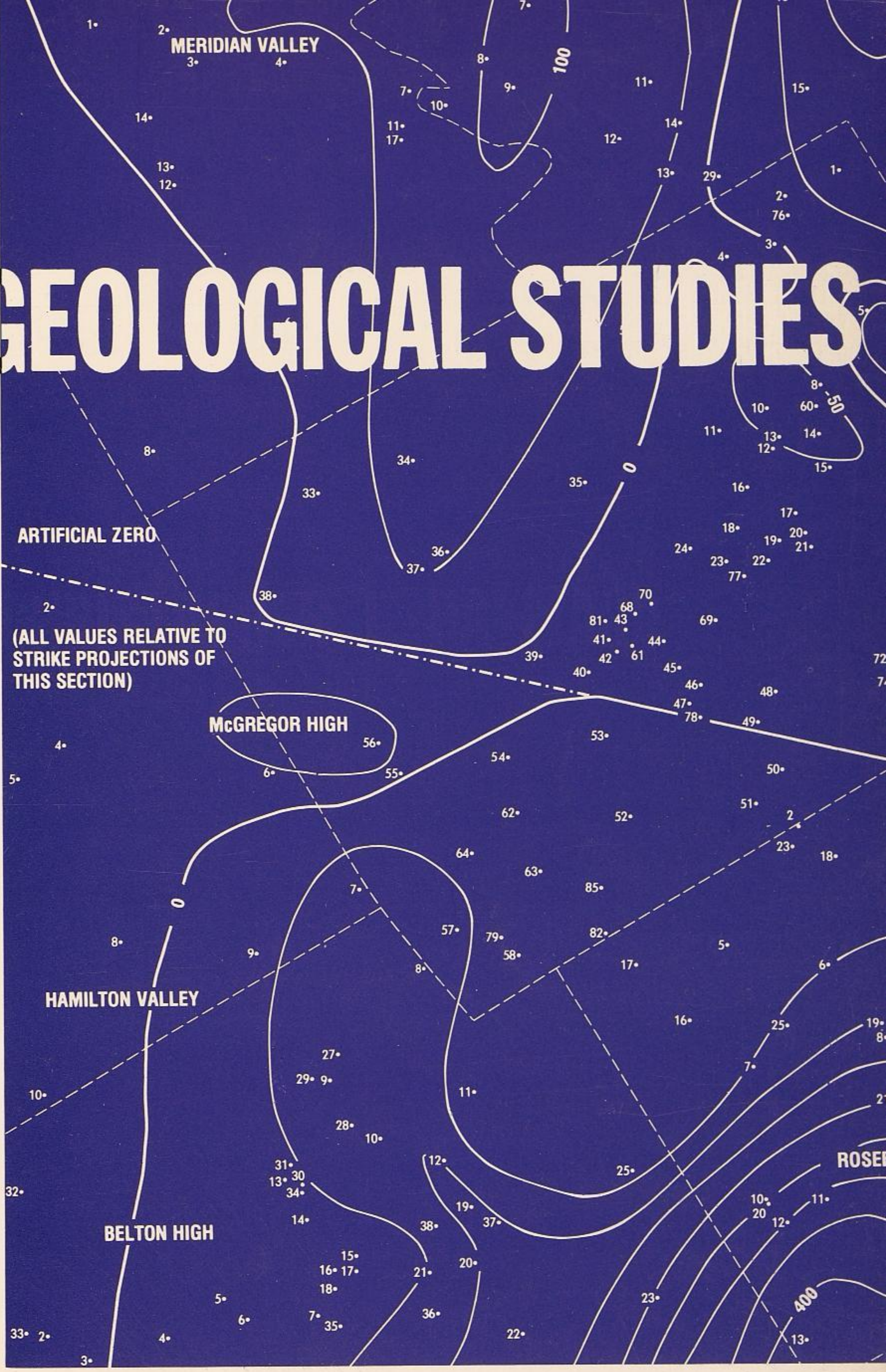
BAYLOR GEOLOGICAL STUDIES



SPRING 1978
Bulletin No. 34

Structural Evolution of the
Waco Region

CHRISTOPHER T. HAYWARD

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

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

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The training of a geologist in a university covers but a few years; his education continues throughout his active life. 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.

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Structural Evolution of the Waco Region

Christopher T. Hayward

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
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Structural Evolution of the Waco Region

Christopher T. Hayward

ABSTRACT

The eastward thickening wedge of Cretaceous sediments dominates the regional structure of the Waco area. Isopachs of eight units (the Hosston Formation, the Pearsall Formation, the Hensel Formation, the Glen Rose Formation, the Fredericksburg Group, the Georgetown Formation, the Del Rio Formation-Pepper Formation-Eagle Ford Group, and the Austin Formation) can lead to interpretations of stress patterns related to faulting along the Balcones fault. Analyses assume that isopach features are controlled by active structural disturbance during deposition.

The pre-Cretaceous surface, which was of low relief, extended far to the east of Waco. Initial fluvial Cretaceous deposition began with subsidence in the East Texas basin and deposition of the Hosston Sand. Streams incised valleys through the Ouachita fold belt and deposited sands east of Waco. By the end of Hosston time, the surface of deposition was essentially flat. The presence of three Pearsall isopach features parallel with known basal Cretaceous faults give evidence of local readjustments and uplift along faults during Pearsall deposition. The overlying Hensel Sandstone exhibits characteristics of strandline deposits, and isopach thicks of this unit are probably depositional rather than tectonic. The isopach of the overlying Glen Rose Formation, the thickest of all mapped intervals, shows very few anomalies, perhaps due to the masking effect of the large total thickness. Tectonic activity during Glen Rose deposition probably continued to areas east of the Balcones fault zone. The Fredericksburg isopach is the most constant of all mapped intervals. The consistent lithology and isopach constancy of the Fredericksburg Group suggest that little tectonic activity occurred during deposition of this unit.

Post-Fredericksburg rocks are exposed only over the eastern half of the area. The Georgetown Limestone directly overlies rocks of the Fredericksburg Group, and southward thinning of its shale units suggests a northward source, hence uplift in the north. The shales of the Del Rio and Pepper Formations and Eagle Ford Group overlie the Georgetown Formation and also suggest uplift in the north and subsidence in the south, perhaps in conjunction with renewed activity along faults. The Austin Chalk, a remarkably uniform section, overlies the Eagle Ford Group and thickens both north and south of Waco, suggesting gentle uplift near Waco.

Surface fitting of the isopach data reveals that regional activity was greatest during Hosston deposition, and least during Fredericksburg deposition, increasing from Fredericksburg to Austin time. Field evidence of faulting during Austin time fits theoretical models of growth faults and faulting due to increased vertical stresses.

INTRODUCTION*

PURPOSE

Previous studies of regional structure in central Texas have been largely descriptive and emphasized Balcones faulting (Goodson, 1965; Hudson, 1972). However, Balcones faulting was simply a final episode in the evolution of regional structure and in itself gives little indication of stress origins or fault timing. The evolution of regional structure as indicated by depositional patterns can provide such information, including the location of major structural warps during sedimentation and some indication of time of greatest tectonic activity. These in turn can be related to stress patterns which may ultimately lead to major faulting. Thus, this initial regional study may define areas of interest where detailed study might follow.

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*A thesis submitted in partial fulfillment of the requirements for the B.S. degree in Geology, Baylor University, 1976.

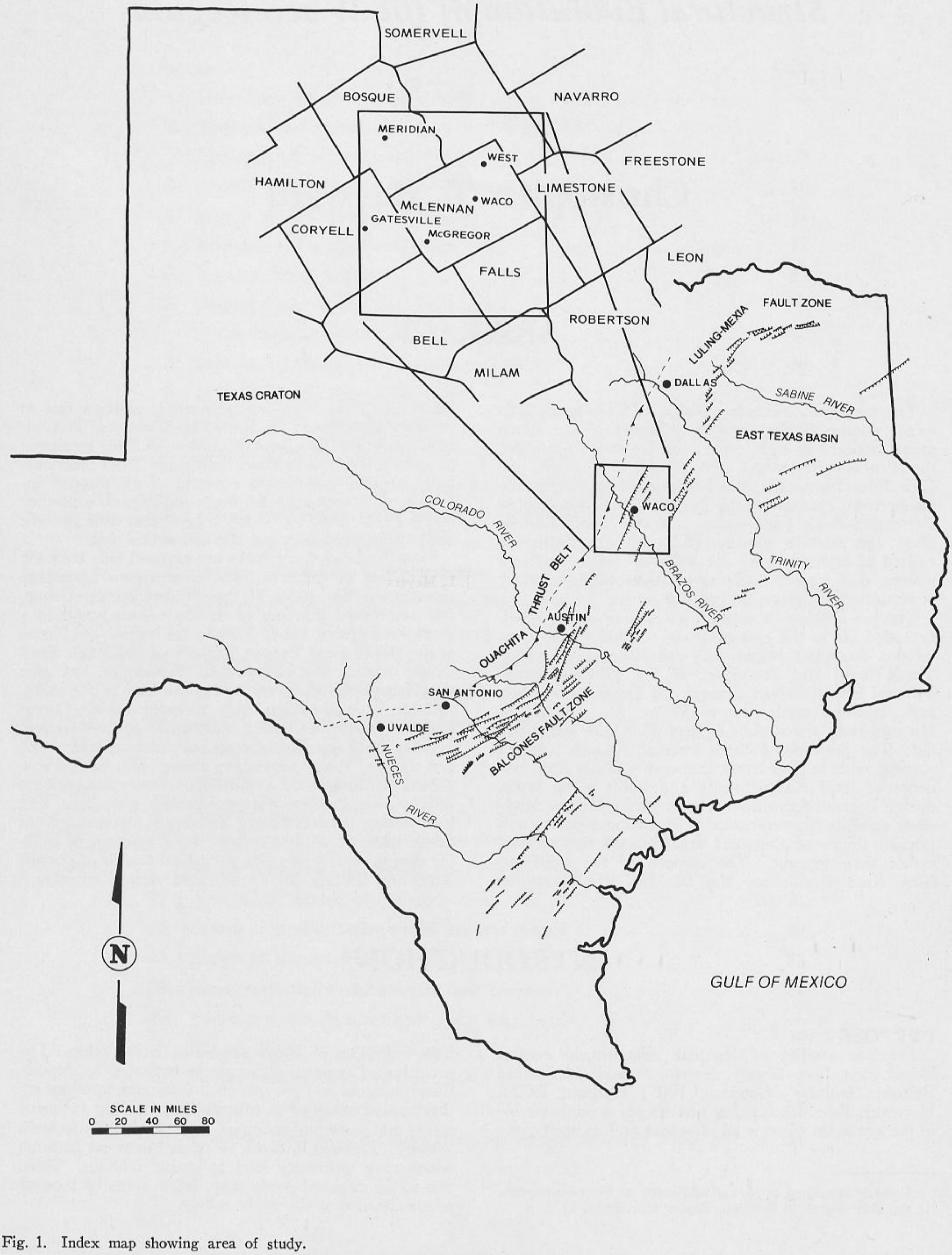


Fig. 1. Index map showing area of study.

The purposes of the present study are 1) to present a generalized idea of the nature, age, and origin of the tectonic history of the Waco region; 2) to define the regional structure peculiar to the craton-basin interface; and 3) to identify areas for further, more detailed studies.

LOCATION

The study area is a one-degree quadrangle centered in Waco, Texas, and bounded by latitudes 31° and 32° north and by longitudes 96° 45′ and 97° 45′ west (Fig. 1). This area includes all of McLennan County and parts of Bosque, Navarro, Limestone, Hill, Bell, Falls, Coryell, and Milam Counties. From the Texas craton on the west it extends eastward to the margin of the East Texas basin. The Balcones fault zone trends north-northeast through the center of the region.

Thus the study area shares characteristics of craton and basin as well as the unstable margin separating the two. The region includes outcrops of all central Texas Cretaceous formations (Fig. 2), except the basal Trinity Group, and contains many wells through the Cretaceous section. Therefore, it is a region with adequate features for the purpose of this investigation.

METHODS

This study is largely based on data from electric well logs, and correlation control was established by construction of three north-south and three east-west cross sections. Sixty additional logs were picked to identify an average of fifty recognizable horizons per well. This process extended control across the entire region and led to early familiarization with stratigraphy and electrical character of the subsurface units. Isopach maps accompanying this report were constructed from data in publications of the Texas Water Development Board, because many of the logs in the region were unavailable elsewhere. This is particularly true for the lowermost Cretaceous units, the Hosston, Hensel, and Glen Rose Formations. Discrepancies between initial control values and Texas Water Development Board values were resolved by establishing control points and rechecking questionable horizons. In the western half of the area structural and stratigraphic surface control was obtained from field work, previously published and unpublished reports, and analyses of 1 : 24000 topographic maps. On the basis of these values a series of isopach maps was constructed, beginning with the present configuration of the base of the Cretaceous and extending to the top of the Gulfian section. These maps were compared with existing maps in the literature, and, in case of disagreement, points were rechecked to establish the most probable values. From the maps and sections, a reasonable structural history of the Waco region was derived.

As an experiment, an intraformation model was developed to generalize the changes in thickness throughout the Cretaceous section, and an attempt was made to fit existing data to the model by least squares fit. In all interpretations sudden and significant changes in thickness were related to probable stress locations and time associated with the evolution of Balcones faulting.

In order to gain a better understanding of Balcones faulting in the Austin Chalk, selected sections along the Brazos and Bosque Rivers were examined and photographed. Also a model of the faulting using Hafner's (1951) approach was developed to suggest possible configuration of subsurface fault planes. Later investigations may utilize more extensive surface and subsurface control, more detailed air photo interpretation and may concentrate in greater detail on a few selected cross sections across the area. Each of these procedures has been tested in reconnaissance fashion in this study.

PREVIOUS WORKS

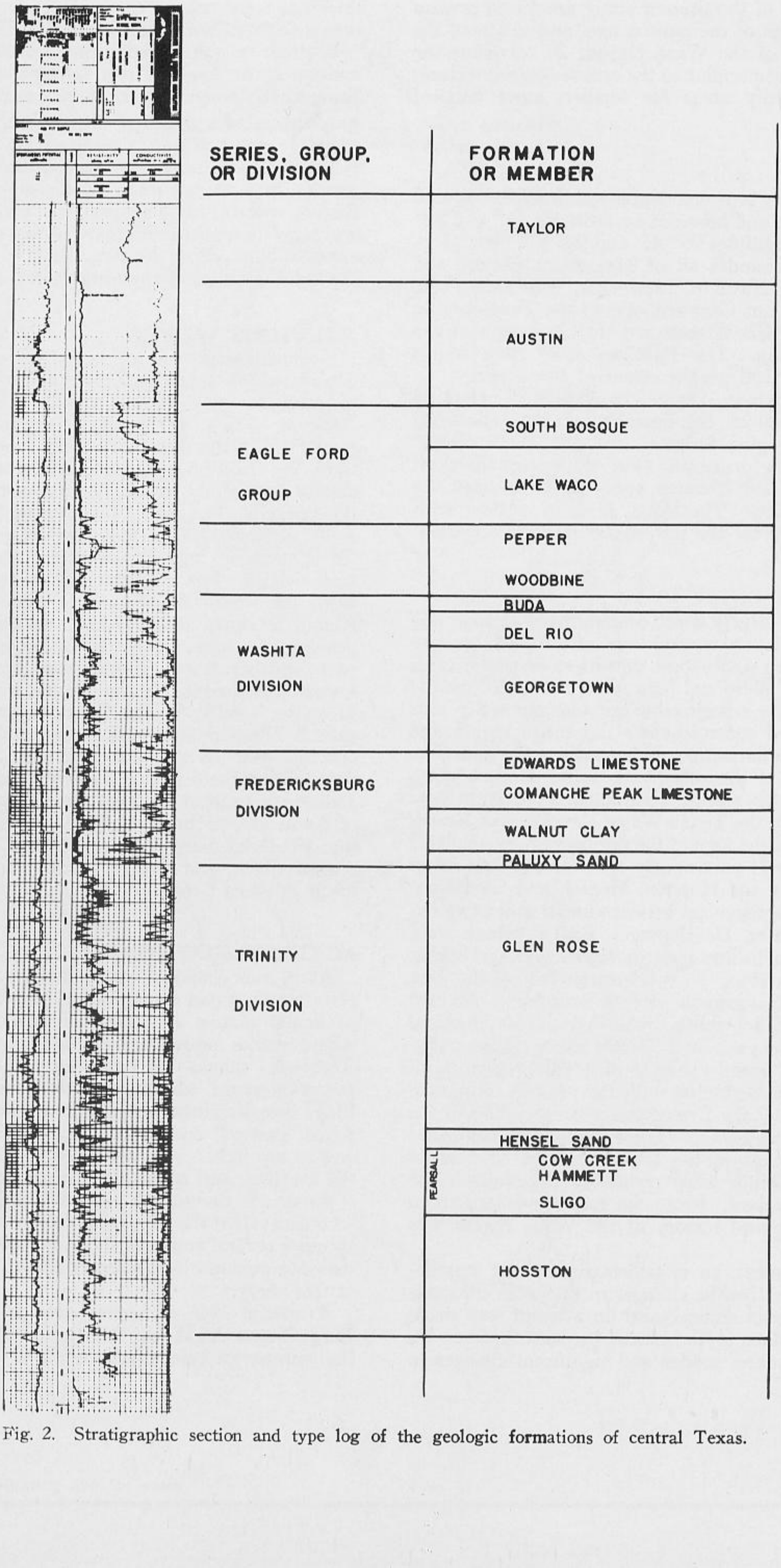
Geologic structure in the Waco region has been considered by numerous investigators, usually as incidental to stratigraphic studies (Holloway, 1961; Rodgers, 1967). Previous structural studies dealing directly with the structure of the Waco region include those by Goodson (1965) and Hudson (1972) based almost exclusively on alignments seen on high altitude photographs. Goodson (1965) includes a particularly good summary of previous investigations of central Texas faulting and a number of studies of possible fault origins. For a comprehensive review of previous work the reader is referred to that report. In 1975 Klemt, Perkins, and Alvarez reviewed the regional geology of central Texas and included substantial isopach and structural information, particularly on the lowest Cretaceous aquifer formations. A study by Mosteller (1970) of the Comanchean stratigraphy of central Texas related basin stratigraphy to that of the outcrop near Waco and was particularly useful in determining the direction of local structural trends. In addition a number of local stratigraphic studies were of direct use, particularly those of Jameson (1969) on the Fredericksburg Group, Sewald (1959) on the Austin Chalk, and Brown (1968) on the stratigraphy of the Washita Group.

