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Near Surface Geophysical Studies of Houston Faults

Engelkemeir, Richard; Khan, Shuhab

Over 300 active gravity-driven faults intersect the earth's surface in the Houston Metropolitan area on the northern edge of the Gulf of Mexico basin. These surface faults have caused damage to roads, pipelines and buildings. LIDAR has proved to be an effective tool for mapping fault scarps and topographic changes related to potential faults. Near-surface techniques such as seismic and GPR have proven effective as an aid in determining whether topographic features that resemble scarps are faults or related to some other natural or anthropogenic surface features.

Background

The northwestern coast of the Gulf of Mexico, including the Houston area, contains many active surface faults. These faults are a consequence of regional depositional tectonics of the Gulf of Mexico basin with many active during the last two centuries. Gulf Coast extension began with Triassic rifting followed by sea-floor spreading during the middle Jurassic. Most active growth faulting occurs at the prograding shelf margin. Even though Houston has not been on the shelf margin since the Oligocene, fault activity has not ceased. The vertical extent of ongoing slip is not precisely known. It may be limited to the near-surface, but surface slip could be coupled with episodic slip at depth. Fault slip in this area also shows temporal variability as well as spatial variations in both strike and dip directions. The depocenters along the northwestern coast of the Gulf of Mexico resulted from sediment deposition prograding into the basin (Figure 1).

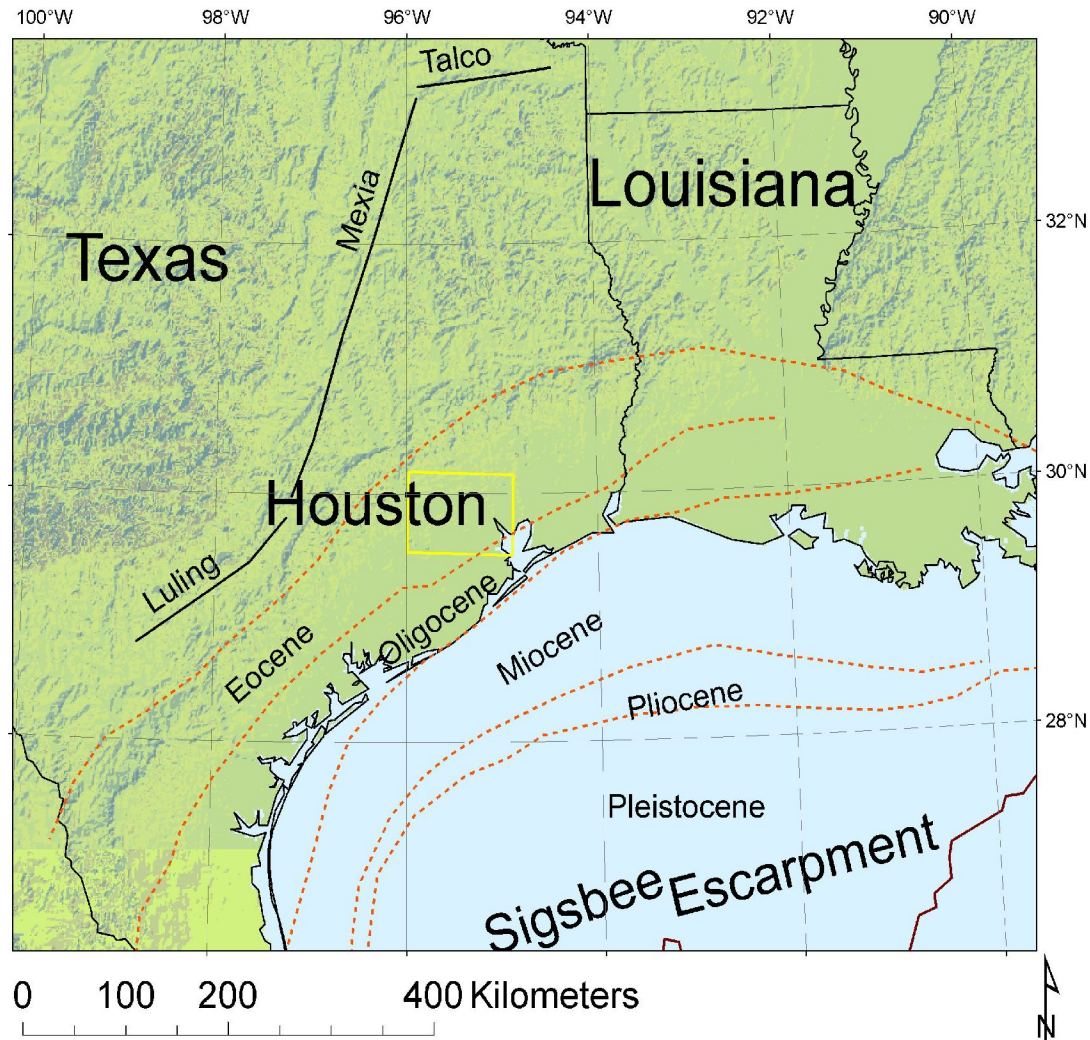


Figure 1) Regional map, showing the northwestern Gulf of Mexico. Red dashed lines show the eastward migration of depocenters. The salt basin extends from the Luling-Mexia-Talco fault zone to the Sigsbee escarpment. The yellow rectangle shows the study area which is detailed in Figure 2.

These growth faults are predominately down to the coast representing extension into the basin. Antithetic surface faults in Houston are found downdip of the most active sections of down to the coast faults. Many of these antithetic faults are currently active. Fault slip can be as great as 1 inch per year. Some of the surface fault scarps have been correlated with deeper subsurface faults. The faults define a regional southwest to northeast trend. As interpreted

from LIDAR images, faults in northwest Houston follow the regional trend, while salt dome related faults interfere with the regional trend in southeast Houston (Figure 2).

