FLUVIAL TO ESTUARINE TRANSITION IN THE MIDDLE BLOYD SANDSTONE (MORROWAN), NORTHWEST ARKANSAS

by

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Abstract

      The Morrowan middle Bloyd sandstone of northwest Arkansas records a fluvial to estuarine transition in a drowned incised valley system. Lower portions of outcrops contain fluvially deposited, planar-tabular cross-stratified sandstone with a uni-directional southwest paleoflow. Intervals with dune scale, intricately interwoven trough cross-stratification with northeastern paleoflow is attributed to strong tidal and wave influence in the outer estuary. Upwards the middle Bloyd changes into a muddy mid-estuarine interval with heterolithic bedding and a bi-directional northeast-southwest paleoflow. Overlying this interval a marine sand about one meter in thickness can be found containing bryozoan and crinoid fossils. Overlying the middle Bloyd, the marine Dye Shale member of the Bloyd Formation marks the transition to a dominantly marine setting.

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Introduction

Ancient fluvial systems have been extensively studied in the past, namely with the use of facies models. Without the use of modern analogs however, the complexity and scope of the paleo depositional setting may not be fully understood. The Lower Pennsylvanian middle Bloyd Sandstone, in northern Arkansas has been one of these misunderstood units. Historically the Morrowan and Atokan sandstones of northwest Arkansas and eastern Oklahoma have been miscorrelated stratigraphically due to their generally similar appearance. The Morrowan-Atokan boundary was not clearly delineated and the various sandstones of the Morrow and Atoka were not differentiated. Subsequently extensive detailed mapping was completed in the early 1970's (Zachry and Haley 1975). In addition to the Atoka-Morrow boundary confusion there has also been misinterpretation of the origin of sand units within the Morrow. This confusion still exists today although current mapping is attempting to resolve this problem (Zachry, 2006; McFarland, Personal Communication).

Previous published works (Zachry, 1979a, 1979b Crowder, 1982 Berry, 1978 Glenn, 1973) have documented evidence for bedload dominated fluvial depositional settings. Nonetheless, comparisons to modern analogs suggest evidence is abundant for more complicated fluvial or fluvio-estuarine systems. The exception to these older works is one which describes fluvial-tidal influence near the end of a large fluvial system (Antia, 2006). The middle Bloyd sandstone exhibits high angle (> 15°) cross bedding which locally contains sets of thick-thin bedding pairs. In the previously mentioned studies, important physical sedimentary features appear to have been overlooked. These thick-thin pairs have been observed in other Pennsylvanian rocks, as well as modern and ancient analogs in fluvio-estuarine environments (Archer and Feldman, 1995; Archer et. al, 1994; Lanier et. al, 1993;

Greb and Archer, 1998; Archer, 2004; Archer et. al, 1996; Nio and Yang, 1991; Lanier and Tessier, 1998). Quartz-pebble conglomerates are also seen in the middle Bloyd and may provide evidence of incised valleys fills as deposited during rising sea level. The conglomerates may have formed in similar incised valley settings as other lower Pennsylvanian conglomerates in Kansas, Illinois, the central Appalachian basin, and the Denver basin (Archer and Greb, 1995). The presence of similar sedimentary features and paleo-flow directions in northwest Arkansas and the Illinois basins suggest there was crossbasinal sediment transport.

Scope and Objectives of Investigation

The objectives of this investigation are to study the middle Bloyd sandstone of northwest Arkansas. This study consists primarily of two parts. The first objective was to observe the character (facies, paleoflow direction, and composition of the sandstone) of the middle Bloyd sandstone in fifteen outcrops across the study area (Fig. 1) and to describe any changes in character from the north-south and east-west directions. These possible changes in character will allow for a better understanding of the paleodepositional system and allow for creation of a depositional model based on relevant modern analogs. The second objective of this investigation was the search for evidence of incised valley fills and tidal influence. This included looking at the physical and biogenic sedimentary features of the outcrops in detail. The outcrops span a strait line distance north-south of approximately 69km, and an east-west span of 85km (Fig. 1).
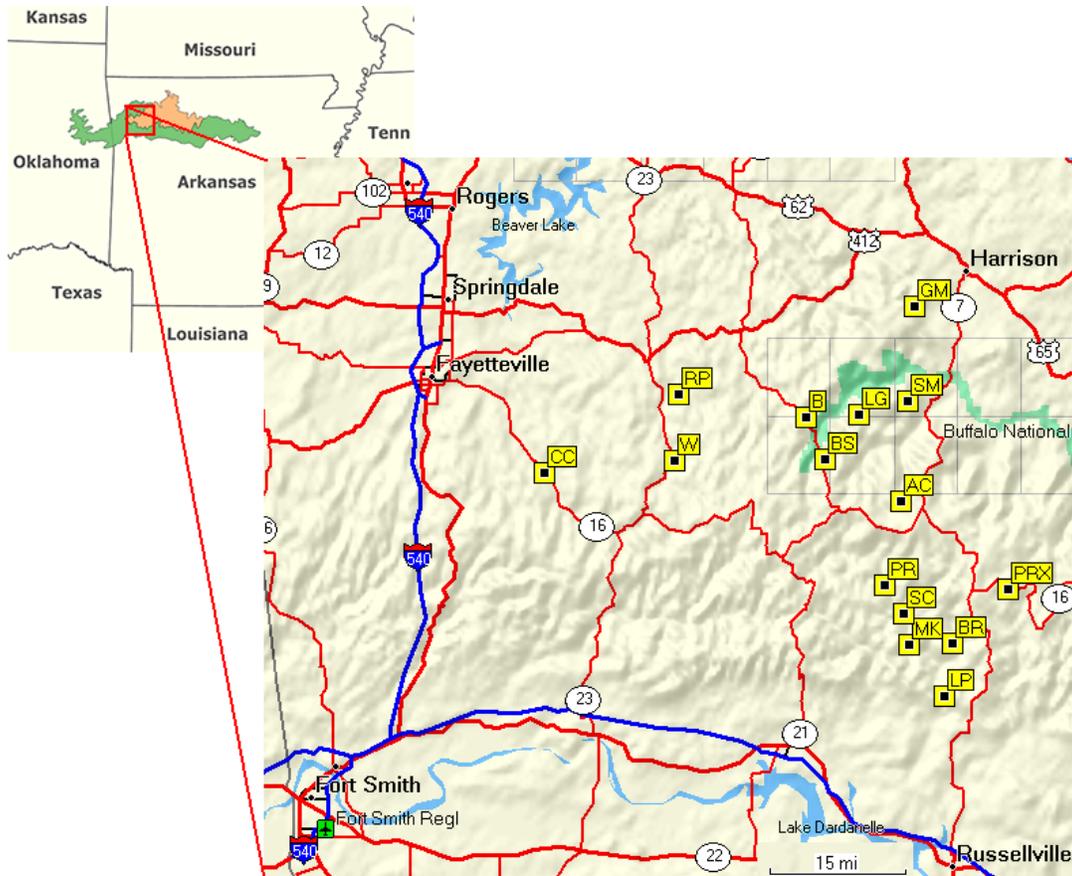
Figure 1 Study area with outcrops highlighted in yellow.
Abbreviations for outcrop locations can be found in Appendix Table 1.
The Boston Mountains are shown in orange (upper) and green (lower).

Previous Works- The Pennsylvanian of North America

The presence of Morrowan conglomeratic sandstones across the interior of the North

American craton suggests extrabasinal clastic sediment transport during the Pennsylvanian.

Potter and Siever (1956), Potter and Glass (1958), Potter and Pryor (1961), have shown

nearly identical petrology and sedimentary features in the Eastern Interior (Illinois),

Appalachian, Michigan, and Mid-Continent (Forest City) basins. Physical sedimentary

features in these basins, namely large-scale cross-beddingding, also indicated a dominant

south-southwest paleoflow direction. It is generally accepted that these basins were not yet

differentiated in the interior craton during the tectonically stable early Pennsylvanian; however this changed following Morrowan time due to tectonic influences (uplift) and erosion which led to the separation of once interconnected basins (Potter and Siever, 1956; Potter and Glass, 1958; Potter and Pryor, 1961; Snyder, 1968; Sutherland and Manger, 1979; Manger and Sutherland, 1992; Sutherland, 1988; Thomas, 1977, 1984; Glick, 1975; Archer and Greb, 1995).

