

Integrated Geophysical Studies Over an Active Growth Fault in Northwest Houston, Texas

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Active growth faults cutting the land surface in the Gulf Coast area can represent a serious geo-hazard. Considering that the average movement of these faults can be as high as a few inches per decade, the potential exists for structural damage to highways, industrial buildings, residential houses and railroads that cross these features.

Common methods to identify these faults include mapping from aerial photographs and field work; subsurface borehole data (on both the down- and upthrown sides of the faults) including geophysical logs, core and other borehole data; and geophysical surveys including gravity, magnetics, resistivity and conductivity. Historically, the geophysical techniques have not been widely used in engineering-scale fault studies because of concerns about their effectiveness.

However, in the past 10 years advances in the quality of the geophysical instruments and consequently the quality of the data produced have made geophysical methods viable tools for characterizing these faults. Data quality has been significantly improved by the advent of continuous data collection. More advanced software has improved data processing, leading to better subsurface imaging and interpretation.

To test the ability of geophysical techniques to characterize faults, we designed an integrated geophysical survey using ground penetrating radar (GPR), resistivity imaging, magnetics and micro-gravity over the Hockley and Willow Creek faults located in northwestern Houston, Texas. Results of this investigation indicate that all methods successfully imaged significant mappable anomalies across the known fault locations.

Introduction

The coastal plain of the Gulf of Mexico (GOM) is underlain by a thick sequence of largely unconsolidated, lenticular deposits of clays and sands (Kasmarek and Strom, 2002). Growth faults are common throughout these sediments. Based on a study of borehole logs and seismic reflection data, many of the larger of these faults have been mapped to depths of 3,000 feet to 12,000 feet below the surface (Kasmarek and Strom, 2002). Most of these faults are associated with natural geologic processes such as differential compaction and salt movement and many have been

active since the Cretaceous. Some of these faults, distributed throughout the coastal plain of the GOM, are currently active and disturb the ground surface (Clanton and Verbeek, 1981).

The Houston area has a very active shallow fault system, as evidenced by surface movement and measurable localized subsidence (Verbeek and Clanton, 1981). Evidence of faulting is visible from structural damage such as fractures and displacement of the ground surface. Fault displacement is predominantly

normal, dip-slip and listric, with most growth faults south-dipping (synthetic) and some north-dipping (antithetic). Some faults are clearly active today and disrupt the surface, causing damage to streets and creating scarps across lots, fields and streets.

The faults that are active today can be the source of damage to pavements, utilities, homes, businesses and other man-made structures in the Gulf region. In the Houston area alone (Harris County), there are more than 300 active or potentially active faults totaling over 300 miles in length (Clanton and Verbeek, 1981). These

faults are often zones of sheared ground tens of meters wide rather than discrete breaks in the surface.

This paper presents and evaluates the use of four noninvasive geophysical methods for imaging the Willow Creek growth fault that cuts across Highway 249 in the northwest Houston, Texas, area (Figure 1).

Geophysical Instruments and Field Survey Design

Ground penetrating radar (GPR), resistivity imaging (2-D and 3-D), magnetic and micro-gravity methods were customized for this study. We used an SIR 2000 GPR unit with a 400-MHz antenna that, considering the soils, was estimated to have a maximum depth of investigation of 8 feet in the study area. A Geometrics G-858 cesium vapor magnetometer allowed automated data collection with samples recorded every 0.2 seconds (or 5 Hz), corresponding to a data point about every 1/3 meter.

Micro-gravity data were acquired using a La Coste & Romberg G-Meter, SN-670. The gravity station spacing was 10 feet across the fault scarp and 20 feet away from the fault scarp. Data were tied to three gravity

