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Paul Edwin Potter
University of Cincinnati

John Grover
University of Cincinnati

Gregory A. Schumacher
Ohio Division of Geological Survey

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Exploring a Small Thrust Fault and Related Features on U.S. Highway 62/68, Near Maysville, Mason County, Kentucky

Paul Edwin Potter[1], John Grover[1], and Gregory A. Schumacher[2]

[1]Department of Geology, University of Cincinnati
[2]Ohio Division of Geological Survey

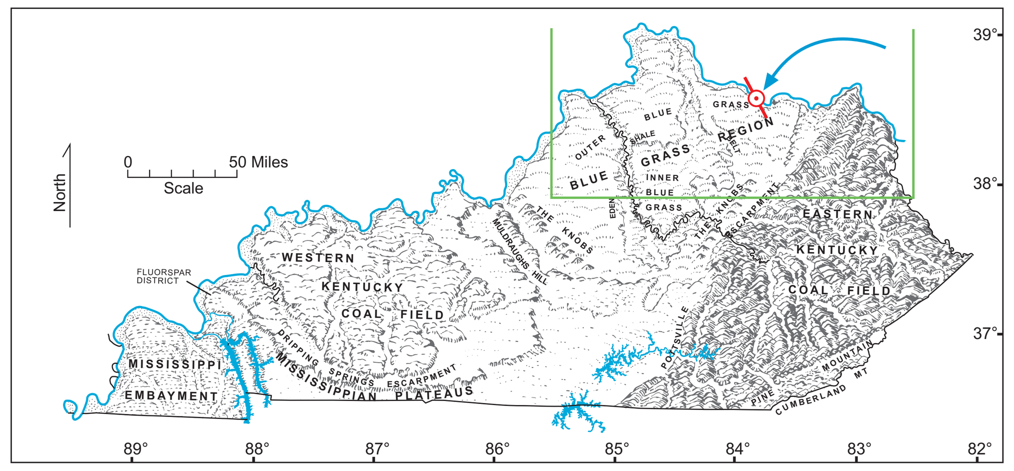

Figure 1. Physiography of Kentucky, showing location of the cut and strike of the fault.

Figure 2. Regional access map. The study site is located near the tip of the arrow, on U.S. Highway 62/68 (Kentucky Highway 3071). See Figure 9.

Introduction

One of the most unusual highway cuts in all of Kentucky is located approximately 395 ft (120 m) south of the high bridge that crosses Lawrence Creek on U.S. Highway 62/68, near Maysville, Mason County (see Figs. 1–2). The Carter coordinate location of the outcrop is 400 FSL x 900 FEL, 24-AA-69, which corresponds to 38°40'3" N latitude, 83°48'10" W longitude. The roadcut is approximately 1,315 ft (400 m) long, and rises in benches to a height of almost 110 ft (33 m). About 30 to 36 ft (9 to 11 m) of the Grant Lake Limestone is exposed at the top of the cut, accounting for about one-third of the total thickness of that formation. Below this, 108 ft (33 m) of the Fairview Formation is exposed, almost its full thickness. A low-angle overthrust fault is revealed in limestones and shales of Late Ordovician age (Fig. 3A–B). Many interesting small-scale deformational structures, a small cave passage, and other karst and solution features are associated with this thrust fault. Two key questions are, "How is this fault related to other, larger scale structural features in the area" and "When did the faulting occur?"

Evidence for Faulting

The thrust fault can be seen on both sides of the cut, where it is exposed for about 330 ft (100 m). It is marked by offset or disruption of the flat-lying beds and by brown clay and other iron-stained debris along the fault plane. The fault surface dips between 11 and 16° to the northeast, and strikes between N35°W and N39°W, almost perpendicular to the trace of the road. Small drag folds, best developed in the thin limestone and shale beds of the Grant Lake Limestone (greater than or equal to 80 percent limestone; less than or equal to 20 percent calcareous shale), at and above the second bench (Figs. 4–5), indicate that the upper plate has moved to the southwest over the lower plate. The shale and limestone interbeds of the underlying Fairview Formation (approximately 50 percent blocky, bioclastic limestone and 50 percent calcareous shale) show both bed-parallel movement and crossbed fracturing and offset, commonly associated with thrusting. Near the road surface on the east side of the cut, some thicker limestone beds broken by the fault are either thrust upward upon themselves (movement in a northeast–southwest sense), wedging into overlying shales; or downward, beneath themselves and into the underlying interbedded shales. This produces a complex pattern of interlayered insertions, including both overthrusts and underthrusts and numerous related folds and fractures (Fig. 6). All the structural features seen in this cut—drag folds, overthrusts and underthrusts, and stacked insertions caused by bed-parallel shortening—demonstrate convincingly that the fault is compressional, and not a slump feature related to the deeply incised valley of nearby Lawrence Creek or to any other contemporary topographic feature.