ACKNOWLEDGMENTS

As in most regional works this present investigation rests largely upon the studies of others and, therefore, particular thanks are extended to those cited authors whose works represent the foundation of this study. Additional thanks are extended to David Durler and Joe Yelderman who accompanied me in the field, to Mary Sue Brigham who assisted with the drafting, to Joyce Shotwell and my mother who typed the thesis, and to my father who discussed the topic, helped with the drafting, and sponsored the project financially.

Particular thanks are extended to Dr. Robert Font, who supervised the thesis, critically read the manuscript through several stages of its development, and provided valuable guidance and support throughout the duration of this study.

A special note of appreciation is due Dr. Robert Berg, Texas A&M University, for his kind review of the manuscript before publication.



SERIES, GROUP, OR DIVISION		FORMATION OR MEMBER
		TAYLOR
		AUSTIN
EAGLE FORD GROUP		SOUTH BOSQUE
		LAKE WACO
		PEPPER
		WOODBINE
WASHITA DIVISION		BUDA
		DEL RIO
		GEORGETOWN
FREDERICKSBURG DIVISION		EDWARDS LIMESTONE
		COMANCHE PEAK LIMESTONE
		WALNUT CLAY
		PALUXY SAND
TRINITY DIVISION		GLEN ROSE
		HENSEL SAND
	PEARSALL	COW CREEK HAMMETT
		SLIGO
		HOSSTON

Fig. 2. Stratigraphic section and type log of the geologic formations of central Texas.

STRUCTURAL EVOLUTION

BASIC ASSUMPTIONS

In order to interpret isopach data in terms of structural evolution, certain basic assumptions are essential. These assumptions are: 1) Cretaceous deposition began upon a surface of low relief inclined gently from west to east, with gradients consistent with suspended-load streams. 2) Initial Cretaceous deposition leveled this earlier surface and created nearly flat floors for later deposits. 3) The active depositional surface at any one time remained essentially horizontal. While this is known to be in error, since sediment transport must always take place on a gradient, such gradients are believed to be small when compared to those caused by structural distortion.

Based on these assumptions the following interpretations are made: 1) Thickening and thinning, particularly in carbonate and fine clastic units, can be interpreted as reflecting structural disturbances. Sudden thickening is indicative of contemporaneous down warping or down faulting of the sedimentary floor. Sudden thinning is caused by uplift through flexure or faulting during deposition. 2) Abrupt loss of section is indicative of faulting if it occurs within a well or of erosion along a surface if it leads to the successive loss of beds along the line of any one section. 3) Thickening of individual units toward the basin is indicative of contemporaneous subsidence.

Thus, in this investigation isopach maps are interpreted as evidence of progressive structural position, and the upper horizon of each interval is assumed to be horizontal at some time before succeeding units were deposited. Sharp deviations in the thickness of mappable intervals are considered evidence of contemporaneous tectonic activity.

In the interest of clarity and simplicity, contouring decisions were conservative, and a fifty-foot contour interval was used so that minor irregularities would not confuse the regional trends. One-point anomalies were ignored, and contours were smoothed in order to emphasize regional characteristics. Thus, at some places contours may be in error when compared with data points.

PRE-CRETACEOUS SURFACE

The initial surface on which Cretaceous deposition occurred has been described by Boone (1968), Mosteller (1970), and Bain (1973) as a surface of moderate relief sloping generally east with stream gradients of approximately three feet per mile. The map (Fig. 3) included with this investigation shows the present configuration of that surface. This is clearly divided into three major structural areas: 1) The craton in the west with a dip of approximately 10 to 30 feet per mile, 2) a band of erratic slopes probably including faults extending into the pre-Cretaceous rocks, and 3) the East Texas basin in the east with dips of approximately 100 feet per mile.

No reconstruction was prepared of this surface because data density in the eastern half of the study area is insufficient to show surface features. However, the final pre-Cretaceous topography is indicated at least in part by the isopach of the Hosston Formation, the initial Cretaceous deposit (Fig. 4).

Hosston Deposition

The Hosston Formation in the western half of the study area consists of "calcite cemented sands and gravels interbedded locally with variegated shales" (Holloway, 1961, p. 16). To the east the Hosston Formation intertongues with sands and shales of more basinal facies of Travis Peak deposition. This intertonguing has been interpreted (Holloway, 1961, p. 19) as minor transgressions and regressions of the Cretaceous seas. However both lithology and basin-craton correlations suggest that such intertonguing may represent lateral migration of fluvial systems across a subsiding platform.

The Hosston isopach (Fig. 5) can be divided into two major divisions: A western half of more or less uniform thickness, and an eastern half consisting of a rapidly eastward thickening wedge of sediments. This isopach suggests that the depositional surface remained essentially horizontal during subsidence of the East Texas basin in Hosston time. While an implied assumption in the studies by Boone (1968) and Bain (1973) was that the early Cretaceous strand line was relatively close to Waco, the lithology of the Rodessa Formation of East Texas, a Travis Peak equivalent (Forgotson, 1957), suggests shallow lagoonal deposition (Fig. 6). Thus, the strandline may have been far to the east of Waco, and initial basal sand deposition could be of fluvial origin throughout the area of study. The lithology of the lowermost Hosston Formation throughout the Waco region is strongly suggestive of fluvial deposition because of its coarse grain size and upward decrease in grain size.

Five isopach anomalies occur in the Hosston Formation (Fig. 4). From north to south these are: The Meridian valley, McGregor high, Hamilton valley (Boone, 1968, p. 12), Belton high (Brown, 1968, p. 4), and Rosebud basin.

Both the Meridian and Hamilton valleys are incised across the interior zone of the Ouachita Fold Belt. East of the McGregor high, a remnant divide of the Wichita Paleoplain, the Hosston Formation thickens rapidly into the Rosebud basin suggesting rapid subsidence in that area during Hosston deposition. The regional depositional strike of the Hosston Formation is N22°E with an eastward thickening of 10 feet per mile east of the McGregor high to 30 feet per mile at the margin of the Rosebud basin. If the effect of eastward thickening is subtracted from the Hosston isopach several residual thickness variations remain. These thickness variations are evident on the residual isopach where values indicate the difference between true values and values expected due to eastward thickening (i.e. positive values are local thick spots, negative values are local thins). The residual isopach of the Hosston Formation indicates a thinning in the vicinity of Waco and along the Ouachita Fold Belt and a thickening of

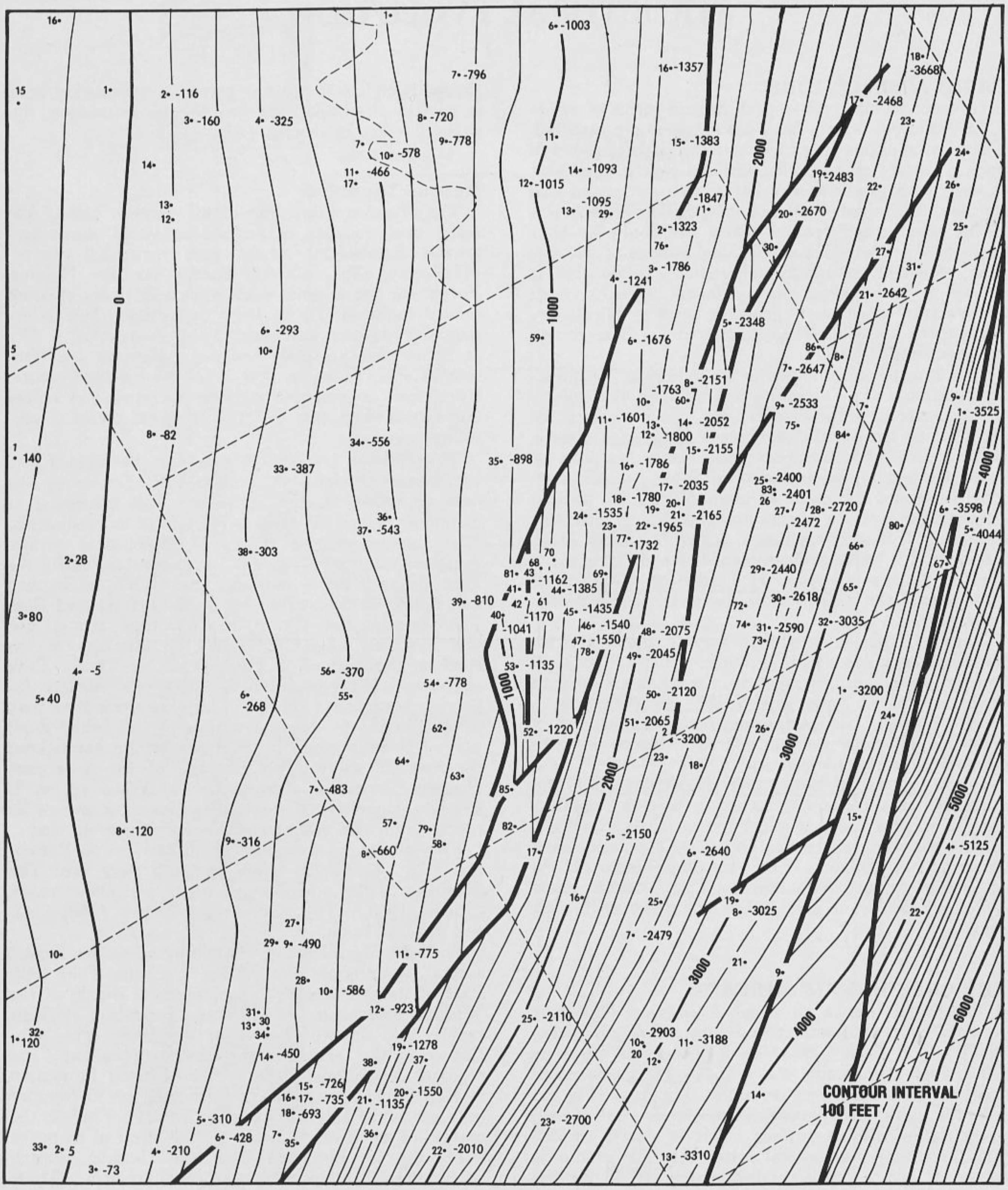


Fig. 3. Altitude of the base of the Cretaceous section. *Modified from* Klemt, Perkins, and Alvarez, 1975.

wedges to the east and west (Fig. 5). These values suggest regional uplift at Waco and along the Fold Belt, and subsidence both east and west of this zone during Hosston deposition. However, these values may also be interpreted in terms of general subsidence in a region characterized by a low upland along the Ouachita Fold Belt transected by several valleys and later buried by Hosston sediments. Thus the peculiar

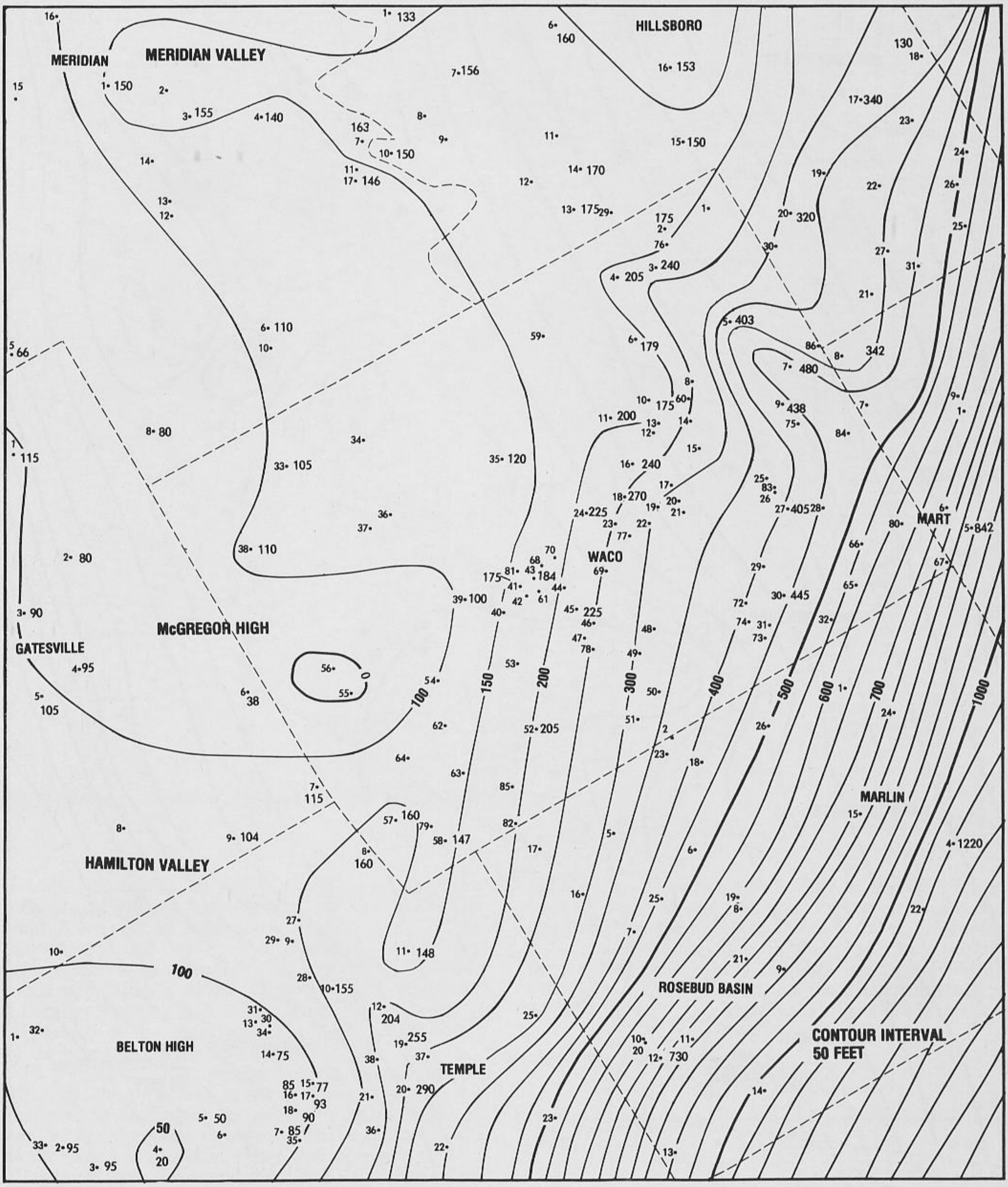


Fig. 4. Isopach of the Hosston Formation.

residual isopach pattern may reflect initial topography rather than disturbance along the Fold Belt. The eastward thickening wedge, however, can be explained only by subsidence during deposition. If the Hamilton valley and Meridian valley extended across the Ouachita Fold Belt and the associated anomalies are a result of valley incision in initial topography, then either subsidence in the east or uplift along the Balcones fault occurred after

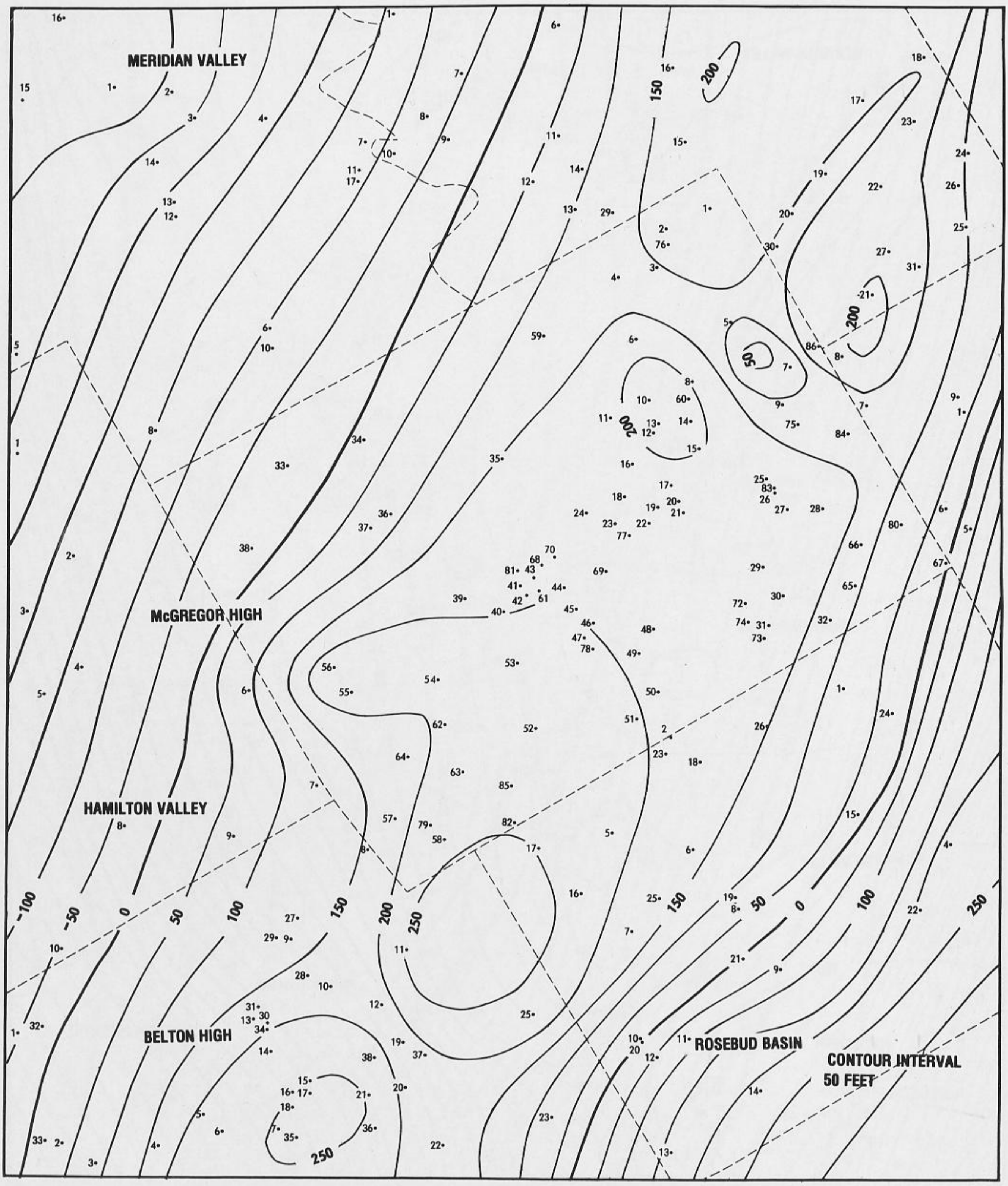


Fig. 5. Residuals of the Hosston isopach.

the Wichita Paleoplain developed and during Hosston deposition. This is evident since incised valleys are younger geomorphic features than a mature paleoplain.

