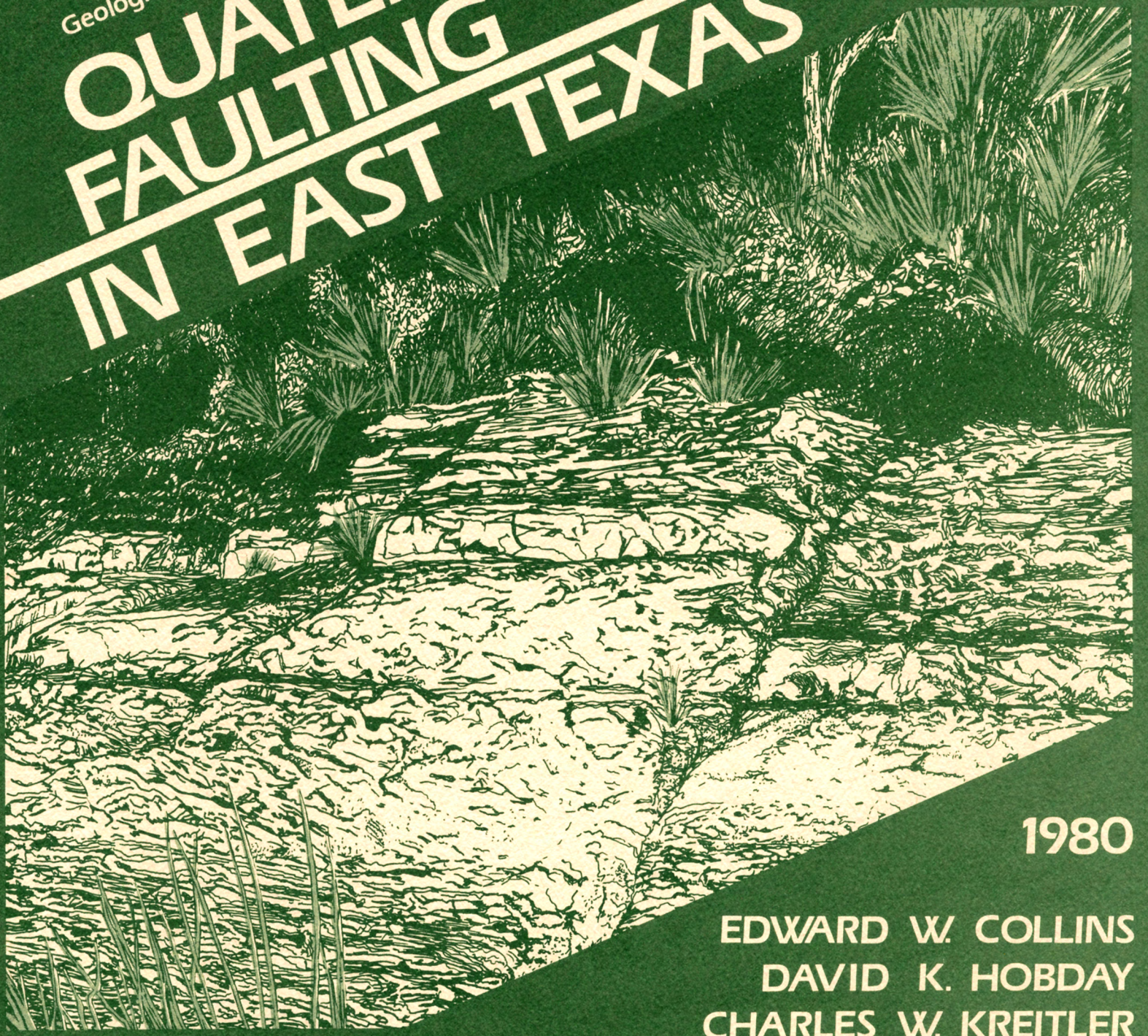
Geological Circular 80-1

QUATERNARY FAULTING IN EAST TEXAS



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Funded by Office of Nuclear Waste Isolation
under Department of Energy
Contract Number DE-AC97-79ET-44605

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QUATERNARY FAULTING IN EAST TEXAS

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Edward W. Collins, David K. Hobday, and Charles W. Kreitler

ABSTRACT

Three closely spaced oblique-slip faults displace a Quaternary gravel and sand unit overlying Eocene Claiborne strata in the Trinity River Valley, Leon County. These steeply dipping faults strike east-northeast; two of them are downthrown toward the south, with a smaller, antithetic, central fault downthrown to the north. Maximum slip on individual faults is 118 cm (46.5 inches), decreasing to 66 cm (26 inches) where these faults displace the overlying Quaternary gravels.

The location and trend of these faults are consistent with the configuration of the Mt. Enterprise-Elkhart Graben system; this relationship is verified by subsurface data and aerial photograph lineaments. The precise age of the Quaternary unit involved is uncertain. It is tentatively correlated with deposits of the Wisconsin interstadial 37,000 B.P., implying late Pleistocene or Holocene reactivation of the fault system.

Mechanisms responsible for the fault may have involved fluid extraction in Long Lake Oil Field to the north, salt movement, or load-induced crustal warping. Coincidence of a belt of seismic activity with the fault trend suggests that faulting was probably related to hingeline effects between the East Texas Basin and the currently active Gulf Basin.

INTRODUCTION

The stability of the East Texas Basin has recently become an important consideration in the investigation of salt domes as potential sites for storage of radioactive nuclear waste. The East Texas area has been regarded as stable, although low-intensity seismicity and sporadic minor earthquakes (U.S. Coast and Geodetic Survey, 1928-1970) indicate a "low risk" potential for damage (Algermissen, 1969). Previous investigators have found no evidence of Quaternary reactivation of regional

structures that were active during Mesozoic and Tertiary time (Netherland and others, 1976), although Holdahl and Morrison (1974) suggested the possibility of broad contemporary warping.

Recent, detailed fieldwork in the area around Oakwood, Palestine, and Keechi Domes provides the first positive evidence of Quaternary faulting in East Texas. Faulting has important implications to the assessment of domes as potential waste repositories. On a broader scale, faults may be significant in demonstrating the interaction between early depocenters such as the Tyler Basin, which are now inactive, and the currently active Houston Embayment of the Gulf Basin.

STRUCTURAL FRAMEWORK

Major structural elements bounding the East Texas Basin are the Mexia-Talco Fault Zone to the north and west, the Sabine Uplift to the east, and the Mt. Enterprise Fault Zone to the south (fig. 1). A rapidly subsiding north-trending belt, the Tyler Basin, received thick accumulations of Mesozoic and lower Tertiary sediments. Post-Eocene sediments were bypassed beyond the southern basin margin to the younger Gulf Basin.

The Mexia-Talco Fault Zone originated early, and may have been associated with the early development of the Gulf of Mexico (Murray, 1961, p. 180). Turk and others (1978) point out, however, that basement faults of the Mexia-Talco system did not undergo post-Jurassic movement. Turk and others relate Mesozoic and Eocene displacement to two possible mechanisms that came into play at a later stage. A line of grabens may have developed along the hingeline between crust of normal thickness and basinward-attenuated crust. Alternatively, fault movement may have been related to downdip salt flowage.

Faults in the Mt. Enterprise system, including the Elkhart Graben, may represent hingeline effects between the East Texas Basin and the subsiding Gulf Basin. Following initial Cretaceous movement, during Eocene time, activity on the Mt. Enterprise faults was pronounced (Eaton, 1956). The general trend of the Mt. Enterprise faults intersects the Oakwood-Palestine-Keechi Dome area, and faults continue intermittently to the southwest (Russell, 1957). The Mt. Enterprise system comprises contemporaneous down-to-the-basin normal faults with dips of 35 to 60 degrees steepening toward the surface. The Elkhart Graben east of Oakwood Dome shows surface displacement on Eocene strata of up to 100 m (300 ft).

