GROUND SUBSIDENCE AND ACTIVE FAULTS IN THE HOUSTON METROPOLITAN AREA

A FIELD TRIP CONDUCTED AS PART OF THE

HGS/ECH Conference On Coastal Subsidence, Sea Level And The Future Of The Gulf Coast

ECH

Engineering, Science
and Technology
Council of Houston

November 03 - 05, 2005

Trip Leaders:
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HGS/ECH

GROUND SUBSIDENCE AND ACTIVE FAULTS IN THE HOUSTON METROPOLITAN AREA

November 5, 2005

ITINERARY

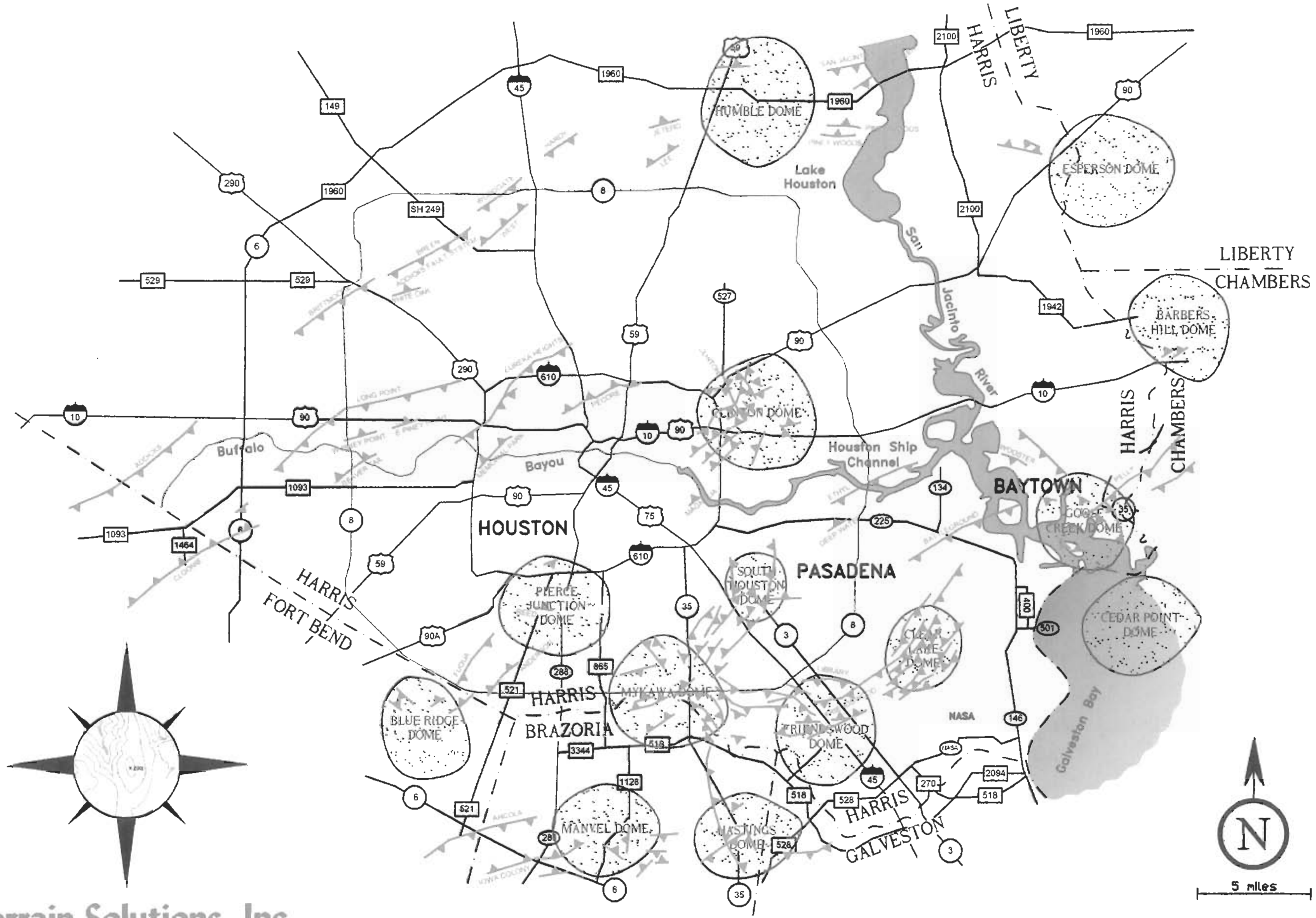
STOP NO.	TIME	MILES FROM LAST STOP	SITE DESCRIPTION
1	9:00	0	Leave Northwest Forest Conference Center
2	9:20-9:40	8.9	Brittmoore Fault, Fisher Road at West Little York Road
3	9:55-10:30	7.3	Addicks Borehole Extensometer and PAM Site
4	10:45-11:15	4.8	Long Point Fault, Westview at Moorhead
5	11:30-12:15	2.0	Piney Point East Fault, Pecanwood at Corbindale
6	1:00-3:00	32	LUNCH. Baytown Nature Center, Brownwood Subdivision, Baytown, Texas
7	3:15-3:30	0.5	Wooster Water Well, Arbor Street at Bayway
8	3:45-4:00	0.5	Wooster Fault, Bayway at Weaver Street
9	5:00	47	Arrive Northwest Forest Conference Center

NOTE: Beginning and ending times are definite and other times are approximate.

Ground Subsidence and Active Faults in the Houston Metropolitan Area

AREA MAP SHOWING FIELD TRIP STOPS

November 5, 2005



Terrain Solutions, Inc.

Principal Surface Faults of the Houston Central Metropolitan Area

(After O'Neill & Van Siclen with additions by C. Norman)

Rev. 05/13/04

ACTIVE FAULTS IN THE TEXAS-LOUISIANA COASTAL ZONE

Carl E. Norman, Emeritus Professor of Geology, University of Houston
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More than 450 active faults intersect the Earth's surface onshore in the Texas-Louisiana Gulf Coastal Zone, and hundreds more have been identified offshore. Each year exploratory efforts uncover a few more. The vast majority are listric normal growth faults with near-surface dips of 70 to 85 degrees. The faults extend hundreds to tens of thousands of feet deep, and they have been intermittently active for hundreds of thousands to millions of years.

About 80 percent of the surface faults occur over columns of salt (salt domes), 0.5 to 6.0 miles in diameter, that have risen from depths that may exceed 40,000 feet. Most salt dome faults are short, ranging in length from 0.5 to 3.0 miles. They extend over and/or radially outward from the domes. The remainder are 3- to 11-mile long regional faults that trend more or less parallel to the coastline. The most active ones are paired with shorter paralleling faults located about 1.5 miles from the parent fault on its downthrown side. They occur opposite only the more rapidly moving parts of the parent fault.

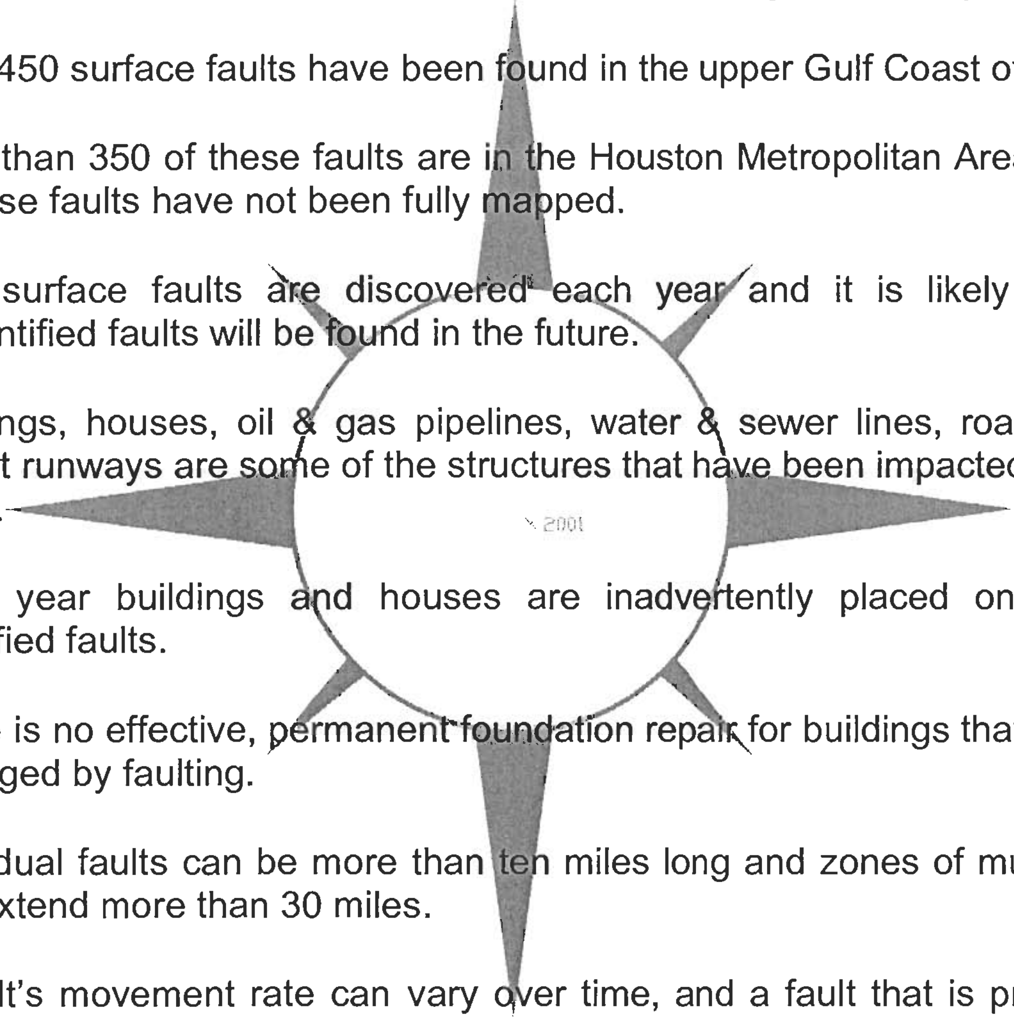
Ground movement across all the faults is directly down dip. No strike-slip component of motion has yet been identified on any surface fault. Rates of dip-slip displacement across the faults vary in both time and space. Currently the highest rates are about 1 inch per year. Along the strike of a fault, the rates decrease progressively from a maximum near its mid-point to zero at its ends. Movement rates are slow enough to make many of the faults difficult to find and map, but fast enough to cause substantial damage to structures built across them. The 10-mile long Long Point Fault in west Houston damages about 240 buildings.