During Morrowan and throughout Pennsylvanian time, there were numerous high magnitude fluctuations in sea level. These fluctuations have most often been attributed to glacio-eustatic causes due to glaciations of Gondwana (Webb, 1994; Schoff, 1975; Archer, 1998; Archer and Greb, 1995). Fluctuations in sea level have been estimated from 45 to 190 meters, but the estimates may be high (Archer and Greb, 1995). Work in similar Pennsylvanian-age settings in Kansas have shown actual ranges of 30-40 meters (Archer and Feldman, 1995; Archer et. al, 1994; Archer et. al, 1996) These eustatic cycles have not been completely recognized in other basins, but work in the Hugoton Embayment has shown seven eustatic cycles during Morrowan time. (Archer et. al, 1994 Archer and Greb, 1995) (Fig. 2).
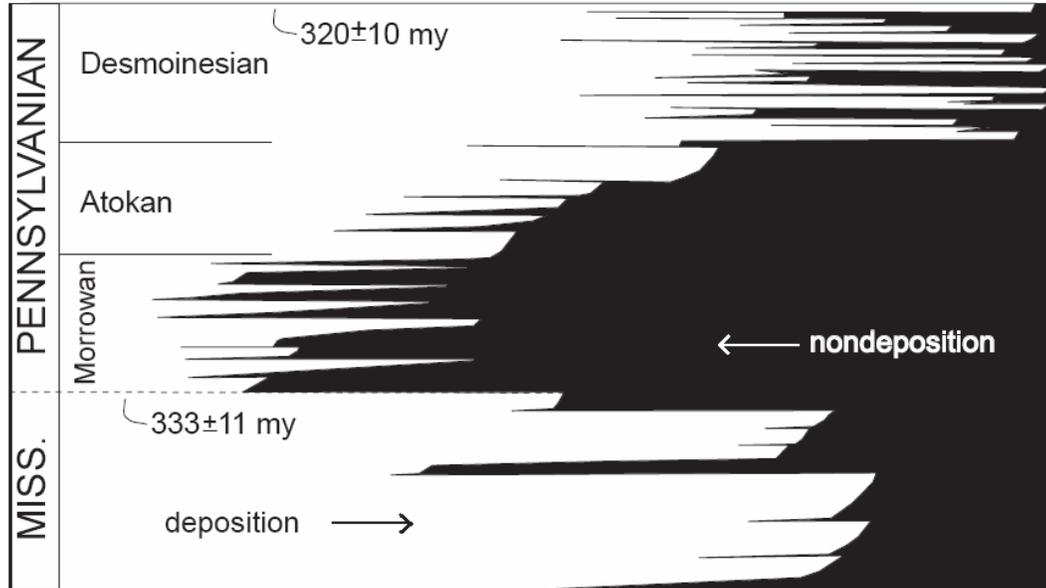
Figure 2 Seven eustatic cycles recognized in Morrowan rocks from the Hugoton Embayment, Kansas (Archer and Greb, 1995 p. 621).

The Morrowan was also a time of low global sea levels with tropical to sub-tropical climates along the paleoequator. Most of Eastern North America was located near the paleoequator (Archer and Greb, 1995). This is in contrast to Mississippian time which was generally a time of higher seas and arid climate (Archer and Greb, 1995; Archer, 1998; Schoff, 1975; Webb, 1994; Kvale et. al 1994). Archer and Greb (1995) further expanded ideas of Morrowan depositional systems by developing a paleogeographic reconstruction displaying interconnected basins making up an Amazon-scale drainage basin across the eastern North American craton (Fig. 3).
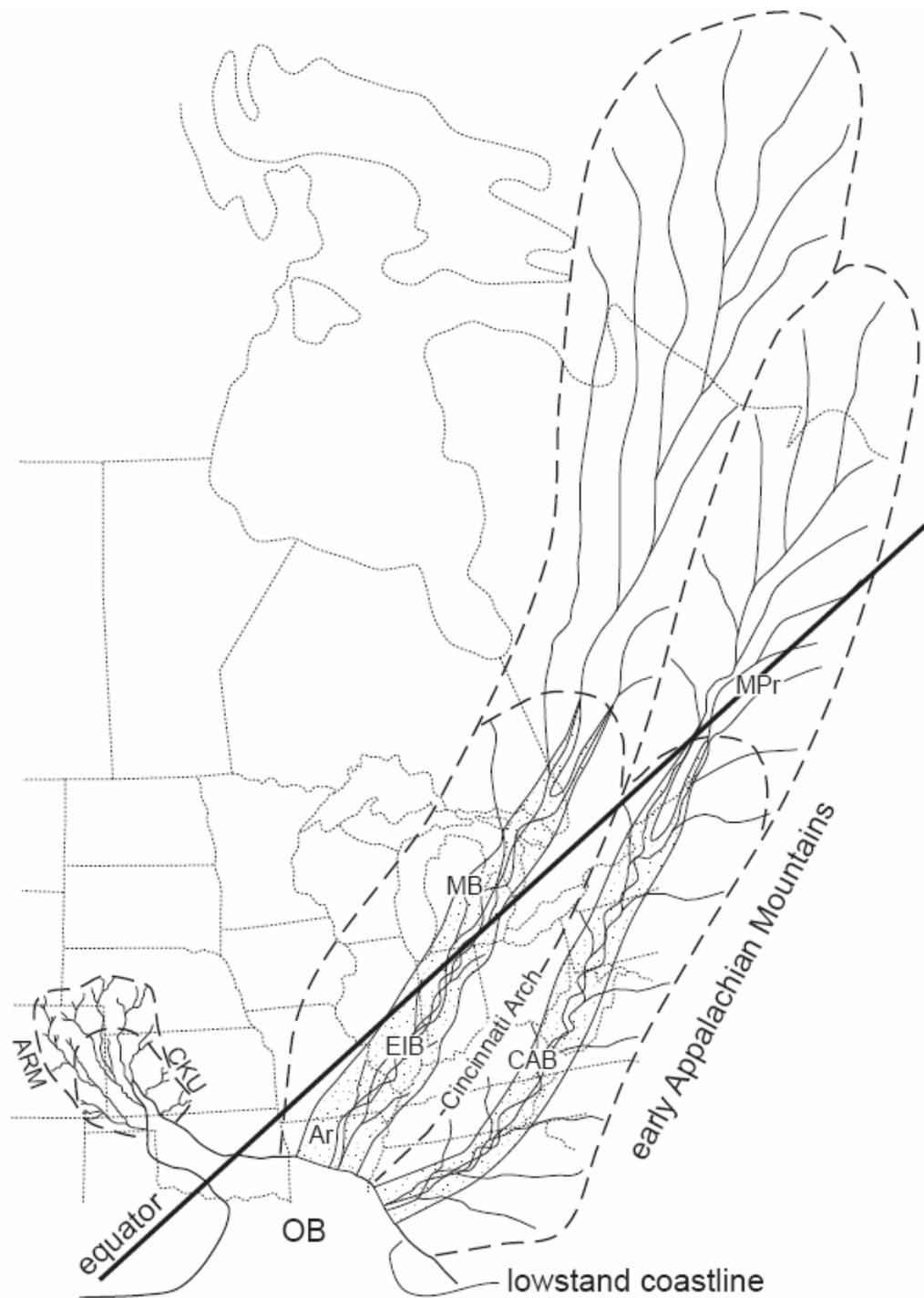
Figure 3 Paleogeographic reconstruction of a Lowstand Morrowan sea illustrating maximum and minimum sizes of drainage basins. OB Ouachita Basin, EIB Eastern Interior Basin (Illinois Basin), CAB Central Appalachian Basin, MB Michigan Basin, ARM Ancestral Rocky Mountains, CKU Central Kansas Uplift, MPr Maritime Provinces of Canada, Ar middle Bloyd sandstone of Arkansas (Archer and Greb, 1995 p. 616).

Archer and Greb (1995) noted that the Morrowan sands across the North American craton were commonly deposited as an incised valley fill, resting unconformably upon Chesterian and Early Morrowan strata. The paleovalleys are variable in size, and range from 15-120 meters deep and 0.5 to 30 km wide. In addition to incised valley fills, sheet-form sandstone belts, which were not restricted to a paleovalley, are also present. The Morrowan sandstones typically contained an abundance of quartz pebble conglomerates near the base of the sandstone, as well as being cross-bedded throughout with a dominant south-southwest paleoflow direction. The Morrowan sandstones across the craton were found to be compositionally dominated by coarse-grained orthoquartzites. Estuarine or fluvio-estuarine facies may locally overlie these sandstones and indicate a eustatic fluctuation in sea level.

During most of Morrowan time, northwest Arkansas was situated along a lowstand sea near the terminus of a large scale fluvial system. Enormous amounts of sediments mostly derived from the uplift of the Early Appalachians, was transported into the Illinois basin. These sediments were subsequently transported south through Arkansas and into the Ouachita Basin (Houseknecht and Kacena, 1983; Glick, 1975; Sutherland, 1988; Thomas, 1977, 1984; Archer and Greb, 1995). Glick (1975) estimated that nearly 200 cubic km of sediments had been deposited in northern Arkansas between early Morrowan to middle Desmoinesian time, with an estimated 305 m on the cratonic shelf, and up to 9,144 m of sediments in the Ouachita Basin. Today these thick deposits are recognized in the subsurface as turbidites in the Arkoma Basin.

During Atokan through Desmoinesian (and potentially later) time the Ozark Uplift (and Ozark Dome) and east-west trending Ouachita Mountains were actively uplifting. The uplift of the Ouachita Mountains cut off the flow of clastic sediments from the northeast into

Arkansas for the remainder of Morrowan time (Sutherland, 1988 Glick, 1975). Post Morrow

deposition into the Ouachita basin came from the northwest, east, west and south directions

due to the uplifts in the region. Small amounts of uplifted sediments were also carried down

off the eroding uplifts from the north and northeast (Thomas, 1984; Sutherland, 1988).