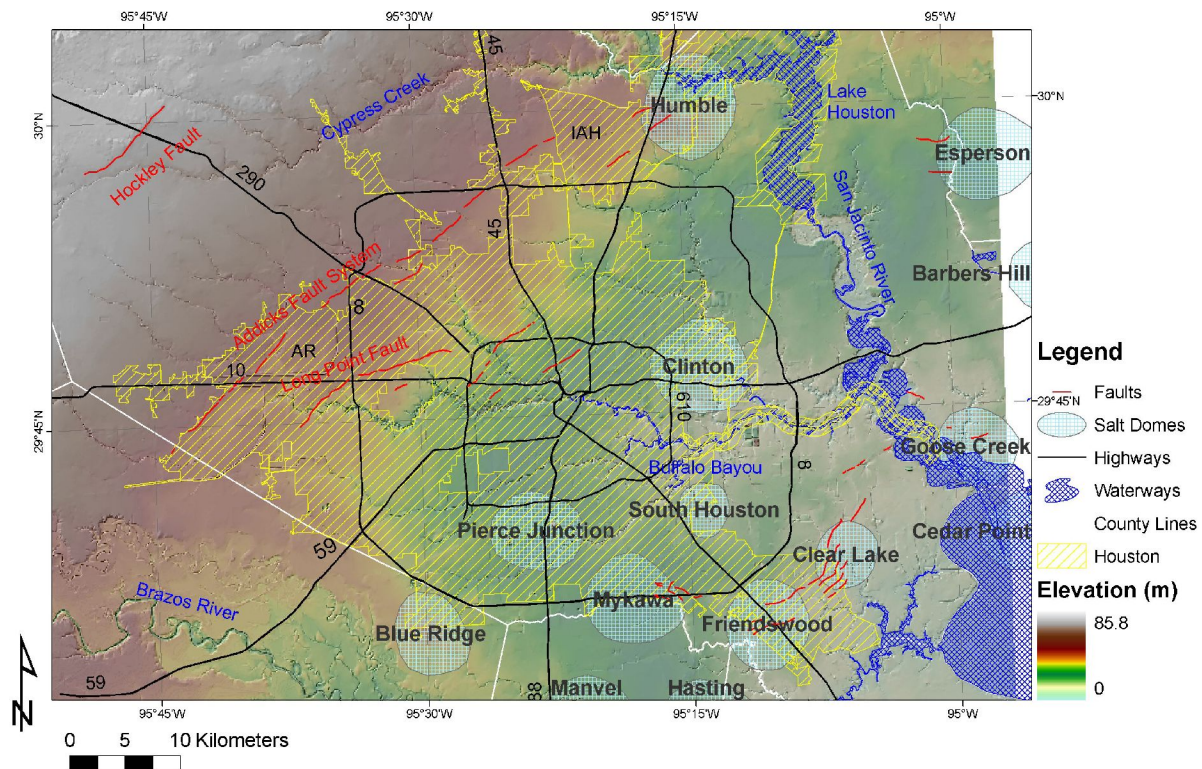


Figure 2) Houston area map showing active surface faults interpreted on LIDAR imagery and the locations of salt domes. Houston is in Harris County and most of Harris County is visible. Note that the faults in northwest Houston have a NE-SW trend while some faults in southeast Houston radiate from salt domes. Salt domes are taken from O'Neil and van Sicken (1984).

Major faults of northwest Houston are shown:

Hockley Fault

Addicks Fault System

Long Point Fault

The interaction between active surface faults and subsidence due to groundwater withdrawal has been debated, with some attributing fault activity to groundwater withdrawal. Others see little spatial or temporal correlation between fault activity and surface subsidence features.

LIDAR

LIDAR stands for Light Detection and Ranging (analogous to RADAR, but with laser light as a source). A laser beam is directed towards the ground as the survey aircraft flies over the area. The laser beam is pulsed so that the time between the pulse and measured reflection can be used to determine the distance between the instrument and the ground. Inertial guidance and GPS units track and record the position and orientation of the airborne platform. The two-way laser travel time, IMU and GPS are integrated to determine the x, y, z position of each reflection. The result is a large number of x, y, z points (Figure 3).

Processing is required to remove points from non-ground returns such as vegetation and buildings. The LIDAR data used here was gathered in association with the Tropical Storm Allison Recovery Project (TSARP). Tropical storm Allison produced up to 39 inches of rain over a 5 day period in June of 2001. The TSARP study was conducted to better map drainages and flood-prone areas.

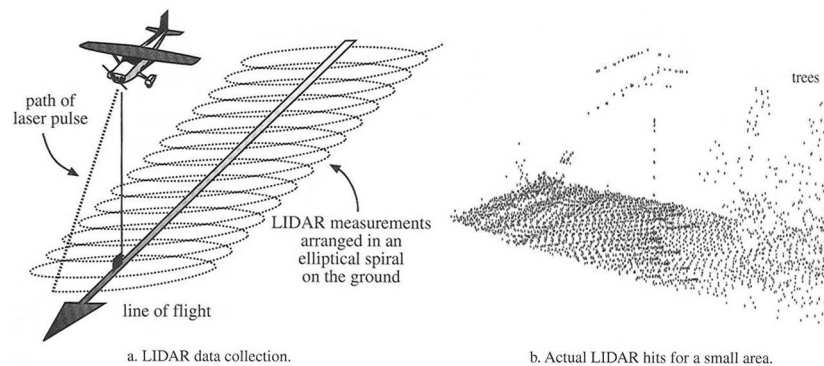


Figure 3) Basic principles of LIDAR data acquisition. The location and motion of the aircraft is tracked to produce the LIDAR point cloud of x, y, z locations.

