SELECTED STRUCTURAL FEATURES AND ASSOCIATED DOLOSTONE OCCURRENCES IN THE VICINITY OF THE KENTUCKY RIVER FAULT SYSTEM

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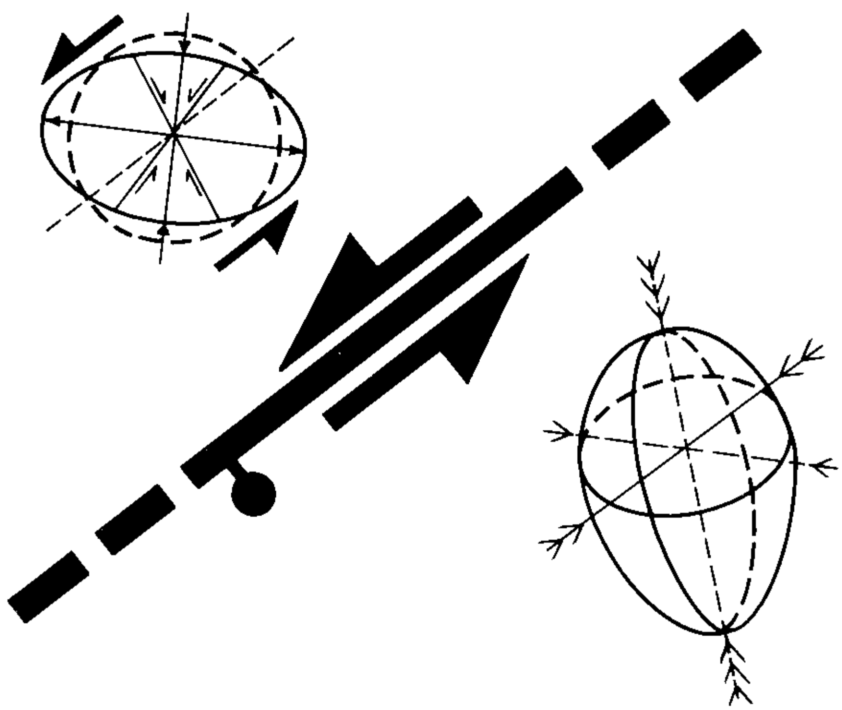

Annual Field Conference of the Geological Society of Kentucky

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Wallace W. Hagan, Director and State Geologist
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by

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and

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Annual Field Conference of the Geological Society of Kentucky
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DEDICATION

In memory of Don E. Wolcott who contributed part of the material contained in this guidebook.

the authors

CONTENTS

ILLUSTRATIONS

SELECTED STRUCTURAL FEATURES AND ASSOCIATED DOLOSTONE OCCURRENCES IN THE VICINITY OF THE KENTUCKY RIVER FAULT SYSTEM

Douglas F. B. Black[1] and Donald C. Haney[2]

INTRODUCTION

The purpose of this field trip is to observe some of the geological features of the Kentucky River fault system. The guidebook is based in part on field data collected by the authors and in part on data collected by others during the Kentucky Geological Survey-U.S. Geological Survey cooperative geologic mapping program. Eastern Kentucky University graduate students Don Phillips, Archie Martin, and Wayne Mandell contributed to the fracture studies. The field trip route is shown on Figure 1 and Plate 1.

The Kentucky River fault system, one of the major structural features of Kentucky, is a narrow band of normal faults and grabens trending northeastward from Casey County to Jessamine County, thence curving east-northeast to Montgomery County. The general sense of displacement is down on the southeast and the throw is as much as 600 feet. The West Hickman Creek fault system nearly joins the northeast trending part of the Kentucky River system in southern Jessamine County and extends northeastward into Bourbon County. The structurally highest part of the Jessamine (Lexington) dome is adjacent to these two major fault systems and parallels them on the northwest, forming part of the larger feature, the Cincinnati arch. In addition to the northeast- and east-northeast-trending faults, there are hundreds of northwest-trending normal faults and grabens in central Kentucky, most having throws of less than 100 feet but some having greater throws, as much as 700 feet.

[1] U.S. Geological Survey, Lexington, Ky. Publication authorized by the Director.

[2] Eastern Kentucky University, Richmond, Ky.

Fracture studies were made at two localities that we shall visit, Boonesborough (first day) and Camp Nelson (second day). At both localities, several joint sets appear to be related to complex normal and reverse faulting; however, two well-developed sets at each locality are interpreted to be conjugate shear joints indicative of left-lateral wrenching. This sense of displacement is contrary to many published reports in which right-lateral displacement of many miles has been suggested. A brief history of geologic studies of the 38th parallel lineament (in which the Kentucky River fault system is included) has been given by Heyl (1972). Though there is considerable difference of opinion as to trend and origin of this major east-trending lineament, much evidence is reported which supports the hypothesis of an ancient structural feature or features of transcontinental proportions in deep-seated rocks. Limited deep drilling in central Kentucky shows major differences in thickness of formations of Cambrian and Ordovician age across both the Kentucky River fault system and the Irvine-Paint Creek fault system to the south; consequently, the depth to the Precambrian basement is greater on the downthrown sides of the faults (Webb, 1969). No appreciable difference in thickness of rock units extending from the base of the High Bridge Group of Middle Ordovician age to the Middle Silurian-Middle Devonian unconformity has been observed across faults in this area, evidence that tectonism in central Kentucky was relatively quiescent during this time period. Tectonism was again intermittently active beginning sometime prior to the Middle Devonian and extending into Pennsylvanian and perhaps Permian time. Surface mapping of the "Mud Cave" bentonite bed (informal usage), preserved locally beneath

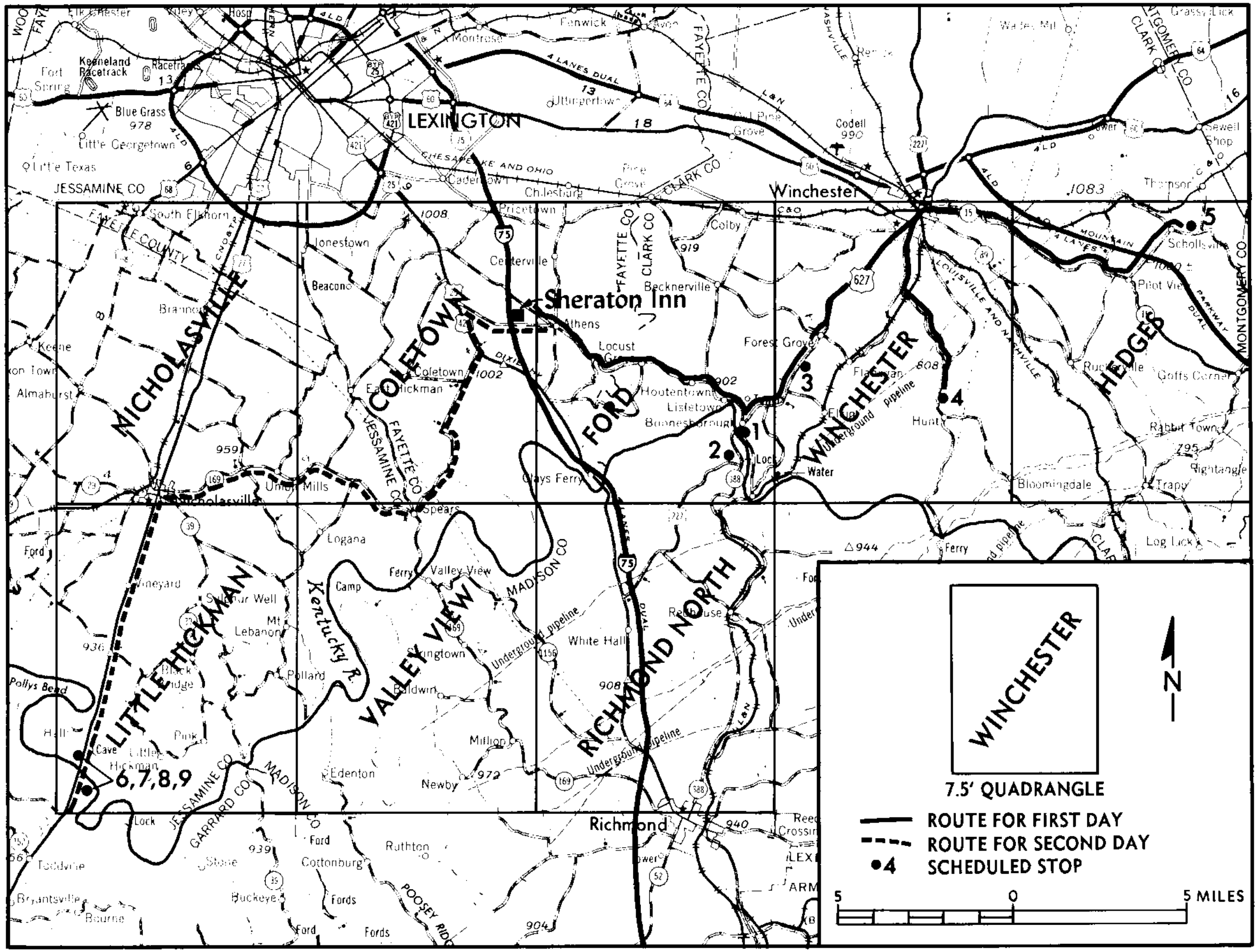


Figure 1. Map showing route of field trip.

the pre-Lexington Limestone unconformity, and isopachous maps of several facies in the Lexington (Cressman, 1973) show that major lateral offset (more than 1 or 2 miles) of surface rocks by faults of the Kentucky River system is not possible. Heyl (oral communication, 1975) noted that right-lateral strike-slip displacements of 40 miles or more suggested for faults of the 38th parallel lineament are based on presumed offset of basement features suggested from geophysical studies, and these fault relations would not necessarily extend to surface rocks.

Part of the field trip will be concerned with dolostone and consideration of its origin. In part, it occurs as widespread stratiform bodies called stratigraphic or S-dolostone (Dunbar and Rodgers, 1957, p. 238). Dolostone of the Oregon Formation (Middle Ordovician), seen at Stops 1 and 6, is this type. Many lithologic characteristics, both in the dolostone and in associated limestone, suggest that this dolostone is synsedimentary or early diagenetic. Many bodies of dolostone bounded by faults have been mapped in central Kentucky. They are of small areal extent, are bordered by unaltered limestone formations, and are distant both laterally and vertically from occurrences of S-dolostone. Some of these are products of alteration of local limestone formations to dolostone and dolomitic mudstone and are called tectonic or T-dolostone (Dunbar and Rodgers, 1957, p. 238, 239). This type will be seen at Stops 3 and 4. In one of the bodies evidence shows that the mineralizing solutions rose from below. Dolomitization was possibly accomplished by hydrothermal brines moving upward along fracture conduits. At Stop 5 we shall see evidence for another mode of local dolostone emplacement—as part of a graben fill in which large blocks, derived partly from regionally dolomitic formations (S-dolostone) and partly from unaltered limestone formations higher in the section, have been downthrown as much as 550 feet. Many other fault-associated dolostone bodies have been mapped in central Kentucky and the origin of some of them is still unknown. These are therefore called U-dolostone bodies.

FIRST DAY OF FIELD CONFERENCE

Friday, October 31, 1975

ROAD LOG

Mileage

0.0 Assemble in parking lot of Sheraton Inn on Athens-Boonesborough Road east of Interstate Highway 75 interchange (Fig. 1 and Plate 1). Rocks seen in roadcuts to west and north are nodular fossiliferous limestone and shale of the Millersburg Member of the Lexington Limestone (Plate 2). Turn right (eastward) onto Athens-Boonesborough Road.

1.2 Cross small stream at border between Coletown and Ford quadrangles.

1.6 Intersection with Cleveland Road in Athens. Stay on Athens-Boonesborough Road.

3.0 Intersection with McCalls Mill Road. Sparse outcrops in area are the Grier Limestone Member of the Lexington Limestone.