Gulf Coast faults are aseismic. Instead of storing strain energy for tens to hundreds of years and releasing it suddenly in an earthquake, they release energy in small increments each year. Individual movement events are in the millimeter to sub-millimeter range, except when surface waves from distant earthquake epicenters trigger centimeter-range events on faults poised for movement.

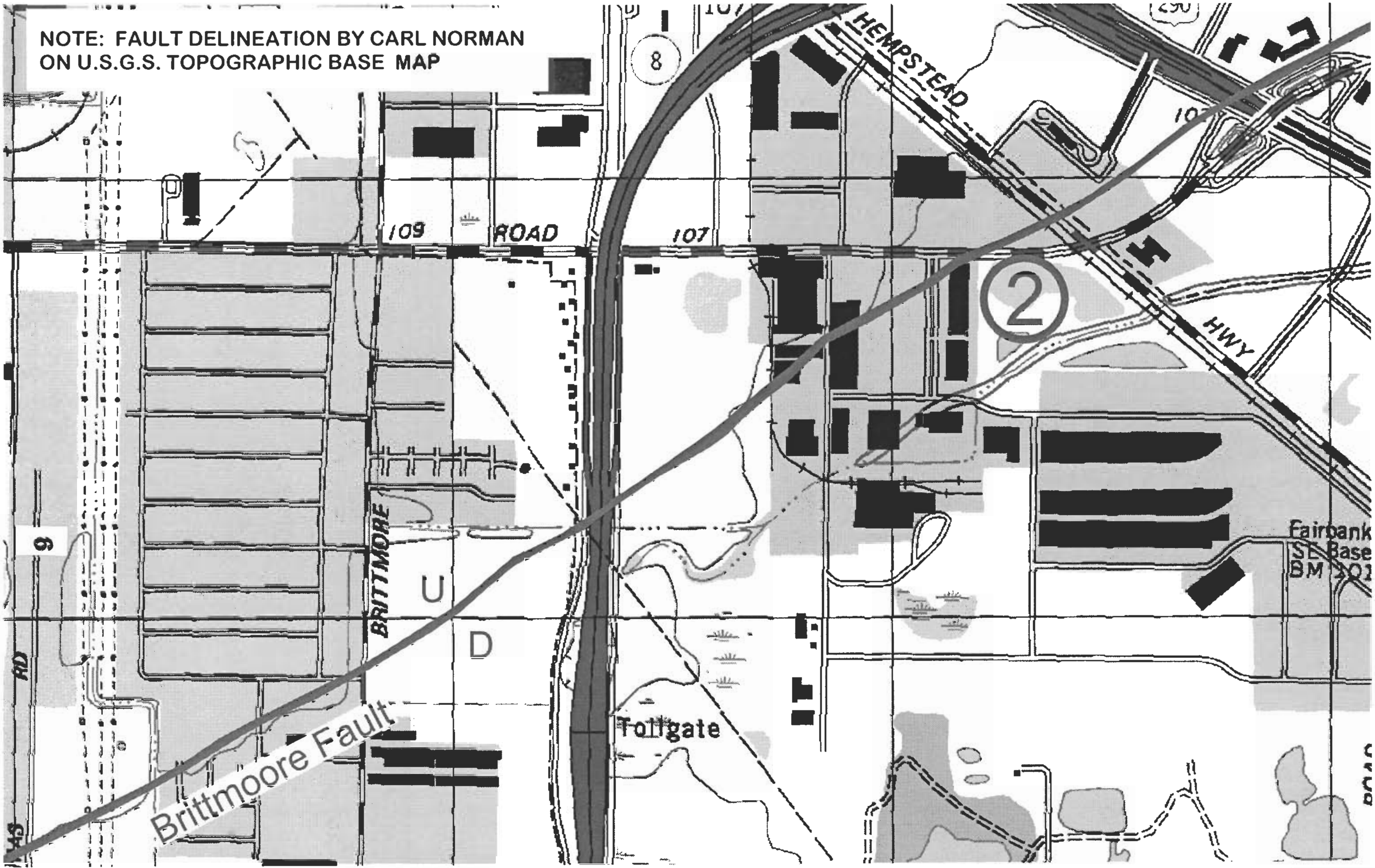
The faults are not discrete fractures. They are zones of intensely sheared ground extending a few tens of feet perpendicular to the strike of the fault. For engineering purposes, it is important that the location and width of the fault zones, as well as their sense of motion, be established as precisely as possible. Where bench mark data are not available, the information can often be obtained by measuring the extent and vertical amplitude of deformation to structures of known age built across the fault zones.

Thousands of structures (homes, schools, churches and other commercial and public buildings) in the Houston Metropolitan Area have been built unknowingly in fault zones. Often the fate of these structures is destruction before their intended life expectancy. The role of the geologist is to provide information on the location, sense of displacement and rate of motion of the fault zones to planners, developers, architects and structural engineers. Surface faults are considered a fatal flaw for waste disposal facilities. Because there are no laws or ordinances that prohibit construction of buildings or other engineered structures in fault zones, such practice is, unfortunately, common.

Fault Facts



- A geologic surface fault is a break in the land's surface along which the ground on one side of the fault moves relative to the ground on the other side.
- Geologic surface faults – a natural hazard along the Gulf Coast of Texas and Louisiana – have caused millions of dollars in damage over the years.
- Over 450 surface faults have been found in the upper Gulf Coast of Texas.
- More than 350 of these faults are in the Houston Metropolitan Area and many of these faults have not been fully mapped.
- New surface faults are discovered each year and it is likely that many unidentified faults will be found in the future.
- Buildings, houses, oil & gas pipelines, water & sewer lines, roadways, and airport runways are some of the structures that have been impacted by surface faults.
- Each year buildings and houses are inadvertently placed on previously identified faults.
- There is no effective, permanent foundation repair for buildings that have been damaged by faulting.
- Individual faults can be more than ten miles long and zones of multiple faults can extend more than 30 miles.
- A fault's movement rate can vary over time, and a fault that is presently not moving or is moving slowly can begin moving at a faster rate over a relatively short period of time.
- The risk of being impacted by faulting can be minimized by determining whether a fault is present prior to development and construction.
- Faults are often not readily detectable, and identification of them usually requires the expertise of qualified geoscientists.



NOTE: FAULT DELINEATION BY CARL NORMAN ON U.S.G.S. TOPOGRAPHIC BASE MAP

Terrain Solutions, Inc.

WEST HOUSTON METROPOLITAN AREA FAULTS

Brittmoore Fault, West Little York at Fisher

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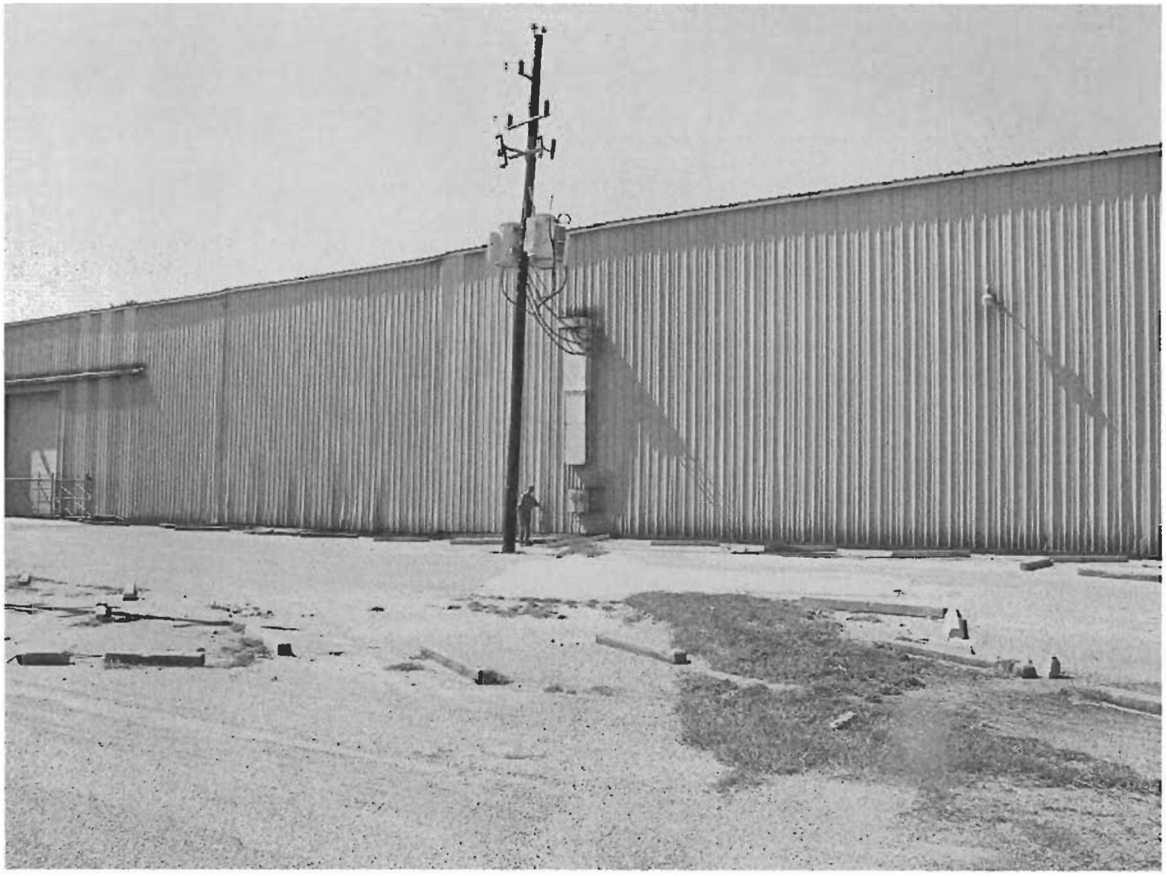
Approx. Scale:
1 in. = 1000 ft.
0 ft. 500ft. 1000 ft.