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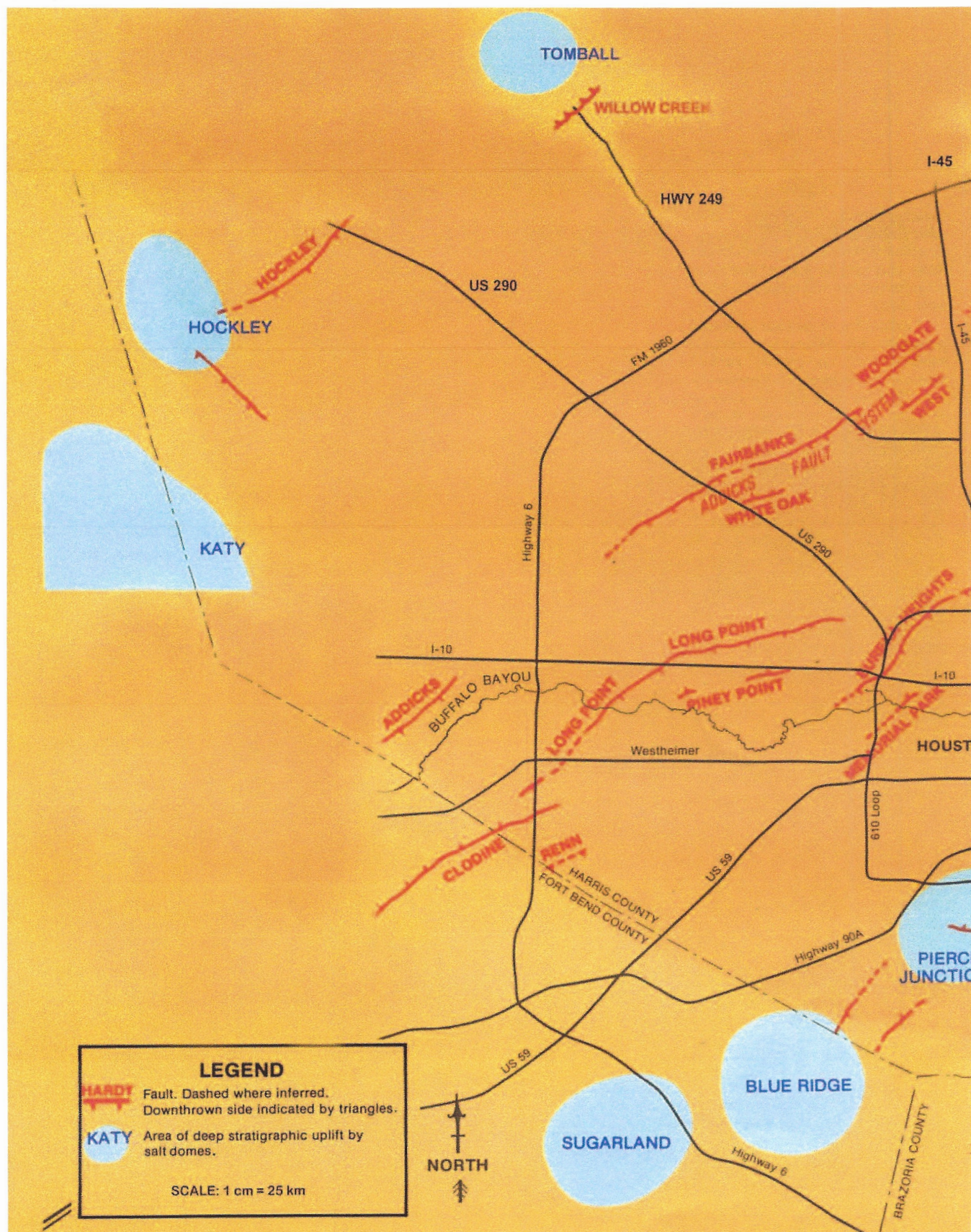


Fig. 1. Willow Creek fault site location, annotated as a green ellipse (after Elsbury et al., 1981).

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Willow Creek Fault

Schematic map over Willow Creek Fault showing location of geophysical profiles. Gravity and magnetic data were collected along Line 2 (L2).