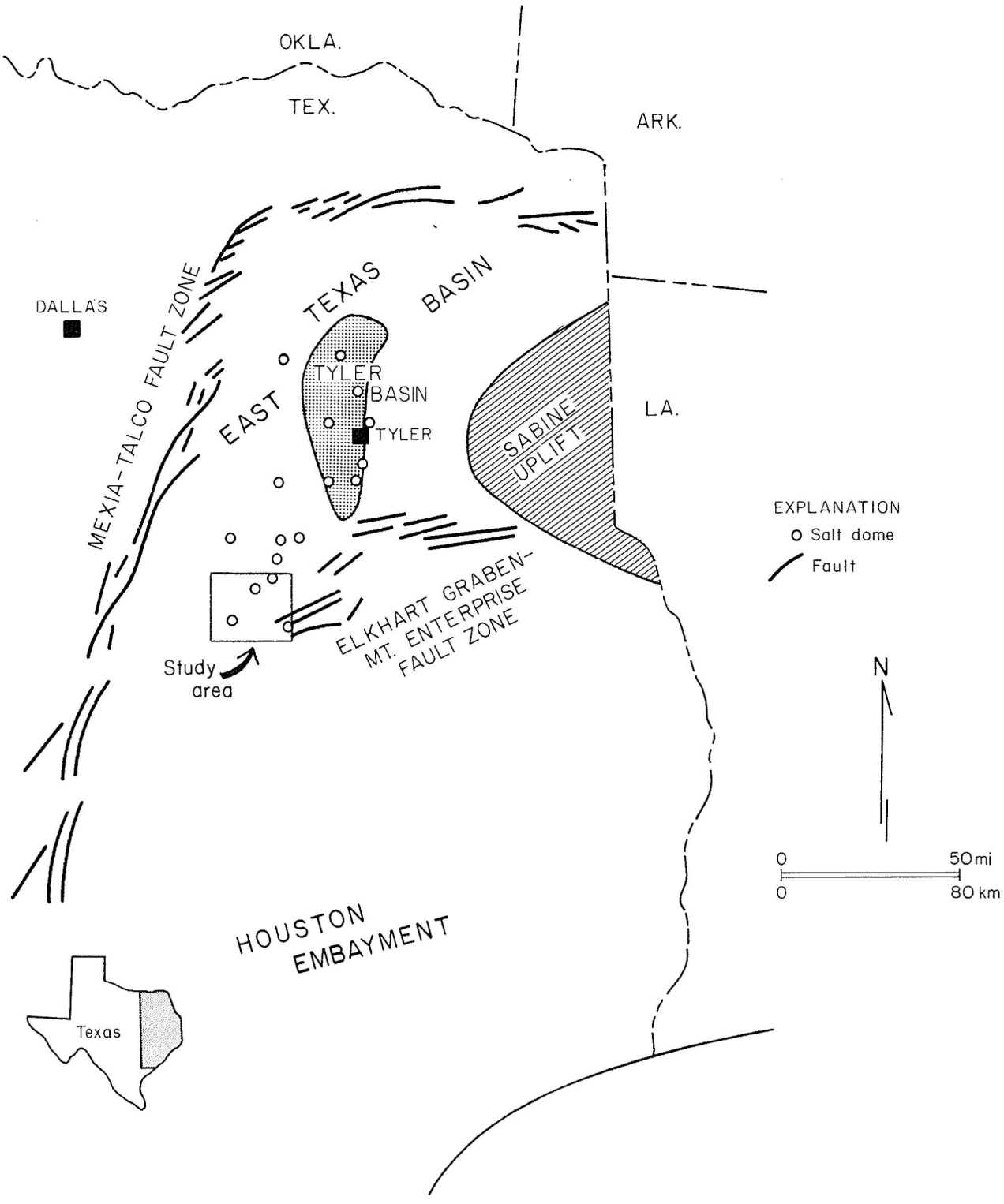


Figure 1. Major structural elements of the East Texas Basin and adjoining area.

Outcrops in Leon County show a clearly defined sequence of pre-Quaternary deformational events. The earliest event is represented by bedding cleavage, which in some areas is slightly discordant to stratification. This bedding cleavage, produced by compactional loading, is well developed in the Claiborne shales and is less evident in the thin sandy units. The bedding cleavage and stratification are displaced by fracture cleavage that dips steeply toward S30°W and shows evidence of strike-slip movement. Fracture cleavage is probably related to regional patterns of simple shear developed in response to differential lateral extension. Both the fracture and bedding plane cleavage are rotated or offset by the younger oblique-slip faults representing the third phase. These oblique-slip faults underwent persistent minor displacement extending into the Quaternary.

QUATERNARY FAULTS

Description

Three closely spaced oblique-slip faults with normal displacement (figs. 2 and 3) are visible in an outcrop of Tertiary and Quaternary sediments in the Trinity River Valley, Leon County, 12.5 km northeast of Oakwood Dome and 15.5 km south of Palestine Dome (fig. 4). All three faults strike between N60°E and N86°E. Two of the faults dip to the southeast at 75 to 87 degrees, with an antithetic central fault of variable dip toward the northwest and southeast; this fault pattern produces a small horst-graben couple. The principal fault passes downward into a ductile shear zone with similar displacement. Differential movement between the faulted and sheared strata and a slightly deformed indurated unit below has been accommodated by décollement sliding, revealed by slickensides on the bedding surface.

The faults extend through shale and sandstone of the Eocene Claiborne Group (uppermost Reklaw Formation or basal Queen City Formation) as discrete, slightly concave surfaces with a maximum oblique slip of 118 cm (46.5 inches) toward S63°W. These faults continue upward into the unconsolidated Quaternary deposits where they become closely spaced, multiple shear surfaces (fig. 5). Small step faults are developed along the Quaternary-Eocene contact (fig. 6); the positions of figures 5 and 6 are shown in figure 2. The Quaternary unit displays cumulative throws of 53 cm