LIDAR points are used to define a Digital Elevation Model grid (DEM) for the region being surveyed. A DEM is a grid of elevation values used to define the bare earth surface (no buildings or vegetation). TSARP LIDAR data generated a DEM with 15-foot (5 m) cell sizes. Refined 5-foot (1.5 m) DEM grids provided further detail for interpretation. Hillshaded

images derived from the DEM grids proved most effective for interpreting elevation contrasts (Figure 4). Hillshaded LIDAR images from the TSARP DEM proved quite effective in locating even small surface fault scarps (generally less than a meter of throw) in the Houston area (Figure 5).

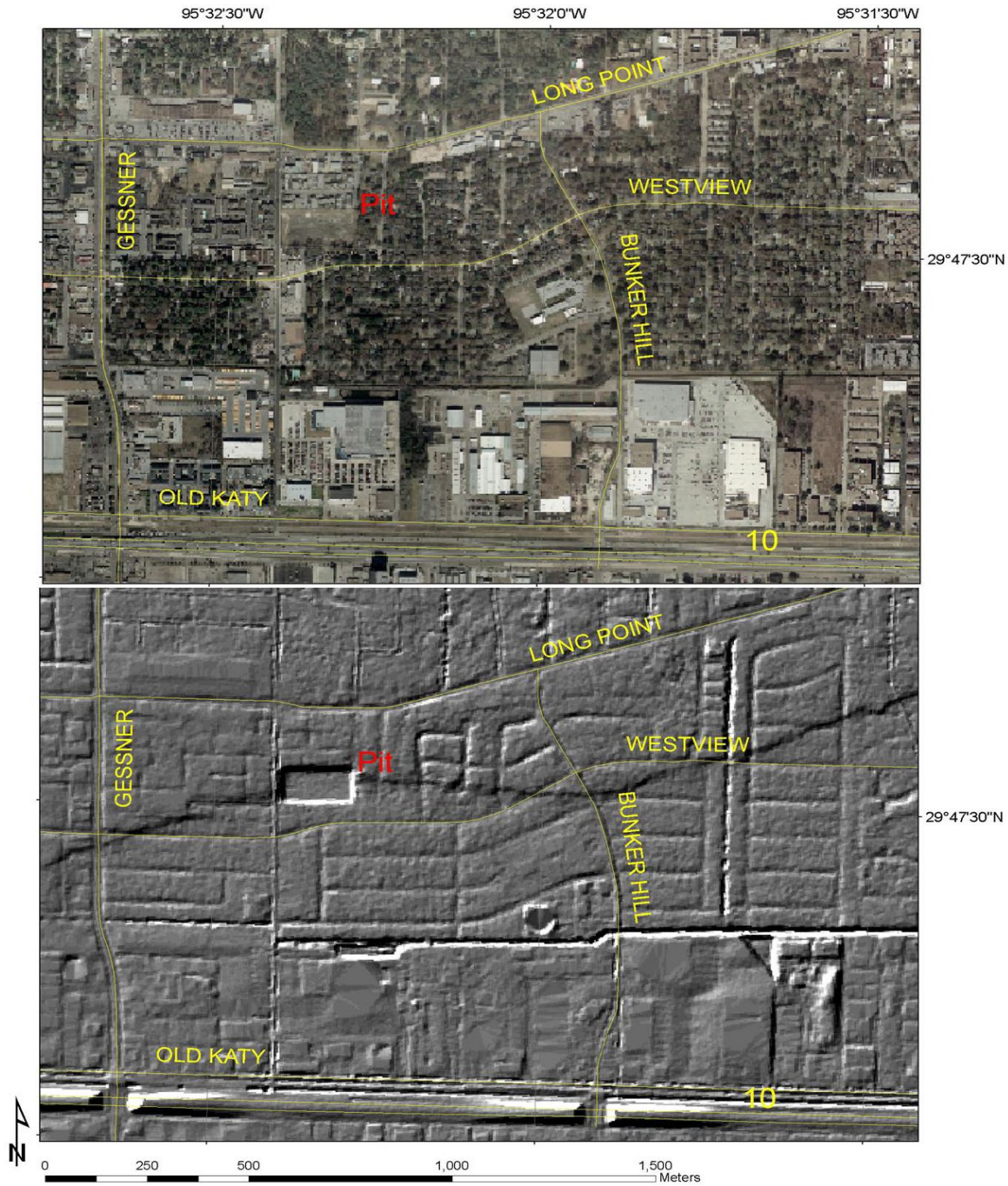


Figure 4) Comparison of Orthophoto with LIDAR for fault detection.

(a) The Long Point Fault is not visible in the orthophoto, except for a slight change in tone within the water detention pond (pit), built on a site previously occupied by an apartment complex.

(b) Hillshade of LIDAR DEM covering the same area as the orthophoto shown in Figure 6a. The fault is clearly visible trending west to east thru the pit.