The structural uniformity of the dip section in southern McLennan County suggests that the Hosston Formation may best be described in terms of depositional wedges (Fig. 7) and that the depositional history may be divided into three stages: 1) Formation of the

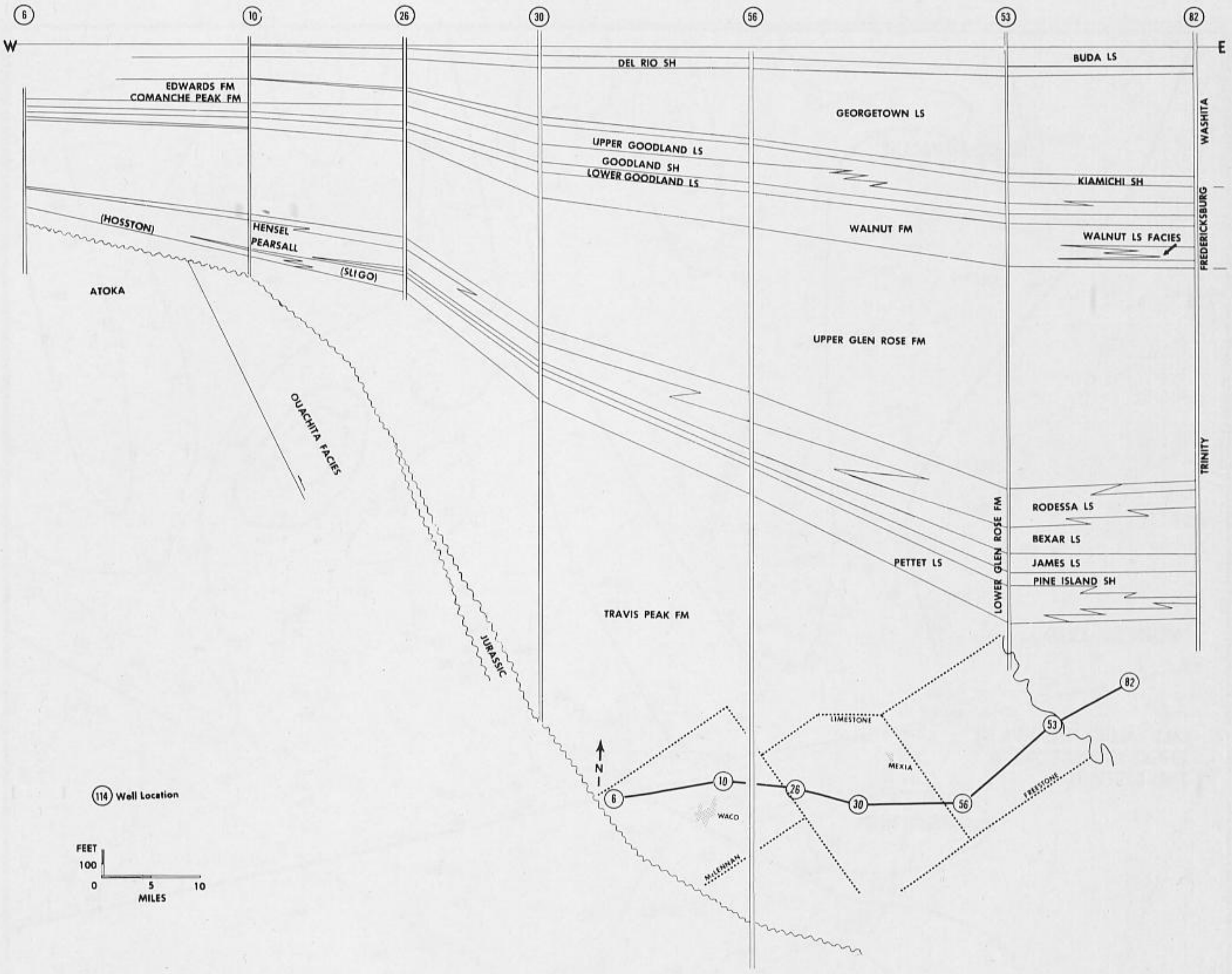


Fig. 6. Regional correlation cross section. *From* Mosteller, 1970, p. 12.

Wichita Paleoplain, 2) rapid subsidence in the East Texas basin with resultant deposition along the Ouachita Fold Belt, and 3) subsequent transgression of Cretaceous seas and deposition of marine sediments over an irregular subaerial topography. The residual surface based upon such a model (Fig. 8) shows additional anomalies which include a thin area slightly south of the mouth of the Meridian valley and a thick region in the northeast corner of the area.

In relation to the present pre-Cretaceous surface (Fig. 3), the thick area to the northeast appears to be the result of faulting in the southeast along the margin and within the Rosebud basin. The thin area south of the mouth of Meridian valley may also be a product of faulting, but the small magnitude of the anomaly makes this unclear.

PEARSALL-SLIGO DEPOSITION

The Sligo Limestone directly overlies the Hosston Sandstone and represents the first readily identified stage of marine deposition. The Sligo Limestone is followed by deposition of the marine Pearsall shales and limestones. The Pearsall Formation is divided into two lithologic members, the Cow Creek Limestone, a "cream to tan, oolitic to finely sucrosic, slightly porous limestone which becomes sandy westward" (Holloway, 1961, p. 16), and the Hammet Shale, a "gray shale with some cream, slightly oolitic crystalline

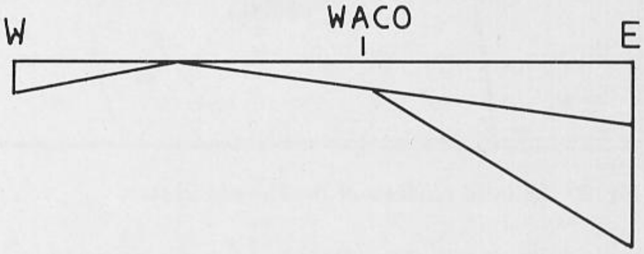


Fig. 7. Diagrammatic west-to-east cross section of the Hosston Formation. The Hosston may be considered a series of three geometric wedges.

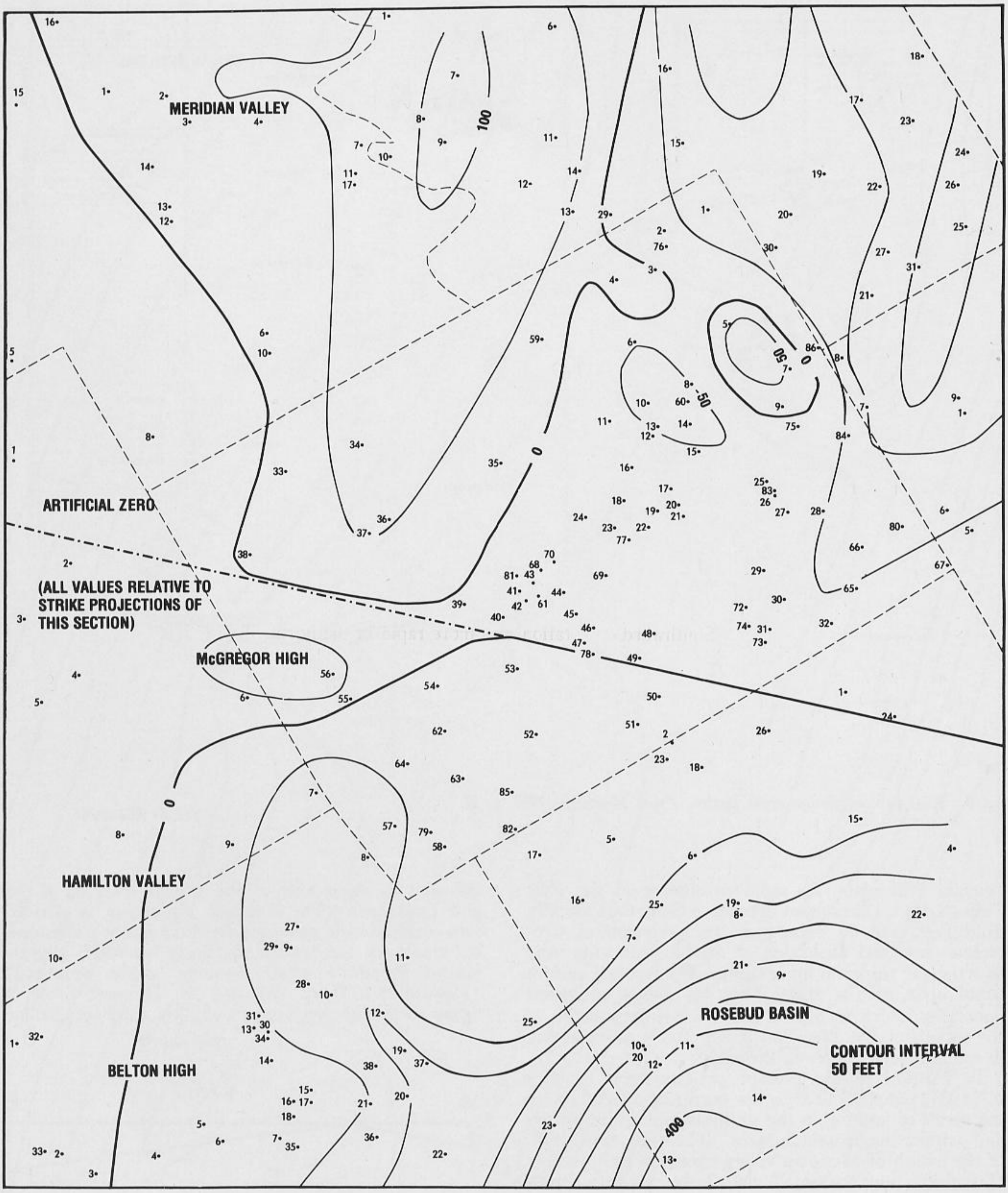


Fig. 8. Adjusted residuals of the Hosston isopach.

limestone beds which becomes sandy westward" (Holloway, 1961, p. 16). During Pearsall time delivery of coarse clastics slowed, indicating marine transgression, strandline retreat westward, and possibly structural quiescence in the source area.

The isopach map of the Pearsall deposits (Fig. 9) is readily divided into two major areas: 1) A western segment west of the Balcones fault zone that is essenti-

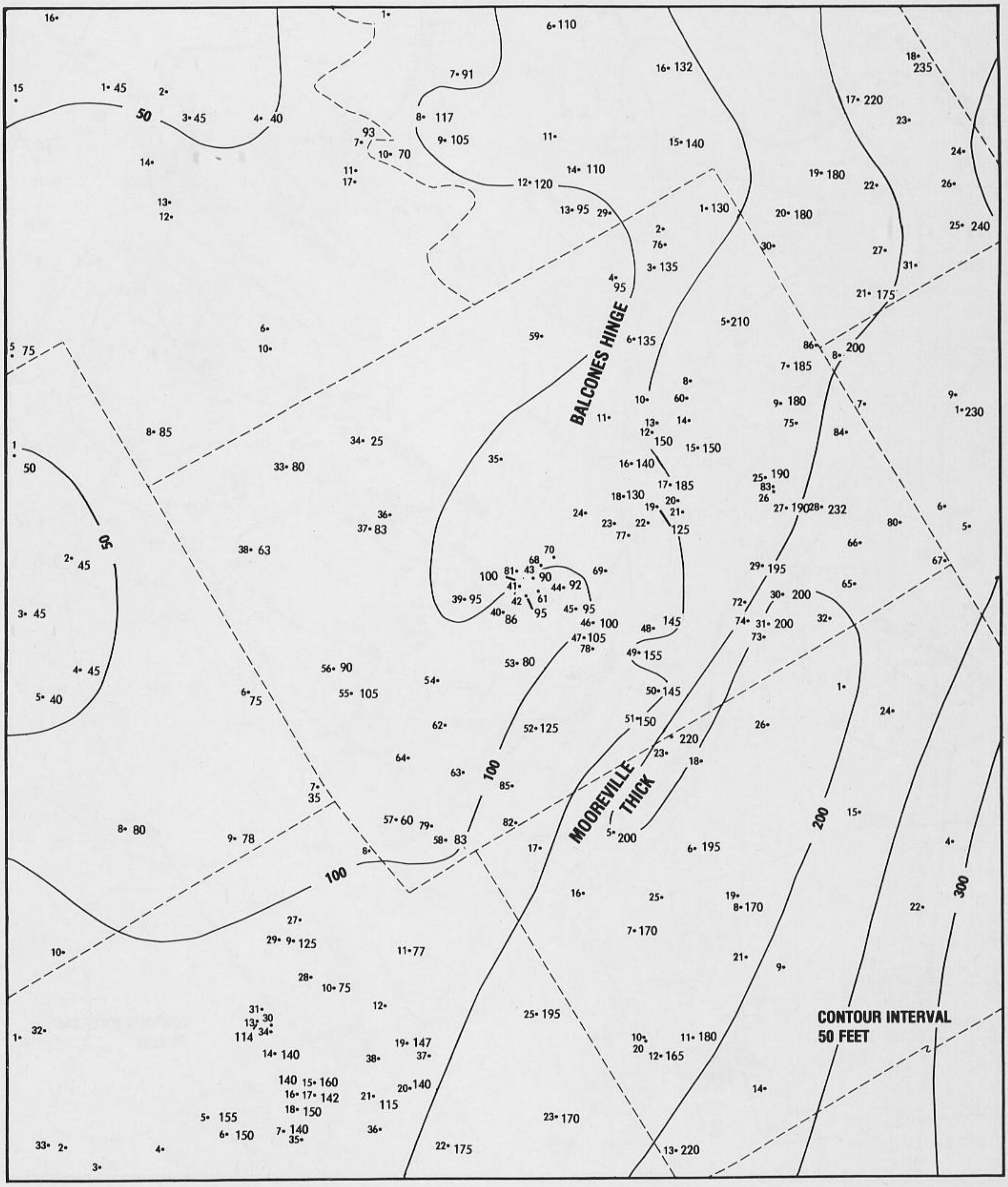


Fig. 9. Isopach of the Pearsall Formation.

ally of uniform thickness, and 2) a gently thickening eastern wedge from the Balcones fault zone to the eastern margin of the study area.

Superimposed upon the regional pattern are three major anomalies: 1) The Balcones hinge, an area of abrupt thickening, 2) the Mooreville thick, a linear feature of sudden thickening, and 3) The Lott thin, a northeast-southwest trending isopach feature parallel

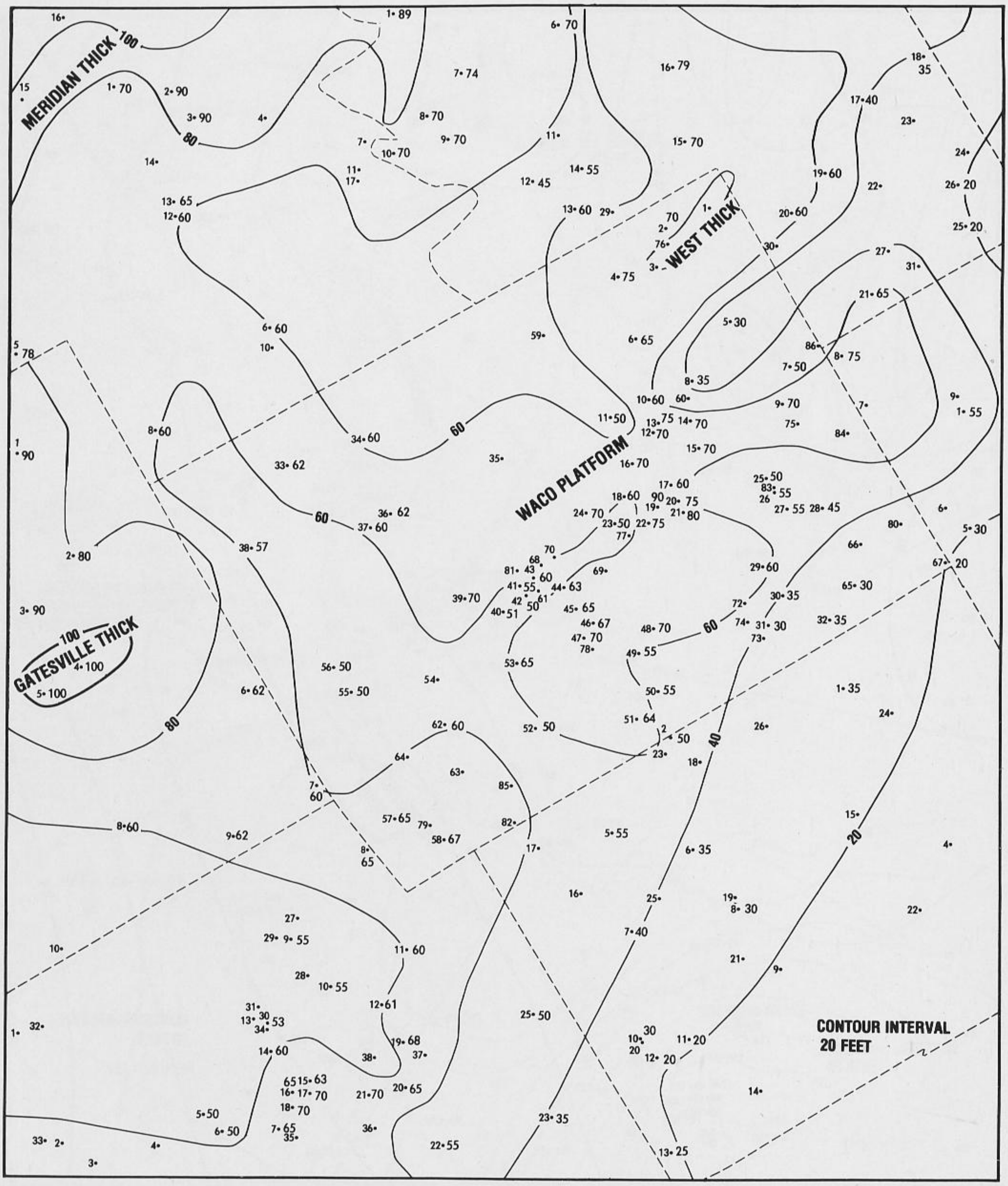


Fig. 10. Isopach of the Hensel Sand.

to the Balcones hinge. The Balcones hinge coincides with the zone of major thickening in the Hosston Formation, but is less well defined north and south of McLennan County. The thickening and latter compaction is at least partly the effect of Hosston structure rather than structural depression during Pearsall time of the pre-Cretaceous surface in the East Texas basin. The Mooreville thick and the Lott thin strongly sug-