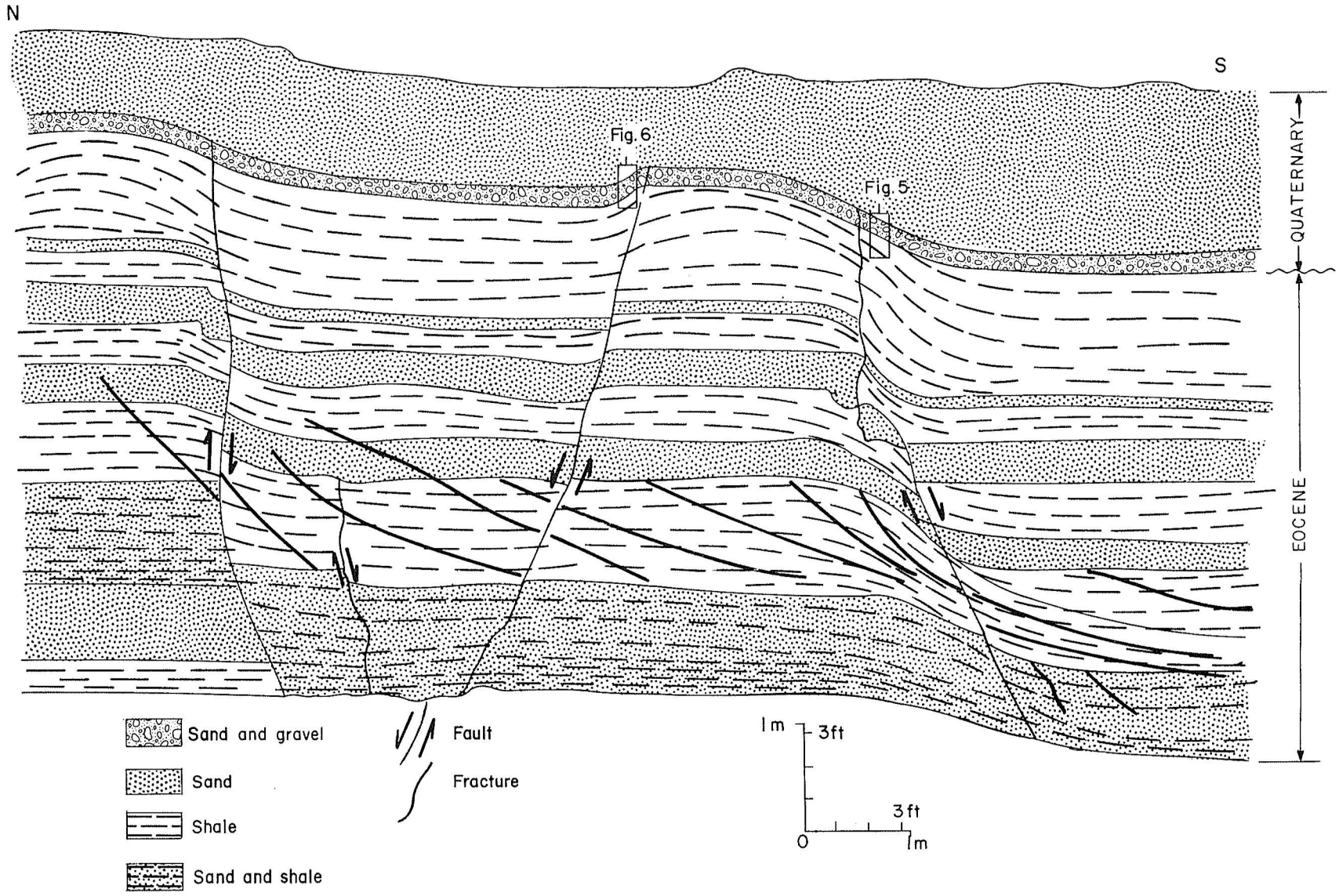


Figure 2. Outcrop section displaying Quaternary faulting. Details of significant minor features are shown in figures 5 and 6.

Figure 3. Outcrop displaying faulting of Eocene and Quaternary sediments. Arrows indicate fault planes. Scale in 10 cm intervals. White blocks (notebooks) lie on Quaternary unit.

(21 inches), 22 cm (9 inches), and 66 cm (26 inches). A backhoe trench approximately 100 m (350 ft) east of the outcrop confirmed the strike of the fault, and a series of power auger holes verified its lateral persistence over a distance of 115 m (375 ft). The vertical displacement of the gravel layer (fig. 7) was estimated on the basis of augering to be between 46 and 60 cm (1.5 and 2 ft). To the southwest, on the opposite bank of the river, an elongate depression appears to be related to a continuation of the fault trend.

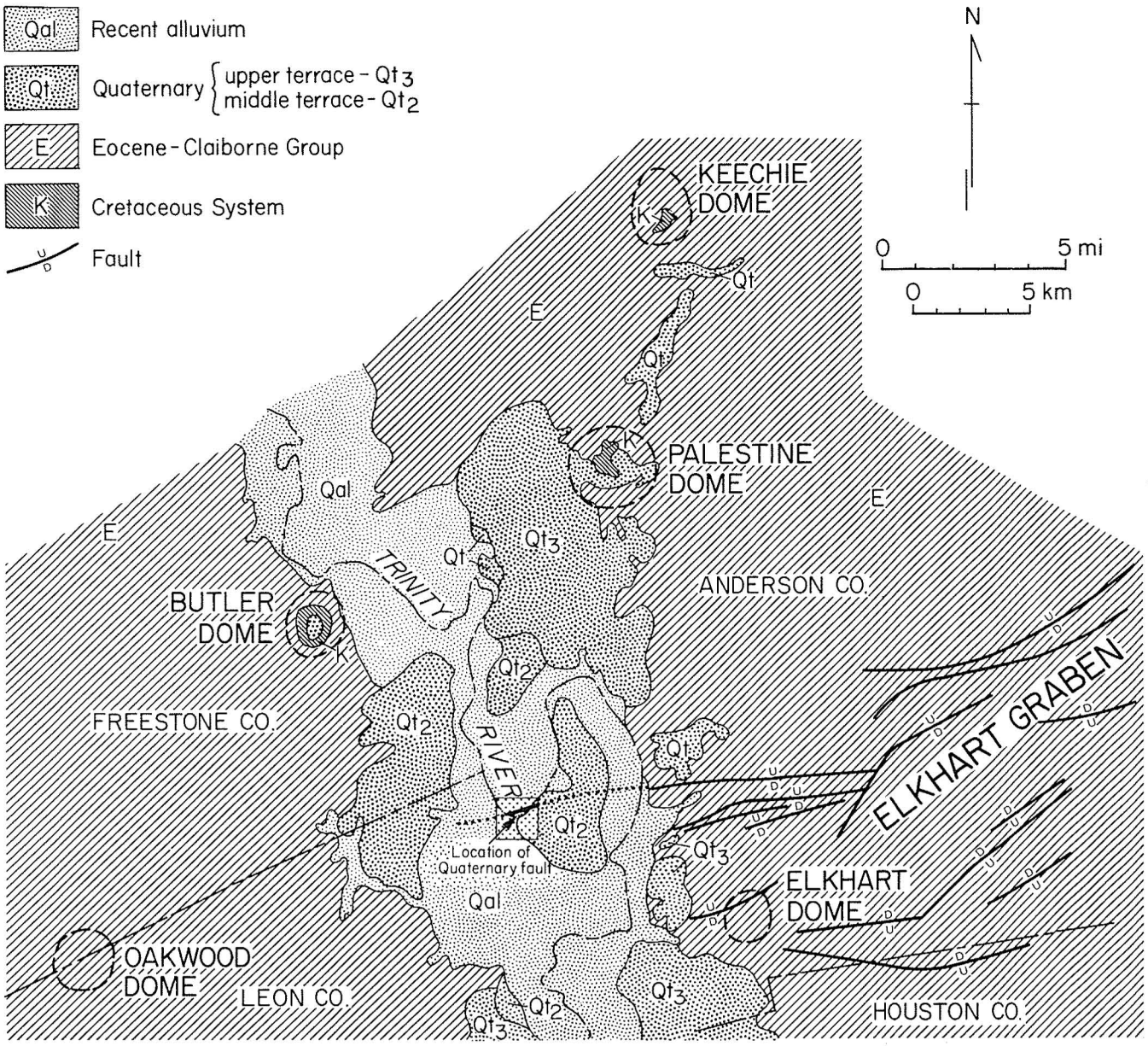


Figure 4. Geologic locality map indicating study area.

