CLODINE FAULT, SOUTHWESTERN HOUSTON

METROPOLITAN AREA, TEXAS

by

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Plate 1. Map of the Clodine fault, western Houston metropolitan area

Clodine fault, southwestern Houston metropolitan area, Texas

Introduction

The Clodine fault* is one of a group of east-northeast-trending faults that have displaced the land surface in western and north-central Houston (fig. 1). Movement has occurred along these faults in the recent geologic past, and most are known to be active* today, as evidenced by moderate to severe damage to manmade structures caused by movement along them.

Nine faults in north-central and western Houston are under study (fig. 1). Seven of them are in developed areas; an eighth, the Renn scarp*, is not known for certain to be a fault. The Clodine fault is in an area of rapid growth on the western outskirts of Houston, a fact that prompted release of our findings. This report is excerpted in part from our more complete study of all nine faults.

Field relations of Clodine fault

The scarp of the Clodine fault can be mapped for at least 12.5 km, extending east-northeast from Figure Four Lake to near Alief-Clodine Road, 2 km east of State Highway 6 (pl. 1). The fault in map view is gently sinuous, a common characteristic of Texas Gulf Coast faults; its general east-northeast trend comprises segments that vary in trend from about N. 45° E. to nearly due east. Offset of the land surface along the fault ranges from an estimated 0.2 m to more than 0.4 m, and averages about 0.3 m along most of its length. This is a low figure,

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*All terms followed by an asterisk (*) are defined in the glossary

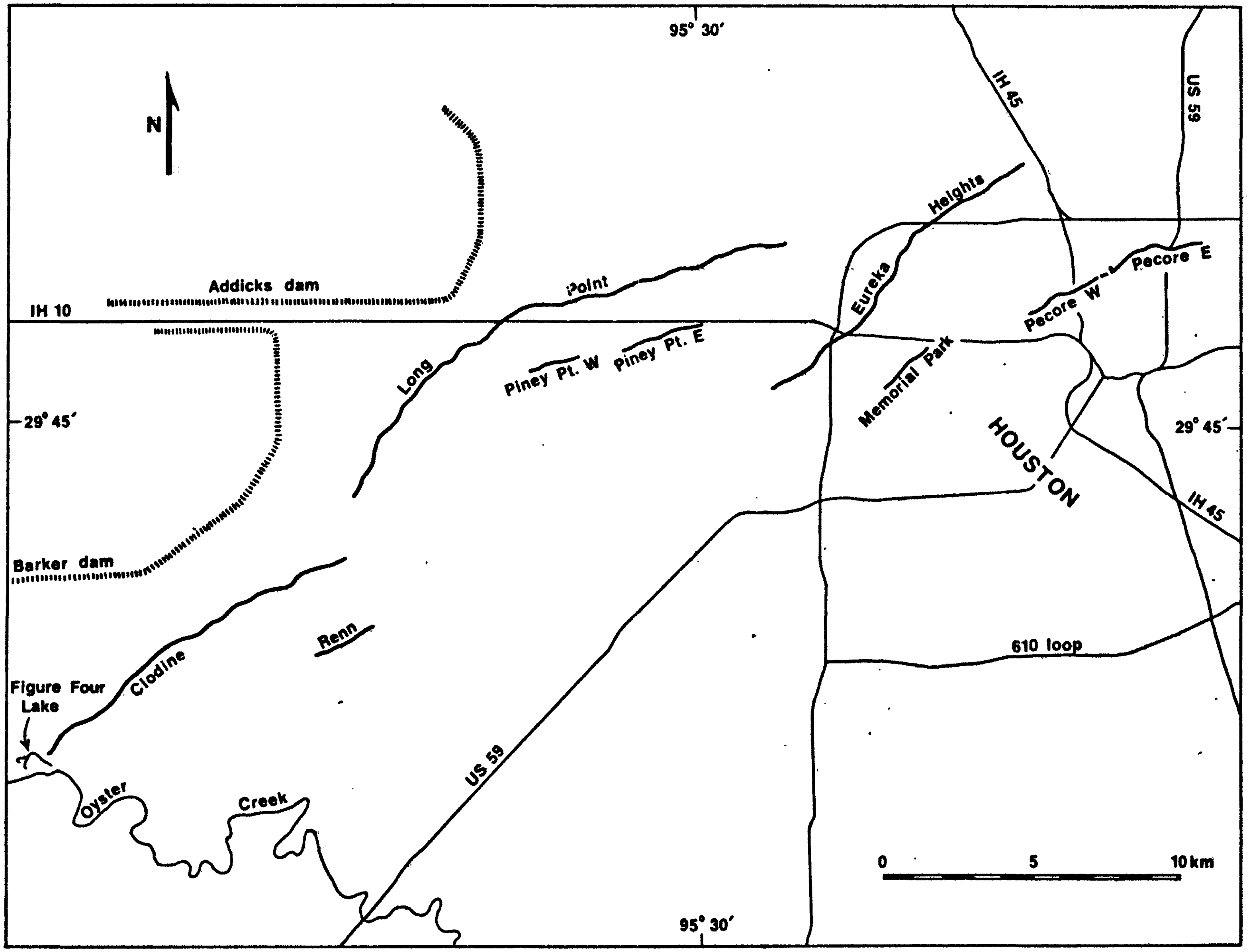

Figure 1.--Faults in northern and western Houston metropolitan area. Faults are labeled on the topographically higher, upthrown* side. IH = interstate highway

but scarps of this height are typical of the Texas Gulf Coast, and stand out as prominent, relatively abrupt topographic features within the otherwise much flatter and more gently rolling landscape that dominates much of the region.