2005 – Brittmoore Fault. View to Southwest

1978 – Brittmoore Fault. Crack in Foundation at Edge of Upthrown Fault Block

STOP 2

THE BRITTMOORE FAULT
FISHER STREET AT WEST LITTLE YORK ROAD
NORTHWEST HOUSTON, TEXAS

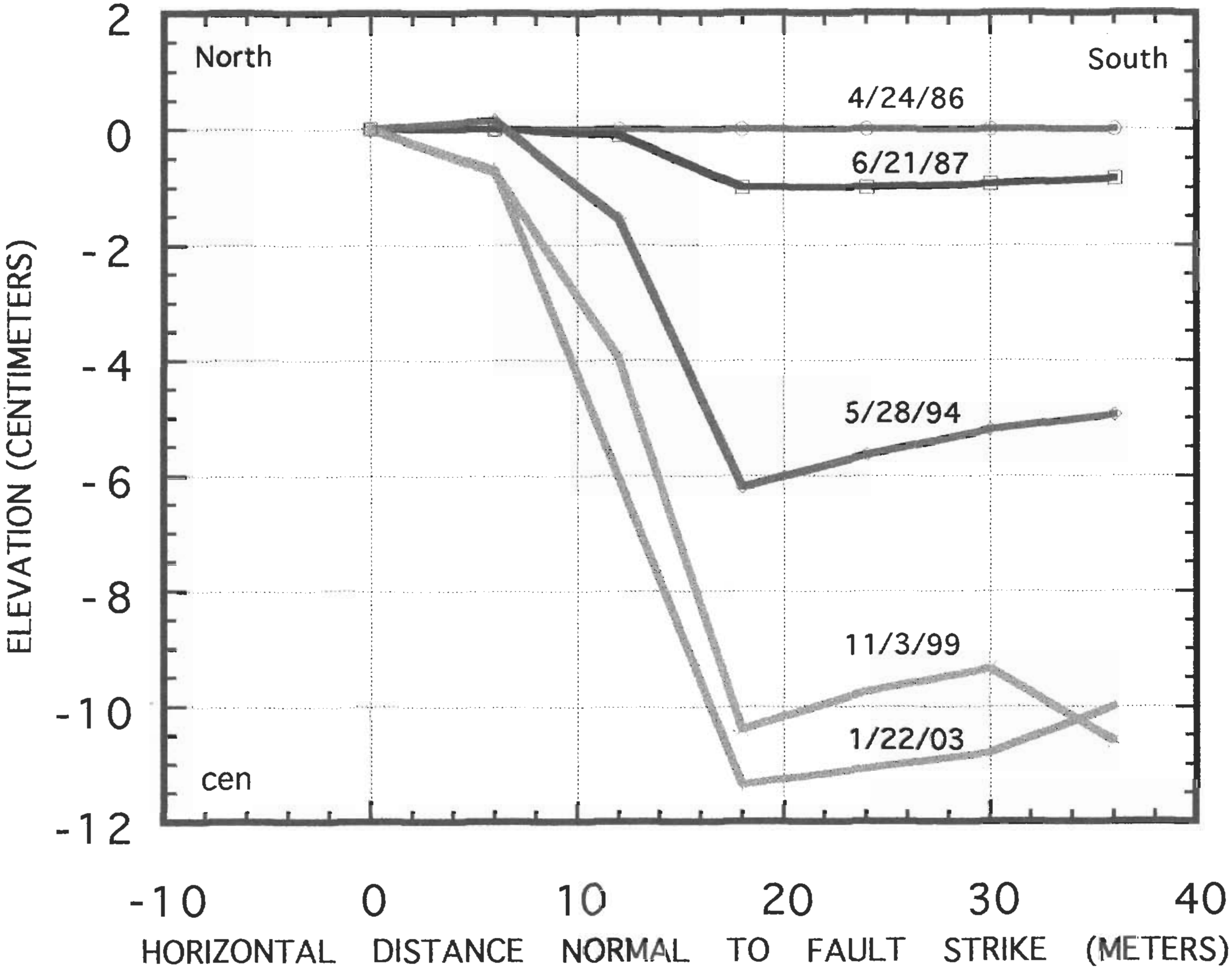
The Brittmoore Fault is a 4.7-mile long segment of the Addicks Fault System. The system itself consists of 5 major down-to-coast faults and 2 smaller up-to-coast antithetic faults (see the O'Neill-Van Siclen map). The system extends about 30 miles from Buffalo Bayou at the western edge of the Barker Reservoir, northeastward to the northwestern edge of George Bush Intercontinental Airport. Another system, comparable in size, extends from Katy-Hockley Road at Cypress Creek, northeastward to a point a few miles southeast of Conroe. Currently faults in these two systems appear to be more active than others in the greater Houston area.

At Stop 2 the Brittmoore Fault passes beneath a large warehouse with a massive foundation, built after October 1964 and before March 1972, to withstand the weight of stacked oil field pipe. The 1978 photograph on the previous page shows a through-going open crack in the 2-foot exposed portion of the steel-reinforced foundation. It is a sobering display for those contemplating construction of a foundation that will withstand fault movement. The portion of the foundation along the fault was reconstructed about 15 years ago. Since then it has bent, but not cracked as it surely will if the fault remains active.

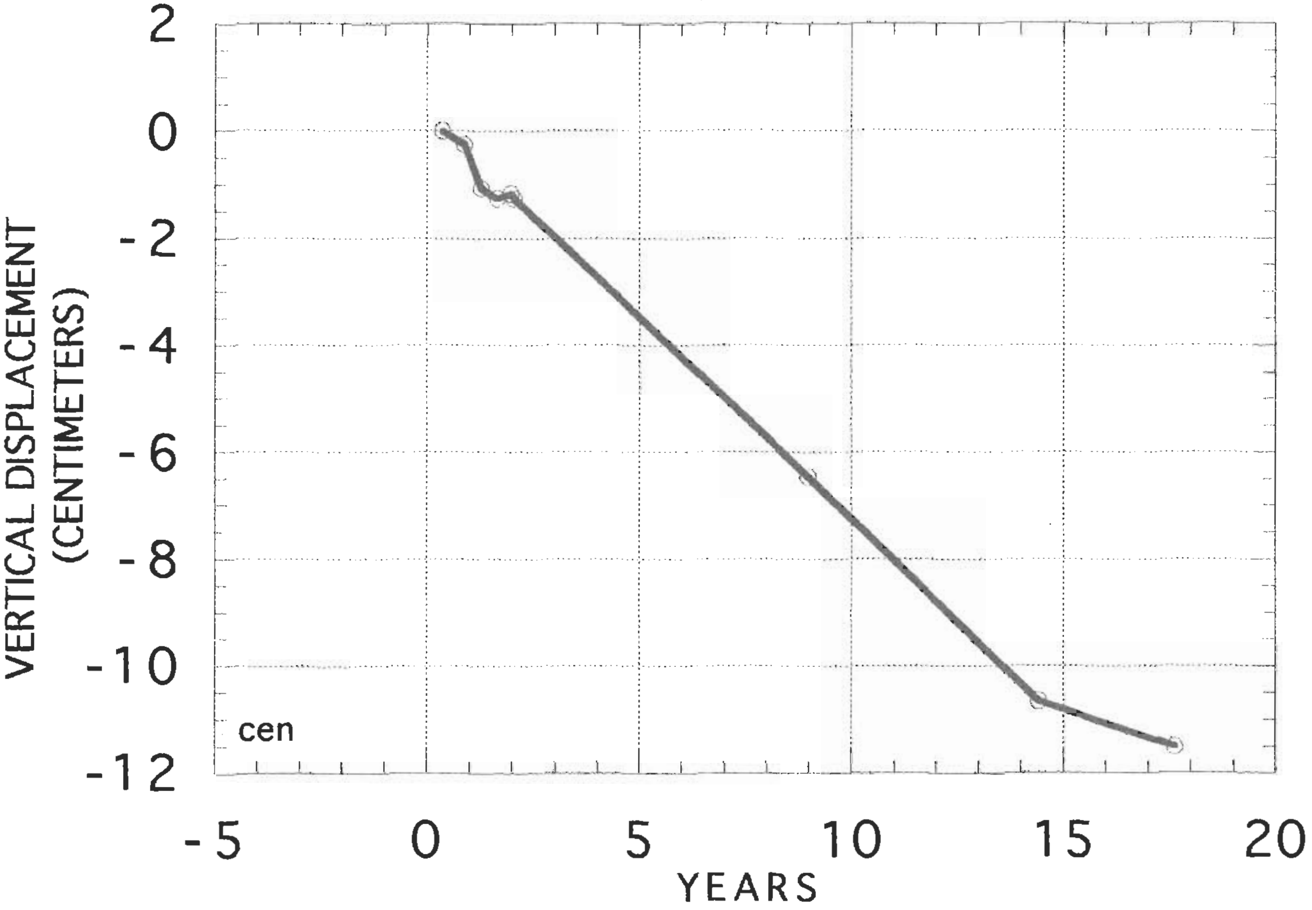
The following 2 pages are graphs of data obtained from repeated measurement of changes in elevation of bench marks placed with 25-foot spacing in the asphaltic concrete pavement along the east side of Fisher Street. You will be able to see most of them today. The first diagram shows displacement vs. distance along the 150-foot line over a period of nearly 17 years. This type of plot is useful for determining the width of the zone of disturbed ground along the fault. The second diagram shows vertical displacement vs. time between the lowest and highest bench marks. From 1986 through 1999 movement was at a nearly constant rate of 0.33 inches per year. It then slowed to 0.1 inches per year. This location is just southeast of Jersey Village, where the Harris-Galveston Coastal Subsidence District reports accelerated subsidence due to excessive pumpage of groundwater. Does an increase in the rate of subsidence cause a decrease in rate of fault movement?