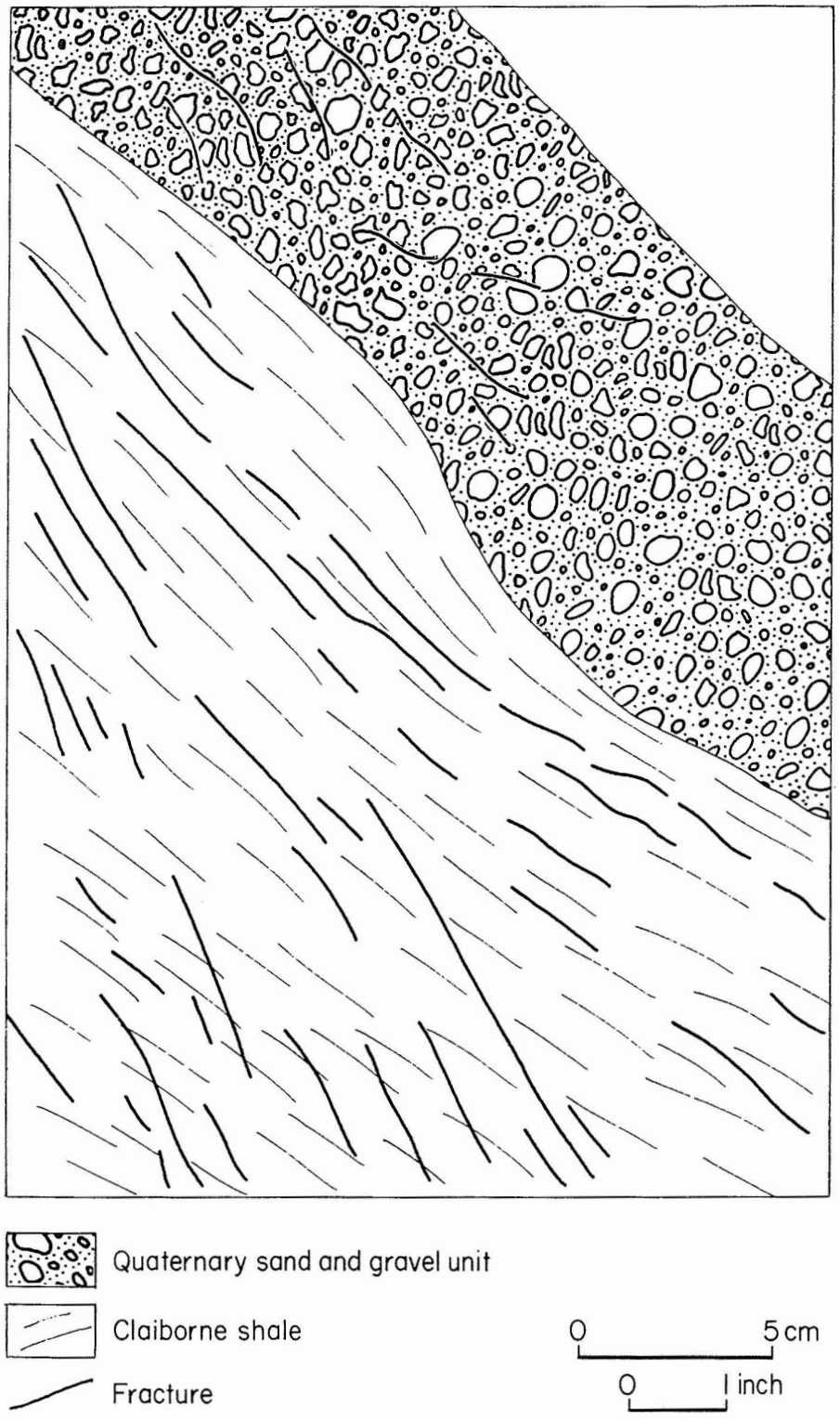


Figure 5. Multiple shear planes in Claiborne shale and Quaternary sand and gravel unit (traced from photograph). Locations of shear planes are referenced to larger displacements in figure 2.

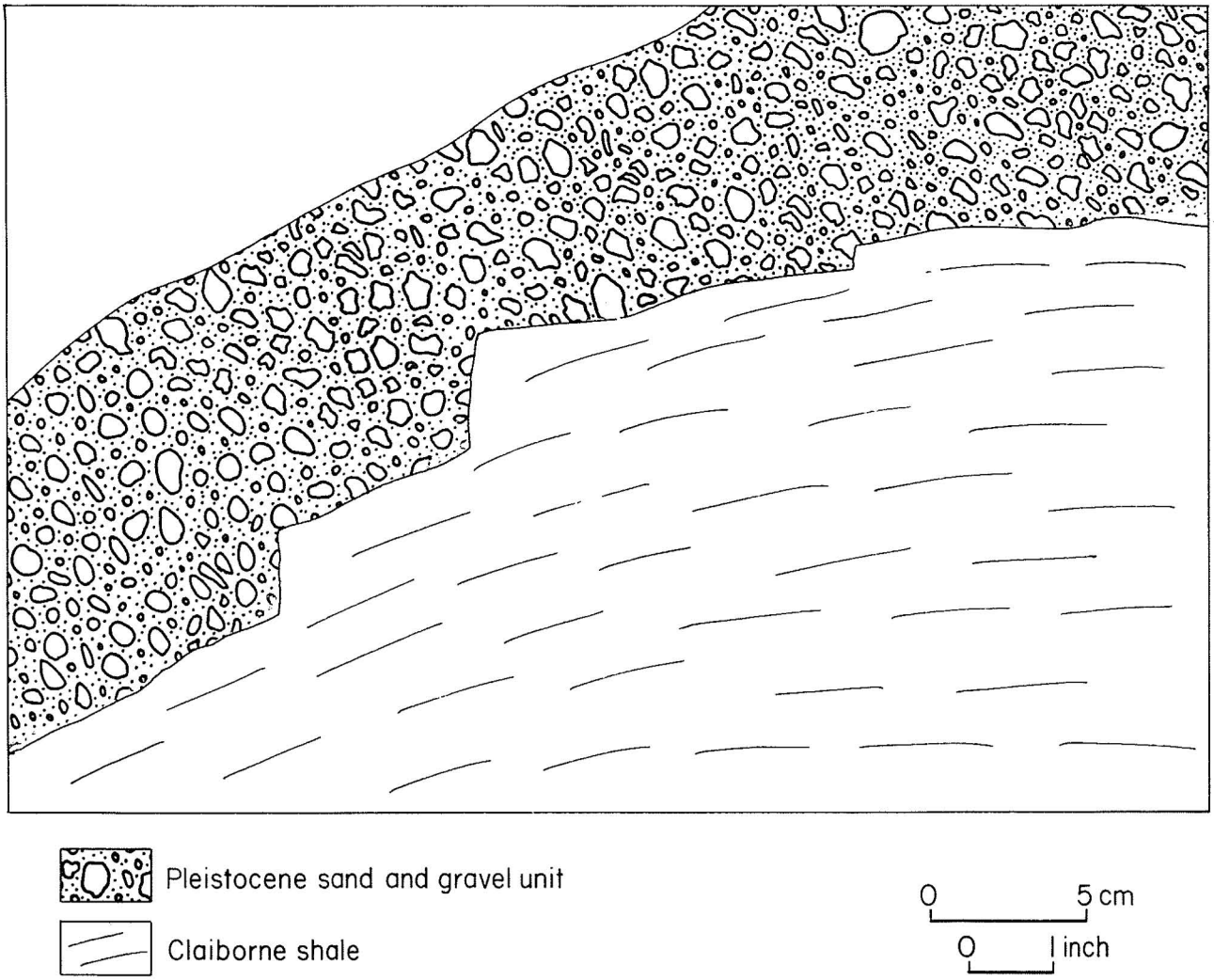


Figure 6. Small step faults in Quaternary unit (traced from photograph). Locations of step faults are referenced to larger displacements in figure 2.

Relationship to Regional Fault Zones

Westward projection of mapped faults of the Elkhart Graben, traced across the Claiborne Group to the edge of the Trinity River alluvium 6 km to the east of the Quaternary fault locality, indicates that the observed displacement probably represents the surface expression of the reactivated Elkhart Graben system. Sellards