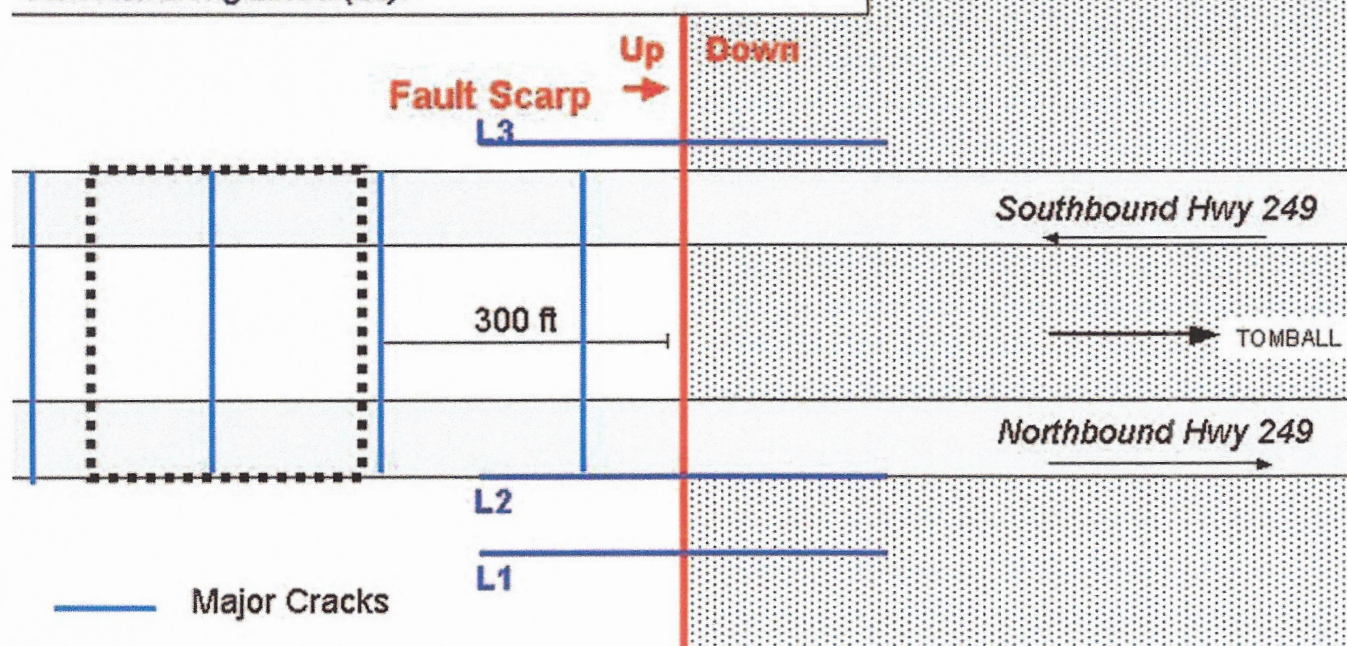


Fig. 2. Schematic map of Willow Creek Fault at Willow Creek Bridge. The thinner blue lines indicate fracture traces. Resistivity data were collected along lines L1, L2, and L3 (dark blue). Microgravity and magnetic data were collected only along line 2 (L2).

base stations located at 1) a building formerly used by Photogravity, Inc. in Houston, Texas; 2) the Willow Creek site; and 3) an intermediary location in Spring, Texas. Having three stations allowed for rapid gravity base station re-occupations and increased gravity data repeatability (< 0.04 mGals) throughout the survey.

For the resistivity survey we used an AGI Super R1 Sting/Swift automatic resistivity unit with a dipole-dipole array of 28 electrodes. This arrangement increases the sensitivity to horizontal changes in the subsurface and provides a 2-D electrical image of the subsurface geology. Electrode spacing was held to 3 meters along all profiles.

Geophysical Results

The Willow Creek Fault crosses Highway 249 about 300 feet north of the Willow Creek Bridge, where it trends in the NE-SW direction and dips to the north (Figure 2). This fault is listric and antithetic to the south-dipping regional Tomball Fault about 5 miles to north. A discrete pavement break crossing both south- and north-bound lanes of Highway 249 clearly marks the presence of the fault (Figure 3).

Many fractures adjacent to and across the bridge may be related to the fault. A GPR survey profile near the north end of the bridge (Figure 4) indicates a significant disturbed zone next to the bridge. We also collected GPR data across the fault scarp, which is visible on the road (see the fault scarp in Figure 3); but the GPR data did not show any anomaly across this scarp. However, the GPR data did detect differential subsidence between the bridge

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Fig. 3. View looking east of the trace of the Willow Creek fault as it crosses Highway 249. The fault is marked by the pavement cracks and asphalt patches.