3.2 Cross one of a series of north-northeast-trending mineral veins (not visible from bus) arranged en echelon in a northeast-trending zone. Minerals include barite, fluorite, sphalerite, and galena. Veins occur in the Grier and Curdsville Limestone Members of the Lexington Limestone and in the underlying Tyrone Limestone.

3.5 Cross Boone Creek, leaving Fayette County and entering Clark County. Home of John Jacob Niles, famous Kentucky folksinger on left across creek. Early in the century, barite was mined from the Smitha and Dugan veins about 0.25 mile up the creek. The Smitha vein occurs along a reverse fault dipping 75° to 80° NW; stratigraphic offset is about 5 feet. Horizontal slickensides on vein walls and within the vein material suggest post-mineralization strike-slip movement; the direction and amount of horizontal offset was not determined at this locality.

3.6 Tyrone Limestone-Lexington Limestone contact on left; micrite directly overlain by calcarenite. Bentonite bed ("Mud Cave") locally found at contact, especially in areas to the west, is absent here. Contact is unconformable.

4.8 Locust Grove. Exposures of the Grier Limestone Member of the Lexington Limestone.

5.2 Intersection with Jones Nursery Road. Irregularly bedded to nodular, fossiliferous limestone of the Grier Limestone Member is exposed in quarry to the left. About 1 mile to the north [See geologic map of the Ford quadrangle (Black, 1968) and Plate 1], a thick vein has been displaced along several en echelon, east-northeast- to northeast-striking right-lateral faults. At least 3,000 feet of lateral displacement is indicated. The vein is locally as much as 9 feet thick; faulted vein segments generally strike north-northeast. Ends of individual segments are locally brecciated and have northeast-striking horizontal slickensides.

6.3 Tyrone-Lexington contact beneath stone wall on left.

6.4 Jouett Creek. Tyrone-Lexington contact is in roadcut to the right. Proceeding uphill, note that calcarenite of the Curdsville Limestone Member, basal unit of the Lexington Limestone, grades into nodular limestone of the overlying Grier Limestone Member of the Lexington. Curdsville-Grier contact is not mapped in this area.

7.1 Intersection of Athens Road with Combs Ferry Road; country store on northwest corner. Proceed to right.

7.5 Tyrone-Lexington contact in ditch on left side of road opposite Kettle Spring Farm entrance.

7.7 Road intersection. Contact between Tyrone Limestone and underlying Oregon Formation, just below the level of the intersection, is exposed at left of road. Oregon is in three parts: a thick lower dolostone sequence, a middle limestone sequence, and a thin dolostone sequence at top.

7.9 Contact between Oregon Formation and underlying Camp Nelson Limestone well exposed on left. In mapping, this contact was placed to include thick beds of dolostone, generally several feet thick, in the Oregon. Perforate "honeycomb" weathered surfaces, well exposed below the Oregon in the roadcut on the left, are caused by differential weathering of dolostone-filled burrows which are interlaced with micritic limestone. This lithology is characteristic of, though not restricted to, the Camp Nelson Limestone.

8.0 Hall's Restaurant--good place to eat.

8.3 Quarry on left exposed Camp Nelson Limestone (at base), Oregon Formation, and Tyrone Limestone.

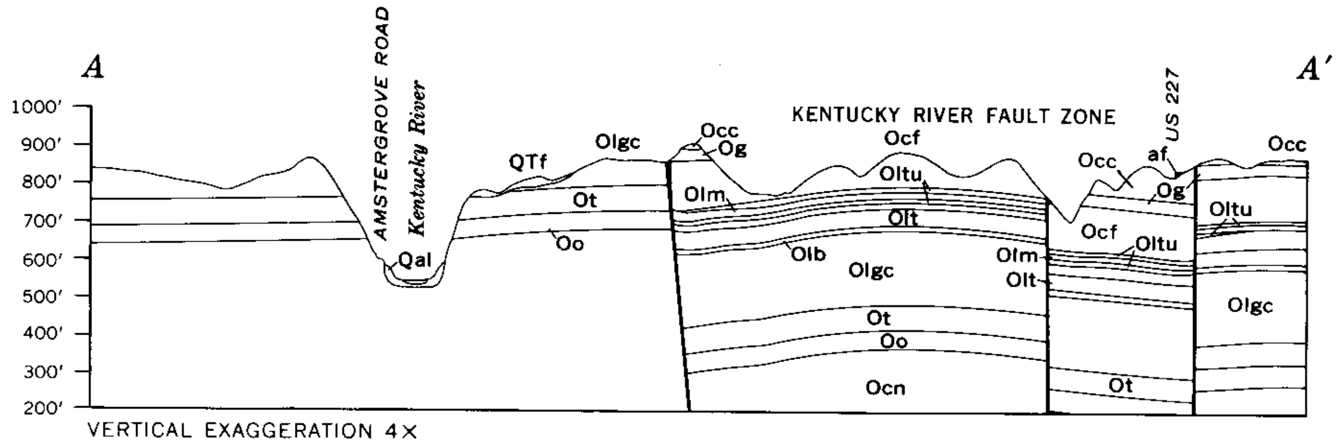
9.1 Stop at 4-way intersection just beyond underpass of Boonesborough Memorial Bridge. Bus will discharge passengers beneath Kentucky Highway 627 overpass and proceed up hill to the parking area at Daniel Boone Inn, east of the bridge.

STOP 1 (Refer to Figs. 2-7 and Plates 1 and 2.)

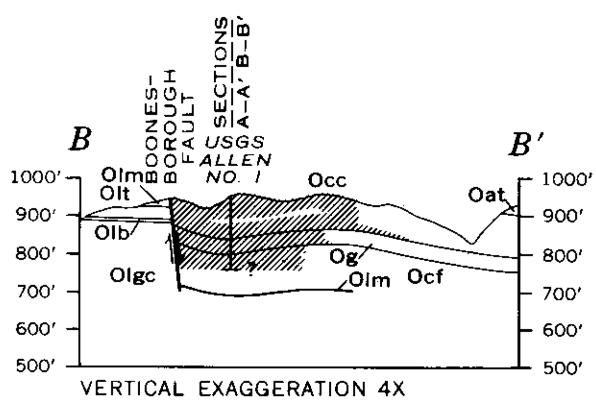
The purpose of Stops 1 and 2 is to show general characteristics of the Kentucky River fault system (Plate 1 and Figs. 2, 3) and certain local features. Proceed uphill on foot. Stratigraphic units (Plate 2) exposed in the roadcuts are the following: (1) at base, the middle tongue of the Tanglewood Limestone Member of the Lexington Limestone whose upper contact approximates the position of the Middle-Upper Ordovician boundary (base of the Cincinnatian) in this area; (2) a tongue of the Clays Ferry Formation whose lithology here is transitional between rock types characteristic of the Lexington Limestone and of the Clays Ferry (the tongue is more typical of Clays Ferry at Stop 2); (3) another tongue of the Tanglewood; (4) the Millersburg Member of the Lexington; and (5) the base of the main body of the Clays Ferry Formation (note concentrations of crinoid columnals and rare *Sowerbyella* brachiopods characteristic of this horizon). The uppermost tongue of the Tanglewood, which is present across the river, is missing here. Evidence of minor-displacement growth faulting in the upper Lexington is shown at this outcrop by differences in thickness of a shale bed underlying the Millersburg on opposite sides of a minor fault (Fig. 4).

Proceed northward across the new road fill to the Boonesborough fault. An unnamed normal fault, downthrown about 50 feet on the south side, is concealed by the fill. This fault is exposed across the river near the Kentucky Stone Company quarry. The Boonesborough fault is normal, dips about 75° S., and has brought steeply dipping Lexington Limestone (possibly the middle tongue of the Tanglewood) against the lower part of the Oregon Formation and upper part of the Camp Nelson Limestone. Several minor steeply dipping synthetic and antithetic normal faults can be seen in outcrops north of the main fault. In addition to vertical stresses shown by the normal faulting, horizontal compression is indicated by nearly vertical shear joints in conjugate sets. These joints (sets S_1 and S_2, Fig. 5) are best developed in dolostone beds. They are commonly smooth and many have horizontal corrugations (Fig. 6). They suggest that at one time the maximum shear stress was horizontal and that the intermediate axis of the stress ellipsoid was vertical. Archie Martin of Eastern Kentucky University measured many joint and fault-plane attitudes in the Boonesborough area. These were plotted on a Schmidt equal-area stereographic net; mean directions for six joint sets were established by contouring, and these directions were then transferred to the strike diagram (Fig. 5). A similar study was made, by Donald Phillips and Wayne Mandell of Eastern Kentucky University, at Camp Nelson where conjugate shear joints were also found. Assuming wrenching, which was postulated by Heyl (1972) and other authors, along the Kentucky River fault system, we compared the joint patterns at both Boonesborough and Camp Nelson

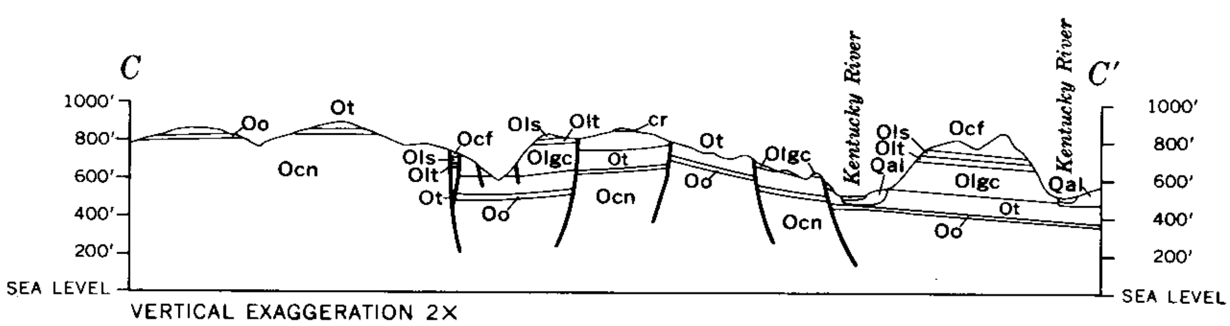
Figure 2. Geologic map of parts of the Ford and Winchester quadrangles (modified from Black, 1968 and Black, 1974). Scale 1:24,000. Structure contours on top of the Garrard Siltstone in southeast corner; on base of the Brannon Member of the Lexington Limestone elsewhere; contour interval 10 feet. Open circles near stops indicate route of walking traverses. See Plate 2 for explanation of bedrock symbols and lithologic descriptions; cross section A-A′ is shown on Figure 3.



Geologic cross section for Stops 1 and 2 (modified from Black, 1968). See Figure 2 for location.



Geologic cross section for Stop 4 (modified from Black, 1974). See Figure 10 for location.



Geologic cross section for Stops 6, 7, 8, and 9 (modified from Wolcott, 1969). See Figure 13 for location.

Figure 3. Geologic cross sections.