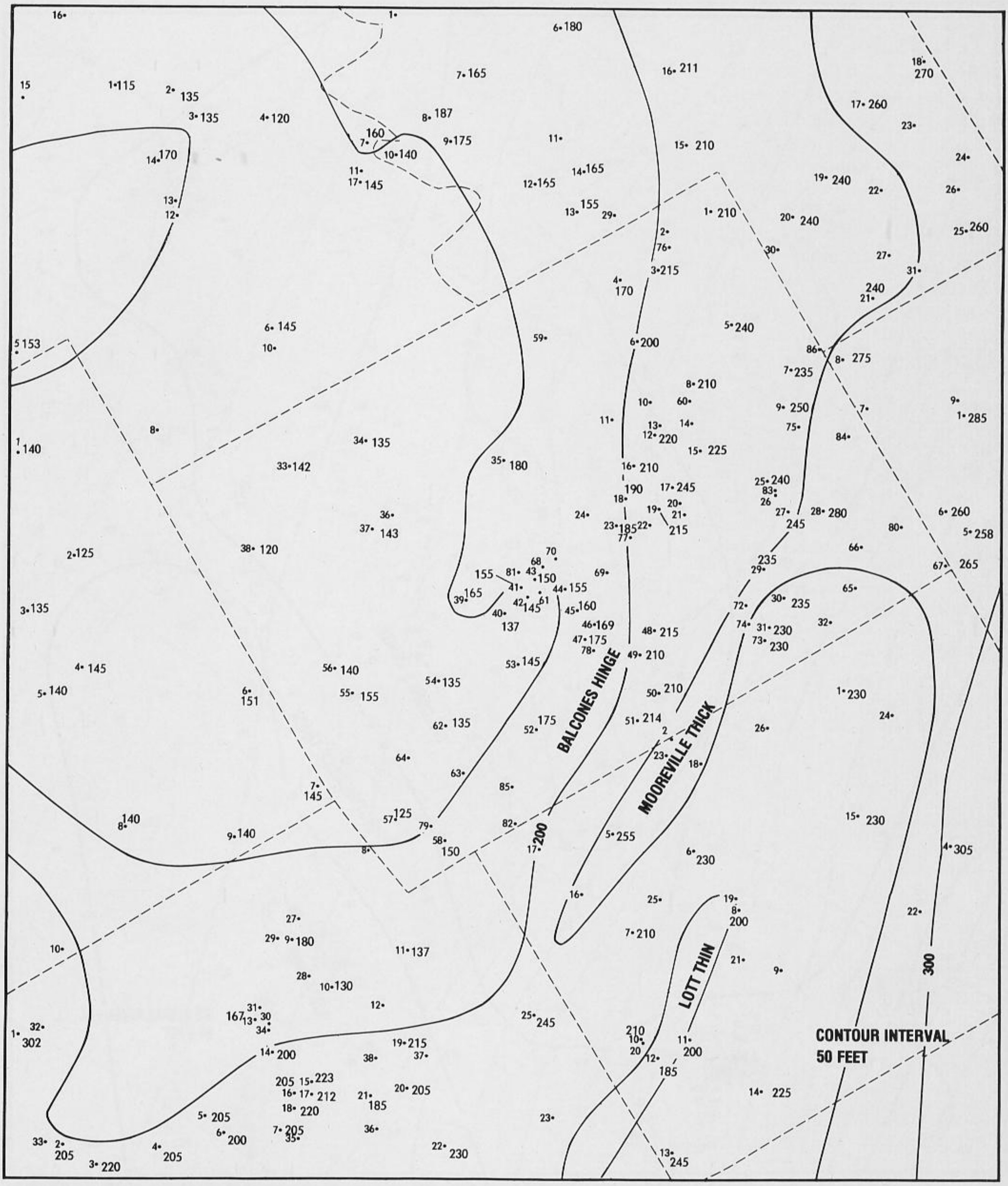


Fig. 11. Isopach from the top of the Hensel Formation to the top of the Hosston Formation.

gest active faulting during deposition of Pearsall sediments. The Mooreville thick is thus the product of nondeposition or erosion on an uplifted block. Evidence for such fault structure is largely in the form of the linear feature and orientation of these anomalies. Well log correlation within this zone and within the Pearsall Formation, particularly along the Balcones fault zone, is not adequate to define the actual nature or structural

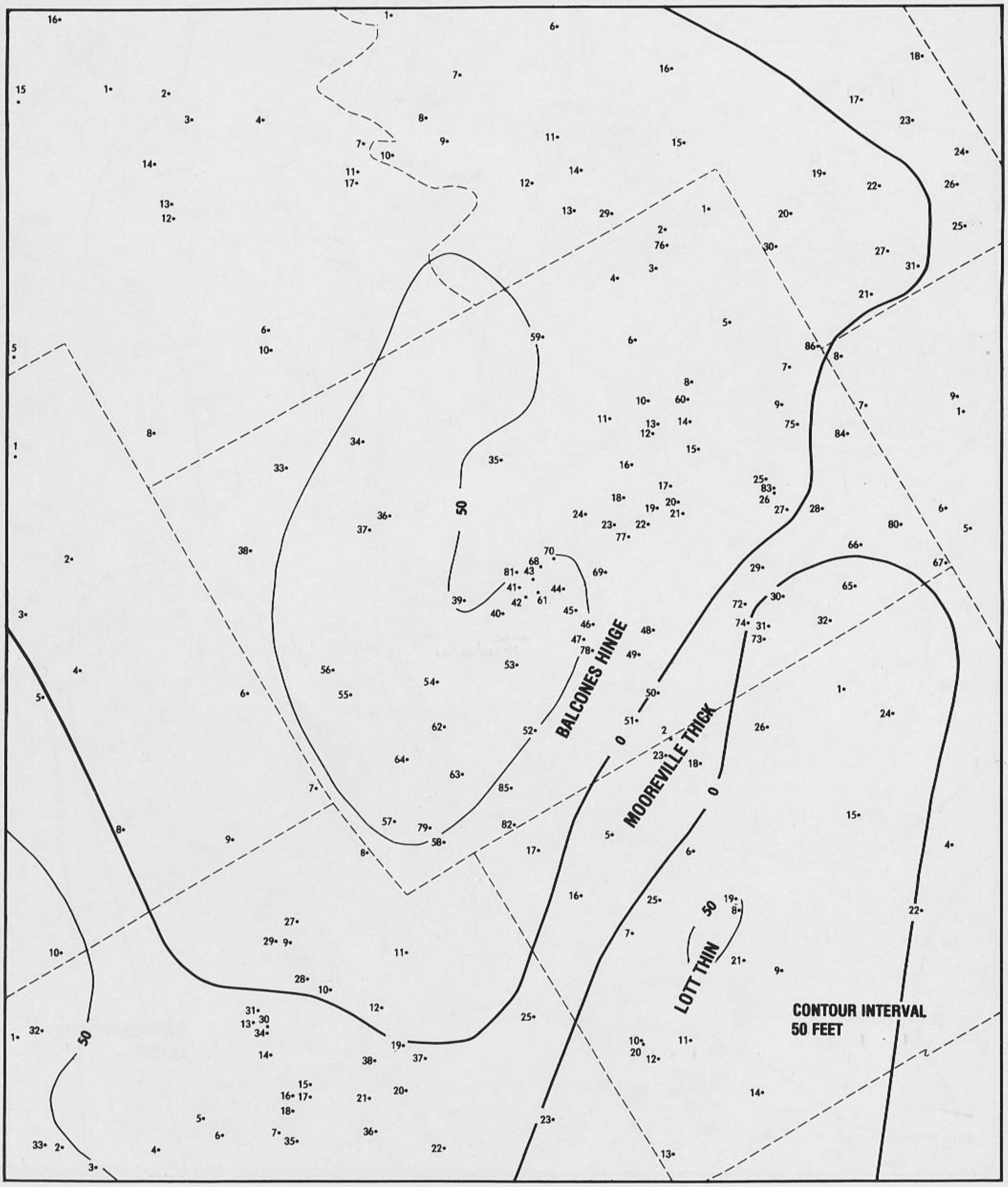


Fig. 12. Residual isopach from the top of the Hensel Formation to the top of the Hosston Formation.

origin of the features.

Although the isopach of the overlying Hensel Formation (Fig. 10) lacks readily obvious features in the areas of the Mooreville thick and the Lott thin, when the Hensel and Pearsall isopachs are combined these two features are even more pronounced (Fig. 11). The Balcones hinge disappears as a conspicuous anomaly when the effect of eastward thickening is subtracted

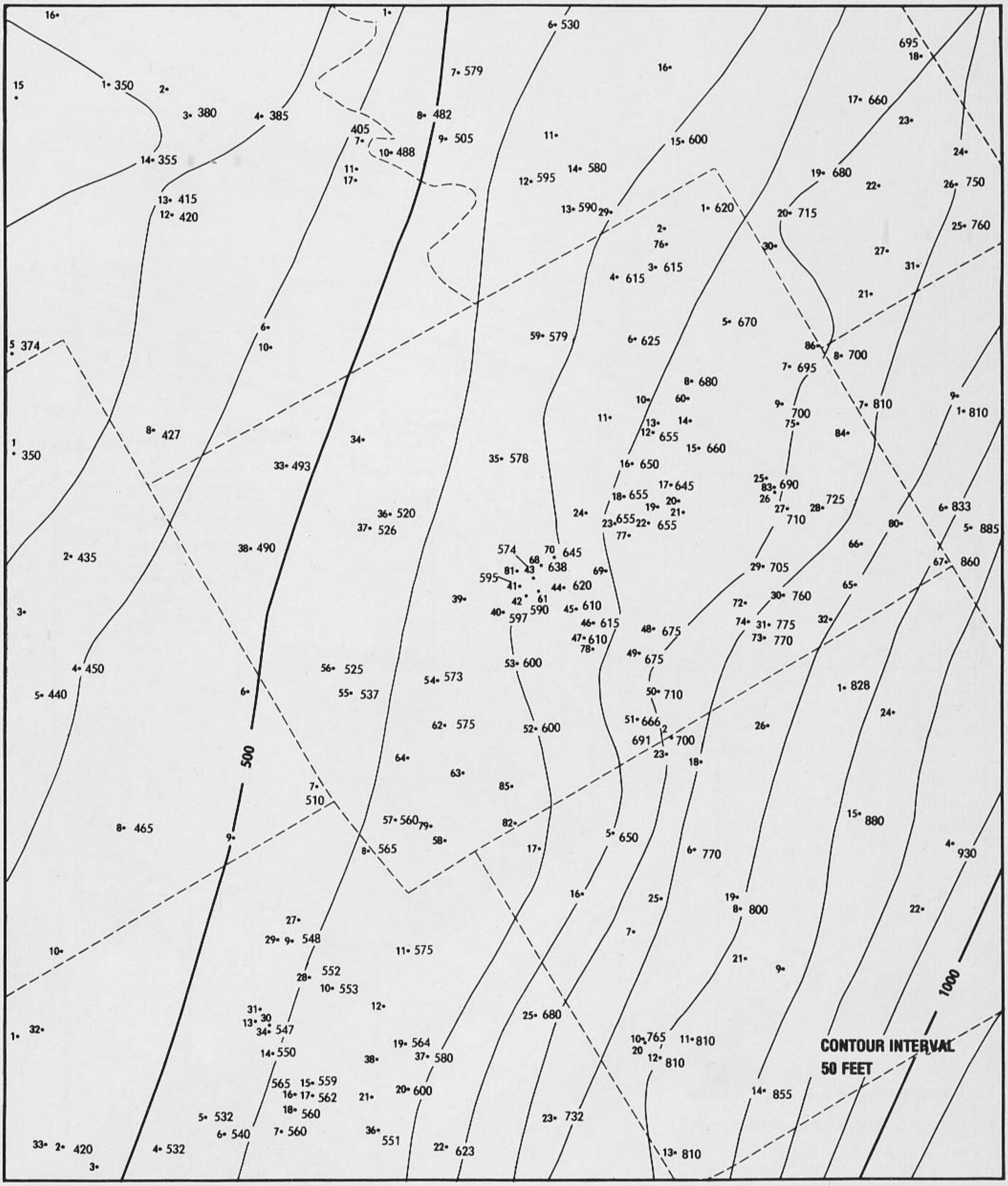


Fig. 13. Isopach of the Glen Rose Formation.

on the isopach residual (Fig. 12). However the two probable fault anomalies are still conspicuous, as are a regional thinning west and north of Waco and a thickening in the far southwest.

Both the lithology of the Hensel Formation and the geometry of the depositional body suggest that Pearsall-Hensel deposition took place during a time of general tectonic quiescence, and that the margin of marine

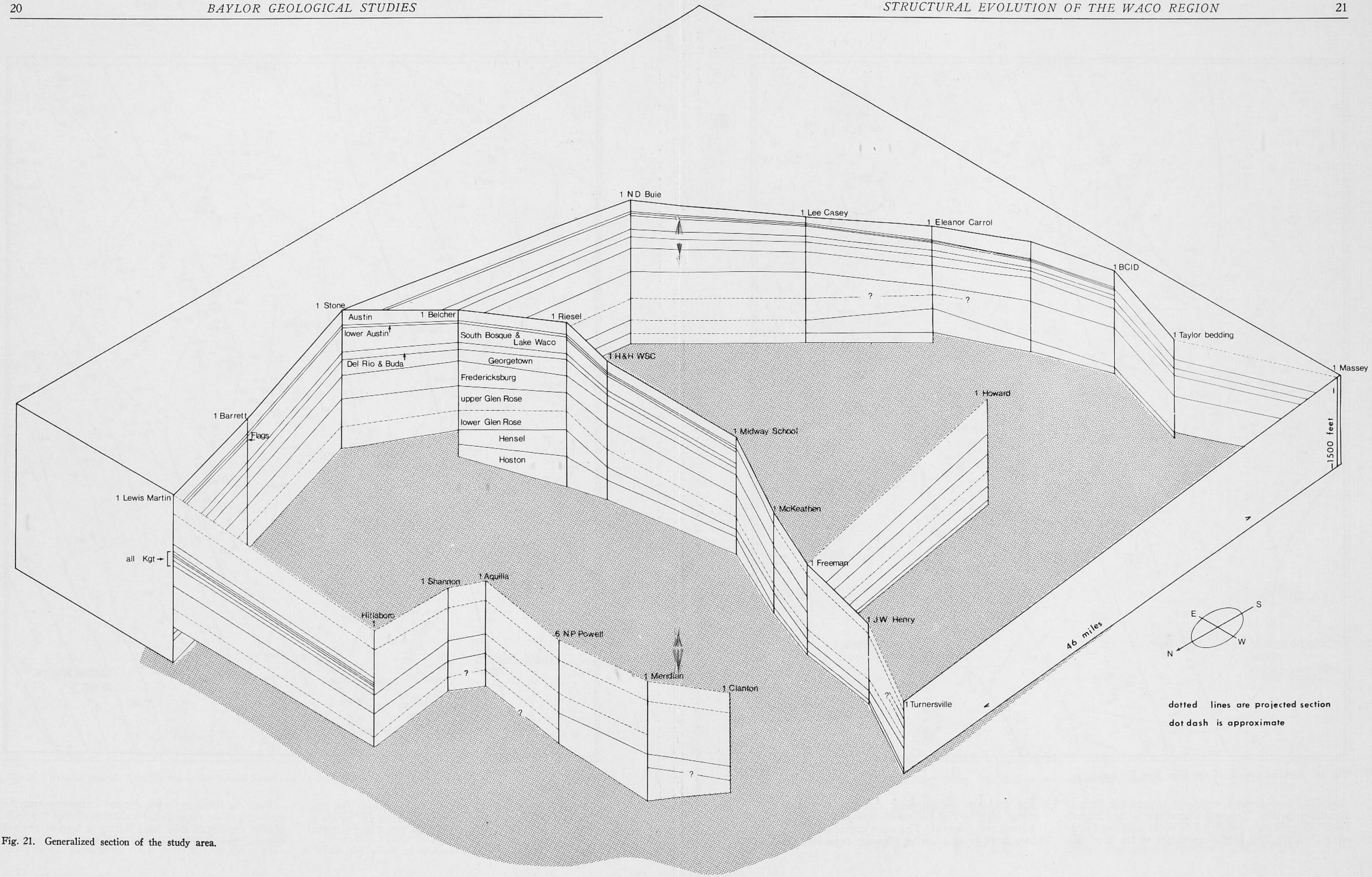


Fig. 21. Generalized section of the study area.

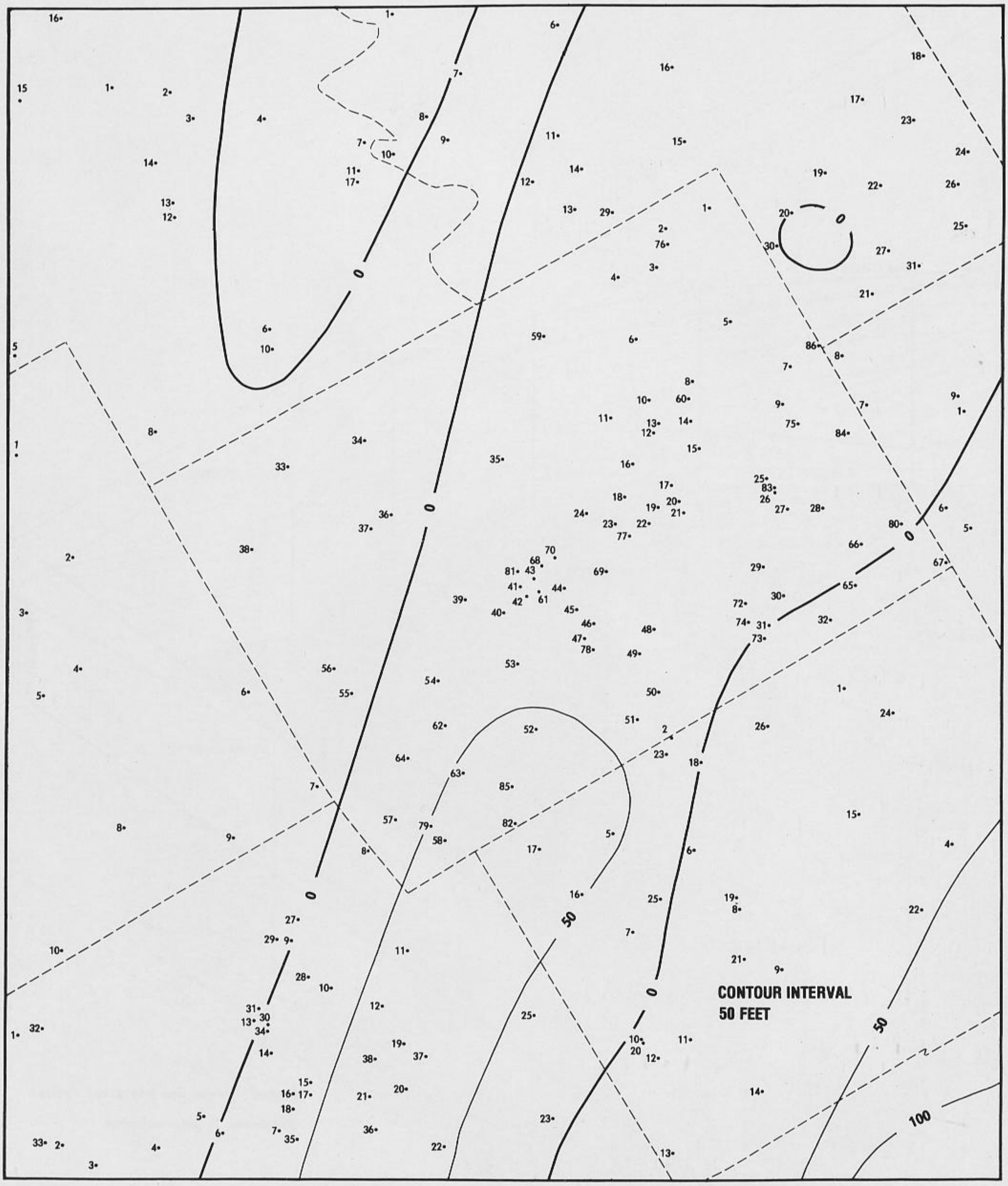


Fig. 14. Residual isopach of the Glen Rose Formation.

