Pennsylvanian deformation and Cambro-Ordovician sedimentation in the Blue Creek Canyon, Slick Hills, southwestern Oklahoma

R.N. Donovan, *Geology Department, Texas Christian University, Fort Worth, Texas 76129*
D. Ragland, M. Rafalowski, D. McConnell, and W. Beauchamp, *Geology Department, Oklahoma State University, Stillwater, Oklahoma 74078*
W. R. Martini and D. J. Sanderson, *Geology Department Queens University of Belfast, Belfast, Northern Ireland*

LOCATION

Blue Creek Canyon is located approximately 15 mi (24 km) north-northwest of Lawton in southwestern Oklahoma (T.4N.,R.13W.). Oklahoma 58 (Fig. 1) runs through the canyon. The area can be most easily reached from Lawton by taking the Medicine Park exit from the H. E. Bailey Turnpike a few miles north of Lawton.

The entire area described here is part of the Kimbell Ranch, owned by Mr. and Mrs. David Kimbell of Wichita Falls. The ranch house is situated at the south end of the canyon (Fig. 2) and is managed by Charlie Bob and Dixie Oliver. Both the Olivers and the Kimbells have greatly encouraged the visits of geologists, and several local universities use the area as a student training ground. Permission to visit should be sought from Mr. Oliver, and the usual common sense and courtesy extended. The ranch address is Star Route A, Box 124, Lawton, OK 73501. The Olivers carry their interest in geology to a remarkable level; during monitoring of the recently active Meers Fault, they had a seismograph installed in their bedroom as part of a regional network.

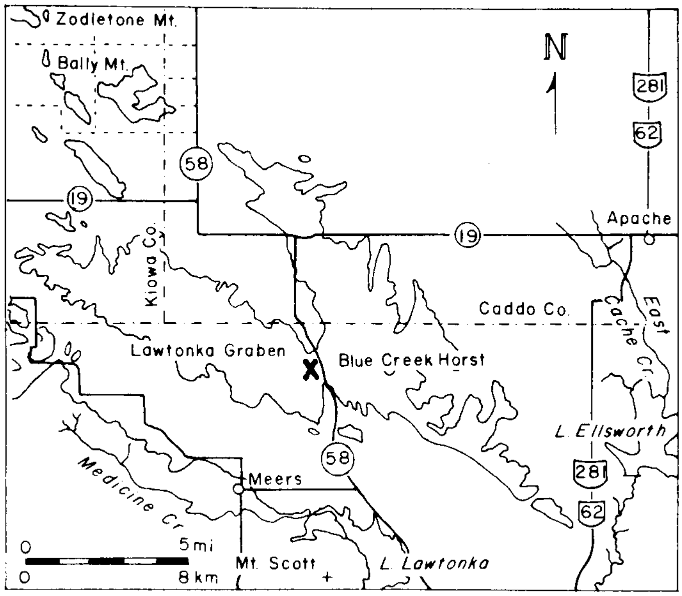

Figure 1. Locations of Blue Creek Canyon.

The descriptions in this field guide are for a series of walks that start approximately 0.5 mi (0.8 km) north of the ranch house at Red Hill (a small hill of Carlton Rhyolite capped by Post Oak Conglomerate which is immediately west of the road) (Fig. 2). The walks are all rough and fairly hilly; exposure is more or less continuous. The area is well drained even after heavy rain, although some difficulty may occur in crossing Blue Creek at such times. Take water on the longer trips (especially in summer when the temperature on the limestone may be 120+°F (49+°C), and beware of rattlesnakes.

SIGNIFICANCE

The relatively small area around the Blue Creek Canyon contains a remarkable number and variety of interesting sites. For this part of the world, exposure quality is very good to excellent. In general terms the exposures illustrate several aspects of the development of the Southern Oklahoma aulacogen: (1) the initial rift-related igneous activity, (2) early sedimentation in a basin with a decaying thermal imprint; (3) late Paleozoic deformation, (4) burial of the resulting Permian relief.

The oldest rocks in the area are part of the Cambrian Carlton Rhyolite Group. The lavas were intruded by a number of diabase dikes, gently tilted, and cut by a number of north-south faults before they were reduced to a range of low hills by late Cambrian (Franconian) time. The subsequent marine transgression (Fig. 3) was initially siliciclastics in character (the Reagan Formation), but eventually a highly productive carbonate "factory" developed (the Honey Creek Formation). By this time the rhyolite land surface had become an archipelago of small rocky islands. These islands were buried by the time deposition of the Arbuckle Group commenced. The Arbuckle Group is more than 5,500 ft (1,680 m) thick in the southern Oklahoma aulacogen and is one of the world's great platform carbonate sequences. (An unbroken section of these rocks at Bally Mountain is described elsewhere in this guide.) Succeeding Lower Paleozoic rocks (the Simpson, Viola Group, Sylvan, and Hunton) were deposited before deformation began in late Mississippian time.