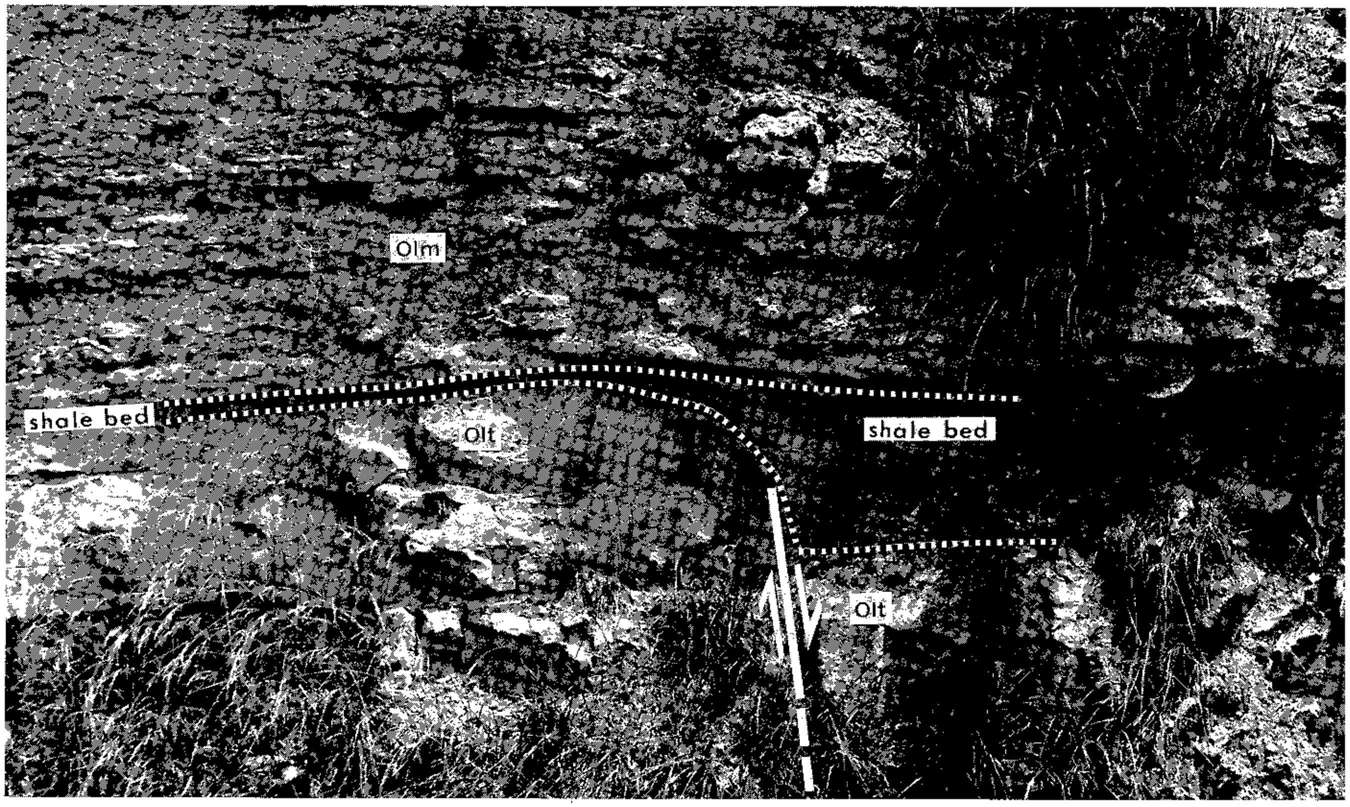


Figure 4. Evidence of minor growth faulting during deposition of the Lexington Limestone. Exposure at Boonesborough on east side of Lisletown-Ford Road south of Kentucky Highway 627. Olm, Millersburg Member; Olt, Tanglewood Limestone Member.

with the fracture array on the strain ellipse for basic wrench tectonics (Fig. 7) and found that left-lateral wrenching (not right-lateral as expected) was suggested.

The Oregon Formation and Tyrone Limestone are well exposed in the new roadcut for Kentucky Highway 627.

9.2 Reboard bus at Daniel Boone Inn at east end of Boonesborough Memorial Bridge. Proceed across bridge; quarry on right is in Camp Nelson Limestone.

9.5 The Tanglewood Limestone Member of the Lexington Limestone is well exposed on the right.

9.9 Intersection of Kentucky Highways 627 and 388.

STOP 2 (Refer to Figs. 2 and 3 and Plates 1 and 2.)

Disembark at the small-displacement normal fault, downthrown on the northwest, in the roadcut opposite the intersection of Kentucky Highway 627 and Kentucky Highway 388. The middle tongue of the Tanglewood Limestone Member and the upper part of the Brannon Member of the Lexington Limestone are exposed on the upthrown side, faulted against the middle Tanglewood. The bus will proceed to the turnaround area at the hilltop and await our arrival.

Proceed southward on foot, observing the middle Tanglewood and the lower tongue of the Clays Ferry Formation, here more characteristically containing thin, tabular-bedded limestone, in large part micrograined (calcisiltite), interbedded with gray shale. Here the thin bed of Tanglewood, seen at Stop 1 overlying the Clays Ferry tongue, occurs near the top of the exposure north of an extensive road fill. This is overlain by the Millersburg Member and the uppermost tongue of the Tanglewood which are mostly covered. However, high on the hillside, ledges of the uppermost Tanglewood are exposed in a few places east of the powerline swath. Proceed across the road fill to exposures of the uppermost Tanglewood tongue, overlain by a thin zone of Millersburg that is included with the Tanglewood on the geologic map of the Ford quadrangle (Black, 1968), and the basal part of the main body of the Clays Ferry Formation containing the brachiopod *Sowerbyella* in the outcrop just above. The Clays Ferry fault exposed in this roadcut is so named because this is the fault across which major displacement occurs at Clays Ferry, Ky. The fault here is marked by an eroded gully, and careful examination of the beds in the gully shows displacement. Here the lower part of the Clays Ferry Formation on the upthrown side (north) is displaced against upper Clays Ferry on the downthrown side. The Garrard Siltstone is exposed up the road and in the hillside above on the downthrown side of the fault. The normal interval of the Clays Ferry in this area, not including the lower tongue, is about 125 feet. This interval has been shortened by faulting here.

Proceed uphill, viewing discontinuous exposures of the upper Clays Ferry, the Garrard, and the lower part of the Calloway Creek Limestone, to the Ford fault, named for excellent exposures of this fault at Ford, Ky., northeast of the river. The Ford fault is downthrown on the northeast, displacing Calloway Creek Limestone against Garrard Siltstone and Calloway Creek Limestone on its southwest side. The fault is not exposed here, but its position can be determined fairly accurately on the basis of stratigraphic offset of units exposed in roadside outcrops on either side of the fault. Note the lithology and the irregular bedding of the Calloway Creek Limestone. Reboard bus and travel northeastward along Kentucky Highway 627.

10.6 Daniel Boone Inn.

11.2 The Tyrone-Lexington contact is poorly exposed near the top of the roadcut on the left, approximately 10 feet above the top of the limestone ledges.

11.7 The Grier Limestone Member, the Cane Run Bed, and lower tongue of the Tanglewood Limestone Member (see columnar section, Plate 2) are exposed in roadcut (note solution-enlarged joints).

11.9 Lower Tanglewood-Brannon Member contact at hilltop (in bank beside farm-access road). Bentonite at least 6 inches thick is exposed just below the Brannon. This bentonite is probably time equivalent to other patches of bentonite occuring in similar stratigraphic positions elsewhere in central Kentucky. In and near Versailles, Ky., about 30 miles northwest of here, it occurs within the Brannon Member about 2 feet above the basal contact. Here it closely underlies the Brannon, separated from it by a little more than a foot of brachiopodal limestone.

12.1 Base of the Brannon is exposed at top of limestone ledges. Bentonite bed is missing here.

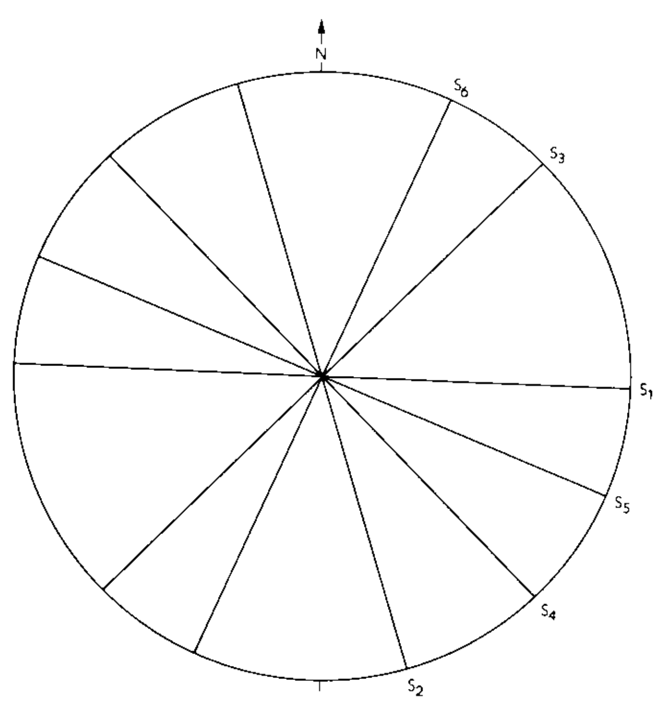


Figure 5. Strike directions of six principal joint sets at Boonesborough. Modified from diagram by Archie H. Martin III, Eastern Kentucky University. Average strike direction determined from polar plot of 237 measured joints made on Schmidt equal-area stereographic net. Sets S_1 and S_2 represent corrugated joints interpreted to be conjugate shears indicative of left-lateral wrenching (compare with Fig. 7).

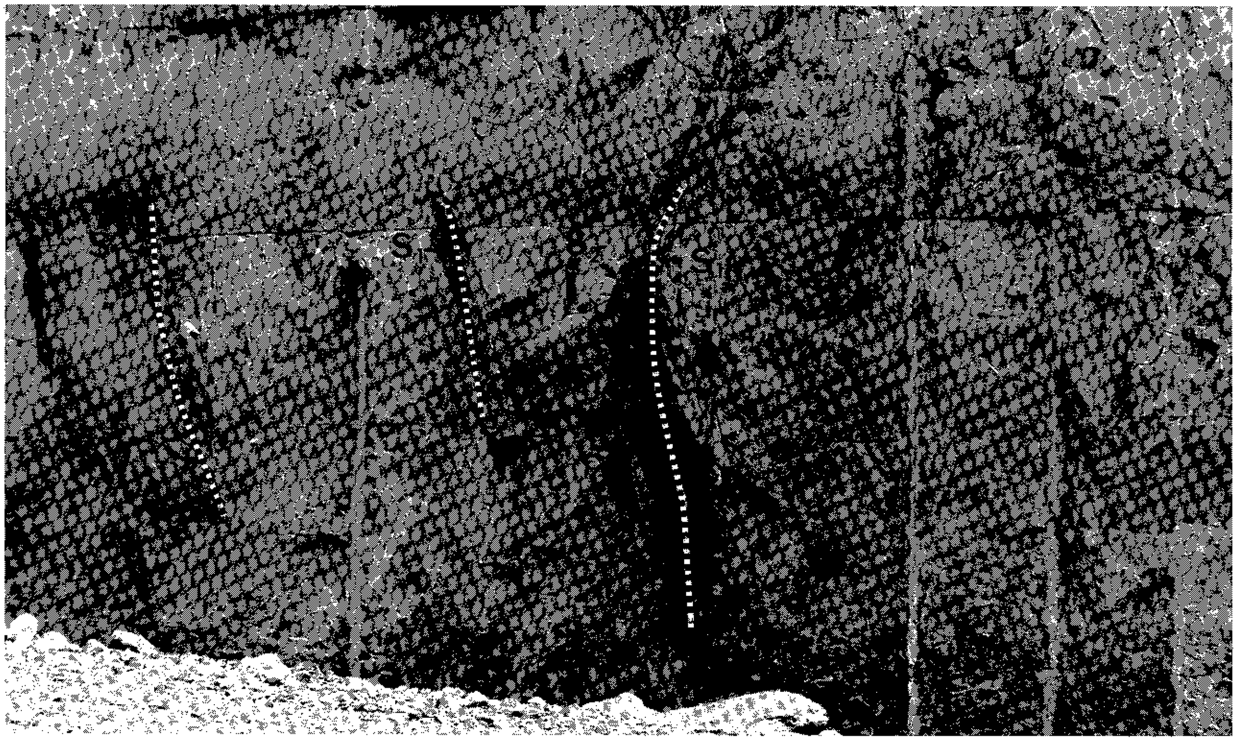


Figure 6. Corrugated wrench shear joints in dolostone beds of the Oregon Formation along the southeast side of Kentucky Highway 627 at Boonesborough.