deposition transgressed westward beyond the limit of this investigation. This was also a time of local adjustment along faults, possible gentle uplift west and northwest of Waco, and gentle subsidence to the southeast. The thickness and lithologic character of Hensel sediments suggest that deposition was rapid, and tectonic activity was minimal. The same degree of activity may have been present during Hosston deposition, but the

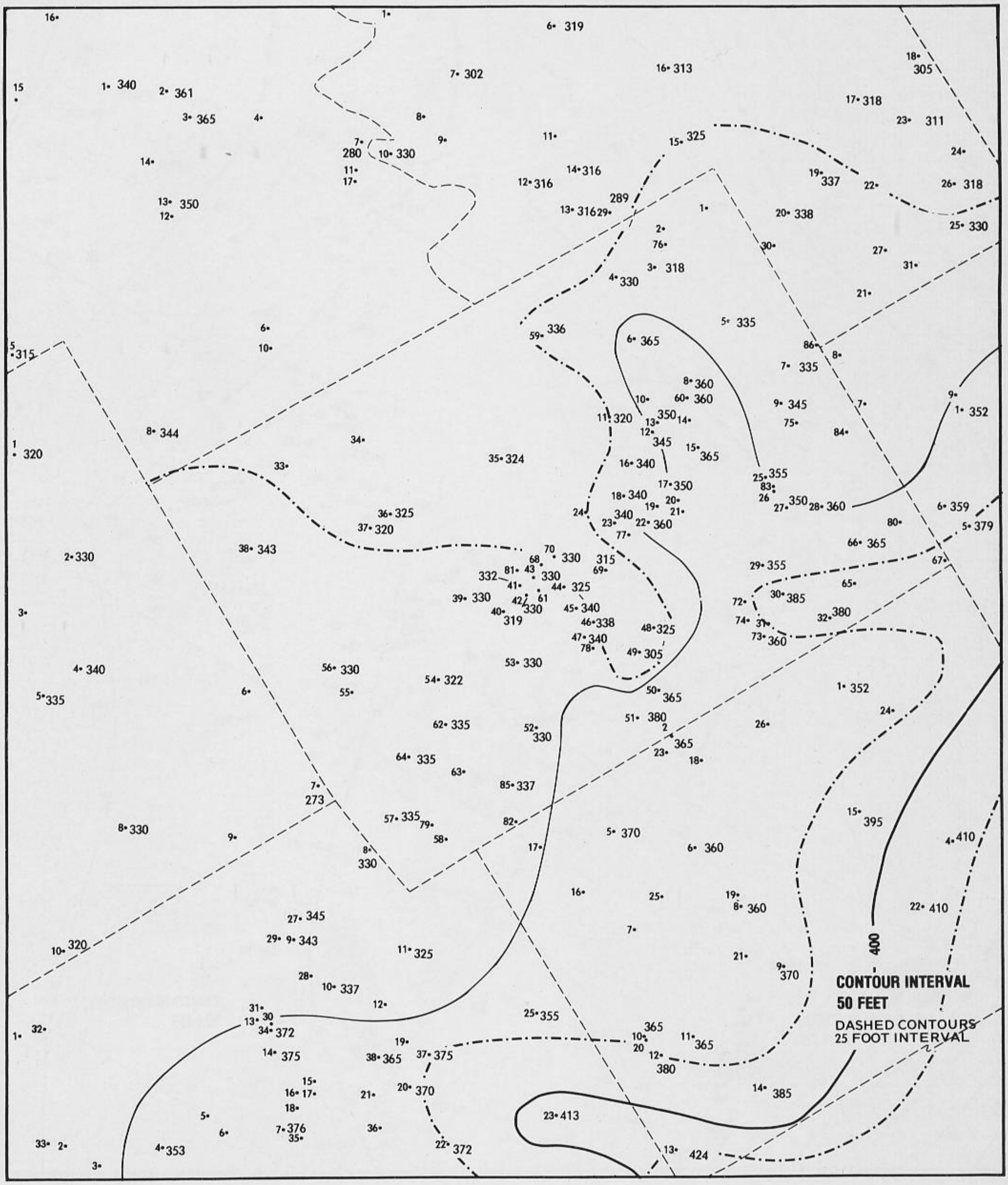


Fig. 15. Isopach of the Fredericksburg Group. Dotted lines are supplemental contours.

unit thickness and regional thickening masked local changes.

HENSEL DEPOSITION

The Hensel Formation thickens toward the source area and thins eastward toward the marine basin. Hensel deposition represents a renewed activity in the

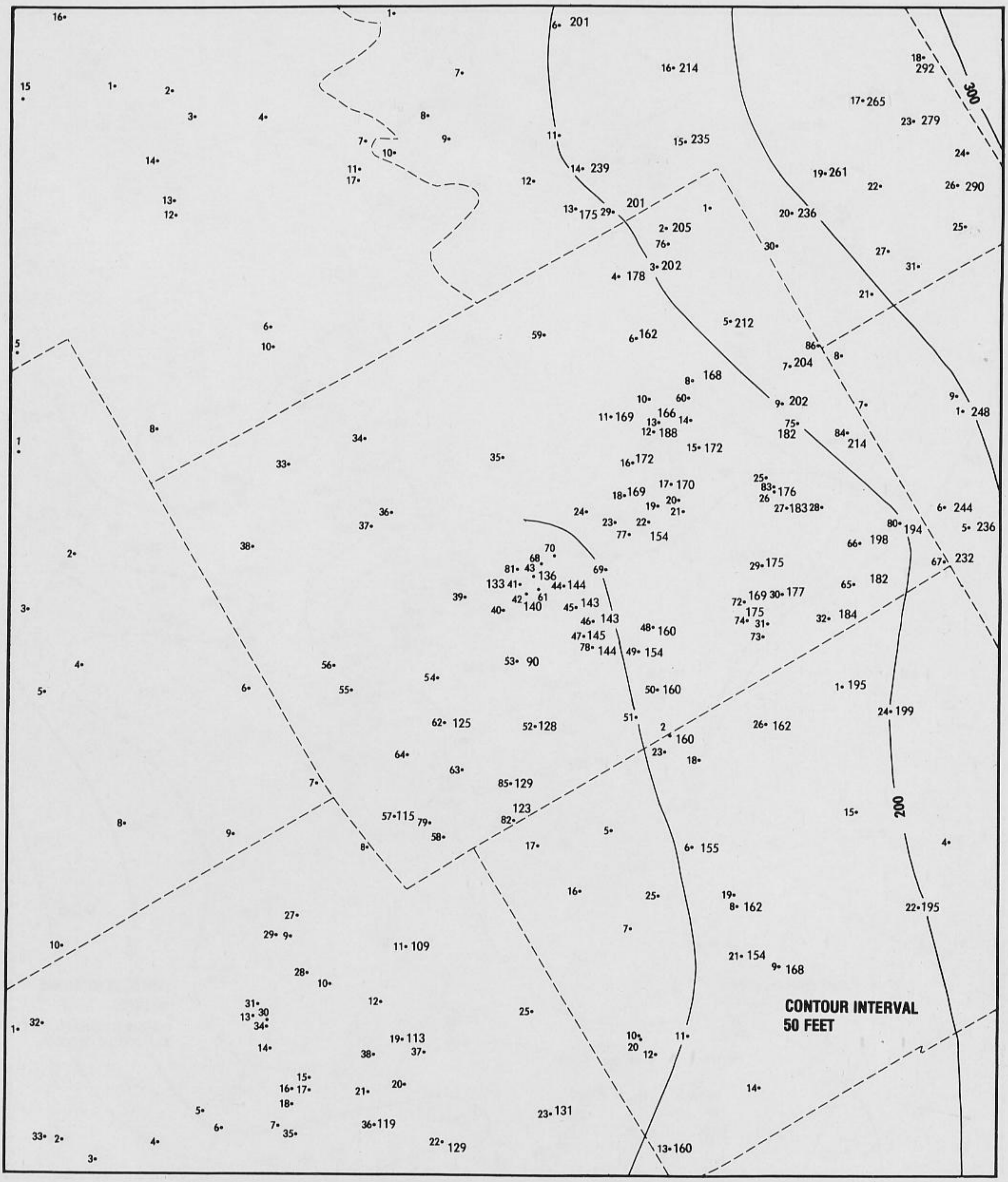


Fig. 16. Isopach from the top of the Georgetown Formation to the top of the Edwards Formation.

source area. Both the isopach character and the lithology of the Hensel Formation suggest strandline deposition. Because of this, the eastward thinning is probably not significant. Further, it may represent relatively fast deposition over an essentially horizontal surface. Hence the Hensel Sand is normally considered a facies of the Pearsall Formation, and the two are here considered as a unit. The Hensel isopach (Fig. 10)

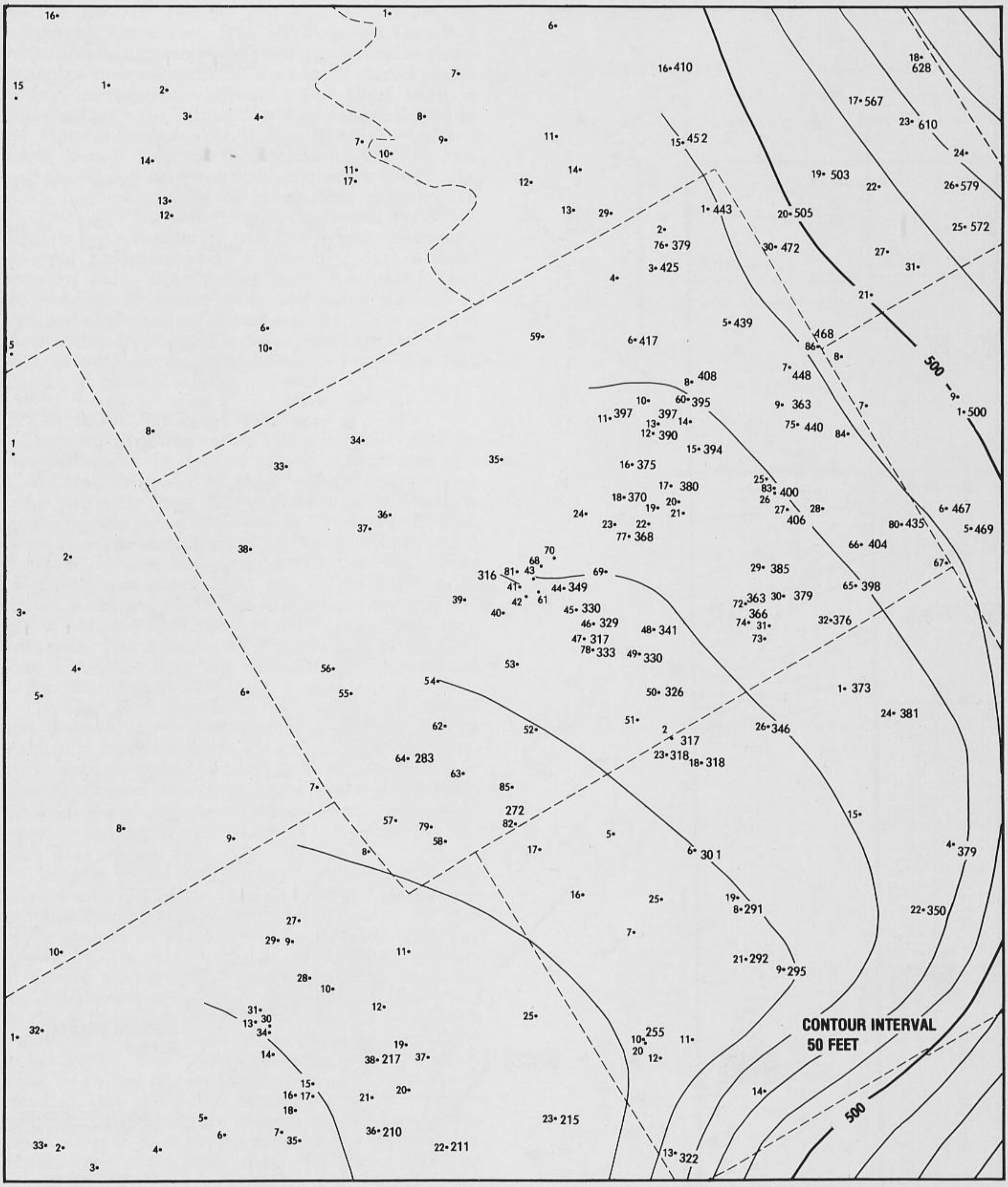


Fig. 17. Isopach from the base of the Austin Formation to the top of the Georgetown Formation. Dotted lines are supplemental contours.

reveals four anomalies: 1) The Meridian thick directly over the Meridian valley mapped in the Hosston isopach; 2) the West thick, near the town of West; 3) the Waco platform, a broad area of constant thickness; and 4) the Gatesville thick west of the Hosston-McGregor high.

Since the Hensel Formation is a thin unit, depositional variations would be more conspicuous than in

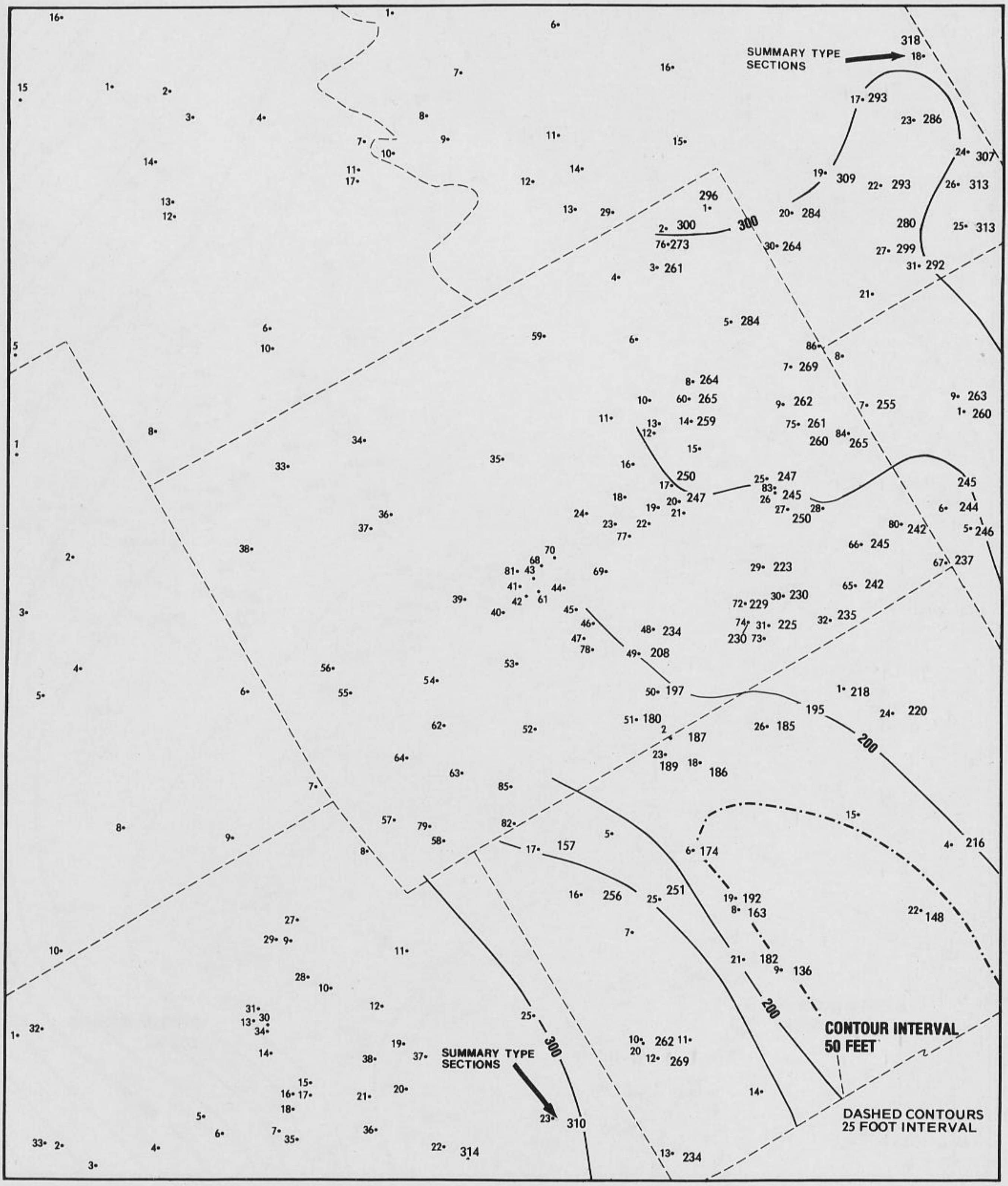


Fig. 18. Isopach of the Austin Formation.

thicker units. Therefore, these anomalies may represent different depositional environments and not the effect of tectonic activity. Nevertheless, the configuration of the Hensel Formation may reflect pre-Hensel terrain and may suggest tectonic activity in areas of rapid thickness change.

Note particularly that the anomalies do not follow the suggested topography of the pre-Cretaceous surface, evidence that by Hensel time most of the original topography was buried. The Meridian and Gatesville thicks probably represent different depositional environments but their proximity to the edge of control makes further interpretation difficult. The West thick is coincident with the incised Meridian valley mapped in the Hosston isopach, but it also directly overlies a major down-to-the-coast Balcones fault. The thin area to the southeast may overlie an upthrown block. The Waco platform consists of broad lobes extending in all directions. The uniformity of the Hensel Formation suggests deposition during a time of tectonic quiescence, or rapid deposition along a strandline over a short period of time. The thinning in the southeast implies the presence of deeper water and hence the end of transport of the coarser Hensel deposits. The anomalies are probably depositional in origin, but their coincidence with known basement structure also suggests that they may be of tectonic origin.