This deformation, which concluded in early Permian time, resulted in dismemberment of the aulacogen into a series of NW-SE trending basins (e.g., Anadarko, Hollis, and Ardmore) and uplifts (e.g., Wichita, Arbuckle, and Criner Hills). As the deformation concluded, the surface of the uplift areas was sculpted by erosion into irregular hills that were subsequently buried by Permian sediments. At present these hills are in various stages of exhumation from beneath the Permian cover. In general terms the Permian rocks are conglomerates close to the old hills (the Post Oak Conglomerate facies) but fine outward into the ancient valleys and basins.

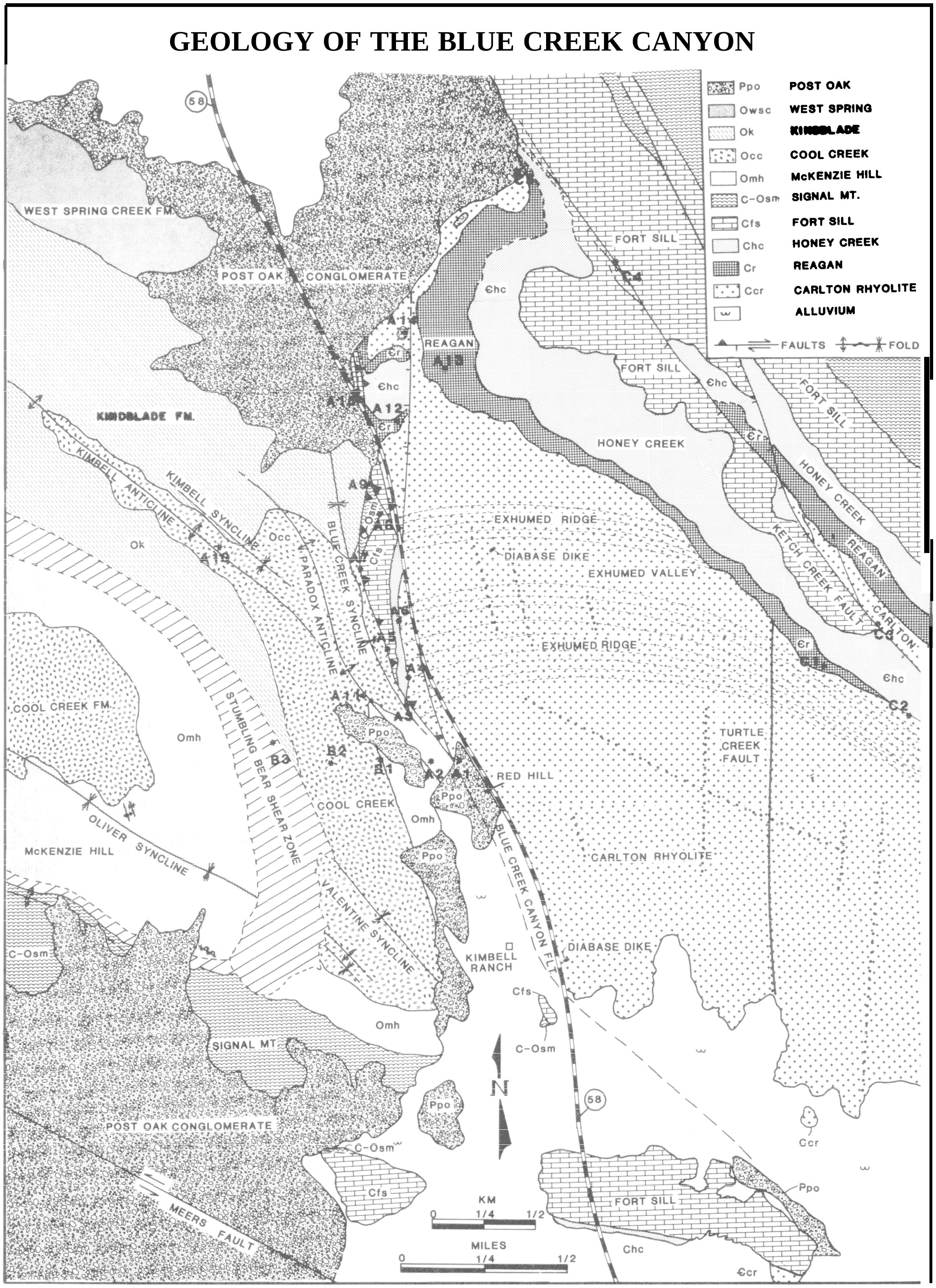

Figure 2. Geological map of Blue Creek Canyon area. A1-A15, B1-B3, and C1-C5 are suggested stops on three excursions.

STRUCTURAL OUTLINE

In a regional context the area forms part of the WNW-ESE trending Wichita Frontal fault zone which constitutes the hinge between the Anadarko basin (to the north) and the Wichita uplift. The zone was the locus for Pennsylvanian tectonism during the late deformation stage of the development of the Southern Oklahoma aulacogen (Donovan, 1982; Gilbert and Donovan, 1984). The principal character of this deformation was transgressive with left-lateral motion along the length of the zone. The zone is broken up into a number of blocks bounded by major faults (e.g., the Meers, Blue Creek Canyon, and Mountain View Faults).