The block of land north of the fault is the downthrown* side, an area which, because of its lower elevation, is more poorly drained than the southern, upthrown* block. Broad, shallow pools of water occupy much of the downthrown block after each heavy or prolonged rain; at such times the approximate trace of the fault is particularly evident, both from the air and in the field, as the well-defined edge of flooded land. Wetter soil conditions prevail on the downthrown side for much of the year and, as a result, the two sides of the fault support different vegetation communities in fields that have lain undisturbed for several years. The vegetation change across the fault, typically from prairie grasses and shrubs on the upthrown block to broad-leafed grasses and local sedges and rushes on the downthrown block, is commonly noted in the field and can be strikingly apparent from the air.

Short segments of a well-defined scarp are preserved in a few relatively undisturbed areas, but most of the fault scarp has been modified by past and present plowing for crops and by recent grading for new homesites.

Despite such modifications of the natural landscape, good evidence of the fault remains. Grading, plowing, and other earth-moving activities commonly decrease the slope angle of a fault scarp, but they do not erase the elevation difference between the upthrown and downthrown fault blocks; the approximate trace of the fault is still discernible in many such areas.

Recent movements of the Clodine fault

Displacement of geologically young sediments by the Clodine fault (fig. 2) demonstrates that movement has occurred within the last 30,000 to 40,000 years. Opportunity to assess its present rate of movement, however, is severely limited. Few manmade structures of sufficient age to show the effects of fault movement have been built. The geologist must resort to less direct, and less conclusive, evidence, as summarized below:

(1) Little or no sign of the Clodine fault is seen on aerial photographs taken in 1930. Tonal contrast, scale, and resolution of these photographs are quite sufficient to reveal any obvious evidence of the fault. The inference is that, in 1930, the fault scarp was not of sufficient height to produce a discernible vegetation or soil-moisture contrast, and much of the 0.2- to 0.4-m offset now seen in the land surface has been produced in the last 50 years.

(2) Several drainage canals and borrow ditches deepen abruptly where they cross the Clodine fault. If the ditches had relatively constant gradients when they were dug originally, as is common practice, movement on the fault since construction of the canals and ditches is suggested.

(3) Until the past few years, the Clodine fault was crossed by only two paved roads. One of these has shown no sign of fault movement since it was first inspected in 1975. The other road is everywhere cut by

Figure 2. (following page).--Oblique aerial photograph (NASA photo S-78-26931) of western part of Clodine fault, looking southwest toward Figure Four Lake (pl. 1). R and S identify ridge-and-swale topographic features typical of point-bar* deposits. A similar but younger point bar is visible on the inside bend of Figure Four Lake (arrow), a remnant of an old and now-abandoned stream channel.

Topographic details of the faulted point bar are best visible on aerial photographs after a heavy rain, when water (light tones) occupies the swales of the point bar and the downthrown side of the fault is flooded. The slope that marks the fault may be followed readily through the fields, but the scarp has been all but destroyed by repeated plowing.

Similar relations have been photographed at other locations along the 12-km length of this fault.


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numerous small fractures, as is usual for asphalt road surfaces, but the fractures appear both more numerous and slightly more open where the road crosses the fault.

The evidence suggests that movement along the Clodine fault is occurring at a seemingly low but undetermined rate. We stress, however, that the various lines of evidence, even collectively, are far from diagnostic and present at best only a weak indication of fault movement.

Environmental aspects of faulting

The Clodine fault is one of nearly 200 faults now known in the Houston metropolitan area. Although this fault is among those for which the level of activity is unknown, review of some common effects of fault movement that we have noted elsewhere during our mapping is nevertheless instructive.

Faults in the Houston metropolitan area typically intersect the ground surface at angles that range from 60° to 75°. Displacement on any such fault surface cannot be purely vertical, but must involve horizontal extension as well (fig. 3). A simple trigonometric relationship exists between inclination of a fault and the ratio of vertical to horizontal offset; for inclinations of 60° to 75°, the vertical component of movement must exceed the horizontal component by a factor of roughly two to three. The division of movement on an inclined fault into vertical and horizontal components is artificial, but instructive: the vertical component of movement leads to breakage by removing support from beneath that part of the structure which rests on the downthrown side of the fault; the horizontal component of movement tends to literally pull the structure apart.