GLEN ROSE DEPOSITION

The Glen Rose Formation conformably overlies the Hosston sands. It consists largely of limestone and is the first indication of major marine transgression across the study area. It grades from sandy limestone on the west to dense limestone and shale on the east. Since limestone deposition is usually slower than that of coarse clastics, the deposition of the Glen Rose Limestone was slower than that of the Hosston or Hensel sands and, therefore, represents more time per foot of sediment than previous units. It is also a very thick unit. Therefore, the time represented by the Glen Rose Limestone is greater than the time represented by the other isopach units.

The Glen Rose Formation was mapped as a single unit because no easily recognizable marker horizon within the section extends completely across the area. This large mapped interval tends to mask minor intermittent local movements and changes in thickness, the evidence of structural disturbance or depositional lobes. Even so, several features are visible on the Glen Rose isopach (Fig. 13).

The map of the Glen Rose Formation is readily divided into two major parts as follows: An area of gentle thickening from the western margin of the map to the latitude of Waco, and a more rapid thickening eastward to the eastern margin of the region. The line of flexure separating the gentle thickening from the rapid thickening is displaced slightly east of Waco and to the axis of thickening in the Hosston Formation. Again the effect of eastward wedging was subtracted to emphasize minor local anomalies. The residuals (Fig. 14) show few anomalies other than a northeast-trending thin along the southern axis of Balcones faulting. In general, the margin of the East Texas basin seems to have prograded eastward almost to the eastern edge of the study area. The line of inflection is indicated by the zero contour. This suggests that the shape of the Glen Rose Formation approximates a geometric wedge. Any tectonic movement during Glen Rose deposition was confined to areas east of the study area, perhaps along the Mexia-Luling fault zone.

FREDERICKSBURG DEPOSITION

The Fredericksburg Group consists of four forma-

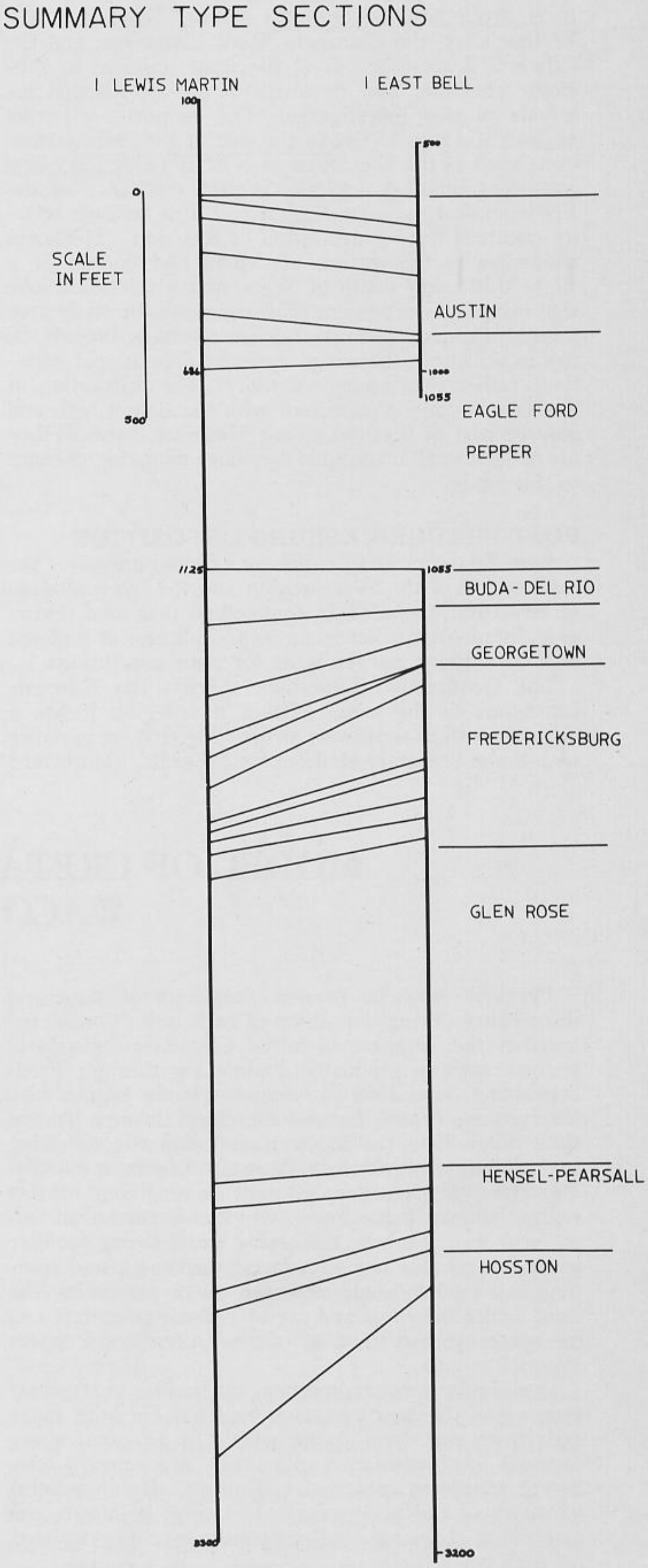


Fig. 19. Summary type sections.

tions, from base to top: the Paluxy Sandstone, the Walnut Clay, the Comanche Peak Limestone, and the Edwards Limestone. It is the most uniform in lithologic character and thickness of all the mapped intervals of this investigation. The sedimentary strike of N45°E (Fig. 15) is to the east of the older formations such as the Glen Rose at N19°E (Fig. 13). The consistent lithology and the isopach constancy of the Fredericksburg section suggest that little tectonic activity occurred during deposition of this unit. Thickness anomalies in the section are small and consist of a slight thickening north of Waco and a thickened lobe that extends from the southeast corner of the study area toward Temple. Because neither anomaly exceeds 50 feet in thickness, they may represent depositional variations rather than tectonic activity. The orientation of the Temple lobe is consistent with the Belton high and may be part of that structure. However, because they are of such small magnitude they have minor significance to this study.

POST-FREDERICKSBURG DEPOSITION

Post-Fredericksburg rocks are exposed only over the eastern half of the Waco region and the interpretation of structural evolution is confined to that area. However, lithologic character can be an indicator of regional tectonic activity and the basis for some conclusions.

The Georgetown Limestone overlies the Edwards Limestone in the area. Within this region it has a general north to northwest strike (Fig. 16), at variance with the sedimentary strikes of older units. Southward thinning of the Georgetown Limestone takes place largely as a result of thinning of shale units (Brown, 1968, p. 24) which suggests a northward source. The greater abundance of coarser clastics to the north also suggests a source far to the north of the Waco region. The northwest depositional strike suggests that uplift occurred in the south near the Belton high during Georgetown deposition.

Overlying the Georgetown Formation is a thicker shale section consisting of Del Rio, Woodbine, Pepper Formations and the Eagle Ford Group. These are grouped together in one isopach map (Fig. 17). These shale units appear to be more or less uniform over the study area. Again the units thin toward the southeast corner. Isopach variations suggest uplift to the north and rapid subsidence to the south and southeast of the study area, perhaps in conjunction with renewed activity along fault planes.

The Del Rio-Eagle Ford shale section is overlain by the Austin Chalk Formation, a remarkably uniform unit consisting largely of chalk and thin marl beds. Isopach relationships in the Austin Chalk (Fig. 18) indicate local uplift in northern Falls County where the chalk thins to 175 feet by loss of uppermost beds. The Austin Chalk thickens northward to 300 feet in southern Hill County. Generally, individual beds in the Austin Chalk are of uniform thickness and can be traced along strike over the entire region. However, correlations of lower Austin Chalk units between widely separated wells (Fig. 19) suggest that sedimentation was more rapid in the north.

MODEL OF CRETACEOUS DEPOSITION, WACO REGION

Previous isopachs present snapshots of structural disturbance during deposition of each unit. Considered together they suggest an initial Cretaceous episode of tectonic activity gradually diminishing through Fredericksburg deposition. A second episode begins with Georgetown deposition and increases through Austin time. Regionally, the activity is reflected as a subsiding surface with the gulfward edge subsiding most rapidly. Therefore, a given isopach will be the sum of this regional thickening common and consistent on all isopachs as well as a local thickening and thinning peculiar to that particular isopach. Local thickening and thinning can further be divided into minor anomalies, the local thicks and thins and major isopach geometry, i.e., the southeastward thinning of the Eagle Ford-Pepper-Woodbine units.

In a similar manner, mechanisms leading to structual warping of the area consist of regional (in both space and time) and local components. In an area where regional mechanisms are dominant, one expects consistent trends in consecutive isopachs. If the general geometry of regional isopach thickening is known, the magnitude of the regional component may be calculated for each isopach.

For the Waco region it is assumed that the regional component of each isopach interval can be closely approximated as the sum of two wedges (Fig. 20). This intraformation model assumes that all deposition is a result of subsidence, and that all subsidence is from a plane with a loosely-fixed hinge point. The top wedge is a constant on all intervals, while the bottom wedge (c and d, Fig. 20) varies in thickness in relation to r,

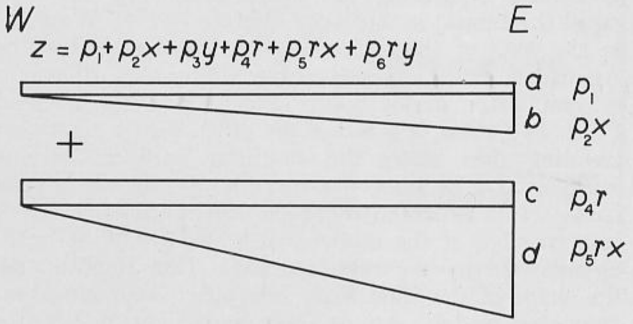


Fig. 20. Diagrammatic west-to-east cross section of the data explained by the intraformation model. The total thickness is the sum of a constant wedge and a wedge defined by the isopach parameter. The greater the isopach parameter, the greater will be the total thickness.

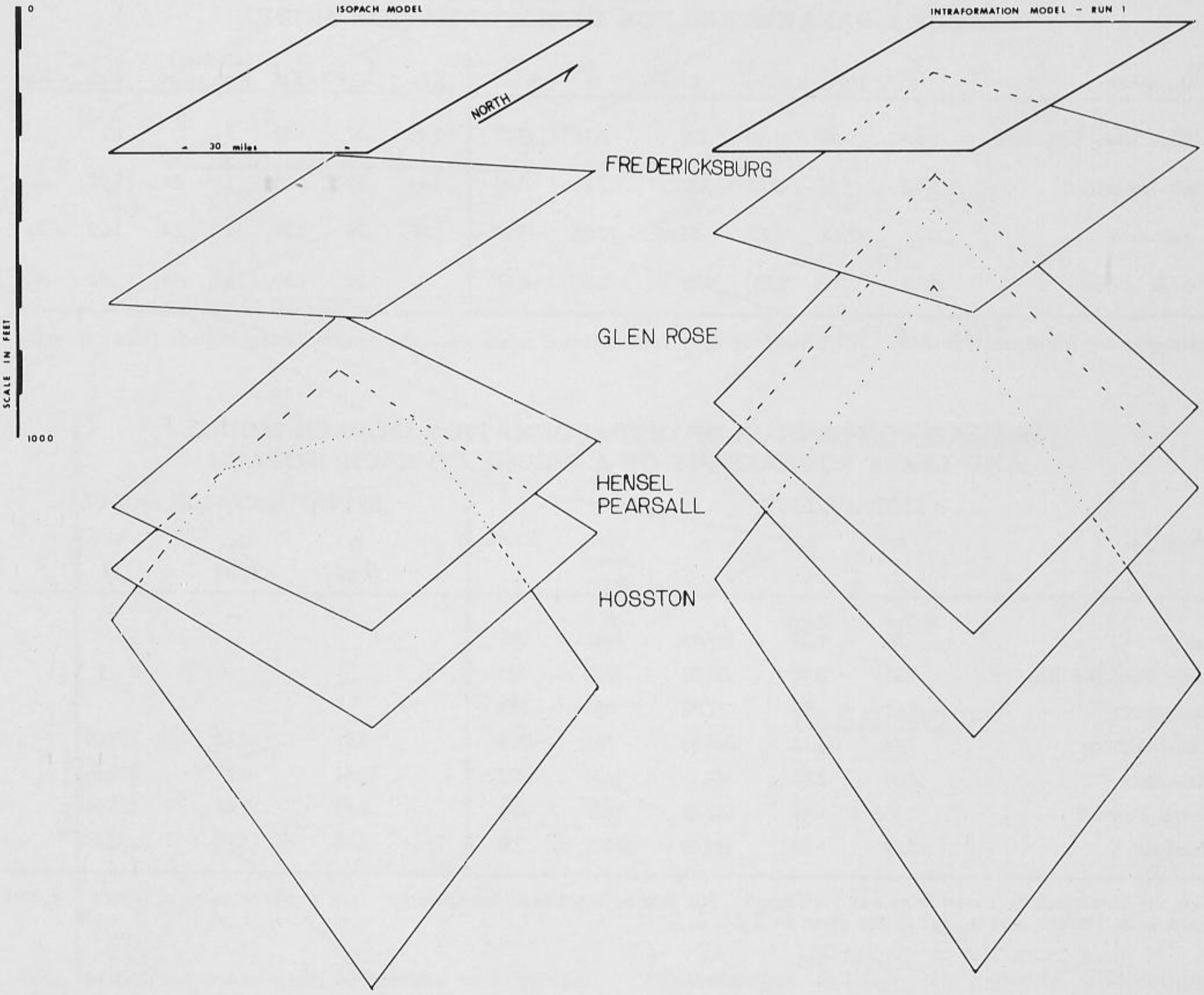


Fig. 22. Sketch of intraformation model run one results.

a measure of the regional component associated with a given isopach interval. Thus r gives an indication of regional tectonism during deposition of the interval.

The model equation is then of the form

$$z = p_1 + p_2x + p_3y + p_4r + p_5xr + p_6yr \qquad (1)$$

where, p_1 is the common thickness in all intervals; p_3 and p_2 are the average thickening in all intervals in the x and y direction; p_4 is the unit c in Figure 20; p_5 and p_6 are the unit d in Figure 20; x is the distance in miles east of the southwest corner of the region; y is the distance in miles north of the southwest corner of the region; z is the total thickness of the interval in feet; and r is a measure of the regional tectonism during deposition of a given interval [r was determined by the least squares fit to equation (1)].

For this least squares fit, isopach maps were divided by a ten mile grid, and the isopach values (z) at each grid point (x,y) recorded for each isopach interval. Then a type section was chosen in the northwest corner of the study area, near the #1 Lewis Martin well. Estimates of r were taken from that section. The gridded isopach values were divided into three overlapping groups, 1) the Hosston, Hensel-Pearsall, Glen Rose, and Fredericksburg isopachs; 2) all thicknesses from all mapped intervals; and 3) thicknesses from the eastern half of the study area. A fourth group included the thicknesses directly from wells used in construction of the fence diagram (Fig. 21).

For each data group equation (1) was least squares fit to the data, varying p_1 through p_6 and r for optimum fit. Then (x,y) values of one or more grid points were varied to optimize the fit. This allowed the wedge to "bend" slightly.

Data group one fits the model well. The constant terms p_1, p_2, and p_3 are essentially zero indicating that when regional activity was minimal, the isopach has no regional thickness component. The subsiding surface was a plane hinged 32 miles west of the southwest corner of the study area and striking N20°E (Fig. 22). The regional activity was greatest during Glen Rose time and the least during Hensel-Pearsall time.

For experiments two through four the results are

TABLE 1. PARAMETERS FOR INTRAFORMATION MODEL

Run no. Intervals	p_1 ft	p_2 ft/mi	p_3 ft/mi	p_4 ft/mi	p_5 ft	p_6 ft/mi	r (unitless)						
							Kho	Khe	Kgl	Ked	Kgt	Ksh	Kau
1 Kho, Khe, Kgt, Ked	-8.4	-.20	.10	202.	6.11	-2.27	1.44	.67	1.97	1			
2 all isopachs	-91.2	-1.36	2.72	253.	7.26	-3.83	1.41	.70	1.85	1	.59	1.02	.67
3 east area	122.	-7.43	5.72	-35.45	13.96	-6.57	1.87	.75	1.94	1	.64	1.09	.71
4 cross section	-13.9	.032	1.53	327.	2.33	-2.61		.52	1.80	1	.46	.82	.46

Parameters for intraformation model. All parameters have been adjusted to set r for the Fredericksburg isopach (Ked) to unity.

TABLE 2. COMPARISON OF INTRAFORMATION ISOPACH MODEL AND LEAST SQUARES FIT OF A WEDGE TO EACH ISOPACH

	ISOPACH FITS					INTRAFORMATION MODEL		
Formation	p_1	p_2	p_3	mean square error	F ratio	p_1 ft/mi	p_2 ft/mi	p_3 ft
	ft/mi	ft/mi	ft	ft^2				
Austin	-.85	1.33	254.44	2441	235			
Eagle Ford-Del Rio	7.81	2.44	-26.00	4735	363			
Georgetown	3.61	.96	11.62	661	687			
Fredericksburg	1.14	-1.13	348.03	346	4378	5.91	-2.17	193.60
Glen Rose	8.36	-2.86	468.	1409	4872	11.84	-4.37	389.54
Hensel-Pearsall	2.655	-.44	141.57	1651	479	3.89	-1.42	126.94
Hosston	16.17	6.80	114.09	47028	90	8.59	-3.17	282.48

Data for intraformation model from run 1 (Table 1). All data adjusted to fit the equation: $p_1x + p_2y + p_3 = z$. Where x, y, and z are as in Table 1, and p_1, p_2, p_3 are given in Table 2.

questionable. Although the model is mathematically correct it is difficult to interpret the results. Run four, based upon data from the fence diagram (Fig. 21), shows anomalous values for all parameters indicating poor equivalence between the fence diagram and the isopach maps, perhaps because of a poor choice of wells. Run two is too complex to interpret, since the lower units extend across the entire study area, and the upper three units occupy only the eastern half. Run three is interesting when compared to Run one. The "hinge point" of the subsiding surface in Run three is 13 miles east of the southwest corner and 45 miles east of the hinge line of Run one.

A second model, the isopach model, was developed to estimate the local structural disturbance during deposition of each isopach interval. Here it is assumed that each interval approximates a geometric wedge, except for areas of local disturbance, and that wedge thickness is given by equation (2) as follows:

$$z = p_1 + p_2x + p_3y \qquad (2)$$

where, z is unit thickness; x and y are geographic coordinates as in equation (1); and p_1 through p_3 are parameters of the wedge for each isopach interval. Then, a measure of the deviation from the wedge is the mean square of the total residual (Table 2; Appendix II). The inverse of the F-ratio gives a measure of the activity (the amount of disturbance per foot of sediment) in each interval (Koch and Link, 1970, p. 137). Of the units studied, the Hosston Formation shows the largest disturbance, followed by the Del Rio-Eagle Ford section, the Austin Formation, the Glen Rose Formation, the Hensel-Pearsall Formation, the Georgetown Formation, and the Fredericksburg Group. The measure of activity, however, indicates that the high value for the Glen Rose Formation is attributable to its large total thickness. Note that the activity decreases continuously from Hosston Formation to Fredericksburg Group and increases continuously from Georgetown Formation to Austin Formation.