Morrowan Stratigraphy of Northwest Arkansas

Morrowan rocks outcrop extensively in northwest Arkansas. The Morrowan Bloyd

Formation containing the middle Bloyd sandstone (an informally named member) is the unit

of interest for this study. The middle Bloyd sandstone outcrop belt is generally oriented in an

east-west direction primarily across the Boston Mountains. The northern boundary is created

by a regional truncation due to modern erosion north of the Boston Mountains (Fig. 4 and 5).
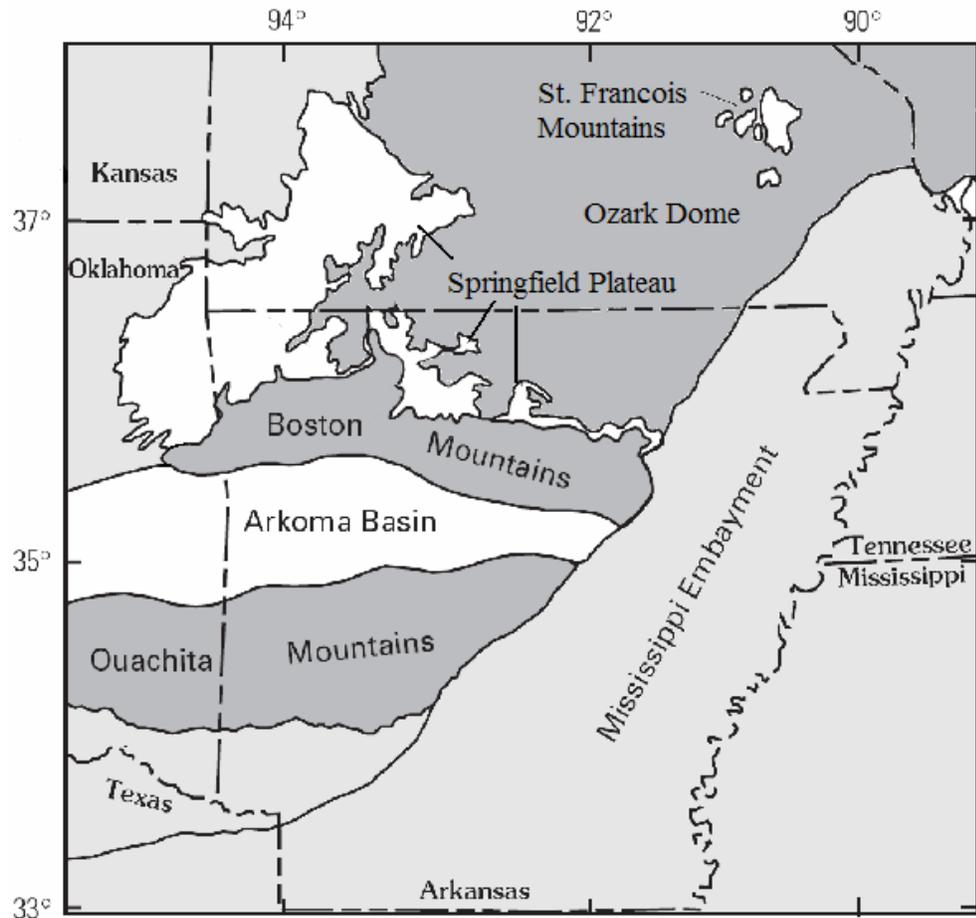
Figure 4 Geologic Provinces of Arkansas and surrounding states
(Modified from Hudson et. al, 2001).

A southern boundary is created by the Mulberry and Cass Fault Zones where normal faulting

dropped the formation into the subsurface Arkoma Basin (Houseknecht and Kacena, 1983;

Zachry, 1979a; Glick, 1975). The middle Bloyd sandstone extends to the east from the

Oklahoma border, but the eastern boundary has not yet been clearly differentiated. To south

and east other sandstones appear where the middle Bloyd sandstone starts to thin;

differentiating these sandstones is difficult complicated by faulting and pinching out of

sandstones at the same time (McFarland, Personal Communication).
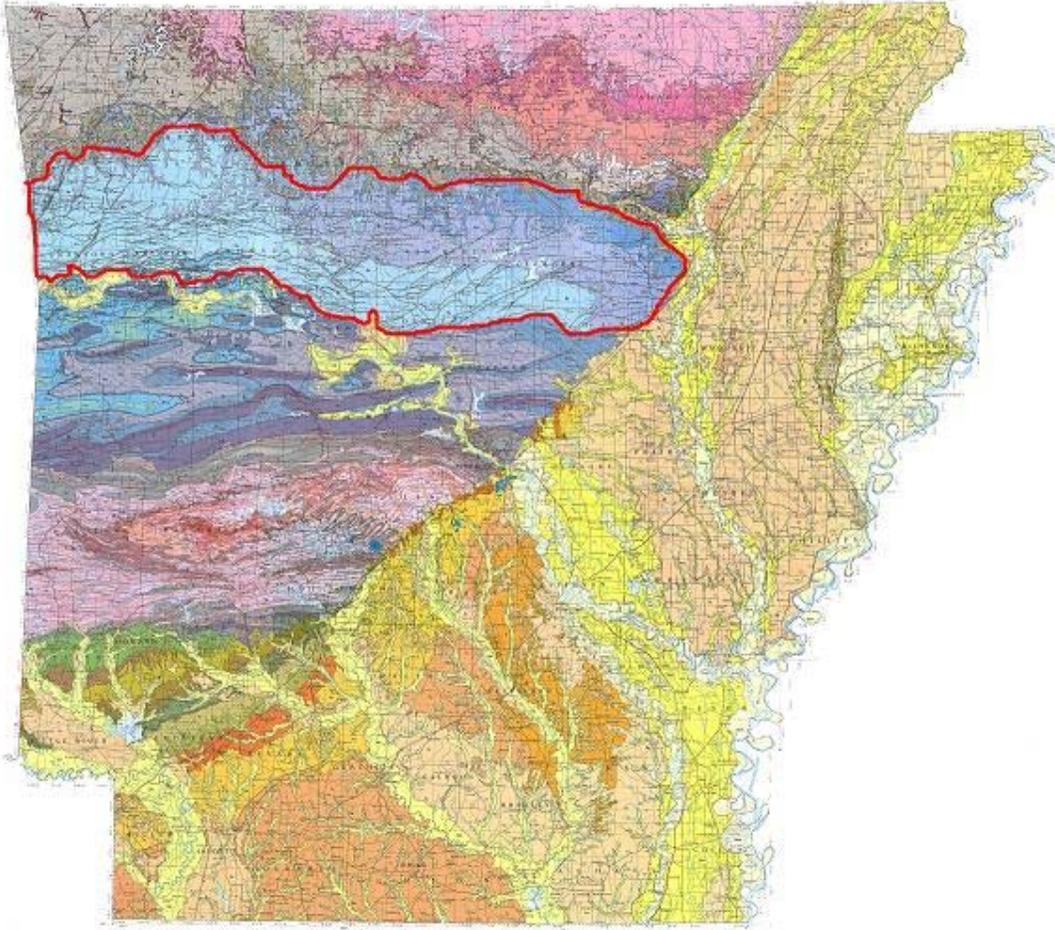
Figure 5 Middle Bloyd sandstone outcrop belt outlined in red (Modified from Haley et. al 1993).

The Morrowan rocks in northwest Arkansas rests upon Chesterian strata (Fig. 6). Morrow-Atoka time records a shelf to basin transition from north to south where units thicken and change facies. Dominant facies of this time period contain sandstone, shale, siltstone and limestone which have recorded rapid marine transgressions and regressions (Sutherland and Manger, 1979; Sutherland, 1988).
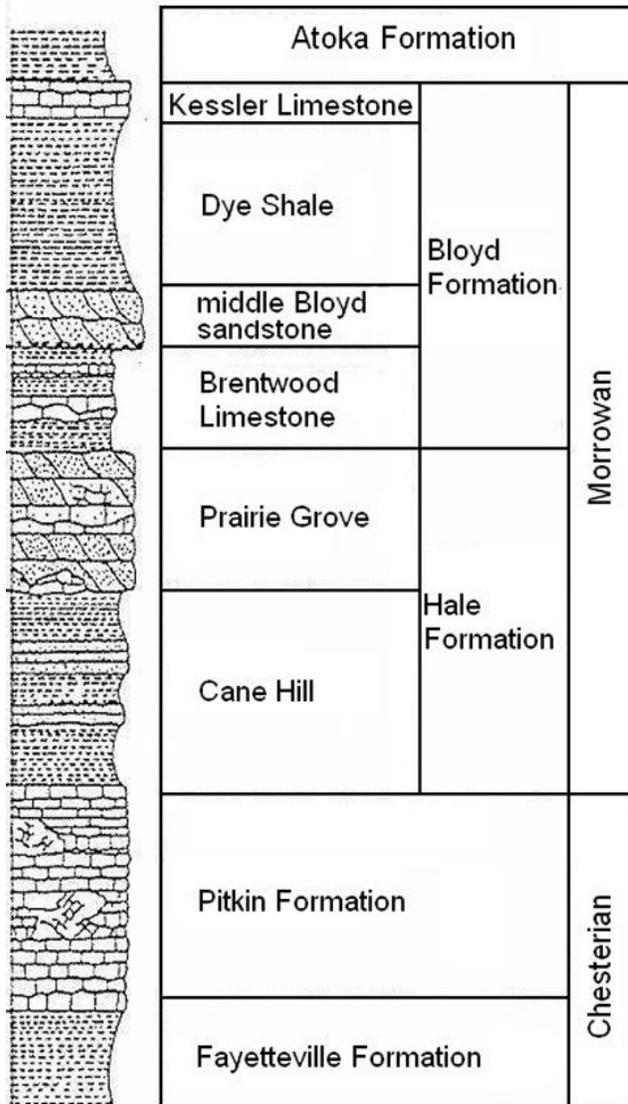
Figure 6 Stratigraphy of the study area in Northwest Arkansas. The middle Bloyd sandstone replaces the Woolsey Shale in this stratigraphic column and across the study area (Modified from Zachry, unpublished).

The Bloyd Formation (of primary interest in this study) contains five recognized members: the Brentwood Limestone, Woolsey Shale, middle Bloyd sandstone, Dye Shale, and Kessler Limestone (Fig. 6). Throughout the study area the Woolsey Shale has been replaced with the middle Bloyd sandstone (Zachry, 1979). All the members of the Bloyd Formation have been formally named with exception of the middle Bloyd sandstone; however the name is generally accepted and has been used by the Arkansas Geologic Commission and United States Geologic Survey in their publications and maps.