The Blue Creek Canyon fault is the only one of these major structures whose Pennsylvanian character can be examined at the surface. It is an oblique high-angle reverse/left-lateral structure, trending just west of north (1 70–350) in the canyon area. It has a stratigraphic downthrow to the west that decreases northward from 2,400 ft (730 m) to 1,800 ft (550 m) along the length of the canyon (this variation in downthrow is not regionally significant but simply reflects fold geometry in the western "footwall" block).

The north-trending segment of the fault exposed in the canyon is anomalous in trend. To north and south, the fault bends until it is almost parallel to the regional WNW-ESE trend. Anomalous fault trends of similar direction are common in both the Wichita and Arbuckle areas. Such segments may have utilized an early north-south fracture trend that is pre-Reagan/post-Carlton Rhyolite in age.

The major faults in the Wichita Frontal zone define blocks of terrain that have undergone differing amounts of deformation. In the present instance the Blue Creek Canyon fault separates the "Blue Creek horst," to the east, from the "Lawtonka graben" (terminology of Harlton, 1972). The "horst" is a relatively undisturbed terrain dominated by homoclinal dips of moderate angles to the NE. The "graben," on the other hand, has been subjected to a "squeeze play" between the "horst" to the NE and the Wichita Mountains (to the SW across the Meers fault). The result is a structural mayhem of refolded reverse faults, rotated en-echelon folds, and brittle shears that together reflect intense left-lateral transgression and constitute the most intensely deformed terrain exposed in either the Wichitas or the Arbuckles (Donovan, 1982, 1984; Beauchamp, 1983; McConnell, 1983; Martini, 1986).

In the small segment of the Lawtonka "graben" exposed in the Blue Creek Canyon, the dominating structures are a group of four major folds that trend WNW-ESE and plunge consistently northward. These folds are the Blue Creek Syncline, the Paradox anticline, and the Kimbell fold pair (Fig. 2). The latter folds have a lopsided "rabbit ear" relationship to the structurally lower Paradox fold. A fifth large fold, the Blue Creek anticline, is located in the "hanging wall" block east of the Blue Creek Canyon fault. A feature of interest is that the Carlton Rhyolite is quite clearly involved in the folding. Farther to the west is the enigmatic Stumbling Bear shear zone, a region of intensively deformed rock

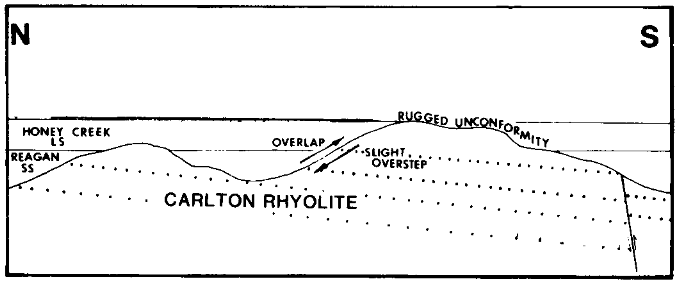

Figure 3. Generalized stratigraphic relationships between the Carlton Rhyolite and the Timbered Hills Group (from Rafalowski, 1984).

across which there is a stratigraphic discontinuity of up to 2,200 ft (670 m). This structure has recently been interpreted as an early thrust that was subsequently subject to considerable left-lateral shear (Marchini, 1986).

WALKS FROM RED HILL

Site 80. First Excursion: Stops A1-A1S, Fig. 2

A1. The Permian Post Oak Conglomerate facies unconformably overlies the Carlton Rhyolite at the eastern end of Red Hill, whereas at the western end of the hill it overlies the McKenzie Hill Formation of the Arbuckle Group. Fracturing in the rhyolite is probably due to the Blue Creek Canyon fault, which can be projected to pass under Red Hill close to the road (and thus accounts for the differing unconformable relationships at either end of the hill [Donovan and others, 1982]). The Permian deposit is a breccio-conglomerate consisting of pebble-sized clasts, crudely bedded in layers derived either from the west (in which case the clasts are Ordovician limestone) or from the east of the canyon (in which case the clasts are rhyolite or Cambrian limestone). The top of the hill is a good vantage point for viewing the Ordovician terrain; the conspicuous anticline in the foreground is the Paradox anticline.

A2. After crossing Blue Creek (with care), the Paradox anticline can be examined in detail. The lithology here is the upper, cherty part of the McKenzie Hill Formation. In common with other major folds in the area, the Paradox anticline is a complex northward-plunging fold of variable tightness (30–130°) and with fairly sharply defined axes ('E classification, Hudleston, 1973). All the large folds are basically parallel (Class I, Ramsay, 1967), and as a result their axial traces are displaced by layer-parallel slippage in a number of places. One of these slippage décollements occurs on the eastern limb of the anticline between A2 and A3, where a group of small-scale drag folds showing asymmetry and locally developed cleavage is confined to a layer about 20 ft (6 m) thick between undisturbed beds in the McKenzie Hill Formation.