A comparison of the intraformation model (Fig. 22) and isopach model shows that the major difference between the two is in the Glen Rose interval. The intraformation model predicts substantial southeast thickening, the isopach model does not. Hence, the assumption of the intraformation model, that isopach wedging is an increasing function of average formation thickness, may be wrong.

The isopach model (Fig. 23) provides a good generalization of regional isopach features. The uniformity of the section from the end of Hosston time to the end of Fredericksburg time is in contrast with post Fredericksburg units.

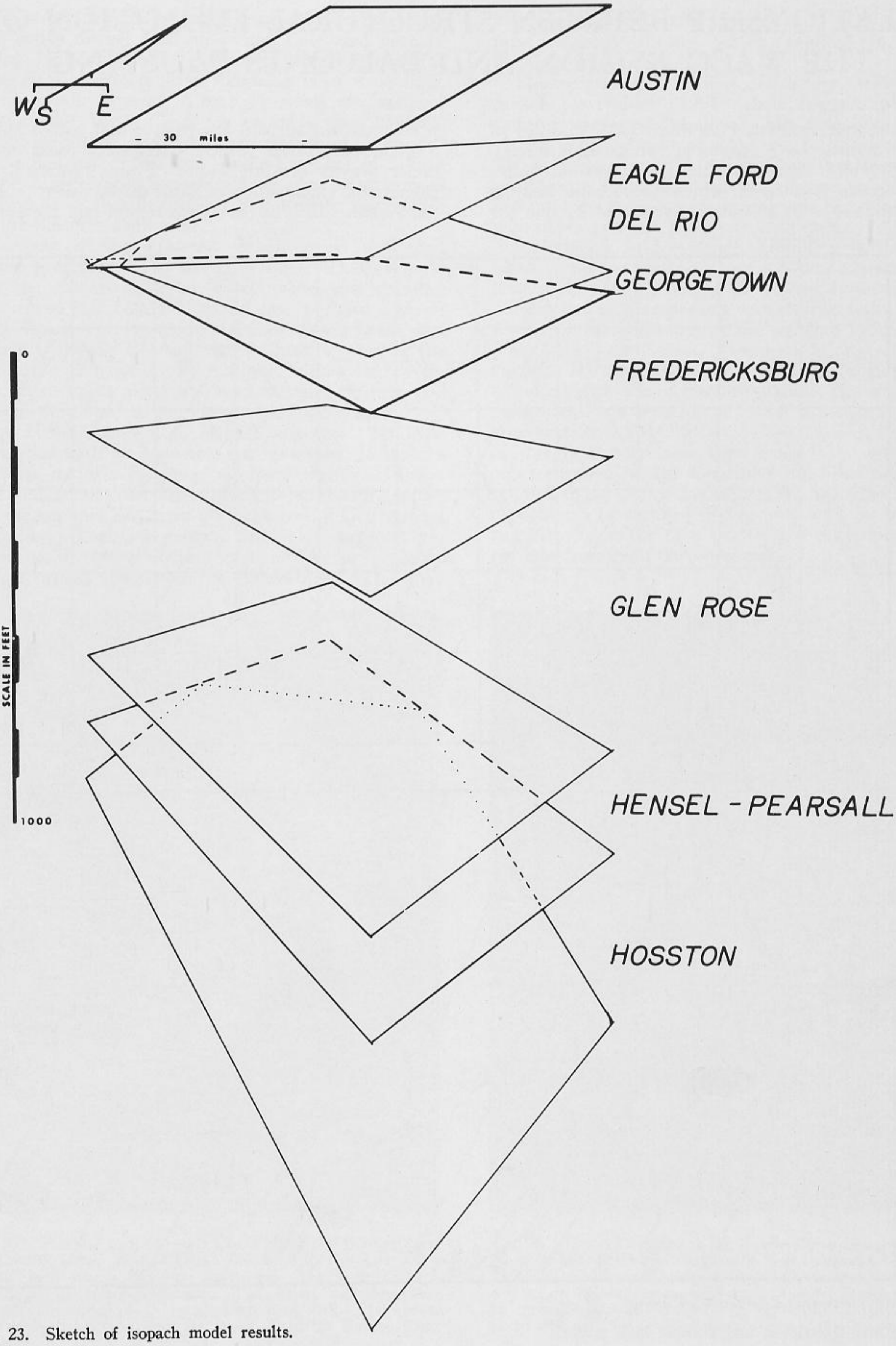
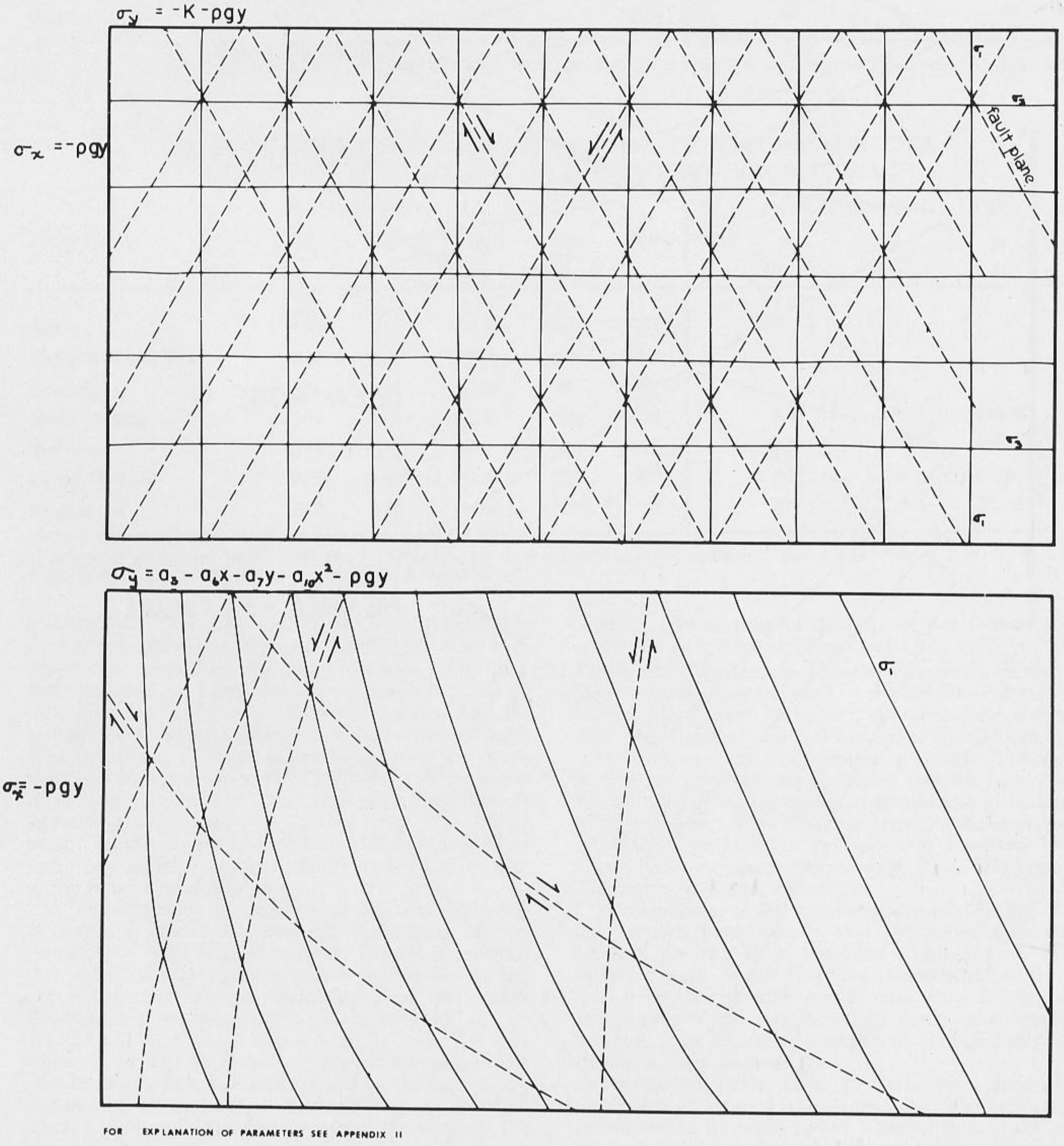


Fig. 23. Sketch of isopach model results.

RELATIONSHIP BETWEEN STRUCTURAL EVOLUTION OF THE WACO REGION AND BALCONES FAULTING

Previous investigations (Goodson, 1965, p. 3-20) of Balcones faulting have suggested two possible mechanisms of fault origin, 1) that there was an active pre-Cretaceous surface in which Cretaceous faulting is a continuation of Ouachita activity, and 2) that the pre-Cretaceous surface was passive and served only as a glide plane over which Cretaceous rocks moved under gravity creating faults. From theoretical considerations, examination of small displacement faults in the Austin Chalk in the Waco region and the isopach



FOR EXPLANATION OF PARAMETERS SEE APPENDIX II

Fig. 24. Stress trajectories and possible fault planes.

information, it appears that 1) some faults may have been active during Pearsall-Hensel time, and perhaps during Hosston time; 2) there is little evidence for large displacement faulting following Glen Rose time, up to Austin time at Waco; 3) small displacement faults in the Austin Chalk are probably growth faults, die out within the Austin, and are a result of differential compaction within that unit; and 4) the line of flexure in the pre-Cretaceous surface may have concentrated faulting along that flexure line and thus be responsible for the Balcones fault zone.

Faulting during Hosston deposition is suggested by the presence of the incised valleys. This suggests that the major Balcones down-to-the-coast faulting commenced just before Hosston time, perhaps a result of the down warping along the East Texas basin, and continued during Pearsall time. The thin area of the Mooreville thin (Fig. 9) suggests either that there was active uplift along a basement fault, or that two grabens developed as the Hosston sediment compacted. After Hensel deposition, isopach character has little correlation with the basement configuration. It appears that the major subsidence occurred during Hosston time and subsequent sedimentation prograded further and further into the basin until the end of Georgetown deposition. Post-Georgetown deposition suggests regional uplift centered southeast of Waco, probably along a broad upwarp of the Belton high. This may have been accompanied by renewed activity of the pre-Cretaceous surface which resulted in faulting through the Austin Chalk.

Theoretical considerations of fracture, using the approach by Hafner (1951) show fracture planes for various stress relationships (Fig. 24). A constant vertical stress should produce two sets of fractures at 30° to the vertical. A vertical and horizontal stress relationship shown in the lower diagram of Figure 24 will produce two sets of fractures, one becoming steeper with depth and one shallower with depth.

Preliminary field evidence of faulting in the Austin Chalk along the Bosque River in Waco suggests that at least some of the faulting is contemporaneous (Figs. 25, 26) and is in agreement with the theoretical models. Note that the faults do not die out into bedding plane faults, but simply stop. Geometry of the cliff faces suggests fracture and faulting with the development of two conjugate sets of fracture planes. The major principal stress was vertical and minor principal stress was horizontal with the cliff face (Figs. 24, 27). Fracturing of this type may have been caused by uplift which occurred after Austin deposition and lithification. The upward dying out of faults suggests a minor hiatus in deposition. Downward dying out into a marl bed suggests the effect of a particularly incompetent bed, perhaps from high pore pressure.

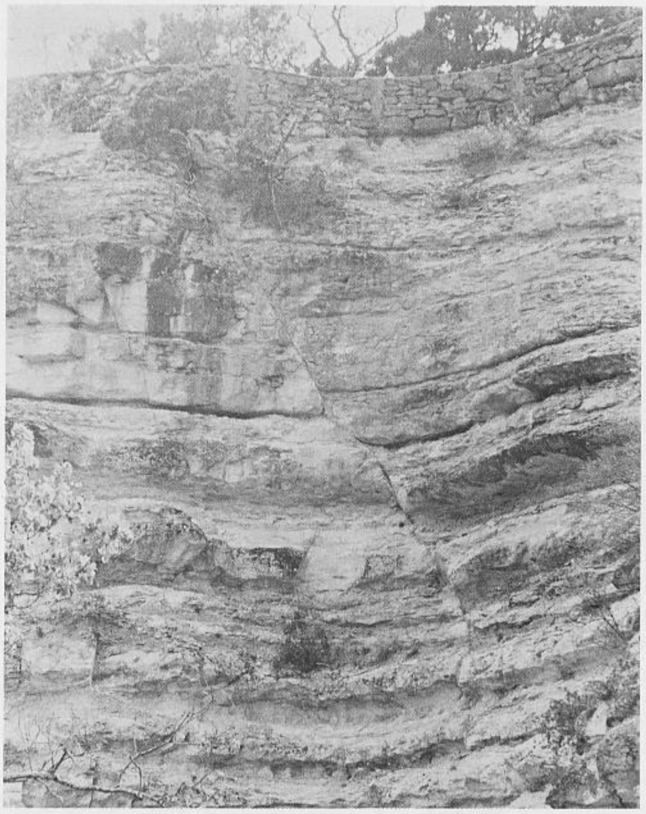


Fig. 25. Faulting in the Austin Chalk along the Bosque River at Lovers' Leap, Waco, Texas. Note that the fault is a normal fault which dies out downward. The fault plane is curved in its lower extension. The dying out downward suggests the effect of an incompetent marl bed. The curved trace of the fault is unusual for faults along the Bosque River at Waco.

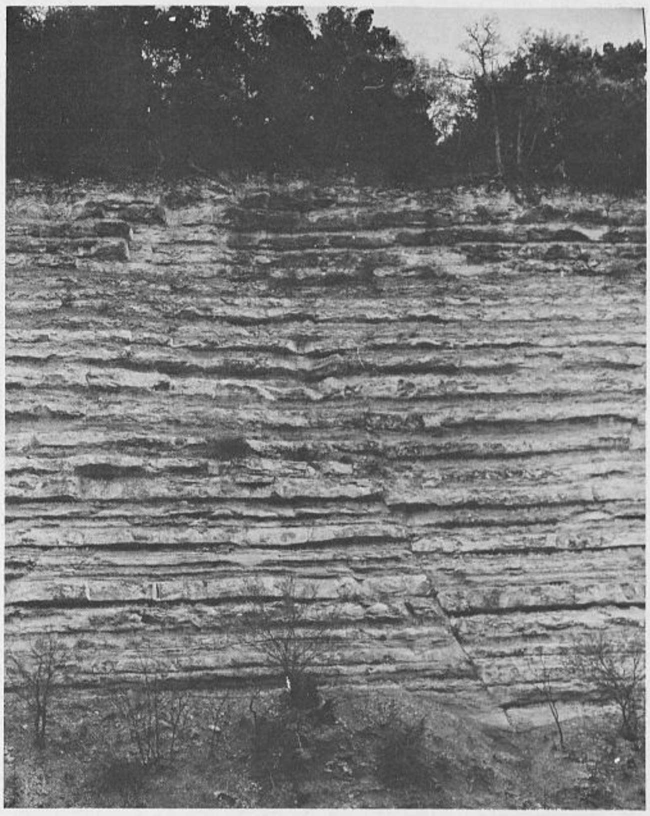


Fig. 26. Growth faulting in the Austin Chalk along the Bosque River at Waco. This is the growth fault mentioned by Goodson (1965). It has a relatively constant displacement up to about a third of the way up the cliff face. Then it begins to die out to zero displacement halfway up the cliff. A fracture plane associated with the fault extends nearly to the top of the cliff.

Fig. 27. **Erosional features in the cliffs along the Bosque River** at Waco caused by fracture zones. The weathering of the Austin Chalk here emphasizes fracture planes within the Austin. The planes intersect at 30° to the verticle, suggesting fracture due to vertical stresses. The angle of the faces of the reentrants is constant for several hundred yards along the base of Lovers' Leap, and is a classic example of the relation between major stress and planes of fracture.

CONCLUSIONS

1. The initial pre-Cretaceous surface was of low relief. Rapid subsidence in the East Texas basin occurred during early Hosston time. Nickpoints apparently developed at the cratonic margins, either a result of sudden subsidence or fault displacement along that line during Hosston time.
2. During Hensel-Pearsall time, local readjustment along faults occurred. Faulting along the basin margin may account for some variations in thicknesses characterized by linear isopach features.
3. During Glen Rose time sedimentation prograded further southward. Any local movements along faults are masked by the extreme thickness of the section.
4. Fredericksburg deposition was a period of regional quiescence.
5. The change in depositional strike of the Georgetown Formation suggests that centers of activity shifted between Fredericksburg and Georgetown time.
6. All shales from the Del Rio to the Eagle Ford thicken rapidly in the east and southeast corner of the study area, suggesting renewed subsidence and associated faulting during that period.
7. The Austin Formation thins southeast of Waco principally by omission of the top beds, suggestive evidence of post-depositional arching and erosion.
8. The concept of a Cretaceous hinge line may be in error. Deposition was apparently prograding into the East Texas basin.
9. At least some of the small displacement faults in the Austin Formation are growth faults.
10. Local tectonic activity decreased continuously from Hosston to Fredericksburg time. Beginning with Georgetown deposition it increased continuously through Austin time.

RECOMMENDATIONS FOR FURTHER STUDY

1. Although the question of origin and mechanics may be answered partially on local scale, it is difficult to relate to other regional activity. A regional study (on the order of 500 miles) should be initiated in order to define Balcones faulting and relate it to the general structural evolution of Texas.
2. The times of faulting previously suggested vary widely depending on the location where the faulting is described. A few detailed cross sections through areas of known faulting might well determine the ages of faulting throughout the length of the Balcones fault zone.
3. For greatest effectiveness, the current study should be extended at least one degree more in an east-west direction in order to determine more precisely the role of the East Texas basin on sedimentation, to relate the movements of the Mexia-Luling and Balcones faults, and to determine the nature of the intervening graben.
4. The geometry of the major Balcones faults and fractures should be determined by air photo analysis and field confirmation. Then theoretical studies of faulting may be compared with the results. A theoretical study by finite element analysis should be made on the effect of the topography and rate of compaction on fracturing.
5. Reliable markers in the shale sections need to be defined. Much of the local movement may be concealed in such sections.

APPENDIX I*

FORTRAN PROGRAM TO CALCULATE AND PLOT MAJOR AND MINOR PRINCIPAL STRESS TRAJECTORIES GIVEN ANY AIRY STRESS FUNCTION

The calculation and plotting of stress trajectories by hand is a long and tedious procedure and discourages experimentation. A FORTRAN program was developed for this study to speed and simplify the process. The desired Airy stress function, the coefficients of the function, and the area over which calculation proceeds is input to the program. The program outputs a plot of major and minor principal stress trajectories.