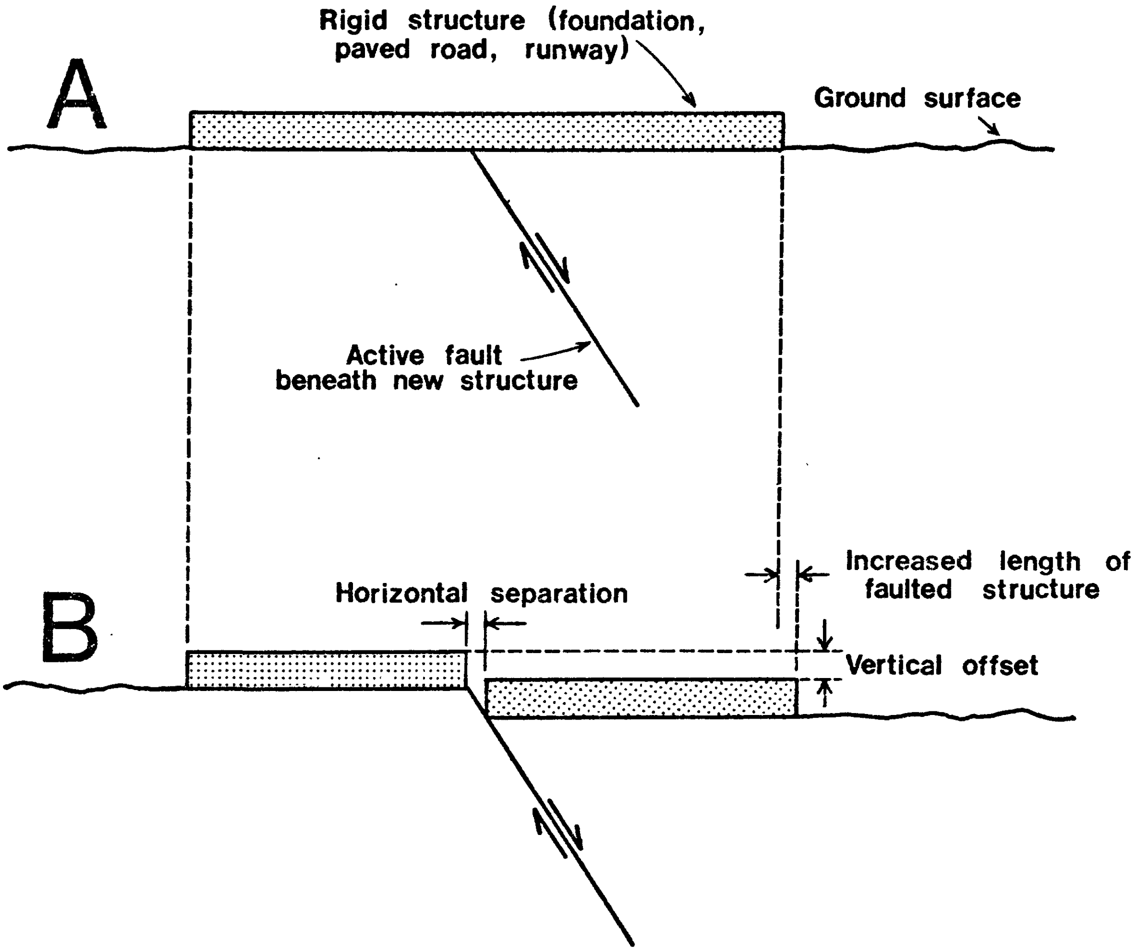

Figure 3.--Effect of fault movement on a rigid structure built on an active fault. A, original construction; B, structure damaged by fault movement. Both vertical offset and horizontal separation are necessary consequences of displacement. Rigid structures may literally be pulled apart as faulting proceeds.

Common effects of fault movement beneath buildings include foundation failure (and attendant periodic infiltration of water), tilted floors, distorted window and door frames, leaking roofs, and extensive damage to facing materials and interior walls. The road network in the Houston area has also been damaged by fault movement at hundreds of locations, some of which have necessitated repair at intervals as frequent as every 2 years.

Most damage by fault movement normally occurs on and immediately adjacent to the fault scarp, within a zone that is typically 2-3 m wide, but which may vary in width from less than 1 m to more than 10 m. To either side of this zone, some limited fault-related failure may be seen in brittle material, but the most visible effect of fault movement here is tilting. The amount of tilt progressively decreases away from the fault scarp, and is, for most faults, minor at distances of 20-30 m from the scarp. Surveying data, however, suggest that detectable amounts of tilt may be found as much as 70 m away from some faults. The effects of fault movement are not identical on both sides of a fault; typically the downthrown block shows more damage and the zones of breakage and tilting are wider than corresponding zones on the upthrown side.

Nearly all fault damage is thus seen to be confined to a moderately narrow zone, and any given fault will directly affect only those relatively few structures built on or close to the fault scarp. Indirect effects of faulting, however, may be felt at locations far removed from the nearest fault. Consequences of a break in water or sewer lines, for example, may affect more residents than those in the immediate vicinity of the break. In addition, structures built on the downthrown side of an active fault lose more elevation with each new increment of fault movement; in some areas this increases the possibility of flooding during periods of heavy or prolonged rainfall.

Appendix A

Mapping Technique

Interpretation of aerial photographs is the primary method by which geologists identify many faults in undeveloped areas of the Texas Gulf Coast. Photos provide a powerful but not necessarily definitive tool for positive fault identification; field examination of each feature tentatively identified as a fault from aerial photographs is essential. We examined the Clodine fault in the field along nearly the entire mappable length of its scarp (some parts several times, from 1975 to 1979) and gathered additional data during helicopter flights in February and June 1978.

The topographically low, downthrown side of a fault is commonly an area of impeded drainage, susceptible to minor flooding after heavy rains and characterized by wetter soils on the average than are found on the higher and better drained upthrown block. The response of vegetation to long-term differences in soil moisture is commonly evident in the field. Shrubs, small trees, and prairie grasses dominate the plant community on the upthrown sides of many faults, whereas the downthrown blocks support only those grasses, sedges, and rushes that can grow in a permanently wet environment.

Differences in soil moisture can be interpreted from aerial photographs; the wetter soils of the downthrown block will appear darker on black-and-white prints. Vegetation changes may likewise be visible from the air, although in this case the darker side does not necessarily correspond to the downthrown fault block. Faults in undeveloped areas, such as much of the area traversed by the Clodine fault, are thus commonly visible on large-scale aerial photographs as sharp, gently curvilinear boundaries between two areas that differ in tone on the photo.

