MAP SHOWING SURFACE FAULTS IN THE SOUTHEASTERN HOUSTON METROPOLITAN AREA, TEXAS

by

E. R. Verbeek
U.S. Geological Survey, MS 913
Denver Federal Center,
Denver, CO 80225

and

U. S. Clanton
National Aeronautics and Space Administration
Johnson Space Center
SN/6, Houston, TX 77058

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Introduction

Damage to man-made structures by movement on faults* in the Houston metropolitan area is a widespread, costly, but largely unrecognized problem. Although these faults must number in the hundreds and constitute an environmental hazard of considerable significance, little systematic mapping of them has been attempted, and maps of faults at scales that would be useful for land use planning have not previously been available to the public. Houston's growth rate currently ranks third in the nation (Sales and Marketing Management, 1977), yet construction and development is proceeding with little regard to the potential threat posed by faulting. Past failure to address this hazard is largely due to the subtle nature of the faults, which are easily overlooked if one is not familiar with the criteria for recognizing them. A fault often becomes obvious only after damaged structures delineate its trace, and even then the affected property owners may not recognize the cause of the damage.

This map is the principal product of a pilot study undertaken jointly by the USGS and NASA to evaluate the magnitude of the faulting problem in the metropolitan Houston area, and to assess its possible effect on the future development of the region. Some construction is proceeding in full cognizance of the location of faults at a given site, and is planned so as to minimize the impact of fault movement while still effectively utilizing all available space; however, such practice

* Terms followed by an asterisk (*) in the text are defined in the glossary.

is not common. Easily available fault maps, however, would make possible widespread mitigation of future fault damage through proper planning of engineered structures.

Nature of Faults: General Approaches to Mapping

The mapped area comprises two very different environments that may be termed, simply, developed and undeveloped land. Stretching across the north-central and northwestern parts of the map area are the densely-populated residential areas of southeastern Houston, South Houston, and Pasadena, which pass northward into the large industrial complexes bordering the Houston ship channel just north of the map area. The southern half of the map, in contrast, is mostly open range- and farmland. Only locally are developed areas to be found, almost all of which are relatively new and are expanding rapidly.

The methods used to map faults in developed and undeveloped areas are quite different. Most of the evidence that can be used to detect and map faults in open country has been obliterated in developed areas by filling, grading, and construction; little of the original topography and vegetation remains. Consequently, faults in developed areas are mapped primarily by tracing an associated zone of damage. An excellent example of such a zone coincides with the trace of a long, northerly trending fault (no. 5 on the map) that passes through the cities of South Houston and Pasadena. Of the 51 streets known to be crossed by this fault, damage caused by fault movement is readily apparent to all but a few roads that have been paved in the last decade. Many houses built on the fault trace have cracked or broken foundations and moderate to severe distortion of walls and roofs. Others, seemingly in good condition, have been rebuilt and releveled to correct the fault-produced damage. This and similar active faults that have caused extensive structural damage are readily traced. However, faults with recent movements that have proceeded at slower rates may be more difficult to trace for more than short distances or may remain undetected.

Aerial photography is the most important mapping tool in open country, where faults can usually be recognized as tonal or textural changes on the photograph. These tonal and textural changes are related to variations in vegetation and soil moisture which result from surface runoff ponding on the downthrown* fault blocks during periods of rainfall. Tonal contrast between the wetter, and therefore darker soils of the downthrown block against the light-toned, better-drained soils of the upthrown* block may be particularly evident in winter. This contrast may be accentuated during periods of intense or prolonged rainfall, when the downthrown sides of some faults are flooded. Moisture differences are somewhat obscured during late spring through early fall, when thick vegetation covers the open rangeland and crops are growing in cultivated fields. During this time of the year, however, contrasting plant communities often reflect the differential moisture content of the soils. It is common, for instance, to see typical prairie grasses and shrubs juxtaposed against sedges and rushes, the latter more typical of a marsh environment. This sharp vegetation transition marks the contact of the drier upthrown side with the wetter downthrown side. In grazed rangeland differences in grass species can often be documented on different sides of a fault. Even in cultivated fields of a single crop, variations in plant vigor can often be detected by differences in plant height and color, and thus delineate a fault.