12.6 Lower tongue of the Tanglewood and the Brannon are poorly exposed in roadcut on left.

12.8 Contact between the Brannon and overlying middle tongue of the Tanglewood is exposed in cut to right of road.

13.5 Stop 3. Bus will discharge passengers and wait on the southwest side of the valley. After we have viewed the outcrops, bus will be flagged forward for boarding.

INTRODUCTION TO DOLOSTONE OCCURRENCES

Dolostone associated with faults has been found at many localities in central Kentucky. Until the discovery of country-rock alteration at Stoner Branch, all was interpreted as belonging to younger S-dolostone units (stratigraphic dolostone, Dunbar and Rodgers, 1957, p. 238), such as the Preachersville Member of the Drakes Formation, downfaulted against older limestone units. Dolostone at these isolated localities has a remarkable lithologic similarity to dolostone in rocks of Late Ordovician, Silurian, and Devonian ages. At present, two modes of occurrence, (1) alteration of country rock to T-dolostone (tectonically controlled dolostone, Dunbar and Rodgers, 1957, p. 238-239) and (2) displacement of S-dolostone as grabens, have been documented on the basis of identification of included fossils, as well as other criteria.

Four bodies of dolostone at Stops 3, 4, and 5 occur in close association with faults. They are isolated and distant both horizontally and vertically from the nearest exposures of regionally dolomitic (S-dolostone) formations. Origin of many dolostone bodies associated with faulting in the area is unknown (U-dolostone), but of those we shall see on the field trip, the first two (at Stop 3) have resulted from local alteration of country rock by solutions rising along faults (first body) and fractures (second body), which acted as conduits for hydrothermal solutions and are called T-dolostones. The dolostone body at

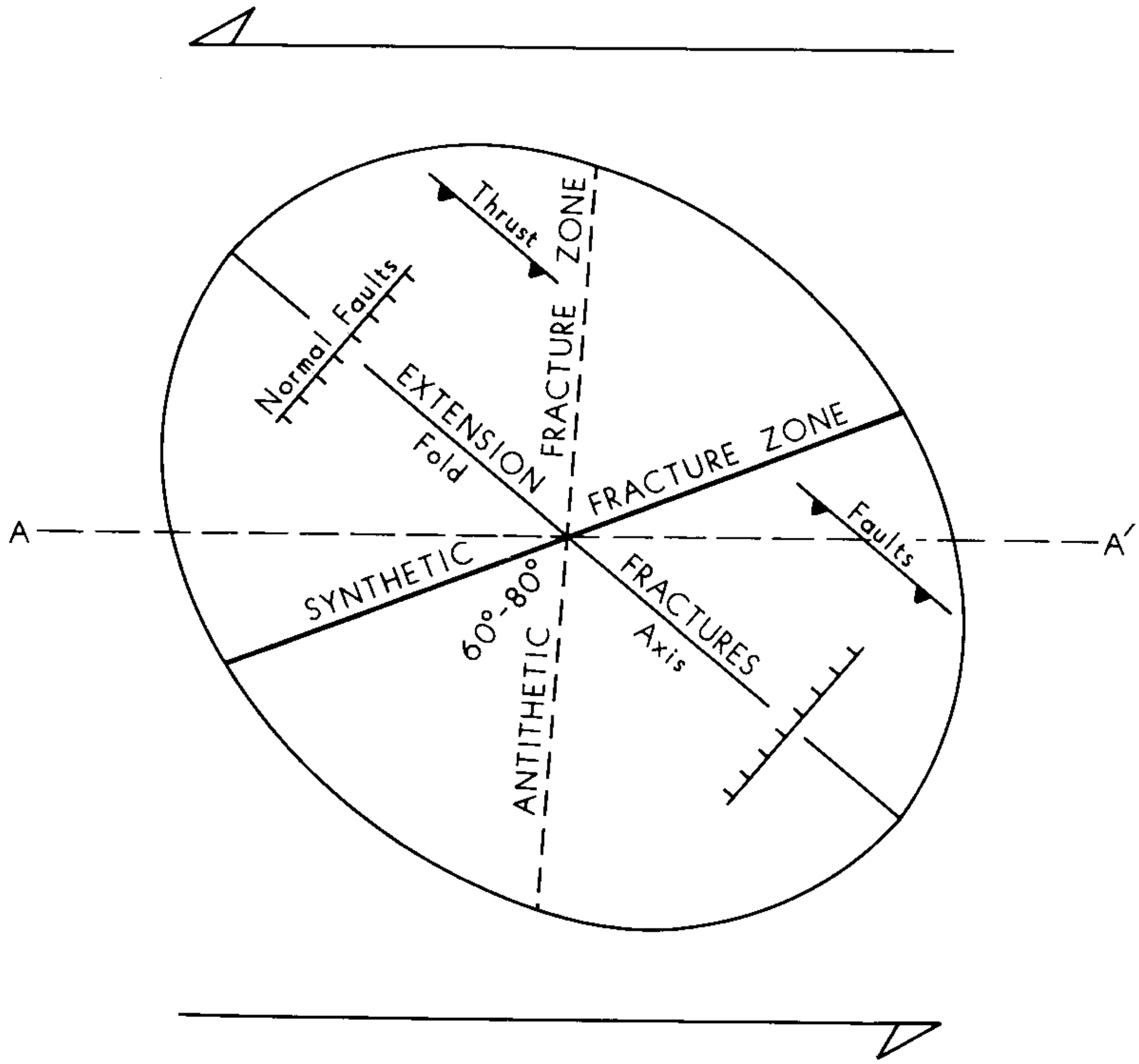


Figure 7. Strain ellipse showing orientation of structural features associated with left-lateral wrenching. Modified from Harding (1974). Wrench strike A-A′.

Stoner Branch (Stop 4) also originated as an alteration product (T-dolostone), whereas the dolostone at Stop 5 is S-dolostone downfaulted from the regionally dolomitic Rowland Member of the Drakes Formation and the Brassfield Dolomite as huge blocks as much as hundreds of feet across. These blocks together with blocks of limestone and shale derived from the Grant Lake, Terrill, and Reba Members of the Ashlock Formation make up a body which we call megabreccia because of the huge size of its component fragments. The megabreccia graben is displaced against the Calloway Creek Limestone and the Garrard Siltstone.

STOP 3 (Refer to Figs. 2, 8, and 9 and Plates 1 and 2.)

During our trip from Stop 2, a leader in your bus has pointed out, in ascending order, the position of the Tyrone-Lexington contact, the Grier Limestone Member, the Cane Run Bed, the lower tongue of the Tanglewood Limestone Member, the Brannon Member (the upper contact of which occurs at the southwest end of this cut), the middle Tanglewood, and, at the top of the cut, the basal Millersburg. As we proceed across the road fill, we shall be crossing a graben (as mapped), or possibly a single fault, along which dolomitization has occurred. Dolostone and dolomitic shale are exposed on both sides of the road fill. We shall walk down the slope to the right. The chert float, abundant in this area, is of a type similar to that common in the Brannon Member and may have been derived from that member. The resistant blocky dolostone of various shades of orange, brown, and green and the unctuous green dolomitic clay are common products of dolomitization of country rock to T-dolostone and also are common components of S-dolostone formations higher in the stratigraphic section.

Proceed to the roadcut northeast of the valley. Dolostone occurs as a roughly semicircular halo surrounding a minor fault on the north western face and as a dolomitized fracture on the eastern face (Fig. 8). Dolomite, occuring both as a mosaic of fine to medium crystals and as large pink saddle-shaped crystals lining cavities, has locally replaced the nodular fossiliferous limestone and shale of the Millersburg Member and, in the lower part of the roadcut, the Tanglewood Limestone Member (Fig. 9). Other included minerals are barite, pyrite, and limonite pseudomorphs after pyrite. Minor offset is seen in the fractured zone, where bedding, traceable on both sides of the structure, is bent slightly and thence fades to obscurity near the center of dolomitization. That the dolomitizing solutions never reached the surface at this locality is evident from the continuous beds that may be traced above the feature. Slightly curved fractures peripheral to the body and a slight sag in the overlying beds suggest volume decrease as a result of dolomitiza-

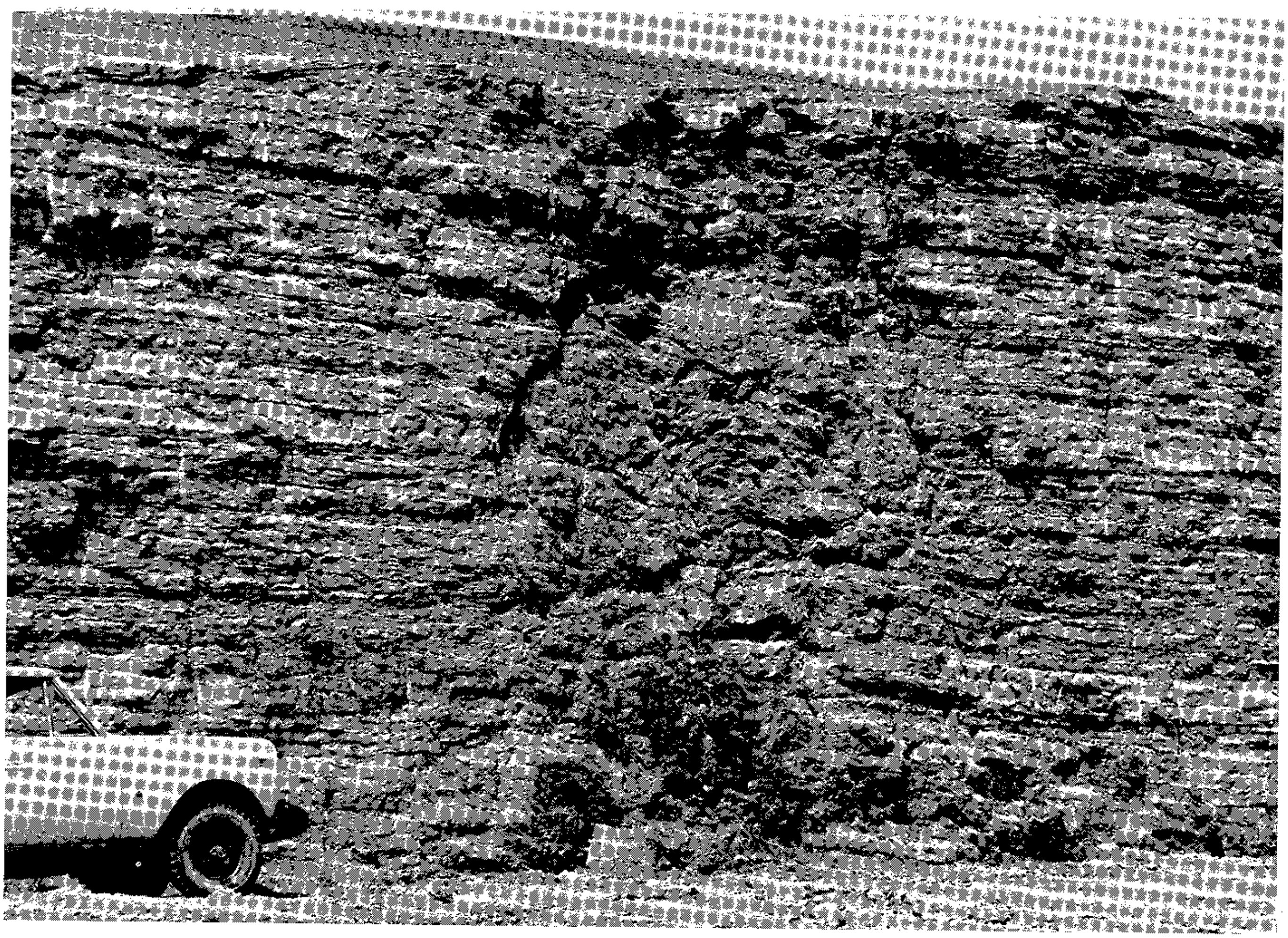


Figure 8. T-dolostone body in Millersburg Member of Lexington Limestone exposed along the northwest side of Kentucky Highway 627 at Stop 3.