Overall, the upper plate of the fault has moved irregularly to the southwest along the fault plane from 3 to 10 ft (1 to 3 m), relative to the lower plate. In the Fairview Formation, compression was accommodated both by fracturing and by internal slip and contortional folding in the weak interbedded shales, as shown by the small bedding-plane thrusts (Cloos, 1964) (Fig. 6). The more competent Grant Lake Limestone, however, has conspicuous rupture- and brittle-failure features. The greater competence of the Grant Lake Limestone is the probable cause of a bifurcation or splay of the fault plane that occurs at the same stratigraphic position on both sides of the cut (Fig. 5).

Associated Fractures and Karst

A cave passage, approximately 7.5 ft (2.25 m) high and 5 ft (1.5 m) wide, is present on both sides of the cut, just above the intersection of the fault plane and the Fairview–Grant Lake contact (Figs. 7–8). At the time of excavation, both exposures of the cave were partially filled with light-brown, weakly laminated or slightly contorted silts, clays, and sporadic sand lenses (Fig. 8), although subsequent ground-water flow has eroded much of this sedimentary fill. Almost certainly the cave passage extended from one side of the cut to the other before it was excavated. Several small sinkholes and other minor karst features are present in the Grant Lake Limestone below the thin soil cover that caps the cut. Some vertical fractures or joints in the cut parallel those mapped by Gibbons and Weiss (1972) (Figs. 3B, 9), but other orientations also occur. Vertical fractures are largely limited to the Grant Lake Limestone, and are highlighted by dissolution features, iron staining, and brown clay fillings.

Ordovician Seismites

A deformed zone with well-defined, medium-size, penecontemporaneous ball-and-pillow structures occurs at the northeast end of the cut near the top of the Fairview Formation (Fig. 3). These structures occur widely in the area and have been interpreted by Pope and others (1997) and other researchers as indicating regional seismic shaking at the time the sediment was unconsolidated. A number of small, poorly developed ball-and-pillow structures, some consisting of only a few small, incipient load clasts, are also dispersed throughout the Fairview Formation at diverse stratigraphic levels and positions along the cut.

Interpretation

How is this thrust fault related to nearby structural features or to regional tectonic patterns? At least five large-scale features or patterns need to be considered.

(1) The thrust is adjacent to the Grenville Front, and strikes parallel to it and to a related complex of probable basement thrust faults that may rise toward the surface near the complex's western margin (Drahovzal and others, 1992; Drahovzal and Noger, 1995, Plate 1); see the heavy dashed line in Figure 10. The Grenville Front is the western limit of a relatively narrow, deep-crustal suture zone between very old continental plates. The suture zone extends north from the Ohio River into southeastern Canada and south into central Kentucky and beyond (Fig. 10).

(2) Locally, this thrust fault seems to mark the eastern limit of the Ohio-Indiana Platform (Wickstrom, 1990, Fig. 3); east of the roadcut the regional dip increases rapidly into the Appalachian Basin (Potter and others, 1991, Fig. 4).

(3) The contemporary principal stress field, which measures the orientation of principal crustal stresses, determined from fault-plane reconstructions for modern earthquakes and from down-well fracture behavior, is oriented nearly at right angles to the strike of the Maysville Overthrust, as shown in Figure 11 (Zoback and Zoback, 1980, 1991; Zoback and others, 1991). The maximum principal stress direction in eastern and central Kentucky has likely had a similar northeast–southwest orientation since Late Devonian time (Grover and Dupuis-Nouillé, 1992, 1995).

(4) Four recent earthquakes, all of small magnitude and all poorly constrained, occurred close to the Maysville Overthrust in Mason County (Fig. 10) (Hansen, 1984). Contours of the seismic intensity for the largest of these, which occurred in 1993 (marked in Figure 10 as lightly dashed lines), center in the vicinity of the Maysville Fault.

(5) The strike of the overthrust parallels a system of well-defined, northwest–southeast-trending surface fractures or systematic joints (dot-dash lines in Figure 9) that extends across the area (Gibbons and Weiss, 1972). Where they crop out in the Grant Lake Limestone, these fractures are marked by solution features, and many of the tributaries to local northeast-trending streams are oriented parallel to this fracture system.