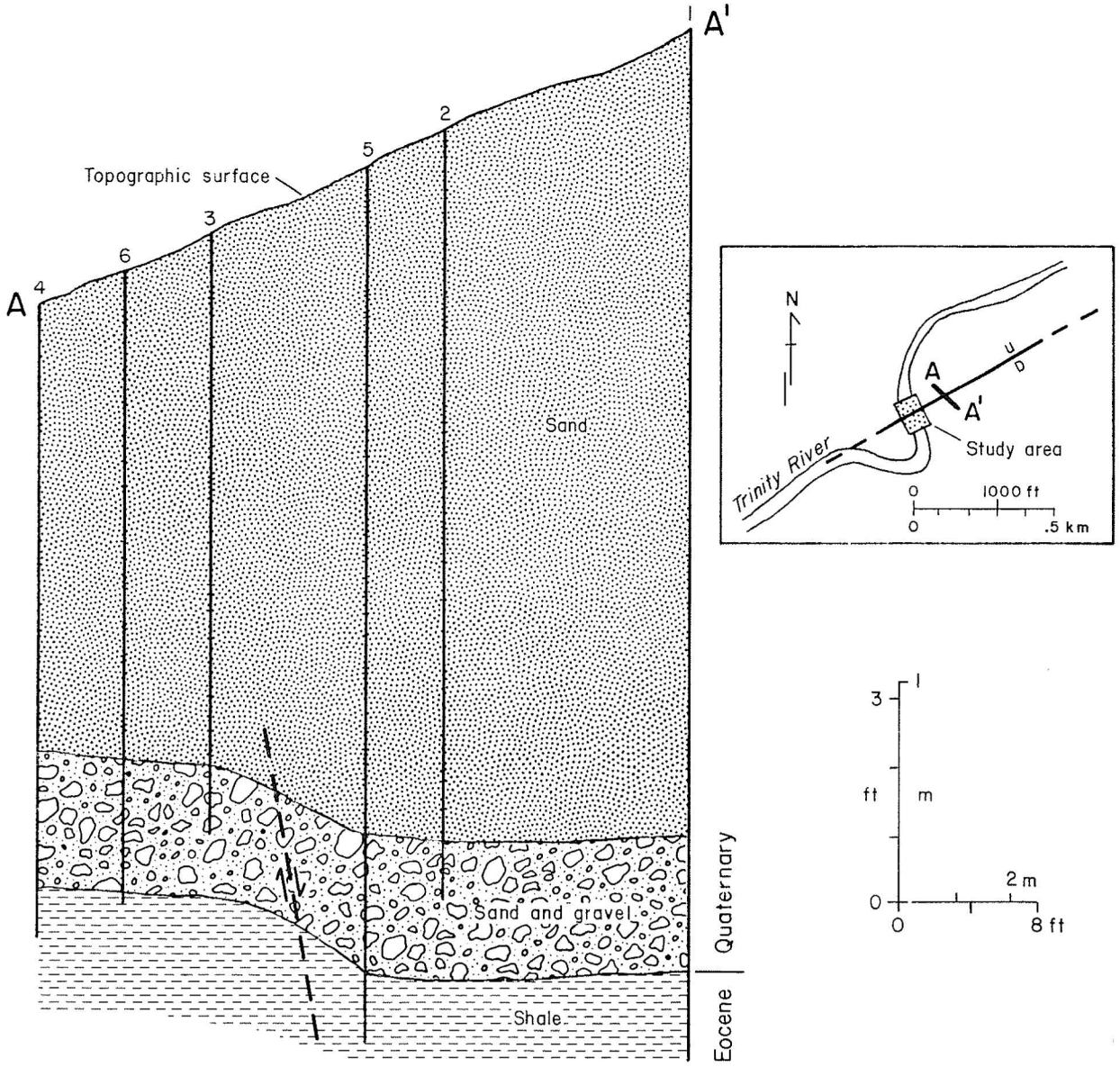


Figure 7. Displacement of gravel unit as revealed by power auger holes.

and Hendricks (1946), using contours of the top of the Lower Cretaceous Georgetown Formation, extended the northern fault of the Elkhart Graben directly beneath the study area. Stenzel (1938) mentioned a small fault in the vicinity. Quaternary surface lineaments visible on aerial photographs (fig. 8) trend east-west, comparable in direction to the Elkhart Graben faults. Subsurface data (fig. 9) confirm the extension of a fault system through the precise location of the Quaternary faulting. This fault system continues westward and appears to swing south of Oakwood Dome.

Age of the Faulted Quaternary Unit

Three terrace levels have been mapped along the Trinity River. The terrace deposit discussed herein belongs to the middle terrace level, as shown on the Palestine Sheet of the Geologic Atlas of Texas (Barnes, 1967). The thickness of this unit varies between 10 and 40 cm (4 and 16 inches). Its strata comprise subangular to rounded pebbles of vein quartz, chert, quartzite, silicified wood, and bone; the bone was too altered for radiometric age determination. Dating of Quaternary deposits in the northern part of the Trinity River drainage basin gives an age of 37,000 B.P. for the corresponding terrace level (Thurmond, 1968). The faulted Quaternary deposits thus appear to correlate with the late Pleistocene Beaumont Formation of the Gulf Coastal Plain, a widespread accumulation related to a Wisconsin interstadial.

Releveling Profile

Elevation releveling lines run by the National Geodetic Survey, extending through Jacksonville to Nacogdoches (fig. 10), indicate that approximately 130 mm of displacement across the Mt. Enterprise fault system occurred between 1920 and the mid 1950's (fig. 11). The break in the releveling line (Benchmark J69 to Benchmark H69) occurs along the southern edge of the fault system. Benchmark elevations on either side of the sharp break have remained relatively constant. The rapid differential subsidence between Benchmark J69 and H69 represents real movement and not measurement error. The sharp, localized deflection (fig. 11) suggests that continued movement along the regional fault system was responsible; this would account for nearly all of the crustal warping observed by Holdahl and Morrison (1974). Field checks in the area did not provide independent evidence, in the form of minor scarps or breaks in the highways, of very recent movement. A displacement of 130 mm in 30 years would probably not be observable because of continual road maintenance.

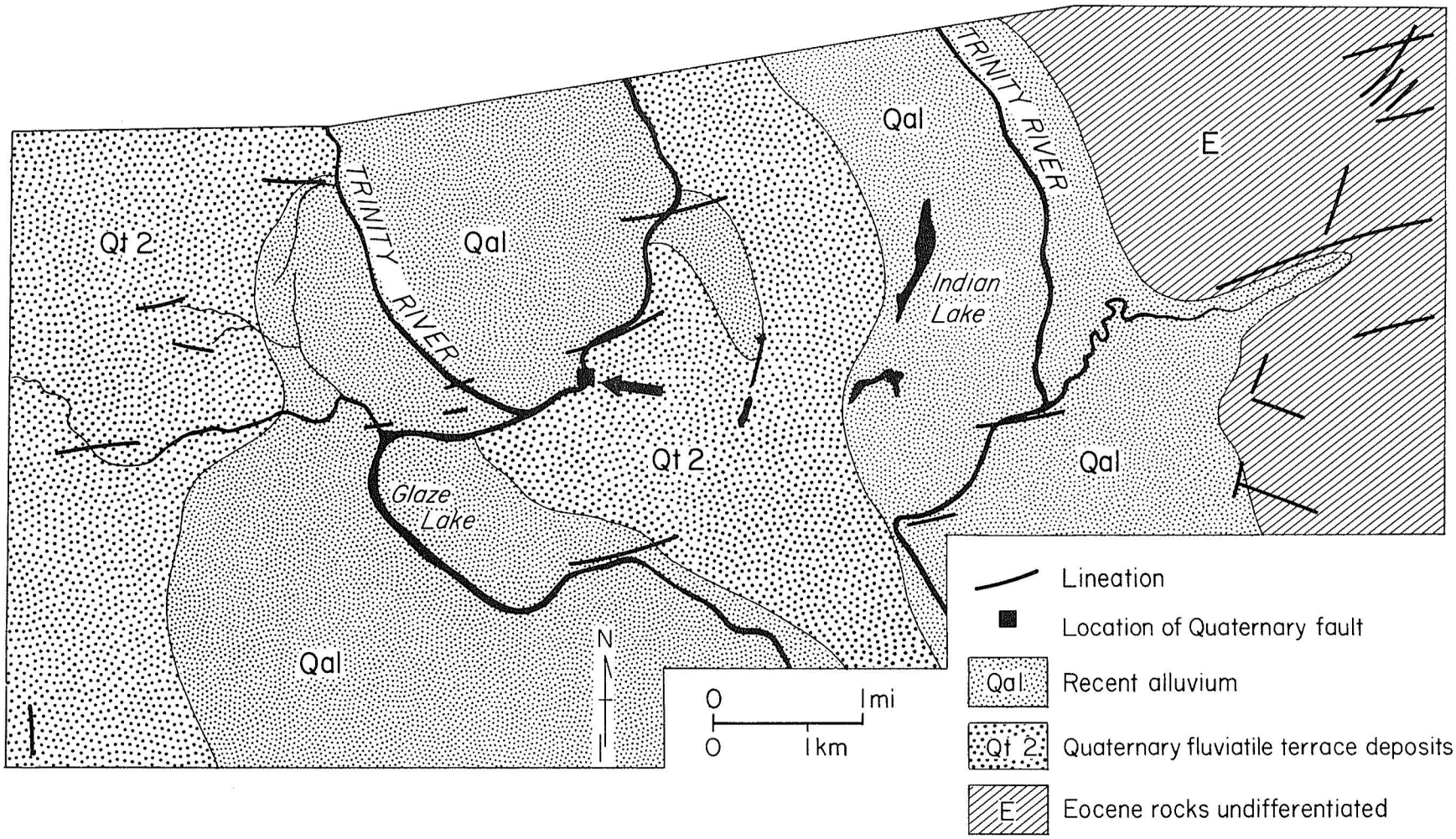


Figure 8. Geologic and aerial photograph lineation map of study area.