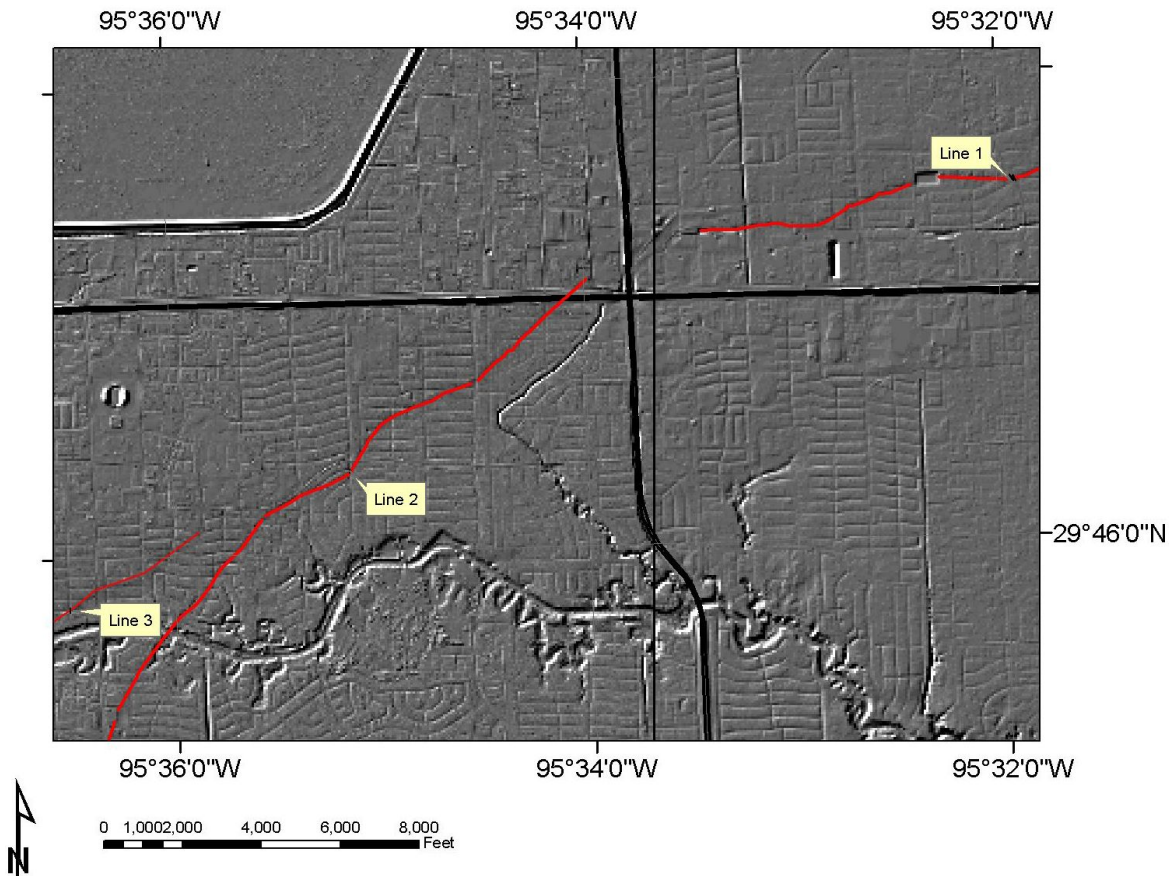


Figure 5) Faults and potential faults interpreted from LIDAR hillshading.

Interpretation which corresponds with known faults is shown in red, while possible faults are shown in green.

Large scale (less than 1:10,000) maps permit detailed interpretation of these scarps and allow more accurate locations for these scarps. Field visits were made to study the scarp characteristics and to look for deformation of roads and buildings. Not every scarp

corresponds to an active surface fault. An example of a scarp that is not fault related is the Renn Scarp in southwest Houston. This scarp was considered a possible fault requiring further investigation with some maps categorizing it as a fault. Drilling confirmed that the scarp is a fluvial terrace riser that has since been obliterated by recent urban development.

Field visits did not provide a clear indication of faulting at many potential fault locations. Subsurface studies were needed to help decide whether these features were likely faults. Possible subsurface imaging tools include Ground Penetrating Radar (GPR) and high resolution seismic reflection profiling. Displacement of horizons and corresponding increases in thickness on the downthrown side would be key fault indicators. The presence of a deformed or disturbed zone also suggests faulting.

Seismic Data

We acquired seismic data at two locations along the Long Point Fault (Figure 6). The sites chosen correspond with a prominent scarp and clear indications of deformation (broken pavement, warped buildings). The Long Point Fault is the most prominent and studied surface fault in Houston. Hammer blows on a metal plate were used as a source, with 15-20 blows stacked to improve the signal to noise ratio. An attempt was made to avoid recording when traffic was passing along the line. For Line 1 receiver separation was 5 feet, while a separation of 3 feet was used for Line 2. Line layout was limited by the available number of receivers and to avoid pavement from streets and driveways. A fixed spread of 30 geophones was used for both lines. For Line 1 only enough shots were obtained for refraction studies, while there was a shot for every receiver on Line 2. A shot was taken off each end of both lines to aid in refraction studies. 1 second of data was acquired with a sample rate of 0.25 ms.