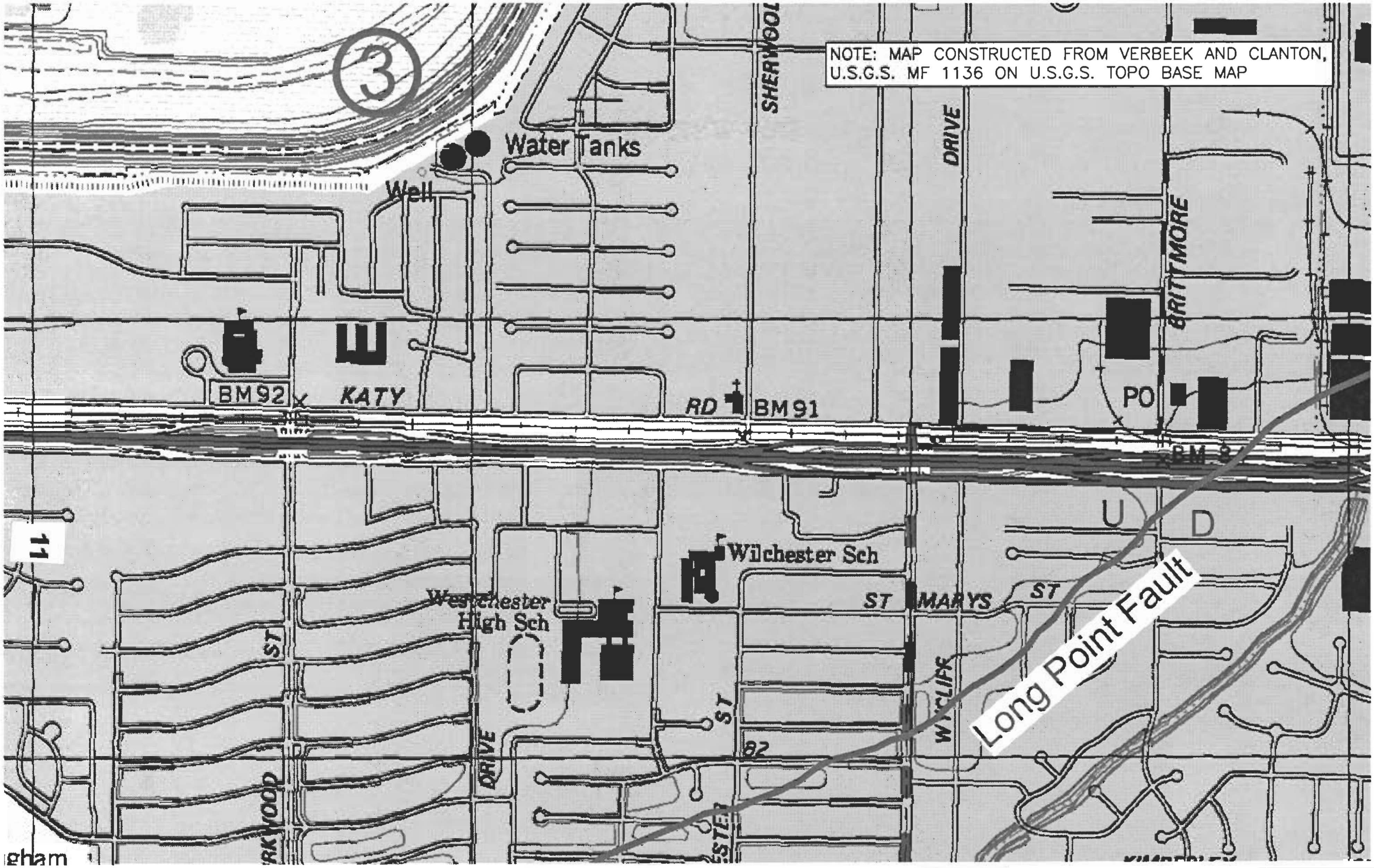
C. E. Norman, 11/05

BRITTMOORE FAULT
FISHER STREET AT WEST LITTLE YORK ROAD
ELEVATION CHANGES, 4/24/86 THROUGH 1/22/03



BRITTMOORE FAULT
FISHER STREET AT WEST LITTLE YORK ROAD
DISPLACEMENT VERSUS TIME, 4/24/86 THROUGH 1/22/03





Terrain
Solutions,
Inc.

WEST HOUSTON METROPOLITAN AREA FAULTS

Addicks Extensometer

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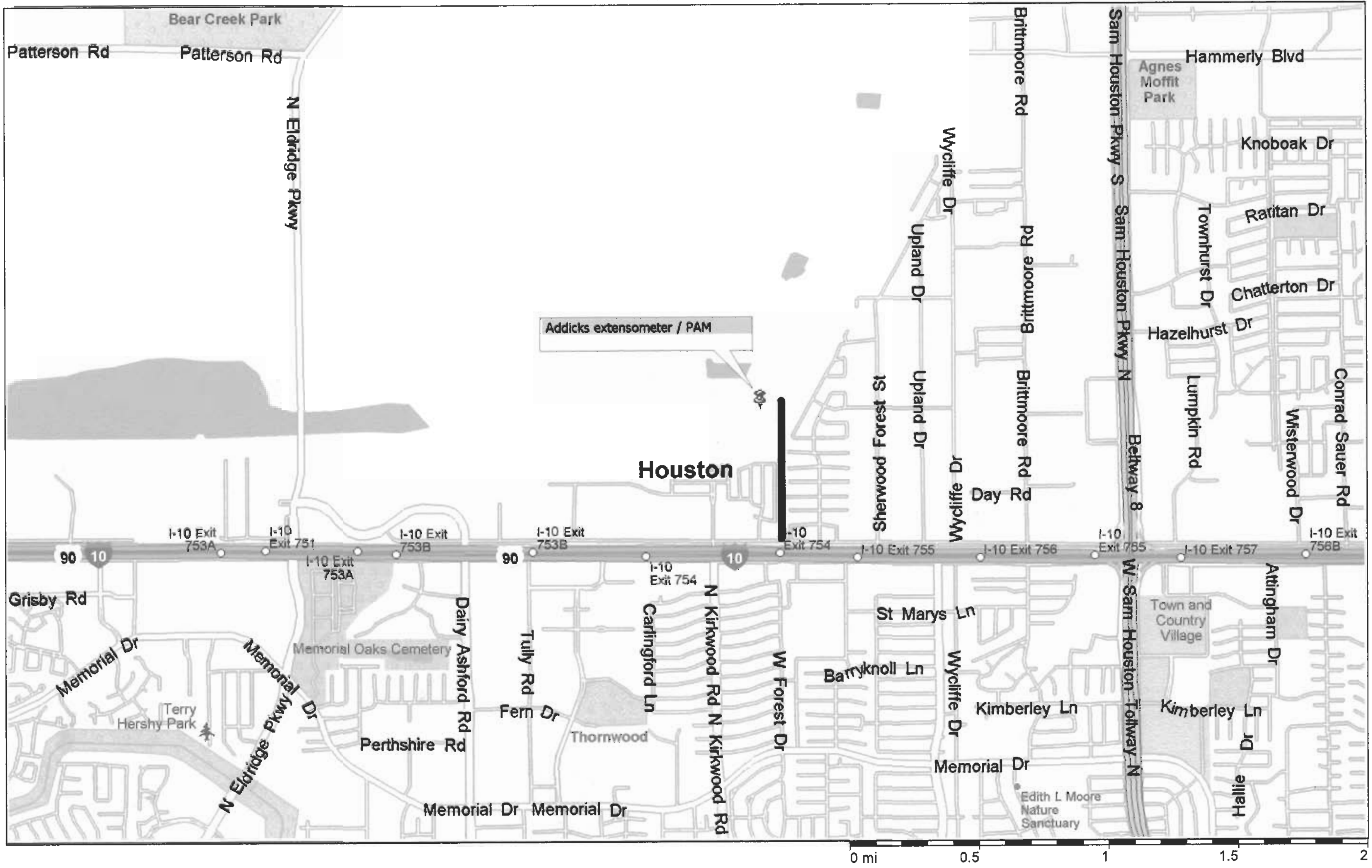
Approx. Scale:
1 in. = 1000 ft.

0 ft. 500ft. 1000 ft.

Thornwood, Houston, Texas



STOP 3

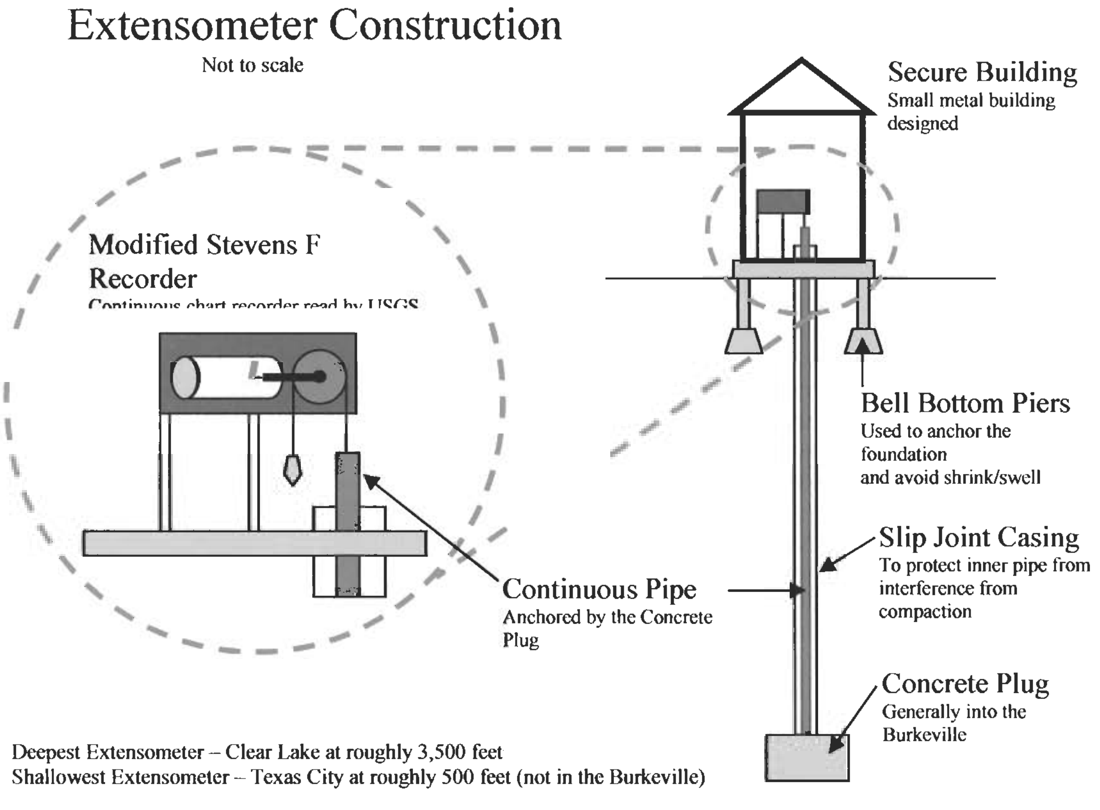
Addicks Borehole Extensometer and Port-A-Measure Site

Borehole Extensometers

The first of 13 deep borehole extensometers (designed and installed by the United States Geological Survey – USGS – in the early 1960s) were used in preparation for the soon-to-be-built manned spacecraft center. Of the 13 in operation today, six of those are "total depth" monitors (meaning their bottom is below the aquifers from which we draw water), and the other seven are less than total depth, or "compaction" monitors.