It is important to realize that faults are rarely seen as topographic features on aerial photographs; rather one observes only a vegetation change or soil-color contrast of sufficient sharpness and linearity that the existence of a fault is suspected. This fact has two important consequences: (1) it forces field confirmation of each fault (even detailed studies of aerial photographs are not sufficient to prepare a reliable fault map) and (2) the photographic evidence of a fault may change markedly with time because plant growth is seasonally dependent, and the moisture contrast across faults depends heavily on recent weather conditions. Several faults within the map area are virtually undetectable on aerial photographs but for a few weeks of the year, when a particular species of grass on the upthrown side goes to seed, imparting a tan color to the side of the fault that stands in sharp contrast to the green of the downthrown side. A number of faults are best visible in late fall, when the maturing seed pods of "rattlebox" trees (*Sesbania drummondii*) turn from green to brown and lend a somber cast to the downthrown side. Still other faults display a profusion of colors from autumn-blooming grasses and forbes on the upthrown side contrasting with brilliant green sedges and rushes in marshy areas of the downthrown side. This changing pattern of plants, with each species flowering, going to seed, and dying at different times, creates a constantly changing visual expression of a fault.

Another complication that must be considered in the mapping of a fault is that its apparent trace as seen on an aerial photograph may be displaced a short distance from its actual trace in the field. This apparent displacement is the result of how the camera/film/filter system records the vegetation and soil conditions and how these conditions vary along the actual trace of the fault at that moment (see fig. 1).