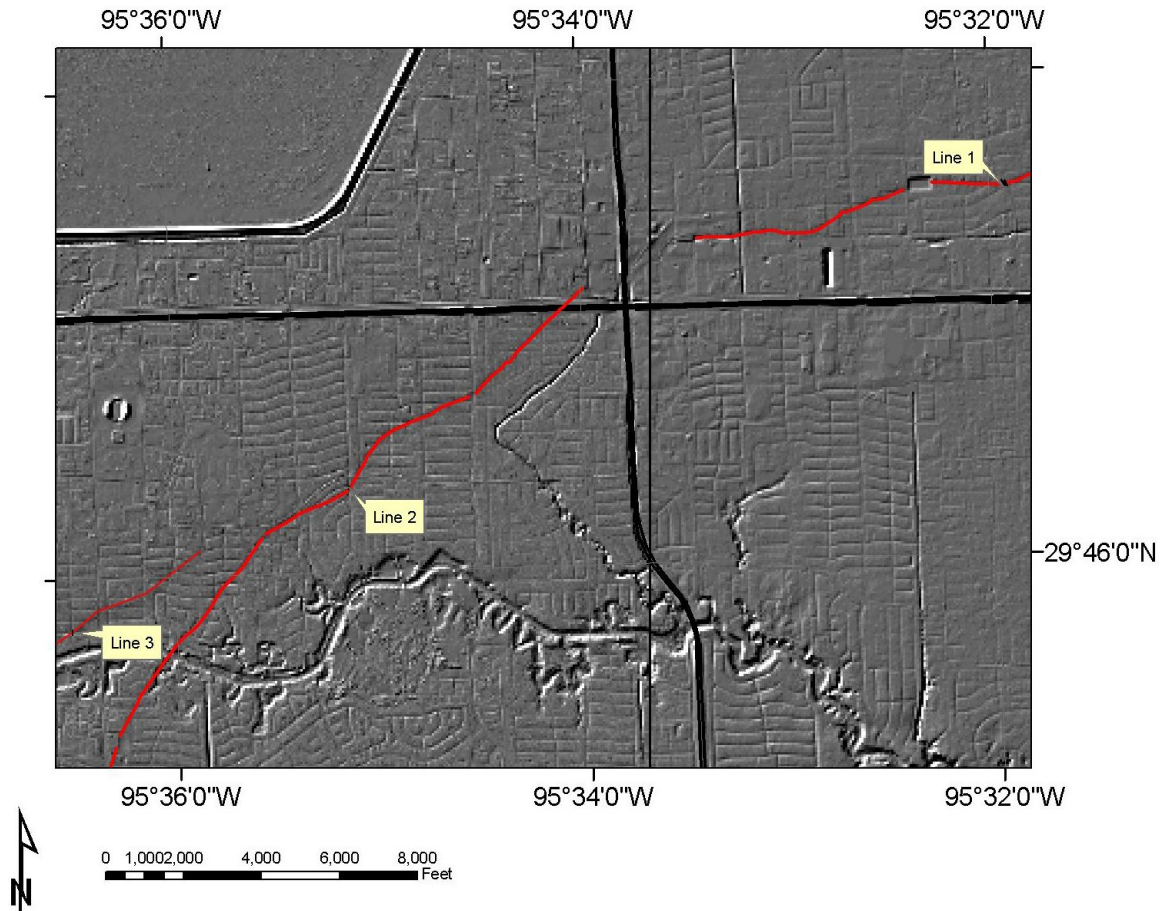


Figure 6) Locations of seismic and GPR lines along the Long Point Fault and a potential splay.

Data were noisy and the receiver adjacent to the shot was often ringy. Coherent energy is predominantly low frequency (30 Hz) and includes the direct arrival, refractions, ground roll and the air wave. There may be multiples or ringing from these linear energy arrivals. Due to excessive noise a meaningful stacked reflection section could not be produced for Line 2 and there was insufficient fold to generate a stacked section for Line 1.

First breaks were picked and refraction inversion was used to determine the depth of the first layer and the first two layer velocities (Figures 7 and 8).

A topographic profile shows the relationship between surface and subsurface features. The

refraction profiles indicate a disturbed zone in the vicinity of the surface fault scarp, possibly indicative of distributed deformation as the fault passes through unconsolidated sediments. It may also characterize the transition from the Lissie Formation on the north side to the Beaumont Formation on the south side. This transition occurs on or near the Long Point Fault.

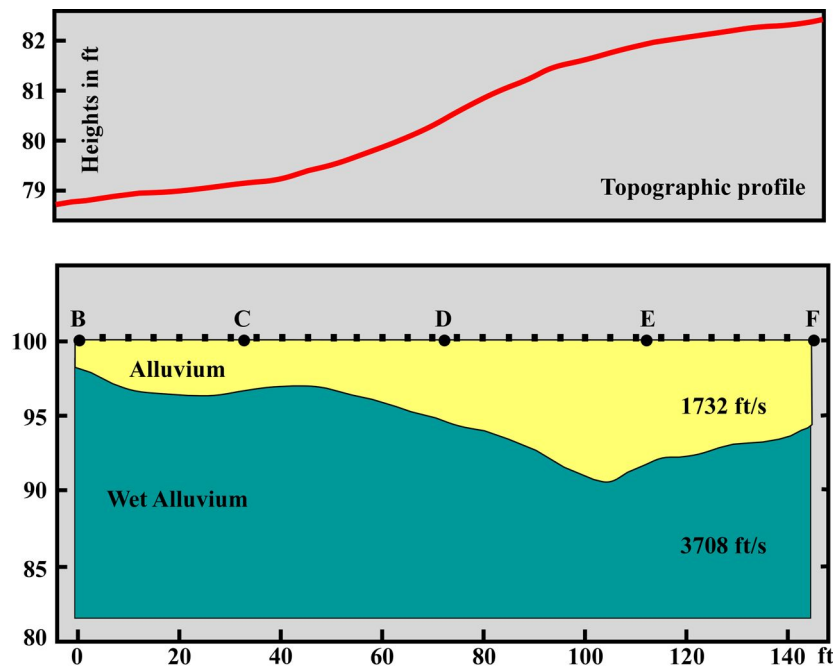


Figure 7) Refraction profile for Line 1. A topographic profile is shown above the line. The ground in the vicinity of the surface scarp appears disturbed, possibly by distributed deformation.

