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# Profiles and Documentation of Fault-Exploration Trenches in the English Hill Area, Scott City 7.5-minute Quadrangle, Missouri

by

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## Introduction

This report presents profiles of fault-exploration trenches excavated from May, 1995 through September, 1996 in the English Hill area, Scott City 7.5-minute quadrangle, Missouri. This work is an integral part of geologic investigations in the area by the U.S. Geological Survey (USGS) and the Missouri Department of Natural Resources/ Division of Geology and Land Survey (MDNR/DGLS) to evaluate and better understand the seismic-hazard potential in the midcontinent United States. Research was supported by the Nuclear Regulatory Commission, the USGS National Earthquake Hazards Reduction Program, the USGS National Cooperative Geologic Mapping Program (Midcontinent Urban Corridor Geologic Mapping Project), and the Missouri Department of Natural Resources/Division of Geology and Land Survey.

Because of the blanketing and draping effect of Quaternary loess deposition, subsequent extensive colluvial sedimentation, and dense vegetation in the English Hill area, outcrops are sparse and geologic contacts are poorly exposed. Thus, fault exploration requires trench excavation. The trenches described in this report were dug with a track-mounted front-end loader in areas of suspected neotectonism indicated by field mapping, drilling, and identification of areas of low topographic scarps.

This work was prompted by reports of possible Quaternary faulting in the area (Stewart, 1942; Stewart and McManamy, 1944; Palmer and Hoffman, 1993; and Harrison and Schultz, 1994; Hoffman and others, 1994) and was preceded by trenching and auger drilling conducted by MDNR/DGLS, acquisition of a seismic reflection profile by the USGS and Missouri DNR/DGLS, and mapping and core drilling conducted by the USGS during 1993 and 1994. Other related articles on results of the 1995-96 trenching are: Harrison and others (1995), Palmer and others (1996a and b), Hoffman and others (1996), and Harrison and others (1996b).

## Geologic Setting

The English Hill area is located along the southeastern escarpment of the Benton Hills- an upland area at the head of the Mississippi embayment (fig. 1) in the extreme southeastern corner of the Scott City, Missouri 7.5-minute quadrangle (fig. 2). The Benton Hills is a region of moderate recent seismicity (Stover and Brewer, 1991; Chiu and others, 1991) approximately 15-20 miles north of the New Madrid seismic zone. English Hill almost directly overlies a prominent geophysical lineament in the Precambrian magnetic basement identified by Hildenbrand and Hendricks (1995). Known as the Commerce geophysical lineament (fig. 1), this feature extends for several hundreds of miles and has a possible affinity with recent earthquakes (Harrison and Schultz, 1994; Langenheim and Hildenbrand, 1997).

Geologic mapping in the Benton Hills (Harrison, in press) has identified numerous north-northeast- and northeast-striking strike-slip faults and associated normal faults, high-angle reverse faults, folds, and transtensional pull-apart grabens. Seismic reflection surveys acquired along the eastern portion of English Hill confirms complex faulting and folding at depth in Paleozoic rocks that extend upward into the Cretaceous and Cenozoic sections (Palmer and others, 1997a, 1997b). These structures have had a long-lived and complex history of reactivation during the

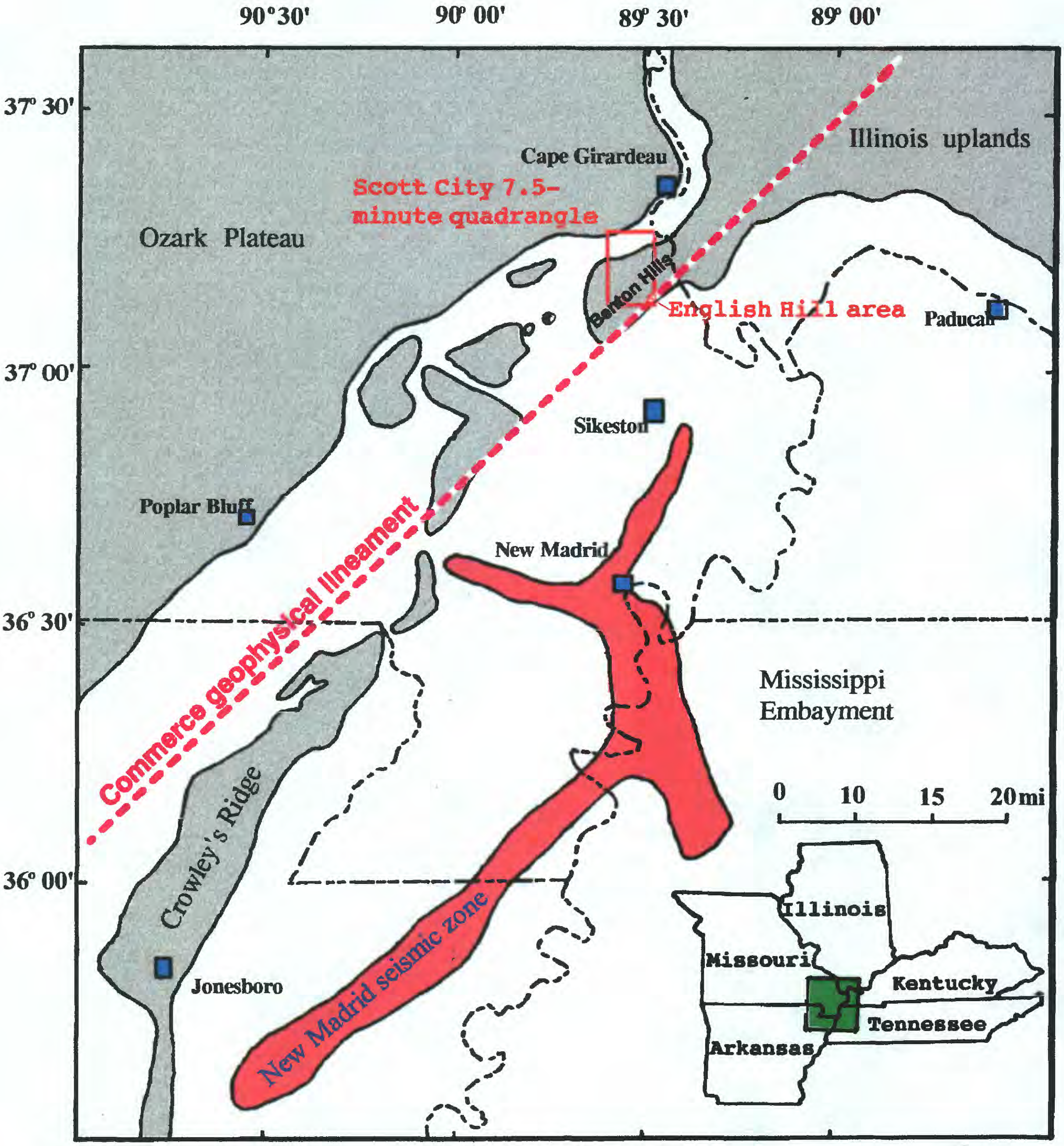

Figure 1. Map showing the location of the English Hill area within the Scott City 7.5-minute quadrangle, Missouri.

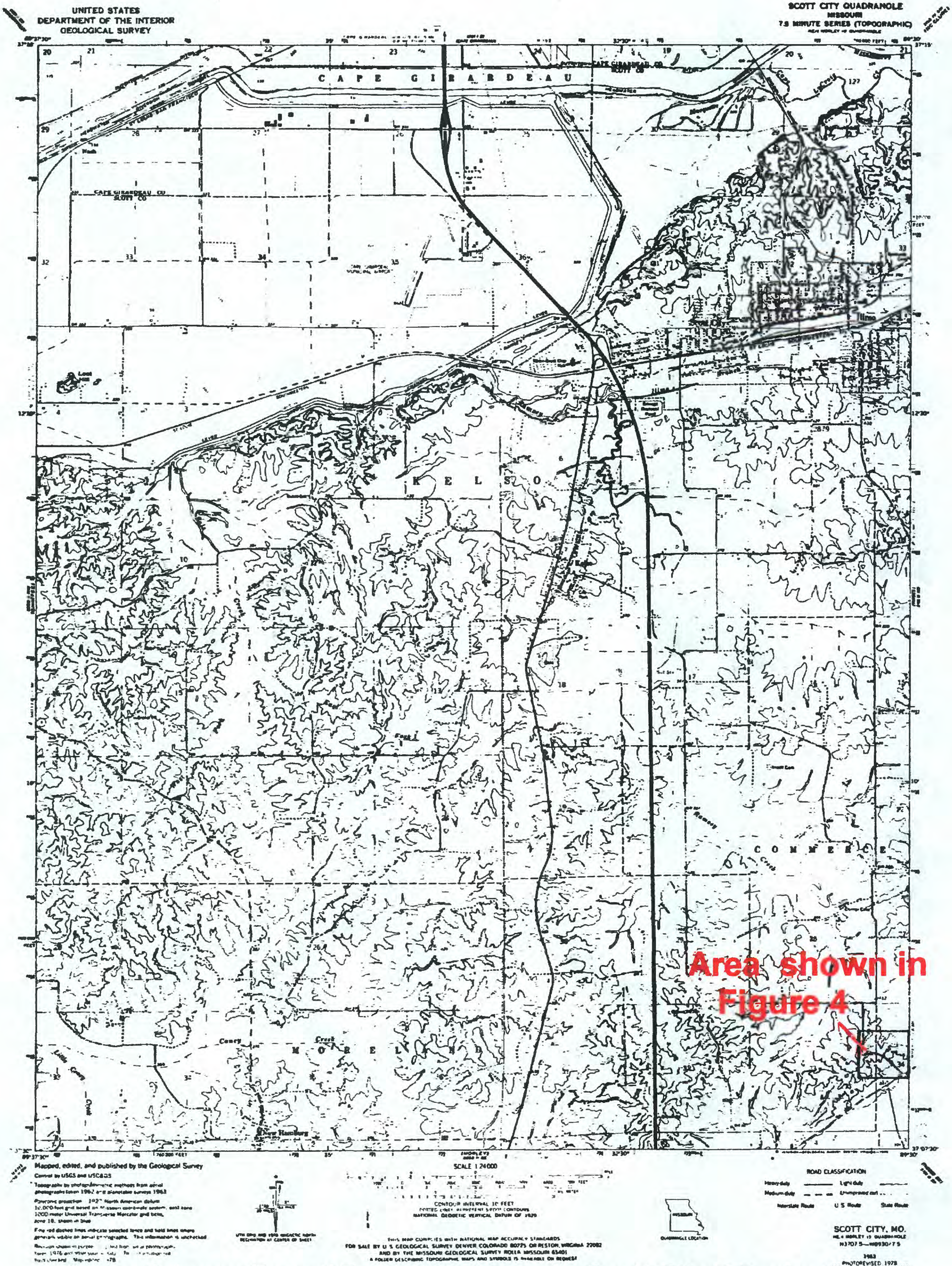

Figure 2. Locaction of English Hill area in Scott City 7.5-minute quadrangle, Missouri.

Paleozoic, Mesozoic, and Cenozoic (Harrison and Schultz, 1994). Fault-zone kinematics indicate a dominant right-lateral sense of movement for events during the Late Cretaceous and Cenozoic and a less prominent left-lateral sense believed to be related to the Ouachita orogeny (Harrison and Schultz, 1994; Cox, 1995).

## Stratigraphy for English Hill Trenches

A composite stratigraphic section for the units exposed in fault-exploration trenches at English Hill is shown in Figure 3. Thicknesses given for the units show the regional variation. Detailed descriptions and analyses of units down to the top of Paleozoic strata are in Harrison and others (1996a).

### McNairy Formation

The oldest unit exposed in the English Hill trenches is the late Cretaceous McNairy Formation. This unit consists of very fine- to fine-grained sand, silt, and clay. It is characteristically micaceous and varies from massive beds to intervals of thinly interbedded fine sand, silt, and clay. Silt- and sand-sized material consists of clear quartz, muscovite, and dark opaque minerals. The formation is largely unconsolidated, however some sandy and silty beds contain local ironstone concretions and cement. Clay intervals generally are medium to dark gray and silty. A dark brown to black massive clay bed, informally known as the “Zadoc Clay member” (McQueen, 1939; Stewart, 1942) or the “Zodoc Clay” (Grohskopf and Howe, 1961), occurs in the upper one-third of the McNairy Formation. This clay bed ranges from 1 to 9 feet in thickness, is commonly lignitic, and contains a diverse microfossil assemblage. Dinoflagellates and

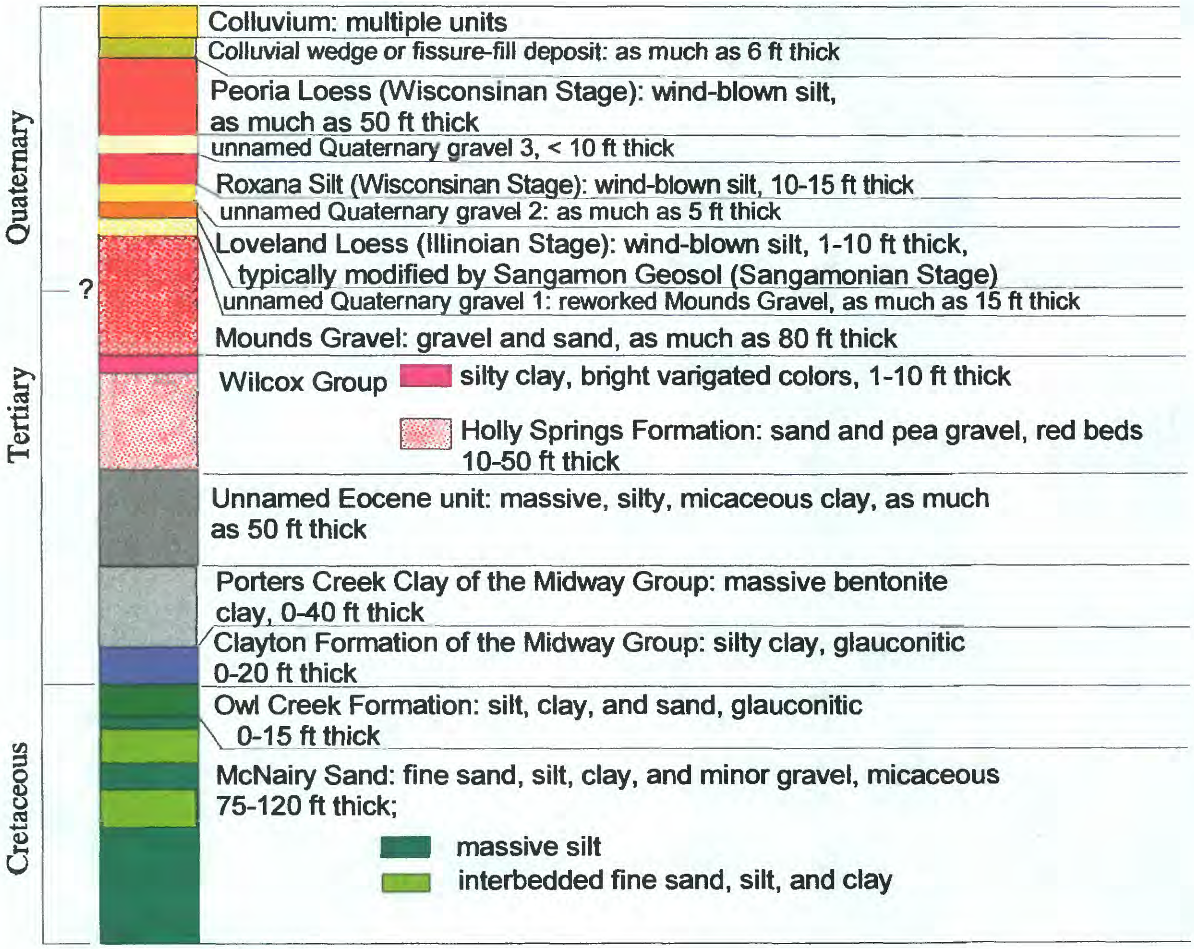

Figure 3. Composite stratigraphic section for English Hill trenches, scale approximate.

foraminiferas are abundant. Fossil pollen suggest an early to middle Maastrichtian age (Harrison and others, 1996a).

## Owl Creek Formation

The Owl Creek Formation consists of silt, clay, and sand. This unit is very slightly calcareous and typically contains glauconite, locally altered to iron oxides. Pollen analysis indicates a late Maastrichtian age for this unit (Harrison and others, 1996a).

The identification of Owl Creek Formation in the fault-exploration trenches is tentative. Glauconitic beds lying between McNairy Formation and Wilcox Group strata were encountered in the Upper Rainbow Trench (profiles 7 and 8), as fault-bound slivers within the McNairy Formation in the Seismic Line Trench (profile 11), and between McNairy Sand and Porters Creek Clay in the Tuesday Trench (profiles 13 and 14). Because of the blocky texture of material in these beds, they were assigned to the Clayton Formation rather than the Owl Creek Formation; however this assignment is problematic. In core-hole BH-1 (see fig. 4 for location and Harrison and others, 1996a for detailed description), the Owl Creek Formation was present and the Clayton Formation was not. Samples collected for pollen analyses from the trenches were barren. Farrar and others (1935) reported fossil marine invertebrates and plant remains in Owl Creek outcrops approximately 1.5 miles northeast of English Hill and the unit is described by Stewart (1942, p. 41 ) as being “abundantly fossiliferous”; no fossils were found in thorough observation of the glauconitic beds exposed in the trenches.

While the identification problem of Owl Creek vs. Clayton remains unresolved, it does not impact the interpretation of structures exposed in the trenches because the two formations are stratigraphically adjacent and faults clearly displace Tertiary strata.

## Clayton Formation

The Clayton Formation of the Midway Group consists of glauconitic, silty to sandy clay. It is typically more glauconite rich and has a more blocky texture than the Owl Creek Formation (J. Masters, oral commun., 1996). Regionally, the Clayton Formation has an unconformable contact with the Owl Creek Formation. The Clayton Formation is as much as 20 feet thick in the Benton Hills. Approximately 4 to 5 ft was encountered in the trenches; it was absent in core-hole BH-1 (Harrison and others, 1996a). As discussed in the previous section, Clayton Formation was mapped in preference to the similar Owl Creek Formation, but this distinction is problematic. All samples collected for pollen analysis from the trenches were barren.

## Porters Creek Clay

The Porters Creek Clay of the Midway Group consists of massive, light- to medium-gray, silty, montmorillonite (bentonite) clay. Identification of abundant relict glass shards and pumice fragments (Grim, 1933; Allen, 1934; and Sims, 1972) indicate that this unit is in large part volcaniclastic. Characteristically, this unit has a blocky texture and breaks with conchoidal fractures. Pollen analysis indicates a late Paleocene (Thanetian or possibly Sabinian) age (Harrison and others, 1996a). Regionally, the contact between Porters Creek Clay and Clayton Formation is conformable. In core-hole BH-1, Porters Creek Clay was 36.7 feet thick. However in the nearby Upper Rainbow Trench (about 400 feet away), it was absent and Wilcox Group sediments rest directly upon older deposits. This relationship was also seen in the Seismic Line and Bollinger trenches.

### Unnamed Eocene unit

A massive, silty, micaceous clay occurs in the Bollinger Trench (profiles 1 & 2) and in draws along the west side of the English Hill area that does not correlate with any previously identified stratigraphic unit in southeastern Missouri or adjacent southern Illinois. Palynological analysis of this material found the following taxa: *Momipites microfoveolatus*, *Momipites coryloides*, *Ulmipollenites undulosus* type, *Ulmipollenites tricostatus* type, *Carya* >28 µm, *Triatriopollenites* cf. *T. intermedius*, and *Celtis* (hackberry) type. An apparent Eocene age is placed on this unit because of the following considerations: *Ulmipollenites tricostatus* probably originates in the latest Cretaceous and occurs as scattered grains throughout the Paleocene and perhaps in the lower Eocene; the large specimens of *Carya* have their first appearance on the Gulf Coast in the Eocene; *Momipites microfoveolatus* and *Momipites coryloides* range from Paleocene to Miocene; *Triatriopollenites* cf. *T. Intermedius* looks like an Eocene species; and *Celtis* (hackberry) type originates in the Eocene. This unit appears to be very local in occurrence, perhaps restricted to the immediate English Hill area. It is interpreted as fill in a structural depression or graben that formed in the Eocene, prior to deposition of Wilcox Group sediment. Infilling material was derived from older Tertiary and Cretaceous units. A local unconformity that represents removal of the Porters Creek Clay, Clayton Formation, Owl Creek Formation, and portions of the McNairy Formation was observed in the Upper Rainbow Trench (profiles 7 & 8) .

**Wilcox Group (or Jackson Formation/Claiborne Formation?)**

The Missouri Division of Geology and Land Survey has consistently referred to Tertiary strata above the Midway Group and below Mounds Gravel as the Wilcox Group since this stratigraphic interval was first recognized in southeast Missouri by Lamar and Sutton (1930) and identified by E.W. Berry of the U.S. Geological Survey as containing plant species typical of the Wilcox Group (reported in Farrar and others, 1935). The Wilcox Group in southeast Missouri subsequently was divided into a basal Ackerman Formation (silty clay), an overlying Holly Springs Formation (sand and lesser gravel), and the uppermost Idalia clay member (informal) of the Holly Springs Formation (Koenig, 1961; Grohskopf, 1955; Stewart, 1942; Farrar and McManamy, 1937; Farrar and others, 1935). More recently, subsurface investigations of the Mississippi embayment divide the Wilcox Group into a basal Old Breastworks Formation (mainly silt), a middle Fort Pillow Sand, and an upper Flour Island Formation (mainly silt and clay) (Moore and Brown, 1969; Frederiksen and others, 1982). Frederiksen and others (1982) determined that the Paleocene-Eocene boundary occurs in the Flour Island Formation and thus most of the Wilcox Group is Paleocene in age.

At first appearance, there seems to be close correlation between the two sets of nomenclature. However, strict designation of strata that generally overlie the Porters Creek Clay in the Benton Hills as Wilcox Group is somewhat problematic, and given the Eocene age of the unnamed massive, silty clay that underlies 'Wilcox Group' (see above section), is probably in error. From work in the Jackson Purchase region of western Kentucky, Olive (1980) describes the occurrence of black chert pebbles as characteristic of the Eocene Jackson and Claiborne formations, but not the Wilcox Group. Black chert pebbles are common in the Holly Springs

Formation in Missouri. Thus based on lithologic similarities, the Holly Springs Formation is probably correlative to either the Jackson or Claiborne formations or both. A perusal of flora species (Berry, 1916) used to name the Wilcox Group in Missouri does not preclude possible correlation with the Jackson and/or Claiborne Formations.

While this matter remains unresolved, this report uses the nomenclature of the Missouri Division of Geology and Land Survey. Since the strata can be handily identified and mapped at English Hill and throughout the region, neither correlation poses a problem regarding structural interpretations for faulting revealed by trench excavation.

### Clay beds within the Wilcox Group

Bright-colored, silty clay beds are typically found at the base of the the Wilcox Group throughout southeast Missouri and are referred to as the Ackerman Formation in Missouri stratigraphic nomenclature (Koenig, 1961). Colors are most commonly pink, yellow, and red. An unconformity at the base of the Ackerman has tens of feet of local relief throughout the region. The contact with the overlying Holly Springs may be unconformable as this clay is not everywhere present beneath Holly Springs in the English Hill area. Another consideration involving this stratigraphic interval is the occurrence of clays resembling the Ackerman Formation (see below for descriptions) above sands of the Holly Springs Formation in several trenches. These clays could be considered as clay bodies within the Holly Springs or as a separate localized depositional unit that interfingers with the Holly Springs.

## Holly Springs Formation of the Wilcox Group

Regionally, the Ackerman Formation is overlain by a unit consisting of coarse- to medium-grained sand and pea gravel referred to as the Holly Springs Formation in Missouri stratigraphic nomenclature. These sediments are poorly sorted, locally cross bedded, and consist of rounded to subrounded grains of variously colored quartz and gray, white, and black chert. Minor amounts of orthoquartzite grains also occur. Abundant iron oxides give this unit a characteristic red color. As mentioned previously, in some of the trenches a clay bed that markedly resembles the Ackerman Formation is present above and within the Holly Springs.

## Mounds Gravel

Mounds Gravel consists of very poorly sorted, matrix-supported, well-rounded to subrounded, heterolithic gravel and intercalated sand lenses. Detailed studies of lithology and mineral composition are given by Lamar and Reynolds (1951) and Potter (1955a). Gravel lithologies are dominantly brownish-colored cherts and lesser amounts of white and light-pink quartz. Chert surfaces are coated with a characteristic yellowish-brown patina. Clasts are generally 3 in. or less in diameter, but cobbles 6 in. or greater are relatively common. Rare clasts of silica-replaced petrified wood also occur, some of which are as much as 1 ft in diameter. Pristine edges on the petrified wood suggest pre-silicification weathering and disintegration, as well as *in situ* petrifaction. Notably absent in the Mounds Gravel in the Benton Hills are clasts of feldspathic igneous rocks or carbonate material. Sand occurs as matrix in gravel beds and as lenses as much as 15 ft thick. Sand grains are typically stained reddish brown by iron oxides and consist of quartz and lesser amounts of lithic fragments. Clay films coat many clasts and impart a slight degree of induration to the beds of Mounds Gravel.

Much confusion of nomenclature and long-standing controversy of age and origin surround this unit. The name, Mounds Gravel, was applied by Willman and Frye (1970) to deposits previously called Lafayette (or Lafayette-type) Gravel, Tertiary gravel, "Plio-Pleistocene" gravel, or continental deposits by many other workers. Mounds Gravel was placed in the Upland Complex of Autin and others (1991) and correlated with the Willis Formation of Louisiana and Texas, and the Citronelle Formation which extends along the Coastal Plain from Texas to Virginia. Similar upland deposits are also found in western Missouri, eastern Kansas, and Oklahoma (Madole and others, 1991).

Based on analysis of terrace levels, Fisk (1944) considered these gravels to be Pleistocene in age and of glacial-outwash origin. Potter (1955b) contradicted Fisk's interpretation and from petrologic and physiographic evidence argued for a preglacial Pliocene age. A Pliocene age is also suggested by Lamar and Sutton (1930), Weller (1940), and Leighton and Willman (1949). Olive (1980) concluded that gravel of two ages occurred in western Kentucky: an upper-level gravel containing pollen of Miocene(?) and Pliocene age, and a lower-level, reworked gravel containing Pleistocene pollen. He suggested that erosion and redistribution of the older gravel to lower elevations began in late Pliocene and probably continued into the early Pleistocene.

Mounds Gravel in the Benton Hills occurs at relatively high elevations, from 450 to 580 ft above mean sea level, and shows no indication of reworking. Thus, this unit is believed to be Pliocene or Miocene(?) in age. It is as much as 80 ft thick in the Benton Hills and both upper and lower contacts are pronounced unconformities.

### Unnamed Quaternary gravel 1

Unnamed gravel deposits of Quaternary age exist in many of the trenches. All of these gravels are very similar in appearance since they consist mainly of reworked clasts derived from the Mounds Gravel. They are distinguishable from Mounds Gravel by their finer-grained ("dirtier") matrix of silt and clay in addition to sand, their typical lack of red color, their typical clast-supported characteristic, a common imbrication of clasts, and a lack of any induration. All of these features are in contrast to those occurring in Mounds Gravel.

Based on their stratigraphic position, the gravels are divisible into three separate units numbered from oldest to youngest. They are interpreted as representing colluvial lag and alluvial deposits laid down upon erosional surfaces of possible tectonic origin. Unnamed Quaternary gravel 1 is the oldest and was encountered in the Lower Fence Line and Seismic Line trenches where it overlaid Wilcox Group and was overlain by the Sangamon Geosol.

### Loveland Loess and Sangamon Geosol

The oldest loess deposit occurring in the English Hill area is the Loveland Loess. This deposit consist of Illinoian Stage wind-blown silt and minor fine-grained sand. Rodbell and others (in press) suggest that the Loveland Loess may consist of multiple loess units pedogenically welded together. In the English Hill area, Loveland has been entirely and ubiquitously modified by the Sangamon Geosol. We have recorded on the trench profiles the Sangamon Geosol rather than the Loveland Loess. Loveland Loess is less than 10 feet thick.

The Sangamon Geosol (Sangamonian Stage) is characterized by a strongly developed *in situ* weathering profile on deposits of Illinoian Stage and older. In the English Hill area, this soil has most commonly formed on the Loveland Loess, however locally it has formed on the unnamed Quaternary gravel 1 deposit, Mounds Gravel, Wilcox Group, Porters Creek Clay, and McNairy Formation. The Sangamon Geosol characteristically has a solum greater than 5 feet thick consisting of a diagnostic red-brown, clay-rich B-horizon.

Sangamon Geosol is treated as a time-stratigraphic horizon. Reported age estimates are: approximately 132-79 ka or all of oxygen isotope stage 5 (Follmer, 1983; Markewich, 1994); 155-55 ka or late oxygen isotope stage 6, all of stages 5 and 4, and early stage 3 (Curry and Pavich, 1996); and 70-53 ka or early stage 4 through early stage 3 (Rodbell and others, in press). While the beginning of soil development is somewhat controversial, the most recent age determinations based on $^{10}$Be inventory and $^{14}$C ages (Curry and Pavich, 1996) and thermoluminescence (TL) dating (Rodbell and others, in press) suggest a youngest age of Sangamon Geosol of approximately 53-55 ka, which provides a maximum constraint for faults that cut this unit.

## Unnamed Quaternary gravel 2

A gravel deposit between the Wilcox Group and Roxana Silt was found near the middle of the Upper Rainbow Trench. There was no Loveland Loess or Sangamon Geosol present. The deposit was clast supported and consists of reworked Mounds Gravel clasts in a silty and sandy matrix. Poorly expressed clast imbrications suggest transport towards S5-20E.

## Roxana Silt

Clayey silts that are typically pale-pink to buff colored and overlie the Sangamon Geosol have been mapped as the Roxana Silt (Wisconsinan Stage, Altonian Substage). Reported ages for this unit range from 60-26 ka (Markewich, 1993), 53-25 ka (Rodbell and others, in press), 55-25 ka (Curry and Follmer, 1992; Leigh and Knox, 1993). Thermoluminescence ages determined from the uppermost portion of Roxana Silt in trench exposures range from approximately 28 to 32 ka (table 1), in good agreement with the published ages and confirming the field identification.

Roxana consists of wind-blown silt and minor eolian sand, and is characterized by a pinkish-tan color. It is as much as 15 feet thick in the Benton Hills, but is typically less than 5 feet thick in the English Hill area. At many locations, the weakly developed Farmdale Geosol is present at the top of the Roxana, imparting a pale-pink oxidized discoloration. Also, colluvial and alluvial gravels and sands are present locally at the base.

### Unnamed Quaternary gravel 3

To the southeast of the N70W, steeply NE-dipping slip surfaces in the Uncle John Trench (profile 4 in appendix A), a deposit of unnamed Quaternary gravel 3 occurs below Peoria Loess and above Porters Creek Clay and Sangamon Geosol. To the northwest of these slip surfaces, Roxana Silt occurs between Sangamon and Peoria. This suggests that the gravel is of post-Roxana and pre-Peoria age. The gravel deposit is 1 ft or less thick and consists of matrix-supported pebbles and cobbles of chert. Matrix is a mixture of silt and sand.

It is interpreted, but not demonstrated, that gravel deposits observed between the Peoria Loess and Wilcox Group in the Hillcrest Trench (profile 6) and at the northern end of the Upper Rainbow Trench (profile 7) are correlative to this unnamed Quaternary gravel 3. Similarly, it is interpreted that a gravel unit below Peoria Loess and above McNairy and Clayton Formations in

## Table 1. Luminescence data and age estimates for samples from English Hill, southeast Missouri from the University of Illinois Luminescence Dating Research Laboratory.

| Field # & Trench | Lab# | Method[1,2] | Temp. (°C) or time (s)[3] | Equivalent dose (grays) | Luminescence age est. (Ka)[4] | Anomalous Fading Ratio[5] | Field ID of unit |
|---|---|---|---|---|---|---|---|
| 6-11-96-1 | UIC594 | TL-Total Bleach:8h UV | 250-400 | 84.4 ± 10.6 | 22.7 ± 3.5 | 0.98 ± 0.03 | Peoria |
| Old Quarry | | TL-Total Bleach:16h SL | 250-400 | 79.2 ± 10.6 | 21.3 ± 3.4 | | Loess |
| Trench | | IRSL[6]-Total Bleach:1h SL | 2-90 | 93.2 ± 5.7 | 25.4 ± 2.5 | | |
| 6-11-96-2 | UIC595 | TL-Total Bleach:8h UV | 250-400 | 78.8 ± 11.8 | 21.9 ± 3.3 | 0.98 ± 0.03 | Peoria |
| Old Quarry | | TL-Total Bleach:16h SL | 250-400 | 73.6 ± 11.8 | 20.5 ± 3.2 | | Loess |
| Trench | | | | | | | |
| 6-11-96-3 | UIC611 | TL-Total Bleach:8h UV | 250-400 | 98.4 ± 10.6 | 28.3 ± 3.4 | | Roxana |
| Old Quarry | | TL-Total Bleach:16h SL | 250-400 | 97.3 ± 10.2 | 28.0 ± 3.4 | | Silt |
| Trench | | | | | | | |
| 6-11-96-4 | UIC610 | TL-Total Bleach:8h UV | 250-400 | 106.5 ± 10.7 | 31.8 ± 3.0 | | Roxana |
| Upper | | TL-Total Bleach: 16h SL | 250-400 | 106.4 ± 10.7 | 31.8 ± 3.4 | | Silt |
| Rainbow | | | | | | | |
| 6-11-96-5 | UIC601 | TL-Total bleach:8h UV | 250-400 | 61.6 ± 9.8 | 17.0 ± 2.7 | | Peoria |
| Upper | | TL-Total Bleach:16h SL | 250-400 | 63.6 ± 9.8 | 17.6 ± 2.8 | | Loess |
| Rainbow | | | | | | | |
| 6-11-96-6 | UIC605 | TL-Total Bleach:8h UV | 250-400 | 73.6 ± 7.5 | 18.4 ± 2.2 | | Colluvial |
| Upper | | TL-Total Bleach:16h SL | 250-400 | 74.8 ± 7.5 | 18.7 ± 2.2 | | Wedge |
| Rainbow | | IRSL[6]-Total Bleach:1h SL | 3-59 | 75.8 ± 2.4 | 19.3 ± 1.7 | | |
| 6-26-96-1 | UIC599 | TL-Total Bleach:8h UV | 250-400 | 103.2 ± 3.8 | 28.0 ± 2.6 | | Roxana |
| Tuesday | | TL-Total Bleach:16h SL | 250-400 | 103.9 ± 3.7 | 28.0 ± 2.6 | | Silt |
| Trench | | | | | | | |
| 6-26-96-2 | UIC600 | TL-Total Bleach:8h UV | 250-400 | 75.9 ± 8.6 | 20.6 ± 2.7 | | Peoria |
| Tuesday | | TL-Total Bleach:16h SL | 250-400 | 76.9 ±8.6 | 21.0 ± 2.7 | | Loess |
| Trench | | | | | | | |
| 6-28-96-1 | UIC602 | TL-Total Bleach:8h UV | 250-400 | 92.4 ± 9.2 | 25.6 ± 2.6 | | Peoria |
| Tuesday | | TL-Total Bleach:16h SL | 250-400 | 94.0 ± 9.4 | 26.0 ± 2.6 | | Loess |
| Trench | | IRSL[6]-Total Bleach:1h SL | 2-90 | 93.5 ± 9.4 | 25.6 ± 2.5 | | |

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1 All TL measurements were made with a Corning 5/58 and HA-3 filters in front of the photomultiplier tube. Samples were preheated to 124 °C for 48 hrs prior to analysis.