In addition, mapped lineaments, shown as thin solid lines in Figure 10 (McHaffie, 1982), mirror the northwest–southeast trend of the strike of the fault or are oriented more or less at right angles to it. The shared alignment approximately perpendicular to the present regional stress pattern of the strike of the thrust fault (Fig. 11), the mapped fracture pattern, some local drainage (Fig. 9), and certain mapped lineaments imply a common origin for these minor structural features.

We consider the proximity of the overthrust to the projected basement faults along the Grenville Front and the overthrust's subparallelism to the strike of the Grenville Front to be the most significant evidence for the origin of this thrust. These basement faults could easily have been reactivated with continuing northeast–southwest compression along the continental suture that forms the Grenville Front. The occasional local earthquakes and the present-day orientation of principal crustal stresses, as well as the presumed directions of crustal plate movement in central North America (Zoback and Zoback, 1980), are all consistent with such a process. Thus, we suggest that the small overthrust in the roadcut south of Lawrence Creek represents a minor surface expression of movement of the basement along the Grenville Front sometime during or after Late Ordovician time. Could the parallel fractures mapped by Gibbons and Weiss (1972) (see also Fig. 1) represent a set of similar small thrust faults as they reached the surface and were etched by solution of the Grant Lake Limestone?

How does the fault behave in the deeper subsurface? It probably flattens significantly in the underlying shales of the Kope Formation, which are dominantly shale and about 280 to 296 ft (85 to 90 m) thick at this location, where plastic deformation and horizontal slip in shales probably prevailed over the brittle rupture seen at the surface. Deeper, in the thick, mostly carbonate section below the Kope, however, the fault should again steepen and have greater slip and appreciably more throw and rupture. In these deeper carbonate units the fault probably has features like those we see at the surface, including drag structures, brittle fracturing, and possibly splays.

When did faulting occur? The thrust fault at Maysville is younger than the Late Ordovician rocks it transects. We believe the cave (and cave fillings) postdate the fault because the base of the cave coincides exactly with the fault surface where it intersects the contact between the Fairview Formation and the Grant Lake Limestone. It seems improbable to us that a fault propagating upward would approach and pass precisely through both the base of a preexisting cave and a formation contact. Evidence from the cave sediment suggests, moreover, that solution of the limestone proceeded upward from the fault-contact intersection, enlarging the cavity progressively as water flowed through it. The large, angular pieces of limestone at the bottom of the cave (Fig. 8) must have fallen from the unsupported roof to lodge in the accumulating silt, mud, and sand. No vertical fractures intersect the cave passage on either side of the cut.

The local karst features, including this cave, probably formed in Late Tertiary time when the base level for local drainage fell abruptly, isolating fluvial sands and silts on local ridgetops and causing streams to cut down rapidly and deeply (Gibbons and Weiss, 1972; Luft, 1980). The Maysville West 7.5-minute topographic map, for example, shows that Lawrence Creek has well-developed incised meanders, and sandy alluvium of Late Pliocene–Early Pleistocene age (approximately 2 million years ago) can be found nearby on ridgetops, as shown in Figure 9. Thus, the fault must be older than the onset of cave (karst) formation, which probably coincided approximately with the beginning of incision of the local Teays drainage system in the Late Tertiary. Faulting, then, must have occurred sometime between Late Ordovician and Late Tertiary times. These time limits span at least 445 million years, and leave unresolved the possibility of post-Tertiary fault movement after formation of the cave.

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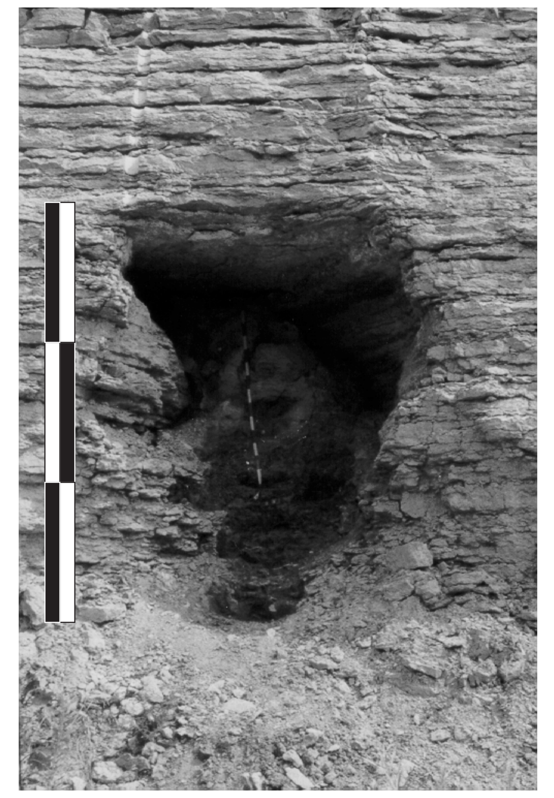


Figure 7. Small solution cave occurs on both sides of the cut; east is side shown here. The cave bottoms at the point where the fault meets the Fairview–Grant Lake Limestone contact, and is filled with silty clays and silts. White segments approximately 10 cm.