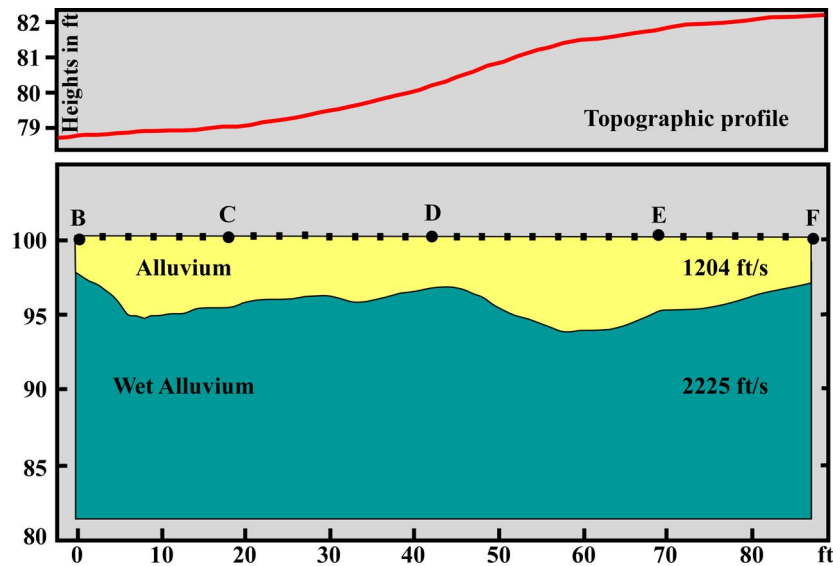


Figure 8) Refraction profile for Line 2. A topographic profile is shown above the line. The ground in the vicinity of the surface scarp appears disturbed, possibly by distributed deformation.

GPR data

100 MHz GPR data has been obtained for three locations (Figure 6). The first two locations correspond to the seismic line locations and cross known fault scarps, while the third location crosses a scarp interpreted from the LIDAR. 400 MHz GPR data were acquired but penetration was not sufficient to yield useful data. A constant source-receiver offset of 1 m was used to gather the 100 MHz data. The sled holding the source and receiver was dragged along the line at as constant a rate as possible to yield uniformly spatially sampled traces. Line 1 and Line 2 had lengths of 20 m (65 ft) while Line 3 is 40 m long.

After conversion to SEG-Y (scaling the sample rate by a factor of 1,000,000 so that picoseconds are treated as microseconds) processing was done using Seismic Unix. A routine

processing flow was employed with bandpass filtering used to remove frequencies outside the 25-200 MHz range. A median trace sum with a width of 11 traces was generated. This was subtracted from the filtered traces to remove the air wave and enhance horizontal events. No gain control was required. Incoherent, high frequency noise dominated the lower half of the raw records..

Line 1 (Figure 9) and Line 2 (Figure 10) show a high amplitude series of shallow horizontal reflections likely related to the pavement. Both lines show a dominant dipping event. We interpret this as the Long Point Fault, rather than some other type of coherent event such as diffractions. Diffractions can be seen on Line 1 but they are relatively low energy, with higher dip angles and higher frequency content. Troubling is the observation that these events do not have the hyperbolic shape expected for diffractions. There are no indications of buried scatters or point features such as pipelines or cables near by.