The activities of man have an obvious effect on the ability of a geologist to map faults. In land under cultivation, where vegetation is limited to a single crop, all evidence of a former vegetation contrast across a fault is lost. After harvest, however, tonal changes due to differences in soil moisture may stand out clearly; and even during the growing season, wetter conditions on the downthrown block commonly affect the rate of growth, and thus the appearance, of the crop being grown there.

Rice fields, however, can often be used to the advantage of the geologist in tracing faults. Rice levees are constructed so as to facilitate flooding of the land between adjacent levees with a uniform depth of water. For this, each levee must be constructed so that it is at a constant elevation along its entire length; a rice levee in the field is thus analogous to a contour line (a line of uniform elevation) on a topographic map. Adjacent levees typically differ in elevation by 10 to 15 cm. The pattern of rice levees is often apparent from the air and furnishes the geologist with, in effect, a topographic map from which fine details of the landscape can be read. Rice levees that are mutually subparallel and closely spaced across a field are indicative of a relatively steep slope of considerable linear extent--an anomaly in the normal, flatter landscape. Some such slopes are fault scarps (fig. 4).

Seasonal changes in the appearance of vegetation and the dependence of soil-moisture contrasts on recent rainfall necessitate examination of aerial photographs from as many different flights (ideally from different years) as practical if a reliable fault map is to be prepared. About 60 percent of the known length of the Clodine fault is visible on most photographs, but because some parts that are subtle on one photo may be clearer on another, the fault can be mapped readily along most of its length.

Appendix B

Limitations of Report

Effective and proper use of this report, especially of the map (pl. 1), is in part contingent upon an awareness of the purpose of this study, and of the limitations imposed by map scale and by aerial photographs.

This report is one small part of a larger project involving examination of several hundred faults in the Texas Gulf Coast. Exhaustive study of any particular fault is neither possible nor desirable in this context. We have attempted to map the Clodine fault carefully and in some detail, but our findings are by no means complete and are not sufficient for many problems concerning land use. Site-specific problems require site-specific studies.

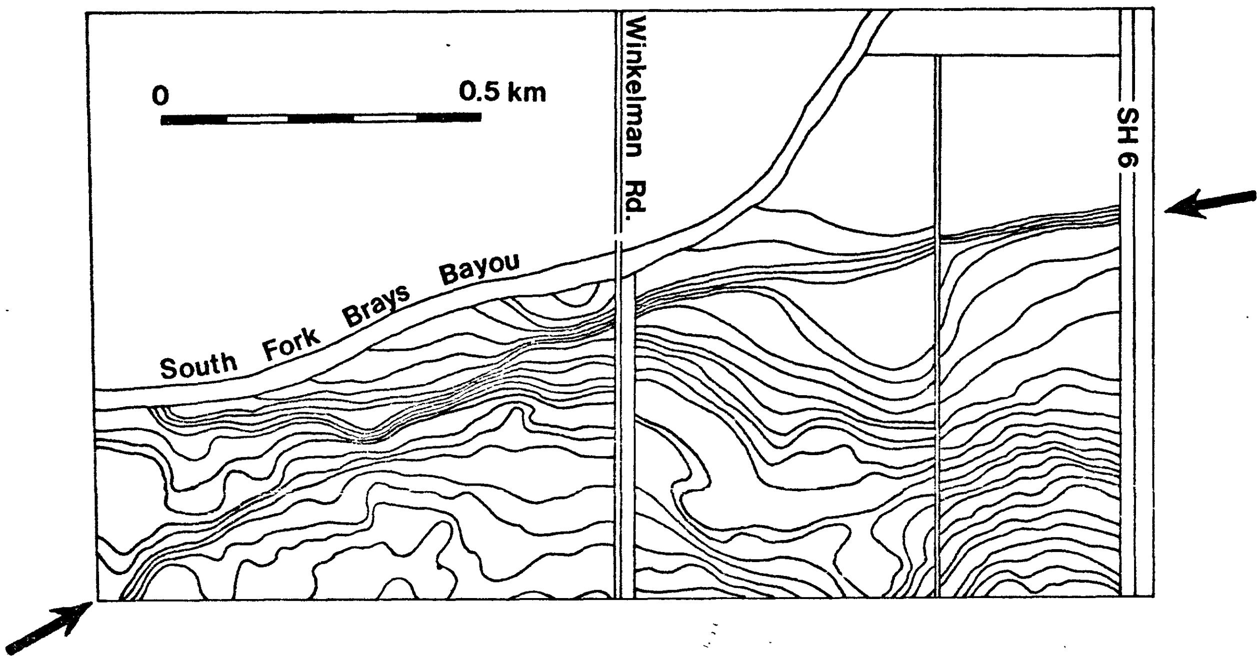

Figure 4.--Pattern of old rice levees, traced from a 1972 aerial photograph, in fields west of SH (State Highway) 6. Each sinuous line in the figure represents the crest of a levee, which is everywhere at a nearly constant elevation. Rice levees approximate contour lines as seen on topographic maps, and, like contour lines, they can be used to interpret the shape of the land surface: the more closely spaced the levees, the steeper the slope of the land. The zone of closely spaced levees that crosses the figure in an east-northeast direction (arrows) is the scarp of the Clodine fault. Although the fault scarp is apparent in the pattern of rice levees, grading of these fields prior to planting has modified and subdued all original slopes. The scarp is now 20-30 m wide. The trace of the Clodine fault can be located only approximately from surface evidence.