2 Hours of light exposure to define residual level for TL analysis. "SL" is natural sunlight in Chicago, Illinois. "UV" is light from 240 watt General Electric sunlamp bulb which is dominated by UV spectra.

3 Temperature range used to calculate equivalent dose.

4 All errors are at one sigma and calculated by averaging the errors across the temperature or time range.

5 All samples were tested for anomalous fading by storing irradiated (100 to 450 gy) samples for at least 32 days and comparing the luminescence signal to an unstored aliquot. Anomalous fading between 1.00 and 0.90 indicate little or no fading within analytical resolution.

6 infrared stimulated luminescence

Note: The 8 hours UV exposure is believed to result in full resetting of TL, particularly for loess that received extended light exposure during deposition and prior to burial, and is the favored age estimate.

the Tuesday Trench (profile 14) is correlative to the unnamed Quaternary gravel 3. At that locality, this unit is poorly sorted and contains clasts derived from the Mounds Gravel and Wilcox Group. Several clasts of iron-cemented conglomerate attest to the reworked nature of the deposit. Prominent imbrication of clasts in the Tuesday Trench deposit indicate a transport direction towards N55E; in the Upper Rainbow Trench deposit, clast imbrications statistically indicate a northeasterly transport direction.

## Peoria Loess

The youngest loess deposit at English Hill is the Peoria Loess (Wisconsinan Stage, Woodfordian Substage). Peoria Loess is a massive, dense, medium-brown, well-sorted wind-blown silt as much as 50 feet thick in the English Hill area. Peoria is the most widespread unit in the Benton Hills, blanketing more than 90% of the landscape. Upper portions display a moderately developed modern soil profile; locally the lowermost portion is colluvial in nature and contains isolated pebbles.

Thermoluminescence (TL) ages for the middle to lower portions of the Peoria Loess (uppermost portions were unsuitable for TL dating because of modern soil development) exposed in the English Hill trenches range from approximately 26 to 17 ka (table 1), in good agreement with published ages for this unit in the Middle Mississippi Valley of about 25 ka to approximately 12.5-10 ka (Snowden and Priddy, 1968; Fehrenbacher and others, 1986; McKay, 1989; Ruhe, 1983; Follmer, 1983; Markewich, 1994) .

### Quaternary (Holocene) colluvium

Throughout the English Hill area, the uppermost surficial materials are admixed colluvial silts, sands, and gravels derived from older strata. These colluvial sediments are as much as several feet thick and vary in color from buff to yellowish brown to dark brown. Few colluvial units persist along slopes for more than a few tens of feet. Radiometric $^{14}C$ ages (table 2) determined from leaves, twigs, and nuts at the base of a colluvial deposit exposed in the Old Quarry Trench (profile 3) indicate that this deposit is less than 150 years old.

## Trench Descriptions

Following are descriptions of trenches excavated in the English Hill area during 1995 and 1996. Emphasis is placed on orientations and interpreted kinematics of structural features exposed in the trenches. The term 'episodes' is used to group structures into sets that have a similar timing and style. The term does not correspond to individual fault events or earthquakes. Timing is determined by cross-cutting relations or the youngest unit effected. Style is interpreted from kinematic analysis of fault-slip data, similar to methods used by Marrett and Allmendinger (1990), and the application of Anderson's (1951) model relating fault geometry and kinematics to controlling stresses . Fault-slip data is measured in the field and includes characteristics such as the orientation of fault surfaces, orientation of slip direction determined from slickenside striations, and sense of slip. Assumptions are made that the sampling is representative and that there has been no reorientation of fault-slip data.

Virtually all of the trenches display some form of surface or near-surface deformation, mainly faulting, of the unconsolidated Cretaceous and Cenozoic section described above. The

**Table 2. AMS $^{14}$C ages for materials collected at English Hill.**

| WW | Sample # | Material | Trench & Unit | δ 13C | 14C age | Calendar age range |
|---|---|---|---|---|---|---|
| 690 | 2-12-96-1 | leaves | Old Quarry Qc | -25 | modern <150yrs | |
| 691 | 2-12-96-2 | nut | Old Quarry Qc | -25 | modern <150yrs | |
| 692 | 2-12-96-3 | leaves | Old Quarry Qc | -25 | modern <150yrs | |
| 693 | 2-12-96-4 | twigs | Old Quarry Qc | -25 | modern <150yrs | |
| 933 | 9-23-96-1 | charcoal | Upper Rainbow colluvial wedge | -25 | 4,980 ± 60 | BC 3899 (3772) 3698 |
| 934 | 9-23-96-2 | charcoal | Upper Rainbow colluvial wedge | -25 | 4,740 ± 50 | BC 3899 (3613, 3600, 3519) 3380 |
| 938 | 9-26-96-9 | charcoal | Upper Rainbow colluvial wedge | -25 | 1,310 ± 60 | AD 662 (685) 779 |
| 939 | 9-26-96-10 | charcoal | Upper Rainbow colluvial wedge | -25 | 4,920 ± 60 | BC 3773 (3698) 3646 |
| 1097 | 12-9-96-4 | charcoal | Upper Rainbow colluvial wedge | -25 | 1,220 ± 50 | AD 727 (789) 886 |
| 1098 | 12-9-96-5 | charcoal | Upper Rainbow colluvial wedge | -25 | 1,240 ± 50 | AD 710 (782) 881 |
| 1099 | 12-9-96-6 | charcoal | Upper Rainbow colluvial wedge | -25 | 1,210 ± 50 | AD 775 (821, 840, 860) 888 |
| 1100 | 12-9-96-7 | charcoal | Upper Rainbow colluvial wedge | -25 | 4,780 ± 50 | BC 3639 (3625, 3569, 3540) 3389 |

-WW- Identification assigned to sample by the USGS 14C Laboratory
-Samples were processed at the 14C Laboratory of the U.S. Geological Survey in Reston, VA
-14C ages were determined at the Center for Accelerator Mass Spectrometry (CAMS), Lawrence Livermore National Laboratory, Livermore, CA
-Libby half life of 5568 years was used to determine radiocarbon years
-Values reported for δ13C are assumed values according to Stuiver and Polach (1977).
-Calibrated ages done using CALIB 3.0.3 software with bi-decadal data set according to Stuiver and Remer (1993); Calibrated ages in calendar years given in parentheses bracketed by 1 sigma range.

rupture characteristics of this unconsolidated material varied greatly, dependent upon the dominant grain-size fraction of strata. Faults cutting the more cohesive silts and clays are typically very sharp and well defined. Faults cutting gravels and sands were more diffuse. Many fault surfaces contained gravel and sand grains transported along the shear plane.

## Bollinger Trench

Profiles 1 and 2 (appendix A) depict the Bollinger Trench which was excavated on a ridge crest located in the southeastern portion of the English Hill area (fig. 4). This trench exposed two complex fault systems, both of which contain high angle and subhorizontal surfaces, and appear to be separated in time although cross-cutting relationships were not observed.

The deeper system consists of a high-angle fault (fault A on profiles 1 & 2, figs. 5a & 5b) and several subhorizontal fault surfaces which steepen and merge into a single high-angle fault to the southeast (fault B on profile 1). Fault A strikes N15E, dips 45-80° SE, and cuts the unnamed Eocene unit and McNairy Formation. No striations or mullions were observed, but deformed fragments of bedded McNairy Formation caught in the fault indicate hanging-wall-up oblique motion. The upward extent of fault A was untraceable into the modern B soil horizon. Fault A showed intertwined relations to the subhorizontal faults; in places it merge into them, in other places it was truncated by them, and at one location, fault A truncates a subhorizontal structure. It is interpreted that these relations indicate a common origin for fault A and the subhorizontal structures. The subhorizontal faults are sharp, well-defined structures that have northeasterly strikes and northwest-southeast striations. A consistent 8- to 12 in.-thick, subhorizontal-fault-bound interval of strongly deformed McNairy strata occurred below the unnamed Eocene unit and

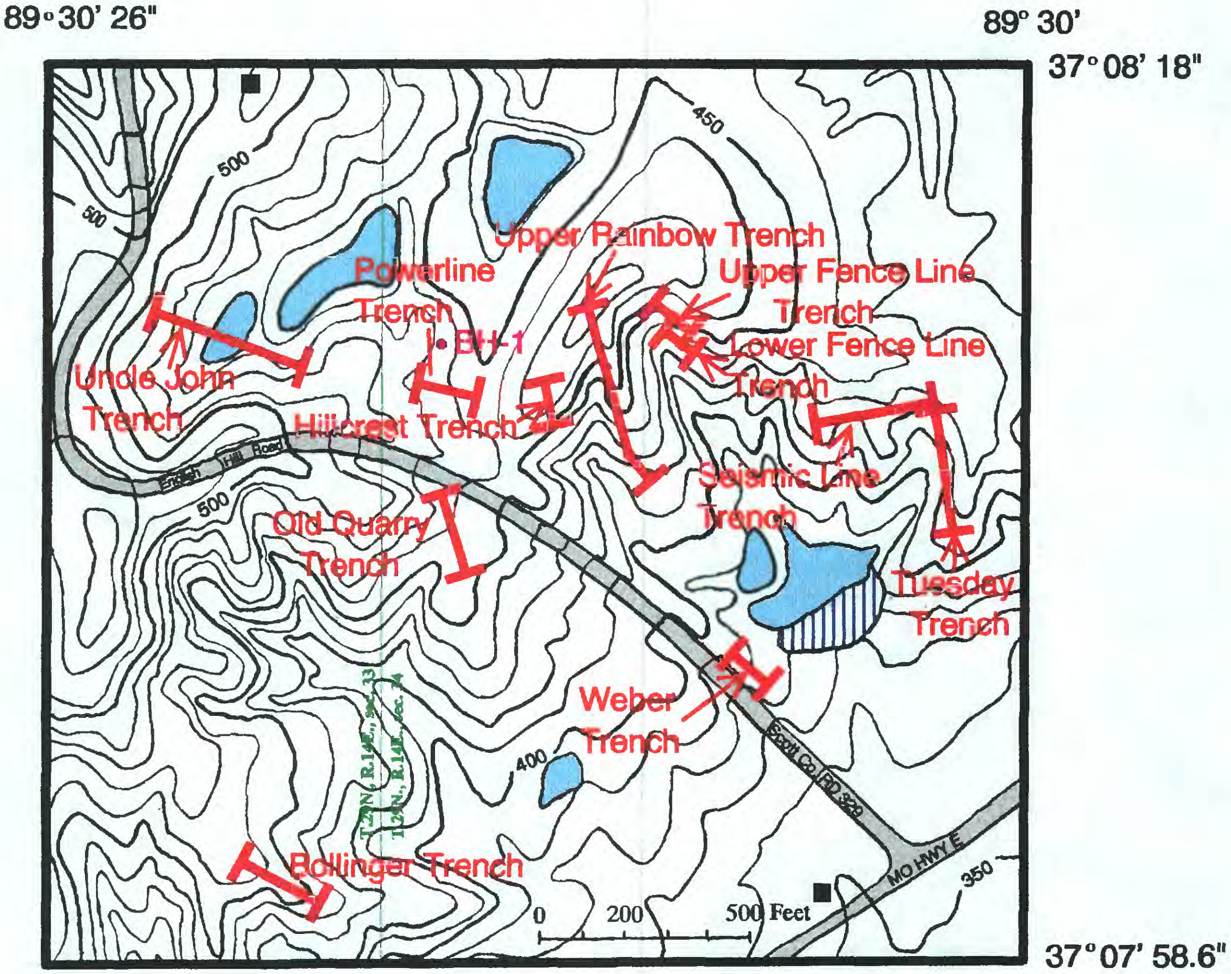


Figure 4. Map showing locations of fault exploration trenches in the English Hill area and core-hole BH-1.

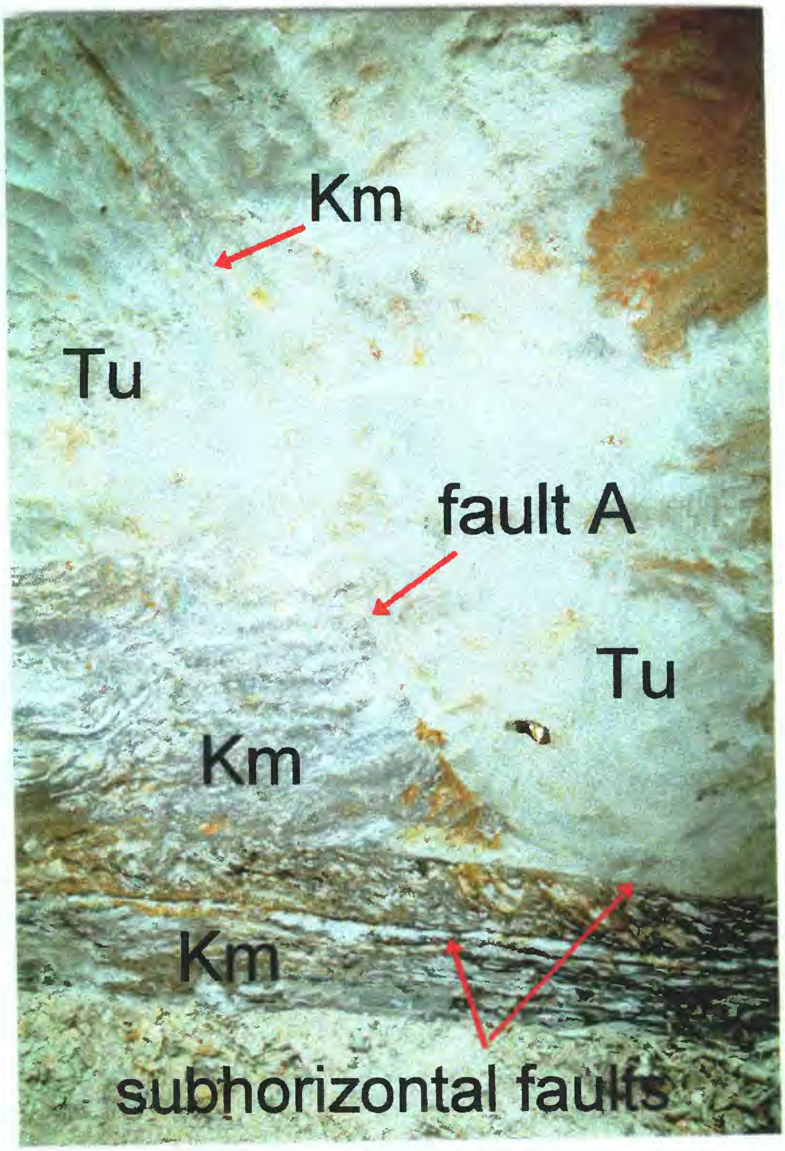


Figure 5a. Bollinger Trench- NE Wall.

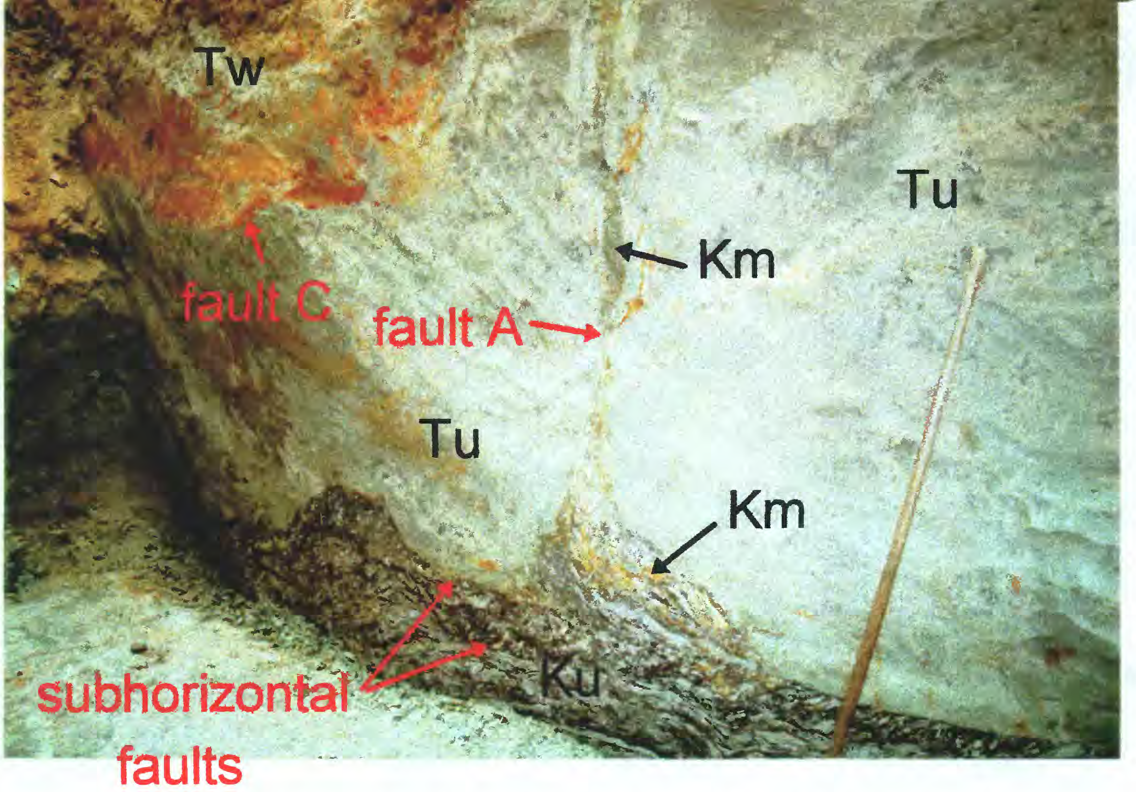


Figure 5b. Bollinger Trench- SW Wall

above undeformed McNairy strata. Asymmetrical folds within this deformed interval indicate a top towards N20-50W. This is consistent with the observed striations on the subhorizontal fault surfaces and with an oblique, reverse motion on fault A (fig. 6 ). To the southeast, the subhorizontal structures merge and steepen into a N60W fault (fault B on profile 1) which dips approximately 52° NE and contains 15-20° NW raking striations and mullions. The kinematics of fault B are consistent with the movement indicated on the subhorizontal faults. Antithetic shears to fault B were observed striking N65E and dipping 42°SE; slickenside striations rake 0-19°NE.

Our interpretation is that this deeper system represents a roll-over, or flower structure, along a left-lateral, northwest-trending, strike-slip fault zone. The age of faulting is only constrained as post-Eocene. Because it cannot be traced into the B soil horizon, it is believed to be older than the upper fault system which offsets the modern B soil horizon.

The upper fault system juxtaposes Wilcox Group sands and clays, and Quaternary colluvial material against the unnamed Eocene unit. Much of the Wilcox is brecciated and contorted. As mentioned earlier the B soil horizon is offset across fault C (profile 2). The Qaternary colluvium consists dominantly of silt (reworked loess) and lesser sand and gravel concentrated at the base. The Quaternary material exposed in the hanging wall of the upper fault system had no resemblance to Quaternary deposits in the footwall (see profile 1) which consist of Sangamon Geosol developed on silty colluvium or loess and alluvial sand deposited in a paleochannel trending S50W, dipping 10° to the southwest across the trench, overlain by gravel- and sand-rich colluvium. The absence of Wilcox Group in the footwall attests to erosion prior to Sangamon time.

The upper fault system consists of a steeply dipping, N13-30E-striking, southeasterly

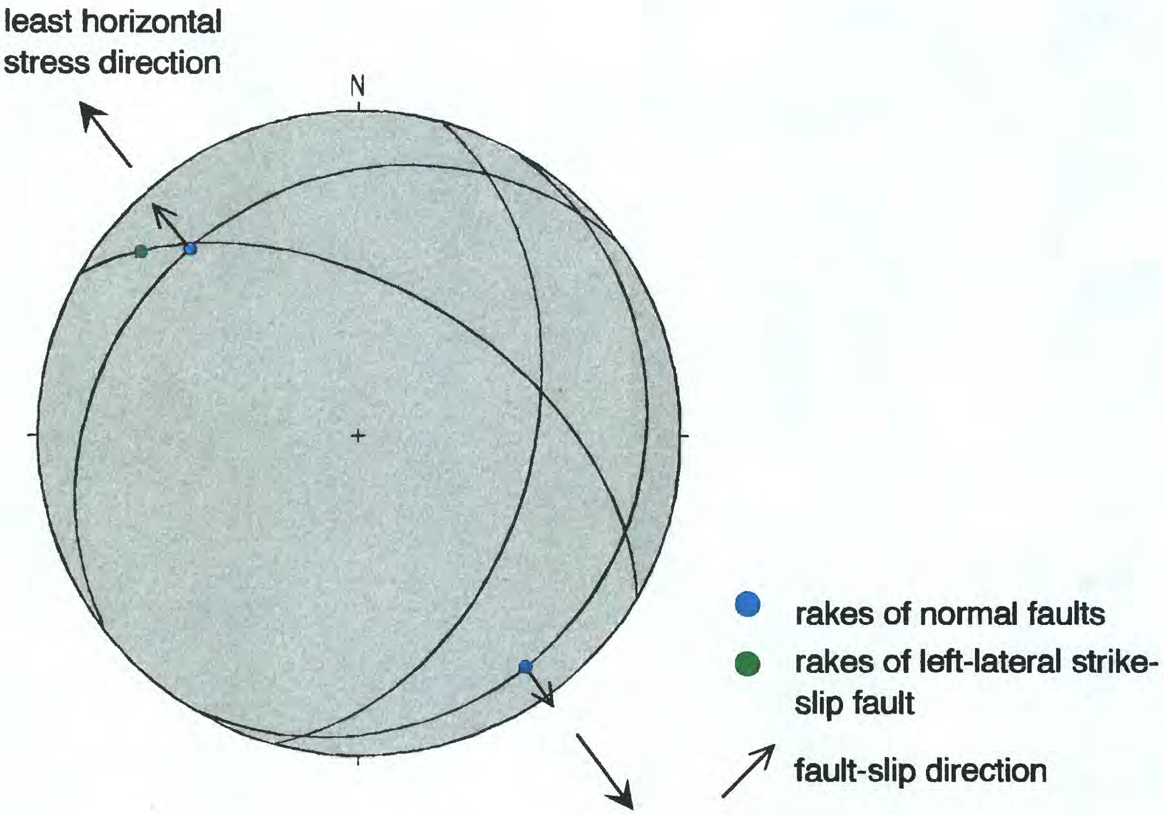


Figure 6. Bollinger Trench- oldest faulting.

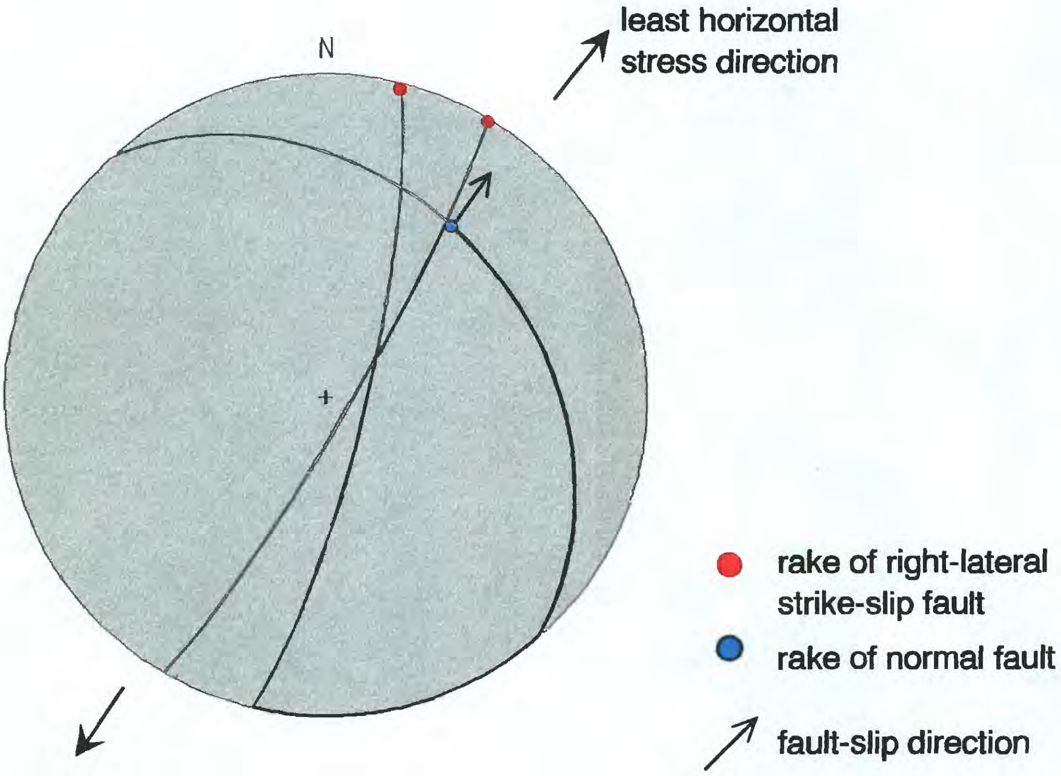


Figure 7. Bollinger Trench- youngest faulting.

dipping, strike-slip fault (fault C on profiles 1 & 2, fig. 5b) which flattens and rotates at depth to a N42W strike, 35°NE dip, and has striations that rake 80°NW. Both Wilcox Group and Quaternary colluvial material have been dragged along the fault trace. Kinematics indicated by slip directions suggest a north-northeast extension direction (fig. 7).

**Old Quarry Trench**

The Old Quarry Trench (profile 3, fig. 8) was excavated approximately 1000 ft north-northeast of the Bollinger Trench along the eastern margin of an old abandoned quarry immediately south of the English Hill Road (Scott County Route 329) at approximately mid-hill elevation (fig. 4). The trench revealed several high-angle normal faults depicted in Profile 3 (appendix A) and shown in Figure 8. All of the faults cut Mounds Gravel and a well-defined Quaternary sequence of Sangamon Geosol (developed on Loveland Loess), Roxana Silt, and Peoria Loess. TL age dating (Table 1) confirms the field identification of Peoria Loess and Roxana Silt, and establishes a maximum age of faulting in this trench of 21.9 ka ± 3.3 ka. Colluvial material caps the stratigraphic sequence and truncates all faults. A horizon at the base of the colluvium contained several pieces of leaves, twigs, and nuts, four of which yielded modern (<150 years) $^{14}$C age dates (Table 2).

The major fault exposed in the trench is called the English Hill fault because it is believed to be the same structure described and named by Stewart (1942). This fault juxtaposes Peoria Loess in the hanging wall against Mounds Gravel in the footwall (fig. 8) and consists of several braided strands that strike N35E, dip 88°SE. Slickenside striations along the fault surfaces rake 90°. Fault-bound slivers of Roxana Silt occurred along the fault. Gouge-like, sandy clay material

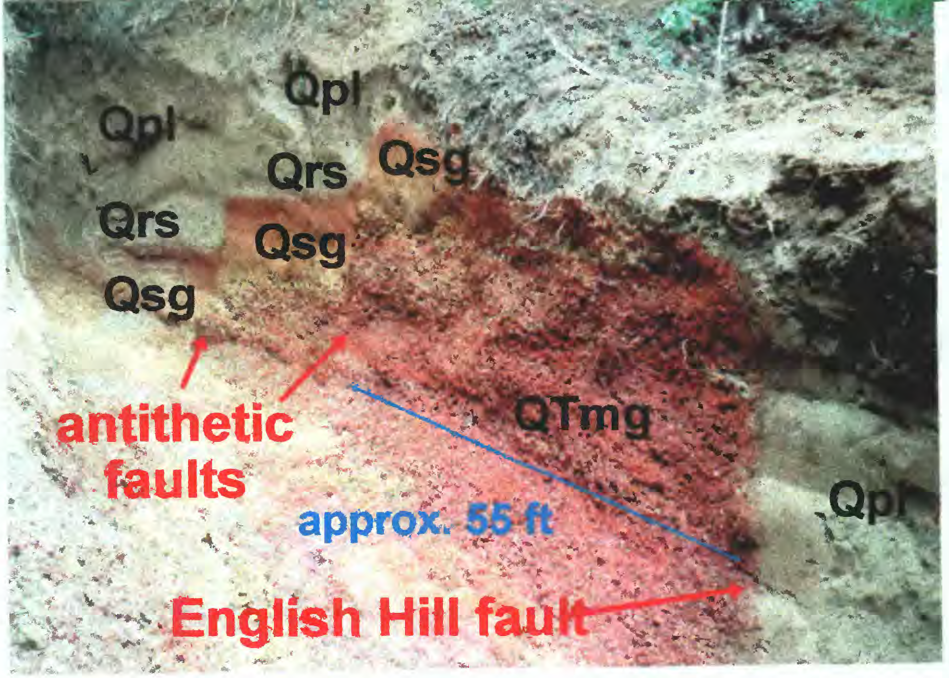


Figure 8. Old Quarry Trench- NE Wall.

and numerous gravel clasts derived from the Mounds also occur along fault surfaces. Shallow holes dug in the floor of the trench in the hanging wall of the English Hill fault encountered Roxana Silt just below trench-floor level, thus indicating approximately 15 ft of dip slip on the structure. A TL age of 28.3 ka ± 3.4 ka confirms the field interpretation of this material as Roxana Silt.

Progressing to the northwest in the footwall of the English Hill fault, three antithetic faults and one synthetic fault were encountered that form a horst-and-graben sequence. Respective attitudes and rakes determined from slickenside striations (when observed) on these faults are: N15E-strike, 78°NW-dip, 69°NE-rake; N35E-strike, 71°NW-dip, 90°-rake; E-W-strike, 74°S-dip; and N43E-strike, 65°NW-dip. Stratigraphic separation on the first three of these faults range from 1 to 4 ft; because of lack of sufficient trench depth, no offset contacts were seen on the northwesternmost fault. A small N35E-trending fold was observed near the center of the graben.

Kinematic indicators provided by slickenside striation data on these larger faults exposed by the Old Quarry trench (fig. 9) suggest overall northwest-southeast extension. A seismic reflection profile acquired along the trench (Palmer and others, 1997b) shows that the English Hill fault remains near vertical to depths of at least 200 ft and that it offsets the Cretaceous-Paleozoic contact.

Several minor fractures, showing small normal displacements of a few inches to fractions of an inch, occur in the Mounds Gravel in the footwall of the English Hill fault. Attitudes vary considerably, both in strike and dip as show in Figure 10. One questionable set of low-angle (15°SE) striations was found on a N17W-striking fracture, suggesting a component of left-lateral shear. If real, this is inconsistent motion for overall northwest-southeast extension.

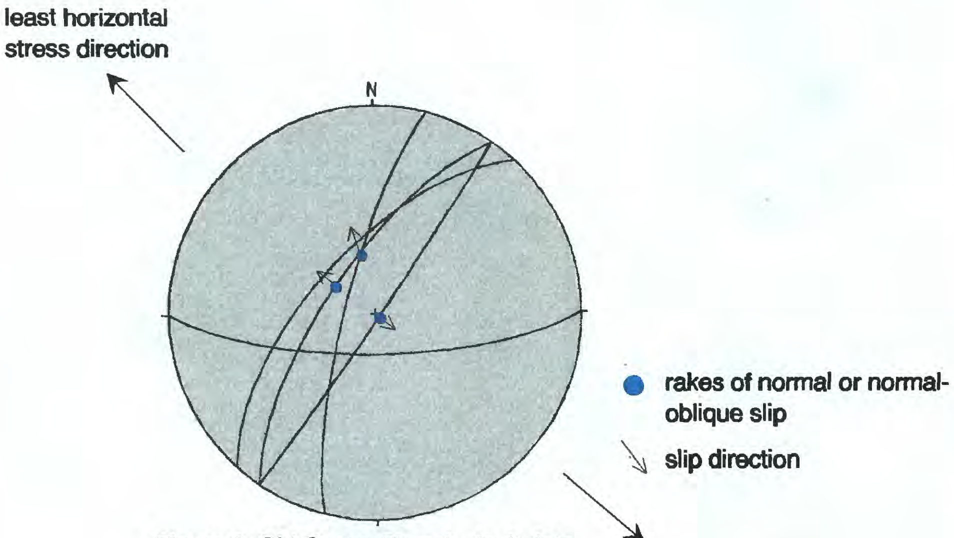


Figure 9. Old Quarry Trench- fault data.