The lower member of the Bloyd Formation is the 10-16 m thick Brentwood Limestone Member which conformably overlies the Hale Formation. The member consists of two to four limestones with thick units of dark gray to black fissile shale in between. The limestones may be composed of bioclastic grainstone and packstone which are often less than 2 m in thickness (Zachry 1979a, 1979b). The limestones within the Brentwood Limestone

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Member as observed in outcrops in this study were gray in color with abundant brachiopod shells, tabulate corals, and many small fossil fragments. In the southern portion of the study area bioclastic grainstones were also seen in the Brentwood Limestone member outcrops. Locally the Brentwood member may also contain thin calcareous sandstones, commonly showing high angle cross-stratification (Zachry, 1979b; Personal Communication).

The next overlying member is the Woolsey. This conformable terrestrial member consists of 3-13 m of siltstone, shale, and interbedded shale and siltstone which may vary greatly in thickness from one outcrop to another. Terrestrial plant remains are commonly found within the shale. The top of the Woolsey contains the Baldwin Coal, a thin sub-bituminous coal ranging in thickness from 2.5-20 cm. The Woolsey becomes increasingly sandy and thins eastward, where it is in a facies relationship with the middle Bloyd sandstone (Zachry 1979a, 1979b).

The middle Bloyd sandstone is 3-46 m in thickness. This unit unconformably overlies and locally incises into the Brentwood Limestone Member. Compositionally the middle Bloyd sandstone is a quartzarenite containing very small amounts of schist particles, polycrystalline quartz, and milky white quartz pebbles thought to be of metamorphic origin (Zachry, 1979a, 1979b; Berry, 1978). Features of the middle Bloyd sandstone include: high angle, trough, and overturned cross-stratification, quartz pebble conglomerates, ripple sets, mud draped ripples, and erosional channels (Zachry 1979a, 1979b). Tabular cross-bed sets can range in thickness from 0.1- 2 m. The contact of the middle Bloyd sandstone and underlying shales and limestones of the Brentwood Member typically consists of quartz pebble conglomerates and/or clay pebbles. Locally at the contact large cobble to boulder size load casts can be found. Zachry (1979b) has also reported that an interval of marine

sandstone ranging from 0.6-1.8 m in thickness has been found in the uppermost parts of some middle Bloyd outcrops.

Unconformably overlying the middle Bloyd sandstone is the marine deposited Dye Shale which ranges from 18-33.5 m in thickness (Henbest, 1962). At the base, the Dye Shale typically contains a sandstone with clay pebbles and conglomerates up to 1.5 m thick. This lower part of the Dye Shale is typically referred to as the "caprock." The remaining portion of the Dye Shale above the "caprock" consists of dark gray to black shale containing some locally scattered calcite rich concretions (McFarland 2004).

The Kessler Limestone is the topmost member of the Bloyd Formation, conformably overlying the Dye Shale. It is typically 3-8 m in thickness (Zachry 1979a). Compositionally the Kessler Limestone Member is made up of bioclastic and oolitic limestone. This limestone contains clay pebbles, thin calcium cemented sandstones, and thin shales. These facies are thought to have been deposited as short-term marine transgressions took place. East of central Madison County, the Kessler Limestone Member is believed to be absent (Zachry, 1979b). Erosional unconformities exist at the base of the Atoka Formation, Dye Shale Member, and middle Bloyd sandstone (McFarland, 2004). The relationship among the facies of the Bloyd Formation in a regional cross-section can be seen in Figure 7.

It is also important to note that previous studies considered the Trace Creek Shale Member of the Atokan Formation to be a part of the Bloyd Formation prior to 1978. Sutherland et. al (1978) redefined the Morrowan-Atokan boundary based on biostratigraphy. They found that there was a significant unconformity between the Morrow and Atoka boundary.
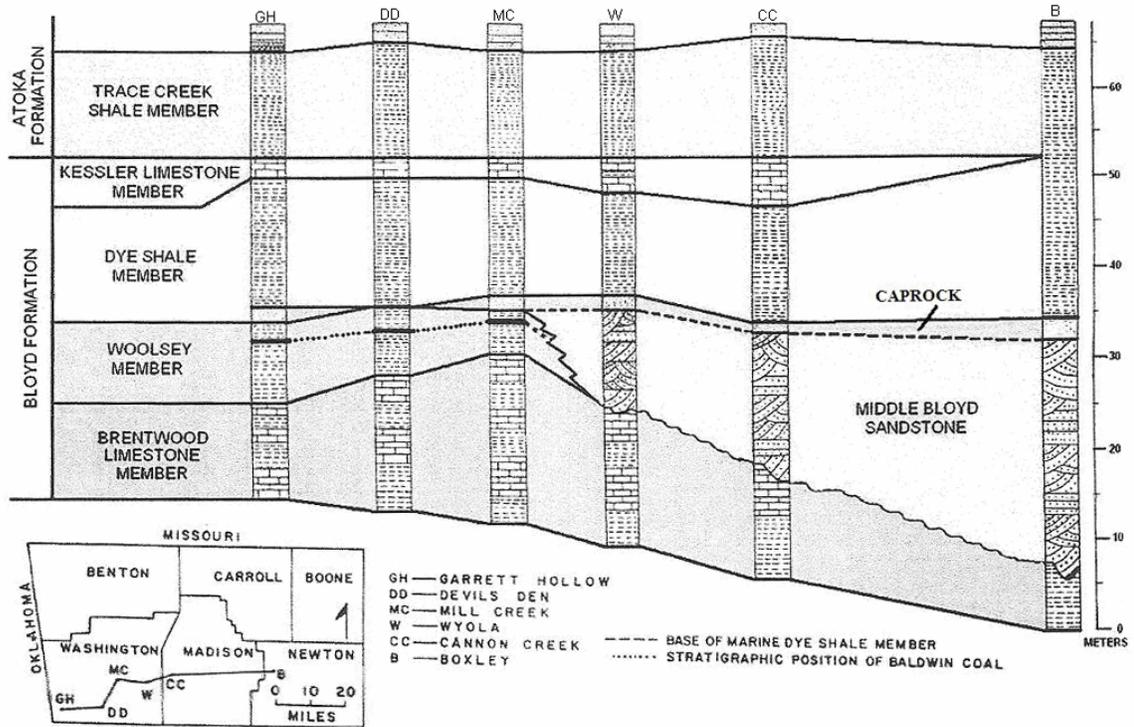
Figure 7 Regional cross-section illustrating relationship among members of the Bloyd Formation (Modified from Zachry, 1979a).

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Methods

The fifteen outcrops in this investigation were selected based on their suitability of study due to lack of vegetative cover and land classification. Most of the outcrops studied were on public lands in the Ozark and St. Francis National Forests, with other outcrops on highway right of ways and in recreation areas. Due to the widespread forest cover in the area, many outcrops have a thick covering of mosses, lichens and other vegetation making study very difficult. For this reason fifteen of the best outcrops in the study area were selected for detailed analysis.

Outcrops locations (Fig. 1) were located using 7.5 minute geologic map quadrangles and utilizing some of the previous locations studied in the 1978 Berry, 1982 Crowder, and 2006 Antia theses. Additional outcrops were pointed out in the field by Doy Zachry of the University of Arkansas. The remainder of the outcrops were found using a transparent overlay of digital 7.5 minute geologic map quadrangles in Google Earth. This allowed for the map to be made semi-transparent so that prominent rock outcrops could be seen through the map. Often the best outcrops could be seen with Google Earth's high resolution imagery. Fortunately, detailed geologic maps existed for about one half of the study area. Sixteen quadrangles were mapped by the Arkansas Geologic Commission and three by the United States Geologic Survey. Access to outcrops that were not on highway right of ways or very close to the paved highways required access by four wheel drive or hiking.

To observe possible changes in character of the outcrops, samples were collected for making thin sections to analyze the petrology of the middle Bloyd and boundaries of physical sedimentary features. At least one rock sample was taken from each outcrop for study. Most of these samples were collected with a rock hammer with only a few cut with a Stihl gas

powered concrete saw. Cut samples were sent to Texas Petrographic for the making of thin sections. The thin sections (17) were studied under a Nikon E600 petrographic microscope and photographed with a Nikon E5000 digital camera.

Quartz pebbles, which are commonly found in the middle Bloyd sandstone, were also measured in the field when found in sufficient quantity. A measurement of 30 randomly selected pebbles was taken at each outcrop where accessible and in a sufficient quantity. The in situ pebbles were measured on the two longest axes with a millimeter scale from the outcrop face itself. These measurements were used to examine any possible trends in pebble size across the study area.

Strike and dip measurements of the physical sedimentary features were also taken using a Brunton compass when acceptable measurement locations could be found. Declination was set to four degrees east for northwest Arkansas. These measurements were used for recording paleo-flow direction. Most outcrops had vertical faces making it difficult to find a place to record a strike and dip measurement, or the extreme weathered surface made the measurements impossible to take. Often the general direction could be identified, but not measured precisely. For this reason paleoflow directions in this study are not reported precisely.

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Stratigraphic Sections

Stratigraphic sections for the middle Bloyd start at the base of the middle Bloyd or the lowermost exposure where the contact between the middle Bloyd and Brentwood may be covered. Additional thicknesses of shale/siltstone covered slopes may exist above the outcrop tops, but were so poorly exposed they were not suitable for study. Additional covered intervals also are present within some outcrops.

Typical middle Bloyd outcrops are tan to brown to gray in color and lie on either the Brentwood Formation limestone, shale, or siltstone. In the western portion of the study area the middle Bloyd lies on the Brentwood Limestone. Further south and east the middle Bloyd lies on shale and then a siltstone deeper in the Brentwood Limestone member. Immediately above the contact a clast supported quartz pebble or clay pebble conglomerate is often present. Large load casts and a zone of soft sediment deformation commonly overlie the contact.