Figure 9. Closer view of dolostone body shown in Figure 8. Matrix of finely crystalline dolomite contains cavities lined with pink, saddle-shaped dolomite crystals.

tion of the original limestone. The feature was not mapped (Black, 1974) because the roadcut postdates the mapping. This outcrop presents strong evidence that mineralizing solutions rose from below. This dolostone body is probably a satellite to the larger body to the southwest, both having been formed by dolomitizing solutions rising along faults and fractures interconnected at depth. Petroleum staining of the fractured area near the top of the southeast face may have been derived from excavating equipment, or it may be natural. Petroleum commonly occurs in T-dolostone bodies, as will be seen at the next stop. Reboard bus and proceed to Stop 4.

13.7 Middle Tanglewood exposed at pond in valley on right.

14.1 Millersburg Member of Lexington; calcarenite marker bed in roadcut.

14.5 Millersburg in roadcut.

14.7 Junction of Kentucky Highway 627 and Flanagan Station Road; turn right.

15.7 Cross Twomile Creek.

15.8 Cross Louisville and Nashville Railroad.

16.0 Bridge across Twomile Creek.

16.7 Millersburg-Tanglewood contact exposed in quarry on right.

17.1 Junction of Flanagan Station Road and Bybee Road; turn right.

17.7 Clays Ferry Formation (float tablets) exposed on farm road to right.

18.4 Barite vein 3 to 4 feet thick in Tanglewood in field to left beyond stone fence. The vein strikes east-northeast and is restricted to calcarenite. The vein does not cross the contact of shale and limestone of the underlying Brannon Member exposed in the creek on the left. Another segment of the vein occurs in the Tanglewood across to the southwest; it does not appear to penetrate the overlying shaly Millersburg.

19.0 Ledges of Lexington exposed on left. Grier Member is near the base of the slope; ledges of Tanglewood are exposed higher on the slope, and Millersburg caps the hill.

19.2 Cross Boonesborough fault; dipping beds exposed in creek on right.

19.4 Cross Stoner Branch of Fourmile Creek.

19.8 Stop 4. Stoner Branch dolostone area. Unload bus at the crest of the hill opposite the farm entrance road. Bus will turn around and park in space provided near entrance road at the base of the hill. This stop will be in two parts, one traverse before lunch and one after lunch.

STOP 4. (Refer to Figs. 3, 10, and 11 and Plates 1 and 2.)

On this traverse, we shall be guests on property owned by the James Allen family. Stepladders will be provided where needed at fence crossings; please leave all gates as you find them. Of course, anyone following this guidebook at a later time should obtain the owner's permission before entering the property.

Proceed eastward across the hilltop to the gully shown on Figure 10. En route

Figure 10. Geologic map of part of the Winchester quadrangle (modified from Black, 1974). Scale 1:24,000. Structure contours on top of the Garrard Siltstone south of the Boonesborough fault; on base of the Brannon Member of the Lexington Limestone to the north; contour interval 10 feet. Open circles near stop indicate route of walking traverse. DDH is location of U.S. Geological Survey Allen No. 1 diamond-drill hole. See Plate 2 for explanation of bedrock symbols and lithologic descriptions; cross section B-B' is shown on Figure 3.

note micrograined-limestone float derived from the Tate Member of the Ashlock Formation. Traverse down this gully through unaltered Calloway Creek Limestone and, at the base of the hill, the Garrard Siltstone. In approaching our present position from the north, we crossed the Boonesborough fault and the zone of T-dolomitization adjacent to it. Now we shall turn northward along Stoner Branch and traverse back to the fault. Note that the Garrard is well exposed in the banks of the creek and that there are no major faults between here and the Boonesborough fault, which is well exposed in the creek bottom. On the upthrown (north) side of the fault, the Grier Limestone Member, the Brannon Member, and part of the middle Tanglewood Limestone Member of the Lexington Limestone are exposed in the creek bottom and are drag folded. A short distance north of the fault, the approximate position of the Brannon Member beyond the zone of folding is marked by two clusters of bushes occurring near wet-weather springs on the hillside west of the road. As we have seen, the upper part of the Garrard is faulted against the above-mentioned rocks, downthrown on the south. The stratigraphic displacement is slightly more than the interval between the base of the Brannon and the base of the Calloway Creek, estimated to be about 300 feet in this area (Fig. 3).

After a break for lunch, we shall return to the tributary stream entering Stoner Branch from the west and walk up this tributary (Fig. 10). Observe the structure, texture, and composition of the dolostone, noting especially: evidence of relict fossils, the presence of petroliferous vugs, and an upper siltstone marker bed. The position of this bed is shown in the log of the U.S. Geological Survey Allen No. 1 diamond-drill core (Fig. 11). On this traverse, we shall observe the following: the fault at a second locality, a tongue of unaltered Calloway Creek Limestone bounded by dolostone both above and below, and exposures of the upper part of the Stoner Branch dolostone.

At this locality we have seen some of the field evidence that the Stoner Branch dolostone body resulted from alteration of normally nondolomitic, or at most slightly dolomitic, limestone. The quartzose Garrard Siltstone, recognizable in spite of dolomitization of its calcitic matrix, was mapped beneath the dolostone at four places (Fig. 10) and was defined in the drill core. The Clays Ferry Formation is also dolomitized to the total depth of the drill core (194 feet). If, as we saw at Stop 3, the dolomitizing solutions rose from below, dolomitization has probably taken place in other limestone formations in the subsurface.

Such areas of localized dolomitization of limestone are potentially of economic interest. In other areas, dolomite is commonly associated with mineral deposits, and commercially important petroleum accumulations are associated with similarly dolomitized structures, for example, in the Albion-Scipio and Deep River oil fields in Michigan.

The T-dolostone at this stop is very similar to S-dolostone of the Upper Ordovician, Silurian, and Devonian formations in this area. Selective dolomitization of the Reba Member of the Ashlock Formation has produced stratiform bodies of dolostone in both the Winchester and Hedges quadrangles adjacent to, and on the downthrown sides of, the en echelon Eagle Nest and Ruckerville faults. This is partly shown on Figure 12 and discussed in the description of the Reba on Plate 2. Both the T- and S-dolostones show considerable lithologic variability, involving a variety of relict bedding types similar to those found in unaltered limestone units in this area, various types of included fossils, and stratal changes in crystal size, corresponding perhaps to compositional differences between original beds. Variations such as these, though much modified by dolomitization, suggest that the original rocks

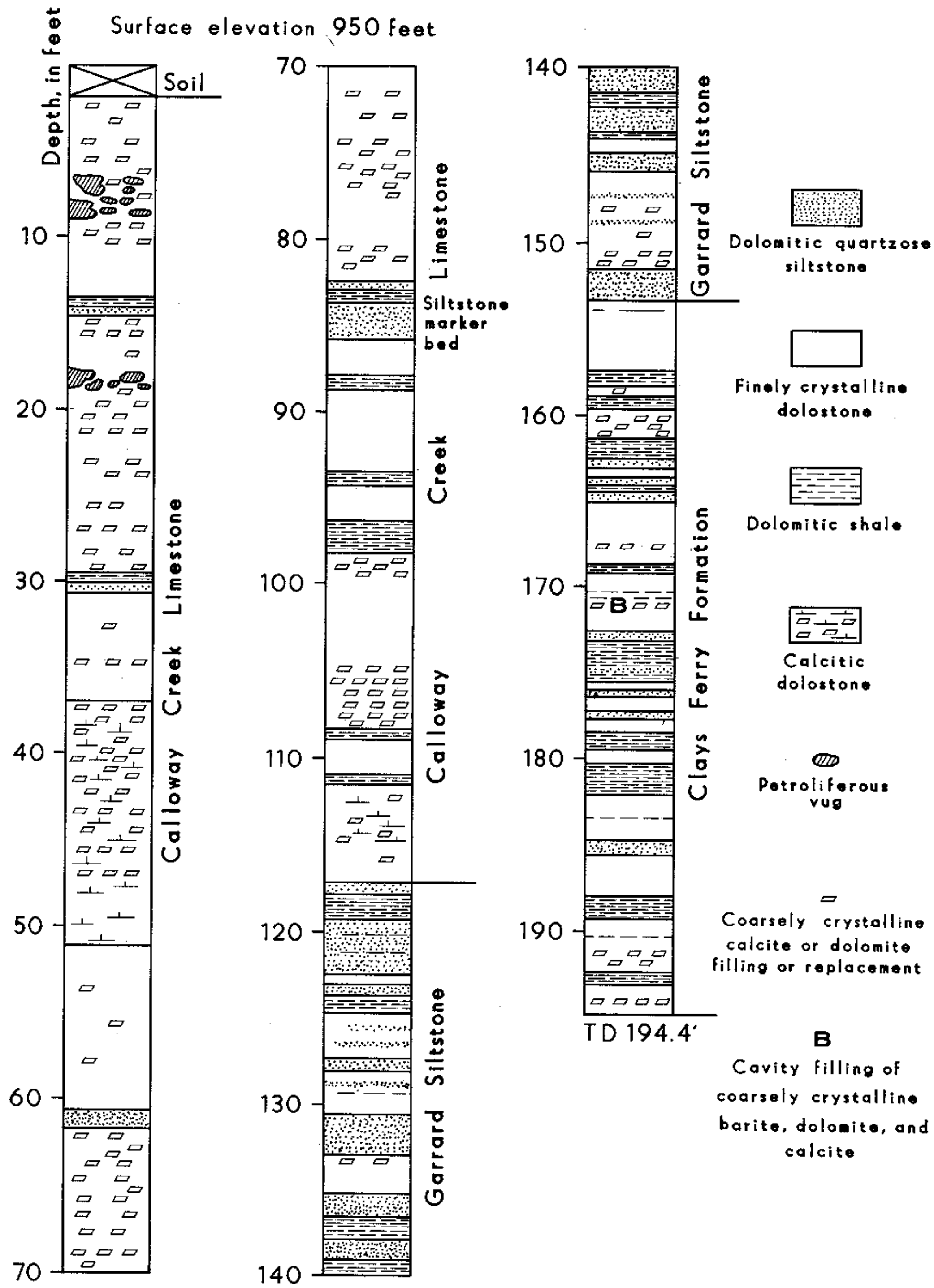


Figure 11. Graphic core log of U.S. Geological Survey Allen No. 1 diamond-drill hole. Location shown on Figure 10.

were deposited under a variety of sedimentary conditions. The Tate and Terrill Members of the Ashlock and the Rowland Member of the Drakes Formation contain mudcracks and may have been deposited, in part, in a supratidal environment; part of the dolomite in these units may have been synsedimentary. On the other hand, dolomite in the Preachersville Member of the Drakes contains abundant marine fossils,

Figure 12. Geologic map of part of the Hedges quadrangle (modified from 1975). Scale 1:24,000. Structure contours on top of the Garrard Siltstone; contour interval 20 feet. Open circles near stop indicate route of walking traverse. Dolomitic part of the Reba Member of the Ashlock Formation is cross hatched. See Plate 2 for explanation of bedrock symbols and lithologic descriptions.

the contact with the underlying nondolomitic Bull Fork Formation is very irregular, and the tidal-flat model of dolomitization does not apply. Reboard bus and proceed to Stop 5.