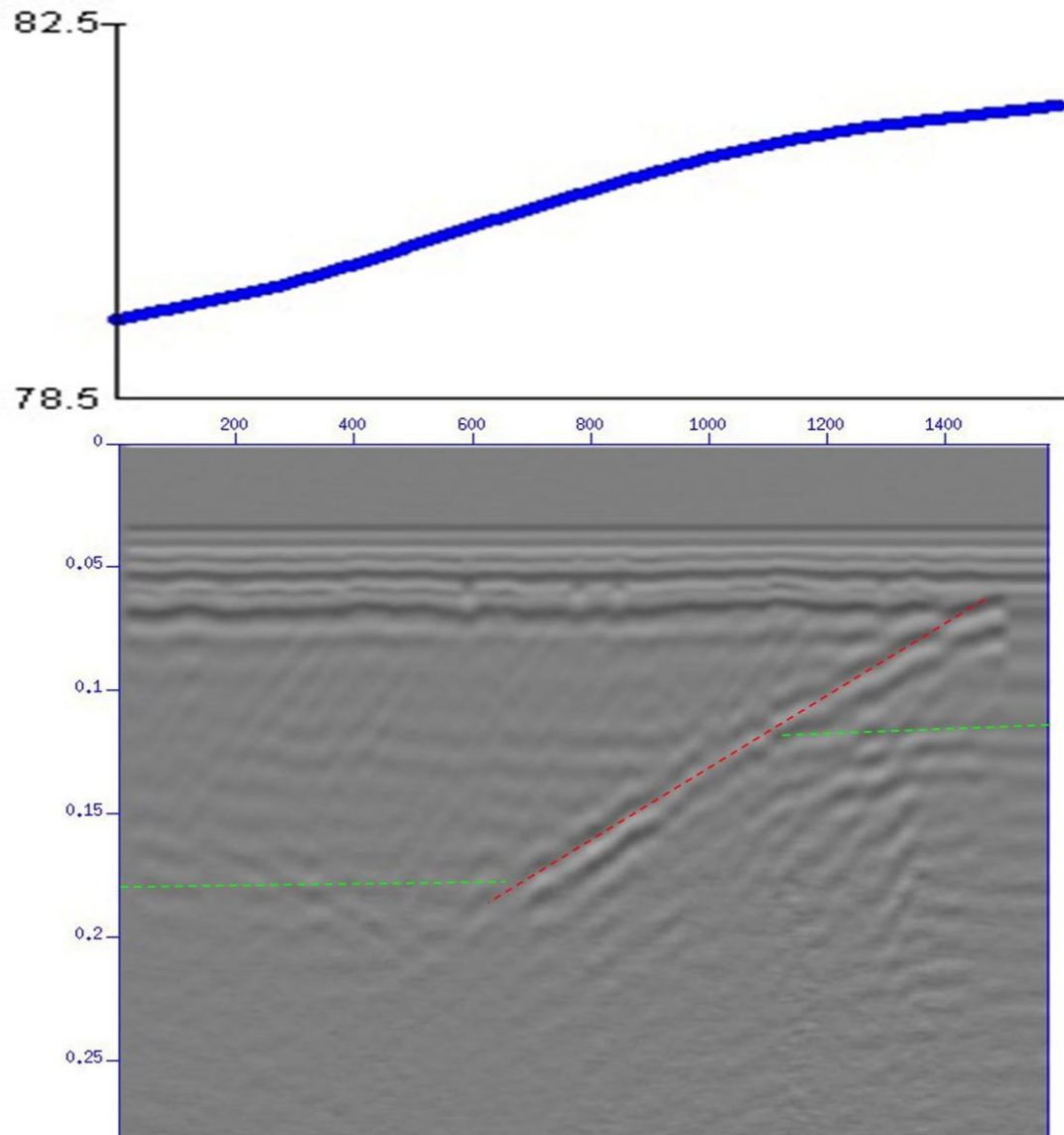


Figure 9) GPR section for Line 1. A steeply dipping structure is interpreted as the fault and there appears to be an offset of horizons across the fault.

We recorded data in both directions for Line 1 and Line 2. Both lines (each acquired along the same traverse but from opposite directions) at each location show a similar structure. Subtle acquisition differences (number of traces, slight variations in trace spacing and positioning) prevented summing these lines. We feel that the strong spatial correspondence

between the top of the scarp and the beginning of the dipping event is convincing evidence, as is the direction of dip. Since we do not know the dielectric constant of the material beneath the lines, we cannot compare the apparent dip on the GPR data with that observed elsewhere along the fault (70-85 degrees near the surface, becoming less steep with depth).

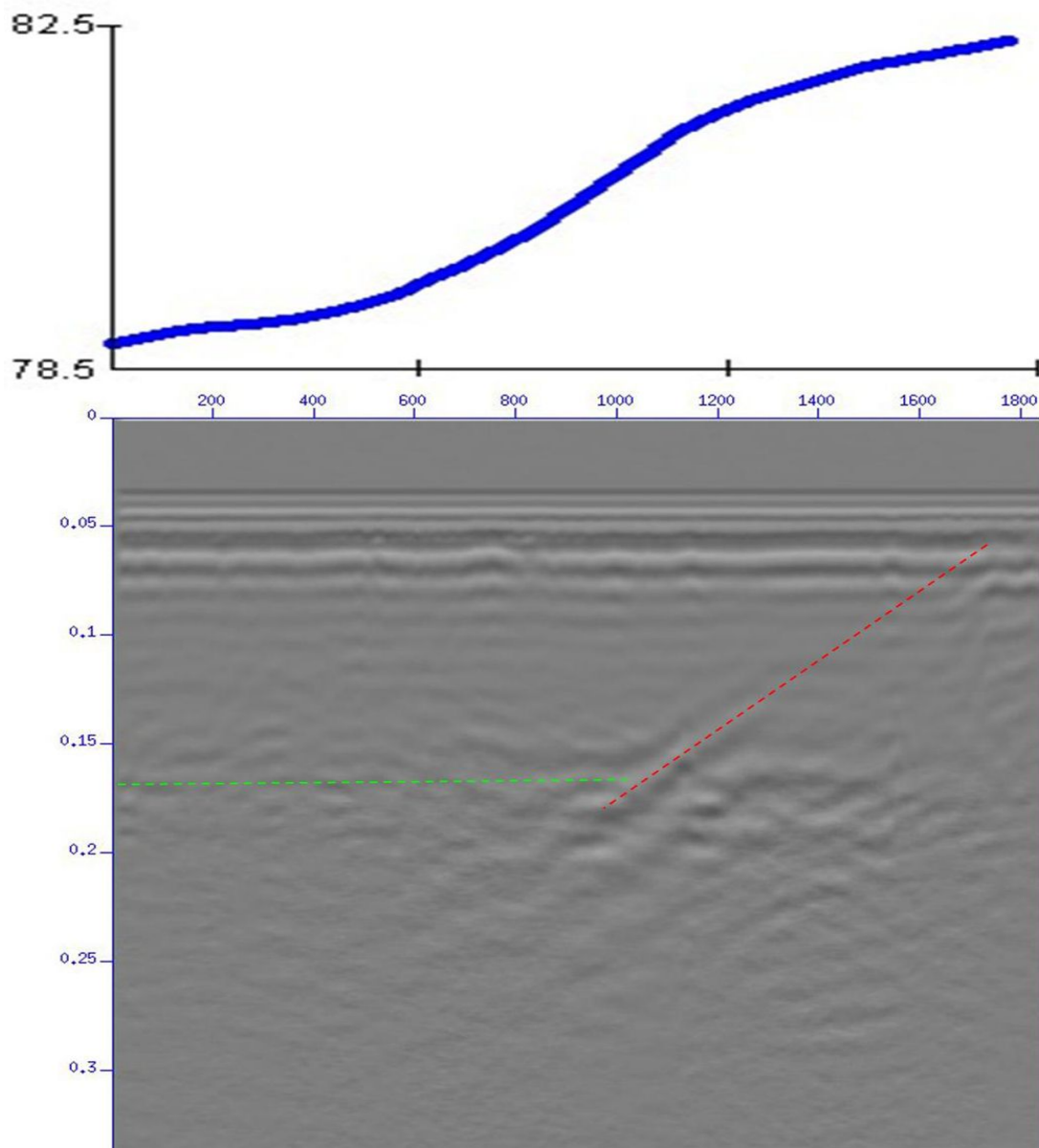


Figure 10) GPR section for Line 2. A steeply dipping event is interpreted as the fault but horizons cannot be seen on both sides of the fault.