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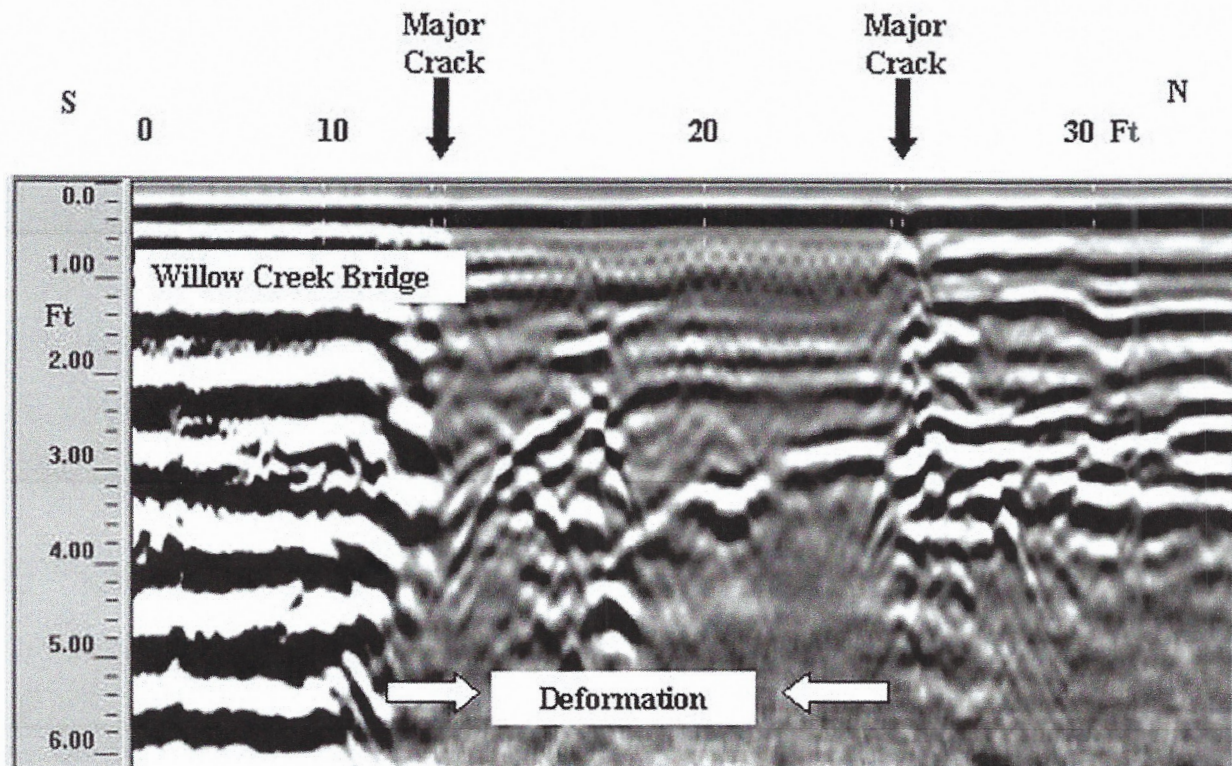


Fig. 4. GPR data taken adjacent to the northern end of the Willow Creek Bridge. Similar GPR results were also obtained at the southern end of the bridge.