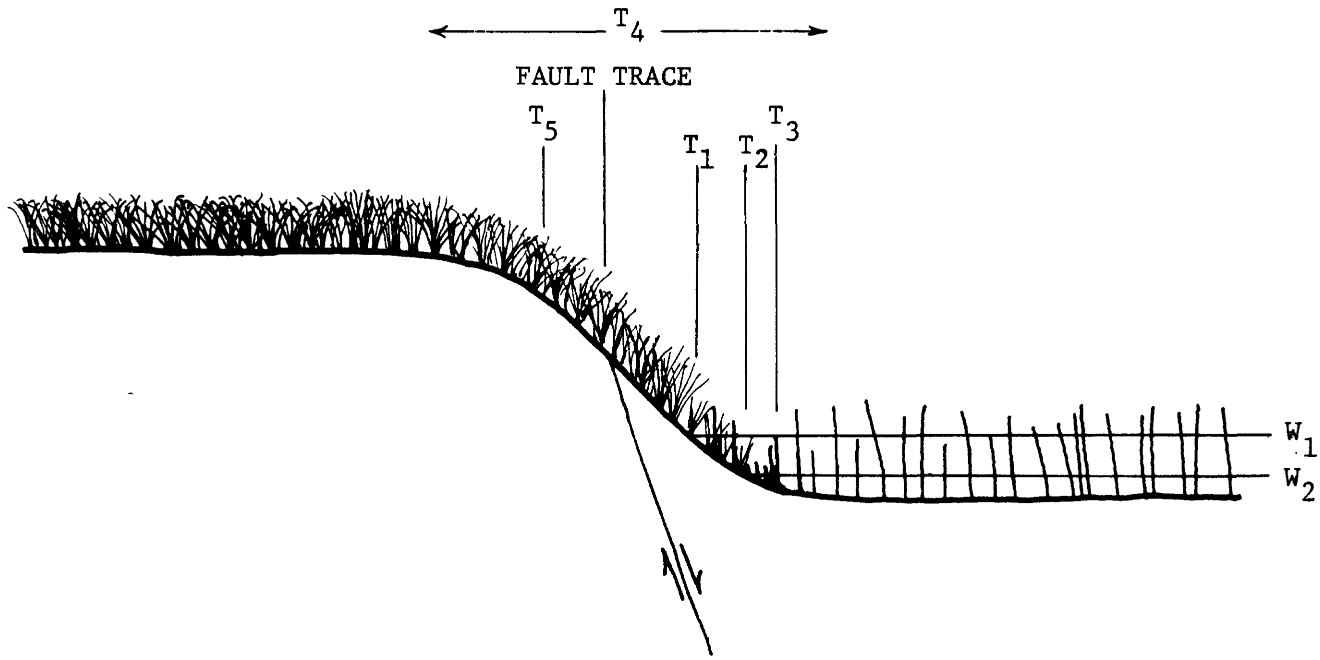

Figure 1.--T_1, winter: after heavy or prolonged rainfall. Visual trace of fault is seen as the edge of flooded land. W_1=water level at this time. T_2, winter: the same fault after some period of dryness. Water level has receded to W_2; visual trace of fault is at position T_2. T_3, early spring: Sedges and rushes of moist downthrown side are bright green. New growth of grasses has not yet begun on upthrown side; this side is still brown-colored from the dead plants of the previous year. Visual trace of fault is at T_3, at tan-green contact. T_4, summer: Green grasses on upthrown side and green sedges and rushes on downthrown side. No appreciable visual contrast; fault may be difficult to detect on aerial photographs. The intermingling of different plant species typically provides a broad but diffuse band of contrasting vegetation that generally locates the fault; the downthrown side may be somewhat wetter than the upthrown side. T_5, late fall: Prairie grasses of upthrown side have gone to seed; many forbes are in bloom. Visual trace of fault at or near T_5. Note that none of the visual traces is coincident with the true trace of the fault.

Procedure Used in Mapping Faults

The general method used to map faults in both developed and undeveloped areas has been outlined above. Presented here are some specifics of the procedures employed so that the map may be viewed in proper perspective.

Because of changes in fault expression over time, it was necessary to study aerial photography from different times of year, and for different years, in order to prepare a reasonably complete map. A wide variety of aerial photographs (table 1) was used to identify approximately 200 linear features that were regarded as possible faults, pending field confirmation. Many of the more vague features, about 20 percent of the total, were later eliminated from the map because of insufficient field evidence to justify a fault interpretation. Field investigation proved most of the remaining features to be only the most visible portions of lengthier faults; approximately 150 fault segments recognized on aerial photographs were demonstrated through ground-based studies to be parts of the 91 faults depicted on the map.

Table 1.--NEAR HERE

TABLE I--Photographs studied in preparation of fault map

	Type of photography*	Year Flown	Scale	Agency	Remarks
(1)	B & W	1930	1:24,000	Tobin Aerial Surveys	Controlled mosaic, complete coverage
(2)	B & W	1936	1:24,000	U.S. Army (Ellington AFB)	Partial coverage only
(3)	B & W	1956	1:24,000	Tobin Aerial Surveys	Controlled mosaic, complete coverage
(4)	B & W	1965	1:40,000	Phil Wilson, publisher	Partial coverage only
(5)	B & W	1969	1:40,000	Phil Wilson, publisher	Coverage over most of area
(6)	CIR	1970	1:40,000	NASA (Mission 145)	Partial coverage only
(7)	C	1971	1:40,000	NASA (Mission 190)	Partial coverage only
(8)	CIR	1971	1:60,000	NASA (Mission 191)	Partial coverage only
(9)	B & W	1972	1:40,000	Phil Wilson, publisher	Nearly complete coverage
+(10)	B & W	1972	1:12,000	Phil Wilson, publisher	Complete coverage; lithograph prints
+(11)	B & W	1972	1:12,000	Wallace Aerial Surveys	Complete coverage; lithograph prints
(12)	B & W	1973	1:40,000	Phil Wilson, publisher	Nearly complete coverage
(13)	CIR	1973	1:60,000	NASA (Mission 253)	Partial coverage only
(14)	C, CIR	1973	1:24,000	NASA (Mission 247)	Partial coverage only
(15)	B & W	1977	1:40,000	Wallace Aerial Surveys	Partial coverage only
(16)	C, CIR	1978	Variable	NASA, U.S. Army	Helicopter overflights of mapped area to obtain large-scale photographic documentation of selected faults.

* B & W = black and white; C = color; CIR = color infrared

\+ Primary mapping base. All faults mapped originally at 1:12,000 scale.

All faults inferred from aerial photographs were visited at every point of ready access, and most faults in undeveloped areas were examined along the entire length of the mappable scarp*. A detailed record of the field relations of each fault was compiled and is planned for issue as a separate publication. Most of the faults were visited several times, once during the growing season when vegetation changes were well defined and again in winter, when the absence of vegetative cover made the topographic relations especially clear. Additionally, helicopter overflights were made at altitudes ranging from 100 to 200 m (about 300 to 600 ft) to confirm fault locations in areas of poor access and to provide detailed documentation of their photographic expression.