The horizon picks are intended to be suggestive only and are not correlated across the fault. There is some indication of thickening on the downthrown side which corresponds with growth faulting. Line 1 shows possible rollover, but this may be a diffraction. Line 3 (Figure 11), which crosses a potential fault location, only possesses pavement reflections and diffractions and provides no indication of structural variation.

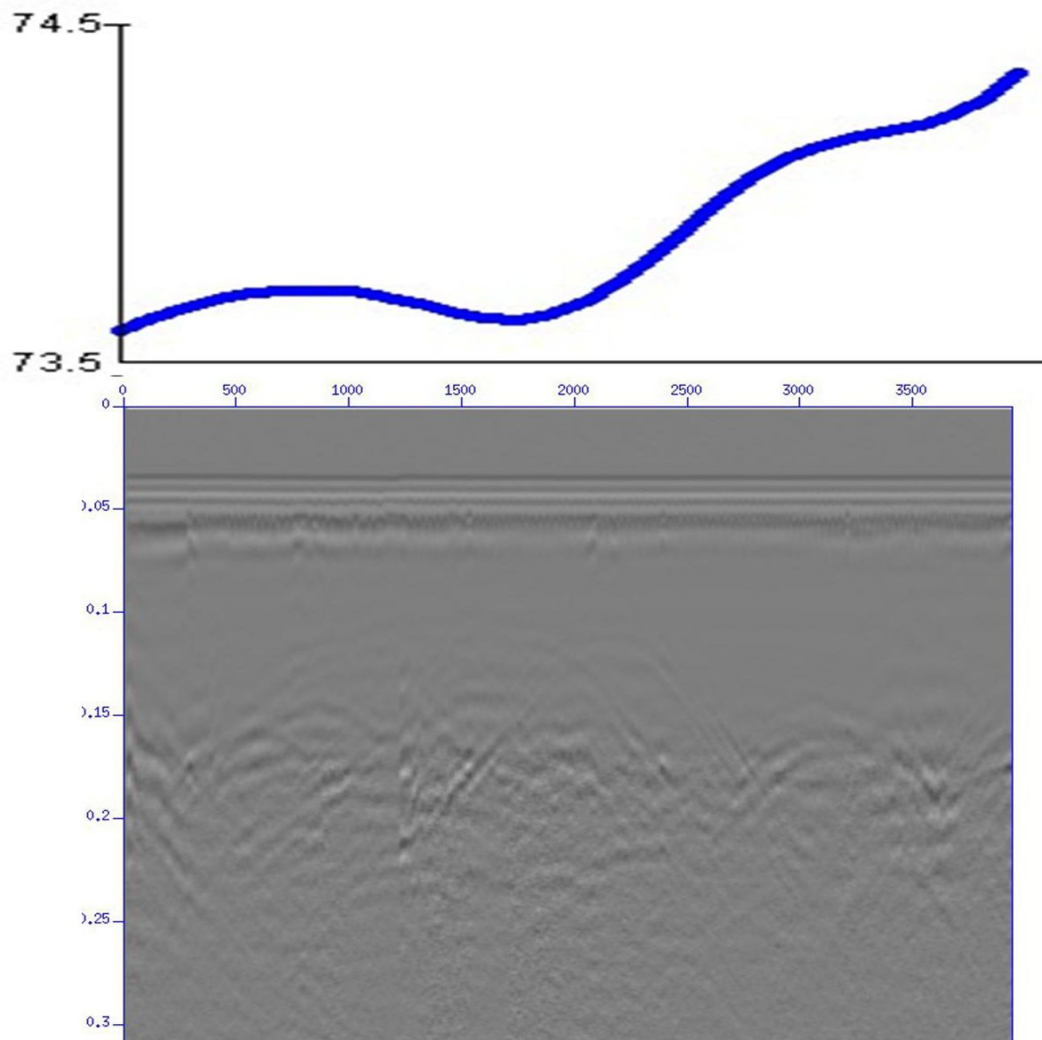


Figure 11) GPR section for Line 3. No clear structure can be detected. The feature may not be a fault.

Conclusions

The near-surface data provide indications of faulting at the two known fault locations and suggest that the scarp at the candidate location studied does not appear to be fault related. It may correspond to an erosional feature such as a fluvial terrace riser. GPR data provided an approximate depth penetration of 75 to 150 ft (20-40 m).

Near surface characterization of active surface faults can aid in determining whether a particular feature is a fault before fault movements result in damage to structures such as houses or roads. In some cases through creative re-zoning the fault affected areas could be used as a park or recreation area. Open space has deliberately been left along a surface fault in several places in the Houston area.

Future seismic work should include a more robust seismic source, such as an assisted weight drop or other high frequency source. This would provide for better signal to noise ratio, deeper penetration and possibly a higher frequency content. More geophones allow a higher stack fold while providing greater offsets to aid in NMO determination. Our geophone spread allowed close sampling of the shallow subsurface, but this is also the region dominated by the direct wave, ground roll and refractions and therefore reflection events could not be confidently identified within these coherent noise arrivals. Longer lines will allow for better mapping of displaced horizons.

Increasing the depth of penetration by using 50 MHz data may be a focus of future GPR surveys. Using variable offsets and following a reflection seismic processing workflow should provide for better signal to noise ratio, velocity determination and increased resolution. The cause of the noise encountered in the lower half of the section needs to be understood and eliminated. Currently the most likely cause is a weak input signal. Dielectric

constants could be measured at selected locations, ideally sampling the near surface by cores to aid in depth conversion. Longer lines, as with the seismic, will provide for better characterization of horizons.

The LIDAR allowed us to accurately map scarps. In the future better near-surface characterization that would avoid the need to drill will be an excellent complement to the LIDAR mapping. This complementary, multi-tool imaging approach will aid fault hazard detection and may shed further insight into Houston area tectonics.

Acknowledgements

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