The lower portions of the outcrops generally are clean sands (though may contain clay pebbles) and contain intensely cross-stratified sandstone with quartz pebbles and thin beds of matrix supported conglomerate. Moving upward in the outcrops, the shale content increases where interbedded intervals of sandstone and shale can be found. Accompanying this transition the paleoflow in cross-stratified sandstone shows strong bi-directionality not present in the lower portions of outcrops. Throughout the outcrops honey-comb weathering and liesegang cementation are common.

Stratigraphic Section Legend

	Planar tabular cross-stratified sandstone
	Planar-tabular cross-stratified sandstone with quartz pebbles
	Trough cross-stratified sandstone
	Ripple bedded sandstone
	Horizontally bedded sandstone
	Horizontally bedded sandstone with quartz pebbles
	Quartz pebbble conglomerate
	Shale
	Siltstone
	Interbedded sandstone and shale
	Limestone (fossiliferous)
	Bioclastic Grainstone
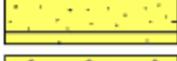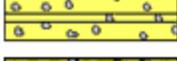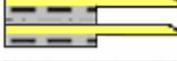
Figure 8 Stratigraphic Section Legend
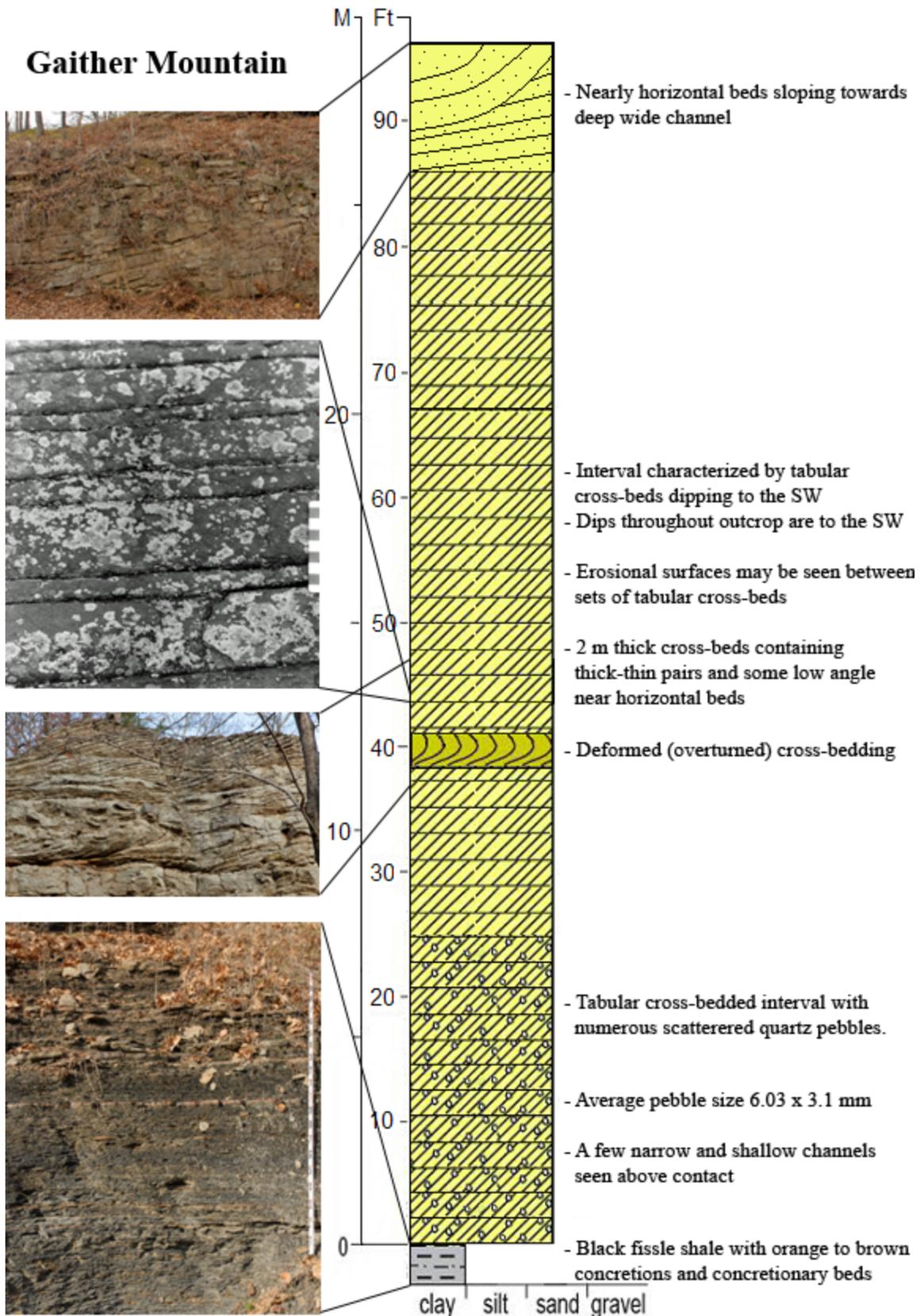
Figure 9 Gaither Mountain stratigraphic column.

The figure includes the following annotations from top to bottom:

- Nearly horizontal beds sloping towards deep wide channel

- Interval characterized by tabular cross-beds dipping to the SW
- Dips throughout outcrop are to the SW

- Erosional surfaces may be seen between sets of tabular cross-beds

- 2 m thick cross-beds containing thick-thin pairs and some low angle near horizontal beds

- Deformed (overturned) cross-bedding

- Tabular cross-bedded interval with numerous scatterered quartz pebbles.

- Average pebble size 6.03 x 3.1 mm

- A few narrow and shallow channels seen above contact

- Black fissle shale with orange to brown concretions and concretionary beds

clay   silt   sand   gravel

Figure 10 Deep, wide channel in left of picture. Pictured interval approximately 4 m in thickness. This is the southern end of the outcrop and top of the middle Bloyd exposure in this outcrop.

Figure 11 Standing on shale slope. Contact at shoulder level. Note thick prominent tabular cross-beds dipping SW. Nearly entire outcrop shown in picture is cross-bedded, though portions are difficult to see. Pictured interval approximately 16 m in thickness.
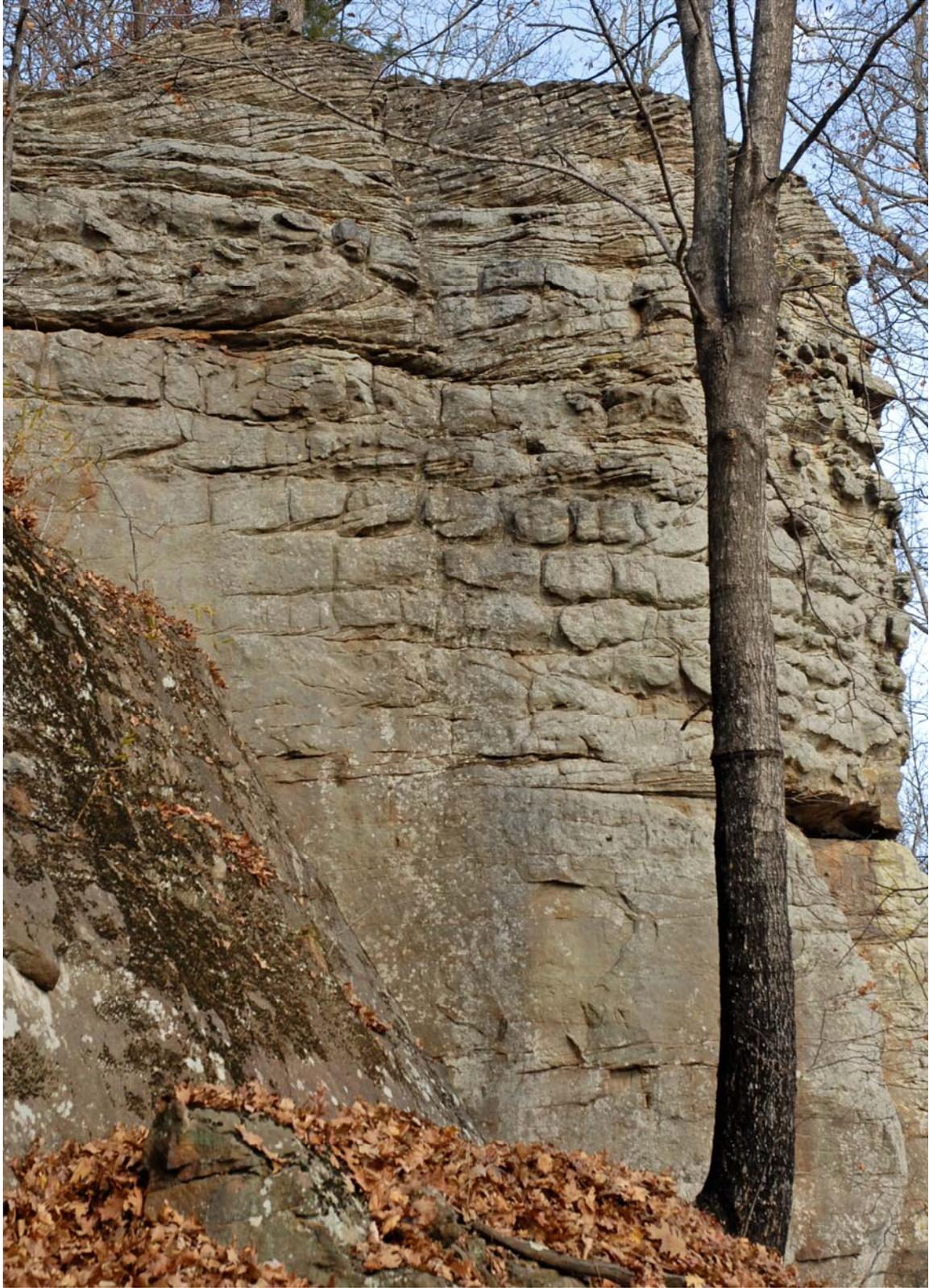
Figure 12 Top of well exposed middle Bloyd at north end of outcrop. Poorly exposed, mostly covered middle Bloyd is seen above this bench on a steep slope. Note blocky weathering pattern on cross-beds. Pictured interval approximately 6 m in thickness.