A3. Here a gully marks the position of the Thatcher Creek member (Ragland and Donovan, 1985), a quartz-rich cross-

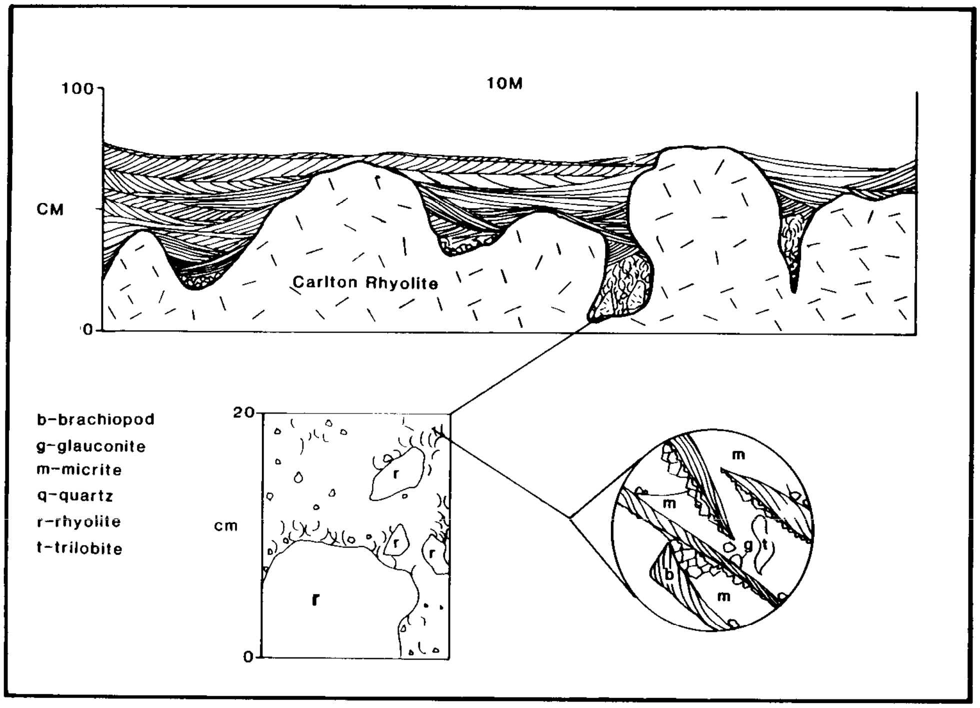

Figure 4. Interpretation of the Carlton Rhyolite-Honey Creek unconformity illustrating rock pedestals and fissures on wave-cut platform. Insets show petrographic details (from Rafalowski, 1984).

bedded limestone that marks the base of the Cool Creek Formation. This member is a critical stratigraphic marker in unraveling the complexities of the Lawtonka "graben," maintaining its character over many miles of outcrop; here it can be followed around the axis of the Blue Creek Syncline. The Blue Creek Canyon fault runs through the trees to the east, and as the fault is approached, the beds become overturned by as much as 30°. The route from A3 to A4 involves entering the trees to the NW, crossing the hidden fault trace, and scrambling over some scrappy orange-brown outcrops of Carlton Rhyolite to the unconformity with the Honey Creek Formation.

A4. The Reagan Formation is missing at this unconformity outcrops along the length of the canyon (e.g., at A6) indicate that this area was an island until late in the history of the Honey Creek Formation. The exposure at A4 is interesting in that a stabilized shell bank consisting of orthid brachiopods valves formed above the thin basal breccia (no hammers here, please—there is plenty of loose material). Small calcite/hematite stromatolites are also present; the section has been interpreted as a sheltered coastline deposit (Donovan and Rafalowski, 1984).

A5. A short distance above the unconformity, the Honey Creek passes up into the Fort Sill, lowest formation of the Arbuckle Group (a general log of these rocks is given in the accompanying guide to Bally Mountain). To the west the Fort Sill outcrop is truncated by the Blue Creek Canyon fault trace. This trace is a conspicuous linear depression that can easily be traced, particularly where the upper massive member of the Fort Sill Formation is faulted against the Cool Creek Formation, as the former is a ridge-forming element. The fault plane dips to the east at a high angle, indicating a reverse element of movement. In addition, prominent phacoidal shearing suggests a left-lateral component of motion.

A6. The unconformity between the rhyolite is well-exposed at a small prospect pit to the northeast of A5 (Fig. 4). The unconformity is most irregular and appears to be a wave-cut platform with numerous fissures and pedestals that was covered by a detrital coarse-grained carbonate sand composed mostly of broken primitive echinoids. This exposure has been interpreted as an exposed shoreline setting on the windward side of an island jutting from the Honey Creek sea (Donovan and Rafalowski, 1984).

A7. From the unconformity, the hanging wall block can be recrossed in a NW direction to rejoin the fault trace at A7. Here the uppermost massive member of the Fort Sill Formation is overlain by the thinly bedded and more poorly exposed Signal Mountain Formation. This contact has been displaced by a number of E-W faults that downthrow to the south. The Cambro-Ordovician boundary is approximately 330 ft (100 m) above the base of the Signal Mountain Formation.