Willow Creek Fault

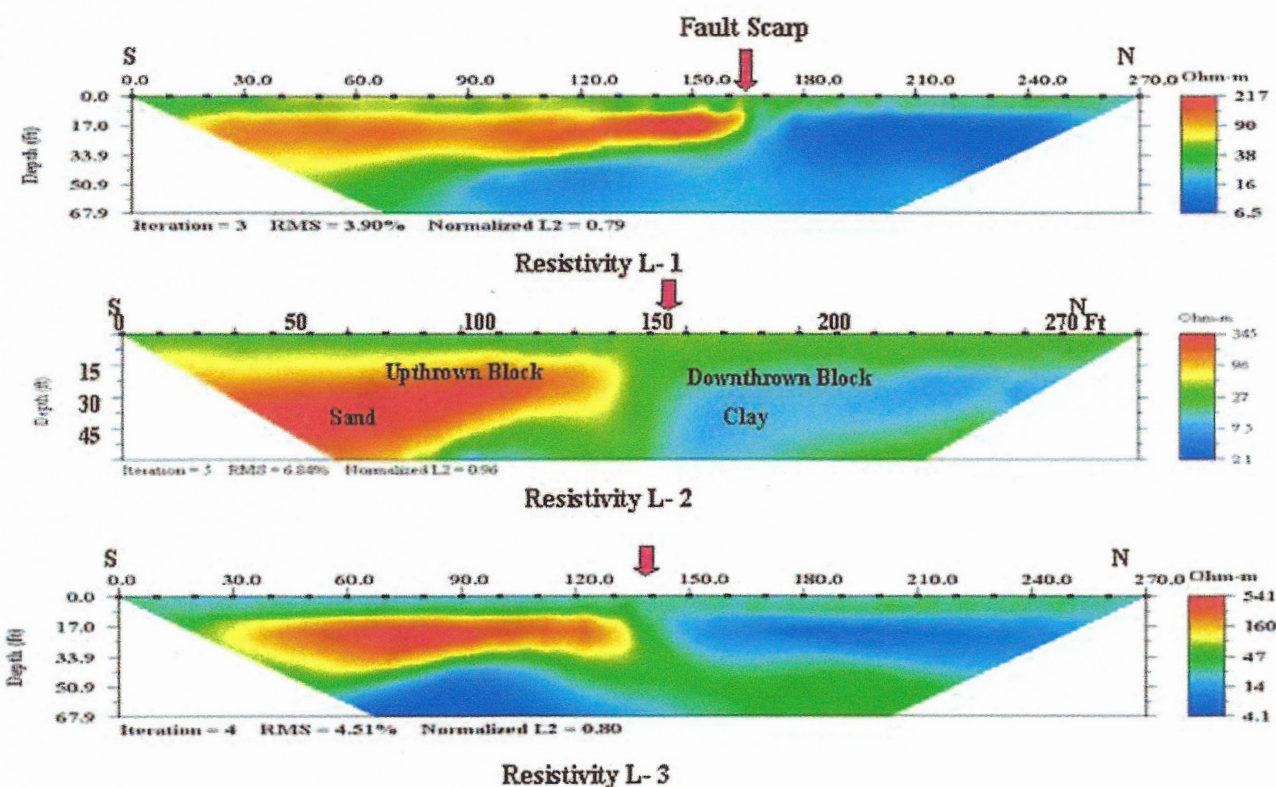


Fig. 5. 2D resistivity profiles L1, L2 and L3 taken along the east- and west-bound lanes of Highway 249 across Willow Creek fault.