In urban areas, where aerial photographs are of limited use, each fault was traced on a block-by-block basis. The nature and severity of fault damage to paved surfaces, to residential, commercial, and industrial structures, and to railroad lines were recorded at every opportunity. Search for faults in developed areas took the form of driving slowly down every other street in, usually, an E-W direction, and then cross-checking the area by driving every other N-S street.

A conservative approach was adopted in mapping so as to increase the reliability of the final product. No feature, no matter how well defined its photo expression or how dramatic the associated vegetation change on the ground, was included on the map unless a scarp was recognized in the field. Well-defined features, visually resembling faults but lacking scarps, were relatively few; most were found to be of either cultural origin (old fence lines, for instance), or related to sand-clay contacts along the banks of filled paleochannels*. Preserved banks of partially-filled paleochannels and the edges of thin sand blankets, presumably of eolian* origin, may locally resemble fault scarps. However, a change in surface materials, commonly from sand on the higher side to silty clay on the low side, aids in recognition of an erosional or depositional origin. Moreover, the traces of such features are normally more irregular than the traces of faults, and the opposite banks of paleochannels are commonly visible both on aerial photographs and in the field.

Care in mapping faults in urban areas is essential, for much damage to cultural features may be ascribed to causes other than faulting (such as swelling clays, general deterioration of structures and streets with age, and occasionally poor construction practices). Each fault depicted on the map in developed areas corresponds to a linear zone of abnormally severe damage, with evidence of vertical displacement everywhere in a consistent sense (for instance, south side downthrown along the entire fault trace) and of sufficient magnitude to explain any observed effects. Along portions of such faults, scarps are still visible in some lawns and empty lots, but most scarps have been modified or destroyed in urban areas by man's activities. The elevation difference between two fault blocks, however, can be obliterated only by massive amounts of fill deposited on the downthrown side or by equally massive removal of material from the upthrown side. Even where the fault scarp has been virtually obliterated by man's activities, the elevation change due to faulting commonly persists as an obvious feature of the local landscape.

The positions of all faults, whether in developed or undeveloped areas, were plotted in the field on 1:12,000 scale aerial photographs and later transferred to 1:24,000 base maps.

Map Symbology

Symbols chosen for use on the map were selected to convey, as concisely and accurately as possible, the confidence with which each fault trace was drawn. Solid lines depict faults whose location has been well-established along many closely spaced points in the field; where such information can be integrated with a clear photographic trace, the fault may be regarded as located accurately at every point along its length. Where the fault trace could be located with less certainty a long-dashed line has been employed. Short connections between two well-located fault segments and extensions of individual segments are commonly long-dashed. In both cases, available data place stringent constraints on the position of the fault but are insufficient to locate it precisely. Recent and extensive modifications of the natural landscape by man's activity is the most common cause of a questioned fault location. Still less certainty is indicated by the short-dashed line, which is used where both the field and photographic evidence of fault connections and extensions are present but weak. It is quite common, for example, for the apparent photographic trace of a fault to persist some distance beyond the point where the fault becomes unrecognizable in the field. Such photographic extensions, unsupported but not disproved by available field data, are short-dashed. Finally, where both field and photographic data are lacking, inferred connections between fault segments are short-dashed and queried. It is important to note that such connections, though reasonable, are hypothetical.

Data gathered along some features, particularly in undeveloped areas, provide only suggestive but not compelling evidence of a fault. Such features, if they find no other ready explanation, are regarded as probable faults (labeled prf) with strong evidence or possible faults (psf) with weaker evidence of an origin by faulting.

Limitations of Map

Effective and proper use of this map is in part dependent on recognition of its limitations. These constraints, discussed below, dictate that this product be used as a general guide to the prevalence of faulting near any particular locality and that it should not be used in the absence of site-specific studies. The map is, in essence, a minimum statement on faulting, and should be supplemented by more detailed local studies wherever faulting may pose a significant hazard to anticipated land use, especially along extensions of mapped faults or in an area of extensive faulting (for example, east of Hobby Airport, shown as Houston International Airport on map).

More faults undoubtedly exist than are portrayed on the map. In part this is due to the large area covered in a limited-- though substantial--amount of time, and also to the conservative approach adopted in mapping. Only those features that clearly displayed the classic characteristics of a fault have been indicated on the map. Some linear features identified on photos but not shown on the map may be faults; however, most of these features lack some characteristics that would establish a fault origin.