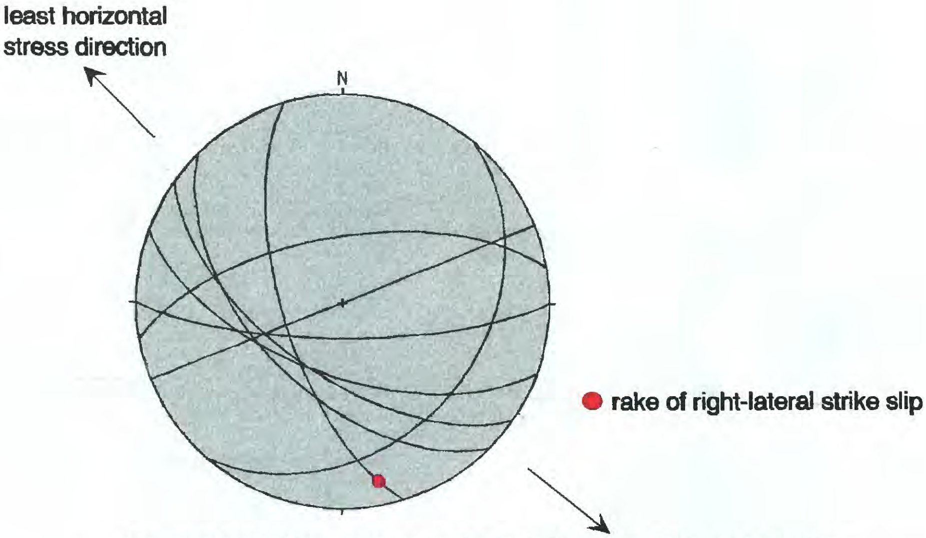


Figure 10. Old Quarry Trench- fractures in Mounds Gravel showing small displacements

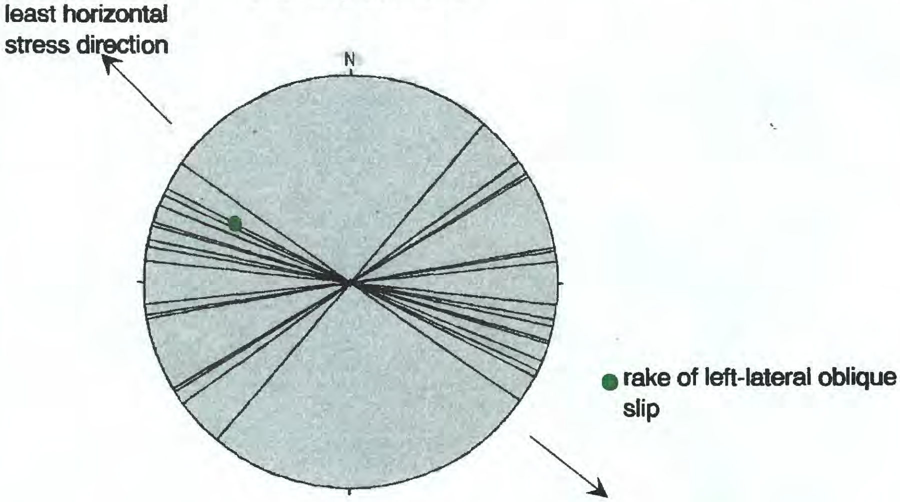
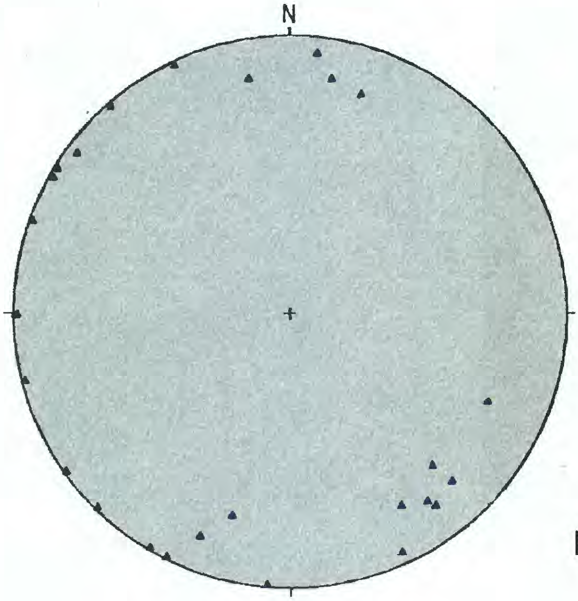


Figure 11. Old Quarry Trench- fractures in Sangamon Geosol.

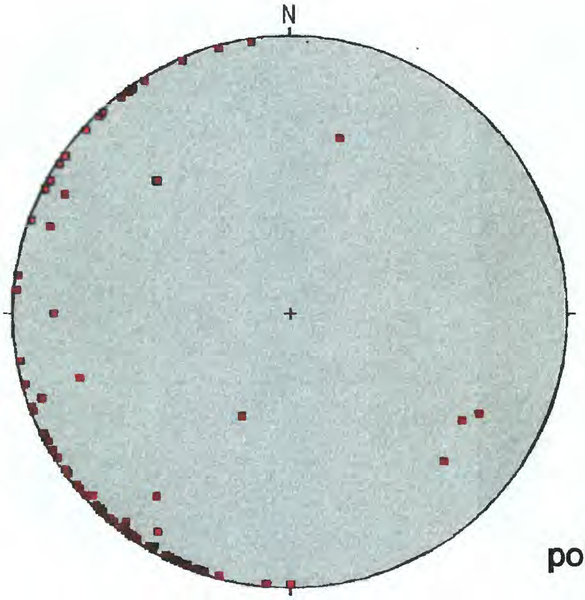
Several minor fractures also occur in the Sangamon Geosol (fig. 11). They were untraceable into overlying or underlying units and except for one fracture showed no discernible displacement. That exception had striations indicating left-lateral, normal oblique slip on a N63W-striking fracture. This is consistent with overall northwest-southeast extension.

Numerous vertical or near-vertical fractures showing no discernible displacement were observed in the Peoria Loess (profile 3), particularly in the hanging wall of the English Hill fault. Although fractures in unfaulted loess are common, the density of fractures in the hanging wall of the English Hill fault are at least three times the density in the footwall, suggesting a tectonic origin. A comparison between Peoria fracture orientations in hanging wall versus footwall (fig. 12) shows an overall polygonal pattern, but the hanging wall contains a much greater concentration of northwest-southeast-trending fractures, further suggesting a tectonic origin. All hanging wall fractures are truncated by the English Hill fault. Without any kinematic knowledge for these fractures, it is impossible to determine if they represent horizontal shear that is compatible with northwest-southeast extension, or an earlier northeast-southwest extensional fabric.

A notable difference in soil profile thicknesses was observed across the English Hill fault. In the footwall, modern soil developed in the Peoria Loess is welded to the buried Farmdale soil which developed on Roxana Silt, resulting in soil profile that extends from the surface all the way down to the Sangamon Geosol. However, in the hanging wall modern soil development is restricted to the uppermost 1 to 3 ft. The footwall soil profile is anomalously thick for the area and probably indicates formation in a trough or depression that experienced relatively high rates of water influx. This suggests the possibility of multiple episodes of faulting, first forming the



poles to footwall fractures



poles to hanging wall fractures

Figure 12. Old Quarry Trench- fractures in Peoria Loess.

graben structure and subsequent faulting along the English Hill fault.

### Uncle John Trench

The Uncle John Trench (profile 4) was excavated across a northeast-trending valley located in the northwestern portion of the English Hill area (fig. 4). This valley was chosen for fault exploration because it is relatively steep sided and deep, and yet it has very little surface drainage area. Furthermore, this valley and another similar-trending valley to the southwest form a conspicuous N55E photolinear feature, parallel to one of the dominant structural trends in the Benton Hills.

The trench exposed a N25W-striking, 50°NE-dipping fault (the Uncle John fault on profile 4) near the center of the valley, a series of N70W-striking, NE-dipping listric faults in the footwall of the Uncle John fault, and several N70W, steeply NE-dipping slip surfaces in the hanging wall. Numerous slickenside striations and scallop-shaped structures on the footwall listric faults indicate that their hanging wall moved towards N30W (fig. 13). Subhorizontal striations and mullions on the Uncle John fault indicate a strong component of shear along its strike, consistent with motion on the listric faults (fig. 13). The hanging wall slip surfaces contain numerous mullions and striations that rake 90°, suggesting at least a local northeast-southwest extensional direction (fig. 14).

Stratigraphic and cross cutting relationships indicate two episodes of movement on the faults exposed in the Uncle John trench. 1) Normal or transtensional displacement occurred on the Uncle John fault which down dropped Wilcox Group sand adjacent to Porters Creek Clay. Both of these units show soil development interpreted to be the Sangamon Geosol, suggesting

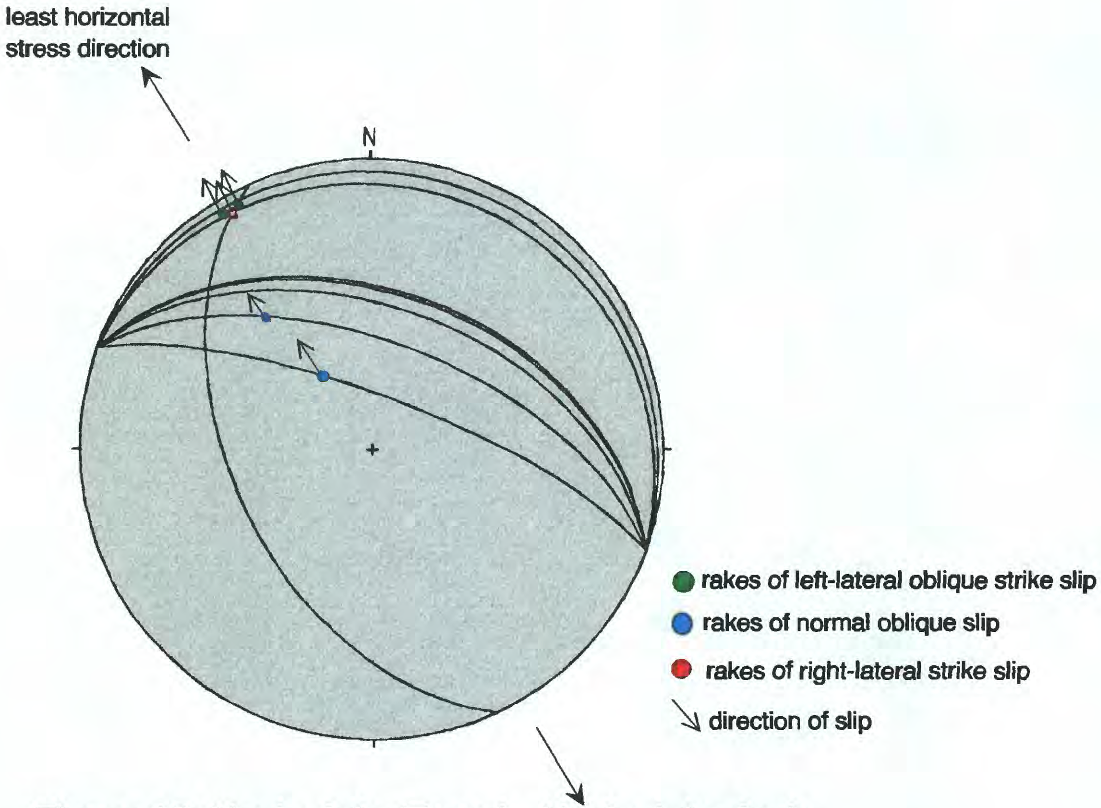


Figure 13. Uncle John Trench- Uncle John fault and footwall fault data.

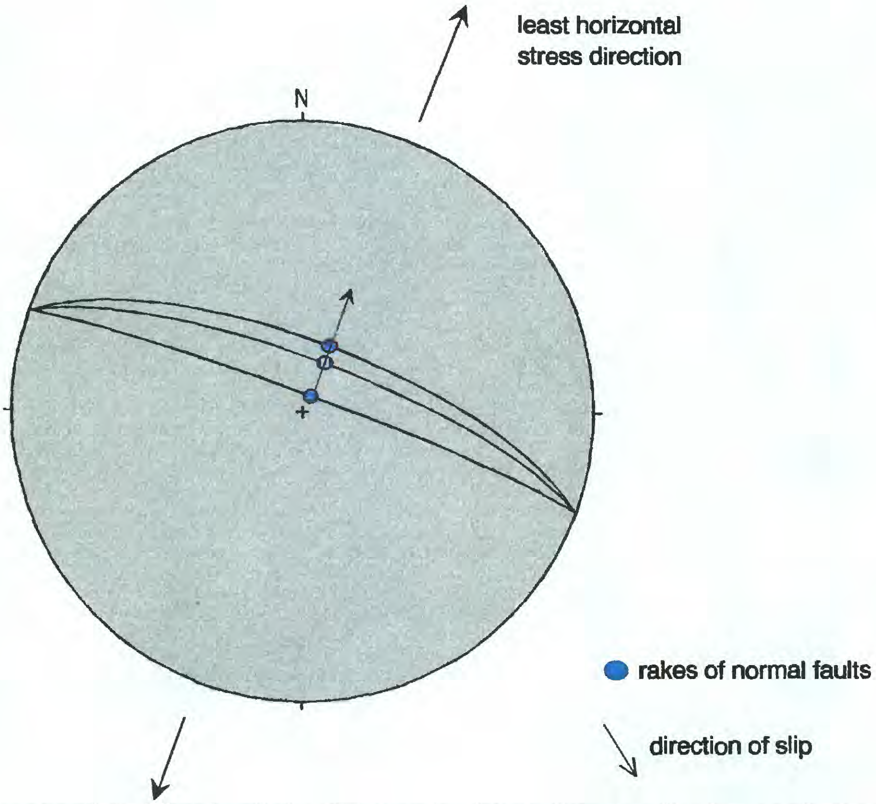


Figure 14. Uncle John Trench- hanging wall shear data.

that this oldest faulting is pre-Sangamon. Displacement was probably on the order of tens of feet. 2) Northwest-southeast extension produced a few feet of displacement on the down-to-the-northwest listric faults exposed in the footwall of the Uncle John fault. The Uncle John fault was reactivated as a transtensional strike-slip structure. This youngest faulting offsets at least the base of the Peoria Loess; but because of extensive soil development throughout the Peoria, it was impossible to determine if its entire thickness was faulted. Also offset by this youngest faulting is the thin unnamed Quaternary gravel (Qg3) deposit consisting mostly of reworked Mounds Gravel and a Quaternary colluvial/alluvial deposit that consists of gravel (less than 2 inches in diameter) supported by a matrix of sand and silt. It is uncertain as to whether this latter unit represents an old channel fill or a fault-related colluvial wedge which would indicate another fault event.

Peoria Loess occurs as a blanket of consistent thickness across the entire valley that the Uncle John Trench was dug in. The lack of loess thickening along the valley axis suggests that it has sagged or down warped post-Peoria Loess deposition. This notion is further supported by the thin Quaternary gravel which also shows no thickening or incision along the valley axis. It is our interpretation that this valley is a synform created by en echelon extensional and transtensional structures along a northeast trend. Where a Mini-Sosie seismic reflection profile traversed an extension of this valley approximately 1,800 ft to the northeast (Palmer and others, 1997a), a well-defined graben structure was imaged that down dropped the Paleozoic-Cretaceous contact. Where a shotgun seismic reflection profile crossed the valley approximately 500 feet to the northeast of the Uncle John Trench, a synform was imaged on the Paleozoic-Cretaceous contact (Palmer and others, 1997b).

**Powerline Trench**

The Powerline Trench was excavated approximately 300 ft east of the Uncle John trench and 200 ft north of the Old Quarry Trench (fig. 4). The main extent of this trench was dug along a S70E-N70W direction and encountered a N78E-striking normal fault at an acute angle; therefore a short perpendicular cutout was dug to better expose the structure (profile 5, fig. 15).

This fault has a dip of 64°SE and slickenside striations that rake 75-80°NE. It juxtaposes Peoria Loess in the hanging wall against Mounds Gravel in the footwall. Stratigraphic separation is a minimum of 8 feet. Bedding in the Mounds Gravel strikes N55W, oblique to the fault, and dips 5-15° SW, steepening adjacent to the fault in a sense of normal drag. The fault consists of a well-defined surface that possessed mullions and striations, and a 3 to 4 inch-wide zone of shearing in the footwall that contained pebbles aligned in a preferred orientation parallel to the fault. Isolated pebbles extended 1 to 2 inches into the hanging wall loess. A pinkish discoloration in the loess adjacent to the fault could be a sliver of Roxana Silt or could be the result of groundwater oxidation.

Numerous fractures occur in the hanging wall loess in proximity to the fault, diminishing rapidly beyond 2.5 feet. Figure 16 is an equal-area stereonet showing poles to fractures and a projection of the fault plane. The northwest-dipping fractures immediately adjacent to the fault and are interpreted as reidel shears. Their orientation and the direction of rake on the fault indicate northwest-southeast extension.

Numerous N60-70W-striking, near-vertical fractures containing silt and iron-manganese-oxide encrustations were found in the southeastern half of the Powerline Trench (profile 5). These occur in proximity to where a traceable bed of Roxana abruptly terminated. However, no

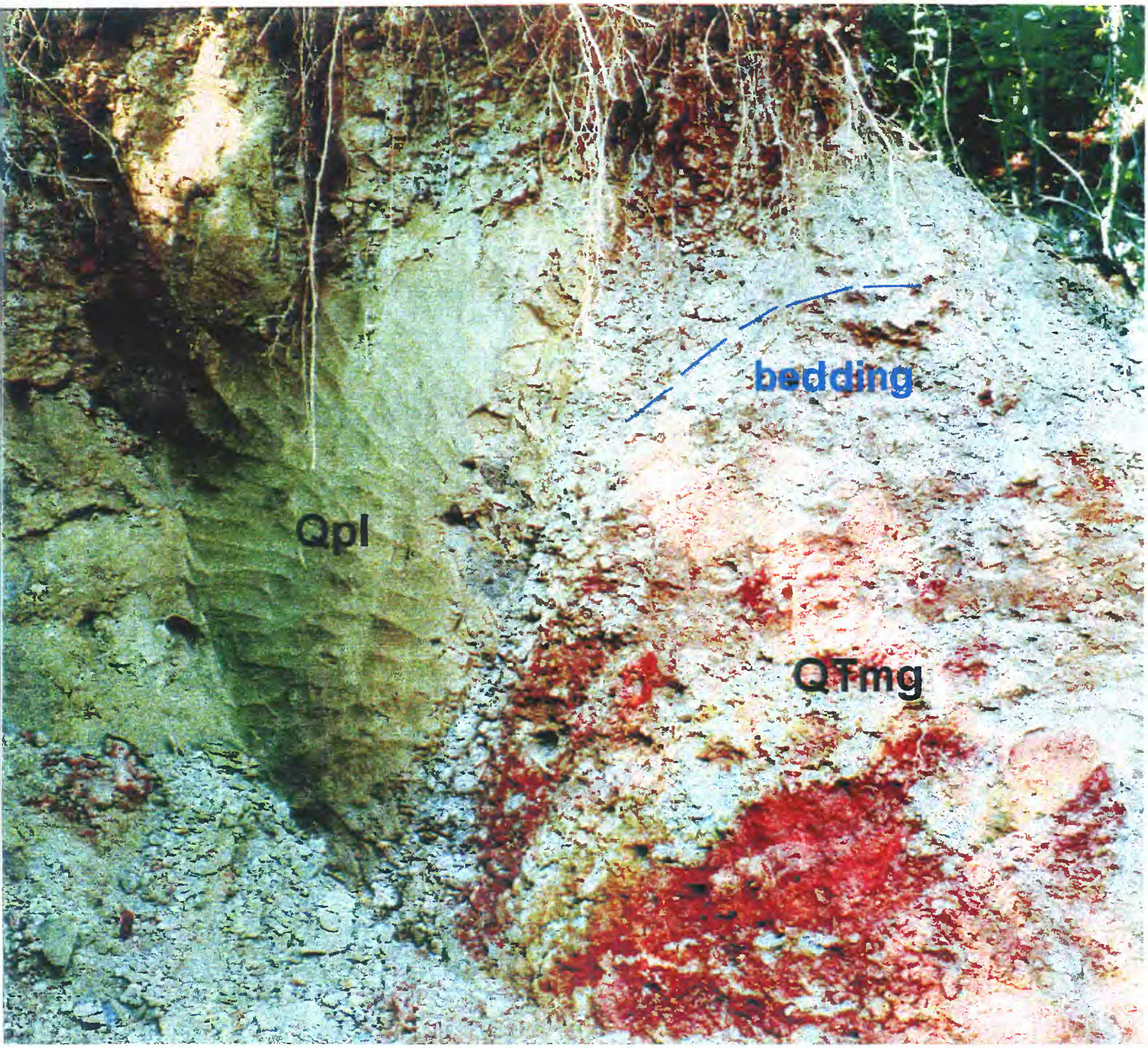


Figure 15. Powerline Trench- cut out looking westward; see Profile 5 for scale.

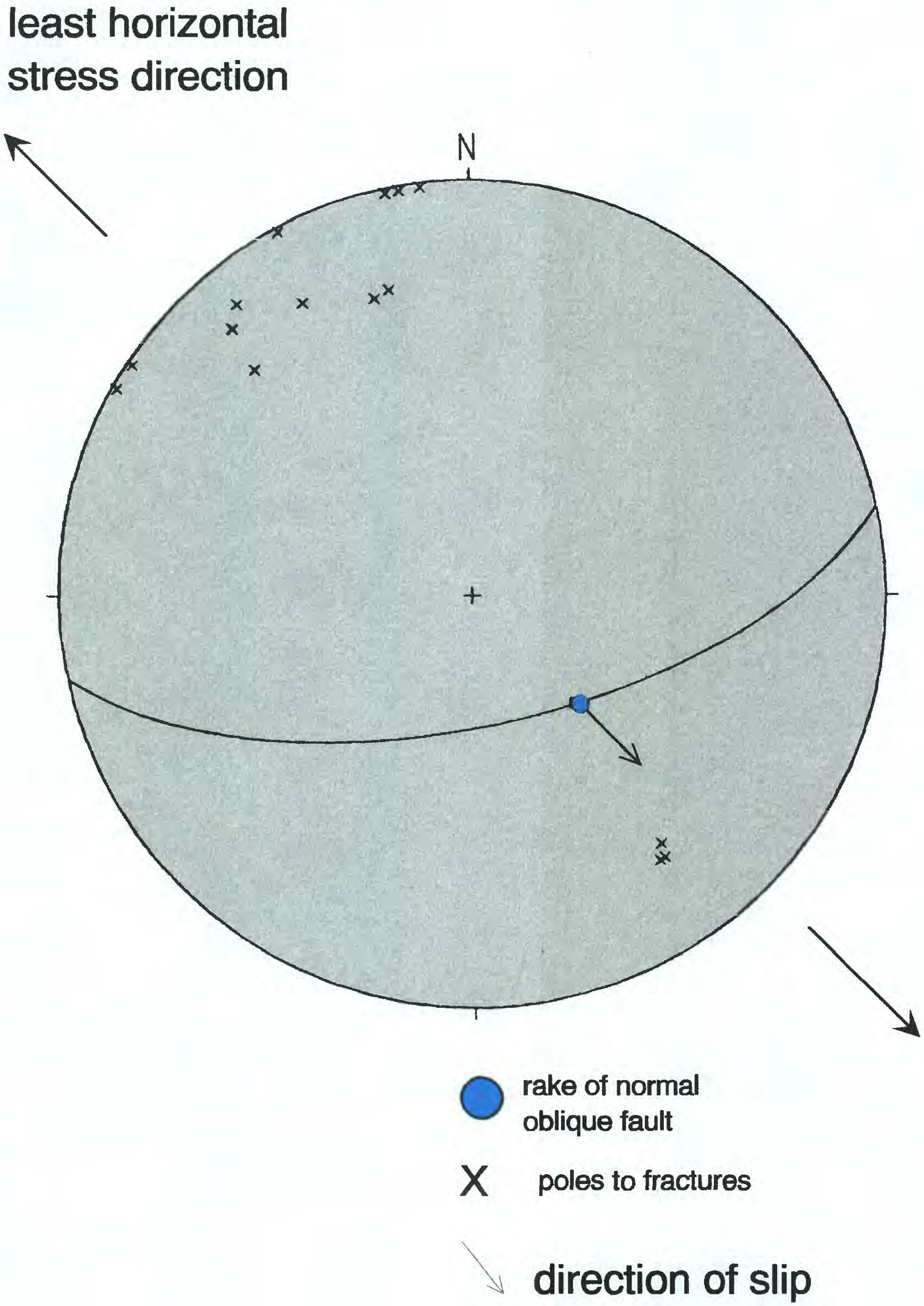


Figure 16. Powerline Trench- fault and fracture data.

definable surface or any other features could be discerned.

### Hillcrest Trench

The Hillcrest Trench was dug approximately 200 ft east of the Powerline Trench (fig. 4). The trench exposed one normal fault which offset Peoria Loess (probably reworked and in part colluvial) the unnamed Quaternary gravel 3, and Wilcox Group sand (profile 6). In the SW wall of the trench, the fault has an E-W to N85W strike and a dip of 57° S high in the wall, steepening to 84° SW low in the wall. In the floor of the trench the fault made a sharp dogleg to N45E with a dip of 60° SE. Slickenside striations on the E-W segment raked 60-75° W and on the N45E segment raked 90°(fig. 17).

Stratigraphic offset on the Quaternary gravel-Peoria contact is approximately 3 ft, and stratigraphic offset on the Wilcox-Quaternary gravel contact is approximately 8 ft. This suggests two episodes of faulting. An older episode that occurred after deposition of the unnamed Quaternary gravel 3 and prior to or during deposition of Peoria Loess, and a younger post-Peoria episode. It is important to note the differences between the stratigraphic section exposed in the Hillcrest Trench and that exposed in the Powerline Trench only 200 feet away. Mounds Gravel, Sangamon Geosol, and Roxana Silt are all absent from the Hillcrest Trench section and their position is occupied by the Quaternary gravel deposit which consists of reworked Mounds clasts in a silty and sandy matrix. This is interpreted to represent local uplift, erosion, and re-deposition in post-Roxana-pre-Peoria time or during early Peoria deposition.

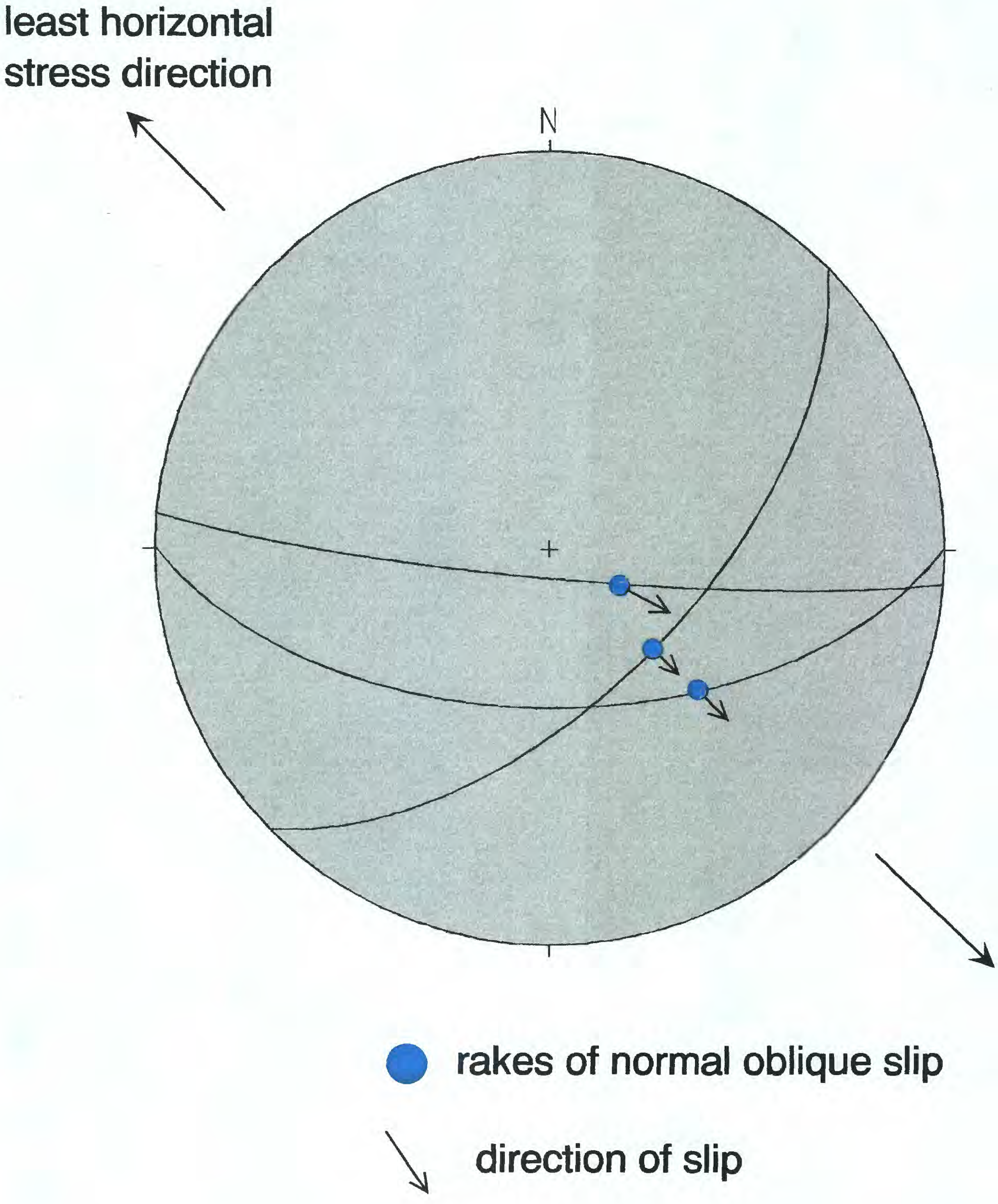


Figure 17. Hillcrest Trench- fault data.

## Upper Rainbow Trench

The Upper Rainbow Trench was excavated along the flank of a northerly trending ridge approximately 150 ft east of the Hillcrest Trench (fig.4). It was the longest trench dug for this project and divulged some of the most complex structures encountered in the English Hill area (profiles 7 & 8). This trench also revealed the most complete record of deformation at English Hill. From cross-cutting relations and stratigraphy, several episodes of faulting are recognized that include normal faults, strike-slip faults, and thrust faults. Reactivation of some faults is strongly suggested. A seismic reflection profile acquired parallel to the Upper Rainbow Trench (Palmer and others, 1997b) shows several high-angle faults, both normal and reverse, in the subsurface that offset the Paleozoic-Cretaceous contact. Unfortunately, this profile does not show reflectors in the Cretaceous-Cenozoic section.

For clarity of description, deformation similar in timing and style is considered an episode and numbered sequentially from oldest to youngest. Some episodes, such as 6, 7, and 8 probably form a continuum. And as discussed at the end of episode descriptions, episodes 7 and 8 can be interpreted as correlative.

### 1st episode

The oldest faulting observed in the Upper Rainbow Trench is Cretaceous in age. It is represented by conjugate sets of normal faults that are only found in the McNairy Formation. Strikes are in a general east-west direction and offsets are a few inches or less. Because of scale, these faults are not depicted on Profile 7 and 8. Similar microfaults in Cretaceous beds have been observed at many locations elsewhere in the Benton Hills and in southern Illinois (Harrison and others, 1996a; Nelson and Harrison, 1993).

### 2nd episode

An early Tertiary (Paleocene/Eocene) unconformity that is expressed as Wilcox Group resting directly upon Cretaceous McNairy Formation at a couple of locations in this trench indicates local uplift and erosion. Porters Creek Clay, which should be present between the these two units is 36.7 ft thick in drill hole BH-1 (see fig. 4 for location) approximately 400 feet to the west. The abrupt local nature of this unconformity is further demonstrated by exposures in the hanging wall and footwall of fault P. In the hanging wall, sand of the Wilcox Group rests unconformily upon McNairy Formation; the unconformity marked by an iron-cemented bed of gravel and sand (fig. 18) . It the footwall of this fault, about 4 ft of Clayton Formation, which is absent in the hanging wall, rests upon McNairy Formation.

Another expression of this unconformity occurs between faults D and E. There beds of the McNairy Formation strike N20E and dip 49° SE, and overlain by subhorizontal beds of the Wilcox Group.