22.5 Junction of Flanagan Station Road and Bybee Road. Continue northward by Rankin's country store and cross railroad on Twomile Road toward Winchester.

24.5 Entrance to Bwamazon Farm on left. Twomile Road now becomes Main Street of Winchester.

25.3 Water tower on right.

26.4 Junction of Main Street (U.S. Highway 60) and Kentucky Highway 15 in Winchester. Turn right on Kentucky Highway 15.

28.4 Cross Louisville and Nashville Railroad. Clays Ferry Formation is in uppermost few feet of the railroad cut; Lexington Limestone is beneath.

28.9 Clays Ferry on left.

29.5 Clays Ferry on left.

30.9 Garrard Siltstone on right.

31.6 Clays Ferry in creek on right.

32.5 Cross Stoner Creek.

32.7 Clays Ferry on left.

32.9 Garrard to left in roadcut.

33.6 Intersection of Kentucky Highway 15 and Schollsville Road at Pilot View. Turn left on Schollsville Road.

34.5 Cross Mountain Parkway; Calloway Creek Limestone exposed to right of overpass in parkway cut.

34.8 Garrard well exposed in abandoned-railroad cuts and tunnel southeast of Schollsville Road.

35.4 Garrard on left.

35.5 Junction of Schollsville Road and Hedges Road; turn right following Schollsville Road.

36.7 Junction of Judy Road and Schollsville Road.

STOP 5. (Refer to Fig. 12 and Plates 1 and 2.)

Unload bus at the entrance to a farm field about 200 yards west of a sharp right turn in the Schollsville Road at its intersection with the Judy Road in the northeast corner of the Hedges quadrangle (Black, 1975). Bus will park here until completion of the traverse. As at Stop 4, we shall be guests on privately owned property. Please observe the same courtesies suggested at our last stop.

At our previous stops, we have seen examples of fault-associated dolostone bodies interpreted to have been emplaced as a result of dolomitization of the adjacent calcitic country rock. At this stop, we shall see an example of another mode of origin for local dolostone occurrences in central Kentucky—bodies emplaced by faulting from regionally dolomitized formations much higher in the stratigraphic section. Here, a megabreccia consisting of huge blocks, some of which are limestone and others dolostone, occurs within a west-northwest-trending graben. A minimum number of faults necessary to explain the existing outcrops are shown on the map (Fig. 12). Maximum stratigraphic displacement is about 550 feet.

The area adjacent to the graben is underlain by the Calloway Creek Limestone and, at shallow depth, the Garrard Siltstone (Fig. 12). Proceed northward from the parking area toward the abandoned farmhouse and barn. The first outcrop we shall see is on the downthrown side of a west-northwest-trending concealed fault. The rock is micrograined limestone of the Reba Member of the Ashlock Formation. A few tens of feet down the small northeast-trending valley south of the farm buildings, greenish-gray dolomitic shale is exposed. This probably is the Terrill Member of the Ashlock which underlies the Reba. Just beyond this outcrop, a cross fault, downthrown on the northwest, separates the Ashlock exposures from Drakes outcrops immediately adjacent. The rather extensive outcrop of dipping dolostone down the valley is sparsely fossiliferous and belongs to the Rowland Member of the Drakes. Neither base nor top is exposed, so the amount of displacement is not known; however, the Rowland directly overlies the Reba, so the throw is small.

Down the valley at the fence crossing, another fault has displaced Rowland dolostone against limestone of the lower part of the Calloway Creek Limestone, down on the southwest. This fault is the northeasternmost graben fault. Traverse down the valley to the drainage fork where the upper part of the Garrard Siltstone is exposed; turn right (southward) up this fork on Garrard and Calloway Creek to another crossing of the same boundary fault. The Grant Lake Member of the Ashlock, nodular limestone containing large *Platystrophia ponderosa* brachiopods, is exposed on the downthrown side, overlain by a covered interval in which the Terrill Member would occur, overlain in turn by micrograined Reba limestone. The Reba crops out as ledges on the valley walls. From these outcrops, proceed across the hill to the northwest, crossing the previously traversed valley, to the outcrop locality of the Brassfield Dolomite near the abandoned farmhouse. The dolostone of the Brassfield is light gray (weathers brownish gray), occurs in blocky outcrops, and contains colonial corals. Grant Lake limestone is again exposed just west of this locality, necessitating another cross fault, down on the east. The graben-boundary fault, though concealed, probably adjoins the Brassfield outcrops on the north. Proceed to bus for the return trip to Athens.

SECOND DAY OF FIELD CONFERENCE

Saturday, November 1, 1975

ROAD LOG

Mileage

0.0	Board bus or private vehicle at Sheraton Inn, Athens-Boonesborough Road. Entrance to Sheraton Inn; proceed east on Athens-Boonesborough Road. (Refer to Fig. 1 and Plate 1.)
1.3	Junction with Walnut Hill Road; turn right.
2.3	Cross Interstate Highway 75. Fault crosses highway at right of bridge; Tanglewood Limestone Member of Lexington Limestone on the north is downfaulted against Brannon Member on the south. Part of the zone of graben faulting is shown on the Coletown geologic quadrangle map (Black, 1967) (Plate 1). The grabens contain dolostone of presently unknown genesis (U-dolostone), though this was mapped as the Preachersville Member of the Drakes Formation before the recognition of T-dolostone.
3.1	Tanglewood exposed on left.
3.8	Crossing Coletown graben. Dolostone is in downthrown block against upper Lexington, Tanglewood Limestone and Millersburg Members.
4.2	Junction with U.S. Highway 25; turn left on U.S. 25.
5.7	Junction with Jacks Creek Road; turn right.
6.7	Shelby Lane on right.
8.2	Junction with Crawley Lane; bear left on Jacks Creek Road.
8.5	Junction of Jacks Creek Road and Kiddville Road; bear right on Jacks Creek Road.
9.1	Tanglewood on right.
9.4	Junction with Spears Road on right; turn right. Fault parallels Spears Road west-southwest for approximately 0.25 mile; lower part of Clays Ferry Formation on the south is downfaulted against Brannon and Tanglewood.
9.7	Exposure of lower tongue of Tanglewood on right just across small creek.
11.0	Junction with Tates Creek Road. Turn left and proceed 100 feet to Kentucky Highway 169; turn right toward Nicholasville.

11.7 Grier Limestone Member of Lexington exposed along road.
11.9 Marble Creek Church on right; Grier exposed on right.
13.2 Lower Tanglewood on right.
13.3 Logan Road on left; Brannon outcrop on right.
13.9 Grier exposed on right.
15.0 Grier in old quarry on right.
15.1 Easternmost fault of the West Hickman Creek fault system; faulted within Grier.
15.8 Another West Hickman Creek fault. Dipping Curdsville Limestone Member of Lexington is on the right; Grier on the east is downfaulted against Curdsville on the west.
16.0 Tyrone-Curdsville contact on right near intersection with old road.
16.2 Cross Hickman Creek; Tyrone-Curdsville contact is in ditch on left at west end of bridge.
16.8 Cross Bethany Road.
17.3 Westernmost fault of West Hickman Creek fault system; Grier on the east is downfaulted against Logana Member of Lexington on the west. Rocks are poorly exposed.
19.6 Junction with U.S. Highway 27; turn left and proceed south through Nicholasville. Road is on Grier for about the next 7 miles.
26.4 Tyrone Limestone exposed on left.
26.8 Road to Canada Dry warehouse on right.
26.9 Tyrone on right.
27.4 Oregon Formation-Tyrone Limestone contact.

DISCUSSION OF STOPS 6-9 (Refer to Figs. 3, 7, 13, 14, 15, 16, 17, and 18 and Plates 1 and 2.)

Stops 6-9 are shown on the Little Hickman geologic quadrangle map (Wolcott, 1969) at Camp Nelson where U.S. Highway 27 crosses the Kentucky River. At Camp Nelson, the Kentucky River fault system is a graben structure formed by multiple fault blocks downthrown along high-angle normal faults having a maximum displacement of about 300 feet (Wolcott, 1969). At these stops we shall observe features in the Camp Nelson Limestone, Oregon Formation, and Tyrone Limestone.

Structural features other than normal faults include small reverse faults, joints, drag folds, horizontal slickensides, bedding slickensides, and mineralized fractures. These features are possibly indicative of several stages of deformation; however, the chronological order of deformation is difficult to determine.

Joints

Five sets of joints are recognized in the Camp Nelson area and for convenience will be discussed as sets S_1, S_2, S_3, S_4, and S_5 (Fig. 14). S_1 and S_3 are best developed and most numerous, and strike N.41°E. and N.39°W., respectively. The average dip of the joints is 83°SE. The angle between the conjugate sets averages 80 degrees. These attitudes represent averages taken from plots on a Schmidt equal-area net. The N.41°E. set (S_1) is best developed and is considered to be synthetic. This classification corresponds to those suggested by Billings (1972), Harding (1974), and others for lateral stresses (Fig. 7).

The joint surfaces of S_1 and S_2 are undulatory or corrugated parallel to strike, resulting in what we interpret to be the mullion structure of Heyl (1972). Also, the joints are best developed in certain layers within the outcrop and appear to prefer the dolomitic lithology of the Oregon and the Camp Nelson over the micritic limestone of the same formations. The angle of intersection of joint sets and the strike of the corrugated surfaces support the suggestion of lateral stresses. There is local and regional evidence for strike-slip movement along faults related to the Kentucky River system. Regional Bouguer gravity anomaly patterns of the basement in eastern Kentucky and West Virginia suggest right-lateral offset along the Kentucky River and Irvine-Paint Creek fault systems (Heyl, 1972). Heyl (1972) also stated that horizontal slickensides predominate in this area. They exist, but certainly do not predominate in the exposures we will see during the field trip.

Figure 13. Geologic map of part of the Little Hickman quadrangle (modified from Wolcott, 1969). Scale 1:24,000. Structure contours on top of the Tyrone Limestone; contour interval 20 feet. Open circles near stops indicate route of walking traverses. See Plate 2 for explanation of bedrock symbols and lithologic descriptions; cross section C-C' is shown on Figure 3.

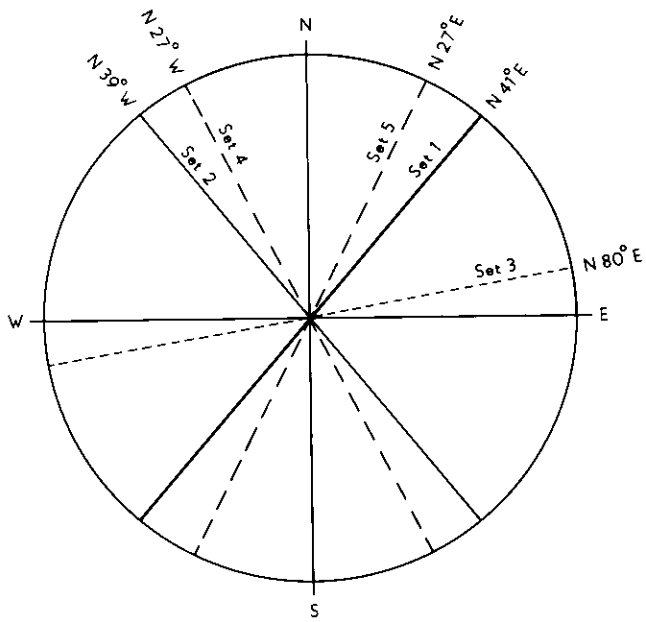


Figure 14. Plot of joint sets from rocks exposed in roadcuts along U.S. Highway 27 at Camp Nelson. From diagram by Donald T. Phillips II, Eastern Kentucky University.