A8. From A7 it is instructive to follow the strike of the Signal Mountain Formation in a NE direction. It will be clear that a major space problem is created by a change in strike (from N-S to NE-SW); as a result the Signal Mountain Formation appears to be on a collision course with the Carlton Rhyolite. However, at A8, a major N-S trending fault cuts the section and emplaces a thin sliver of upper Fort Sill Formation between the

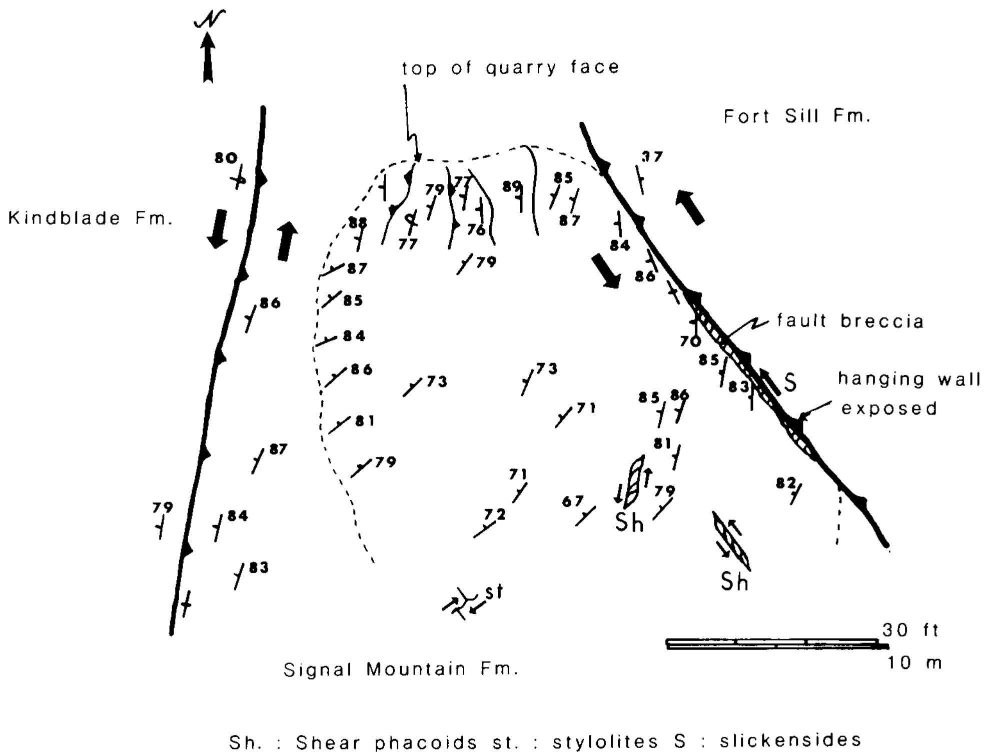

Figure 5. Sketch illustrating structural deformation in quarry (location A9). Note “squeeze” effect between converging oblique left-lateral, high-angle reverse faults.

Signal Mountain and the rhyolite. A second fault between the Fort Sill and the rhyolite can be inferred to run more or less beneath the existing road (Fig. 2). The pond next to the road (which is home to beavers and snapping turtles) is fed by springs emerging from this fault plane.

A9. The fault at A8 can easily be traced northward into an old quarry excavated when the road through the canyon was made. The quarry was excavated into Signal Mountain Formation in a zone that was crushed between the Blue Creek Canyon fault (to the west) and the “pond” fault (Fig. 5). The hanging wall of the latter fault is exposed on the eastern wall of the quarry and shows oblique slickensides and gouging suggestive of left-lateral transgression. Left-lateral shear phacoids are exposed on the floor of the quarry.

A10. Immediately north of the quarry the two major faults almost come together. However, the inferred contact is hidden under the highway. From this point a walk of 0.5 mi (0.8 km) west to the top of the hill on the horizon crosses all four of the major folds in the area (Fig. 2). The most photogenic of these folds is the Kimbell anticline at the top of the hill (where else?). The view from the hilltop (Kimbell Mountain) is an impressive one. To the west lies the contorted terrain of the Lawtonka “graben”; to the north is the valley eroded along the Blue Creek Canyon fault; to the east lies the Blue Creek “horst” where the Cambrian Timbered Hills Group unconformably overlies Carlton Rhyolite (the conspicuous peak is Ring Top Mountain); to the south the igneous Wichita Mountains rise across the Meers Valley.

A11. The Red Hill can easily be seen from the top of the hill at A 10. The recommended return route is along the axis of the Kimbell anticline until this fold merges into the western limb of the Paradox anticline. The “space problems” of parallel fold geometry are clearly apparent on this walk—nowhere more so than at Al 1 where the Paradox anticline is spectacularly well exposed. The paradox here is provided by an interplay of plunge and hill slope that results in the fold having the convincing appearance of a syncline with a very tight axis. Sitting astride this axis and looking generally northward is a good place to reflect on the geometries of the four major folds in the area. Because of the consistent plunge to the north, their form can be studied through a stratigraphic thickness of over 3,000 ft (914 m). From this point it is an easy walk back to the Red Hill.