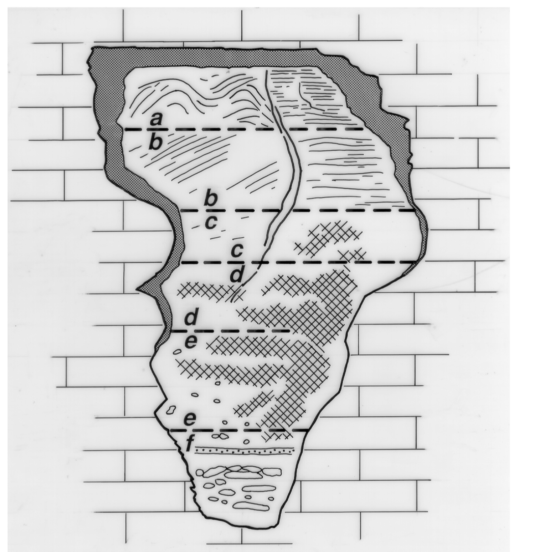


Figure 8. Properties of zones in the cave-sediment plug:
- a. Light tan to orange, deformed, silty clays; layering on the left is contorted.
- b. As above, but left side of the unit is laminated.
- c. Light-brown, poorly laminated, silty clays with some manganese mottles (cross-hatchures).
- d. Orange clay with abundant manganese mottles and small clay laminations.
- e. As above, with some small, angular limestone clasts.
- f. Sandy unit, with large, angular limestone clasts and manganese crust at the base.

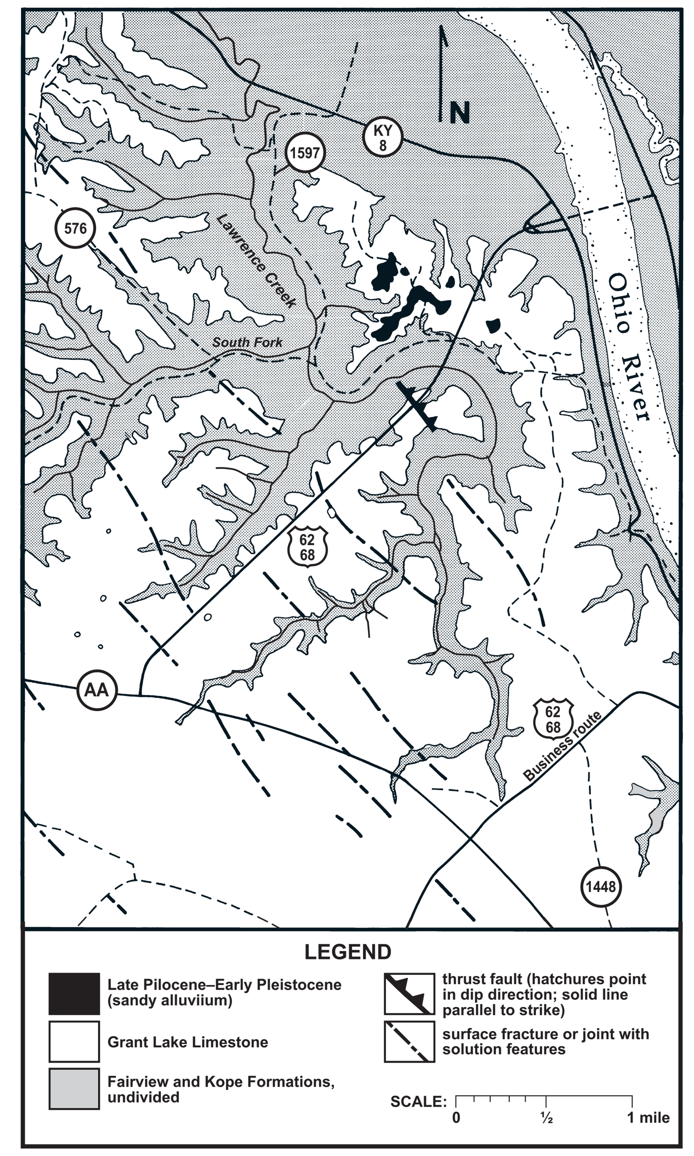


Figure 9. Simplified geology of the area, showing access highways, the base of the Grant Lake Formation, and local lineaments, as mapped on the Maysville West geologic quadrangle map (Gibbons and Weiss, 1972).