Figure 13 Close up view from top of Figure 12. Tabular cross-bed sets containing thick-thin pairs. Pictured interval 2.8 m thick. Note layer of deformed (overturned) cross-bed sets.

Figure 14 Close up of thick thin pairs on high angle cross-beds at Gaither Mountain. Photo taken from same interval pictured in Figures 12 and 13. Scale in cm.
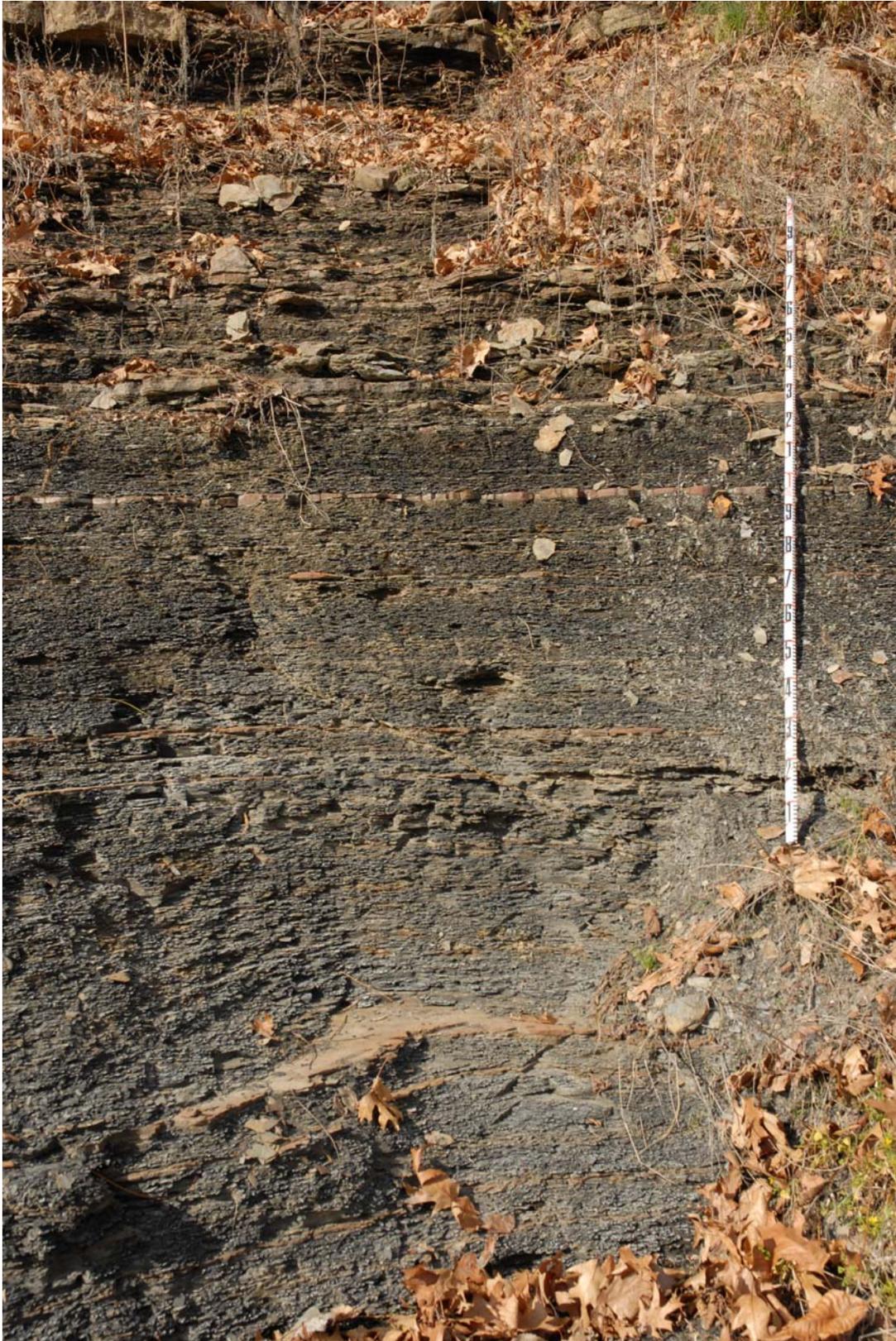
Figure 15 Black fissile shale of the Brentwood Limestone member just below the middle Bloyd contact. Shale has brown to orange concretions and concretionary beds. A calcarenite lens within the shale can be seen in the northern portion of the outcrop.

Roadside Park

- Underside of overhang shows ripples on cross-bed sets with west paleoflow
- Honeycomb weathering also seen on portions of overhang

- Tabular cross-bedded sandstone dipping to SW throughout outcrop

- Abundant scattered quartz pebbles with pebbles concentrated along horizontal reactivation surfaces.

-Average pebble 8.8 x 4.9 mm

- Quartz pebble conglomerate
-Brentwood Limestone

clay   silt   sand gravel

Figure 16 Roadside Park stratigraphic column.

Figure 17 Example of honey comb weathering commonly seen in the middle Bloyd. This is the best example of any outcrop seen in this study. Looking up at underside of ledge. Decimeter scale.

Figure 18 View of underside of erosional overhang. Paleoflow is to the west. Close up of ripple slabs can be seen in Figure 19.

Figure 19 Close up of ripples in wall identical to ripples overhead shown in Figure 18.

Figure 20 Tabular cross-stratification with abundant quartz pebbles. Note concentration of quartz pebbles at horizontal reactivation surface. Paleoflow is to the SW.

Figure 21 Wrinkle marks or small-scale loads on float block indicating very shallow flow possibly influenced by wind.

Figure 22 Trace fossil of terrestrial plant (similar to modern "horse tails") just above contact.

Figure 23 Quartz pebble conglomerate at Bloyd/Brentwood contact. Scale in cm.
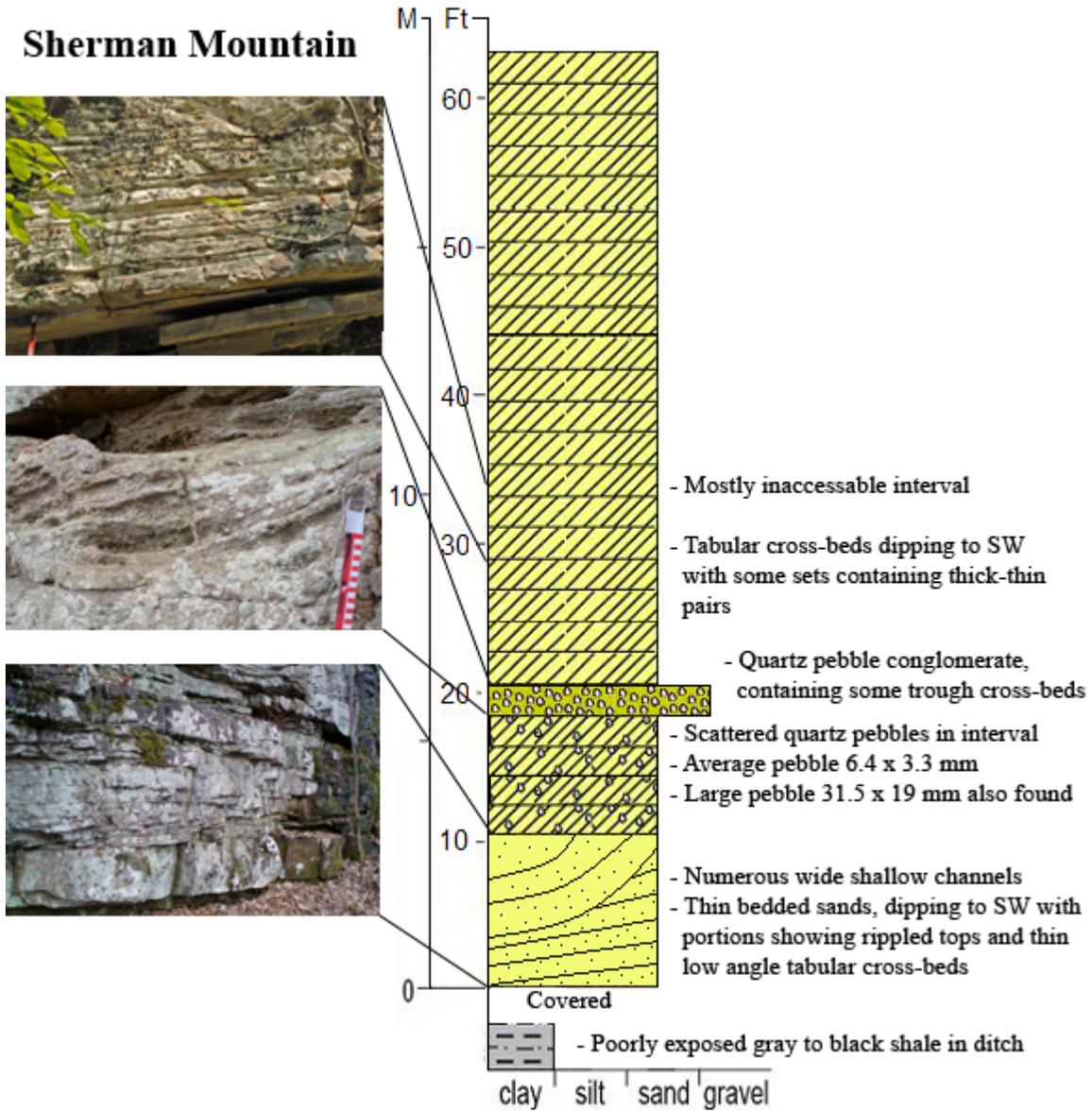
Figure 24 Sherman Mountain stratigraphic section.