Borehole extensometers are deeply anchored benchmarks. To construct each, a hole is drilled to a depth at which the strata are stable. The hole is then lined with a steel casing with slip-joints to prevent crumpling as subsidence occurs. An inner pipe rests on a concrete plug at the bottom of the borehole and extends to the top. This inner pipe then transfers the stable elevation below to the surface. A measurement of the distance from the inner pipe to the surrounding land surface provides us with the amount of compaction that has occurred. (See picture for visual reference)

Although the accuracy of this measurement method is impressive, there is one drawback. The high cost to construct and install the equipment prohibits their use in sufficient numbers, resulting in a lack of adequate information for the entire Harris-Galveston and Fort Bend areas. Over time, as technologies have evolved, we have moved toward more cost-efficient and equally accurate forms of measurement ... but borehole extensometers are playing an important role in this new era. Three of our existing extensometers have been outfitted with GPS (Global Positioning System) antennas, and are now incorporated directly into the national CORS (Continuously Operating Reference Station) system maintained by the National Geodetic Survey.



Deepest Extensometer – Clear Lake at roughly 3,500 feet
Shallowest Extensometer – Texas City at roughly 500 feet (not in the Burkeville)

Inside a CORS

GPS Port-A-Measure Sites

From feeds to our television sets to national security, the use of satellites has become almost commonplace, and our world of subsidence measurement is no different. In fact, we began working with GPS technology as far back as 1987, and the class-A benchmarks established for that very GPS releveling have proven to be the most valuable benchmarks in the Houston area.

One of the most important advantages to GPS is the ability to have *constant* data. Using dual-frequency, full-wavelength GPS instruments (with geodetic antennas), data is collected at 30-second intervals and averaged over 24 hours. That means that specific stations being monitored can be assessed on a *daily* basis. And just as important, the measurements are more reliable and handled at a fraction of the cost. Improved GPS techniques and processing have reduced the cost of releveling from millions of dollars to less than $100,000, and the data provided is accurate to + or – one centimeter.

GPS measurements are taken using a system of CORS and PAMs. Because of the broad extent of subsidence in the Houston-Galveston area, there were no stable benchmarks. Therefore, stable borehole extensometers were equipped with GPS antennas to provide a reference frame to measure subsidence at other stations throughout the area. These permanent stations are known as local GPS Continuously Operating Reference Stations, or CORS. In the mid 1990s, the

District and NGS began developing the use of GPS Port-A-Measure sites, or PAMs, to provide subsidence measurements.

Seven, portable trailers were built to house and secure GPS receivers and associated equipment (batteries, recording equipment and solar panels). The trailers are moved weekly to different PAM sites where they record Phase data every 30 seconds, allowing for a week's worth of observations on each PAM, every month. The District also operates four permanent CORS sites, which provide Phase data continuously, providing a basis from which change comparisons may be made and analyzed.

Inside PAM Trailer #2

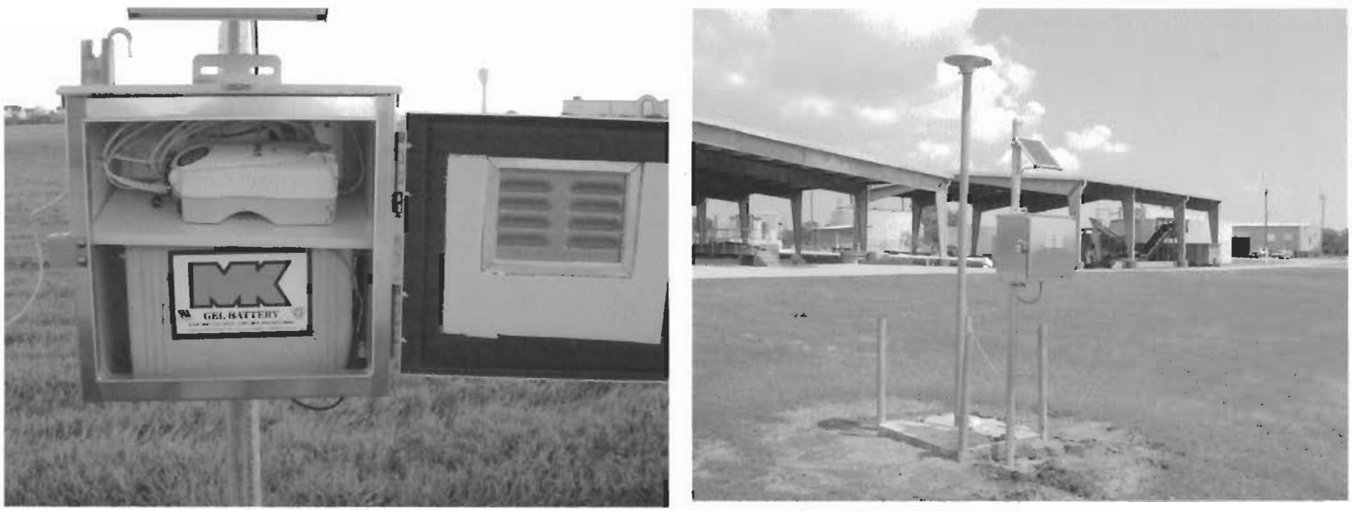
In addition to the points operated by the District, there are a number of additional CORS and Cooperative CORS, which can also be used for monitoring purposes. They include:

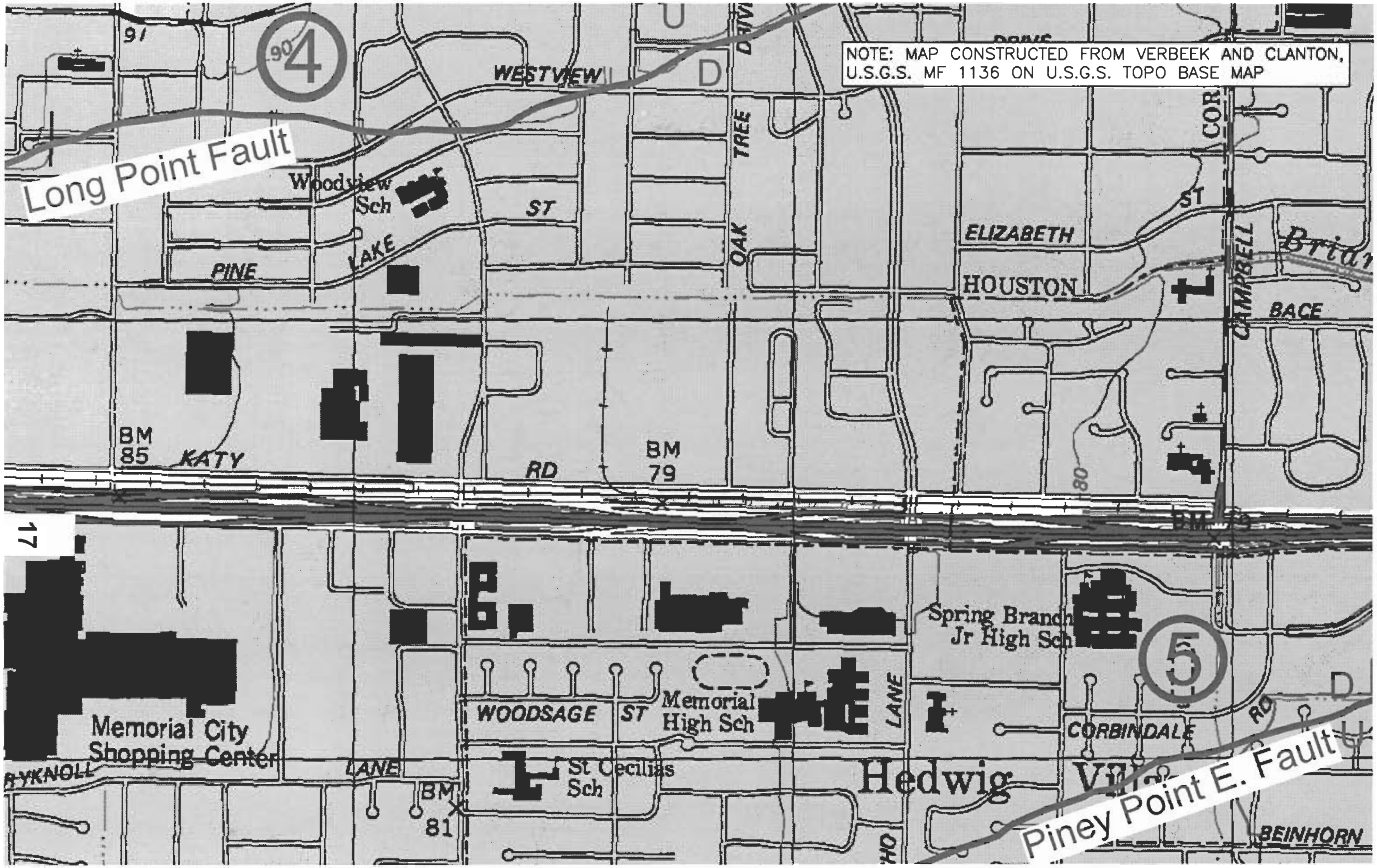
- Eight CORS operated by TxDOT
- Seven CORS operated by the City of Houston
- A CORS in Angleton operated by the U.S. Coast Guard
- A WAAS (Wide Area Augmentation System) CORS in Houston operated by the FAA
- Six other Cooperative CORS throughout the area

All additional CORS are relatively new and will require several months before they can be reliably used for monitoring.

Historical comparisons between the existing CORS and PAMs have indicated that some sites are subsiding at rates of seven centimeters per year. This correlates well with rates observed at the extensometers.

The District plans to double the number of PAM sites from 28 to 56, and this will be accomplished **without** an increase in personnel, equipment, or overhead costs. Improvements in GPS equipment have recently eliminated the need for the seven trailers, and they are currently being phased out. The expansion of the monitoring network will not only permit a more comprehensive view of what is occurring in Houston and the surrounding areas, but will also serve as a future model for other localities facing similar problems.