A fault must exceed a certain size before it is likely to be recognized. A tally of scarp heights of mapped faults illustrates the problem. Only a few faults, 5 percent or less, have scarp heights in excess of one meter (3 ft). A larger number, perhaps 15 percent or so, have scarp heights in the 0.67 to 1.0 meter range, and by far the greatest proportion of recognized faults have scarps ranging from 0.33 to 0.67 meter in height. The number of recognized faults with scarp heights of less than 0.33 meter, however, is small. Such faults are difficult to map because their scarp heights are so low that they fall within the range of normal elevation differences of the local landscape and therefore do not stand out as anomalous features. The inference here is that faults with low scarps are very common, but present field techniques are not sensitive enough to detect them with sufficient regularity.

Faults in urban areas are probably especially underrepresented, for here only active and damaging faults are readily detected. Inactive or slowly moving faults, and all faults in newly developed areas where damage is not yet severe, may escape notice unless the scarp is of substantial height or has not been destroyed during urban development.

The pitfalls of mapping faults in open country, where one depends on moisture and vegetation differences across faults to aid in detecting them, are well illustrated northeast of Pearland. Here, on the west side of Clear Creek, during the winter months when the soybean fields are bare, numerous faults (nos. 58 to 63 on the map) are readily mapped as sharp tonal (soil moisture) contrasts on aerial photographs. Each scarp, though rounded by the plow, is traceable with little difficulty through the open fields. North of the soybean fields, however, in brushy rangeland, the faults are traceable only with great effort, and even then for only short distances. The situation becomes more difficult east of Clear Creek, where almost no signs of fault continuations can be seen, though some must certainly exist. The paucity of mapped faults in this area is more likely due to the uncertainties of tracing faults in a heavily vegetated environment than to real differences in fault density on the two sides of Clear Creek.

Several other factors limit the mapping of faults. Where both sides of a fault are well drained and water has little chance of ponding on the downthrown side, little or no moisture and vegetation contrast can be expected along the fault. Indeed, the largest fault on the map (fault no. 72), in terms of scarp height (1.1 m) has yet to be observed on an aerial photograph. Faults through wooded areas are exceedingly difficult to detect from the air, and normally ground surveys are required to map them. Oil fields also pose special difficulties where numerous well sites, slush pits, and pipelines obscure natural relationships. Especially notable in this respect and deserving of additional work is the Mykawa field, which is characterized by greater local relief than surrounding areas and by a complex pattern of divergent faults.

One of the more severe constraints on use of this map concerns the recognition of historic fault movement--that is, those faults that have damaged man-made structures. The map is not an active fault map; rather it is meant to portray all faults known to us that have reached and displaced the Quaternary* sediments exposed at the land surface throughout the studied area. Most faults, where they underlie cultural features at some point along their length, can be demonstrated to be active and are labeled as damaging faults on the map (symbol A). For faults in undeveloped areas the opportunity to make this assessment is frequently lacking and the prospect of historic fault movement remains untested. Such faults should not be regarded as inactive but as having an unknown history of movement. The chance that an easily-recognizable fault in a rural area is moving today at damaging rates is relatively great.

A kilometer on the ground, at a scale of 1:24,000, is represented by a little more than 4 cm on the map (a mile by about 2-5/8 inches). At this scale, faults that are plotted on the map to an accuracy of ± 1 mm may be located to within about 25 m (about 80 ft) on the ground. It is thus impossible to determine from the map whether a fault goes through a particular house in an urban area. In industrial or sparsely populated areas, however, individual structures are commonly depicted on the map, and here we have endeavored to portray faults in true relation to all cultural features. Even here caution is necessary, for some few buildings, and more commonly powerline standards, are mislocated on the map base. In these areas the faults are mapped in their true position but are misregistered in reference to some cultural features.

Geologic Meaning of Faults

A look at the map reveals that nearly all of the faults are confined to two well-defined, curvilinear belts, and that these belts bear a close relationship to oil fields in the area. The association is not accidental. All four major fields shown on the map are known or thought to be producing from sediments above or peripheral to salt domes*; formation of both the domes and the faults (with but few exceptions) is believed to be genetically linked. The faults are thus natural geologic features of some antiquity. Space does not permit adequate treatment of the evidence here, but such data as are available, chiefly seismic and drilling data for a limited number of faults, reveal that the faults persist to depths of thousands of feet and show clear indications of prehistoric movement extending over millions of years.