A12. From the Red Hill drive northward along Oklahoma 58 for 3,000 ft (910 m) to a point 300 ft (91 m) north of the pond described in A8. Go through the gate to the east of the road, walk north 600 ft (182 m), and cross Blue Creek. In this area, flow-banded Carlton Rhyolite is well exposed. Above the rhyolite lies the Reagan sandstone, which here comprises a 5-ft (1.5-m) thick basal conglomerate consisting of pebbles of rhyolite cemented by hematite. Above this is a 2-ft (60 cm) lithic sandstone followed by about 8 ft (2.3 mF) of highly glauconitic cross-bedded greensand, which is interbedded with a thin rhyolite pebble conglomerate. Throughout the Slick Hills the greensand is everywhere the top unit of the Reagan, consisting of up to 60 percent fine sand-sized pellets of glauconite, plus quartz, rhyolite, and broken phosphatic shells of inarticulate brachiopods, all either set in a matrix of iron-rich illite or (toward the top) cemented by calcite.

The passage from the Reagan into the Honey Creek Formation (marked by the incoming of lenses of cross-bedded coarse grainstones) is located in a prospect pit a few yards to the northeast. Such prospect pits are a common feature in the area. Some of the later ones were uneconomic attempts to mine iron ore (hematite is an abundant cement in parts of the Reagan), while others seem to have resulted from a confusion of glauconite with malachite.

A13. By crossing an obvious fault-controlled gully to the northeast, a second exposure of Reagan can be examined in A 13. The basal facies is a very coarse grained lithic sandstone (which at one time was quarried as a building stone), overlying which is a coarse-grained, cross-bedded (sets up to 2 ft; 60 cm) quartz arenite, some shale (mostly covered), and the upper greensand unit. This sequence is about 60 ft (18 m) thick and passes up into a full sequence of Honey Creek limestone on the slopes of Ring Top Mountain to the east.

A14. Six hundred feet (180 m) to the NW of A13 lies an enigmatic exposure of Post Oak Conglomerate consisting of angular boulders of the Fort Sill Formation up to 20 ft (6 m) in diameter. The deposit, which rests unconformably on the Carlton Rhyolite, is one of a number of similar deposits in the Slick Hills, all of which seem to be related to nearby fault scarps (Donovan and others, 1982).

A15. From A14, cross the small stream that runs north of the conglomerate and follow the track that runs down the stream valley to the main road. The north slope of the valley is a more typical exposure of the Post Oak (pebble conglomerate); in the valley bottom, close to the road, are near vertical exposures of the Fort Sill Formation caught up in the most northerly exposures of the Blue Creek Canyon fault. On rejoining Oklahoma 58, turn south for the pond (A8). After about 600 ft (180 m) examine the ditch to the east of the road (Al 5), where Post Oak Conglomerate, composed of diverse types of locally derived clasts up to 2 ft (60 cm) in diameter, rests on an irregular surface of Fort Sill Limestone. The relationships here suggest that Blue Creek Canyon was first sculpted in Permian times. Pebble imbrication hints that drainage at this spot was to the north (not south, as now). Of particular interest are the coarsely crystalline fibrous calcite cements located close to or on the unconformity. These cements are coatings up to 2 in (5 cm) thick that record initial vadose conditions (i.e., flowstone, precipitation) followed by phreatic crystal growth, suggesting that the water table gradually rose through a highly porous gravel.

Second Excursion: Stops B1-B3, Fig. 2

B1. After crossing Blue Creek as for stop A2, bear northwest up the valley of the perennial Thatcher Creek. The first exposures encountered are impressive cliffs carved in the boundstones and associated sediments that form the top part of the McKenzie Hill Formation. A band rich in the brachiopods *Finkelnbergia is* present but different to find. More obvious are silicified sponges and a variety of cherts, including burrow-fills and nodules. Above the McKenzie Hill, where the valley widens and runs parallel to strike, is the type locality of the Thatcher Creek Member (Bl, Fig. 2; Fig. 6; Ragland and Donovan, 1985; see also A3).