### 3rd episode

Normal faulting of post-Mounds-pre-unnamed Quaternary gravel 3 age is indicated by the northwesternmost faults exposed in the trench- faults D and E on Profile 7. Fault D strikes N50W and dips 70° NE; it cuts only beds of the McNairy Formation and Wilcox Group, and is truncated by the Quaternary gravel. The clay-sand contact within the Wilcox Group is offset less than 1 foot, yet the contact dips steeply (~60°) towards the fault in the footwall. Fault E strikes N50E, dips 78° SE, and shows stratigraphic separation on the Wilcox-Quaternary gravel 3 contact of approximately 4 ft. However, the thickness of the Wilcox Group increases from approximately 4 ft in the footwall to approximately 22 ft in the hanging wall indicating post-Wilcox faulting and

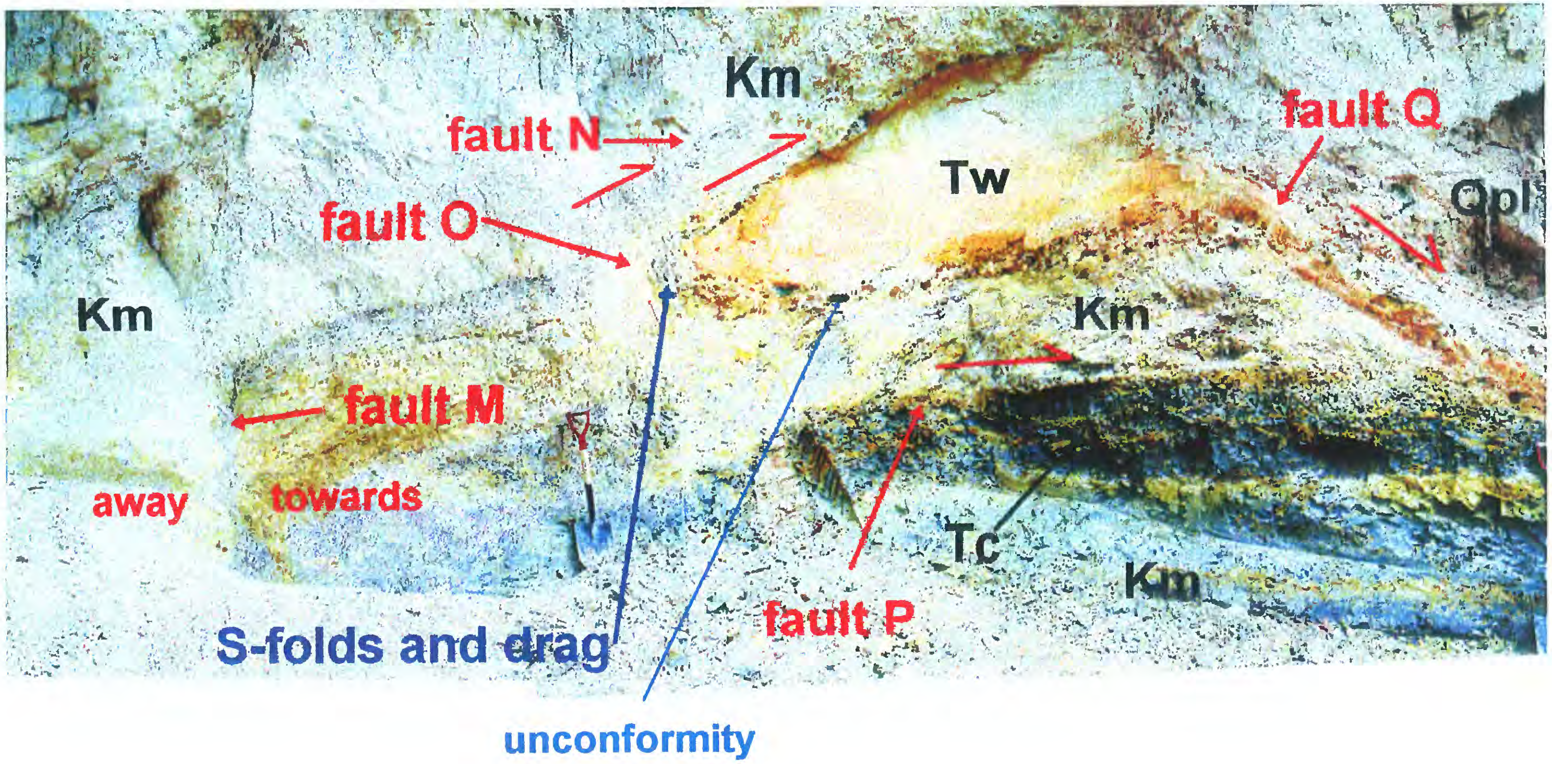


Figure 18. Upper Rainbow Trench.

erosion prior to Quaternary gravel 3 deposition. The fact that Quaternary gravel 3 was preserved on the erosional surface and not Mounds Gravel indicates that this faulting is post-Mounds.

No kinematic indicators were found in association with either of faults D or E, so they are assumed to be normal faults. As so, they can be interpreted as a conjugate set that formed under east-west extension (fig. 19). Other faults, exposed down trench to the southeast such as J, K, Q, Z, AA, AB, AC, AD, and AE, could also have been active during this period of faulting.

### 4th episode

Faulting contemporaneous to deposition of the unnamed Quaternary gravel 3 deposit is indicated by fault F which offsets the lower contact of the gravel and Wilcox Group, but not the upper contact of the gravel with Peoria Loess. Fault F strikes N50E and dips 78°NW. In the floor of the trench, fault F is cut off by fault G. No kinematic indicators were found in association to fault F so it is assumed be a normal fault. Fault Q was also possibly active during deposition of the Quaternary gravel 3, since its hanging wall thickness is approximately 8 ft and its footwall thickness is only 2 ft at maximum.

### 5th episode

Thrusting occurred along faults H, I (?), N, O, S, T, V, and X. All of these structures dip at low angles to the northwest and except for fault I place older units over younger. The youngest unit displaced by thrust faults in this trench is the Wilcox Group, however in the Lower Fence Line Trench (profile 9) Sangamon Geosol is involved in thrusting, in the Seismic Line Trench (profiles 11 and 12) the unnamed Quaternary gravel 1 is involved, and in the Tuesday Trench

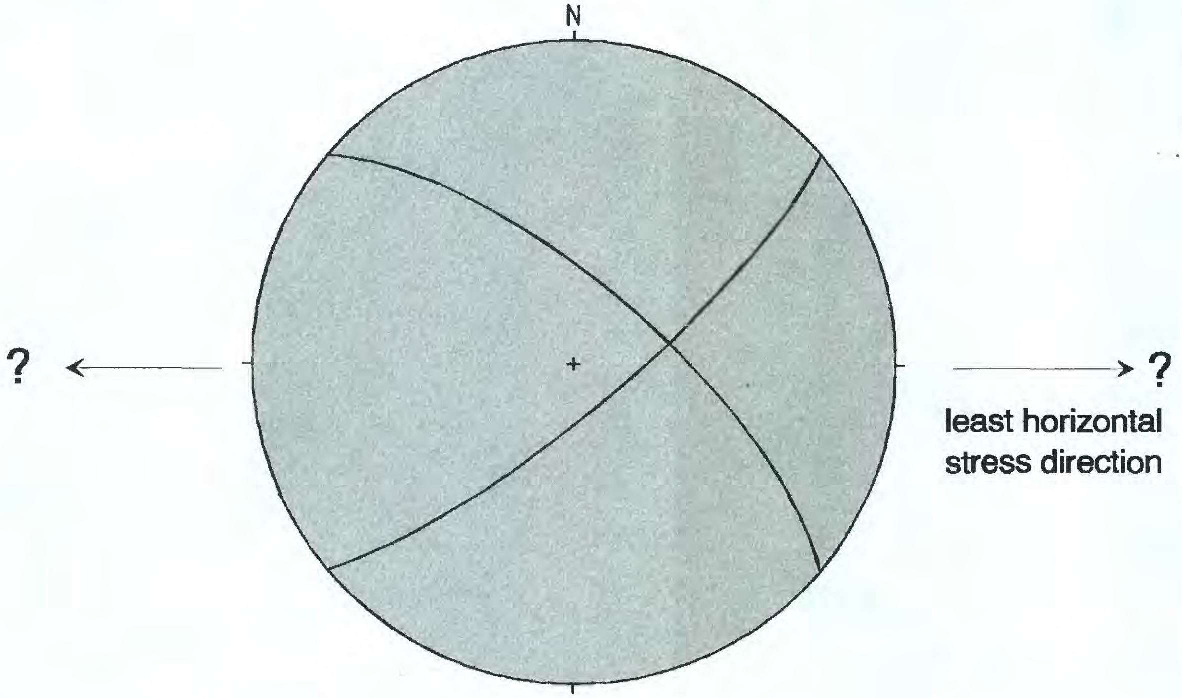


Figure 19. Upper Rainbow Trench- fault data for episode 3.

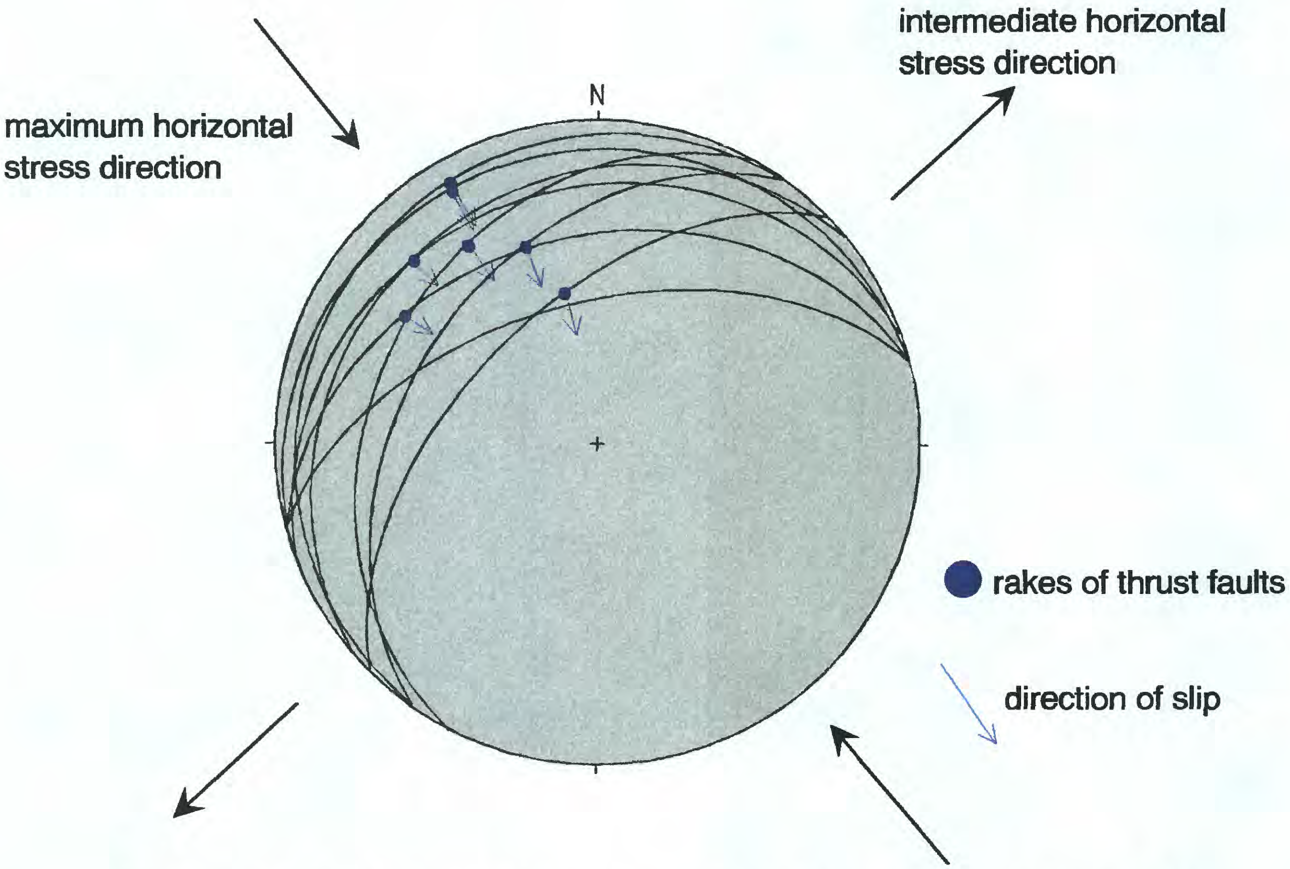


Figure 20. Upper Rainbow Trench- thrust fault data

(profile 13) Roxana Silt is cut by strike-slip faults believed to be part of this episode. At some places in the Upper Rainbow Trench, normal faults of the 3rd and 4th events are truncated by thrusts.

In the footwall of fault O, S-folds in the McNairy Formation and drag on the unconformity between the McNairy Formation and Wilcox Group indicate top-towards-S35E motion which is consistent with slickenside striations observed on the thrusts (fig. 20).

### 6th episode

A post-Roxana and pre-Peoria or syn-early Peoria episode of faulting on fault Q is indicated by the presence of about 4 ft of Roxana Silt in the hanging wall and an absence of Roxana in the footwall. A TL age of 31.8 ± 3.0 ka (table 1) confirms the field identification of Roxana in the hanging wall. A TL age from the base of the loess sequence in the footwall is pending.

### 7th episode

Faults E, G, and Q define the 7th episode as normal faulting that involves Peoria Loess. The field identification of Peoria Loess is confirmed by a TL age of 17.0 ± 2.7 ka (table 1) near the base of this unit in the hanging wall of fault Q (see profile 8 for sample location). This age date also provides a conservative maximum age constraint for this faulting episode. Near the northwestern, uphill end of the Upper Rainbow Trench, faults E and G bound a nearly symmetrical graben that down drops Peoria Loess approximately 4 feet. Near the center of the trench, fault Q is the master fault for an asymmetrical half graben which down drops Peoria Loess approximately 50 to 60 feet. Fault Q can be traced all the way to the present day erosional surface where a 2.5 to 3 ft scarp, or break in slope, occurs. Kinematic indicators provided by slickenside striations and sense of displacement indicate that this faulting episode is the result of northwest-southeast extension (fig. 21).

Faults AE and AF at the lower (southeast) end of the trench are also believed to be part of episode 7 deformation. Fault AE zig-zags from N80E to N80W, dips to the south from 29° to 60°, and slickenside striations indicate a pure dip-slip rake of 90°. This fault extends to the present day surface where a small 1 ft-high scarp occurs. A 2 to 4 inch-thick zone of fine- to medium-grained quartz sand, rimmed with clay film, and mica occurs along the fault surface. Fault AF strikes N75W, dips 57°NE, and is antithetic to and truncated by fault AE.

Along the trench profile these two faults form a v-shaped graben that is filled with unsorted colluvial material (micaceous silt, loess-like silt, fine- to medium-grained quartz and glauconitic sand, pebbles, and cobbles as much as 2 inches in diameter) derived from all of the other Cretaceous and Cenozoic units exposed in the trench. The colluvial material is approximately 6 to 7 ft thick and extends to the surface. There is a gross stratigraphy in the colluvial material in that glauconite is abundant in the lowermost 2 ft and virtually absent in the upper 4 to 5 feet, and gravel clasts are rare in the lowermost 2 to 3 feet becoming more abundant upward. Slickensided fracture surfaces are very abundant throughout the the colluvial material.

Subsequent trenching (after preparation of profile logs) approximately 17 ft into the hillside provided additional exposures of the colluvial-wedge deposit. This deposit was laid down against a scarp along fault AE. Adjacent to the fault, the deposit consists of above 8 ft of dominantly gravel, sand, and minor silt. It fines outward, away from the fault, to sand and silt.

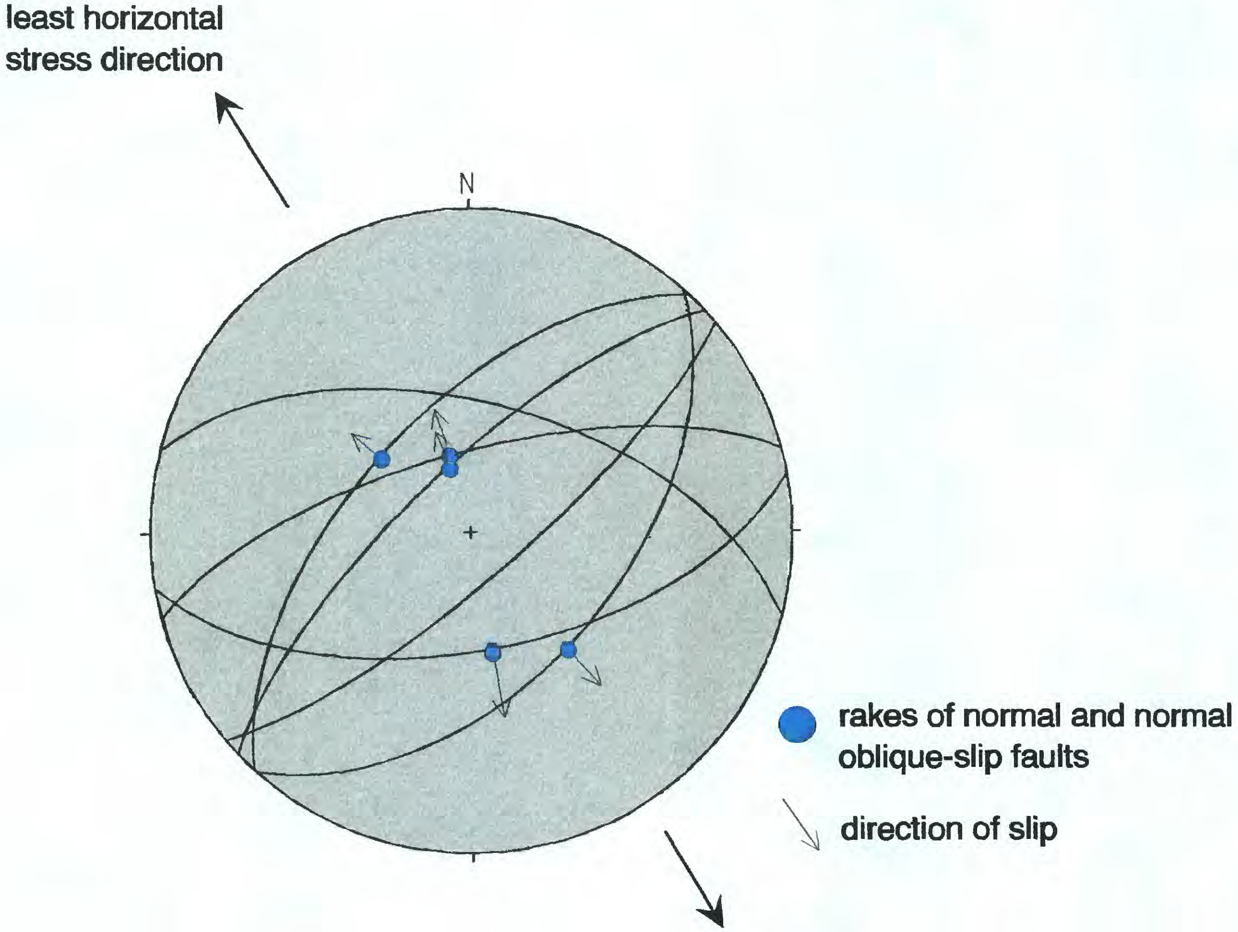


Figure 21. Upper Rainbow trench- episode 7 fault data.

Fault AF on Profile 8 juxtaposes the coarse proximal material against the distal fine material.

Charcoal is common throughout the colluvial material. Radiometric $^{14}C$ age dates (table 2) on eight pieces of this charcoal are strongly bimodal: 4980 ± 60 yrs, 4740 ± 50 yrs, 4920 ± 60 yrs, and 4780 ± 50 yrs; 1310 ± 60 yrs, 1220 ± 50 yrs, 1240 ± 50 yrs, and 1210 ± 50 yrs. Within the graben, these two groups are segregated by an obscure, near-vertical boundary, such that the older (4740-4980) charcoal pieces are found down hill from the younger (1210-1310) pieces. A TL age of 18.4 ± 2.2 ka was obtained from the lower third of the colluvial material (table 1). This indicates that most of the silt in the colluvial material was derived from Peoria Loess and it was not re-exposed to sunlight long enough to reset the luminescence signal, ie. the colluvium was rapidly deposited.

### 8th episode

The 8th episode is defined by strike-slip faulting on faults L, M, and U. Faults L and M have northeasterly strikes, steep dips, and merge upward (profiles 7 and 8). Mullions and striations on both faults indicate subhorizontal movement. Fault U is a vertical structure that strikes N35E and branches upward into a network of dipping faults, forming a classical flower structure (fig. 22). Mullions and striations on the vertical segment and the branches indicate subhorizontal movement.

From cross-cutting relations between strike-slip fault M and thrust faults N and O (see profiles 7 and 8, and fig. 18), and strike-slip fault U and thrust fault T (fig. 22) in this trench,

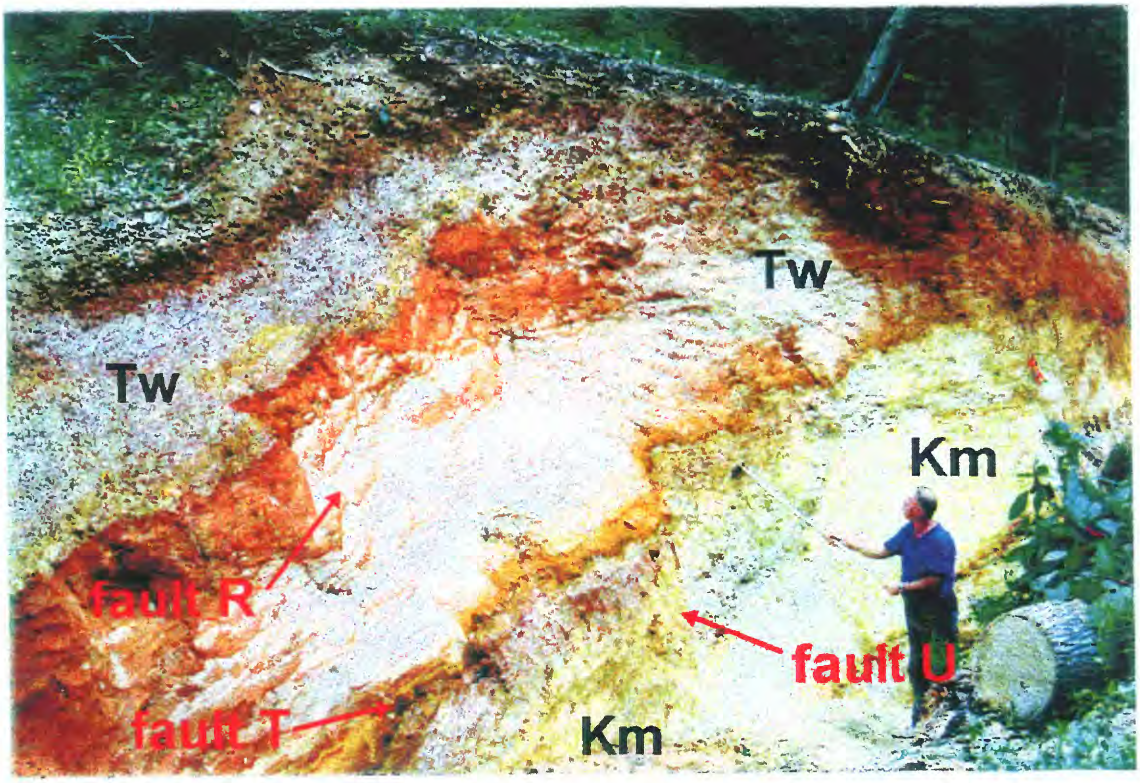


Figure 22. Upper Rainbow Trench

strike-slip faulting is known to be younger than the thrust faulting (5th episode). From exposures in the Seismic Line Trench (profiles 11 and 12) and Tuesday Trench (profiles 13 and 14), strike-slip faulting is known to cut Peoria Loess. The relative age relationship between the 7th and 8th episodes is not straightforward as to which occurred first or if they were concurrent.

Scallop-shaped structures on fault surfaces and the vergence direction of subsidiary shears indicate right-lateral displacement under a northeast-southwest-oriented maximum horizontal stress direction (fig. 23). Piercing points are lacking, therefore the precise amount of displacement is unknown. However, the mismatch of stratigraphy across fault U (profile 8 and fig. 22) suggests at least several tens of feet of displacement.

### Discussion/Interpretation of episodes 7 and 8

It is our interpretation that episodes 7 and 8 are probably one and the same. The basis for this interpretation is twofold. 1) They have similar stress orientations (figs. 21 and 23) indicating that the styles and orientations of faulting are compatible. 2) Structural features related to faults Q and U are best explained when the faults are considered coeval. Tertiary and Quaternary beds in the hanging wall of fault Q are rotated to about 30° dips, but only as far as fault U, where they abruptly flatten out. The Cretaceous-Tertiary contact immediately southeast of fault U on Profile 8 does not show the same rotation as contacts between faults Q and U. Furthermore, the contacts between units in the hanging wall of fault Q strike N60-70E, at an acute angle to the N42E-striking fault Q. This is somewhat inconsistent with what would be expected in the hanging wall of a normal listric fault, where bedding attitudes should be parallel to fault strike. The implied clockwise rotation is consistent with right-lateral strike-slip motion on fault U.

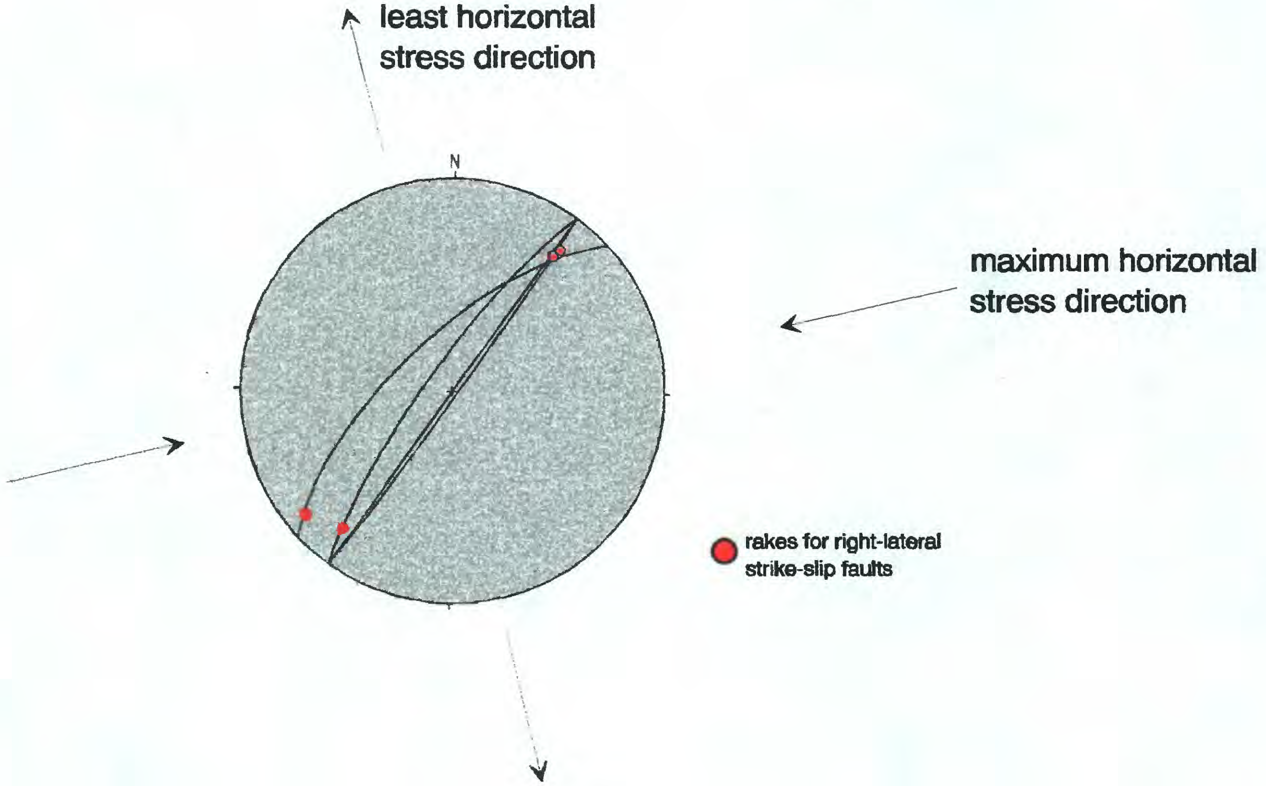


Figure 23. Upper Rainbow Trench- event 8 fault data.

Our proposed model for linking coeval strike-slip faulting on faults L, M, and U to normal faulting on fault Q is illustrated in Figure 24. In this model fault Q is a transtensional structure that developed in an area of extension between strike-slip faults L-M and U. Also note that it is impossible to balance the cross section in Figure 24- a characteristic of strike-slip deformation.

The colluvial material in the graben bound by faults AE and AF is of upmost significance to this study. This is the only material found in all of the English Hill trench sites that offers the potential to date individual surface-rupturing events. Subsequent trenching confirms this material to be a colluvial wedge deposit that formed at the toe of a fault scarp along fault AE. The ages of charcoal contained within this deposit provide maximum constraints on two recent fault events: one which occurred just after 4740-4980 $^{14}$C years BP (Calendar Years- 3389 to 3899 BC), and one just after 1210-1310 $C^{14}$ years BP (Calendar Years- 662 to 888 AD).

9th episode

The fact that the colluvial wedge deposit containing charcoal is itself faulted indicates the occurrence of yet another fault episode, the most recent indentified at English. Movement along fault AF is interpreted as part of this episode. No kinematic indicators were found on fault AF, so it is assumed that this N75W, 57° NE-dipping structure is the result of north-northeast- to south-southwest-extension. This episode prossibly corresponds to similar-oriented faulting exposed in the Bollinger, Old Quarry, Uncle John, and Upper Fence Line trenches.

## Lower Fence Line Trench

The Lower Fence Line Trench was excavated approximately 150 ft east of the upper end

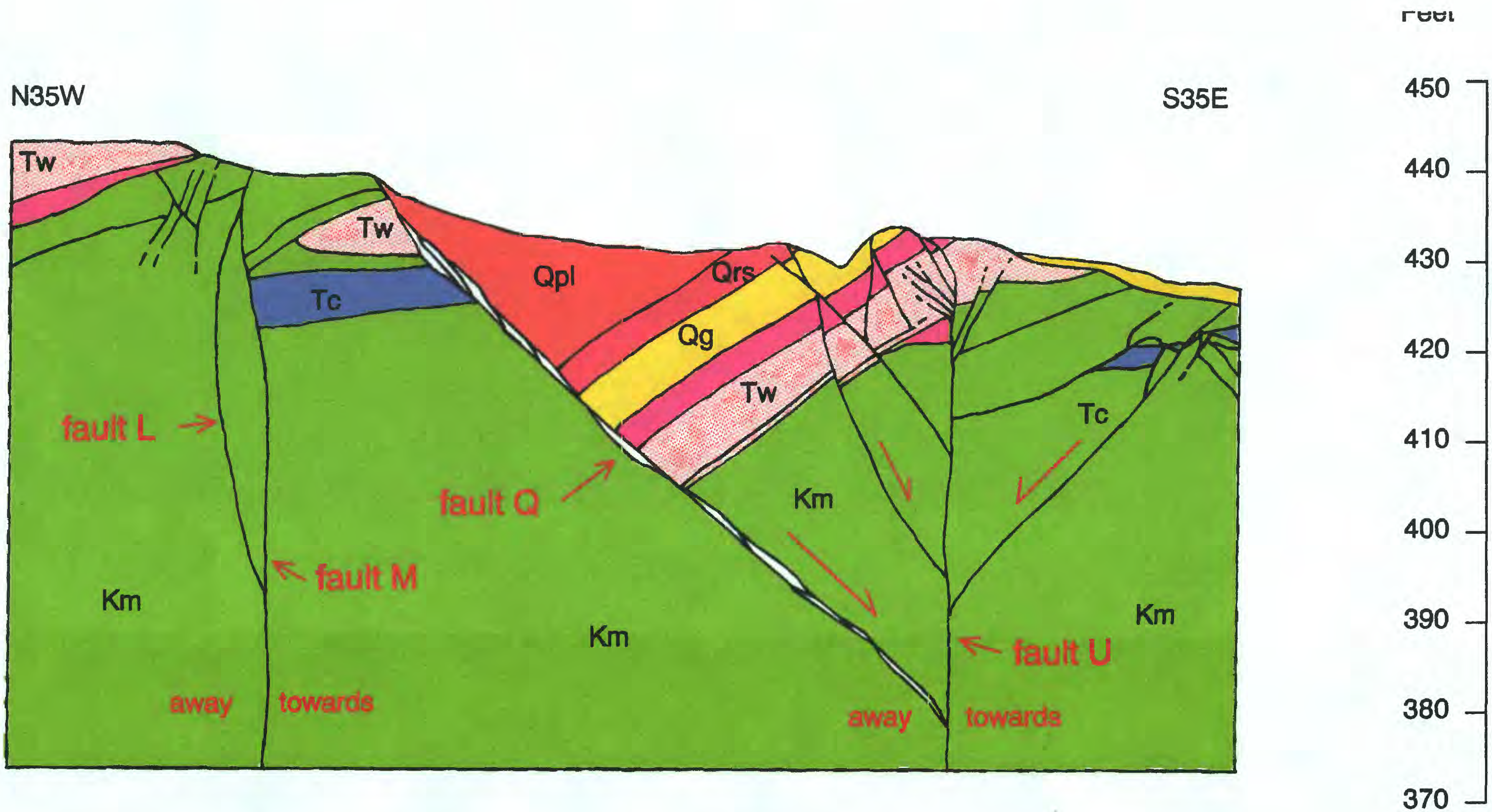


Figure 24. Interpretation of structural relationships between strike-slip faults L, M, and U, and transtensional normal fault Q in the Upper Rainbow Trench, units are the same as in Profiles 7 and 8 in appendix A. McNairy Formation is undivided.

of the Upper Rainbow Trench (fig. 4). The trench exposes a single thrust fault striking N35E, dipping 10-40°NW (profile 10), and on strike with thrust faults in the Upper Rainbow Trench. The fault surface was poorly defined and no striations or mullions were observed. Beds of the Porters Creek Clay, striking N25W and dipping 20°NE, were thrust over the unnamed Quaternary gravel 1 deposit which consists of colluvial silt and gravel deposits with a red clay matrix that had been modified by the Sangamon Geosol. Recent surface colluvial material is unfaulted.