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Inverted Resistivity Image

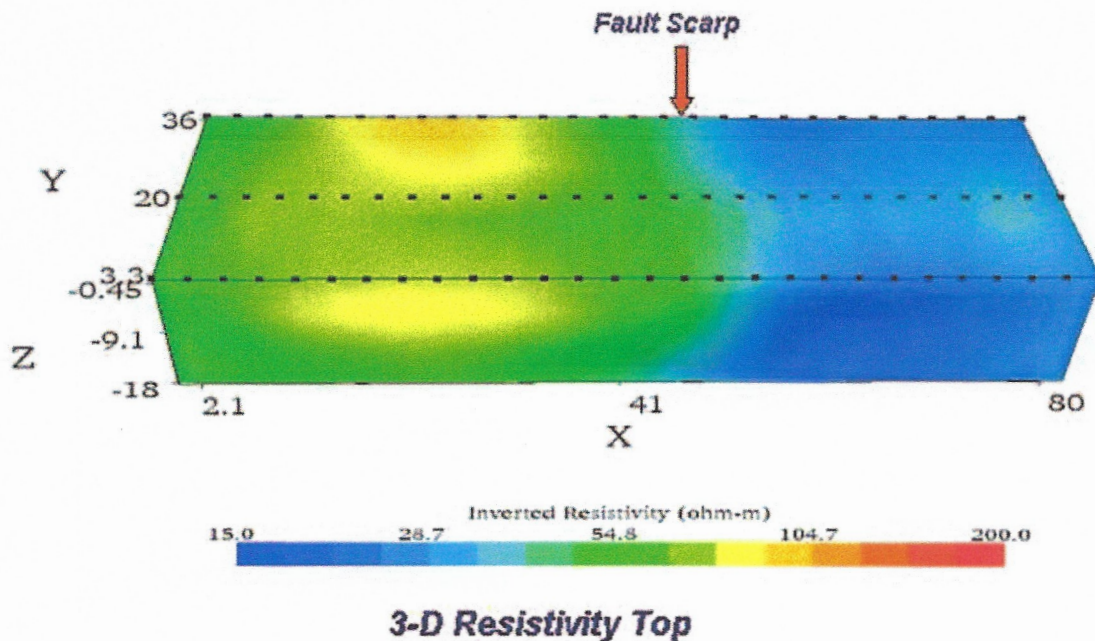


Fig. 6. Inverted 3D resistivity image of the Willow Creek fault.

and the footing, as seen in the disturbed zone adjoining the bridge that may be related to movement on the Willow Creek Fault.

2-D resistivity data (three profiles) collected across the fault along Highway 249 indicate a sharp resistivity contrast over the fault scarp (Figure 5). This contrast may be caused by a combination of increased moisture content and changes in the clay content of the subsurface lithology on the downthrown side of the fault. Increased surface moisture has been observed on the downthrown side of the Willow Creek Fault on every visit to the site.

A 3D resistivity image (Figure 6) was created by combining the three (L1, L2 and L3) resistivity profiles. The fault trace observed at the site corresponds to a plane of significant resistivity contrast in