Joint set S_1 is the synthetic fracture and is almost parallel to the trend of the main Kentucky River fault system. If the strain ellipse for basic wrench tectonics (Fig. 7) is oriented to the fault and the shear joints of the Camp Nelson area, it is evident that the movement is not right lateral, but clearly left lateral. Similar observations were made at Boonesborough where the synthetic fractures also essentially parallel the main fault. Left-lateral stresses have been suggested for a series of en echelon normal faults that trend northwest from the Camp Nelson area.

Joint set S_3 strikes N. 80°E. and bisects the obtuse angle between shear joints S_1 and S_2. This is the direction of extension (or minimum compression); therefore, this joint set is interpreted as an extension joint (Fig. 14). These joints are commonly calcite mineralized, which is also interpreted as evidence of extension.

Sets S_4 and S_5 strike N.27°W. (S_4) and N.27°E. (S_5), and the angle between conjugate sets is 54 degrees. The average dip of the joint surfaces is 77°SE. These joints are poorly developed and occur only near the fault zone. They are mineralized and in places are offset along bedding surfaces by low-angle reverse and bedding-plane faults. These joints appear to be related to normal faulting.

Faults

Three normal fault zones are exposed south of Camp Nelson (Fig. 13). Locally, the faults appear as single lines on the map, but they are, almost without exception, fault zones. All the principal faults strike northeastward and dip at angles of 75 to 90 degrees. The northwesternmost fault has Camp Nelson Limestone on the northwest upthrown against the undifferentiated Grier and Curdsville Limestone Members of the Lexington Limestone on the southeast. According to Wolcott (1969), vertical displacement is approximately 300 feet (Fig. 3). The southeasternmost fault which forms the margin of the graben structure is within the Lexington Limestone and is downthrown on the northwest. Vertical displacement is 100 feet or less (Wolcott, 1969).

A third fault, which according to Wolcott (1969) is antithetic to the northern fault, occurs almost in the center of the graben (Fig. 13). Vertical displacement is about 100 feet, and the Grier Limestone Member of the Lexington Limestone on the northwest is in juxtaposition to the Grier Limestone Member on the southeast. On the Little Hickman geologic quadrangle map, Wolcott (1969) shows other faults of little displacement antithetic to and synthetic with the main Kentucky River fault.

Although the sense of movement along these faults is normal, evidence indicates more than one period of movement. Strong reverse drag folding has taken place on the upthrown Camp Nelson block. Data from other outcrops along the trend of the Kentucky River fault system support the idea of recurrent movement. Flexure slip or adjustment in the drag features of the main fault has formed slickensides on bedding surfaces along with small-displacement, low-angle reverse, adjustment faults.

Similar faults have been observed at Blackbridge near Sulphur Well, Ky., about 5 miles northeast of Camp Nelson along the same fault system.

Interpretation

Chronological interpretation of the structures at Camp Nelson offers a tremendous challenge. Insufficient data have been collected to offer a well-documented interpretation; however, from what has been observed in the vicinity of Camp Nelson and other areas of the Kentucky River fault system, an interpretation is presented for consideration.

1. Joint sets S_1 and S_2 appear to be due to left-lateral wrenching and are considered to have formed first. Pre-Ordovician activity along this system has been well documented; therefore, the area is known to have been periodically active throughout the Paleozoic, and perhaps earlier. There is support for strike-slip movement before and after Ordovician time (Webb, 1969; Heyl, 1972; Goble, 1972). The shear joints observed in outcrop could have resulted from deep-seated lateral stresses. The S_1 synthetic joints essentially parallel the main faults at Camp Nelson and Boonesborough and the sense of movement is interpreted as left lateral. Evidence does exist for right-lateral stresses in central Kentucky in the form of right-lateral offset of mineral veins in the Ford quadrangle (Black, 1968); however, those veins are not in juxtaposition to the Kentucky River fault system. In fact, they are several miles removed from it.

   Joint set S_3 is essentially perpendicular to the greatest stress axis of sets S_1 and S_2 and is interpreted as an extension fracture due to tension as shears S_1 and S_2 were formed (Figs. 7 and 14).
2. Normal faulting took place in post-Early Mississippian time as evidenced by the Borden Formation preserved in the graben at Burdette Knob a few miles south of Camp Nelson. Also, joint sets S_4 and S_5 appear to have formed during normal faulting, as evidenced by the proximity of the joints to the fault. Calcite mineralization of these veins predates reverse drag of the main fault, which is evidenced by offset of veins along bedding-plane faults.
3. The major drag fold observed along the northern fault at Camp Nelson is reverse to the sense of the relative displacement in which Lexington Limestone on the southeast is downthrown against the Camp Nelson Limestone on the northwest. The rock units in the main drag zones should dip toward the southeast; however, the drag in the thick-bedded Camp Nelson Limestone dips 35° NW. This reverse drag could be a result of a late stage of deformation in which the displacement was reverse to the stratigraphic offset shown by the Camp Nelson and the Lexington. The structures attributed to flexure slip formed during this phase of deformation. Joint sets S_4 and S_5 have been offset by bedding-surface slip in the vicinity of the fault and have also been rotated. Likewise, joint set S_1 has been rotated counterclockwise approximately 10 degrees in the drag zone of the Camp Nelson Limestone. Perhaps there were other minor stages of structural development, but they are not obvious in outcrops observed.

STOP 6. (Refer to Figs. 13, 14, and 15 and Plates 1 and 2.)

The purpose of Stop 6 is to observe the general characteristics of the lower part of the Tyrone Limestone, Oregon Formation, Camp Nelson Limestone, and the joint systems. Note the Tyrone-Oregon contact near the top of the cut. Bentonite crops out at the top of the roadcut. Two well-developed joint sets and one poorly developed set can be observed at this outcrop. Set S_1 is best developed and strikes approximately N.41°E. (Figs. 14 and 15). Set S_2, which is conjugate to S_1, strikes approximately N.30°W. Set S_3 is poorly developed and strikes approximately N.80°E. All sets are essentially vertical. Near the base of the Oregon, S_1 does not appear to cut certain rock layers. The joints of this set do not always cut the limestone units and appear to favor the more dolomitic layers. When weathered, the joints are more obvious and appear to cut all lithologies. Joint set S_1 has a corrugated or undulatory surface which may be related to shear forces. The Camp Nelson-Oregon contact may be observed lower in the roadcut. Proceed southward across the river to Stop 7 on the southeast side of the graben (Fig. 13).

STOP 7. (Refer to Fig. 13 and Plates 1 and 2.)

The fault at Stop 7 strikes northeastward and forms the southeast margin of the graben. Here the fault is within the Grier Limestone Member and may be observed to the south for several miles along U.S. Highway 27 toward Burdette Knob where the graben is very well developed. Proceed northward back along U.S. Highway 27 to Stop 8 (Fig. 13).

STOP 8. (Refer to Fig. 13 and Plates 1 and 2.)

The purpose of this stop is to observe a small fault within the graben. The fault is within the unit mapped as undivided Grier

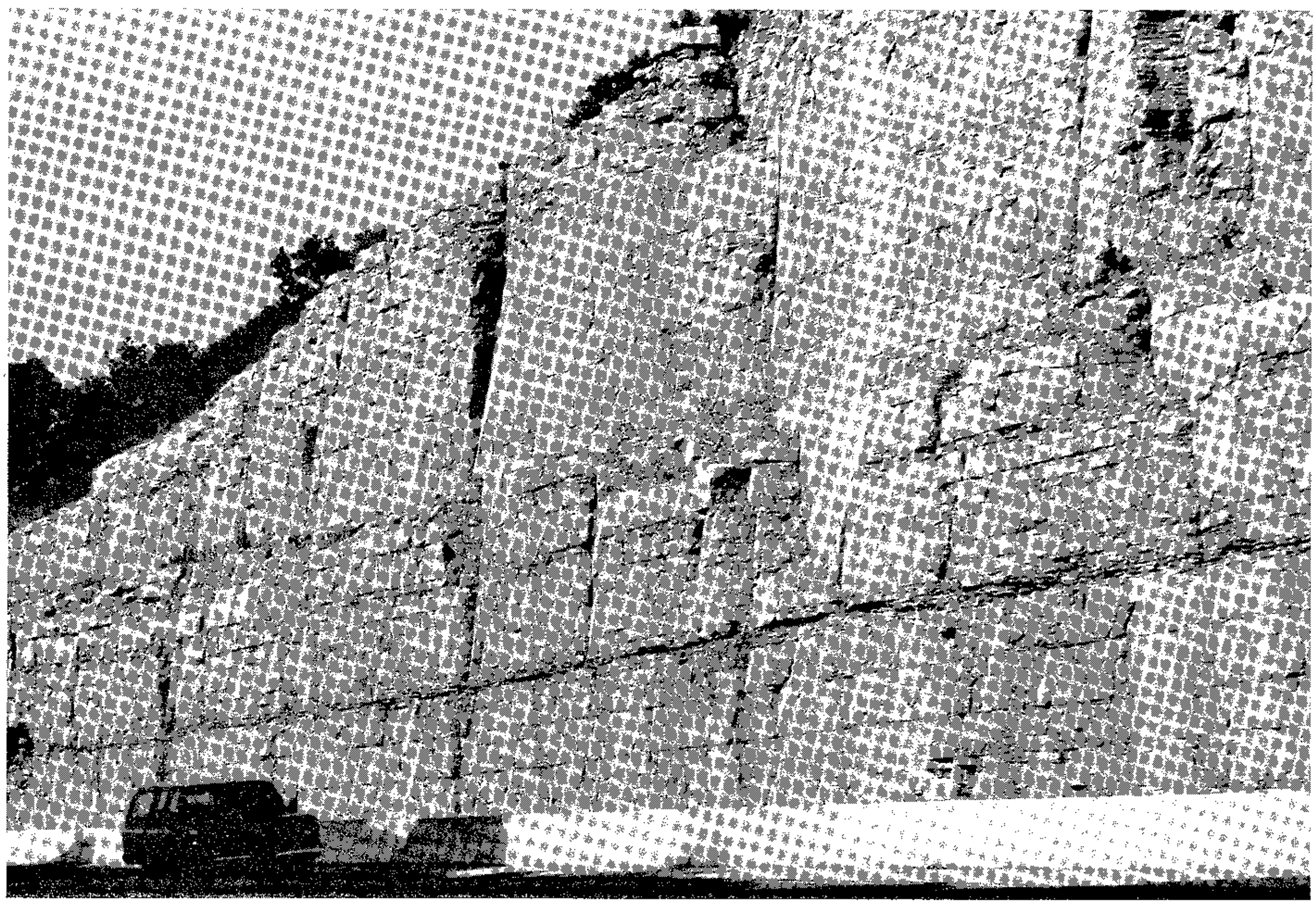


Figure 15. Synthetic shear fractures (S_1) in Camp Nelson Limestone along the west side of U.S. Highway 27 at Camp Nelson.