The occurrence of Porters Creek Clay is significant because it helps define the extent of the area where this unit is absent, presumedly from uplift and erosion during the Eocene (pre-Wilcox). Figure 25a shows the known area of no Porters Creek. This area may extend further to the southwest, as there is no subsurface data in that direction.

### Upper Fence Line Trench

The Upper Fence Line Trench was excavated about 13 ft uphill and to the northwest of the Lower Fence Line Trench (fig 4). No faults were found in this trench (profile 10). However, closely spaced N55-60E fractures were observed cutting Roxana Silt and Peoria Loess.

Several examples of stratigraphic relationships and the attitudes of contacts imply structural deformation. 1) The absence of Mounds Gravel in this trench further delineates the area of its removal by erosion. Figure 25c shows this area of no Mounds Gravel at English Hill. This is interpreted as as a local area of uplift prior to deposition of Roxana Silt. 2) Comparison of the stratigraphic position of the gravel deposit exposed in this trench with the unnamed Quaternary gravel 1 deposit in the nearby Lower Fence Line Trench shows that they are different units. The gravel in this trench is interpreted to be the unnamed Quaternary gravel 2 unit since it underlies Roxana Silt. Uplift and erosion in post-Sangamon and pre-Quaternary gravel 2 time is indicated and possibly the same as the erosional event that removed Mounds Gravel. 3) The Sangamon Geosol is absent in this trench, but well-developed only 10 ft away in unlogged shallow excavation pits. From the trench profiles presented in this report, other (unpublished) data accumulated by the Missouri Department of Natural Resources, Division of Geology and Land Survey, and surface mapping, the extent of Sangamon Geosol removal can be fairly accurately mapped as an elliptical-shaped region near the center of the English Hill area (fig. 25c). 4) The contact between the unnamed Quaternary gravel 2 and Roxana Silt and Peoria Loess strikes N40W and dips 25°NE. This suggests structural rotation in post-Peoria time.

### Seismic Line Trench

The Seismic Line Trench was excavated approximately 350 ft southeast of the Fence Line Trenches (fig. 4). Illustrations of the northwestern wall of this trench are shown in Profiles 11 and 12 (appendix A). As in the Upper Rainbow Trench, several episodes of complex faulting were found in the Seismic Line Trench.

The oldest faulting is a sequence of NE-striking, NW-dipping thrust faults. These faults were observed cutting the McNairy Formation in the southwesternmost portion of the trench. Asymmetrical folds (fig. 26) and slickenside striations indicate dip slip towards the southeast (fig. 27). Because of similar orientations and proximity, these thrust faults in the Seismic Line Trench are interpreted as being correlative to episode 5 faulting seen in the Upper Rainbow Trench.

Several faults are recognized in the Seismic Line Trench that are younger than the thrust

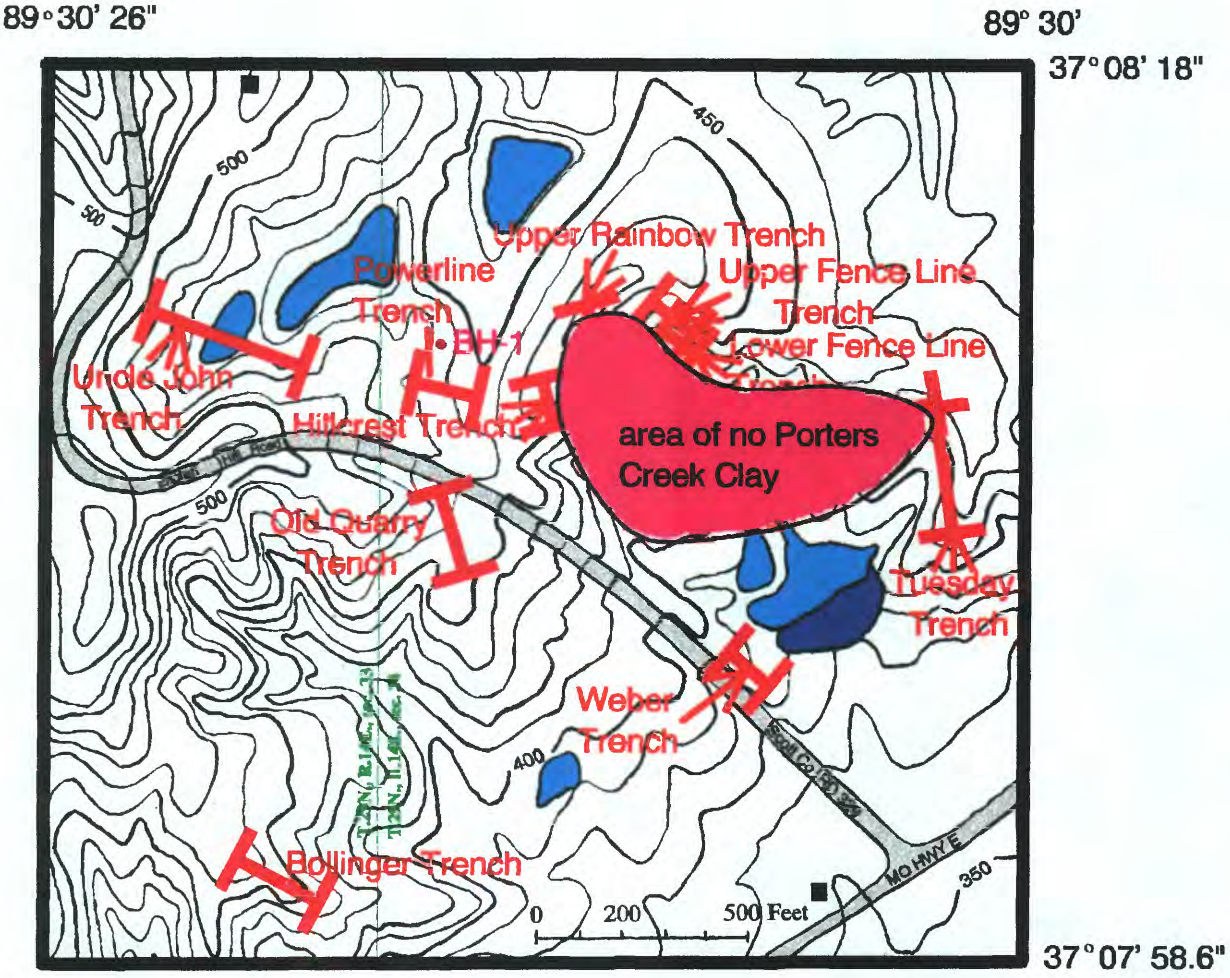


Figure 25a. Portion of the English Hill area were Porters Creek Clay has been removed by pre-Wilcox erosion.

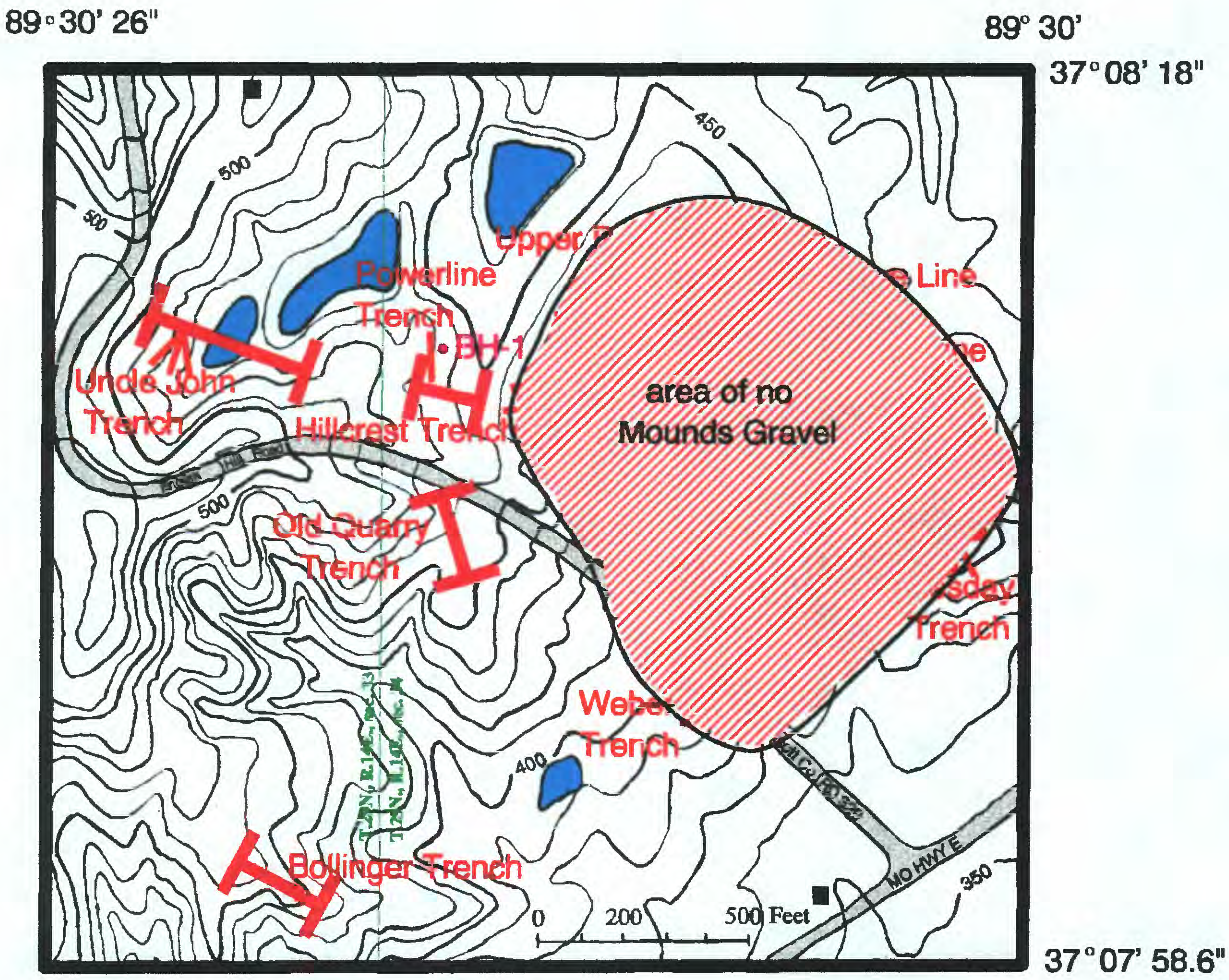


Figure 25b. Portion of English Hill area were Mounds Gravel has been removed by pre-Sangamon or pre-Roxana erosion.

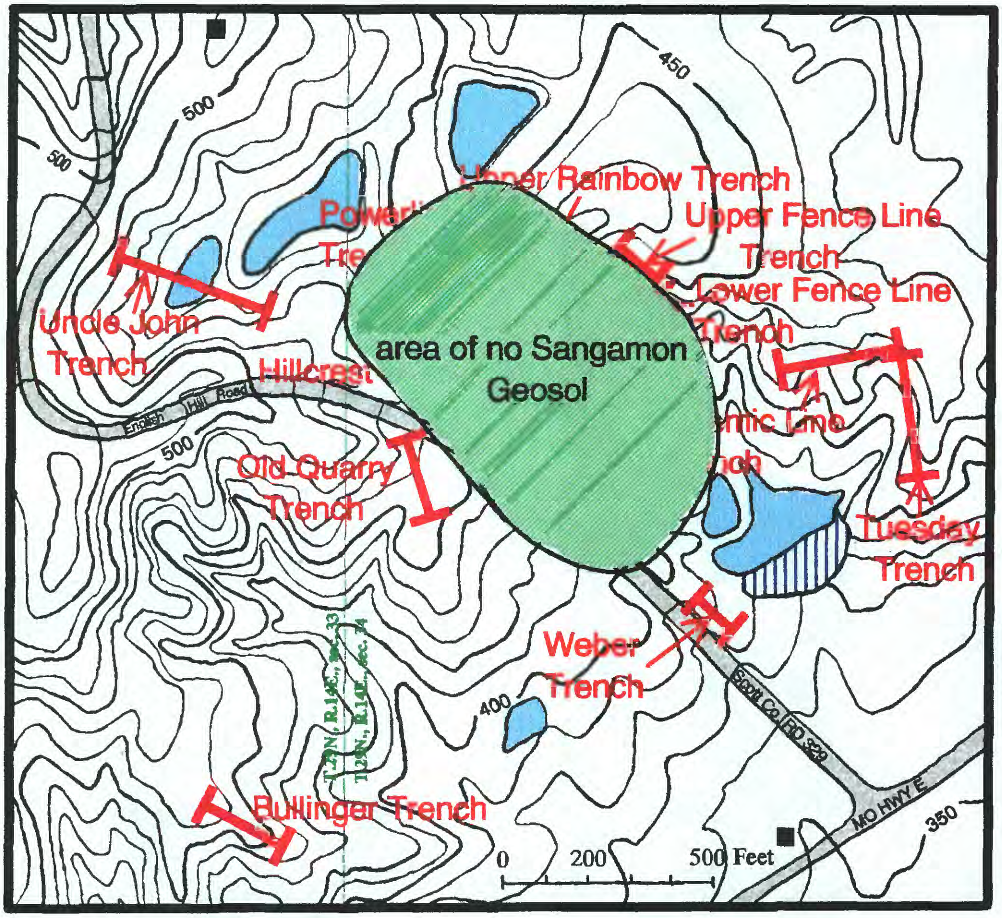


Figure 25c. Portion of the English Hill area were Sangamon Geosol has been removed by pre-Roxana erosion.

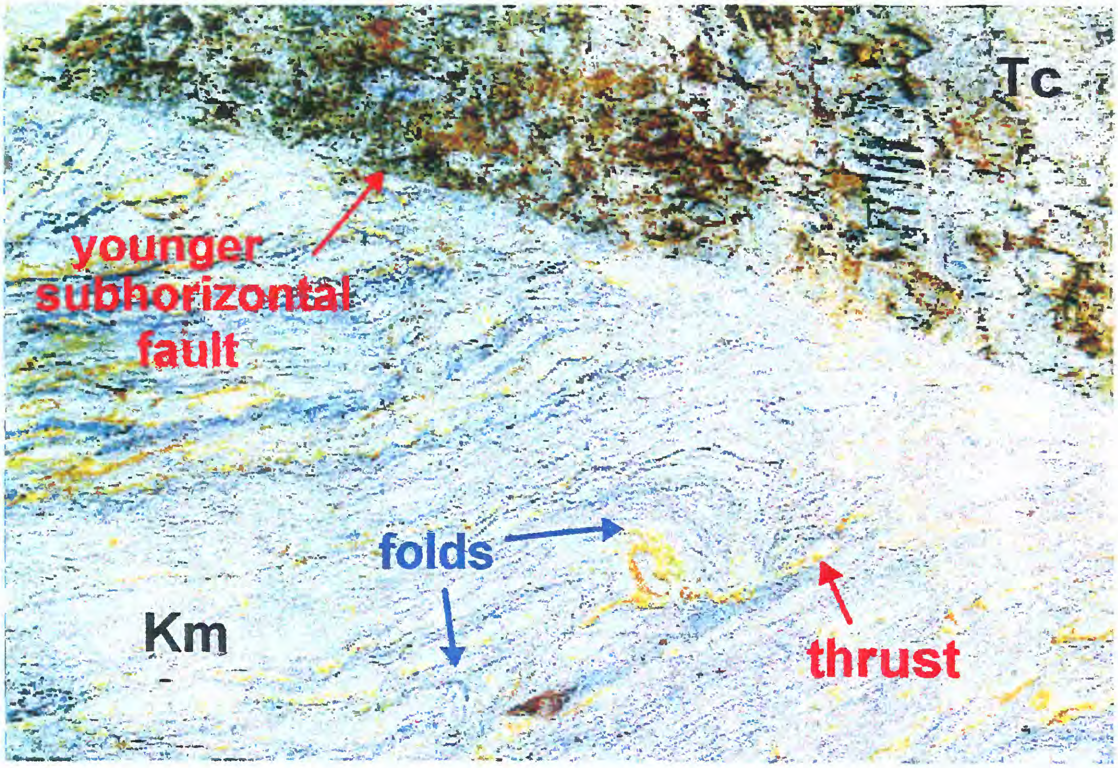


Figure 26. Seismic Line Trench- asymmetrical fold in hanging wall of thrust faults.

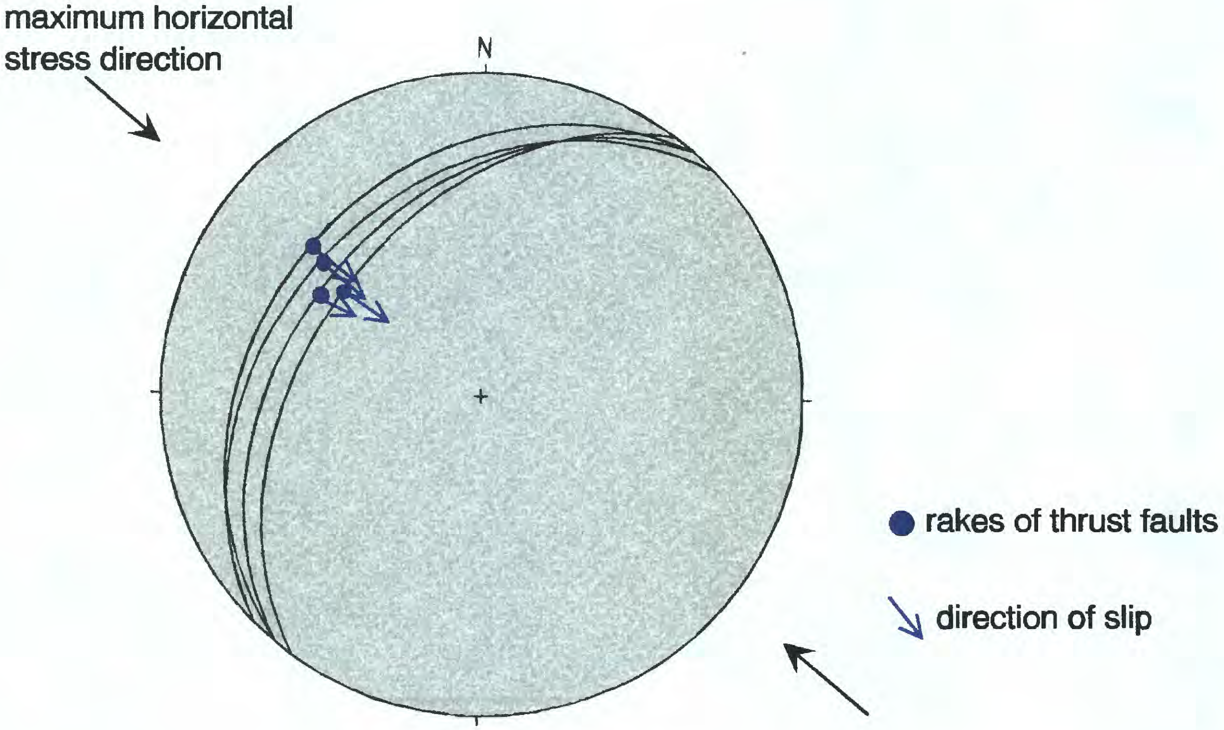


Figure 27. Seismic Line Trench- thrust-fault data.

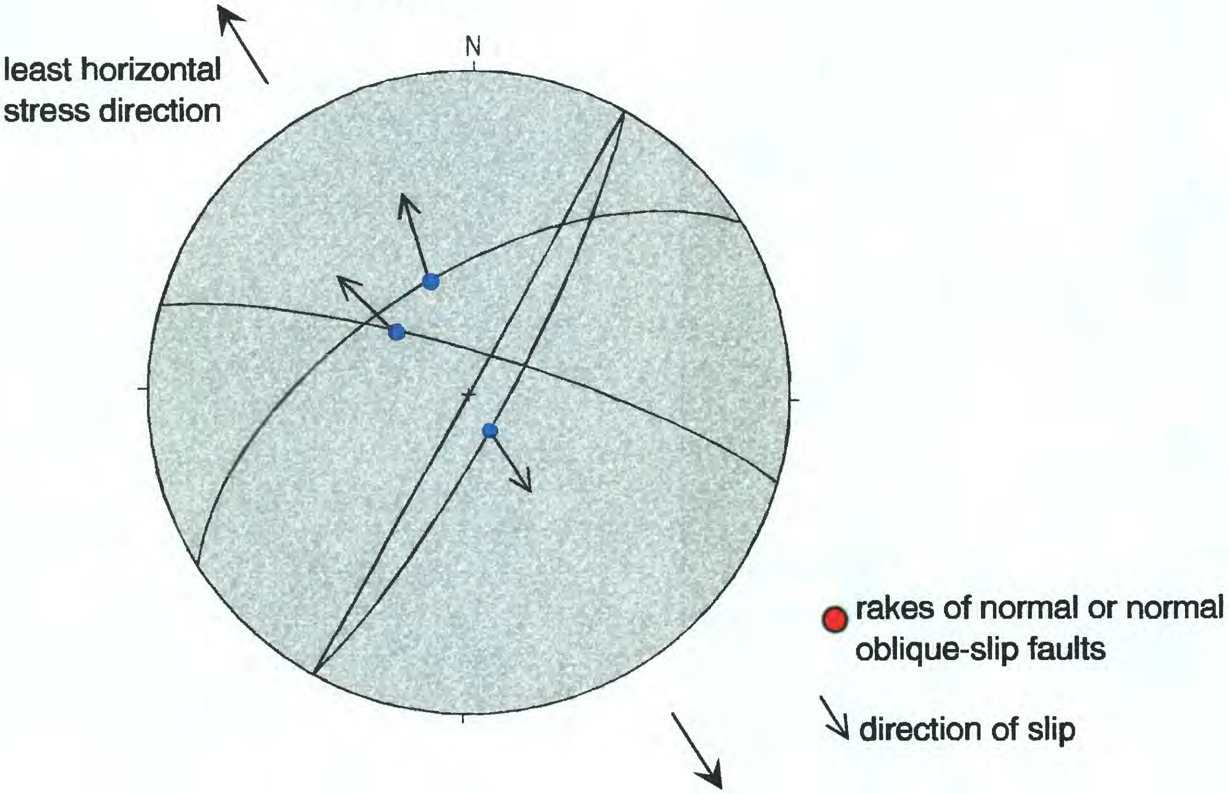


Figure 28. Seismic Line Trench- normal-fault data.

faulting. These younger faults display complex relationships with each other and occur as normal faults produced by northwest-southeast extension; a northeast-striking, right-lateral strike-slip fault; and R shears, R' shears, and P shears related to the right-lateral strike-slip fault.

The normal faults are represented by faults AL (actually two faults), AO, AP, and AQ. Kinematic indicators provided by fault-surface striations on the normal faults indicate northwest-southeast extension (fig. 28). Normal fault AQ (profile 12) displaces the Roxana-Peoria contact and at several locations the normal faults are truncated by strike-slip faults. It is therefore interpreted that the normal faulting in this trench is correlative to episode 7 faulting observed in the Upper Rainbow Trench, based on similar timing and strain.

Fault AM is the principal strike-slip fault occurring in this trench. It is best described as a roll-over structure, in that it is concave downward, steepening with depth (see profiles 11 and 12). The steepening with depth along fault AM is not readily apparent from Profile 12 because of the acute angle between the trench and the fault. Figure 29 is a view looking to the northeast along the Seismic Line Trench and along strike of fault AM. In the floor of the the trench in this figure, fault AM strikes N55E and dips 85°SE; in the wall, it flattens to as low as 10°SE dip. Slickenside striations and steps along the fault surface indicate right-lateral motion along fault AM. Fault AM truncates normal faults AO andAP (profiles 11 and 12), and offsets units as young as Sangamon Geosol.

Several structures observed in the Seismic Line Trench are interpreted as antithetic (R') shears, synthetic (R) shears, and P shears that formed in conjunction with right-lateral slip along fault AM. Northwest-striking faults AR and AS, both of which have horizontal or subhorizontal slickenside surfaces and cut Peoria Loess, are interpreted as left-lateral R' shears. Figure 30 is a

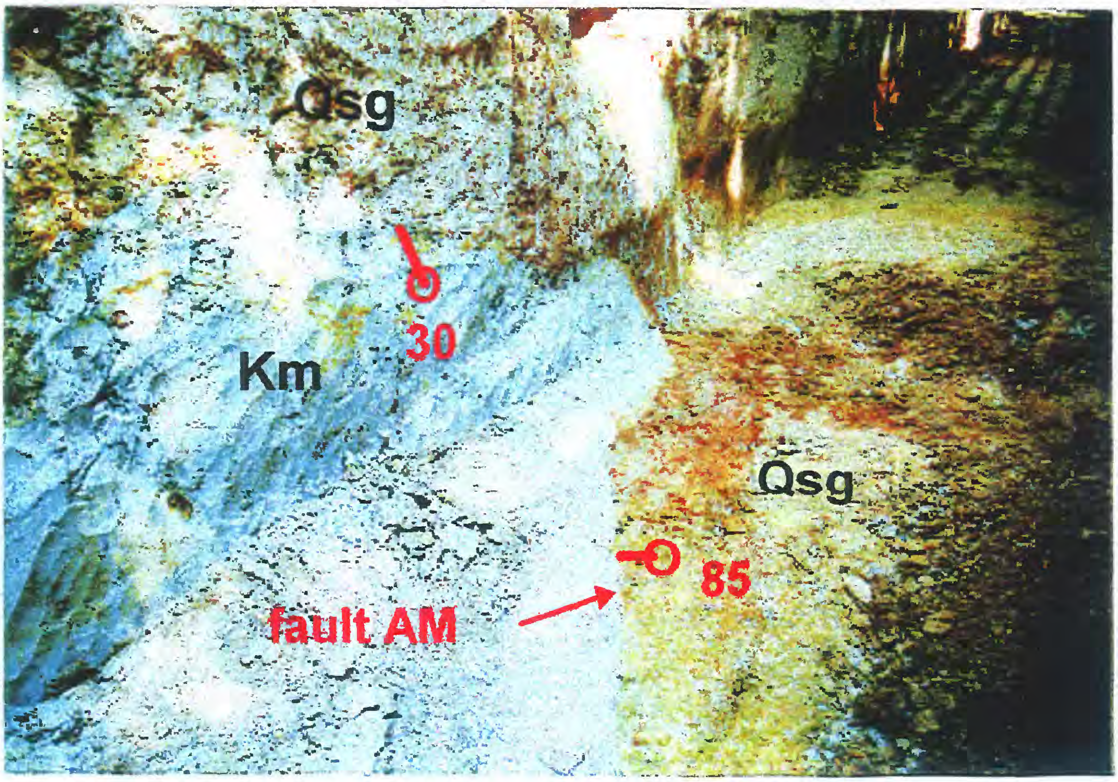


Figure 29. Seismic Line Trench-view towards northeast, down strike of fault AM; fault dip indicated by bar and ball symbols and numbers.

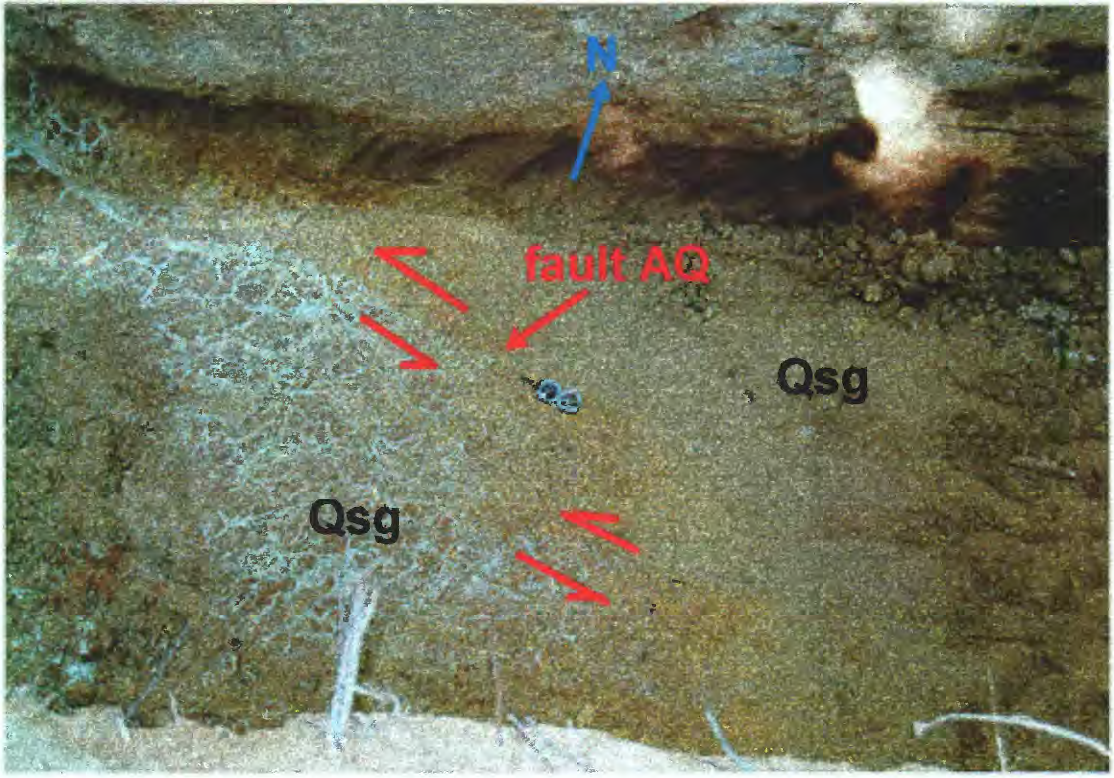


Figure 30. Seismic Line Trench- view looking down on fault AQ and unnamed parallel fault, arrows indicate relative displacememt.

view looking down at the floor of the Seismic Line Trench at fault AQ and an additional parallel R' shear. Respectively, there is approximately 2 ft and 1.5 of left-lateral displacement of mottled, polygonal patterns in the Sangamon Geosol. The northwest-striking fractures mapped on Profile 12 in the eastern portion of the trench are also probably R' shears, although no striations or offsets were observed.

The west-northwest-striking fault AG (profile 11) is interpreted as a synthetic R shear to fault AM. Fault AG has subhorizontal slickenside striations, displays a concave downward, or roll over, characteristic, and truncates older normal faults. The northerly striking fault AN is interpreted as an antithetic P shear to fault AM. Fault AN has slickenside striations that rake 10° SW and side-wall rip outs indicating a left-lateral motion.

Figure 31 is an equal-area stereonet projection of the strike-slip fault data described above. A Reidel model of right simple shear for this data indicates a west-northwest-east-southeast maximum-horizontal-stress direction for this faulting (fig. 32). The relatively high $\phi/2$ angle (angle between R and PZD) is attributed to unconsolidated nature of the faulted sediments and a corresponding low coefficent of friction.

### Tuesday Trench

The Tuesday Trench was excavated from the eastern end of the Seismic Line Trench at approximately 90 degrees (fig.4) and revealed the most complex faulting found in the English Hill area (profiles 13 and 14). An assortment of strike-slip, normal, and thrust styles were observed on the faults, and reactivation of many structures was indicated. Fault strikes are dominantly north to northeast, although several northwest strikes also occur (fig. 33). The evaluation of fault

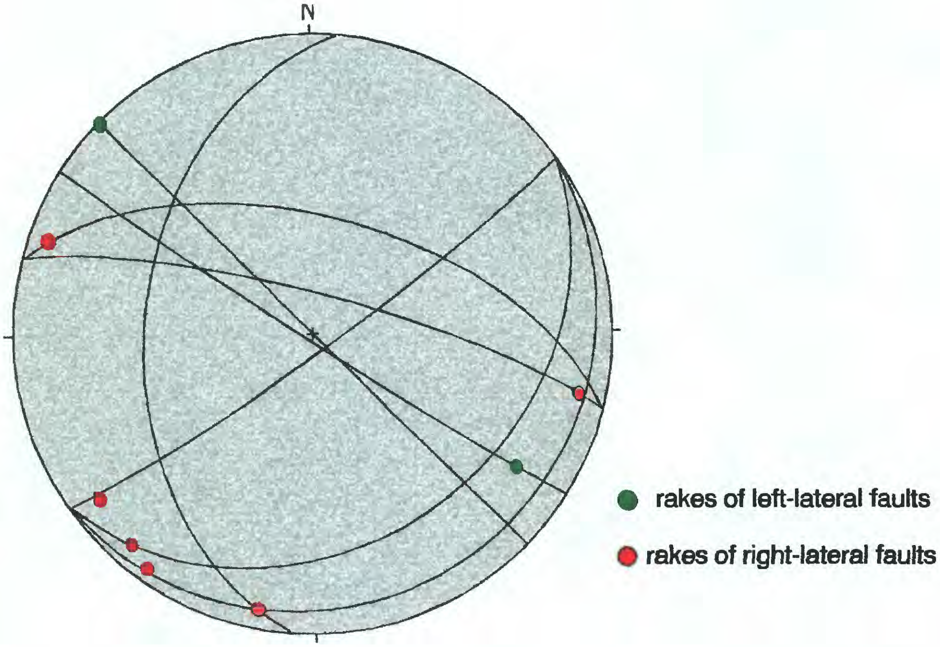


Figure 31. Seismic Line Trench- strike-slip fault data.