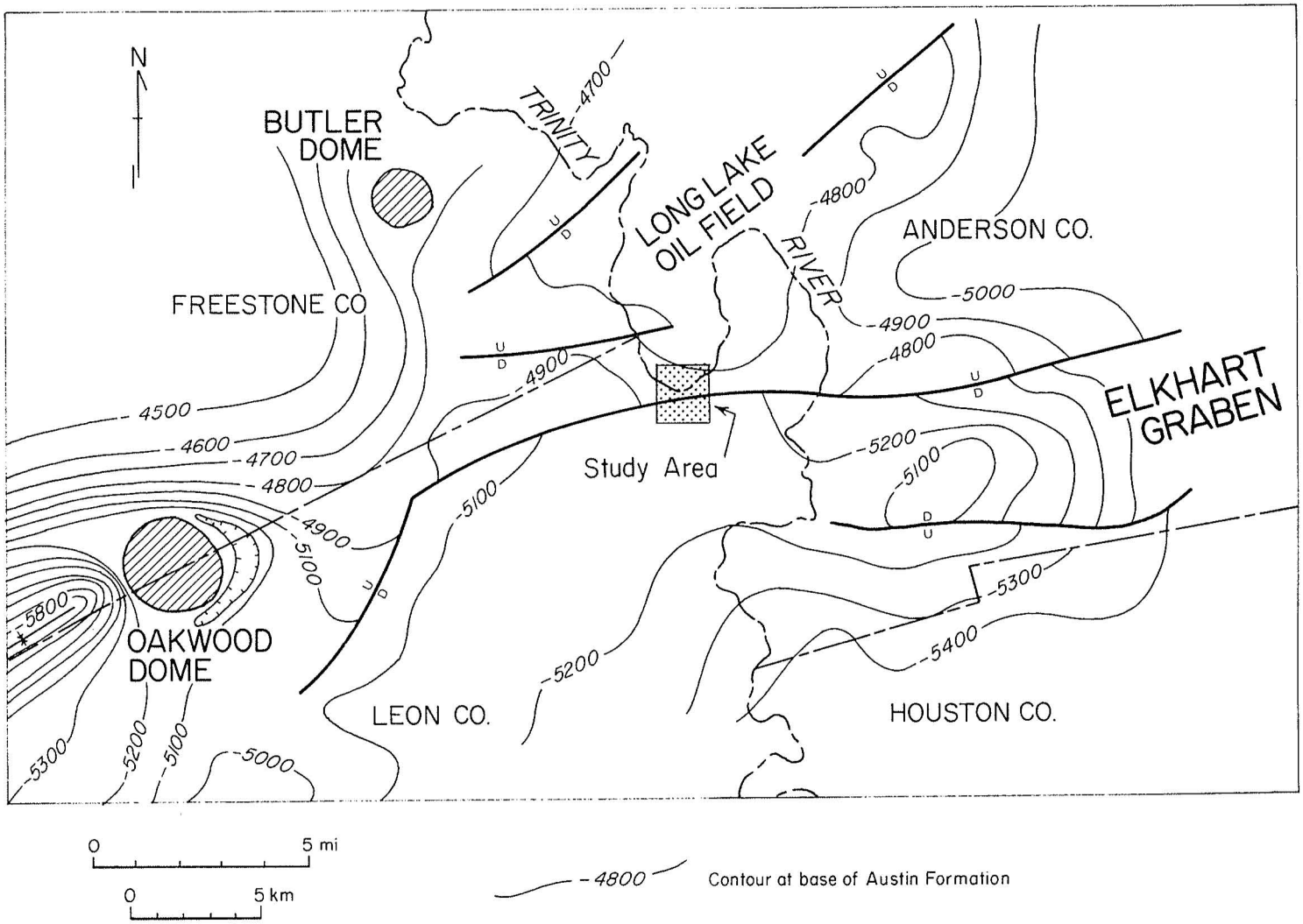


Figure 9. Structure map of study area with contours (in feet) at base of Austin Formation.

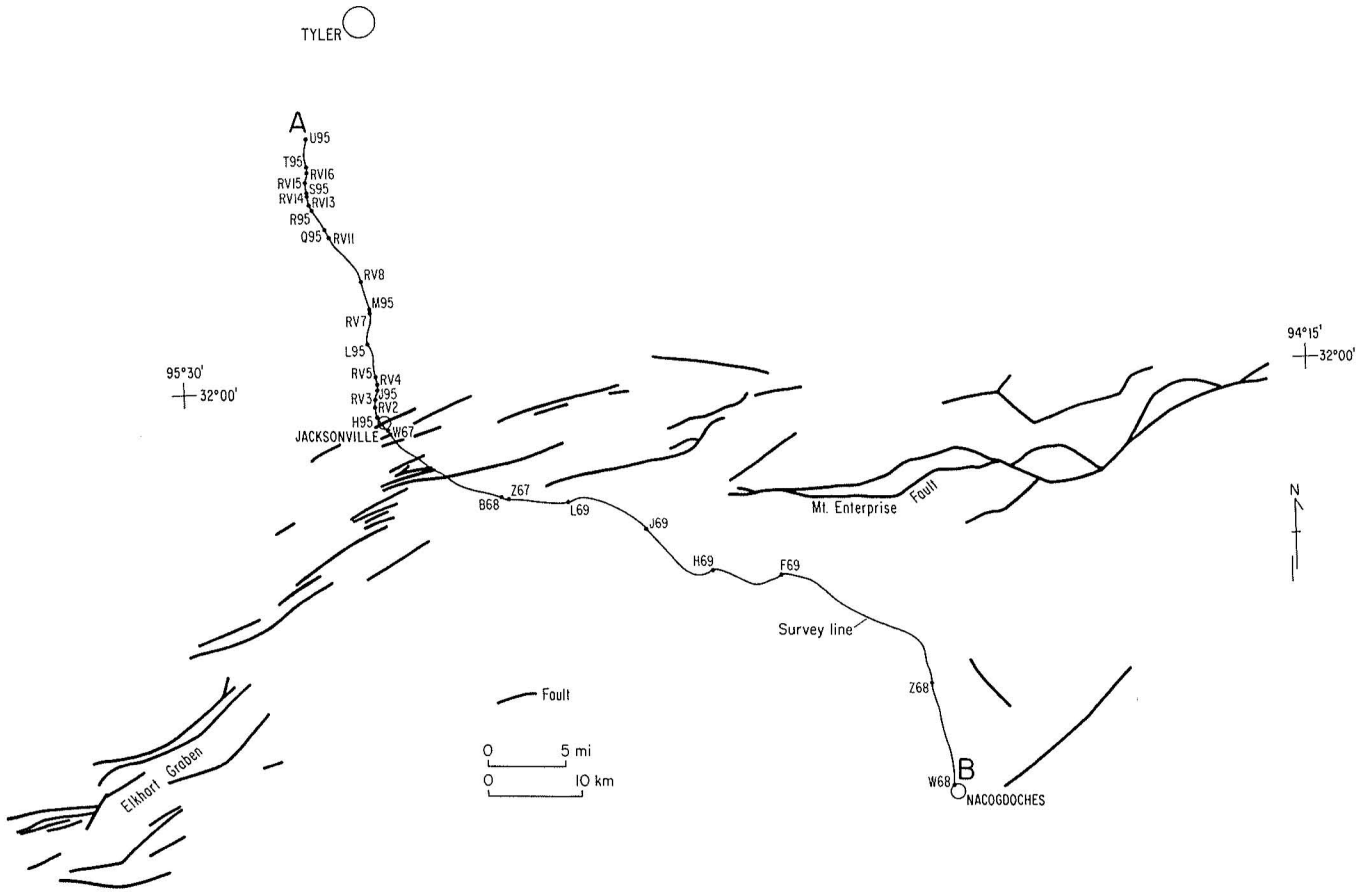


Figure 10. Location map for releveling profile across Mt. Enterprise fault system. See figure 11 for relative elevation changes.