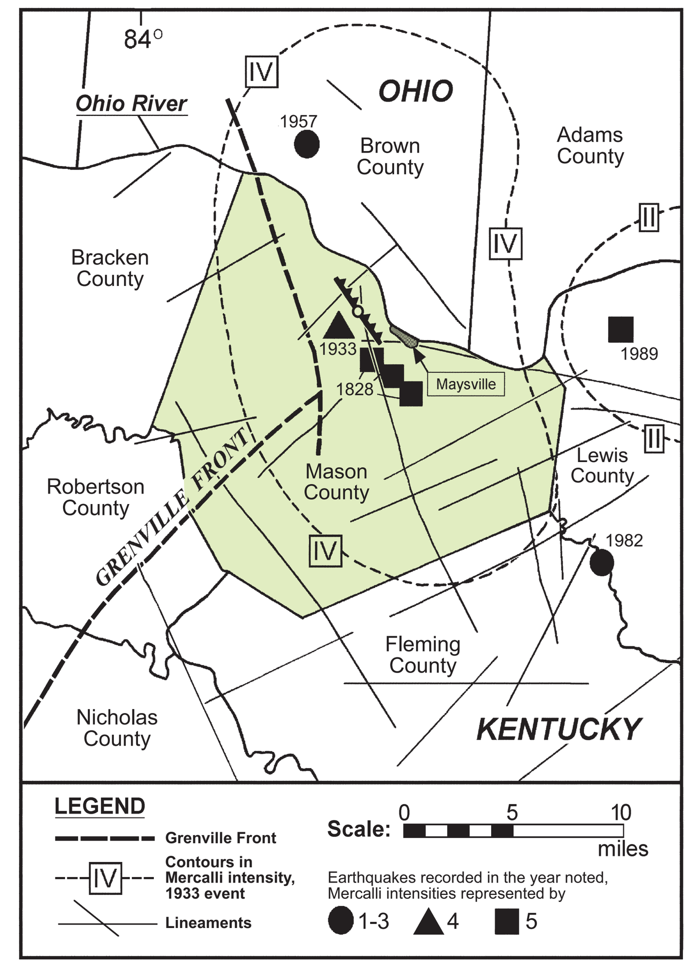


Figure 10. Seismic and structural information for Mason and adjacent counties in Kentucky. Note the proximity of the thrust to the Grenville front, their similarity in strike, and that mapped lineaments (McHaffie, 1982, sheet 8) are oriented subparallel or approximately perpendicular to the fault's strike. Note also the concentration of seismic epicenters near the thrust fault and the location of the thrust near the center of the contour pattern for level IV Mercalli intensities (Hansen, 1984).