NOTE: MAP CONSTRUCTED FROM VERBEEK AND CLANTON, U.S.G.S. MF 1136 ON U.S.G.S. TOPO BASE MAP

Terrain Solutions, Inc.

WEST HOUSTON METROPOLITAN AREA FAULTS

Long Point and Piney Point East Faults

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Approx. Scale:
1 in. = 1000 ft.
0 ft. 500ft. 1000 ft.

STOP 4

THE LONG POINT FAULT
WESTVIEW DRIVE AT BUNKER HILL ROAD
WEST HOUSTON, TEXAS

The Long Point Fault is the longest single-segment fault in the Houston area. It extends 10.3 miles across west Houston from the vicinity of Eldridge Parkway at Whittington northeastward to a point near Hempstead Highway and Dacoma. Data from a seismic profile shows the fault to a depth of at least 17,000 feet. It is a typical concave-upward growth fault. From measurements of the vertical displacement of originally horizontal home foundations, the rate of movement of the fault in this area in the 1950's through 1970's was slightly more than 1 inch per year. Since that time it has slowed considerably, but nevertheless is still active. Generally rates of movement are highest near the centers of surface faults, decreasing to zero at their ends. This fact is well illustrated by the LIDAR photograph of the Long Point Fault on the next page.

Two pages ahead is an illustrated discussion of a house on Moorhead Street, one block west of Bunker Hill Road, that was built in 1956. As you view the house today, you will be able to see how much its roof line has warped since the house foundation was releveled in 1979. The scarp in the street is 31 inches high.

One-half block to the east of Moorhead at Westview, a home owner could no longer drive his car up the fault scarp and into his garage. He solved the problem by converting the garage into a playroom and constructing a carport in front of it.

One the south side of Westview, just west of Bunker Hill Road, the fault passes beneath a wood frame house that may soon have to be abandoned. Homes are built to withstand strong vertical thrusts due to the force of gravity, but not strong, persistent horizontal thrusts that a component of gravity delivers to tilted walls. Usually owners of homes inadvertently built on faults tire of making repairs and remove the damaged structures by their own volition. Occasionally City of Houston engineers will condemn and force removal of fault-disturbed buildings that have become structurally unsound. Just east of Bunker Hill, one block south of Westview, you will see two vacant lots where homes damaged by the fault have been torn down.

C. E. Norman, 11/05

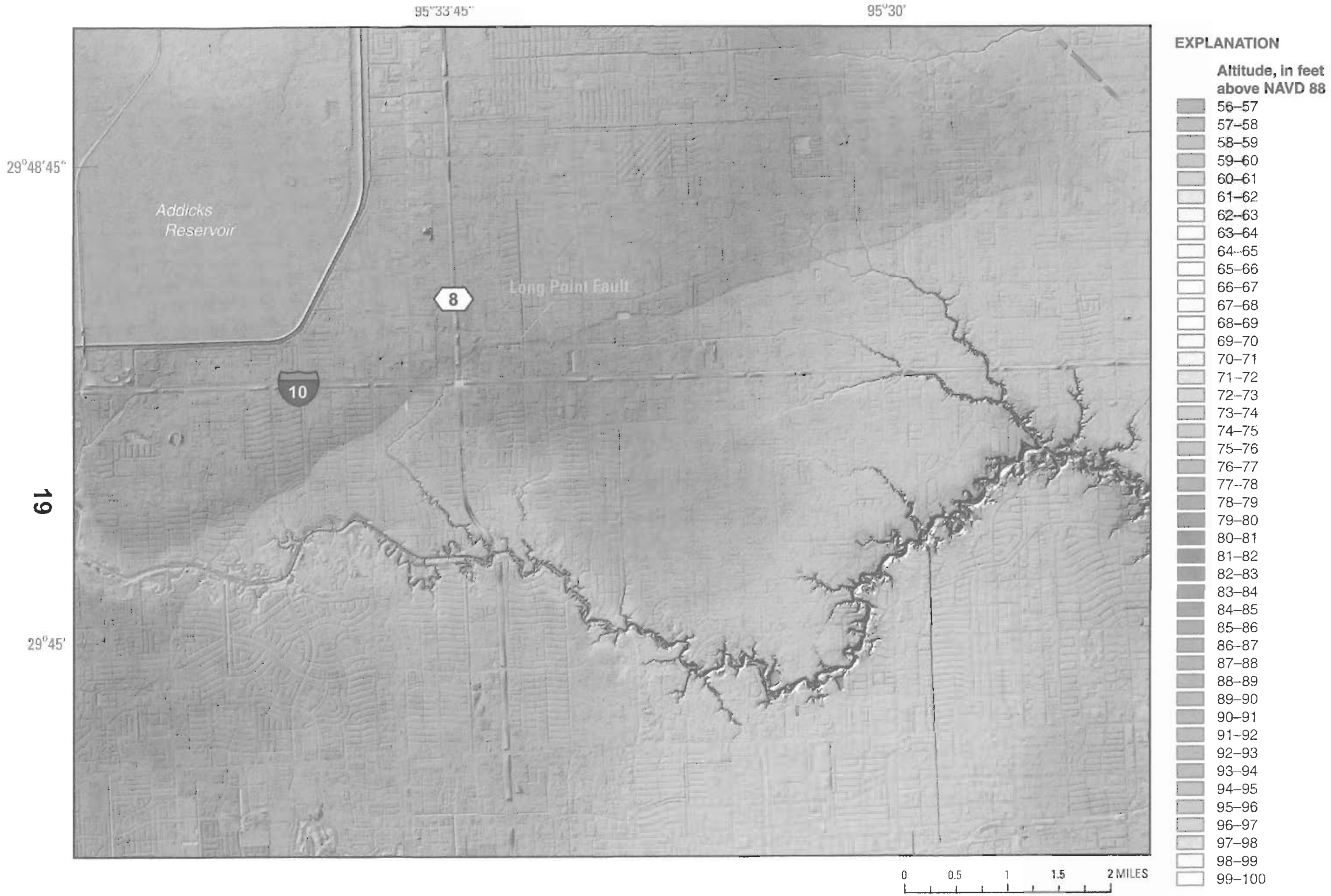


Figure 3. Segment of the hillshaded 15-foot bare-earth Lidar-derived digital elevation model of the area of Harris County showing the Long Point fault.

From PRINCIPAL FAULTS IN THE HOUSTON, TEXAS, METROPOLITAN AREA (Shah and Lanning-Rush, 2005)

Continual Foundation Problems

Repairs to a building foundation overlying a surface fault are not effective over extended periods of time since the subsequent movement of the ground will continue to tear the structure apart.

The photographs to the right are of the same house and were take over a span of about 26 years. This house was built in 1956 and thus started out with a level and intact foundation.

The top photograph was taken in 1977. The sag along the roofline indicates that the foundation has been broken by fault movement. The fault is visible in the foreground of the photo where it has warped and cracked the street surface.

The middle photograph was taken in 1984, five years after the foundation was leveled and repaired in 1979. Close inspection of the picture reveals a sag in the roofline which is a result of continued fault movement.

The roofline in the bottom picture shows that by 2003 the damage to the foundation is almost what it was back in 1977. Again, the fault is visible in the foreground of the picture.

Repeated repairs to a building's foundation and structure ultimately make the cost of occupancy prohibitive. Failure to perform continual repairs to the foundation can ultimately lead to structural failure that can in turn threaten the safety of any occupants.

Terrain Solutions, Inc.

1977: House with broken foundation
(photo by E. Clanton)

1984: House 5 years after foundation repair
(photo by C. Norman)

2003: House with recurring foundation problems
(photo by TSI)

STOP 5

THE PINEY POINT FAULT
PECANWOOD STREET AT CORBINDALE
HEDWIG VILLAGE, HOUSTON, TEXAS

The purpose of this stop is to view a house under construction, its foundation designed to mitigate damage from possible ground deformation adjacent to the Piney Point East Fault. The new house is supported on piers, all of which are set on the upthrown side of the fault. Because the fault dips (slopes downward) to the north, none of the piers enter the zone of significantly disturbed ground along the fault. A house built on the lot in the mid 1950's had a slab-on-grade foundation that rested on both the upthrown and downthrown fault blocks. Fifty years later it had become structurally unsound and had to be torn down. Any small movements of ground beneath this house can be accommodated by readjusting the foundation on the piers.