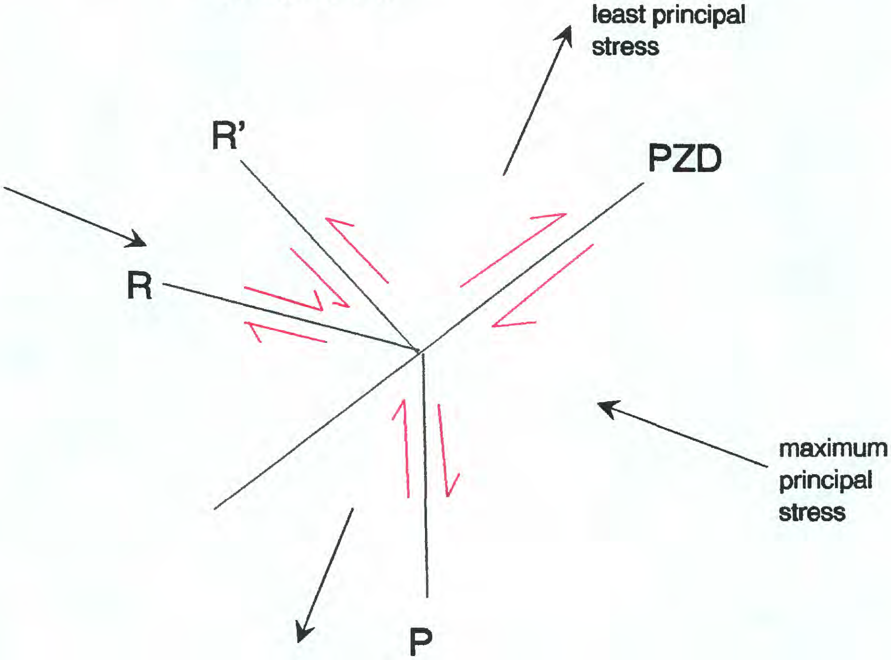


Figure 32. Reidel model of right simple shear for strike-slip data ffom Seismic Line Trench, N55E principal zone of displacement (PZD)

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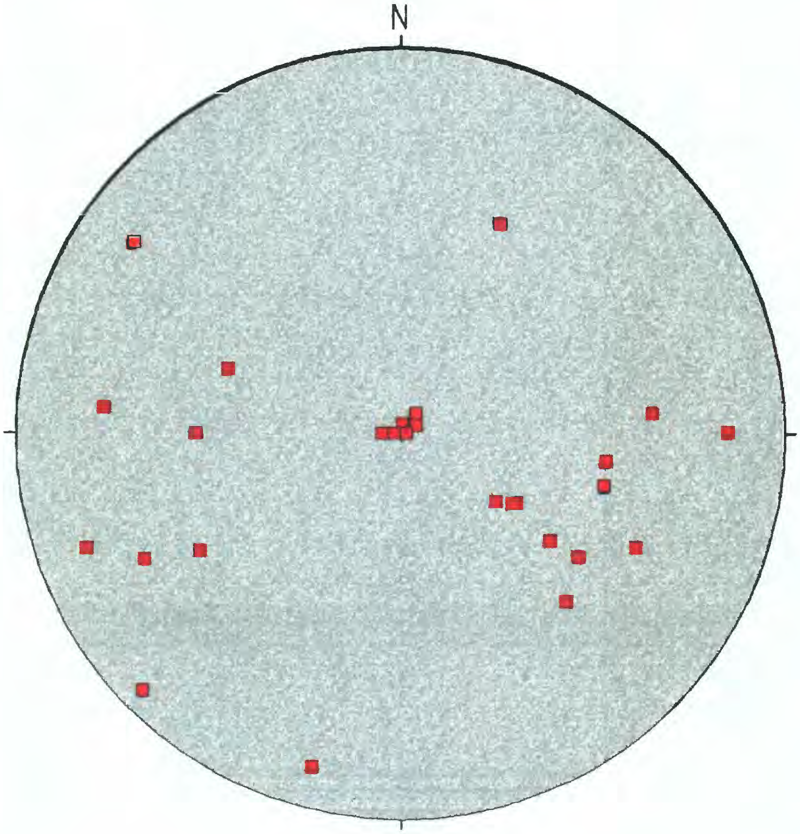

Figure 33. Tuesday Trench- poles to all faults.

episodes in this trench is not straightforward, therefore interpretation is presented after the description of the better documented major structures.

Fault AY has a northerly strike and a steep western limb which dips from 45-50° W, rolling over to subhorizontal to the east (see profile 13 and fig. 34). A subhorizontal (about 4° N) rake on the steep limb is indicated by slickenside striations and mullions. From carrot-shaped scours along the fault surface of the steep limb, a left-lateral strike-slip motion is interpreted. This is supported by a sinistral vergence direction between Reidel (R) and Reidel prime (R') shears and the fault (fig. 35). Along strike to the south, in the wall opposite to the wall logged in Profiles 13 and 14, fault AY cuts Peoria Loess; there are numerous subhorizontal shear surfaces in the Roxana Silt in the vicinity of this fault (fig. 36). One TL age date of 28.0 ± 2.6 ka from the uppermost Roxana Silt (table 1, see profile 13 for location) verifies the field identification of this unit.

Fault AZ (profile 13) strikes N5E (parallel to fault AY), dips 67°SE, and has a 34°NE rake determined from striations. This fault separates entirely different Quaternary stratigraphic sequences. Immediately to the south of this fault, Mounds Gravel is overlain by sandy, gravelly, and silty colluvial deposits (Qc2 and Qc1 units). Further to the south (see profile 14), Mounds Gravel is absent and is replaced in the stratigraphic section by the unnamed Quaternary gravel 3 (Qg3) and coarse-grained silty sand (Qs) beneath a possibly reworked Peoria Loess and colluvial deposits (Qc1); Sangamon Geosol, Roxana Silt, and most of Peoria Loess are absent. To the north of fault AZ, a relatively thick Quaternary loess sequence of Sangamon Geosol (developed on Loveland Loess), Roxana Silt, and Peoria Loess occurs. These stratigraphic relations across fault AZ indicate significant localized post-Roxana uplift, followed by erosion.

Figure 34. Tuesday Trench- view to north, looking down strike of fault AY.

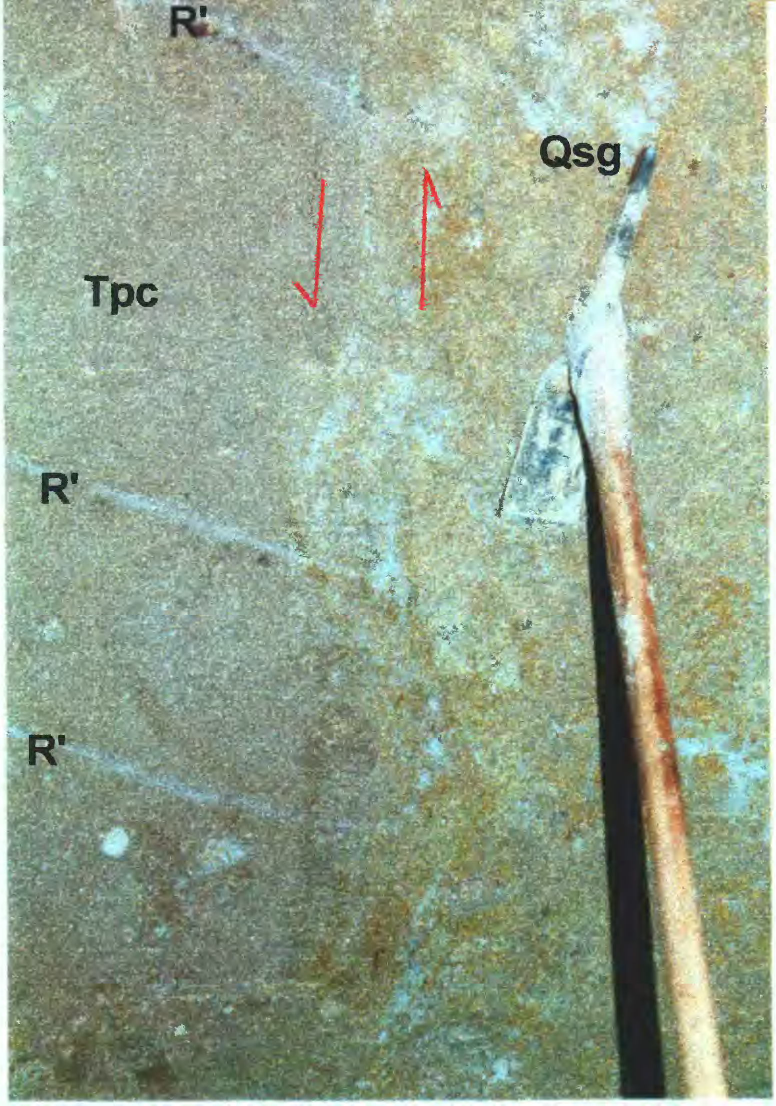

Figure 35. Tuesday Trench- R' shears for fault AY; view is down on trench floor, south is towards top of photo.

**Figure 36. Tuesday Trench- subhorizontal slickenside surfaces and mullions on vertical shear in Roxana Silt- striking N20W, raking 14 degrees to NW**

Fault BM (profile 14) strikes N35E and dips approximately 40° NW. A rake of 8° SW is indicated from slickenside striations and mullions. This fault consists of numerous braided surfaces that juxtapose McNairy Formation in the hanging wall against the Clayton Formation in the footwall (fig. 37). Fault-bound slivers of both McNairy and Clayton occur along the fault and in places Clayton slivers overlie McNairy slivers. In the hanging wall, McNairy Formation is cut by a complicated array of branching and curving faults that have both steep and subhorizontal attitudes. The steep faults are generally northwest striking, oblique to fault BM. Slickenside striations on the subhorizontal surfaces indicate either northeast or southwest sliding, parallel to fault BM. Bedding is strongly rotated and, despite the complexity of faulting and horizontal movement, is always parallel to fault BM (fig. 38).

The upper tip of fault BM places McNairy Formation over the Quaternary gravel deposit (fig. 37), but the fault was not observed cutting any higher in the section. This gravel is poorly sorted and consists of chert cobbles with a brown patina derived from the Mounds Gravel, polished black chert and quartz pebbles derived from the Wilcox Group, and iron-cemented conglomerate clasts in a sandy, silty matrix. Pebble imbrications indicating flow towards the northeast were numerous and prominent. Multiple movements along fault BM are indicated by the existence of Quaternary gravel directly over McNairy Formation in the hanging wall and directly over Clayton Formation in the footwall. No datable materials were found in any of the Quaternary units that overlie fault BM.

## Discussion and Interpretation

Because of the fault complexity and scarcity of cross-cutting relationships, it is very

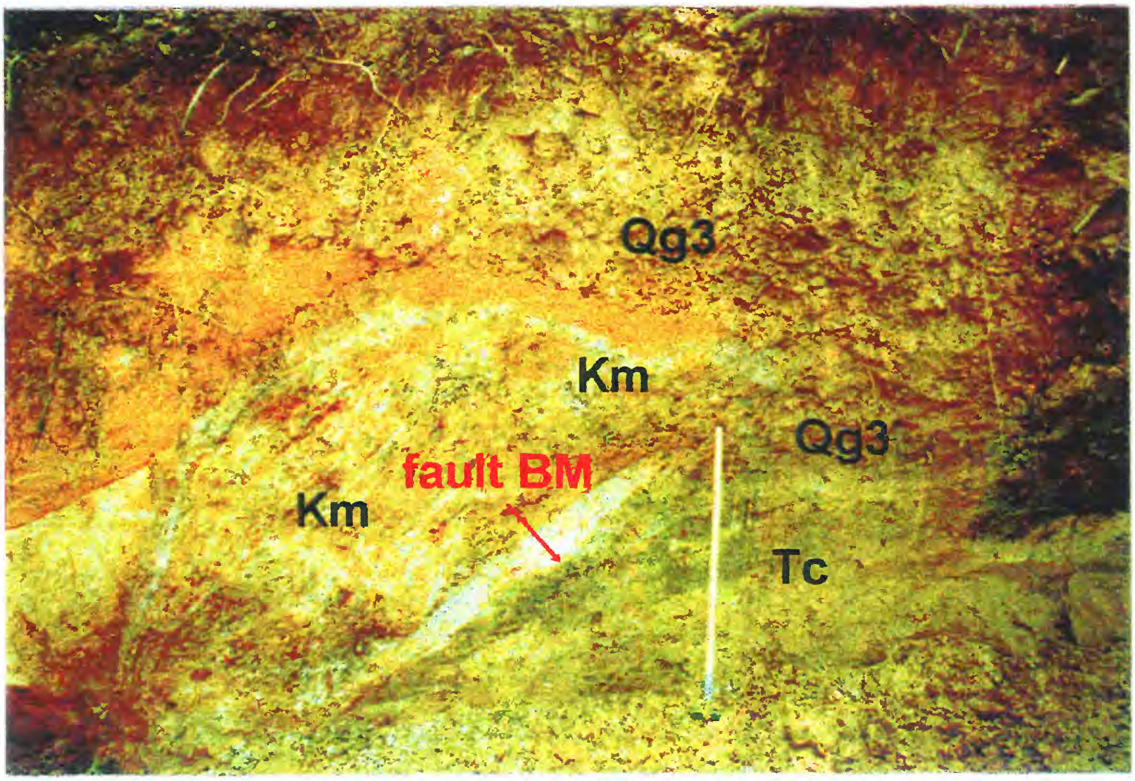

Figure 37. Tuesday trench- fault BM.

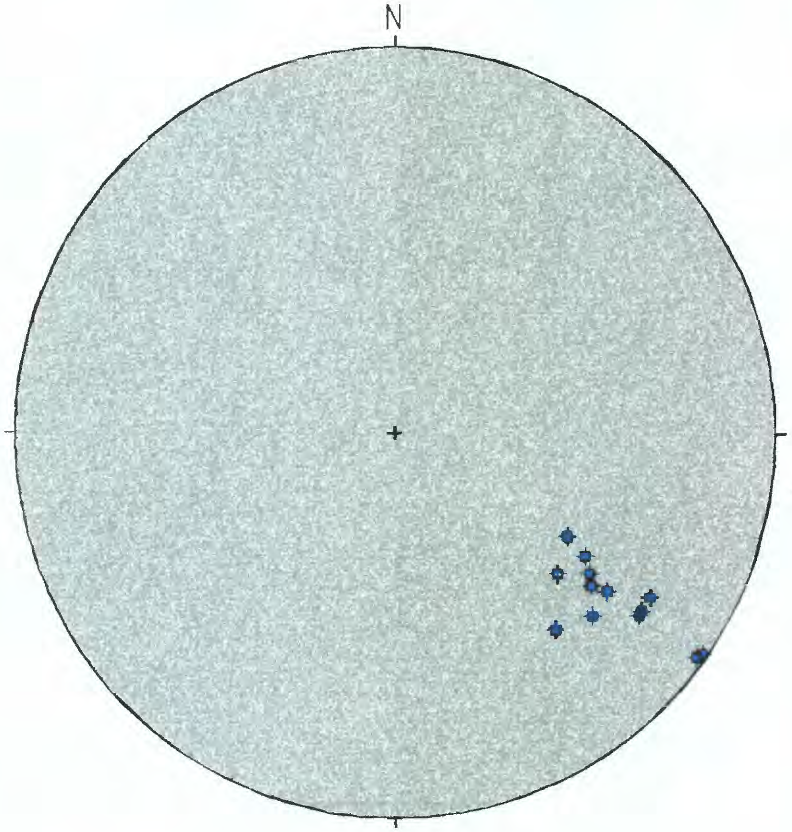

Figure 38. Tuesday trench- poles to bedding of McNairy Formation in hanging wall of fault BM.

difficult to decipher different episodes of faulting in the Tuesday Trench. From kinematic indicators observed along the faults in this trench and the timing of stress orientations developed from analyses of the other trenches in the English Hill area, at least three episodes of faulting in the Tuesday Trench are interpreted.

The first episode of faulting is believed to be the result of northwest-southeast compression. Northeast-striking thrust faults (faults BM and BO) developed and left-lateral strike-slip deformation occurred along faults AX, AY, and AZ. Figure 39 is an equal-area stereonet projection of fault data for this oldest interpreted episode. Localized uplift and subsequent erosion removed the Quaternary loess section south of fault AZ as discussed previously.

The second interpreted fault episode involved east-northeast-west-southwest extension along faults AZ, BB, BC, BD, BF, BG, and BH. At some locations, the subhorizontal faults that formed earlier are believed to have been reactivated, producing the observed northeast-southwest slickenside striations. At other places, the subhorizontal faults are offset by this episode of faulting. The graben between faults AZ and BG probably formed during this episode and the Qc2 deposit may in part represent graben fill. Figure 40 is an equal-area stereonet projection of fault data for this interpreted episode.

The final episode of faulting at the Tuesday Trench is interpreted as strike-slip faulting along fault BM. Other faults may have been reactivated, particularly fault BO. The principal evidence for this episode is juxtaposition of McNairy Formation over the unnamed Quaternary gravel 3 deposit on fault BM (profile 14 and fig. 37) and the presence of fault-bound slivers of Clayton Formation physically above McNairy Formation along fault BM. Slickenside striations on

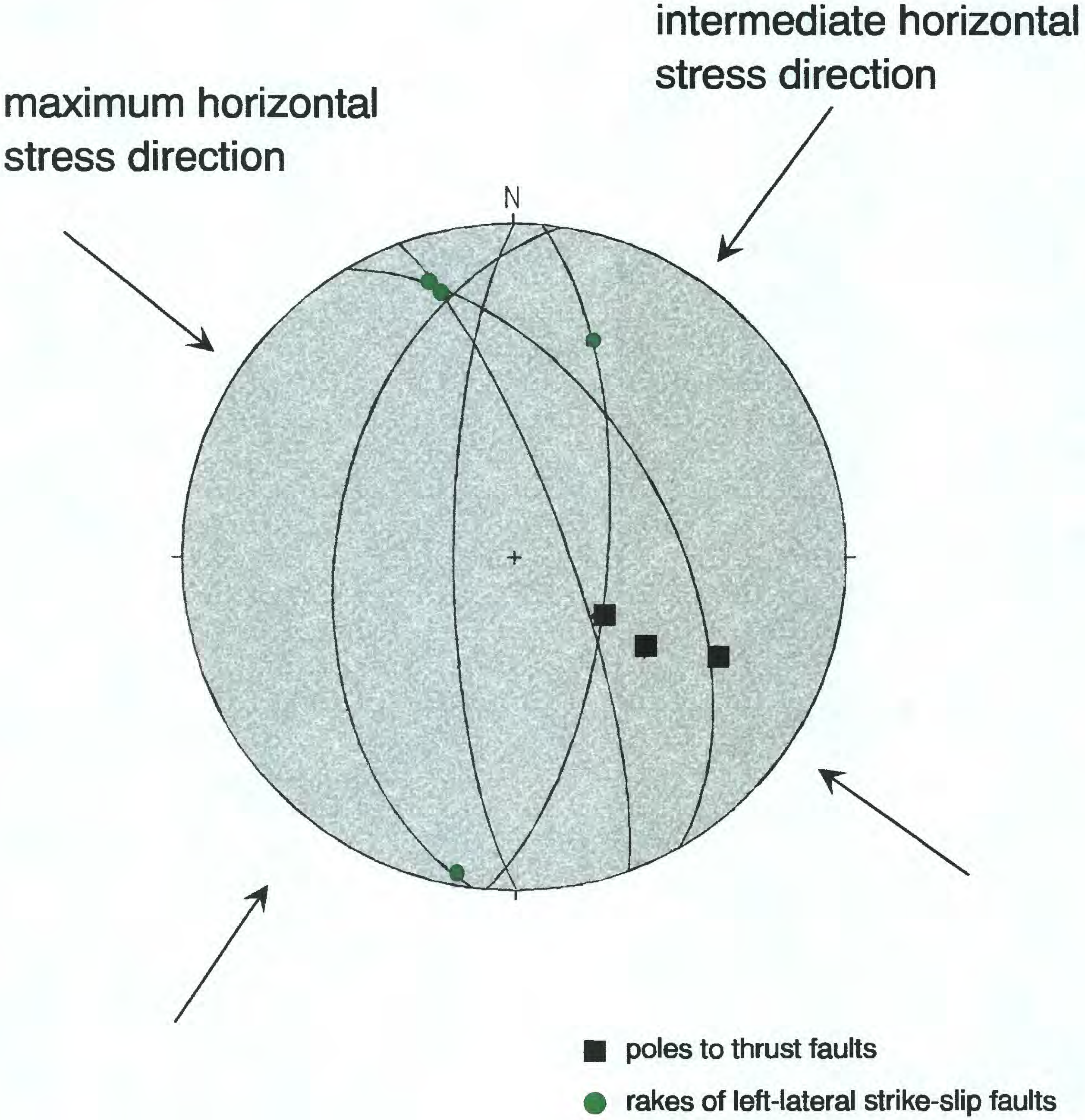

Figure 39. Tuesday Trench- fault data for oldest interpreted fault episode.

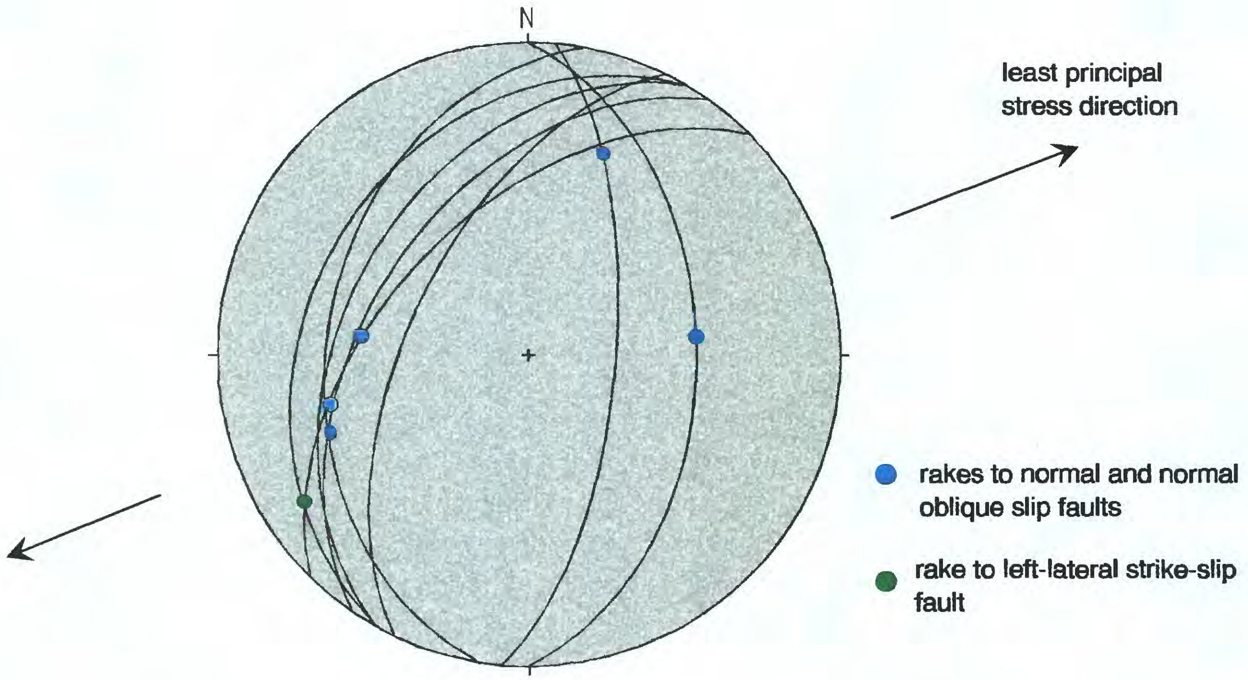

Figure 40. Tuesday Trench- fault data for interpreted second fault episode.

fault BM rake 8° SW and should represent the last movement along the fault. In order to move the hanging wall upward and produce these striations, right-lateral strike-slip motion is required. The fault-bound slivers of Clayton are interpreted as rip-out structures produced by this strike-slip faulting; earlier episodes of thrusting and normal faulting cannot be envisioned as capable of generating such features.

The only other faults exposed in the Tuesday Trench that can be readily interpreted as late strike-slip deformation are faults AT and AU at the extreme north end of the trench (profile 13). These faults display the proper orientation for a Reidel prime (R') shears accompanying northeast-trending right-lateral strike-slip faulting. These faults are located where an on-strike projection of fault AS exposed in the Seismic Line Trench (profile 12) should cut the Tuesday Trench. Figure 41 is an equal-area stereo projection of fault data for this last interpreted episode of faulting.

### Weber Trench

The Weber Trench was excavated approximately 500 ft southwest of the southern end of the Tuesday Trench (fig.4). It is the southeasternmost and topographically lowest trench dug in the English Hill area. A series of horsts and grabens were exposed in the trench (profile 15). The bounding faults are marked by light-colored silt infilling; no slickenside surfaces were observed.

Stratigraphic relationships across the faults suggest two, and possibly three, episodes of faulting. Fault BT juxtaposes Wilcox Group sand and Sangamon Geosol, and both are directly overlain by Peoria Loess. This implies a post-Sangamon and pre-Peoria episode. Roxana Silt occurs in the hanging wall of fault BP, but is absent elsewhere in the trench. This suggests a post-

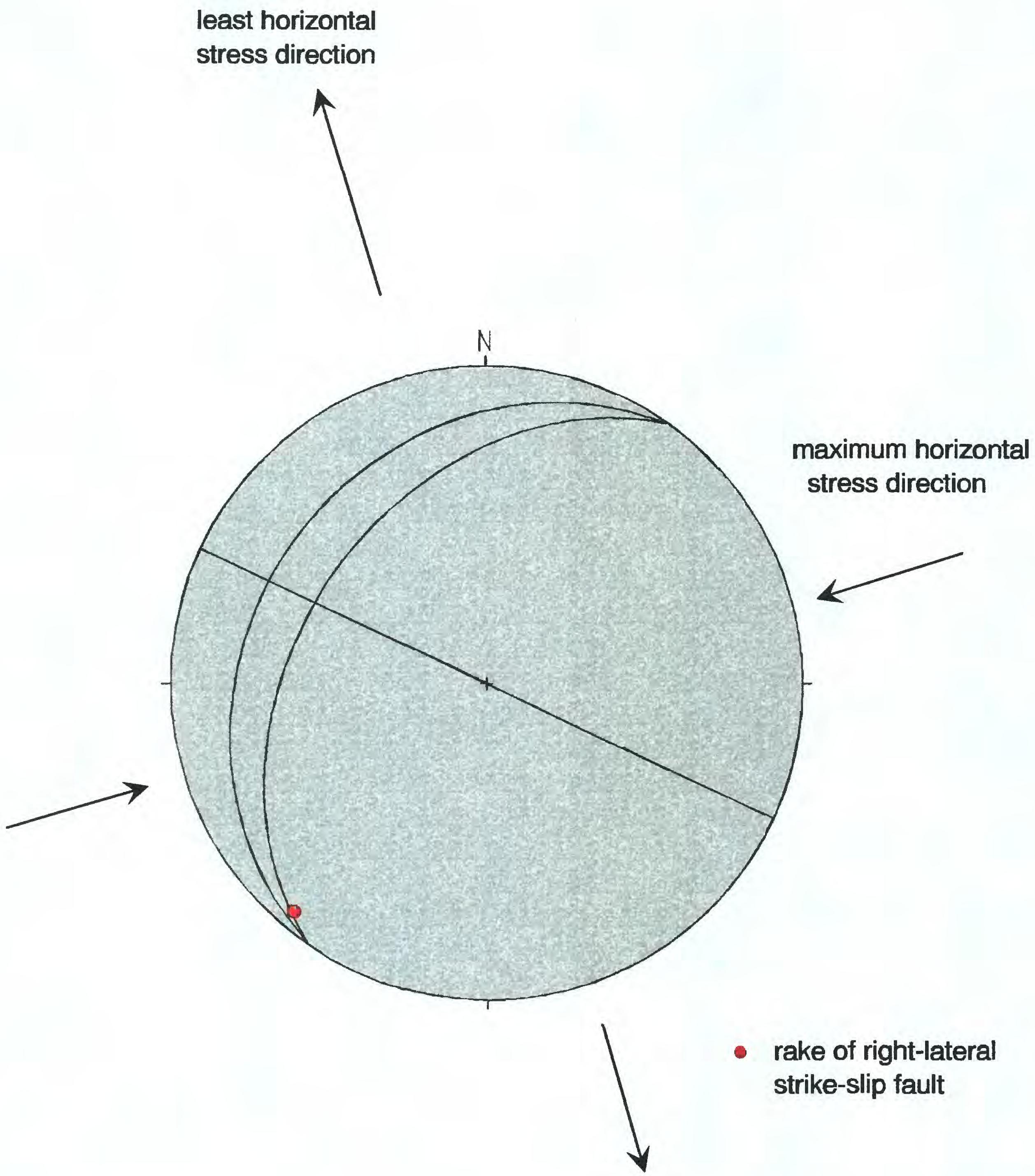

Figure 41. Tuesday Trench- fault data for youngest episode of faulting.

Roxana uplift and subsequent erosion. It is not known if these episodes occurred at the same time or not. The final episode involved Peoria Loess. All faults except BT cut Peoria Loess.

Lacking any kinematic indicators, it is not possible to accurately evaluate stress orientations. However given the fault orientations (fig. 42) and the normal sense of stratigraphic separation across the faults, northwest-southeast extension is suggested.

### Correlation of Fault Episodes and Geology of English Hill

Exposures in the Upper Rainbow Trench provide the most complete tectonic record found in the English Hill area, one that is transferable to faulting found in the other trenches (table 3). Cretaceous deformation is the oldest episode (UR-1) and is expressed as microfaults and minor displacement normal faults confined to the McNairy Formation. Some of the faulting in the McNairy exposed in the Tuesday Trench (profiles 13 and 14) is probably Cretaceous deformation, but the complexity of subsequent faulting precludes positive verification. Cretaceous faulting has been documented elsewhere in the Benton Hills (Harrison and Schultz, 1994) and recognized in nearby southern Illinois (J. Nelson, personal oral commun., 1993).

Eocene deformation (UR-2) is suggested by localized, and rather dramatic, unconformities observed in the Upper Rainbow and Seismic Line Trenches (profiles 7, 8, 11, and 12) and in the unique existence of the greater than 20 ft thick unnamed Eocene unit exposed in the Bollinger Trench (profiles 1 and 2). Core hole BH-1 [see fig. 4 for location and Harrison and others, (1996a) for description] encountered 36.7 ft of Porters Creek Clay which is absent in the Upper Rainbow Trench only 400 ft away. It is interpreted that these phenomena represent localized fault-related uplift and erosion of horst blocks and deposition in a graben.

## Table 3. Interpretative correlation chart for faulting episodes exposed in English Hill trenches.

| Upper Rainbow episodes | UR-1 | UR-2 | UR-3 | UR-4 | UR-5 | UR-6 | UR-7<br>possibly correlative | UR-8<br>possibly correlative | UR-9 ? |
|---|---|---|---|---|---|---|---|---|---|
| Bollinger Trench | | unique Eocene deposition | post-Tw pre-Qsg erosion | | | | | post-Eocene<br>↖ ↙<br>↗ ↘ | post-reworked Qpl cuts modern B soil<br>⤢ |
| Old Quarry Trench | | | | | | | post-Qpl<br>⤡ ? | post-Qpl<br>⤡ | post-Qpl<br>⤢ ? |
| Uncle John Trench | | | post-Tw, pre-Qsg<br>? ⤢ | | | post-Qrs, pre-Qg3<br>⤡ | post-Qpl<br>⤡ | | post-Qpl<br>⤢ ? |
| Powerline Trench | | | | | | | post-Qpl<br>⤡ | | |
| Hillcrest Trench | | | | | | post-Qg3, pre- or syn-Qpl<br>⤡ | post-Qpl<br>⤡ | | |
| Upper Rainbow Trench | K microfaulting | Eocene unconformity | post-QTmg, pre-Qg3<br>? ↔ | syn-Qg3<br>⤡ | post-Tw thrusting<br>↘ ↖ | post-Qrs, pre- or syn-Qpl<br>⤡ | post-Qpl<br>⤡ | post-Qpl<br>↖ ↙<br>↗ ↘ | post-Qcw<br>⤢ ? |
| Lower Fence Line Trench | | | | | post-Qsg<br>↘ ↖ | | | | |
| Upper Fence Line Trench | | | post-QTmg, pre-Qrs<br>⤡ ? | post-Qsg, pre-Qrs<br>⤡ ? | | | | post-Qpl rotation | ⤢ ? |
| Seismic Line Trench | K microfaulting | Eocene unconformity | | | post-Qg1<br>↘ ↖ | | post-Qpl<br>⤡ | post-Qpl<br>↘ ↗<br>↙ ↖ | |
| Tuesday Trench | K microfaulting | | | | post-Qrs<br>↘ ↖ | | post-Qpl<br>⤢ | post-Qpl, post-Qg3<br>↑ ↙<br>→ ↓ | |
| Weber Trench | | | post-Qsg, pre-Qpl<br>⤡ ? | | | | post-Qpl<br>⤡ | | |

⤡ direction of extension or least horizontal stress

↘ ↖ direction of compression or maximum horizontal stress

↖ ↙ ↗ ↘ orientation of maximum and least horizontal stress directions for strike-slip faulting

? uncertain orientation or occurrence

Qcw- Quaternary colluvial wedge deposit

Qpl- Peoria Loess

Qg3- unnamed Quaternary gravel 3

Qrs- Roxana Silt

Qg2- unnamed Quaternary gravel 2

Qsg- Sangamon Geosol

Qg1- unnamed Quaternary gravel 1

QTmg- Mounds Gravel

Tw- Wilcox Group

K- Cretaceous strata

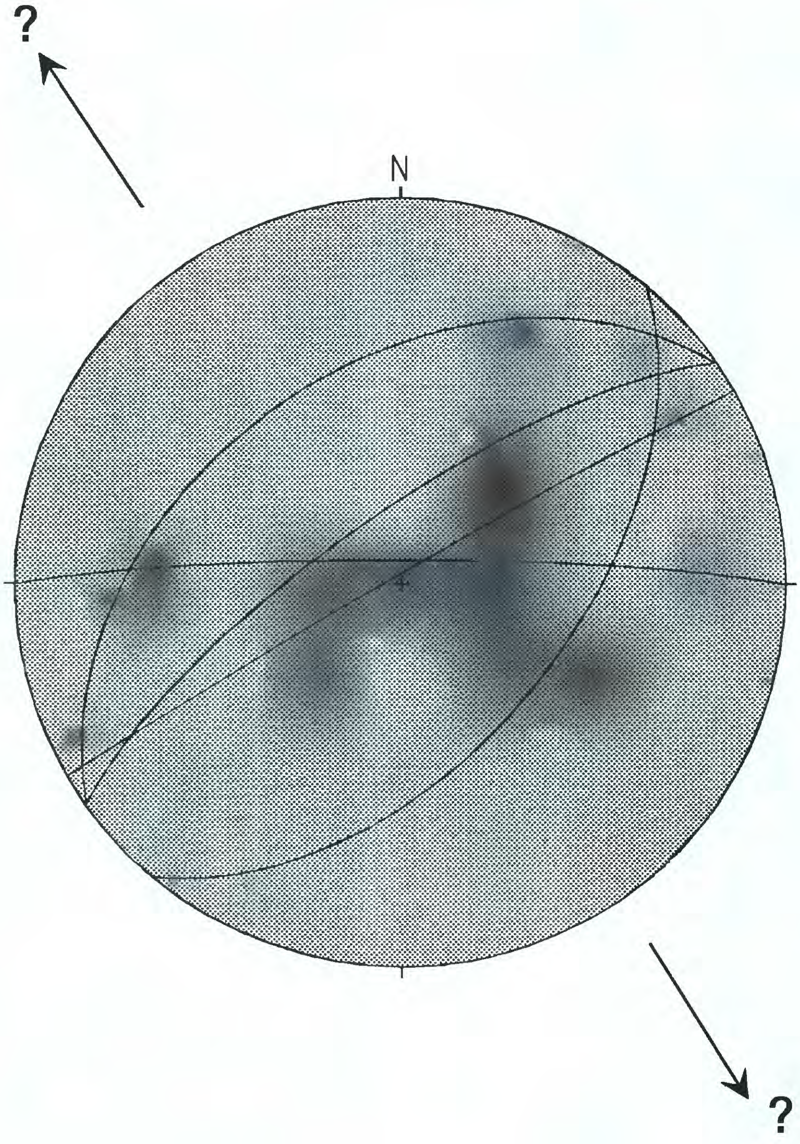

Figure 42. Weber Trench- all fault data.