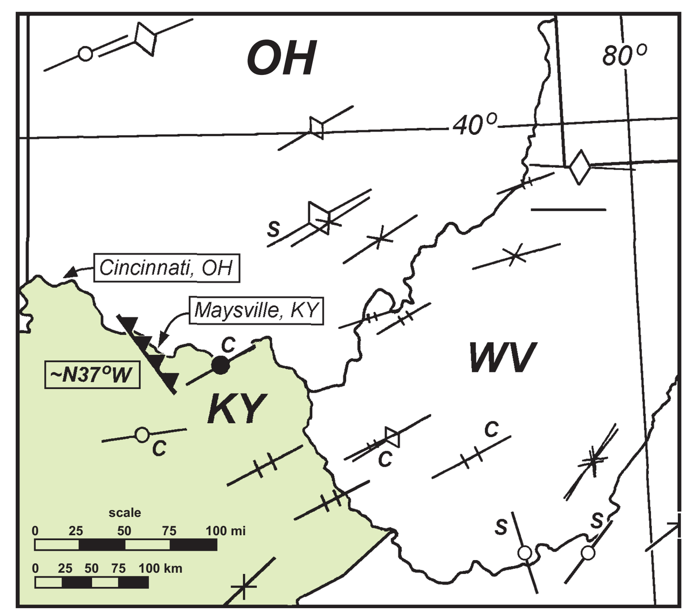
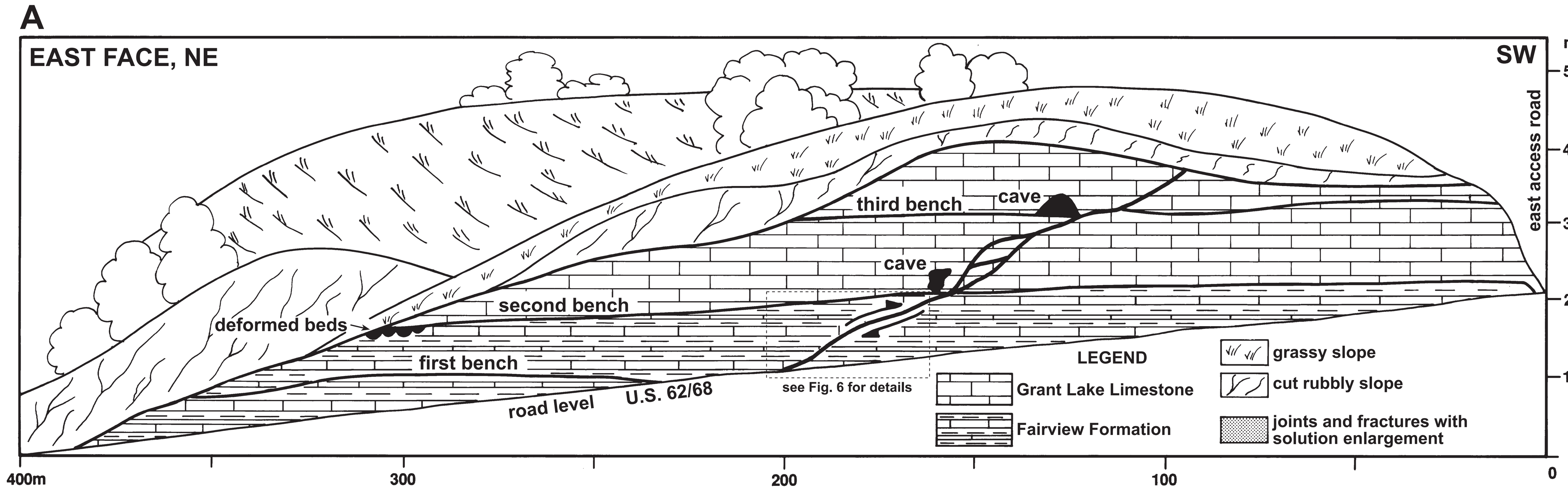


Figure 11. Measured directions of modern principal crustal stresses, σ_1, in northeastern Kentucky, southern Ohio, and western West Virginia, as determined from well-bore breakout [X] and stress relief [I I] measurements, seismic focal mechanism solutions [O], or hydraulic fracturing studies [◊]. *C* and *S* denote compressional and strike-slip stress regimes, respectively; where σ_1 is unmarked, there is no information on the relative magnitudes of component stresses (modified from Zoback and others, 1991).