the 3D block diagram. Note the low resistivity on the downthrown (north) side, interpreted to be indicative of more clayey soil with respect to the upthrown block.

Micro-gravity and magnetic data (Figure 7) were acquired along resistivity line 2 (L2 in Figure 2). The simple Bouguer gravity data are referenced to the IGF 1967 and the GRS 1967. The data were terrain and elevation corrected using elevation from a Berger/CST auto-level tied to local reference and bench marks. A Bouguer correction density of 2.2 g/cc was used for the shallow, unconsolidated sediments. Micro-gravity data were filtered using a 20-ft low-pass filter. Data can be interpreted to indicate a gravity high that is correlated to the downthrown side of the fault. The magnetic data, reduced to pole and filtered using a 20-ft low-pass filter, show a magnetic low on the downthrown side of the fault.



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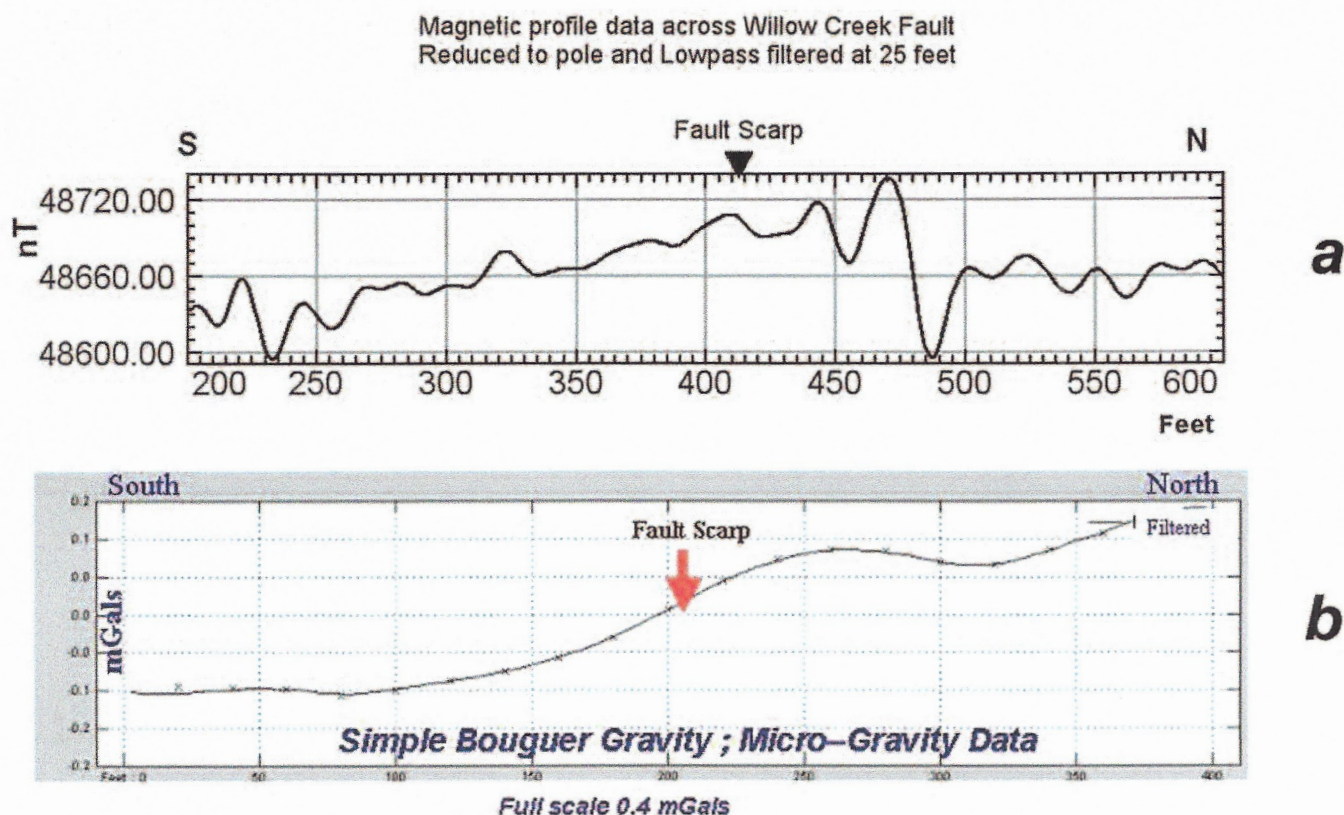