In general the routine is simple and the programmer familiar with scientific FORTRAN and elementary numerical analysis should have little difficulty in following the procedure. The Airy stress function is placed in statements 1320-1350 in standard FORTRAN notation. The values for the coefficients are punched onto multiple cards and read in statement 150. Following coefficient data is the size of the block considered and read in statement 160. The program calculates the various derivatives numerically using six point difference equations. However it does not check to see that the biharmonic function ($\nabla^4 0 = 0$) is satisfied. This is left to the user.

Because the program does not calculate the major and minor principal stress vectors directly, but just the direction of the vector, it is necessary for the user to determine which set of trajectories (periods or commas) is the major stress trajectory. The label at the top of the print out may be in error.

APPENDIX II*

PROCEDURES FOR MODEL OF CRETACEOUS DEPOSITION

Two models for Cretaceous deposition were considered in the study 1) a least squares fit of a simple wedge to each isopach interval (the isopach model), and 2) a non-linear least squares fit of equation (1) to all intervals simultaneously (the intraformation model). In preparation for both models, a ten-mile grid was superimposed on each isopach map, and the coordinates x and y and the thickness in feet, z, recorded for each grid point. The coordinate information was originally recorded in inches from the southwest corner of the map area, and later converted to scale miles. A type section was chosen near the #1 Lewis Martin well. The thickness of the given formation at the type locality was recorded as a fourth parameter for each data point of the given formation.

The formations were first considered singly. The simple wedge fit was done using standard multiple linear stepwise regression computer program BMD02R (Dixon, 1973, p. 305-330). The wedge described by this fit was contoured on tracing paper to the same scale as the base map. Then the wedge was subtracted from the original isopach and the residual values contoured to produce the various residual maps. When the simple wedge was not an adequate generalization of the data (as in the case of the Hosston Formation) an arbitrary dip section was chosen in the center of the area. Then the contours of the wedge were moved to match the true values along the dip section. The strike of the wedge contours was not changed. The modified wedge contours were then subtracted from the true contours.

The non-linear generalized fit to all isopach intervals was done with a modified version of standard non-linear least squares regression model BMD07R (Dixon, 1973, p. 387-396). The least squares program was modified to vary input independent variables in a systematic manner to improve the fit to equation (1). An initial fit is made to the data and the coefficients for the equation printed. Then the isopach parameter, the fourth parameter (r), is varied for each formation to minimize the error mean square of the fit. Then the process is repeated, least squares fitting the data with the modified parameter and printing the coefficients for the equation. This continues for fifty itinerations. By that time the process converges and no further improvements in the fit are possible by modifying r. The procedure now begins modifying the x values. All grid columns are moved together so that the final coordinate points will fall on an irregularly spaced grid. After fifty itinerations the y values are modified in the same manner. This in effect is allowing a slight flexibility to the wedge. In practice the modification of x and y values improved the fit very little.

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*The print out for each of these programs is available for reproduction costs from the Department of Geology, Baylor University—Editor.

APPENDIX III

WELL INDEX

BELL COUNTY

1.	#1 Ed Huess	Ralph Roberts
2.	#1 Curb Fee	Gilchrest Drilling Co.
3.	#1 Massie	Shell Oil Co.
4.	#1 T. E. Sandeford	J. L. Meyers
5.	#1 Dog Ridge WSC	J. L. Meyers
6.	#1 Stillhouse Hollow Dam	Ward & Ward
7.	#4 City of Belton	J. L. Meyers
8.	#1 Howard	A. B. Johnson
9.	#1 Lee Casey	A. S. Hudgens
10.	#2 Temple Airport	J. L. Meyers
11.	#1 Pendleton WSC	West Texas Tool
12.	#1 Peppers Creek	C. M. Stoner
13.	#1 Temple Lake Park	J. L. Meyers
14.	#1 Belton Dam	Texas Water Wells
15.	#3 City of Temple	Layne Texas Co.
16.	#1 Taylor Bedding	Layne Texas Co.
17.	#1 Brazos River Electric Co-Op	J. L. Meyers
18.	#2 City of Belton	J. L. Meyers
19.	#2 City of Temple	J. L. Meyers
20.	#1 Acres WSC	Triangle Pump Co.
21.	#1 J. W. Marrs	J. L. Meyers
22.	#1 BCID	J. L. Meyers
23.	#1 E. Bell WSC	West Texas Tools
24.	Tex. well no. AX 58-05-202 *from* Klemt, Perkins, and Alvarez (1975) p. 28, 29, 32.	
25.	#1 O & B WSC	J. L. Meyers
26.	#1 Alter Ranch	T. D. Meacham?
27.	#1 Leona Park	V. O. Ward
28.	#1 Cedar Ridge Park	V. O. Ward
29.	#1 Moffat WSC	C. M. Stoner
30.	#1 Temple Lake Park	J. L. Meyers
31.	#2 Rodgers Park	Adams Drilling Co.
32.	#1 Harvey Bacon	Falcon Drilling Co.
33.	#1 Wineford Cosper	J. B. Sarguhanson
34.	#1 Live Oak Ridge Park	J. L. Meyers
35.	#3 City of Belton	?
36.	#1 Taylors Valley WSC	West Texas Tools
37.	#4 City of Temple	J. L. Meyers
38.	#1 Ralph Wilson Plastics	Texas Water Wells

BOSQUE COUNTY

1.	#3 City of Meridian	C. M. Stoner
2.	#1 C. G. Golden	?
3.	N. P. Powell, Hill House	J. L. Meyers
4.	#2 Meadow Pasture N. P. Powell Ranch	J. L. Meyers
5.	#1 Mrs. George Adams	C. M. Stoner
6.	#1 Edwin McMillen	Frank Baker Place
7.	#1 Cedron Creek Park	U. S. Corps Eng., Watts Drilling Co.
8.	#1 J. W. Henry	O. C. Proffitt
9.	#1 Clanton	American Liberty Oil
10.	#1 Herbert Reichert	American Liberty Oil
11.	#1 Lake Whitney Enterprises	J. L. Meyers
12.	#1 Ellie Moore	Shell Oil Co.
13.	#2 Ellie Moore	Shell Oil Co.
14.	#1 Matthews	Shell Oil Co.
15.	#1 Eugene Allen	Rufus Smith
16.	#1 E. R. Hatfield	Rufus Smith
17.	#1 R. T. Greenway	Southland Oil and American Liberty Oil
18.	#1 Mosheim WSC	H. Meadows

CORYELL COUNTY

1.	#1 Turnersville WSC	J. L. Meyers
2.	#1 V.L. Turner	Gulf Oil Co.
3.	#4 Gatesville School	Layne Texas Co.
4.	#1 Mountain WSC	Jones Drilling and James Adams
5.	#1 Fort Gates WSC	J. B. Ferguson
6.	#1 Oglesby WSC	Key Water Well Drilling Co.
7.	#1 Earnest Day	General Crude Oil Co.
8.	#1 Flat WSC	H. Meadows
9.	#1 Grove WSC	H. Meadows
10.	#1 Rabbe	Shell Oil Co.
11.	#1 Thomas Young	N. H. Schwald and Sugarload Mtn. Oil

FALLS COUNTY

1. #1 Perry WSC	J. L. Meyers
2. #1 Golinda WSC	J. L. Meyers
3. #1 Gilliam	Cockburn & Gilliam
4. #1 N. D. Buie	H. C. Cockburn & Zephyr Oil Co.
5. #1 Mooreville WSC	West Texas Tools
6. #2 City of Chilton (?)	H. B. Glass
7. #1 Cego-Durango WSC	Key Water Well Drilling
8. #1 C. L. Trice	Maury Hughes
9. #1 Lee Casey	A. S. Hudgens
10. #1 Westphalia WSC	J. L. Meyers
11. #2 Emma Pieper	Humble Oil Co.
12. #1 Eleanor Carroll	Humble Oil Co.
13. #1 Voltin	W. P. Luse
14. #1 J. A. Cobb	Delhi-Taylor Oil Co.
15. #1 Marlin Hot Wells Co.	H. G. Johnson
16. #1 J. B. Scott	H. E. Rails
17. #1 Stifelman	Shallow Sands Oil Co.
18. #1 Avery	Abshier & Jones
19. #1 Harrison	Ace Oil Co. & Ray Holbert
20. #1 D. V. Doskocil	A. Delcambre
21. #1 Keyser	E. Fletcher
22. #1 J. G. Barganier	Dail Goodson
23. #1 Guderian Estate	Hamilton et al.
24. #1 Herman Weiting	J. Jackson & M. Mays, Jr.
25. #1 Porter	Perkins
26. #1 Mitchell	Mid-States Oil Co.
27. #1 J. E. Green	Seaboard Oil Co. of Delaware

HILL COUNTY

1. #1 Beachville Acres	C. M. Stoner
2. #13 Webb Well, City of Hillsboro (?)	Layne Texas (1947)
3. #1 Certainteed Products	Layne Texas
4. #16 Sambo-Curtis, City of Hillsboro	Texas Water Wells (1961)
5. #A-1 Posey	Phillips Petrol.
6. #14 City of Hillsboro	Layne Texas (1952)
7. #1 Hill Co. WSC	J. L. Meyers
8. U. S. Corps Eng. Lake Whitney	Watts Drilling Co.
9. #1 Shannon	Brandon Oil (location?)
10. #1 Mixon	J. L. Meyers
11. #1 Shannon	Brandon Oil (location?)
12. #1 Aquilla WSC	J. L. Meyers (1960)
13. #1 H. Norris	A. P. Merrit
14. #1 Menlow WSC	C. M. Stoner
15. #1 City of Abbott	J. L. Meyers
16. #1 Chatt WSC	J. L. Meyers
17. #1 Malone WSC	J. L. Meyers
18. #1 Lewis Martin	George Rahal
19. #1 Penelope WSC	J. L. Meyers
20. #1 Birome WSC	West Texas Tool
21. #1 City of Mt. Calm	West Texas Tool
22. #1 Vasburg	A. O. Phillips & American Liberty Oil
23. #1 McDaniel	Glen McCarthy
24. A-1 Hight	C. A. Lee
25. #1 E. W. Barrett	Shell Oil Co.
26. #2 City of Hubbard	J. L. Meyers
27. #2 Easter Doherty	Joseph Thompson
28. #1 Brandon-Irene WSC	J. L. Meyers
29. #1 John Gerek	Robert M. Bass
30. #1 Cartright	Camtex Oil Co.
31. #1 Grant	Davidson & Fitzpatrick

LIMESTONE COUNTY

1. #1 Prairie Hill WSC	J. L. Meyers
2. #1 Union Central Life Ins.	Hunt Oil
3. #1 W. D. Stone	O. W. Killiam
4. #1 J. C. Rodgers	M. M. Miller
5. #1 J. R. Gilliam	Farrell Drilling Co.
6. #1 Jackson	Balcones Oil
8. #1 Paul Collins	Ralph Spence
9. #1 J. J. Bower	J. S. Cosden

McLENNAN COUNTY

1. #1 Cottonwood WSC	West Texas Tool
2. #3 City of West	J. L. Meyers (1953)
3. #1 Hilltop WSC	J. L. Meyers
4. #1 Bold Springs WSC	C. M. Stoner
5. #1 Leroy-Tours-General WSC	Layne Texas Tool

6. #1 Ross WSC	H. B. Glass
7. #1 R. F. Ferguson	Simon Korsoj
8. #1 J. R. Patterson	J. L. Meyers
9. #1 Axtel WSC	J. L. Meyers
10. #2 McLennan County WID	J. L. Meyers
11. #1 Chalk Bluff WSC	H. B. Glass
12. #1 Lakeview School	J. L. Meyers
13. #3 City of Lacy-Lakeview	J. L. Meyers
14. #1 State of Texas	Layne Texas (1952)
15. #1 Tirey	J. L. Meyers
16. #1 Plantation Foods	Smith and Bradshaw Pump Co.
17. #2 City of Bellmead	J. L. Meyers (1949)
18. #1 Pure Milk Co.	J. L. Meyers
19. #1 General Tire	Layne Texas (1945)
20. City of Waco	J. L. Meyers (1958)
21. City of Waco	J. L. Meyers (1949)
22. Tex. well no. AX 40-32-405 *from* Klemt, Perkins, and Alvarez (1975) p. 28, 29, 32.	
23. #1 Colcord Laundry	J. L. Meyers
24. City of Waco	J. L. Meyers (1945)
25. #1 Mt. Carmel Center	J. L. Meyers
26. #1 Oak Lake WSC	J. L. Meyers
27. T. P. & L.	Layne Texas (1957)
28. #1 City of Mart	J. L. Meyers
29. #1 H & H WSC	J. L. Meyers
30. #1 Meir Settlement WSC	J. L. Meyers
31. #1 T. P. & L. Lake creek	Layne Texas
32. #1 Riesel School	J. L. Meyers
33. #1 Freeman	E. J. Muth
34. W. B. Bass and Sons	H. Meadows
35. #1 Lake Waco Country Club	C. M. Stoner
36. #1 McKethan	H. Meadows
37. #1 East Crawford WSC	Triangle Pump Co.
38. #1 Henry Mattlage Jr.	Falcon Oil
39. #1 H. C. McKethan	R. C. Smith and Falcon Oil Co.
40. #1 Universal Atlas Cement	Texas Water Wells
41. #1 Midway Water Co.	C. M. Stoner
42. #1 Midway School	J. L. Meyers
43. #2 Midway Water Co.	C. M. Stoner
44. Bryan-Maxwell-Bryan	Layne Texas
45. #1 Dr. Barnes	J. L. Meyers
46. #1 Waco Memorial Park	J. L. Meyers
47. #1 Chapel Hill Park	H. B. Glass
48. #1 Weldon Youngblood	J. L. Meyers
49. #3 Robinson WSC, E. H. O'Dowd	J. L. Meyers (1961)
50. #1 Mickey O'Dowd	H. B. Glass
51. #1 Levi WSC	West Texas Tools
52. Lorena WSC	J. L. Meyers
53. #1 Myrtle Trice	Beacon Oil
54. #2 J. B. Todd-Tilton	J. L. Meyers
55. #1 Horstman	Delta Drilling
56. #4 City of McGregor	H. Meadows
57. City of Moody	J. L. Meyers
58. #1 Elm Creek WSC	C. M. Stoner
59. #1 Roxell-Quillen	Frank Place
60. #Ed Mazanec	C. R. Proctor
61. #1 Dr. Broughton	J. L. Meyers
62. #1 Spring Valley	C. M. Stoner
63. #1 H. McKethan	R. C. Smith
64. #1 Willis	Jet Oil
65. #1 Hurt	Helm
66. #1 Slaughter	Caraway
67. #1 Mae Belcher	Smith
68. #1 Midway Park	J. L. Meyers
69. #1 Shelby	Joe Thompson
70. #2 Midway Park	J. L. Meyers
71. City of Crawford	Fulton T. Place
72. #1 Wordlane	S & H Oil Co.
73. #2 T. P. & L. (Lake Creek)	Layne Texas Co.
74. #1 Wardlaw	Max McCotter
75. #1 Barron	Hamilton & Smith
76. #1 Alfred Brem	Smith & Breyer
77. #1 H. C. Buchannan	H. C. Buchannan
78. #1 Goodman	Davis Drilling
79. #1 H. Howard	General Crude
80. #1 J. M. Thompson	Gragg Drilling
81. Well not used	
82. #1 C. W. Scott	W. H. Mahon
83. #1 EOL	J. L. Meyers
84. #1 Prairie Hill WSC	J. L. Meyers
85. #1 H. C. Eubank	Henry C. Paine
86. #1 Grandstaff	S. H. Riggs

MILAM COUNTY

1. #1 W. F. Crawford	Rimrock-Tidelands Oil

NAVARRO COUNTY

1. #1 J. C. Keitt	Falcon Oil

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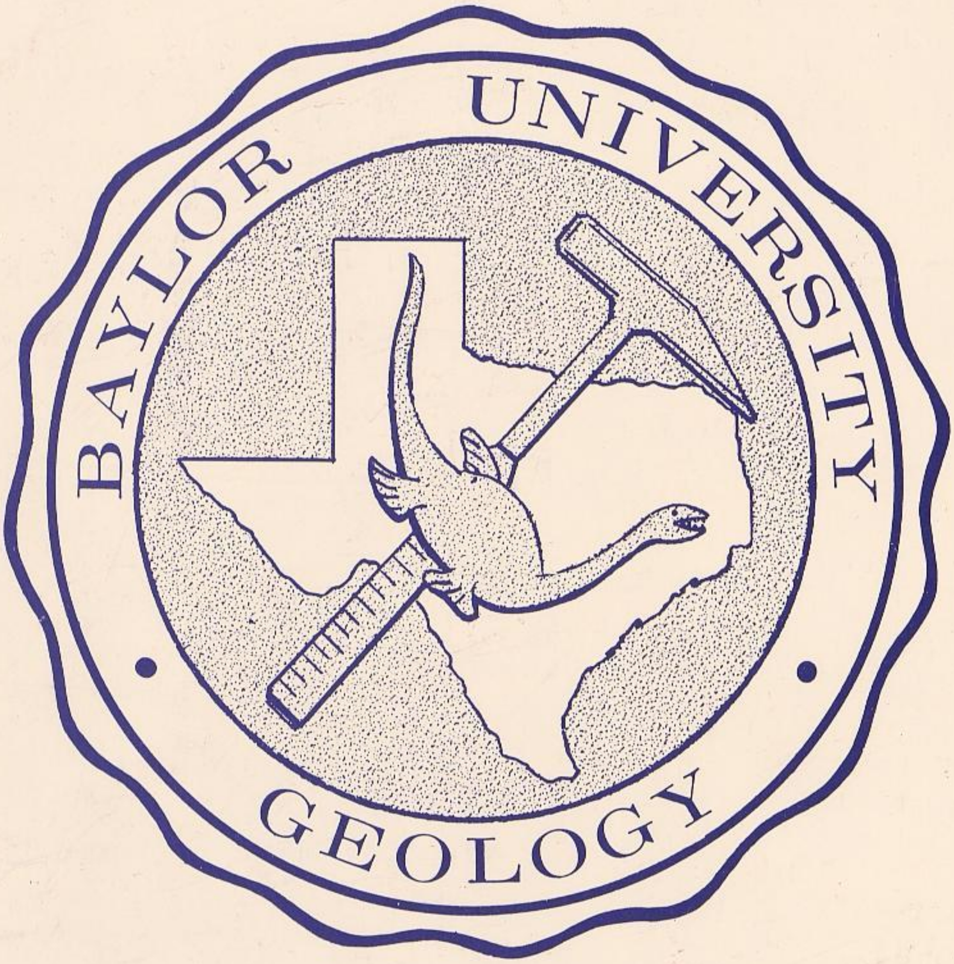
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