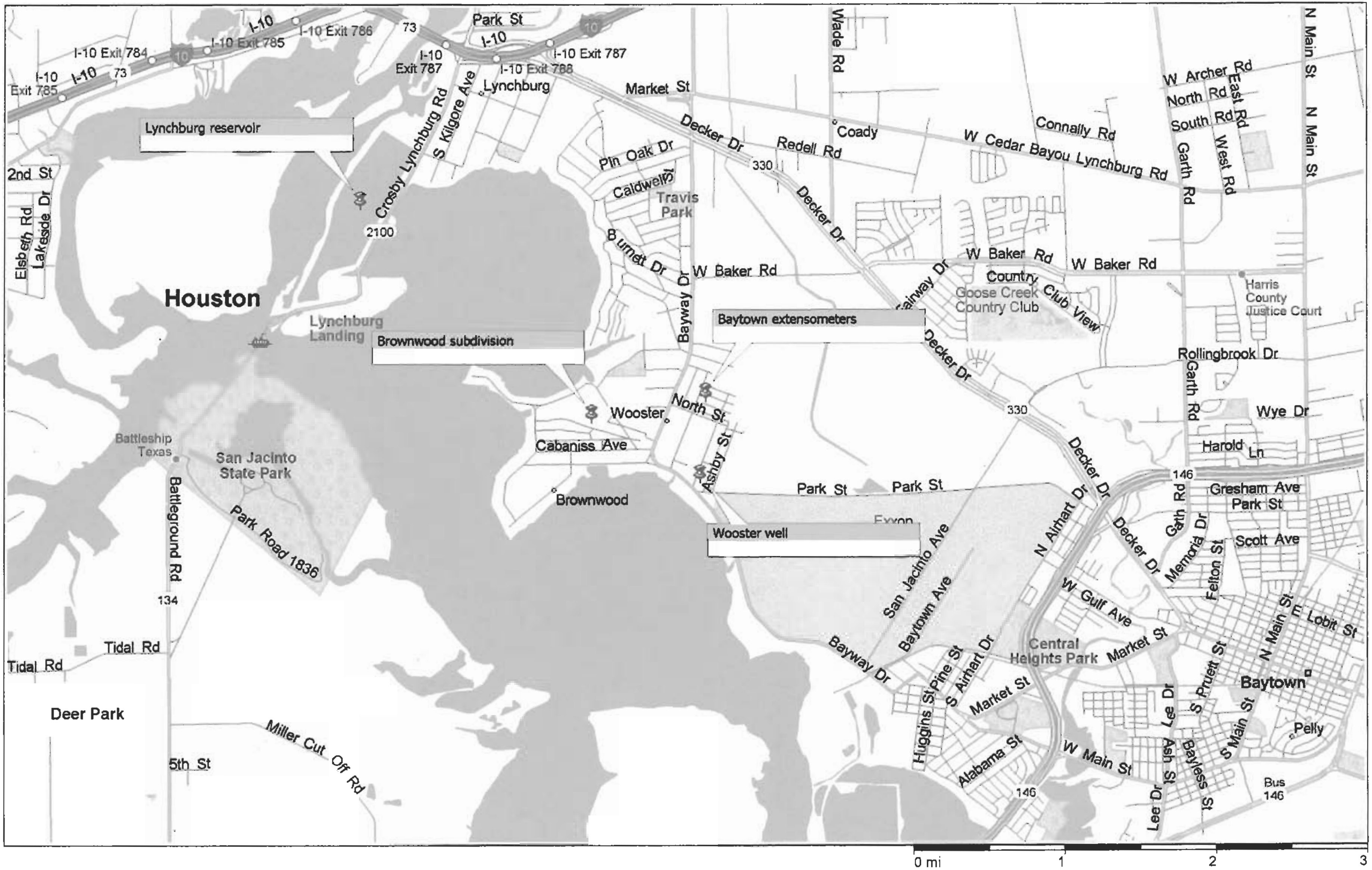
The Piney Point East fault can be traced at ground level for about 2.0 miles between Frandora Lane, a few hundred feet north of Taylorcrest, to the Katy Freeway at Voss Road. It dips northward at an angle of about 70 to 76 degrees. It is antithetic to the Long Point Fault, located about 6000 feet to the north, and probably extends no deeper that its intersection with that fault at a depth of approximately 10,000 feet.

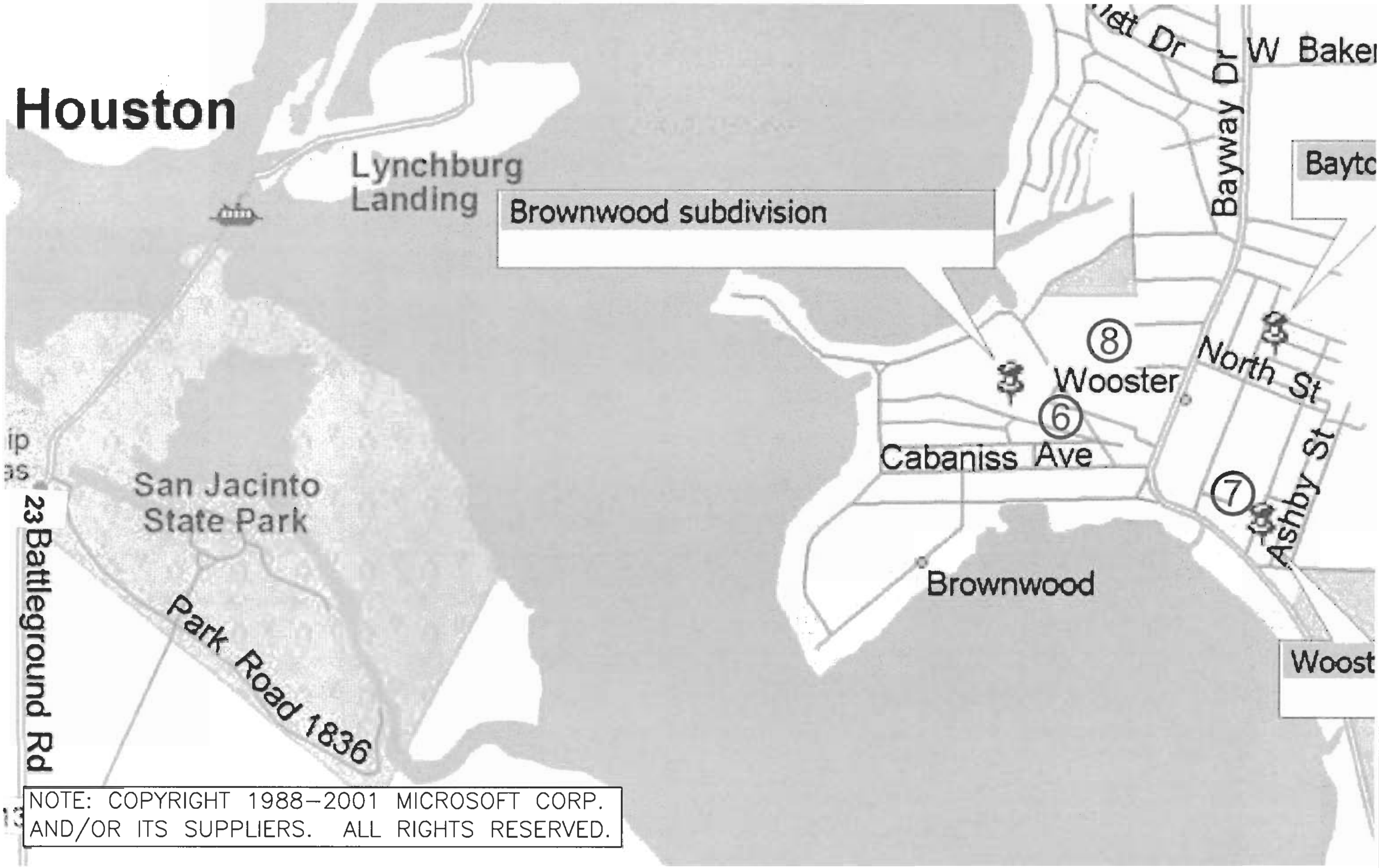
About 50 years ago the Villages Water Authority unknowingly drilled one of their water wells through the fault, just north of Corbindale. The fault caused the well casing to bend at a depth of 1234 feet, and the hole had to be reconditioned to restore its functionality. The well is located 450 feet north of the outcrop of the fault. Thus the mean dip angle of the fault here is 70 degrees. At depths of only a few hundred feet the dip angle is greater.

Main fault-antithetic fault pairs like that seen here are common along the regional fault systems along the Gulf Coast. Because the main faults are listric (i.e. they have a concave-upward shape) there is a horizontal extensional component of movement in the dip direction. If the subsurface materials were rigid, an open gap would form as the fault continued active movement. Since Gulf Coast subsurface sands, silts and clays are ductile, they cannot support such a gap. It will be closed by either ductile deformation, forming anticlinal (rollover) folds on the downthrown side of the fault, or by brittle deformation, forming antithetic normal faults on the downthrown side. Antithetic faults form only opposite the very active parts of the main faults where strain rates are high enough to cause brittle rather than ductile failure.

C. E. Norman, 11/05

Texas, United States, North America





Terrain Solutions, Inc.

BROWNWOOD SUBDIVISION
BAYTOWN, TEXAS

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Approx. Scale:
1 in. = 2000 ft.
0 ft. 1000ft. 2000 ft.

STOP 6

Brownwood Subdivision

Building first began in the Brownwood subdivision in 1938. It was predominantly an upper-class subdivision isolated from the nearby city with comfortable wooded lots bordering the bay. When it was constructed, the majority of the homes in Brownwood were at about 10 feet (3 m) or less above mean sea level. Subsidence, due primarily to the removal of groundwater for industrial purposes at the nearby petrochemical complexes, began to significantly lower land surface elevations shortly after the subdivision's beginning. The early 1940's saw a rapid expansion of the petrochemical complex at the nearby ship channel and also in the City of Baytown itself. All of that additional expansion was supported by the withdrawal of groundwater from wells. It was in 1961, with Hurrican Carla, that the residents of Brownwood first began to realize they had a problem. At that point, Brownwood had already been subjected to approximately four feet (1.2 m) of subsidence.

Shortly after Hurricane Carla, Brownwood residents petitioned the City of Baytown to raise the level of the perimeter road. This afforded some protection to those living inside the perimeter road. Once the levy was built, rain water became trapped behind the levy and therefore it was necessary to install flood gates at points where drainage systems would normally flow to the bay. To handle normal rainfall during periods of high tide, pumps were installed to pump the rain water through the dikes and finally into the bay.

Unfortunately, subsidence in the area continued and by 1978 over eight feet (2.4 m) of subsidence had occurred in the Brownwood subdivision area. During this period many people struggled to keep their homes and to repair the damage caused by high tides throughout the years. The ultimate end for Brownwood subdivision occurred in 1983 with the arrival of Hurricane Alicia. Alicia was not an especially powerful hurricane, barely registering a three on the hurricane scale. Nonetheless, the storm surge caused by Alicia resulted in the destruction of virtually all the homes that were remaining in the Brownwood subdivision. Today the Brownwood subdivision stands deserted, but the area has been incorporated into a beautiful park and wetland area known as the Baytown Nature Center (see below).

The signs of subsidence are obvious throughout the park. Some of the things to look for are the few remaining foundations from the original homes and the perimeter road (which was built up to serve as a dike protecting the homes on the interior part of the subdivision). The original drainage system and pump stations have been replaced by the manmade wetlands, marshes, and channels of the Baytown Nature Center.

PROFILE

Baytown Nature Center

Restoring, protecting & sustaining a natural environment

For further information, call: 281-420-7128

History

The area now known as the Baytown Nature Center was formerly the Brownwood subdivision. A peninsula surrounded by Burnett, Crystal and Scott Bays, the subdivision had frequent trouble with flooding. High tides, subsidence and hurricanes all contributed to these problems. The last straw for Brownwood was Hurricane Alicia, which destroyed much of the subdivision in August 1983. In September of that year, the process of buying the land began. By 1990, most of the land had been acquired, and in 1991, funding was approved for creating a nature center. In November of 1997, the Baytown City Council approved the master plan for the Baytown Nature Center. When completed, the center will include an Interpretive Center, the Myra C. Brown Bird Sanctuary, a trail system and many other features.