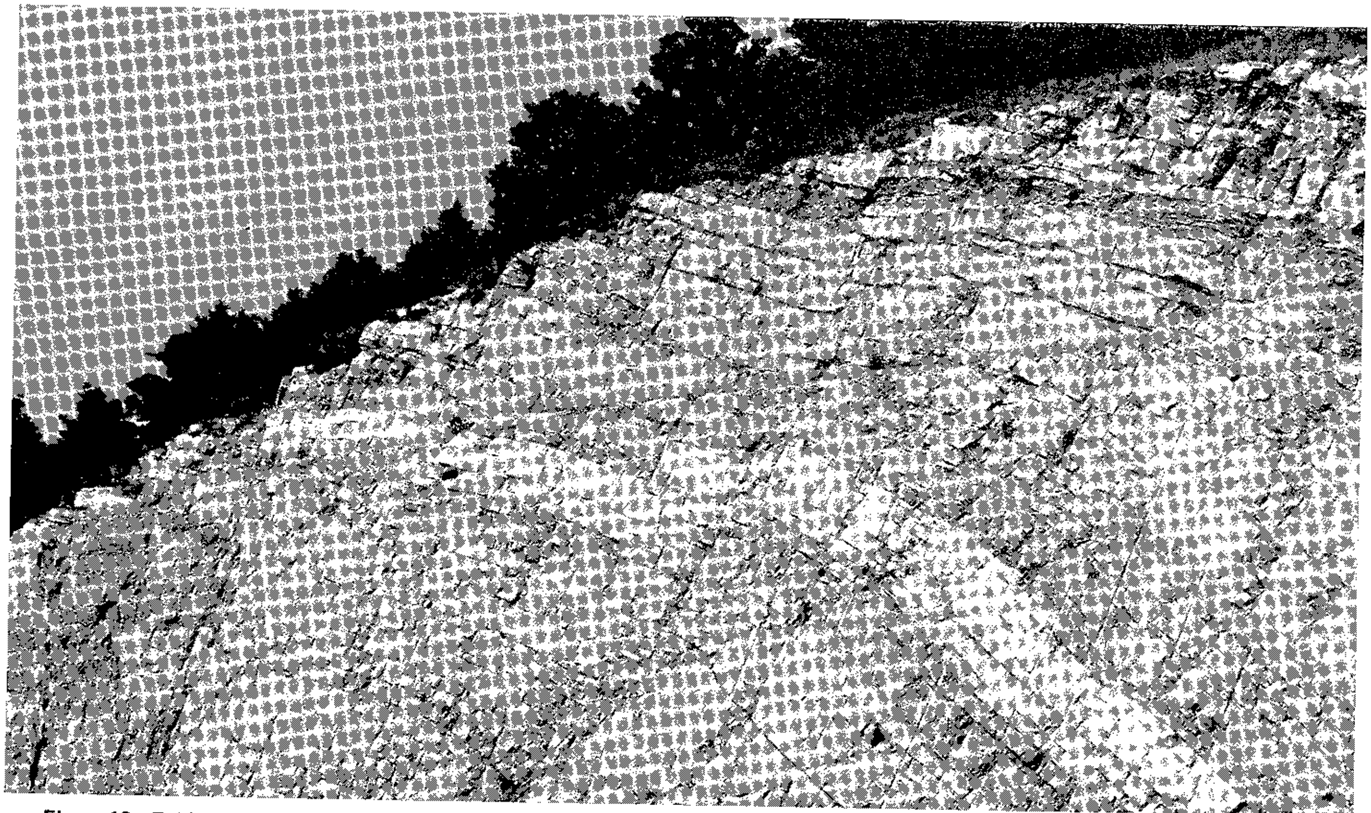


Figure 16. Folding and faulting in upthrown block of Camp Nelson Limestone along the west side of U.S. Highway 27 at Camp Nelson.

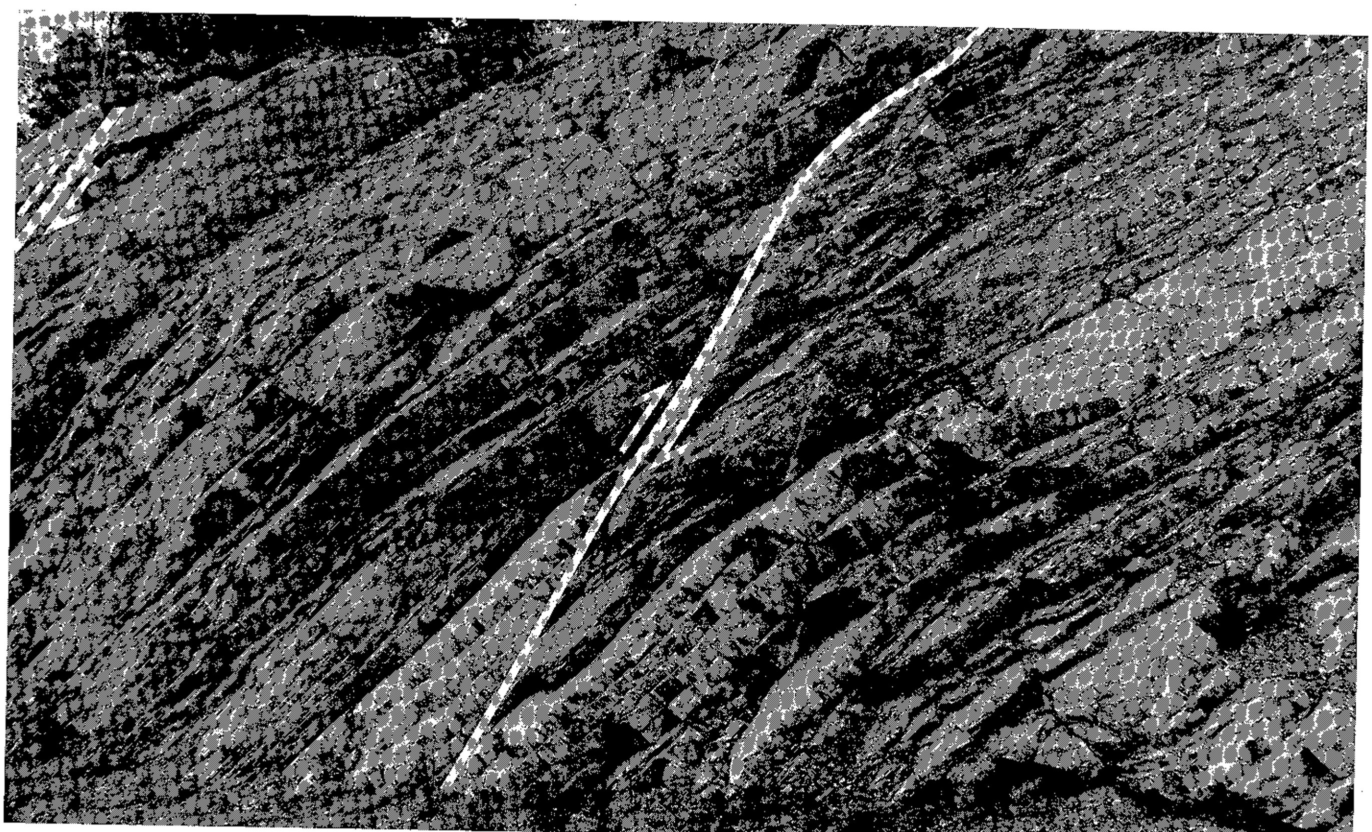


Figure 17. Low-angle reverse faults in the Camp Nelson Limestone along the east side of U.S. Highway 27 at Camp Nelson.

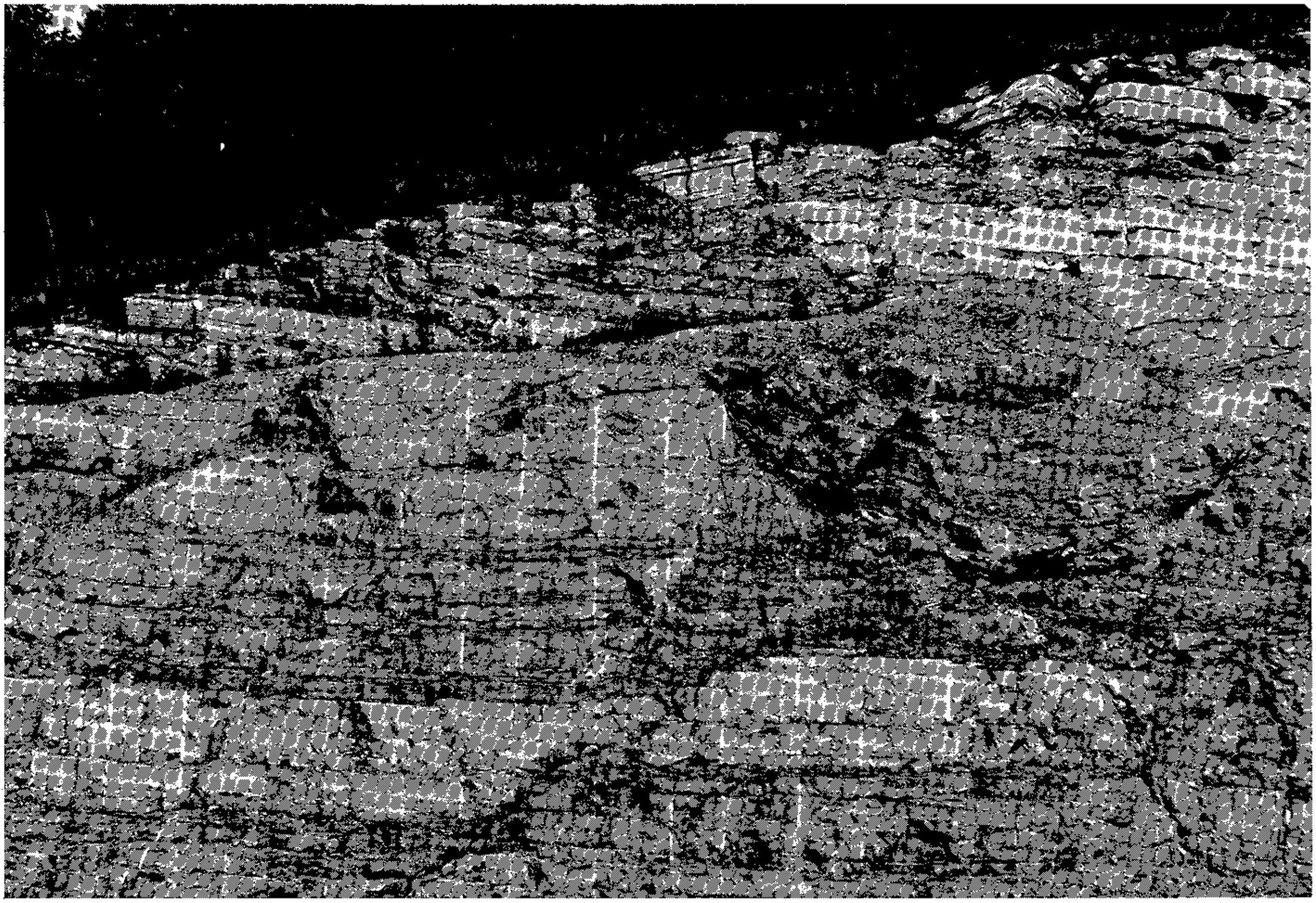


Figure 18. Multiple block faulting in the Camp Nelson Limestone along the west side of U.S. Highway 27 at Camp Nelson.

and Curdsville Limestone Members of the Lexington Limestone (Wolcott, 1969). Small drag folds occur near the fault in the upthrown block. This small fault is shown to terminate just north of the Kentucky River. Proceed northward to Stop 9 (Fig. 13).

STOP 9. (Refer to Figs. 13, 15, 16, 17, and 18 and Plates 1 and 2.)

This is the main fault of the Kentucky River fault system. The Grier Limestone Member on the southeast is downfaulted against the Camp Nelson Limestone on the northwest. The fault zone is approximately 50 feet wide, is very distorted, and includes large angular blocks, drag folds, and fractures (Fig. 16). Reverse drag can be observed in the Camp Nelson Limestone along with other features associated with drag, including slickensides, flexure slip, and small reverse faults (Fig. 17). Joint sets S_1, S_2, S_4, and S_5 occur in the outcrop, and sets S_1, S_4, and S_5 have been rotated in the vicinity of the fault. Also, the joints appear to be more highly mineralized near the fault. The mineralized joint sets (S_4 and S_5) strike approximately N.27°E. and N.27°W., respectively.

Directly across the highway are small block faults which show normal and reverse movement (Fig. 18). Note the white limestone bed which can serve as a marker within the Camp Nelson Limestone. The main fault surface, which is essentially vertical at Stop 9, strikes northeastward and is the northwestern margin of the Kentucky River fault system at Camp Nelson.

END OF FIELD CONFERENCE

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