There is ample evidence for a prehistoric origin of the faults, and for prehistoric motion along them, but still unresolved is the question of why many faults are so active today. It can be demonstrated readily that natural movement on some faults persisted into the very recent geologic past and, by inference, is likely continuing. However, comtemporary rates of movement on many faults (commonly in the range of 0.5 to 2.0 cm/yr displacement) are far in excess of what is expected from natural causes, for if such rates were characteristic of the recent geologic past there would be many fault scarps tens of meters high. The largest fault on the map has a scarp height of little more than one meter. It is partly for this reason that some geologists look to man's activities, specifically fluid withdrawal, as the cause of the currently high rate of fault movement in the Houston area. The extraction of large quantities of water from shallow sediments beneath the city, and production of petroleum from somewhat deeper levels, has resulted in large declines in fluid pressures within the subsurface sediments. Inasmuch as a link between fluid-pressure declines and land-surface subsidence seems well established (Gabrysch, 1969), it may be that the withdrawal of water and petroleum products is somehow triggering or accelerating motion along preexisting faults as well. This hypothesis has considerable merit. A comparison of the present-day landscape with detailed topographic maps surveyed in 1915-1916, for instance, reveals that a large percentage of faults have grown markedly in scarp height within the past 60 years. Moreover, many faults that are obvious on aerial photographs today are only faintly, if at all, seen on similar aerial photographs taken in 1930. Although the faults themselves are rooted in antiquity, the most significant displacement of the land surface appears to have taken place within the last half-century or so, and is continuing.

REFERENCES CITED

Gabrysch, R. K., 1969, Land-surface subsidence in the Houston-Galveston region, Texas: in Land Subsidence, Proceedings of the Tokyo Symposium, International Association of Scientific Hydrology, v. 1, p. 43-54.

Gary, Margaret; McAfee, Robert, Jr.; and Wolf, C. L., eds., 1974, Glossary of geology: American Geological Institute, Falls Church, Va., 805 p.

Sales and Marketing Management, 1977, Survey of Buying Power, Part II: Bill Publications, New York, N.Y., 184 p.

GLOSSARY*

Active fault--as used here, denotes a fault which has caused damage to man-made structures.

Downthrown fault block--Displacements along faults in the Houston area are essentially vertical; that is, the land on one side of the fault appears to have moved downward relative to the other side. The side of the fault that appears to have been displaced downward is termed the downthrown fault block (fig. 2).

Eolian--A term used to denote those sediments that have been transported or deposited by wind action.

Fault--As used in this report, a surface of breakage within the sediments beneath the Houston area (fig. 2). Vertical movement has taken place along this plane, resulting in displacement, or a mismatch of sedimentary layers, across the fault. The line defined by the intersection of the fault surface and the land surface is termed the fault trace.

Paleochannel--A remnant of an old, abandoned stream channel. In the Houston area paleochannels are partially or completely filled with sediment, which tends to obscure the true nature of the feature. The sinuous channel traces are often apparent on aerial photographs. On both photos and in the field the banks of some paleochannels may locally resemble scarps formed by faulting.

Quaternary--The youngest period of the geologic time scale,

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* The terminology used in this report has been extracted and modified from the American Geological Institute Glossary of Geology (Gary and others, 1974). The intent of these modifications is two-fold: first, to utilize the more general term in a stricter context as applied to the Houston problem, and second, to state the scientific definition in a way that will be more meaningful to nongeologists.

embracing the last two or three million years.

Salt dome--A roughly cylindrical mass of salt, generally one to two kilometers in diameter, that has risen through the overlying sediments from a deeply buried source layer of salt. During the intrusion of the salt the enclosing and overlying sediments may be contorted and complexly faulted; most of the faults shown on the map probably originated from such salt movement.

Scarp--A relatively steep face or slope of considerable linear extent. A scarp may be 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. The scarp represents the exposed surface of a fault, usually modified to some extent by erosion on the upthrown side and deposition on the downthrown side (fig. 2).

Upthrown fault block--The side of a fault that appears to have moved upward relative to the other side (fig. 2).

Figure 2.--Vertical section through a hypothetical fault in the Houston area. Land surface was originally level and sedimentary layers were unbroken; both have since been displaced by motion along the fault.