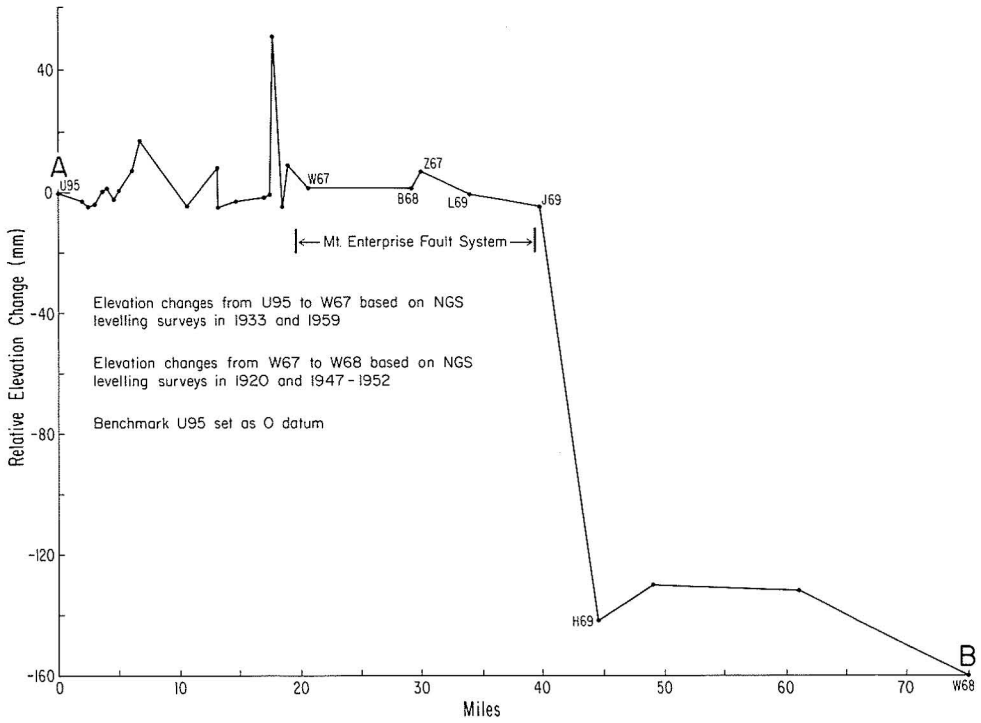


Figure 11. Releveling profile across the Mt. Enterprise fault system. Note relative elevation changes at southern edge of fault system, measured over approximately 30-year period. The profile is composed of two National Geodetic Survey lines, Benchmark U-95 to W-67, Texas 140 (1933 and 1959) and Benchmark W-67 to S-11, Texas 127 (1920 and 1947-1952). The two lines are tied at Benchmark W-67, which is north of the fault system.

Cause of Faulting

Three mechanisms might be responsible for the observed Quaternary faults: (1) subsidence due to fluid extraction, (2) salt movement, and (3) load-induced crustal warping.

Fluid extraction is confirmed as the cause of contemporary land subsidence and faulting in the area of Houston (Kreitler, 1976, and Verbeek, 1979, among others). The nearest producing well of Long Lake Oil Field (fig. 12) is located 2.5 km (1.5 mi) north of the faults; no producing or injection wells are located along the fault. For this reason it seems highly unlikely that fluid extraction was a triggering mechanism. Furthermore, there is no evidence of pronounced subsidence in the vicinity of Long Lake Oil Field, and the mean downthrow of the faults is away from the oil field, rather than toward it.

Faulting as a result of salt movement in the area of East Texas salt domes (fig. 4) appears to be unlikely. The Long Lake Oil Field (fig. 12) is on a structural high, probably a residual feature produced by salt withdrawal in adjacent areas. In this area, there is to date no structural and geomorphic evidence of Quaternary movement related to salt dome growth or solution collapse, apart from sinkholes induced by brine operations on Palestine Dome. Downdip salt flowage may have caused faulting early in the development of the basin, but cannot be regarded as a likely cause of Quaternary displacement because the sites of maximum sedimentary loading and associated salt movement migrated south of the study area in post-Eocene time.

Regional crustal warping resulting from differential rates of load subsidence is considered to be the most probable faulting mechanism. Warping generates a tensional stress field; flexure faults of the Mt. Enterprise-Elkhart Graben system formed along the hingeline between the East Texas Basin and the Gulf Basin. The sharp break in the subsidence profile at the southern edge of the fault system (fig. 11), indicating uplift of the East Texas Basin by 130 mm relative to the Houston Embayment, further supports the concept of faulting related to hingeline effects, rather than faulting resulting from local hydrocarbon production or salt flowage. Concentration of seismic activity in the area of the Mt. Enterprise fault system (fig. 13) may indicate that the process is still operative and is tied to continued sediment accumulation in the Gulf Basin.

The only "high damage" earthquake in East Texas was reported from Rusk, in 1891, and its occurrence has been questioned by Von Hake (1977). This event caused violent shaking of buildings and toppled chimneys in Rusk, but the fact that surrounding towns were unaffected has led to the opinion that the damage may have been produced by a severe storm. On the other hand, the sharp break in the releveling profile (fig. 11) is only 8 km (5 mi) from Rusk, and subsequent tremors have originated from the same vicinity. This suggests that the Rusk disturbance may indeed have been seismic. Unconfirmed large fractures were reported in 1900 by local inhabitants of Grimes County, approximately 100 km south of the fault locality (Russell, 1957). Fissures developed along straight lines over distances of about 1 km, with an east-northeast strike. These too may have been a product of hingeline effects.

Ten earthquakes of intensity V MM have been recorded in East Texas since 1891. On March 19, 1957, four shocks of intensity V MM occurred, with the epicenter on the Mt. Enterprise faults (fig. 13). Shocks of intensity I-V were felt over an area of 26,000 km^2 (10,000 mi^2), and the towns of Elkhart, Gladewater, Marshall, Nacogdoches, and Troup all recorded intensity V (U.S. Coast and Geodetic Survey, 1957).