Inaccuracies in the base map are unavoidable, although considerable effort was made to minimize them. The primary base map is from U.S. Geological Survey 7 1/2-minute topographic maps, which predate most construction in the area. All roads that have been constructed since 1970 were added to the map. This process required photographic and xerographic reproduction of additional maps (of unknown accuracy), and then optical reduction of these products for transfer of relevant information to the primary base map. Errors are introduced at every stage of this process; indeed it was impossible to achieve perfect registration of any map to the primary base map for all visible points. Positional errors in the placement of new roads on the base map are thus a certainty, and, although we believe these errors are minor, we have no way to test this. Because of these uncertainties, site-specific studies are recommended for areas near the fault.

Information on the location of the Clodine fault was compiled on several sets of aerial photographs, at scales of 1:12,000, 1:40,000, and 1:60,000, depending on which photo showed the clearest visual trace of the fault segment being mapped. All aerial photographs contain planimetric errors due to a variety of causes, most of them quite unavoidable and all of them leading to difficulties in transferring information from photos to the map. Good, but not perfect, registration between photos and the base map was achieved for most photos. The fault trace as shown on plate 1 thus represents only a close approximation to where it is seen on aerial photographs. Inasmuch as the placement of roads and the trace of the fault on the map involve small but perhaps significant uncertainties, it follows that the position of the fault relative to the road network is also subject to error. Again, these errors are believed to be minor, but awareness of their existence is essential to avoid use of the map beyond its capabilities.

One other aspect of mapping faults deserves special attention. In older, developed areas, two factors combine to facilitate mapping of an active fault: the fault can be located quite accurately at many points where it has damaged buildings, roads, and other manmade structures, and each such location is readily identifiable on aerial photographs and maps. Neither fact holds true for the open areas that dominate the outskirts of western Houston (and it has not been established that the Clodine fault is active). In these and similar fields, one sees only a fault scarp. The precise position of the fault itself, relative to the scarp, is somewhat in question, and the degree of positional certainty drops as the natural landscape is modified by plowing, or by grading and smoothing the land in rice fields (fig. 5). Positional accuracy is assured only to the extent that the present landscape resembles its original form. In addition, even where a well-defined scarp may be followed readily in the field, the common lack of nearby control points from which one can determine exact map positions deters accurate portrayal of the scarp on maps. Unless the position of a scarp is apparent from aerial photographs, because of a visible change in vegetation and soil tone from the upthrown to the downthrown side, the geologist must simply estimate his or her position on the map.

A related problem concerns the identity in the field of a feature first observed on aerial photographs. In large fields where one's map position is in some doubt, the feature being traced in the field can not