Figure 25 Tabular cross-bedding locally containing low angle cross-bed sets with thick thin pairs. Cross-beds dip to the SW. Horizontal sandstone seen at top of 2 m rod (lower left) has abundant quartz pebbles. This is directly overlain by trough cross-beds containing quartz pebble conglomerate and horizontal layers of conglomerate. Pictured interval approximately 6 m in thickness.

Figure 26 Close up of thick-thin pairs at Sherman Mountain on low angle tabular cross-bed sets.

Figure 27 Quartz pebble conglomerate in trough cross-beds. Note the horizontal layer of quartz pebble conglomerate seen directly overlying the trough cross-beds. A 1.5 m thick interval below this conglomerate also contains abundant quartz pebbles. but not as densely packed.

Figure 28 Thin bedded sandstone with a few low angle tabular cross-beds. Shallow, narrow channels may be present at this interval. Thin sand beds may have rippled tops in some areas. Lateral variability can be clearly noted at this interval of the outcrop. Below this interval a sequence of wide shallow channels can be seen. Pictured interval approximately 2.5 m in thickness
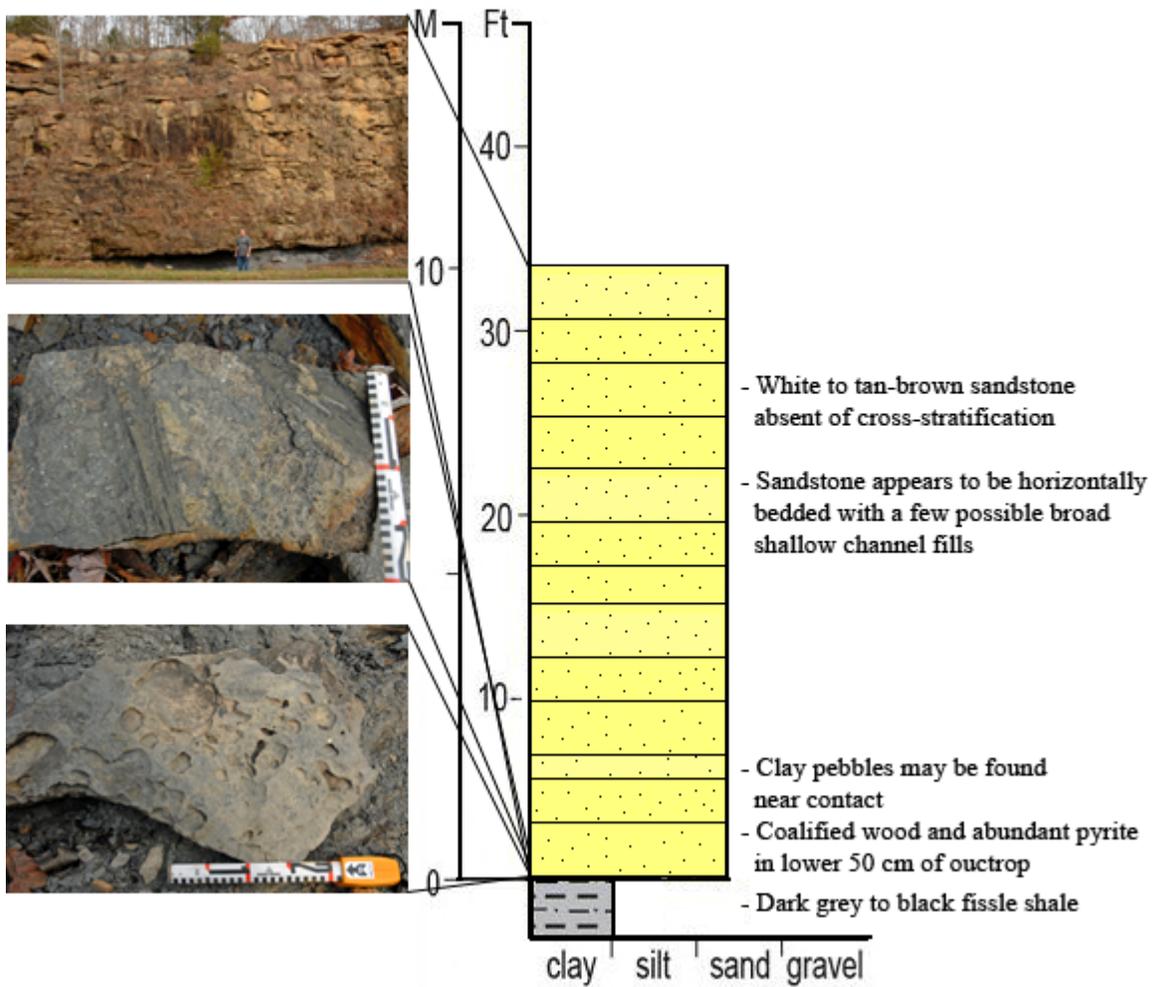
Figure 29 Boxley stratigraphic section.

Figure 30 Boxley outcrop with Brentwood shale at base.

Figure 31 Coalified wood found in lower portion of outcrop just above Bloyd/Brentwood contact. The coalified wood can be found in a clean white sandstone which may be stained from abundant pyrite present along with the coal

Figure 32 Voids produced by weathered out clay chips from float block near Bloyd/Brentwood contact.

Low Gap
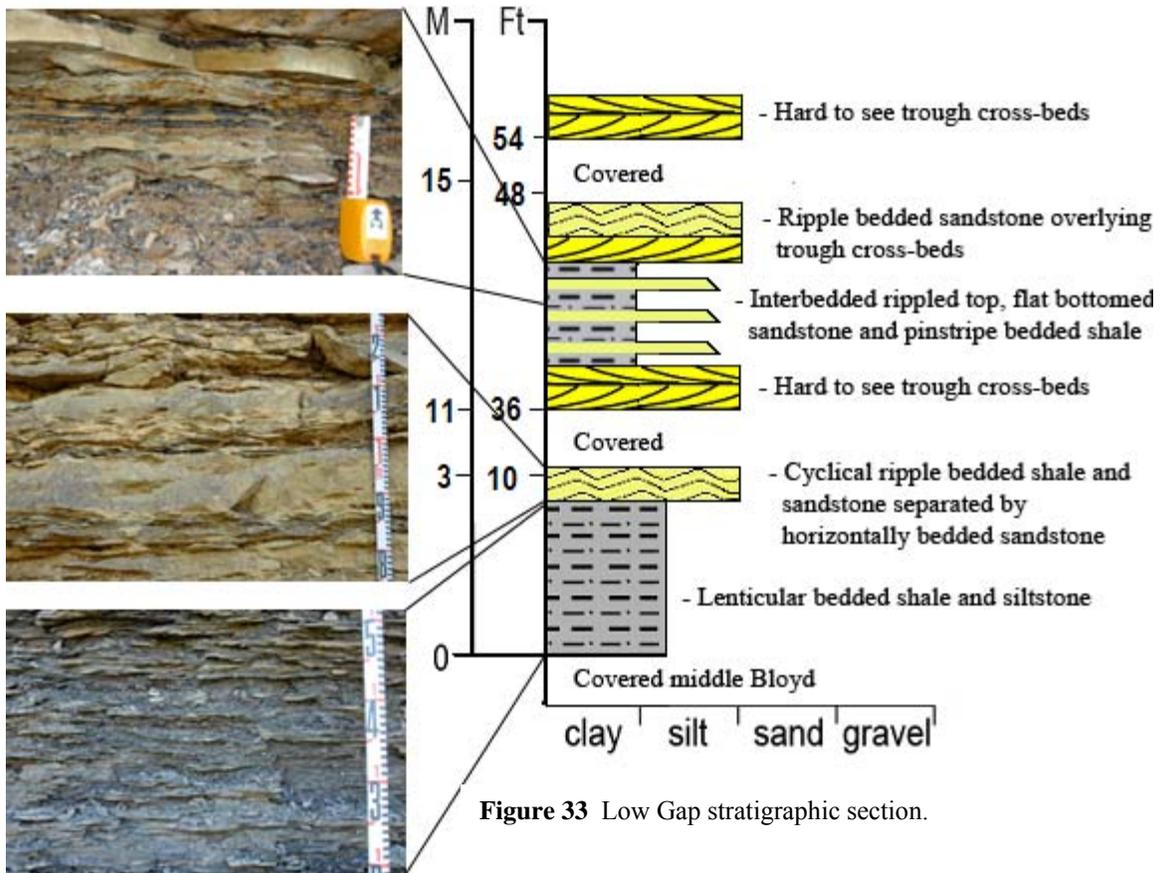
Figure 33 Low Gap stratigraphic section.

- Hard to see trough cross-beds

Covered

- Ripple bedded sandstone overlying trough cross-beds

- Interbedded rippled top, flat bottomed sandstone and pinstripe bedded shale

- Hard to see trough cross-beds

Covered

- Cyclical ripple bedded shale and sandstone separated by horizontally bedded sandstone

- Lenticular bedded shale and siltstone

Covered middle Bloyd

clay | silt | sand | gravel

Figure 34 Shale with pinstripe bedding. Sandstone interbedded with the shale has rippled tops and a flat bottom. Bedding appears very cyclical.