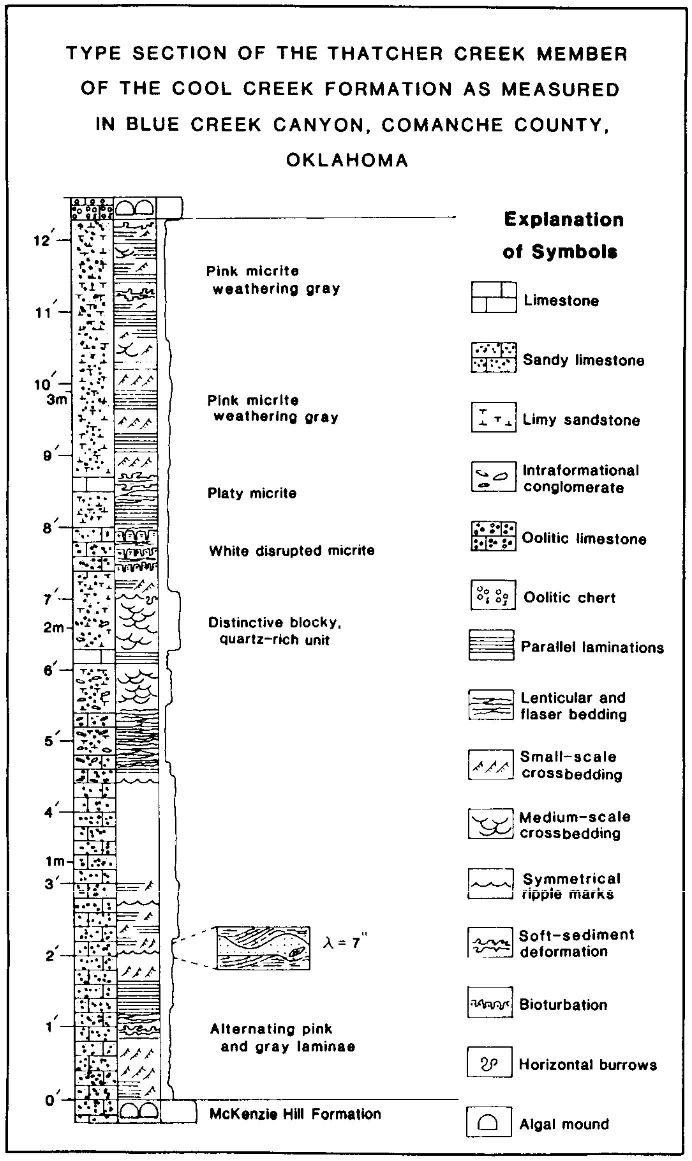

Figure 6. Type log of Thatcher Creek member of Cool Creek Formation in Thatcher Creek (location B1) (from Ragland and Donovan, 1985).

B2. Above B1 the Cool Creek Formation is well exposed and quite interesting, particularly on the lefthand (southern) side of the valley (Ragland, 1983). At a point due south of the first major junction in the valley, just above the valley rim, is the termination of an algal boundstone reef (B2; Fig. 7).

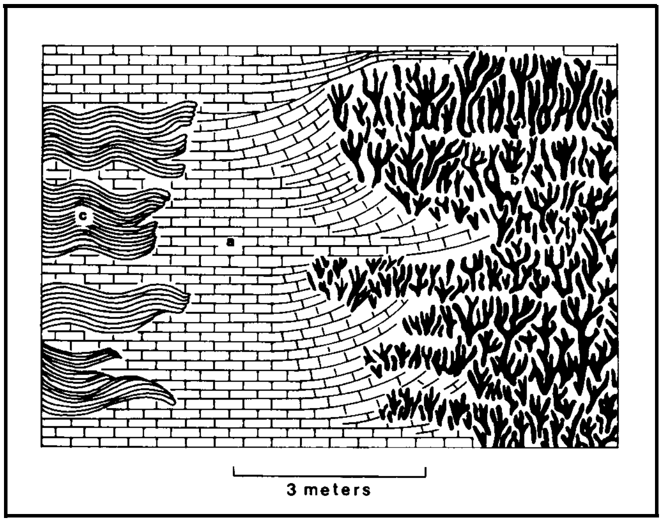

Figure 7. Schematic representation of the termination of an algal boundstone reef in the Cool Creek Formation at location B2. A compactional draping of laminated lime mudstone and intraformational conglomerates (a) against a bioherm (b); (c) is an algal mat interbedded with micrite and intraformational conglomerate (from Ragland, 1983).

B3. From B2, follow the minor lefthand (southern) valley due west across a homoclinal sequence of Cool Creek and Kindblade rocks disturbed only slightly by minor folding and fracturing to B3, where the Stumbling Bear shear zone is encountered. Within the shear zone the rocks are of Signal Mountain and McKenzie Hill age, indicating a stratigraphic discontinuity of over 2,000 ft (610 m). The zone, which extends throughout the Slick Hills, is up to 1,800n ft (550 m) wide and is probably the most structurally complex terrain exposed in Oklahoma. Dismembered folds, small faults, left-lateral shear belts, and pervasive pressure solution cleavage are well developed throughout. The intensity of deformation gradually decreases to the west into relatively undeformed McKenzie Hill rocks.

Site 81. Third Excursion: Stops C1-C5, Fig. 2

C1. Enter the gate on the east side of Oklahoma 58 at the Red Hll and walk up the rough track across the Carlton Rhyolite to a farm pond. From the pond climb the rhyolite hill to the northwest. On the other side of the hill lies a strike parallel valley which closes to north and south and is eroded in the Reagan Formation. There are several good exposures of the valley, particularly at C 1. Here a tan-colored lenticular quartz arenite displays medium scale cross-bedding, reactivation surfaces, and a tine display of *Skolithos* trace fossils (Donovan, 1984). Some herringbone cross-bedding is present in subjacent sandstones. The whole sequence appears to record a storm-tide interplay in a shallow marine environment.