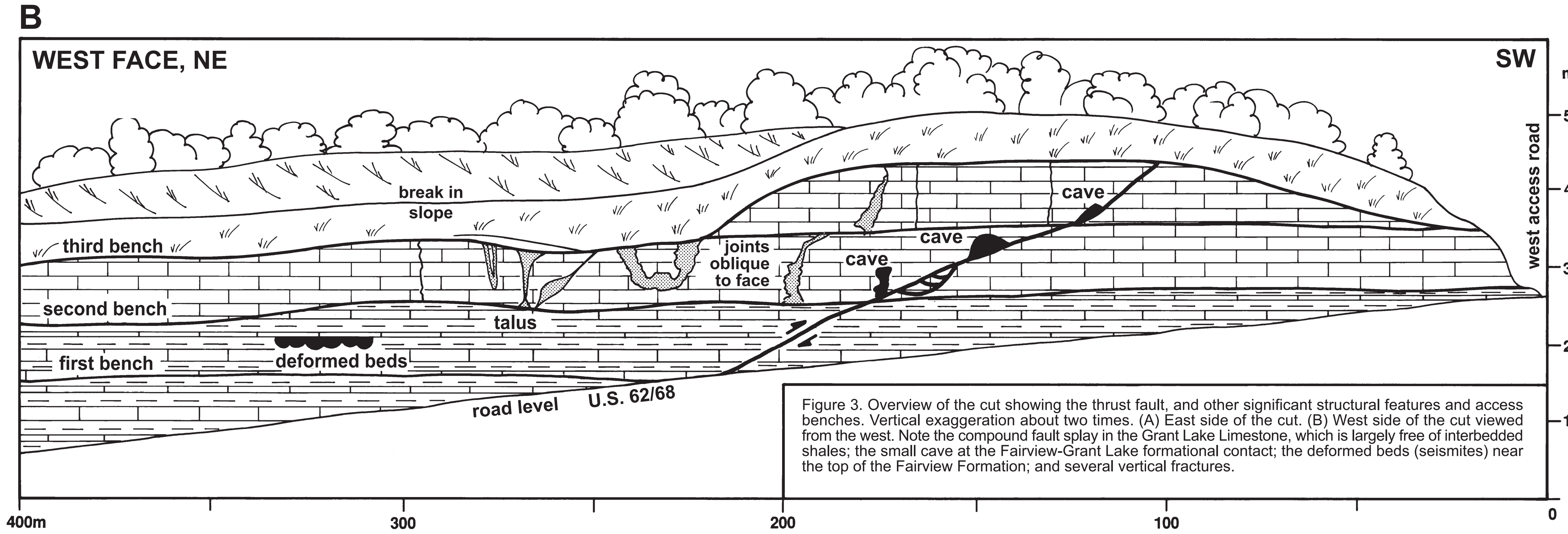


Figure 3. Overview of the cut showing the thrust fault, and other significant structural features and access benches. Vertical exaggeration about two times. (A) East side of the cut. (B) West side of the cut viewed from the west. Note the compound fault splay in the Grant Lake Limestone, which is largely free of interbedded shales; the small cave at the Fairview-Grant Lake formational contact; the deformed beds (seismites) near the top of the Fairview Formation; and several vertical fractures.

Figure 4. Drag folds in the Grant Lake Limestone showing the relative movement of the upper plate to the southeast over the lower plate.

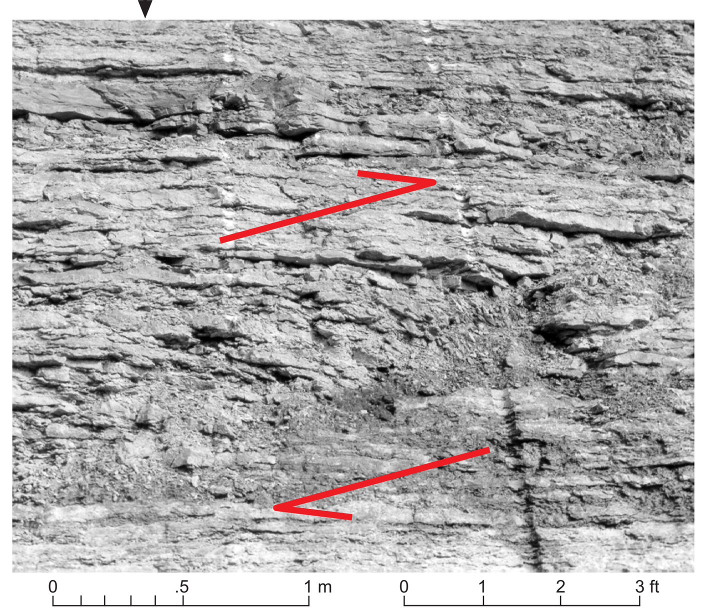


Figure 5. Overview of part of the east side of the cut showing bifurcation of the thrust to form a splay in the thin-bedded, less shaly Grant Lake Limestone. Note the small cave, located where the fault intersects the contact between the Fairview Formation and the Grant Lake Limestone. The cave (Figs. 7–8) contains a stratified and partly contorted silty clay sequence. No vertical exaggeration.