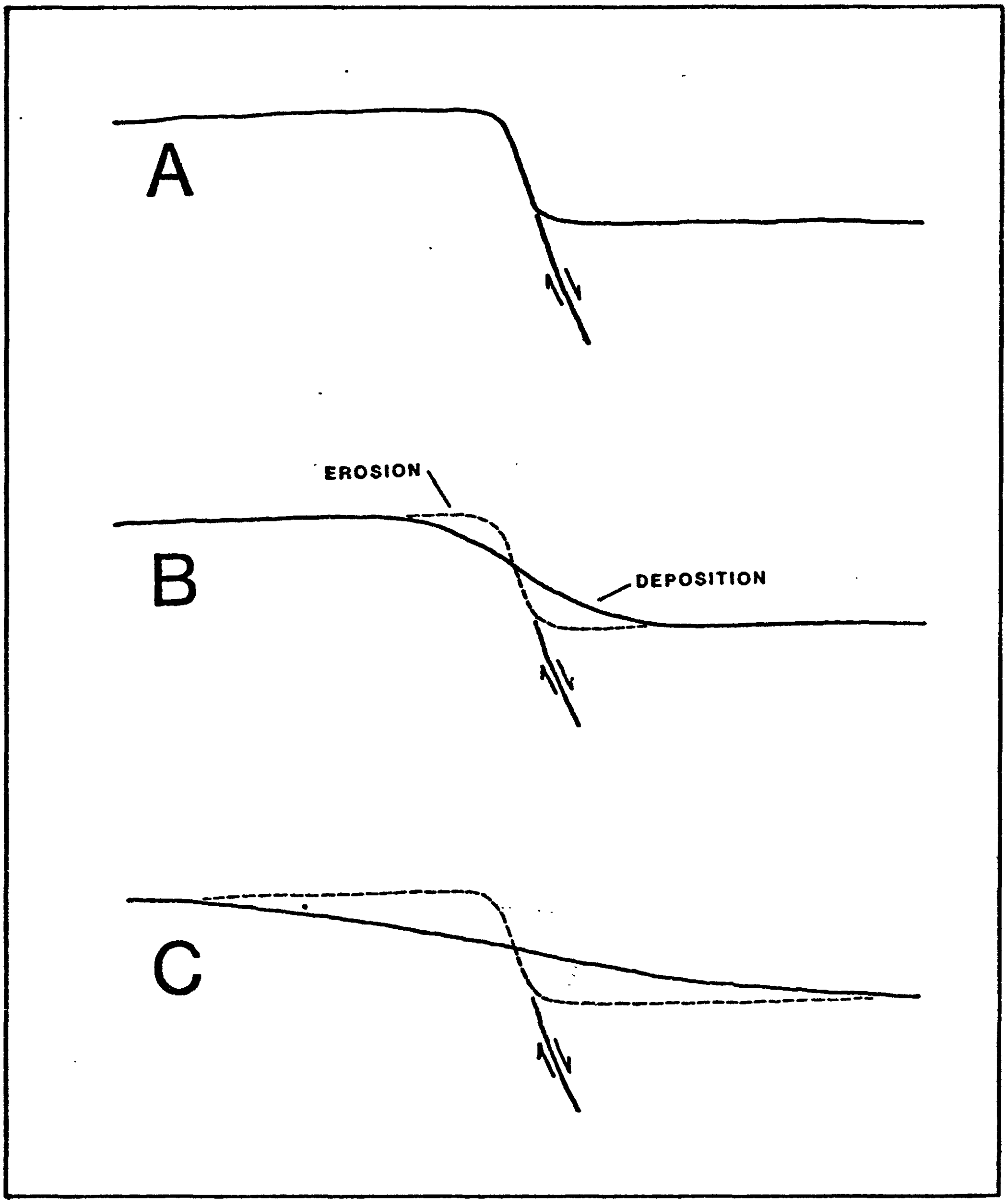

Figure 5.--Topographic profiles across a hypothetical fault in the Houston area. A, shortly after displacement of the land surface. Scarp is sharp and has a steep slope. B, the same fault scarp modified by erosion. Material eroded from the upthrown side is deposited near the base of the scarp. The scarp now has a rounded form and a relatively gentle slope. Location of the fault trace in the absence of structural damage can only be approximated. C, fault scarp after grading for construction or after preparation of a field for rice cultivation. The scarp is all but destroyed; only a gentle slope remains in its place. The elevation difference between the upthrown and downthrown fault blocks remains, but the location of the underlying fault can only be estimated within broad limits because of extensive modification of the original topography.

always be definitely identified as the same feature that appears on the photo. This problem is normally overcome with little difficulty and is not considered significant for any part of the Clodine fault, with the possible exception of the area near point G (pl. 1).

Whenever fortunate circumstances prevailed--the fault scarp was well defined, its trace was clear on aerial photographs, and there was little difficulty in registering the photo to the map--the fault is plotted to an accuracy of within 1 mm on our original base map. This distance corresponds to 24 m on the ground. Limitations inherent in the map scale thus make it difficult to determine whether the fault goes through or merely lies near a particular site, even under the best of conditions. Additional studies are required where the location of the fault must be known to within the nearest few meters; and, here, acquisition of subsurface data may be needed to supplement surface evidence of faulting. The location of the fault can then be surveyed to desired standards of accuracy.

Appendix C

Field evidence of the Clodine fault

The Clodine fault, for descriptive purposes, may be divided into a number of segments (pl. 1). Field relations vary from segment to segment, due for the most part to man-related rather than natural factors. The description below is a brief summary of evidence gathered in the field for the presence of the fault. Noted as well is the appearance of each fault segment on aerial photographs.

Segment A-B

Repeated plowing in these croplands has modified the original fault scarp, which now appears as a broad, gentle slope between the upthrown and downthrown fault blocks. The difference in land elevation across the fault is still apparent, however, and permits delineation of the approximate trace of the fault. The fault is most readily traced in the field shortly after heavy or prolonged rainfall when, for a brief period, the downthrown fault block is flooded. At these times, too, the fault shows up clearly from the air (fig. 2); it is otherwise indistinct on most aerial photographs.

Offset of point-bar deposits in this area (fig. 2) furnishes the most conclusive evidence that the observed feature is a fault scarp.

Segment B-C

This area is used chiefly for grazing of cattle, but much of it appears to have been cultivated in the past. The fault scarp, although modified by man's activities, remains well-enough defined that confident mapping of the fault is possible, particularly from point C halfway to point B. The trace of the fault is sharp and clear on most aerial photographs we have seen of this area.

Segment C-D

This is the most indistinct segment of the fault, both in the field and on photographs. Closely spaced levees across more than 1.5 km of rice fields approximate the fault trace. The elevation difference between the upthrown and downthrown blocks can be followed across the countryside, but nowhere is a well-defined scarp evident. This is typical of those localities where a fault scarp crosses a rice field, for efforts are often made to make the land as flat as possible. The pattern of rice levees and darker (wetter) soils on the downthrown side of the fault are evidence by which the fault may be recognized on some photographs. Visual evidence from photographs or helicopter overflights, however, does not permit accurate delineation of the fault trace.

Segment D-E

Before recent clearing and plowing, an abrupt, fault-controlled vegetation change was visible in the field between Farm-to-Market Road 1464 and point E. Shrubs at that time were confined to the relatively dry upthrown block; broad-leafed grasses carpeted much of the often-soggy downthrown side. A well-defined, 0.2-m-high scarp, coincident with the vegetation change, was measured here in 1975 (fig. 6). The scarp has since been modified by the plow, but it is still visible. A sharp and clear tonal change on most aerial photographs, even those taken after recent plowing, permits confident placement of the fault in this segment.

Segment E-F

This segment of the fault is indistinct on most aerial photographs because of proximity to a fenceline, but in the field the scarp is well defined to moderately well defined. Thick vegetation obscures the scarp from view for much of the year, but its presence is reflected in a vegetation change among the grasses as the fault is crossed and, during wet periods, by the abrupt passage from firm soil to discontinuous pools of standing water. The scarp is more readily traced in winter, when minimal vegetation makes topographic relations more obvious. Short