C2. The closure of the valley to the southeast of Cl is an expression of buried Cambrian relief that is best appreciated by walking the rhyolite-sediment unconformity to C2. From a maximum thickness of 120 ft (36 m), the Reagan gradually thins until it is completely overlapped by the Honey Creek. Among many interesting features are an ankerite band at the contact of the Honey Creek and Reagan and wedges of rhyolite conglomerate and breccia shed from the gradually disappearing rhyolite island (Donovan, 1984).

C3. The view east from C3 is across the valley of Ketch Creek, which is eroded along a fault with a stratigraphic downthrow of 500 ft (150 m) to the west at this point, decreasing to zero to the NNW. The fault bifurcates and gradually passes into a number of small fractures and west-facing monocline in this direction. The dip of the fault plane wavers on both sides of vertical but is always steep; some springs are associated with the fault about 600 ft (180 m) north of C3.

C4. A walk along the Ketch Creek fault from C3 to C4 shows that while most of the related deformation (including some tight folding) is located in the downthrown (western) block, the stratigraphic disparity is reduced by the gradual appearance of younger beds in the eastern block. On this walk the view to the northeast encompasses almost 5,000 ft (1,500 m) of unbroken Arbuckle Group carbonates dipping northeast at angles of 20-30°.

C5. The final stop on this walk is a spectacular double unconformity involving the Reagan–Carlton Rhyolite relationship and the Post Oak Conglomerate and Lower Paleozoic sequence. The latter unconformity is especially impressive; one side of a steep-sided Permian valley is clearly exposed, and the Post Oak clasts marked fine upward and outward from the unconformity. From here the best route back to Oklahoma 58 is to walk along the rhyolite outcrop to A 14; good examples of flow folding can be found in the rhyolite.

REFERENCES

Beauchamp, W. H., 1983, The structural geology of the southern Slick Hills, Oklahoma [M.S. thesis]: Oklahoma State University, 119 p.

Donovan, R. N., 1982, Geology of Blue Creek Canyon, Wichita Mountains area, *in* Gilbert, M. C., and Donovan, R. N., eds., Geology of the Eastern Wichita Mountains, Southwestern Oklahoma: Oklahoma Geological Survey, Guidebook 21, p. 65-77.

— , 1984, The geology of the Blue Creek Canyon area, *in* Gilbert, M. C., and Donovan, R. N., eds., Recent developments in the Wichita Mountains, Guidebook for Field Trip No. 1: 18th Annual Meeting, Geological Society of America South-Central Section, Richardson, Texas, p. 40– 101.

Donovan, R. N., and Rafalowski, M. B., 1984, The nature of the unconformity between the Honey Creek Limestone and the Carlton Rhyolite in the Slick Hills of southwestern Oklahoma Geological Society of America, Abstracts with Programs, v. 16, no. 2, p. 82.

Donovan, R. N., Babaei, A., and Sanderson, D. J., 1982, Blue Creek Canyon, *in* Gilbert, M. C., and Donovan, R. N., eds., Geology of the Eastern Wichita Mountains, Southwestern Oklahoma: Oklahoma Geological Survey, Guidebook 21, p. 148-153.

Gilbert, M. C., and Donovan, R. N., 1984, Recent developments in the Wichita Mountains, Guidebook for Field Trip No. 1: 18th Annual Meeting, Geological Society of America South-Central Section, Richardson, Texas, 101 p.

Harlton, B. H., 1972, Faulted fold belts of southern Anadarko basin adjacent to frontal Wichitas: American Association of Petroleum Geologists Bulletin, v. 56, p. 1544–1551.

Hudleston, P. J., 1973, Fold morphology and some geometrical implications of theories of fold development: Tectonophysics, v. 16, p. 1-46.

McConnell, D., 1983, The mapping and interpretation of the structure of the northern Slick Hills, southwest Oklahoma [M.S. thesis} Oklahoma State University, 131 p.

Martini, W. R, D., 1986, Transpression: an application to the Slick Hills, SW Oklahoma [Ph.D. thesis] Belfast, Northern Ireland, Queens University of Belfast, 286 p.

Rafalowski, M. B., 1984, Sedimentary geology of the late Cambrian Honey Creek and Fort Sill Formations as exposed in the Slick Hills of southwestern Oklahoma [M.S. thesis]: Oklahoma State University, 147 p.

Ragland, D. A., 1983, Sedimentary geology of the Ordovician Cool Creek Formation as it is exposed in the Wichita Mountains of southwestern Oklahoma [M.S. thesis] Oklahoma State University, 170 p.

Ragland, D. A., and Donovan, R. N., 1985, The Thatcher Creek member, basal unit of the Cool Creek Formation, in southern Oklahoma Oklahoma Geology Notes, v. 45, no. 3, p. 83–91.

Ramsay, J. G., 1967, Folding and fracturing of rocks: New York, McGraw-Hill Book Company, 560 p.