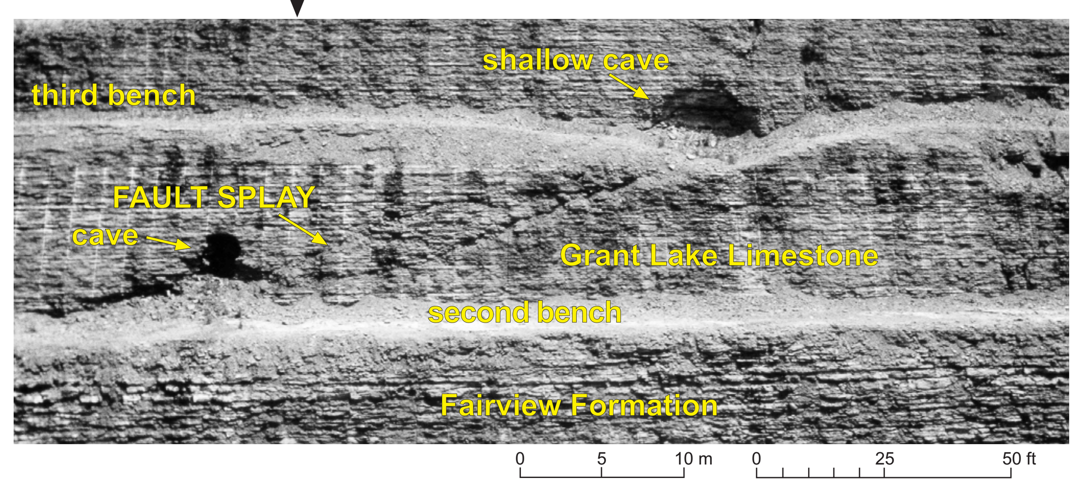
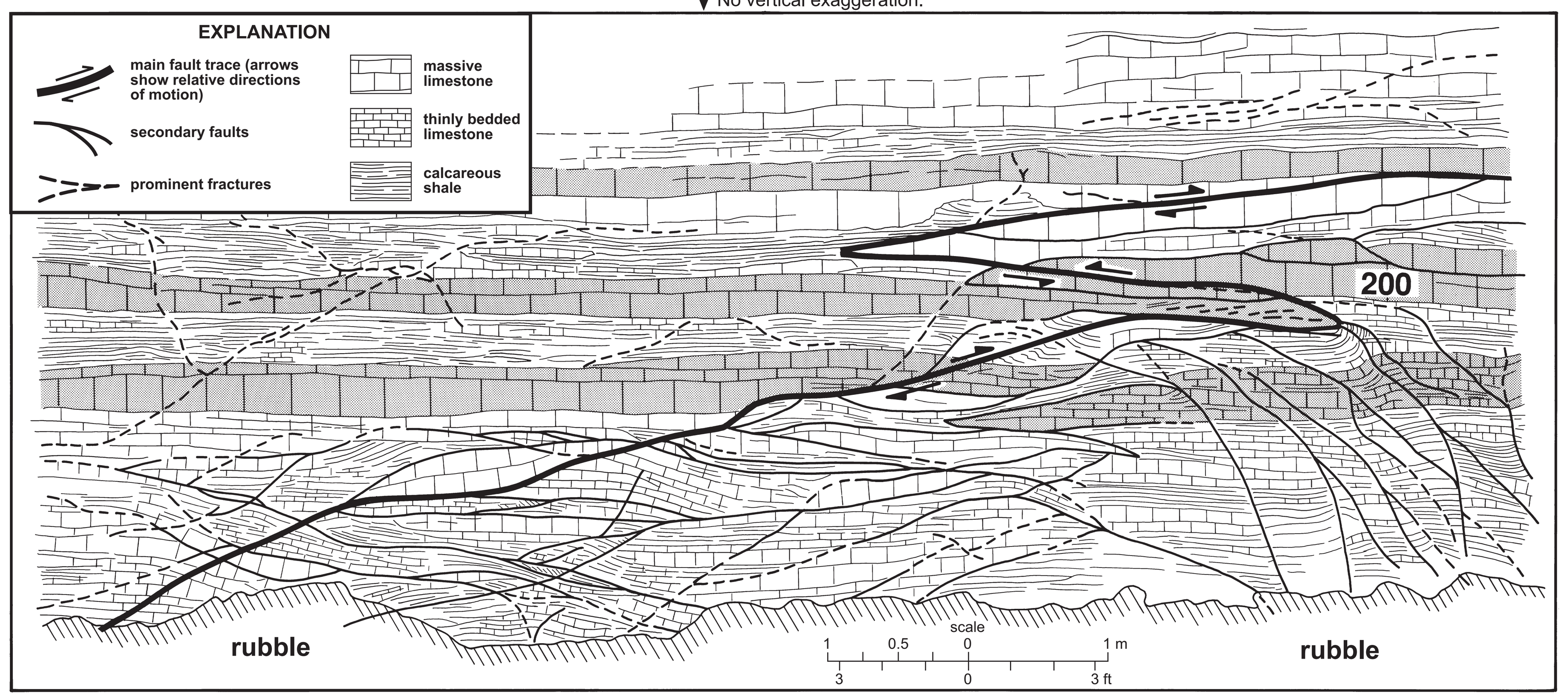


Figure 6. The main fault trace, showing complex bedding-plane slips and small thrusts in the interbedded shales of the Fairview Formation. Note how the thin shales facilitate underthusting where the fault plane intersects thicker and more competent limestone units above, and compare these features with the drag folds and simple rupture pattterns in the overlying Grant Lake Limestone (Fig. 5), which consists predominantly of limestone. Some blocky limestone layers are shaded to emphasize offset. Small faults and prominent fractures are shown with thin lines, and lightly dashed lines represent incipient fractures. No vertical exaggeration.



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