Although poorly understood, Upper Rainbow episodes 3 and 4 (UR-3 and UR-4) document early Quaternary faulting, possibly the result of east-west or northwest-southeast extension. These episodes are probably related to post-Wilcox-pre-Sangamon faulting observed in the Uncle John Trench, the post-Sangamon-pre-Roxana inferred faulting in the Upper Fence Line Trench, and post-Sangamon-pre-Peoria faulting in the Weber Trench.

Upper Rainbow episode 5 (UR-5) thrust faulting provides a distinctive northwest-southeast compressional stress signature. This is a stress orientation not observed in any of the other episodes. This episode has correlative deformation exposed in the Lower Fence Line, Seismic Line, and Tuesday Trenches. Constraints provided in the Lower Fence Line Trench indicate that this episode is post-Sangamon Geosol and in the Tuesday Trench it is constrained as post-Roxana.

Episode 6 (UR-6) begins the late Pleistocene and Holocene deformational record that is dominated by a northwest-southeast-oriented least horizontal stress direction. This episode is post-Roxana and either pre- or syn-early Peoria Loess.

Episodes 7 and 8 (UR-7 and UR-8) are the best exposed and most widely expressed deformation at English Hill. It is possible that these episodes are one and the same, ie. that UR-7 is a transtensional expression of the same stresses responsible for UR-8 strike-slip faulting. These episodes are clearly post-Peoria Loess and therefore probably Holocene in age.

A possible episode (UR-9) is suggested by middle to late Holocene faulting that cuts the colluvial wedge deposit at the southeast end of the Upper Rainbow Trench. However, since the relation between this faulting and UR-7 and UR-8 is unknown, they could all be the same. Additional evidence for this possible UR-9 episode lies in the northeast-southwest extensional faulting that cuts the modern B soil horizon in the Bollinger Trench and questionable similar extension in the Old Quarry and Uncle John Trenches.

Using the trench data described in this report, previous trench and auger hole data accumulated by the MDNR/DGLS, shallow excavations, and surface mapping, it is possible to produce a generalized geologic map of the English Hill area that shows major faults (fig. 43). These faults have strongly developed northeast and east-northeast trends that define rhomb-shaped grabens. It is interpreted that these faults are the surface expression of basement-controlled strike-slip faulting. Furthermore, it is interpreted that step-overs in displacement along the basement faults have at different times produced transtension (pull-apart or rhomb grabens) or transpression (thrust faulting) in the overlying Cretaceous-Cenozoic section.

## Tectonic vs. Landslide Origin

Since Stewart's (1942) report that indicated Quaternary faulting existed at English Hill, there has been much unpublished debate over a landslide versus tectonic origin. A large portion of our evaluation was therefore directed towards this controversy. Our preferred interpretation is a tectonic origin. Following is a tabulation of data and arguments supporting or disfavoring each of the possible origins.

### Landslide-Origin Support Data

1) The area is in proximity to the New Madrid seismic zone where great historical and prehistorical earthquakes are known to have occurred- earthquakes probably strong enough to have generated large landslides on the scale of observed deformation at English

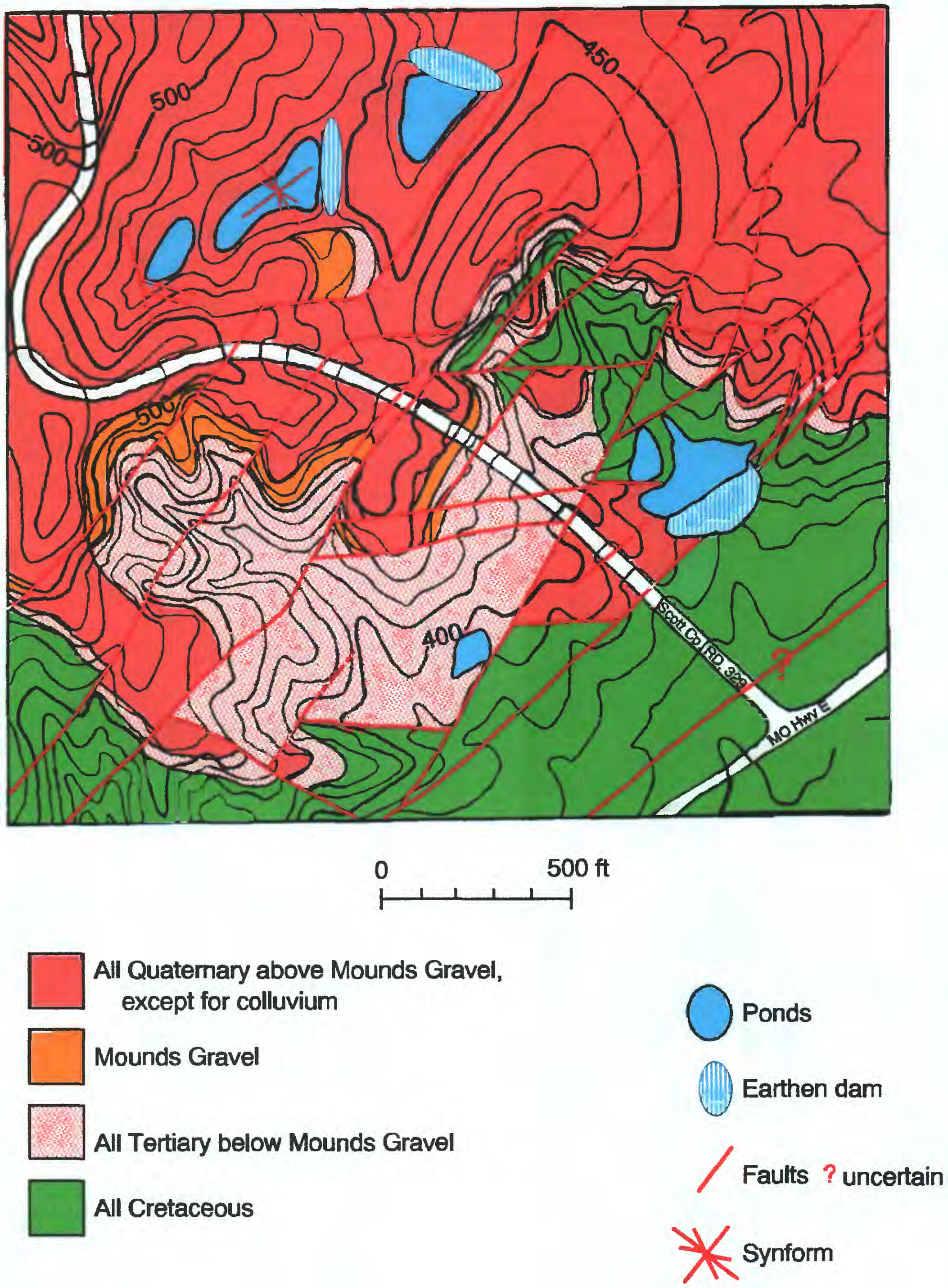

Figure 43. Generalized geologic map of the English Hill area showing major faults and folds.

Hill. Small pre-historic landslides have been oberved in the Benton Hills (Harrison, in press).

2) Most of the observed faulting does occur on the southeast-facing slope and crest of English Hill- a site where landslides or slumping could be expected.

3) Cretaceous and Cenozoic deposits down to approximately 200 ft of depth are unconsolidated and therefore remain susceptible to slumping or landsliding.

4) The kinematic indicators interpreted for several of the faults exposed in trenches do indicate extension has occurred at English Hill.

Tectonic-Origin Support Data

1) Numerous faults that cut the lithified Paleozoic section, as well as the Cretaceous and Cenozoic sections, have been recognized in the region around English Hill (Harrison, in press; Harrison and Schultz, 1994; Johnson, 1985). These regional faults have the same trend as structures observed at English Hill and have had a long-lived, episodic history of activity throughout much of the Phanerozoic (Harrison and Schultz, 1994).

2) Seismic reflection profiles acquired at English Hill indicate the presence of deep-seated faults in the Paleozoic section beneath the observed surface deformation (Palmer and others, 1997a, 1997b).

3) Faulting at English Hill has been episodic, probably occurring throughout the Cenozoic. This is not a characteristic of landslides which become relatively stable after initial movement. Otherwise the same landslides must have been re-activated throughout the Cenozoic. In addition, the scarp along the southeast margin of the Benton Hills did not exist until early

Quaternary time, therefore the site would not have been favorable for landsliding.

4) At English Hill, faulting has occurred as much as 1,200 ft back from the slope crest in the Uncle John Trench (profile 4)- an extremely anomalous distance for landslides which typically have break-away scarps along the crest (Varnes, 1978; Jibson and Keefer, 1993).

5) In the Uncle John Trench (profile 4) extensional motion is towards the northwest, away from the slope. This is consistent with bi-directional tectonic extension, but is in contrast with the uni-directional extension that would be produced by landsliding to the southeast. Fault motions 'into the hill' were observed at other trench sites, most notably the Bollinger Trench (profiles 1 and 2) and the Tuesday Trench (profiles 13 and 14).

6) The occurrence of similar-striking normal, thrust, and strike-slip faults in close proximity, and even cross-cutting each other, is more characteristic of tectonic deformation than landsliding. While all three styles of faulting can occur in landslides, they are segregated with normal faults at the head and sometimes in the body of the slide, thrusts at the toe, and strike-slip faults along the margins; and, the strikes of the strike-slip faults should be nearly orthogonal to those of the normal and thrust faults. The complex relations between the three types of faults observed in several of the trenches is more reminiscent of tectonic deformation, particularly deformation occurring in strike-slip regimes (see examples of faulting in the Mecca Hills shown in Sylvester, 1988; Sylvester and Smith, 1976).

7) The rotation of bedding observed at English Hill is multi-directional and Cretaceous beds have been rotated more than Cenozoic beds (fig. 44). Rotation during landsliding should be more uni-directional, and young and old deposits should be rotated equally. On the other hand, tectonic deformation can produce varying bedding attitudes and older deposits that

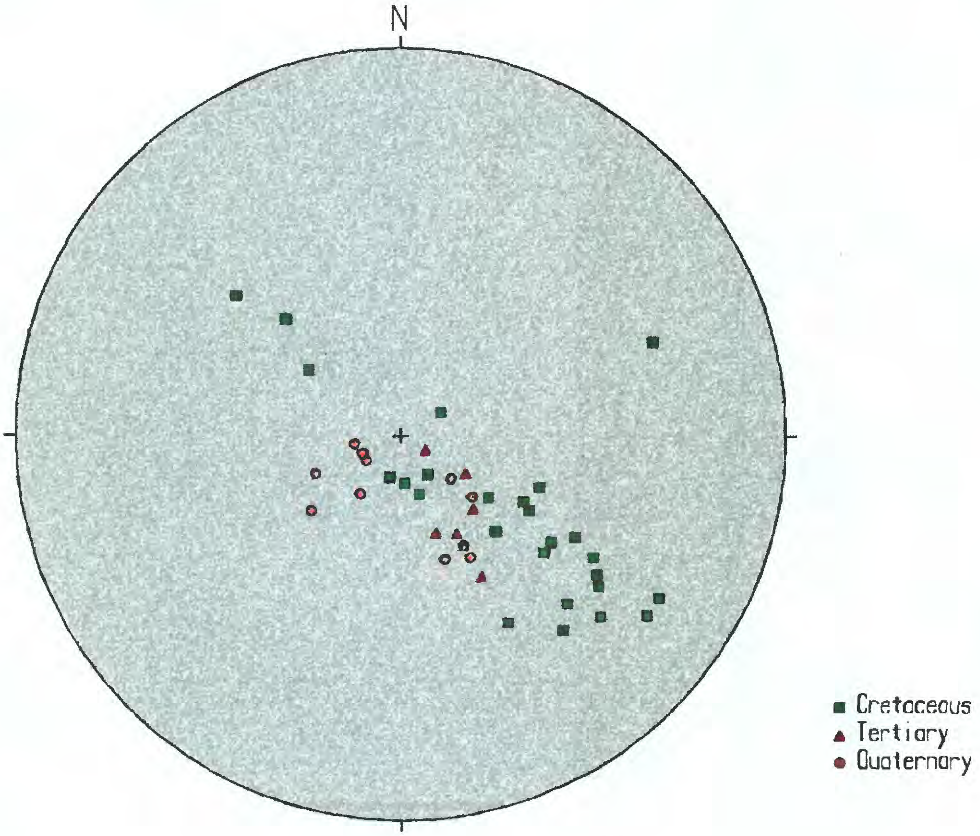

Figure 44. Poles to bedding at English Hill.

are rotated more than younger deposits if faulting is time-transgressive.

8) The concave-downward or roll-over faults observed in the Seismic Line Trench (profile 11 and 12) and the Tuesday Trench (profiles 13 and 14) are characteristic of strike-slip deformation and inconsistent with landslide deformation. Such features have been reported in many strike-slip systems (Naylor and others, 1986; Sylvester and Smith, 1976; Lowell, 1972; Steel and others, 1985; Ramsey and Huber, 1987). In contrast, all faults produced by landsliding are concave upward, flattening out with depth.

## Conclusions

1) Faults at English Hill are predominantly of a tectonic origin, although some minor slumping cannot be totally ruled out.

2) Faulting is the surface expression of basement-controlled strike-slip faults imaged on the seismic reflection profiles.

3) Faulting has been episodic throughout the Cenozoic and at least four and possibly as many as six episodes occurred during the late Quaternary.

4) Extensive faulting cuts the Peoria Loess section at English Hill and this faulting has a maximum age constraint of approximately 17 ka provided by TL dating of this loess unit.

5) $^{14}C$ ages of charcoal contained in a faulted colluvial wedge deposit suggest fault events occurred around or just after 4,700-4,900 and 1,200-1,300 radiocarbon years.

6) Trenching is necessary in settings such as English Hill to adequately evaluate and understand neotectonism.

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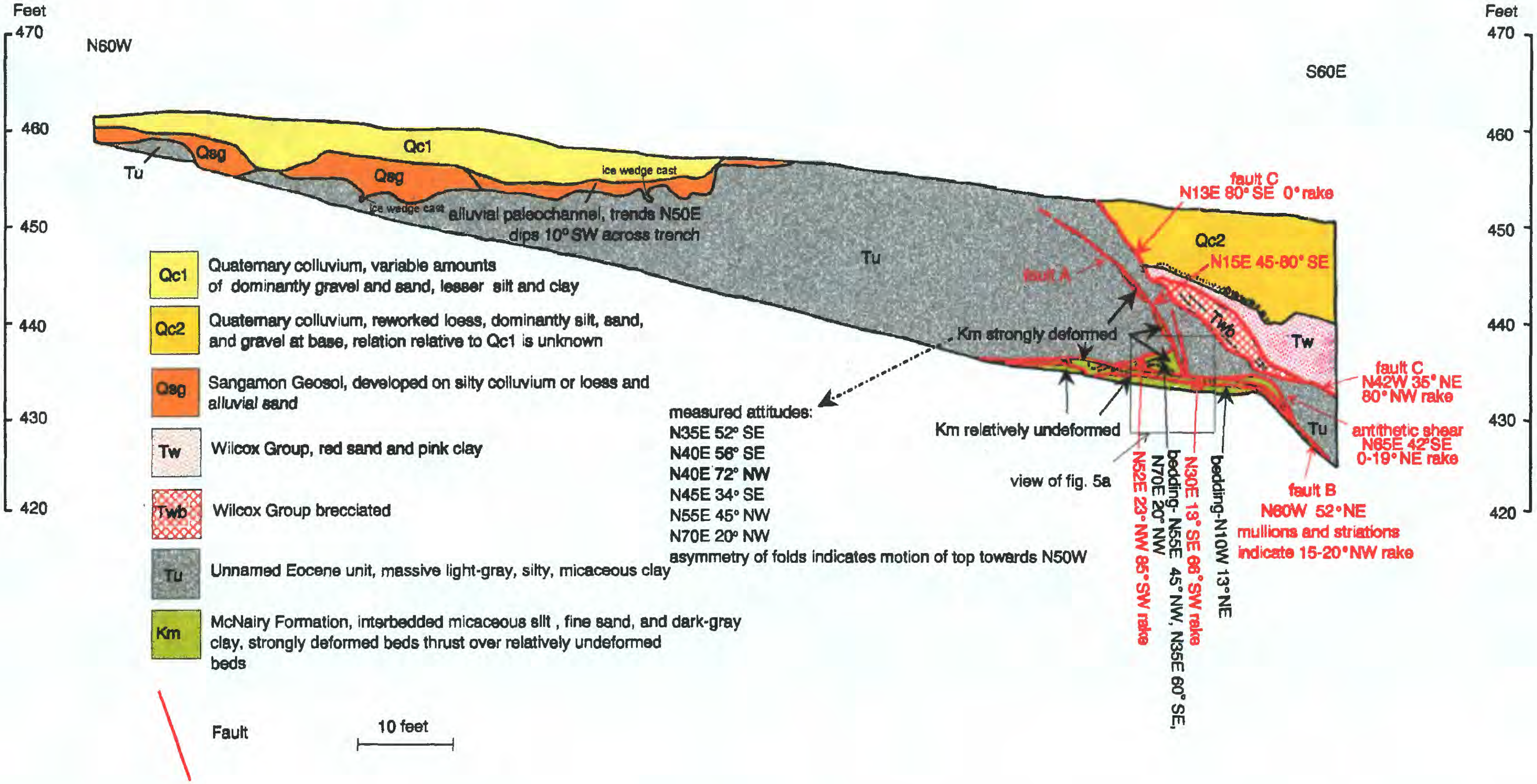
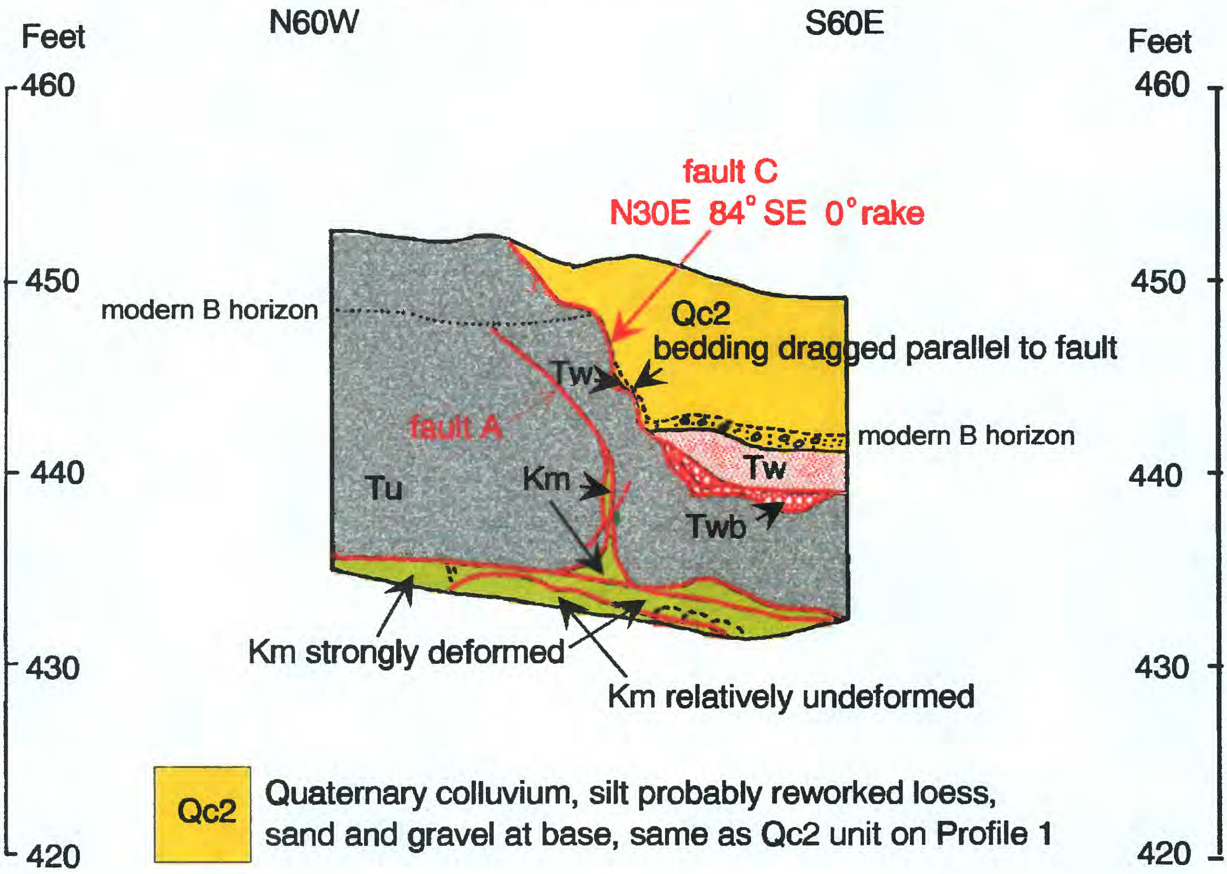
# Appendix A. Profiles of trenches excavated in the English Hill area during 1995-96.

## List of Profiles

Profile 1. Bollinger Trench-NE Wall



# Profile 2. Bollinger Trench- SW Wall, reversed

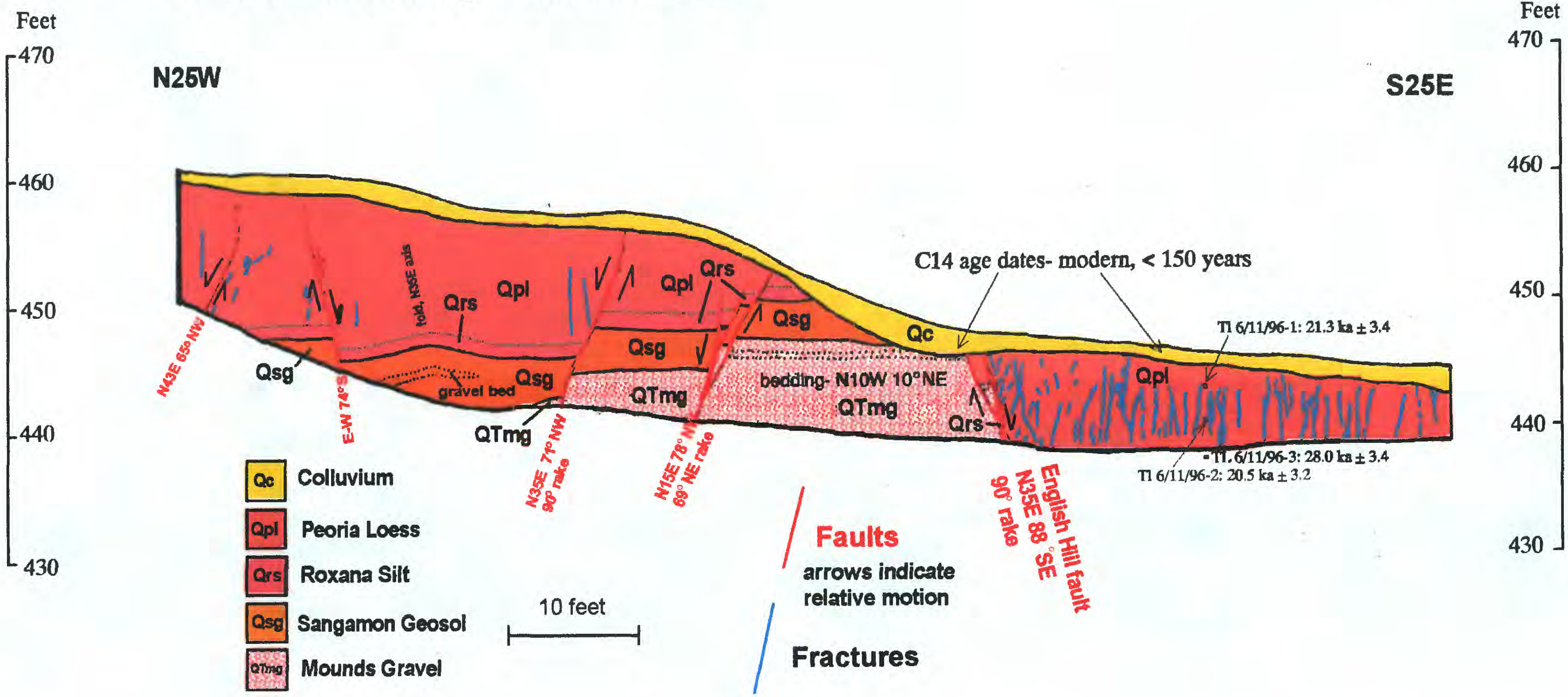


| | |
|---|---|
| Qc2 | Quaternary colluvium, silt probably reworked loess, sand and gravel at base, same as Qc2 unit on Profile 1 |
| Tw | Wilcox Group, red sand and pink clay |
| Twb | Wilcox Group, brecciated |
| Tu | Unnamed Eocene unit, massive ligh-gray, silty, micaceous clay |
| Km | McNairy Formation, interbedded micaceous silt, fine sand, and dark-gray clay, strongly deformed beds thrust over relatively undeformed beds |

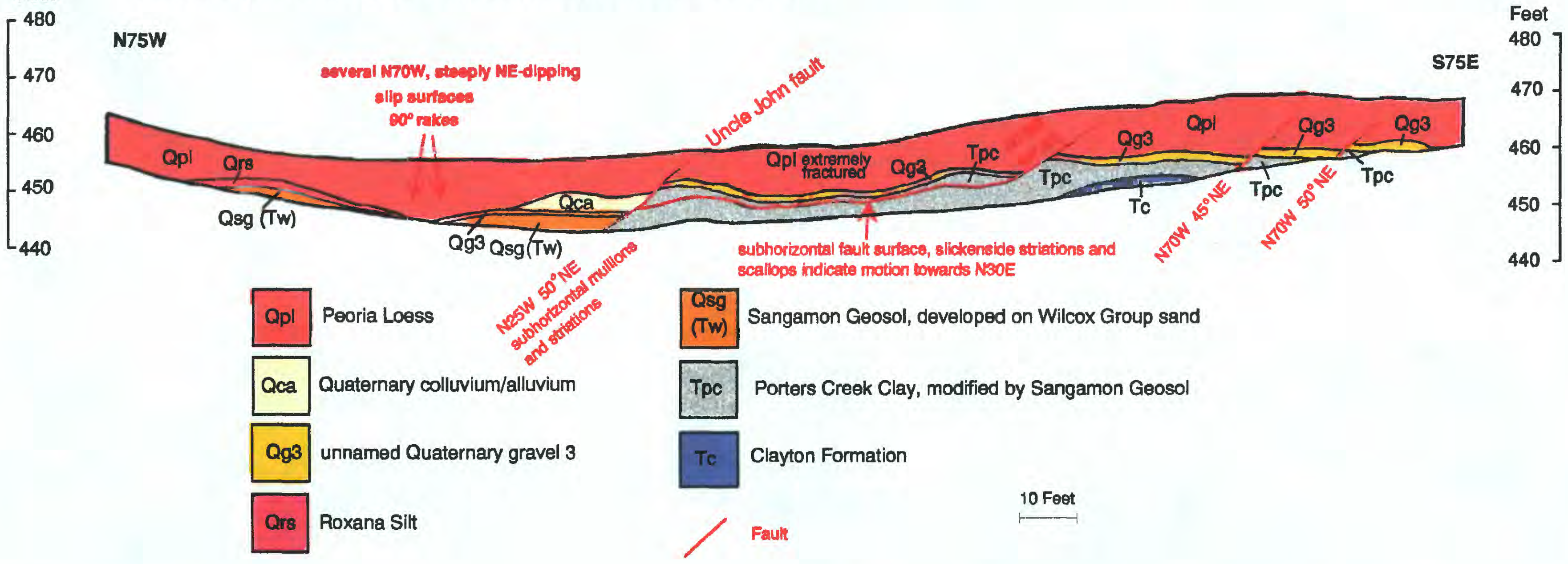
╲ Fault

10 feet

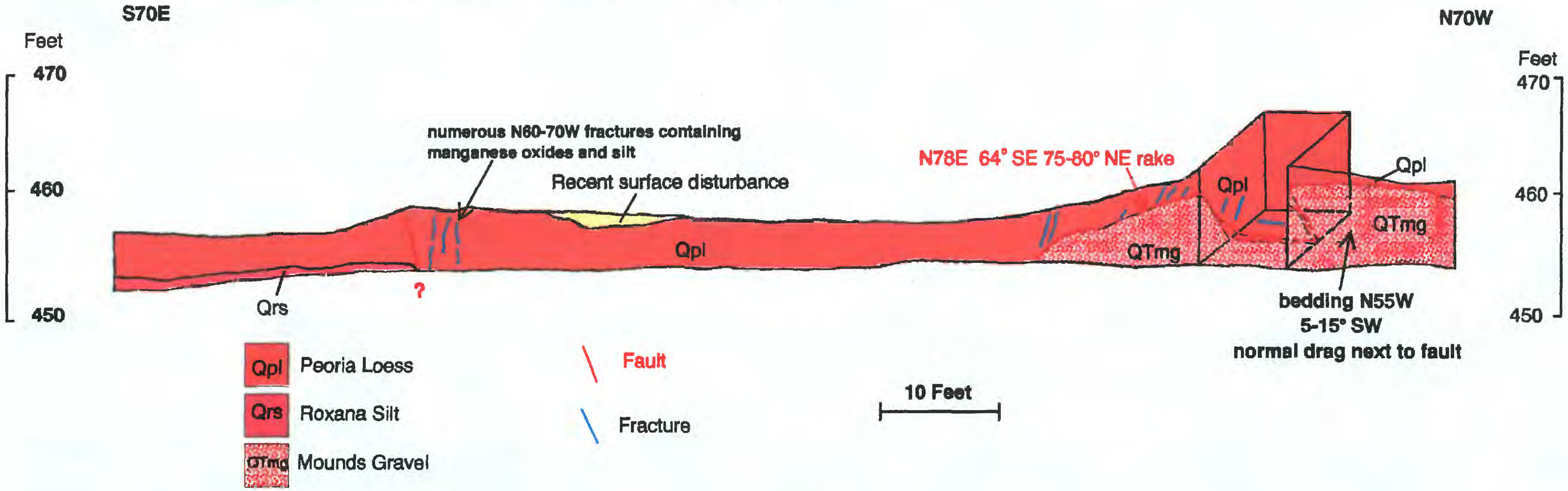
# Profile 3. Old Quarry Trench-NE Wall



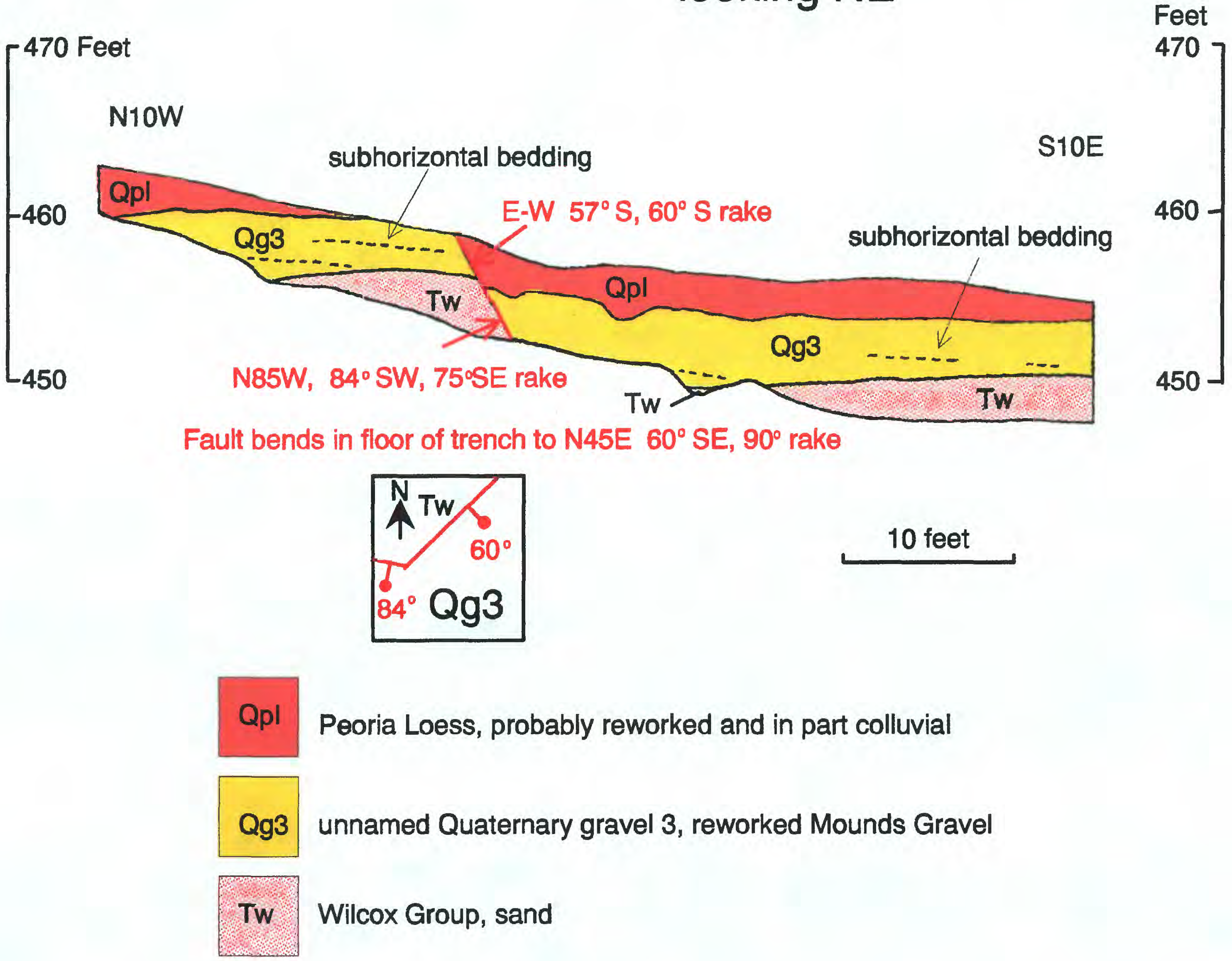
Profile 4. Uncle John Trench, SW-Wall reversed