Status

The Baytown Nature Center has been open to the public since its creation in 1991, with the exception of a one year period in 2001/2002.

Programs

One of the first major restoration projects to take place at the Baytown Nature Center was the French Limited Marsh Creation Project, a mitigation project which was largely complete as of 1995. As part of this project, workers removed most of the remaining houses, utilities and roads from the area. Afterwards, they created 60 acres of high quality tidal marsh with three channels through it to allow tide flow to keep the marsh alive and a productive part of the adjoining nursery bays. Two elevated areas were converted into islands, and four freshwater ponds were created.

A variety of other mitigation projects have been completed or are currently underway at the Nature Center. On April 1, 1999, construction of a parking lot, pier and picnic areas at the San Jacinto Point Recreation Area was completed. There are now three fishing piers, a butterfly garden and a children's nature discovery playground. In the near future, construction of a new entry to the nature center will get underway and improvements are to be made to the Myra C. Brown Bird Sanctuary.

The Baytown Nature Center is currently used for both educational and recreational purposes. Members of the public routinely use the area for picnics, fishing and birdwatching. The Eddie V. Gray Wetlands Education and Recreation Center utilizes the nature center as an outdoor classroom for its Wetlands Ecology Program. Each year, every fifth grade student in the GCCISD system is taken through the BNC and introduced to the importance of this ecosystem through their studies of the marsh plant, animal and aquatic life found there.

Project Area

The Baytown Nature Center consists of approximately 400 acres of hardwood uplands, high quality tidal marsh, and freshwater wetlands. This unique site is listed on the Great Texas Coastal Birding Trail. It provides habitat for 317 species of resident and neo-tropical migrant birds. The American Bird Conservancy designated the BNC as a nationally important bird area.

Partners

City of Baytown -- Parks and Recreation Department, Baytown Nature Center Planning Subcommittee, Lyondell Chemical Company, French Limited Task Group, ExxonMobil Chemical Company, Chevron Phillips Chemical Company, Stolthaven Houston, Inc., U.S. Fish and Wildlife Service, Texas General Land Office -- Coastal Management Program

Stop 7

Wooster Well

A brief stop at the former site of the Burnett School reveals an interesting phenomenon. Behind the former school site is an old utility district supply well which is unique in that it has behaved like an extensometer. The casing of this well has been set at approximately 500 feet (152 m) below the land surface. In this particular case, the bottom of the casing has remained stable at the point at which it was originally set, and the ground has subsided around it. This phenomenon, while interesting, is not a common one because the friction of the strata on the well casing will often cause compressive failure. Close inspection of the concrete well pad would seem to indicate that as the ground subsided around the well, the utility made several more pours of concrete to fill the gap between the old pad, which was suspended in mid-air, and the ground surface. For this reason, it is nearly impossible to determine the exact amount of compaction that this well is showing us, but certainly it is on the order of several feet.

1986

October 2005

STOP 8

THE WOOSTER FAULT
BAYWAY DRIVE AT NORTH STREET
BAYTOWN, TEXAS

The Wooster Fault is one of 7 known surface faults in the Baytown area. All of the faults occur in association with the Goose Creek Dome, a prolific oil-bearing structure discovered from gas seeps in 1906. Although the structure is believed to be a salt dome, no drilled well has yet encountered salt. Approximately 20 faults are known at depth over and around the edges of the dome, the Wooster being at the dome's northwest flank. According to M. J. Quinn, Chevron Oil Company (Typical Oil and Gas Fields of Southeast Texas, Vol. 2, p. 242, 1987) some wells have problems with casing, suggesting continuing fault movement at depth.

On land, the Wooster Fault extends about 2 miles from the east shore of Burnett Bay at Schreck Street, east-southeast across Bayway Drive and into the Exxon refinery. Petroleum industry maps show the fault extending another 10 miles to the west, ending in Pasadena near State Highway 225 and Red Bluff Road. However, there are no known surface faults across that distance that would correspond in location, direction and sense of movement with that subsurface extension of the fault. ExxonMobile has purchased the former residential properties east of Bayway Drive and removed the buildings, most of which were small wood frame structures. The fault, downthrown to the south, crosses paved north-south streets just north of North Street. West of Bayway Drive, 2 or 3 houses still remain astride the fault. Pier-and-beam construction allowed the owners to relevel their foundations by jacking and shimming the beams resting on piers.

C. E. Norman, 11/05

Baytown Borehole Extensometers

The two Baytown extensometers were installed in 1973 by the USGS as part of a cooperative agreement with the U.S. Army Corps of Engineers. The Corps was primarily interested in obtaining clay samples at various depths that could be used for consolidation tests in a laboratory. This data was used to make projections of subsidence in the nearby Brownwood Subdivision. After the drilling of the two test holes, the USGS equipped the test holes to serve as extensometers. Although two extensometers had been installed in the Houston area prior to the Baytown extensometers, these were the first to use pipe as a mechanism to transmit the stable point from the bottom of the hole to the surface, as opposed to previous installations that used aircraft cable. This made for a much better installation that gave data that was far more consistent.

The deep extensometer (LJ-65-16-931) has a total depth of 1,475 feet (450 m) below land surface.

The shallow extensometer (LJ-65-16-930) has a total depth of 431 feet (131 m) below land surface.

By using both extensometers in conjunction, it it possible to determine what part of the total compaction in the area occurs between ground surface and 431 feet bls and what part of the total compaction occurs between 431 feet and 1,475 feet bls.

Both extensometers have a 10' screened interval at their base that allows the extensometers to not only record compaction, but also to serve as a piezometer. The first compaction data and water-level measurements began on July 24, 1973. So compaction and water-level measurement data has been continuously collected at these two extensometers and the six associated nested piezometers for more than 32 years.

San Jacinto Monument and Battleground

"In future time, then may the pilgrim's eye see here an obelisk point toward the sky...."
— Anonymous poet

The above prediction was penned in the poem: "Ode to San Jacinto", even before the Republic of Texas became the State of Texas. Today, the world's tallest war memorial stands at San Jacinto—15 feet taller than the Washington monument—honoring all those who fought for Texas's independence.

Immediately after the Battle of San Jacinto, the land—then privately owned—commanded respect from all who walked on its soil. The Texas Veterans Association began planning a formal monument, and the state finally received funding to purchase land in the 1890s.

Building the monument was hard work. In the 57 hours that the foundation was poured, the builders consumed 3,800 sandwiches and 5,700 cups of coffee.

San Jacinto Museum of History © 2003

A full-scale model of the 34 foot, 220 ton star was built to test its assembly before the star was constructed at the top of the monument.

San Jacinto Museum of History © 2003

After years of pushing by the Sons and Daughters of the Republic of Texas, as well as help from President Roosevelt's Secretary of Commerce Jesse H. Jones—a prominent Houstonian—its proponents raised enough money to build a fitting monument. And the time was right, with San Jacinto's 100-year anniversary at hand.

The design was the brainchild of architect Alfred C. Finn, engineer Robert J. Cummins, and Jesse H. Jones. Construction ran from 1936 to 1939. With continued support, the San Jacinto Museum Historical Association has occupied the facility since its doors first opened.

Its builder was the Warren S. Bellows Construction Company of Dallas and Houston. The monument building alone—apart from its great historical significance—is worth a trip to the San Jacinto Battleground Historical State Park. At 570 feet, this Texas giant one of the finest examples of Moderne (Art Deco) architecture in the United States. The monument has been recognized as a National Historic Civil Engineering Landmark by the American Society of Civil Engineers.

The museum is located in the base of the monument, greeting visitors with bronze doors emblazoned with the six flags of Texas. The base is 125 feet square, with text panels highlighting significant events in history leading up to and resulting from the Texas Revolution.

The shaft itself is octagonal, 48 feet at its base, 30 feet at the observation level and 19 square feet at the base of its crowning jewel—a 220-ton star made from stone, steel and concrete. Despite the scale, danger and novelty of the project, not a single life was lost during its construction.

Subsidence and San Jacinto

Both the monument and the battleground are historically important to the people of Texas. However, subsidence of over nine feet (2.7 m) in this area has caused the loss of over 100 acres (40 ha) of its 900 acre (364 ha) total area. The signs of subsidence are present throughout the park and will be pointed out during your tour. One of these is the reflection pool, which is a prominent feature of the park. In the early 1970's, subsidence had so affected the area around the reflection pool that it was necessary to virtually reconstruct the pool and build a dike along its northern edge to prevent the waters of Buffalo Bayou from spilling over into the reflection pool. The building of the dike created an area that would trap rain water, so it was then necessary to put in a series of fresh-water pumps to remove the rain water from the park area. There is a small creek area in the park called Adams Crossing. At one point fences could be observed, which during periods of normal tides are virtually submerged. The road to this crossing has been raised over eight feet (2.4 m) to allow access to the eastern most edge of the park. This same road was once a circular route that doubled back and crossed the same bayou. However, subsidence at the second crossing had progressed so far that it was judged too expensive to build up the road. You can not drive to a point where the road actually dives down into the bayou, and careful observation will allow you to see the road rising again from the bayou on the far side.

The monument itself, like most structures in this area, covers too small of an area to be affected by subsidence - that is to say that the entire monument has been lowered approximately nine feet along with the rest of the battleground, but that subsidence has had no affect on the foundation of the monument. Interestingly, the area of the monument is one of the few in the country where long term studies have been done on soil consolidation as it relates to foundations. When the monument was first built, 50 settlement reference points were installed in its foundation. Over a 44-year period, the elevation of those 50 points has been related to a nearby stable benchmark (stable with respect to soil expansion, not with respect to subsidence), and as of 1991, it was found that the settlement at the monument averaged about 12.3 inches (31 cm). The minimum settlement was about 11.6 inches (29 cm) near one edge of the monument, and the maximum about 12.9 inches (33 cm) near the center. The data seemed to indicate that the south side of the monument's foundation settled about 0.8 inches (2 cm) more than the north side. At the observation level within the monument at the top, this would yield approximately 4 inches (10 cm) of tilt towards the south.

The Pasadena and Baytown extensometers are the two closest extensometers to the battleground area. Data from both of those extensometers indicate that the area has stabilized and the battleground should lose little or no additional land to subsidence.

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