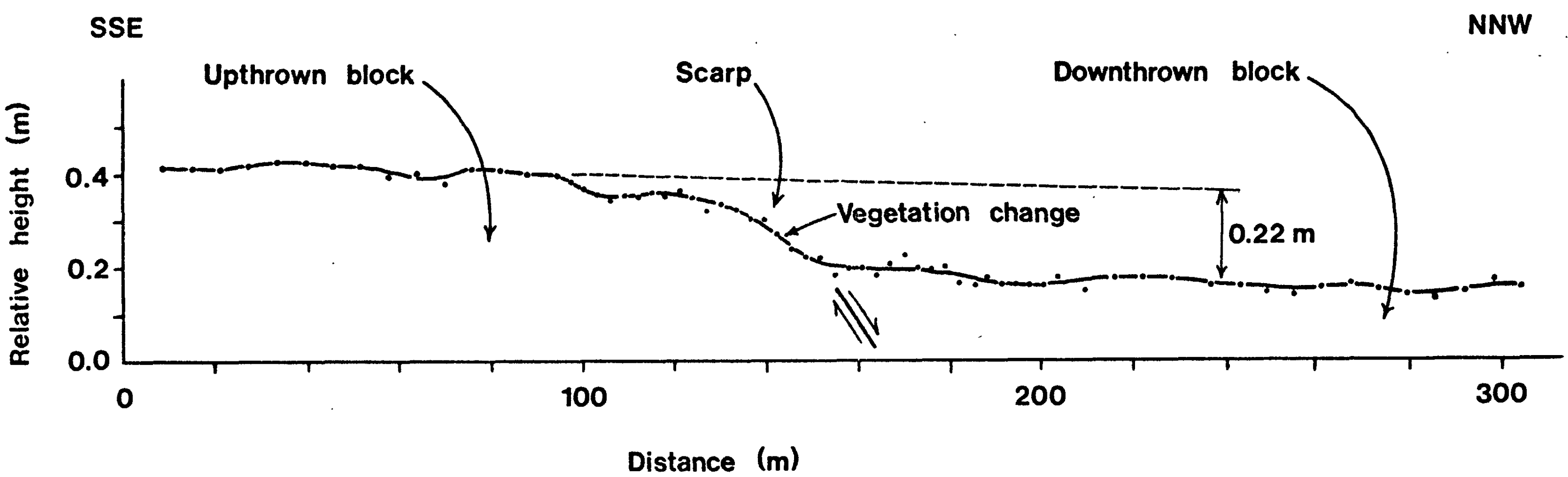

Figure 6.--Topographic profile of Clodine fault in field east of Farm-to-Market Road 1464 (pl. 1). The fault scarp, although well-defined, is also rather broad (about 20 m) and has probably been disturbed by past cultivation. Recent plowing has further subdued the scarp, yet it persists as an obvious element of the local landscape.

A well-defined vegetation break, from shrubs and prairie grasses on the upthrown block to broad-leafed grasses on the downthrown block, was noted during our 1975 survey at the location indicated above.

Dots represent actual field measurements of relative elevations.

segments of the scarp are most easily seen in cleared areas, such as the dirt road and the pipeline right-of-way near point F.

Segment F-G

Several factors combine to deter accurate mapping of the fault here. East of point F, the fault traverses an area densely overgrown with wild rose bushes for over 300 m; within this area the trace of the fault can be dimly seen on aerial photographs, but access to the scarp in the field is difficult at best. The fault then crosses a wide canal, crosses a rice field, and recrosses the canal. Natural topographic relations near the canal had been destroyed before field work began, so the trace of the fault can only be approximated.

Segment G-H

Little field work was done by us in this segment, which lies wholly within fields that were once cultivated for rice. As is usual for such areas, levees are the most prominent topographic feature in the field; and, whereas they aid in locating the fault scarp, the scarp itself has been extensively modified by cultivation. The apparent trace of the fault is well defined but faint on most photographs taken before recent development; it is manifest principally by the pattern of rice levees, rather than by any appreciable tonal contrast between the upthrown and downthrown blocks. On a few photographs, however, tonal contrast across what we interpret to be the fault is prominent, and little difficulty is experienced in defining its approximate trace.

Segment H-I

Closely spaced, subparallel rice levees (fig. 4) allow easy identification of the fault in this segment. The spacing of rice levees is indicative of a well-defined but broad scarp, an observation confirmed by field work before the land west of State Highway 6 was cleared and graded. The fault scarp was then the site of a prominent vegetation change. The downthrown fault block in this area was commonly muddy, the upthrown side typically dry.

Segment I-J

The trace of the fault in this segment is well defined, both in the field and on all photographs in our possession. Most of the land between points I and J was, at the time of our investigations, under cultivation. Furrows in the fields ran north-south, at a high angle to the fault. After periods of rainfall, as much as 15 cm of water lay in each furrow on the downthrown side; furrows on the upthrown side held no water. At such times the trace of the fault was sharply defined as the edge of flooded land.

A substantial (about 0.3 m) southward rise in elevation of Howell-Sugarland Road (labeled Howell Road on map), about 240 m south of Alief-Clodine Road, is the fault scarp. To either side of this feature, the road surface is nearly level.

The Clodine fault is typical of many other faults in the Texas Gulf Coast. Much of it is visible on aerial photographs and, although some segments of the fault are only faintly visible on any given photograph, they may be distinct on others, so that study of several photographs taken at different times permits confident mapping of the fault for most of its known length. Observed field relations are not everywhere sufficient to locate the fault accurately ($\pm$ 3 m), but even where man has most strongly modified the local landscape, evidence of the fault remains. The evidence is consistent from one location to the next. It collectively demonstrates the presence of a feature that is continuous, or nearly so, for 12.5 km, and along which the land to the north is lower than that to the south by about 0.2-0.4 m. Identity of this feature as a fault is confirmed in that it cuts across, and has displaced, point-bar deposits near Oyster Creek.