Fig. 7. Comparison of a) magnetic and b) gravity data across Willow Creek fault. Note the gravity high on the downthrown side. The regional gravity field has not been removed.

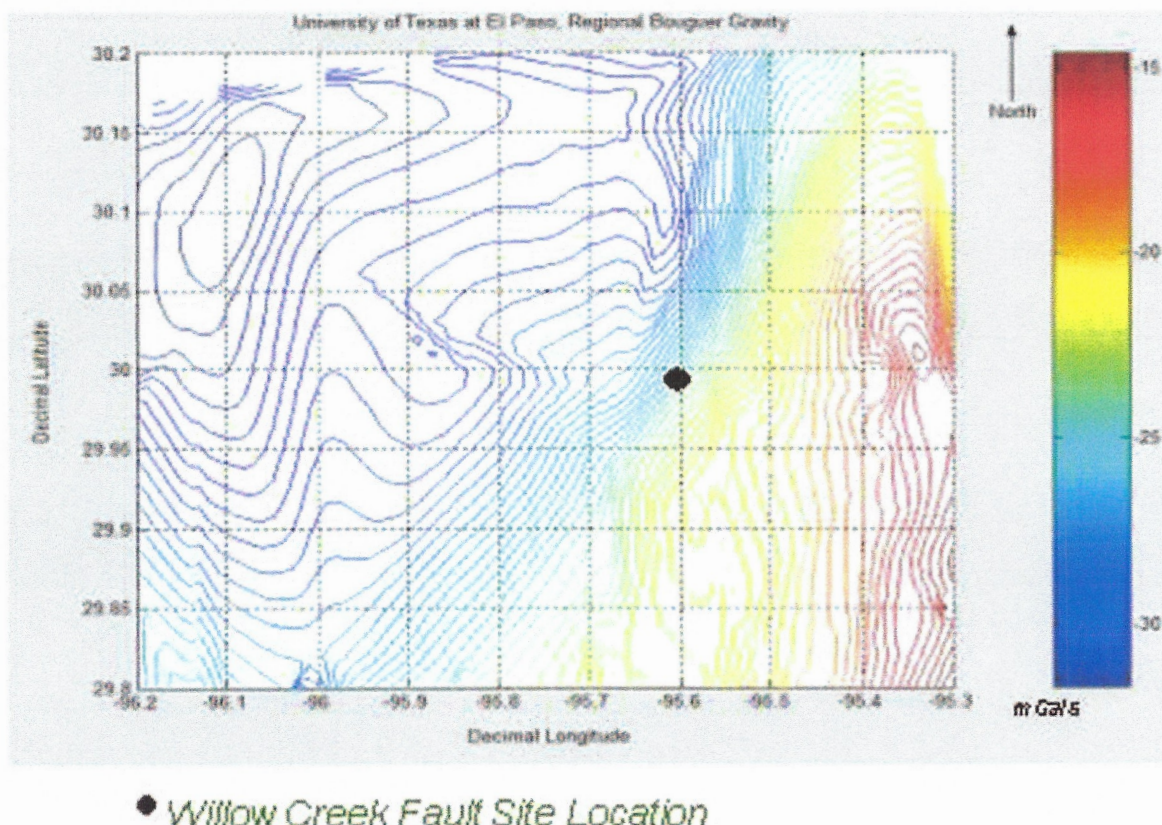


Fig. 8. Map showing University of Texas El Paso regional complete Bouguer gravity of NW Houston. Note the steep gravity gradient at the location of the Willow Creek fault site.

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The fault location interpreted from the magnetic and gravity data correlates very well (+/- 5 feet) with the location of the pavement break (fault scarp) observed on the ground.

Gravity data across the fault have been modeled and interpreted using the analog equation for a thin fault, the thin-slab equation (Dobrin, 1976), and Talwani-type 2-D modeling (Talwani et al., 1959). The results obtained from the thin-slab equation and analog equation for a thin fault indicate that the vertical throw for the shallow fault at Willow Creek could possibly be as small as 10 ft whereas the main fault appears to have a vertical throw of approximately 60 ft. The full vertical throw of the fault is not detectable on the micro-gravity data whereas it appears detectable in the regional data (Figure 8). This difference is due to the scale of the feature detected by the micro-gravity versus that of the feature detected by the regional gravity. The regional gravity field was not removed from the micro-gravity because we are attempting to detect an extremely low-amplitude (< 0.25 mGal) effect.

Discussion of Results and Conclusions

The geophysical data are interpreted to indicate that significant anomalies exist within the known Willow Creek Fault zone. The 2-D and 3-D resistivity data appear to indicate the downthrown side of the fault is less resistive than the upthrown side; i.e., sand on the upthrown side is juxtaposed against either sandy clay or sand with a higher moisture content. A gravity high observed in the micro-gravity data on the downthrown side of the fault may be caused by increased compaction of the downthrown sediments compared with the upthrown. The GPR survey imaged a shallow disturbed zone next to the Willow Creek Bridge. The magnetic data indicate a well-defined low on the downthrown side of the fault, indicating that shallow sediments of similar magnetic susceptibility ($< 200 \times 10^{-6}$ cgs units) are offset by a small fault (< 20 feet offset).

In conclusion, data acquired and used to evaluate the effectiveness of geophysical methods in detecting faults in the northwest Houston area successfully imaged anomalies (contrasts) across a mapped fault zone. Although it is not yet clear that these methods could be used independently to map faults, it is very likely that they can be used to map extensions of known faults, at least in certain areas. Further studies of the geophysical response of these shallow faults will increase interpretation confidence and should eventually lead to more routine use of these methods for detecting and characterizing these important features. Depending on site conditions, future fault studies should consider using as many of the geophysical techniques described here as possible to both improve and extend characterization of the shallow subsurface. ■

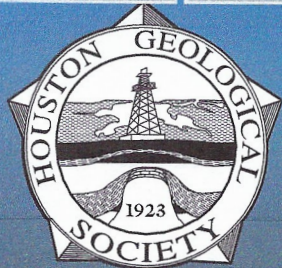
Acknowledgments

We thank Bob Neese of Gravity Map Service, Inc. for providing the La Coste & Romberg G-670 meter. We also thank Dr. Carl Norman for showing us the faults in the field and a number of friends and colleagues who helped in the data acquisition. This project was funded by Environmental Geophysics Associates and Earth-Wave Geosciences, LLC.

This paper was originally published in *The Leading Edge* (Saribudak and van Nieuwenhuise, 2006). We are grateful to the SEG for permission to reproduce it (with changes) in this *Bulletin*.

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HGS Bulletin

Volume 49 Number 9

Houston Geological Society

May 2007

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