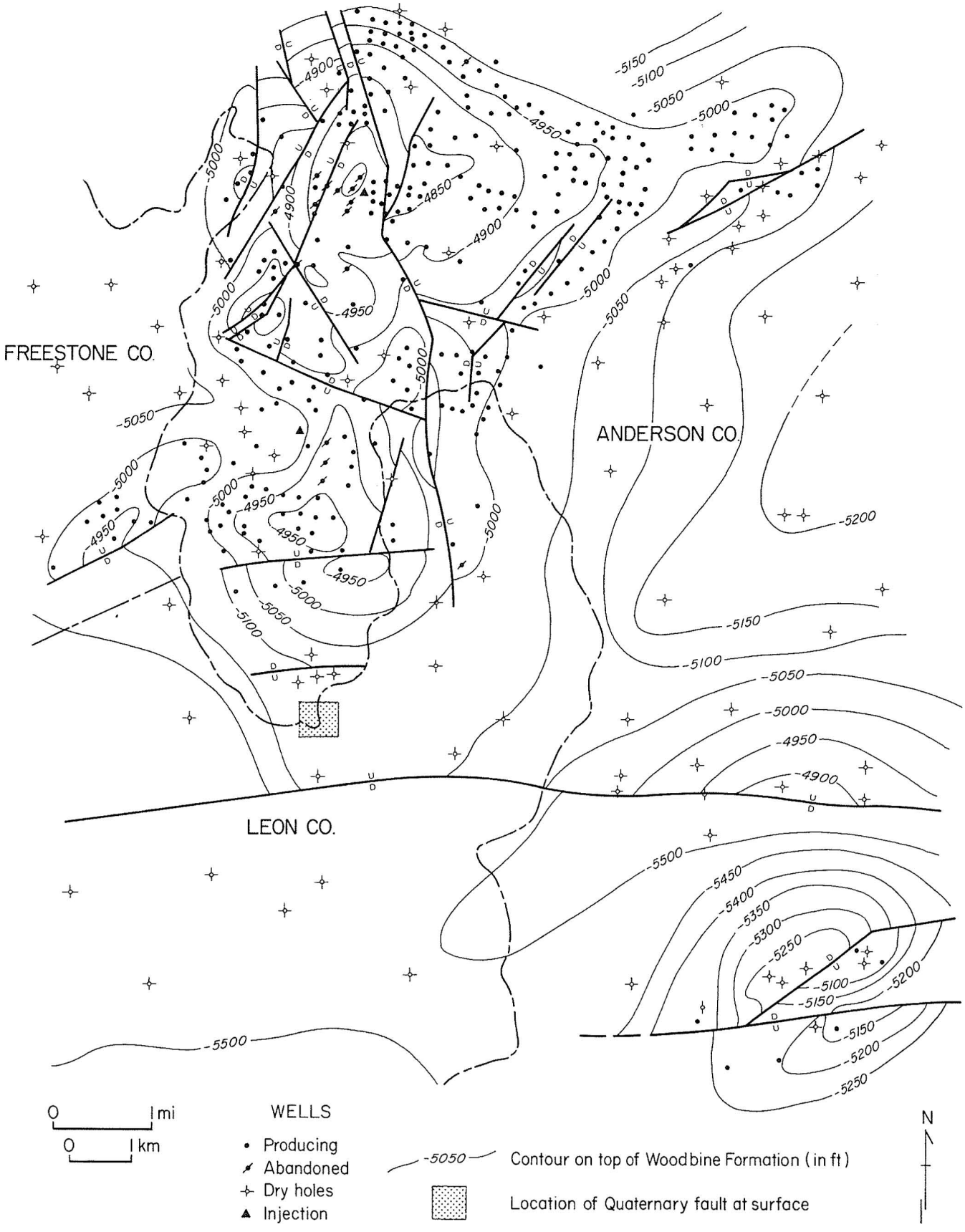
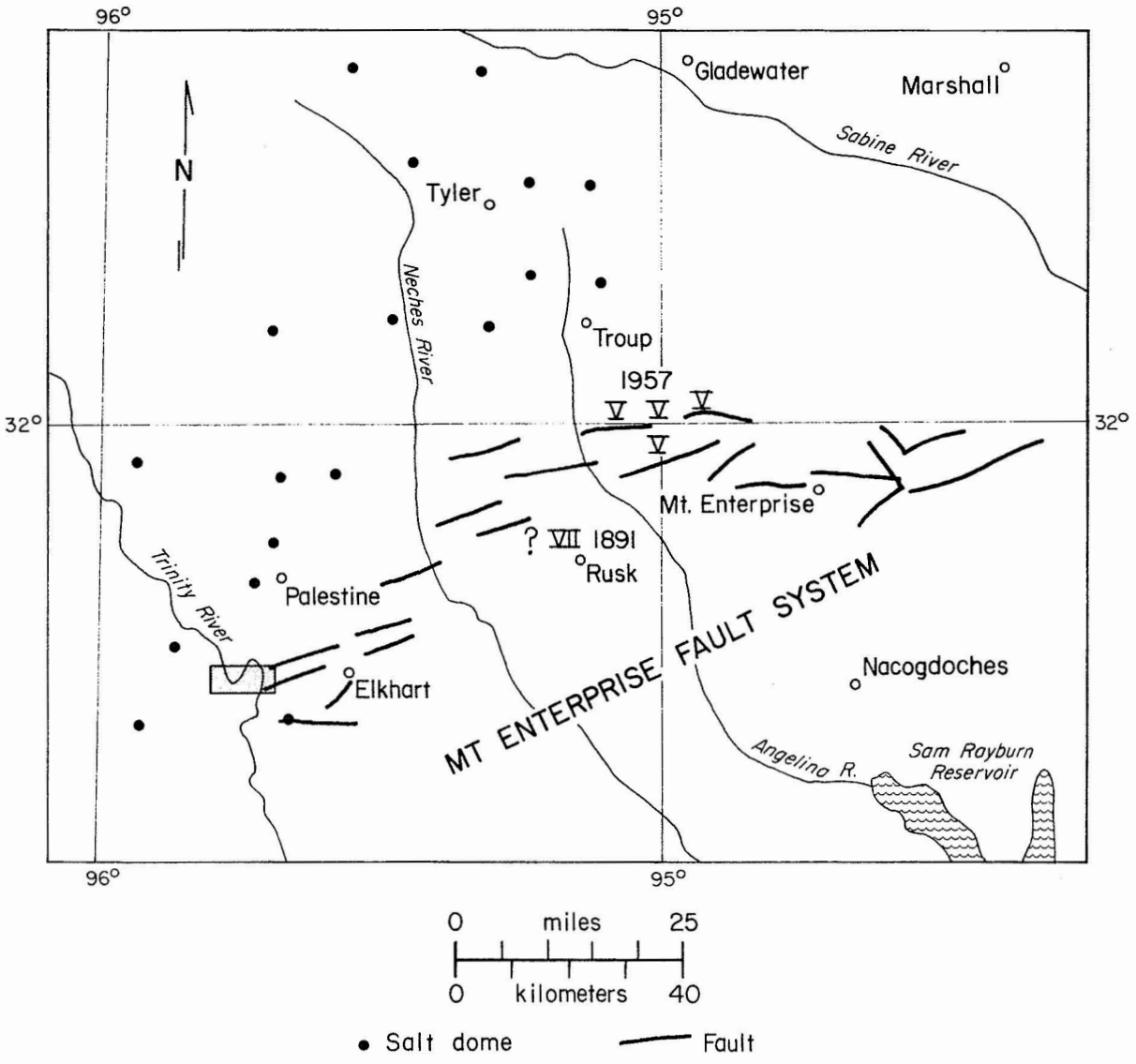


Figure 12. Structure map of Long Lake Oil Field with contours (in feet) at top of Woodbine Formation. Contours modified from Schmidt (1950) and Schoeneck (1950). Wells updated to 1978.



V 1957 Epicenter of four earthquakes that occurred on March 19, 1957

VII 1891 Epicenter of "questionable" Rusk earthquake that occurred on January 8, 1891

Figure 13. Earthquake distribution along Mt. Enterprise fault system (from U.S. Coast and Geodetic Survey, 1957).

CONCLUSIONS

In Leon County, Texas, faults previously considered to have been inactive since early Tertiary have been reactivated during the Quaternary. Maximum throw of 66 cm has occurred on one fault that displaces Quaternary sediments possibly as young as 37,000 B.P.

These faults are part of the Mt. Enterprise-Elkhart Graben system, which is located along a zone of crustal warping separating the older East Texas Basin from the subsequently active Gulf Basin. Greater than normal seismic activity has been associated with this structural trend, suggesting that the driving mechanism involving crustal warping may still be operating. This hypothesis is supported by releveling data that show a relative movement of 130 mm on another section of the Mt. Enterprise fault system, indicating that the fault system has been active during the past 30 years.

Although rates of Quaternary fault displacement have been low, these faults do have important implications to the evaluation of certain East Texas salt domes as repositories for nuclear waste. Oakwood Dome, one of the potential repository sites, is situated 12.5 km to the west-southwest in the direction of the fault trend.

ACKNOWLEDGMENTS

This work is funded by the Office of Nuclear Waste Isolation, contract number DE-AC97-79 ET-44605. We benefited from discussions with G. E. Fogg and R. O. Kehle. Alice Giles helped construct figure 9. M. P. A. Jackson provided insight into some of the structural complexities. The manuscript was reviewed by V. E. Barnes, W. R. Kaiser, and R. Sharpe.

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