Glossary of terms

Active fault--(1) A fault that has caused damage to manmade structures, or (2) a fault whose current rate of movement is sufficient to cause such damage, but where no manmade structures exist to document effects of movement.

Existing definitions of this term are both numerous and partly contradictory. By almost any of them, however, all faults that have been recognized at land surface in the Houston area are active, regardless of whether they have moved in historic times or not. We employ a more restricted and informal usage in discussing the Houston area and use active fault only as a term of convenience to signify those faults that are, in effect, an immediate hazard to property.

Downthrown side--The side of a fault that appears to have moved downward relative to the other side (fig. 7). Another name is downthrown fault block.

Fault--A surface along which the nearly horizontal sediment layers beneath the Houston area are broken and offset (fig. 7).

Point bar--A low, arcuate ridge of sand deposited by a stream on the inside of a bend, or meander, in its course. A series of such ridges,

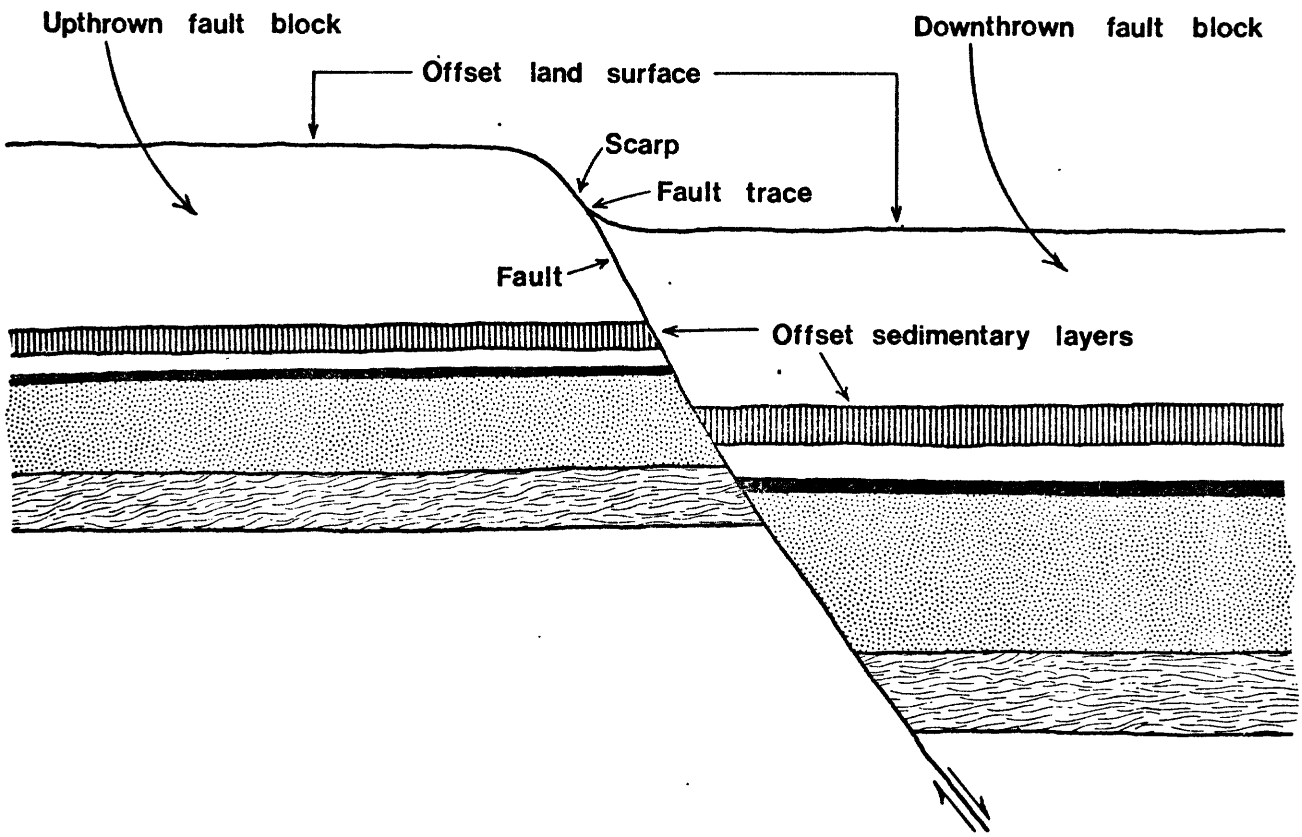

Figure 7.--Vertical section through a hypothetical fault in the Houston area. Land surface was originally level, but has since been displaced by movement on the fault. Note thickening of sedimentary layers on the downthrown side. This indicates that fault movement occurred repeatedly over a long period of time, while the sediments were being deposited. Such faults are common in the Texas Gulf Coast.

separated by intervening troughs, may be deposited along some meanders.

Scarp--A relatively steep face or slope of considerable linear extent, irrespective of origin. Some scarps are formed directly by movement along a fault surface; the scarp separates two blocks of land that were originally at the same or nearly the same elevation but which now are at different levels due to fault movement. A scarp represents the exposed surface of a fault, commonly modified to some extent by erosion on the upthrown side and deposition on the downthrown side (figs. 4 and 7).

Upthrown side--The side of a fault that appears to have moved upward relative to the other side (fig. 7). It is also called upthrown fault block.

Open-File Report 78-797 Map showing surface faults in the southeastern Houston metropolitan area, Texas, by E.R. Verbeek, et. al. shows the following area:

On the SE corner to include Camp Tejas

On the NE corner to include Deer Park

On the SW corner to include Pearland

On the NW corner to include Mayfair

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