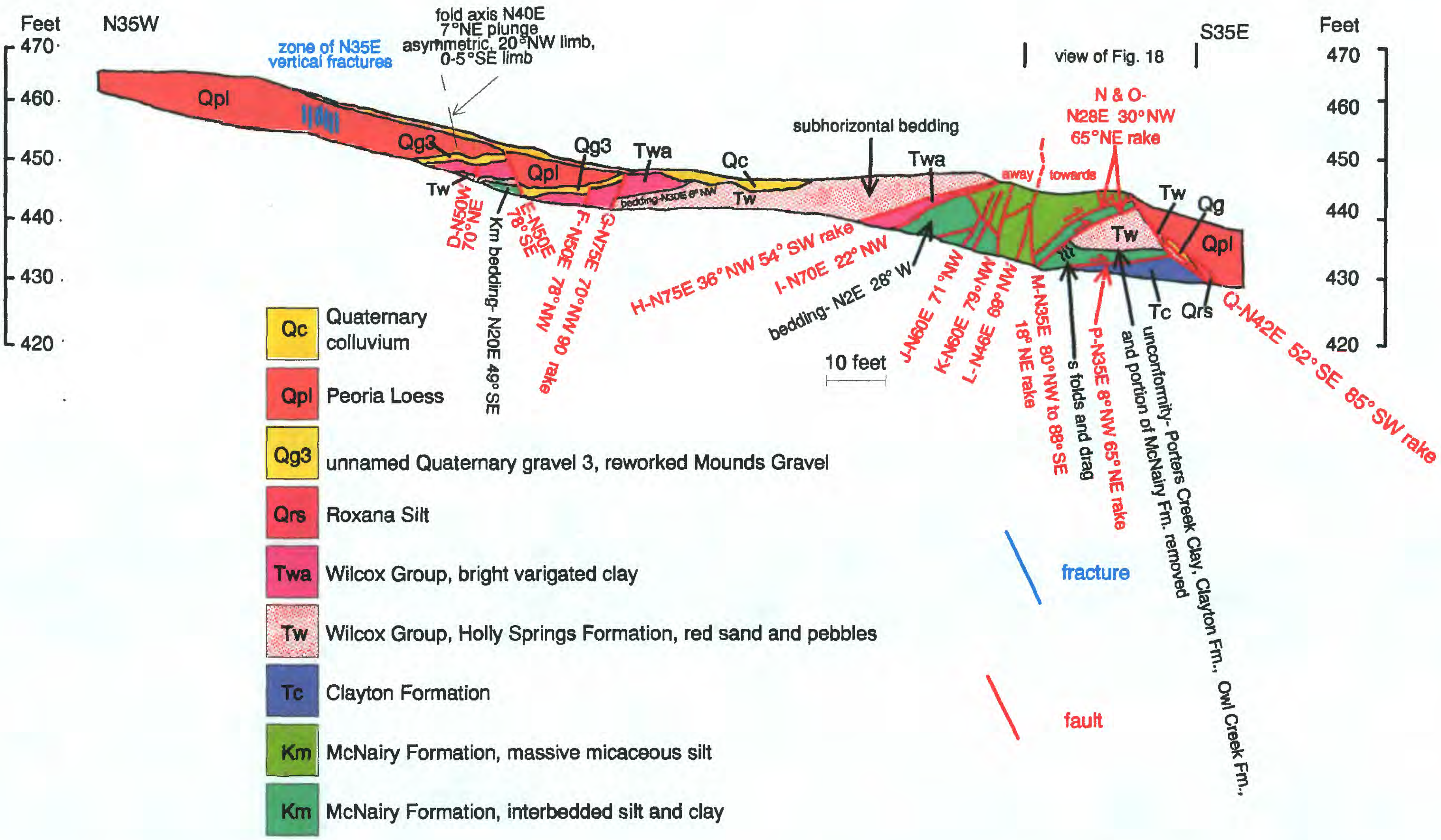
# Profile 5. Powerline Trench- SW Wall.



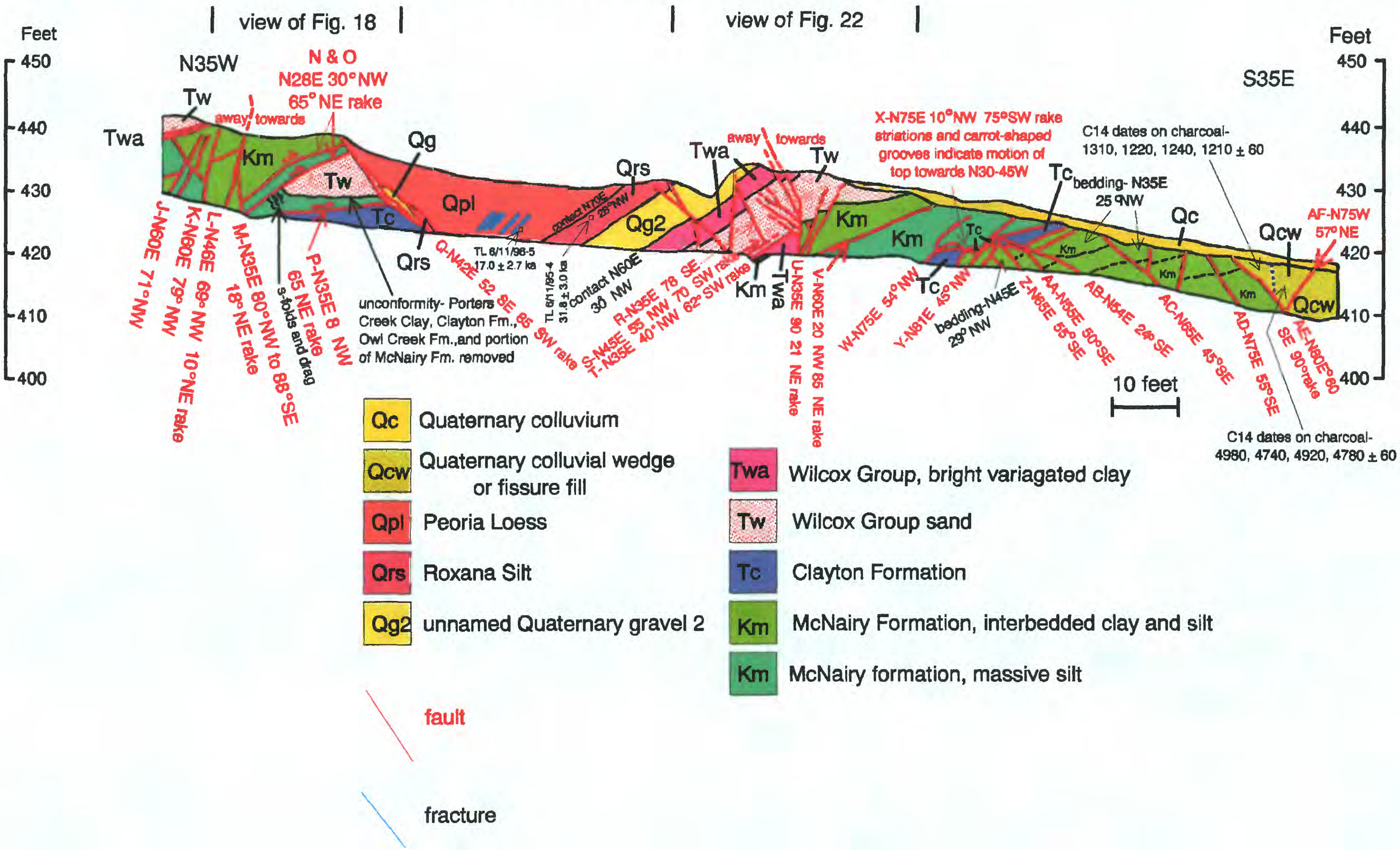
# Profile 6. Hillcrest Trench- SW Wall, reversed, looking NE



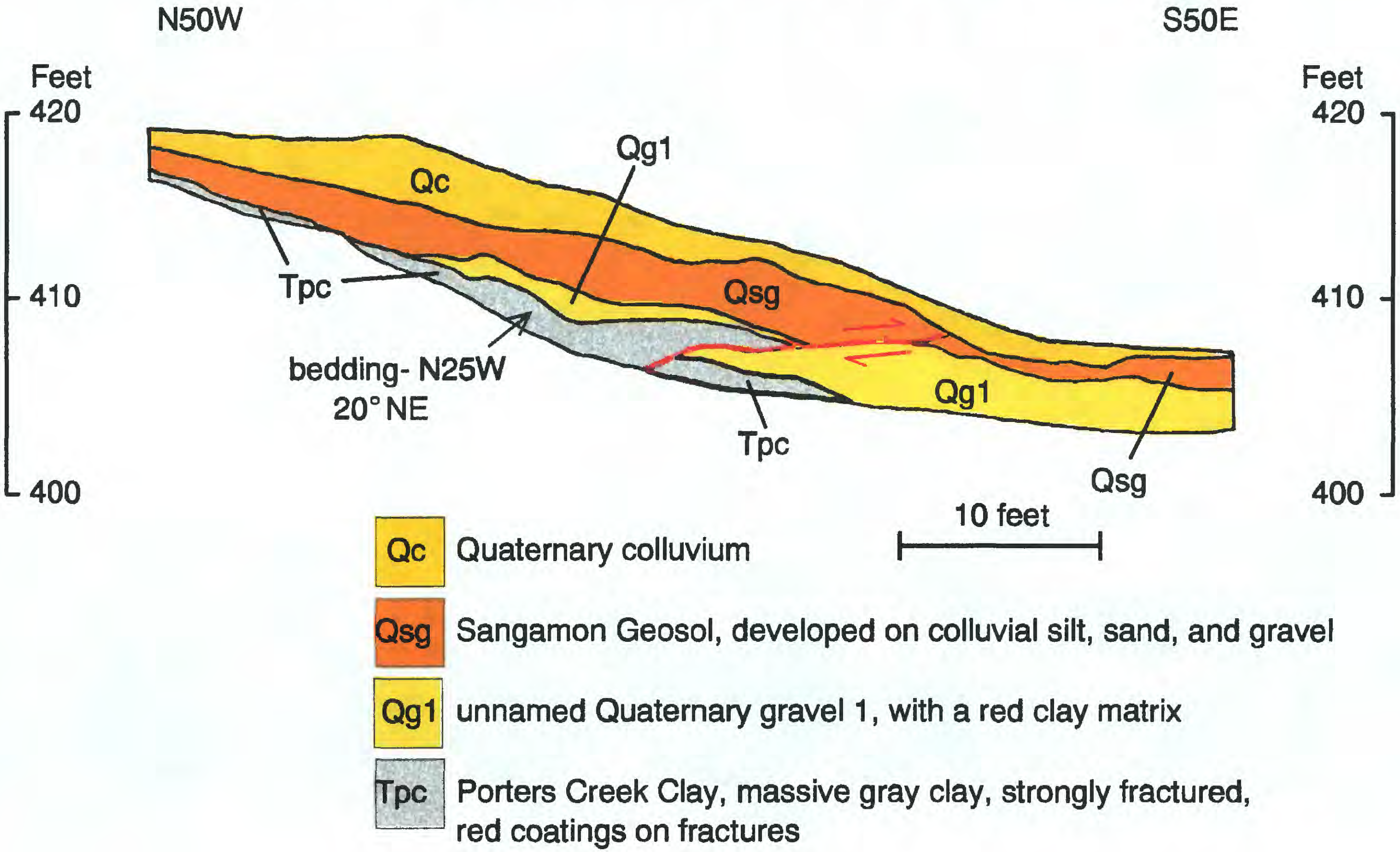
Profile 7. Upper Rainbow Trench-NE Wall, upper portion.



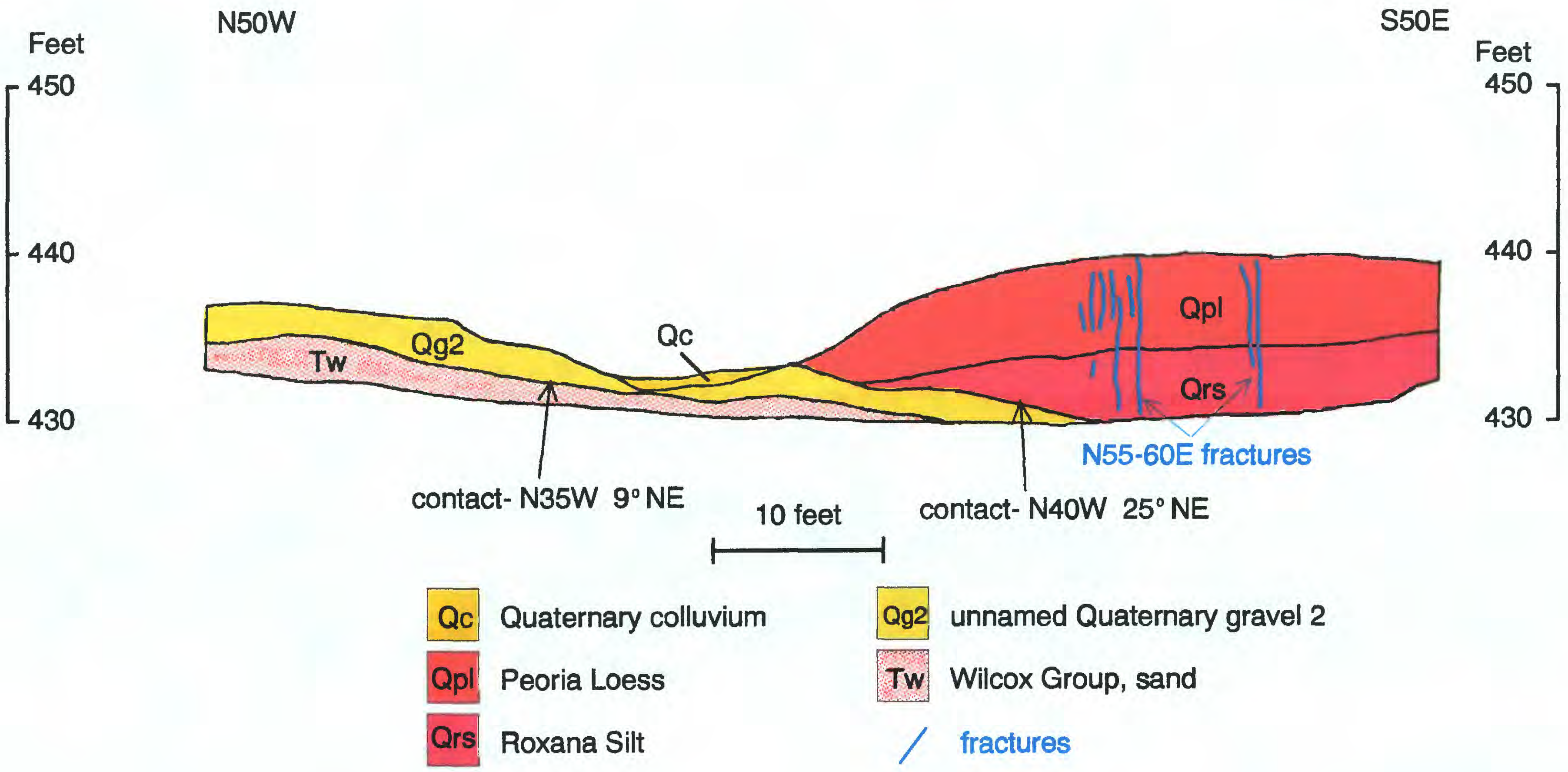
Profile 8. Upper Rainbow Trench- NE Wall, lower portion.



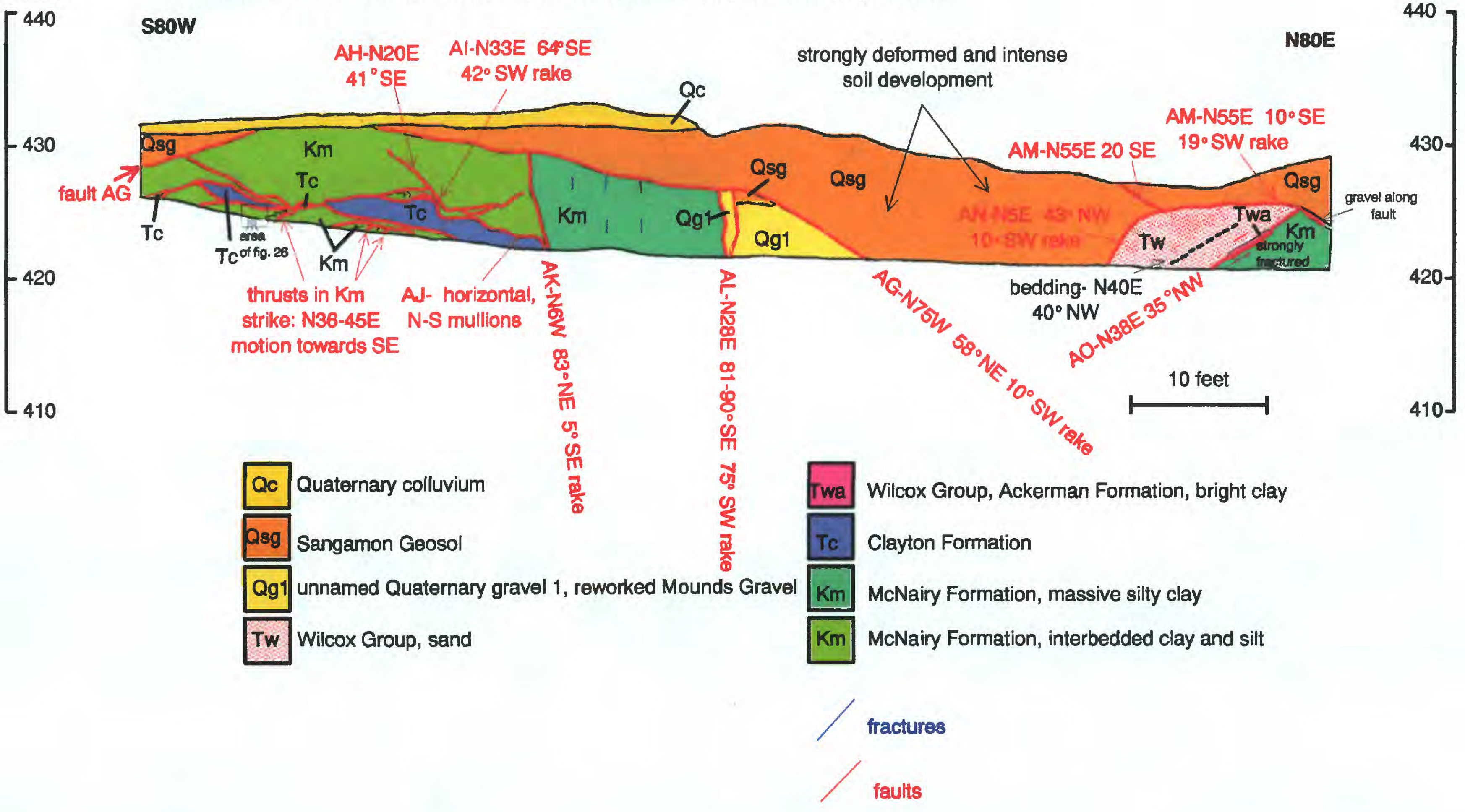
# Profile 9. Lower Fence Line Trench- NE wall.



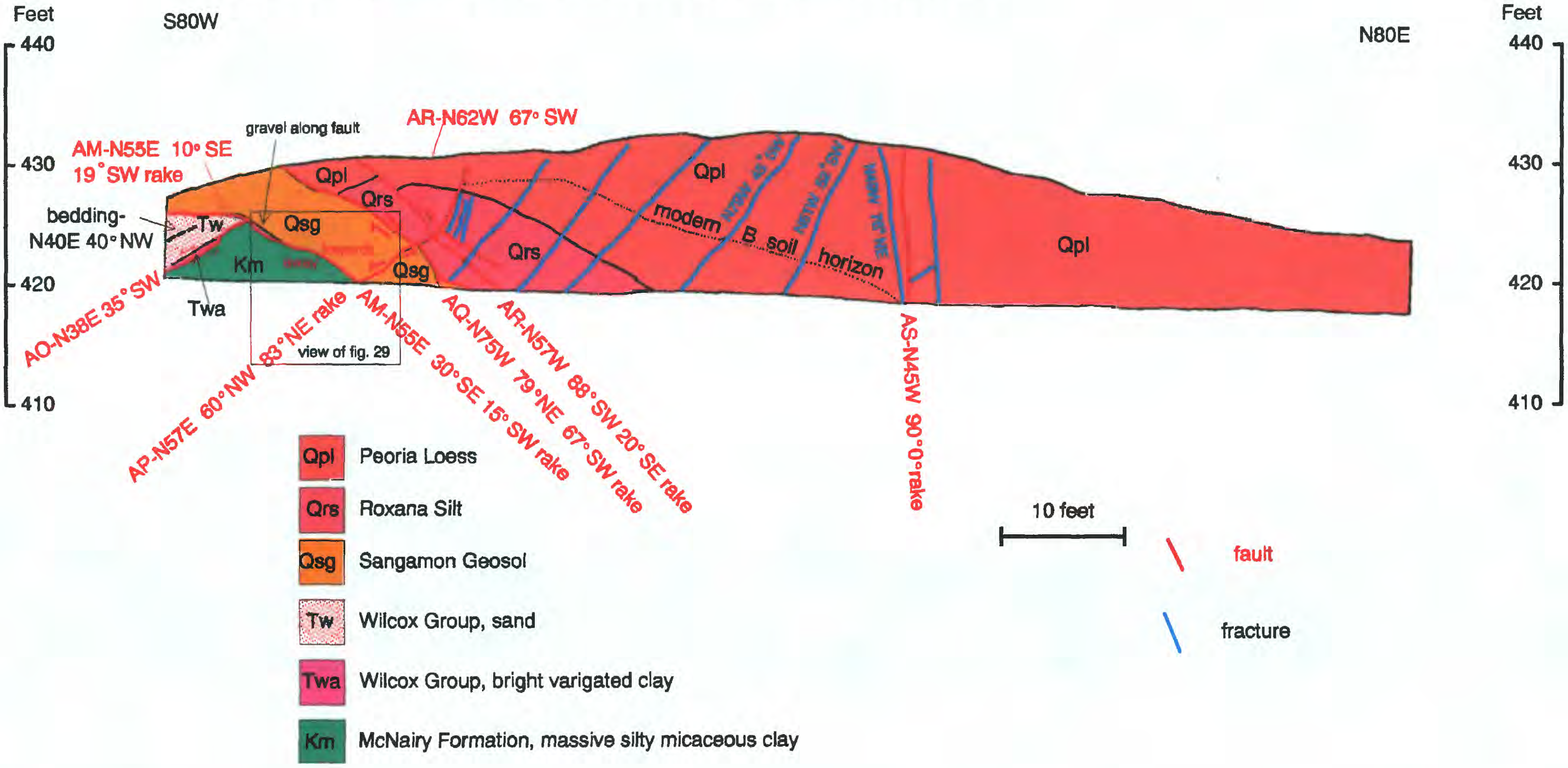
# Profile 10. Upper Fence Line Trench- SW wall, reversed



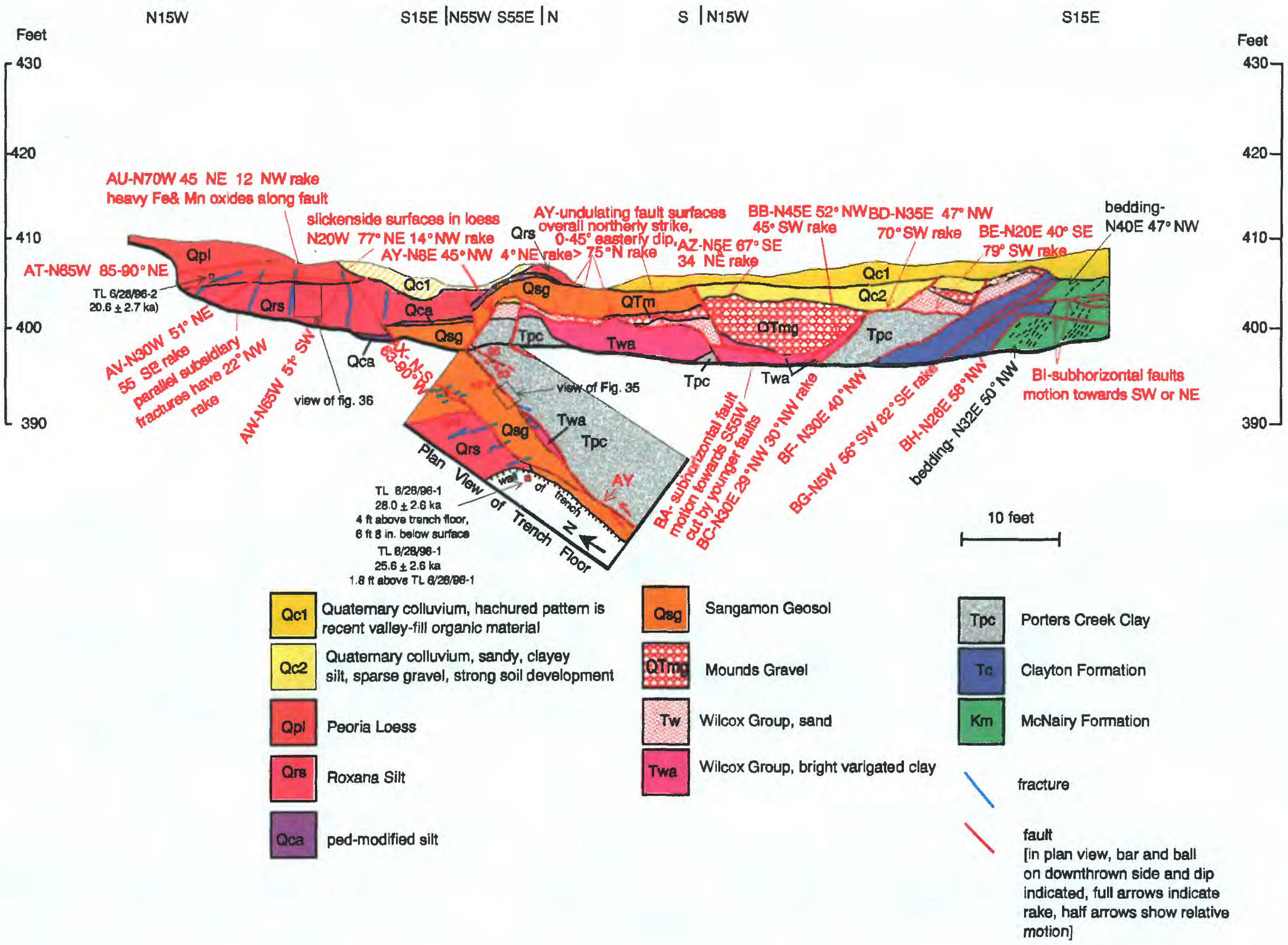
Profile 11. Seismic Line Trench- NW Wall, western portion



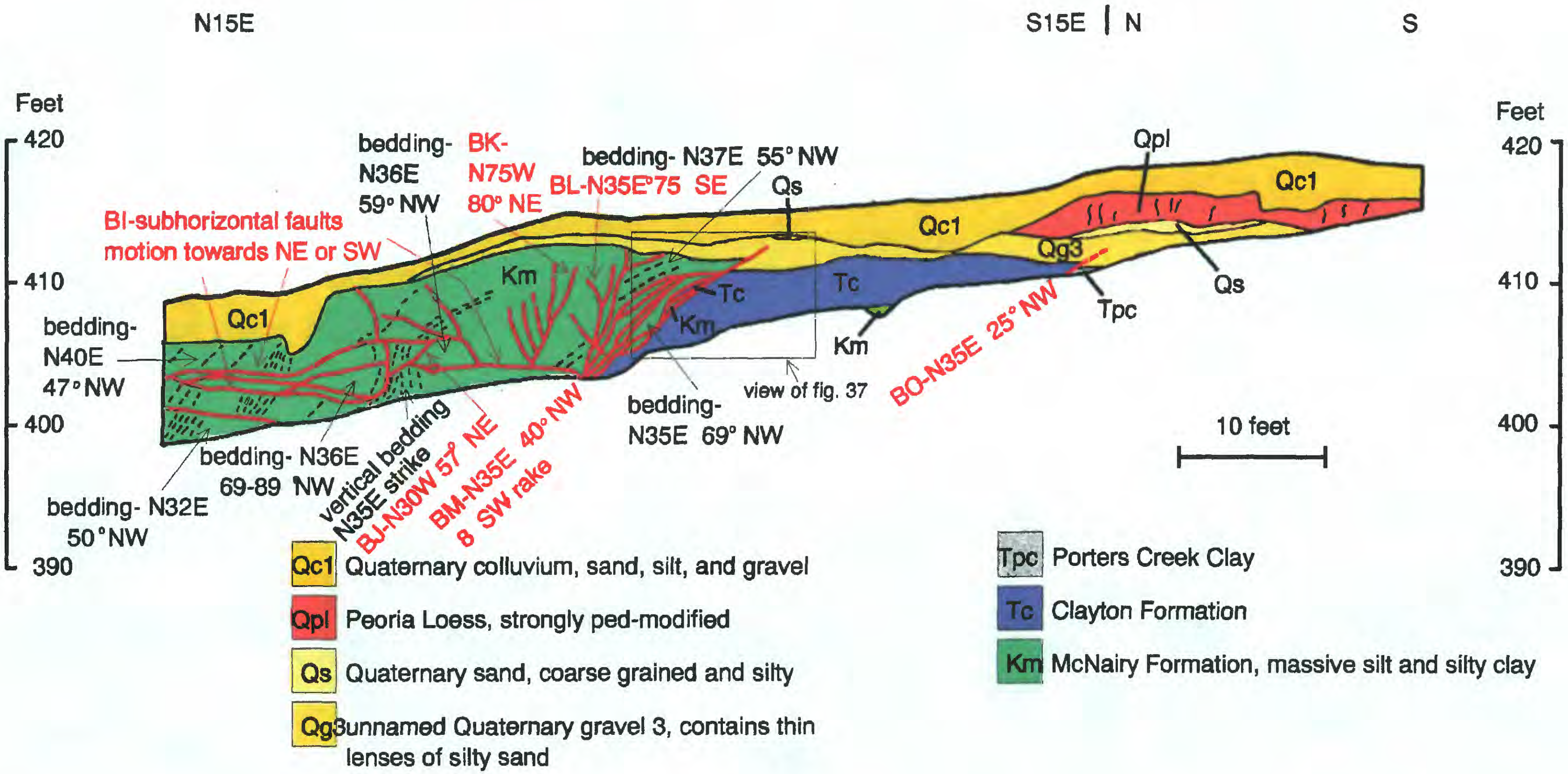
Profile 12.  Seismic Line Trench- NW Wall, eastern portion



Profile 13. Tuesday Trench-East Wall, northern portion.



# Profile 14. Tuesday Trench- East Wall, southern portion



# Profile 15. Weber Trench- SW wall, reversed.