Figure 35 Full view of interval with interbedded sandstone and shale. Figure 34 shows the upper portion of this picture. Pictured interval approximately 2 m in thickness.

Figure 36 Cyclical rippled/non rippled sandstone. Some rippled intervals show mud drapes.

Figure 37 Close up of ripple bedded sandstone with mud drapes from Figure 36.

Figure 38 Lenticular bedded shale and siltstone at base of section.
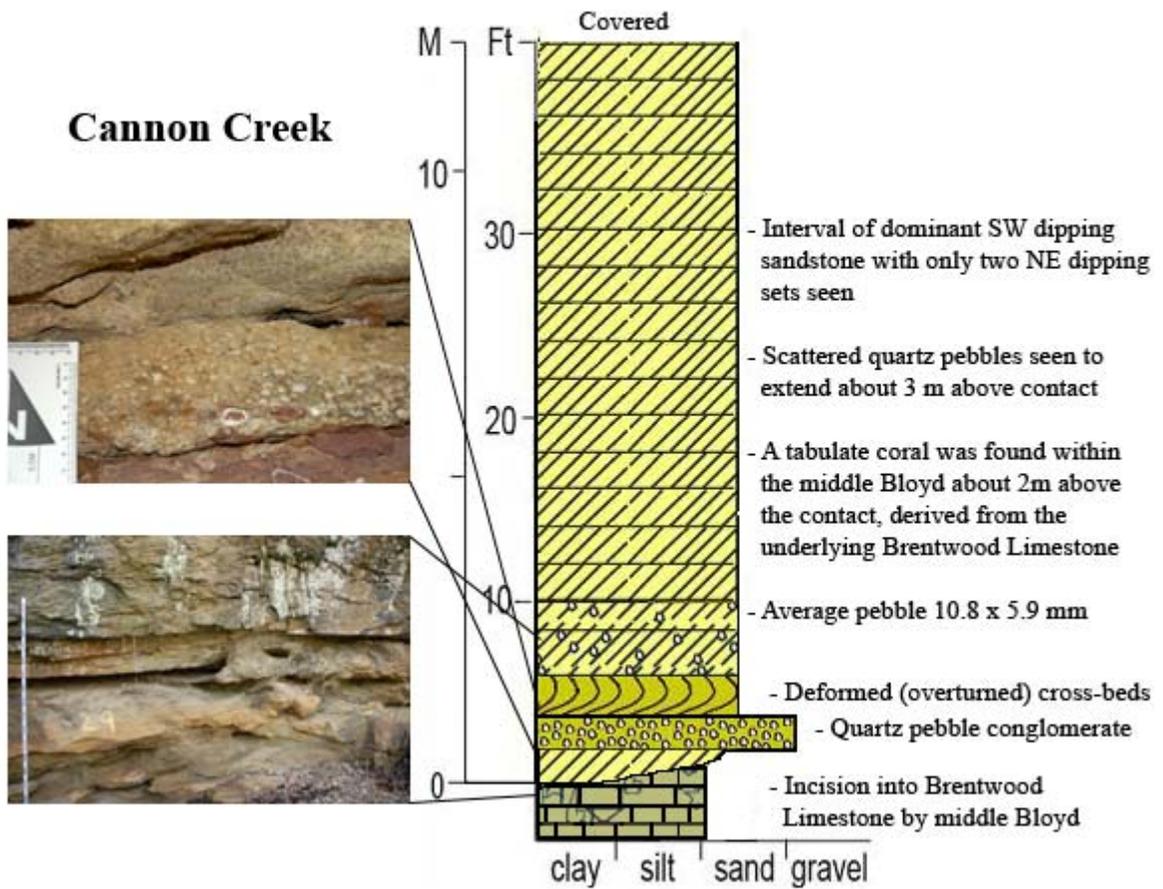
Figure 39 Cannon Creek stratigraphic column.

Figure 40 Incision into the Brentwood. Several places incise into the Brentwood by about 1 m. Pictured interval approximately 2 m in thickness. Contact is at the base of the 5 on the scale rod. In the lower left 2/3 of the photograph the middle Bloyd is seen incising into the Brentwood.

Figure 41 Quartz pebble conglomerate at base of middle Bloyd, overlying the Brentwood Limestone. This conglomerate has very little matrix, it is almost entirely quartz pebbles. Other quartz pebble conglomerates in the middle Bloyd consists mostly of matrix with scattered pebbles. Triangle is 5cm tall.

51

Figure 42 Close up view of contact, finger pointing at quartz pebble conglomerate between middle Bloyd and underlying Brentwood limestone.

52

Figure 43 Contact between middle Bloyd and Brentwood seen at neck level of people. At this level large troughs contain quartz pebble conglomerate. At head level there is a zone of overturned cross-beds due to soft sediment deformation.

Boxley South

- Ripple bedded sandstone

- Tabular cross-bedded sandtone with dominant SW dips, some biredirectional sets observed with NE dip directions toward top of outcrop

- Interbedded zone with flat bottomed ripple topped sands and highly weathered shale
- This interval pinches out northward

- Thick horizontally bedded sandstone

- Ripple and trough cross-bedded sandstone
- Scattered pebbles may be found in the lower 4 meters of the outcrop

clay   silt   sand   gravel

Figure 44 Boxley South stratigraphic column

Figure 45 Underside of rippled slab from shaley zone with with burrows at about 9 m. Note large burrows on edge of slab and smaller burrows throughout the slab.

Figure 46 Shale zone that pinches out. Note alternating layers of rippled sandstone and shale. Pictured interval is about 1m in thickness. Color variation due to shading of upper part of view.

Figure 47 Thin shale and rippled sandstone near base of outcrop. Rippled sandstone and two shale layers are each about 4 cm thick. Shale in portions of the outcrop appears to have pinstripe bedding.

Figure 48 Clay pebbles in float block found near base of middle Bloyd. Clay pebbles/cobbles can be found intact up to 12 cm in size.

Figure 49 Base of outcrop with at least 2 m of incision into the underlying Brentwood Shale

59
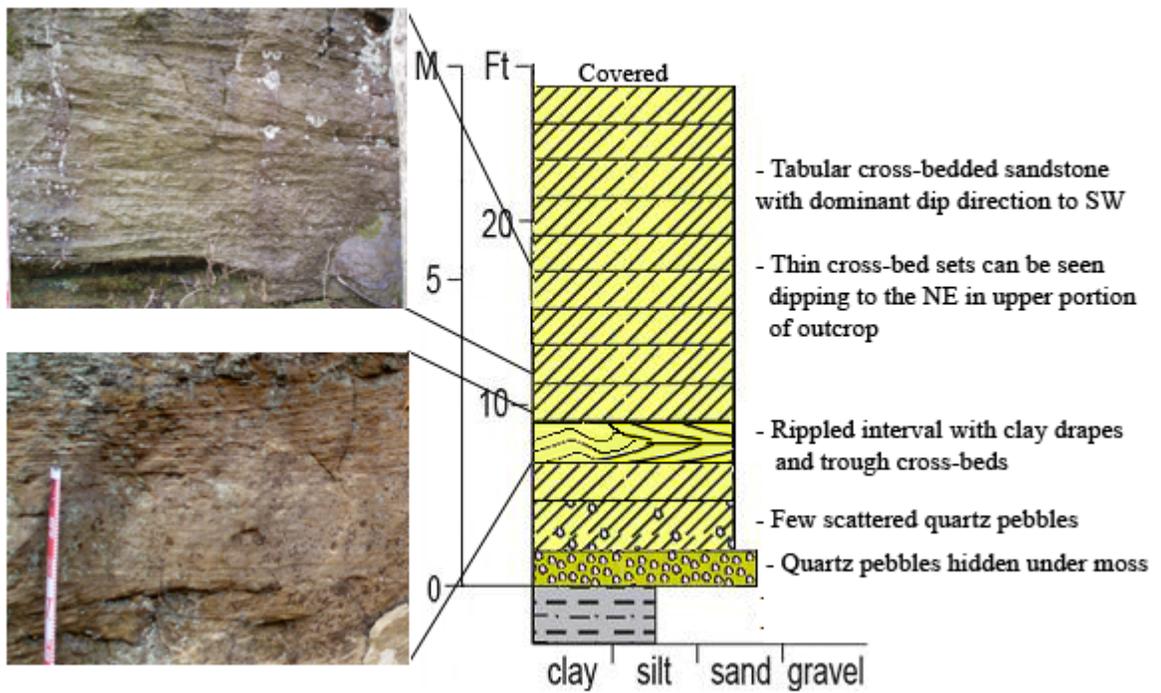
Figure 50 Witter stratigraphic column.

Figure 51 Wet exposure of tabular cross-bedded sandstone. Small thin sets are often less than 15 cm. Pictured interval approximately 1.5 m in thickness.

61

Figure 52 Rippled interval in close proximity to trough cross-beds. Ripples appear to have mud drapes replaced by iron cements.

Alum Cove

Figure legend / column labels:

M Ft
10 —
      Covered
30 — - Interval of ripple bedded sandstone

      - Interval of trough cross-bedded
        sandstone with high moss and lichen
        cover
20 —
      - Trough cross-beds have low angle
        nearly flat cross-bed sets in portions
        of the outcrop, small trucations of
        trough cross-beds can also be seen
10 —

      - Rippled bedded sandstone with
        feeding tracks
0 —   - Poorly exposed and covered interval
      Covered   of middle Bloyd
      - Dark gray to black ripple laminated
        shale/siltstone

clay | silt | sand | gravel

Figure 53 Alum Cove stratigraphic column.
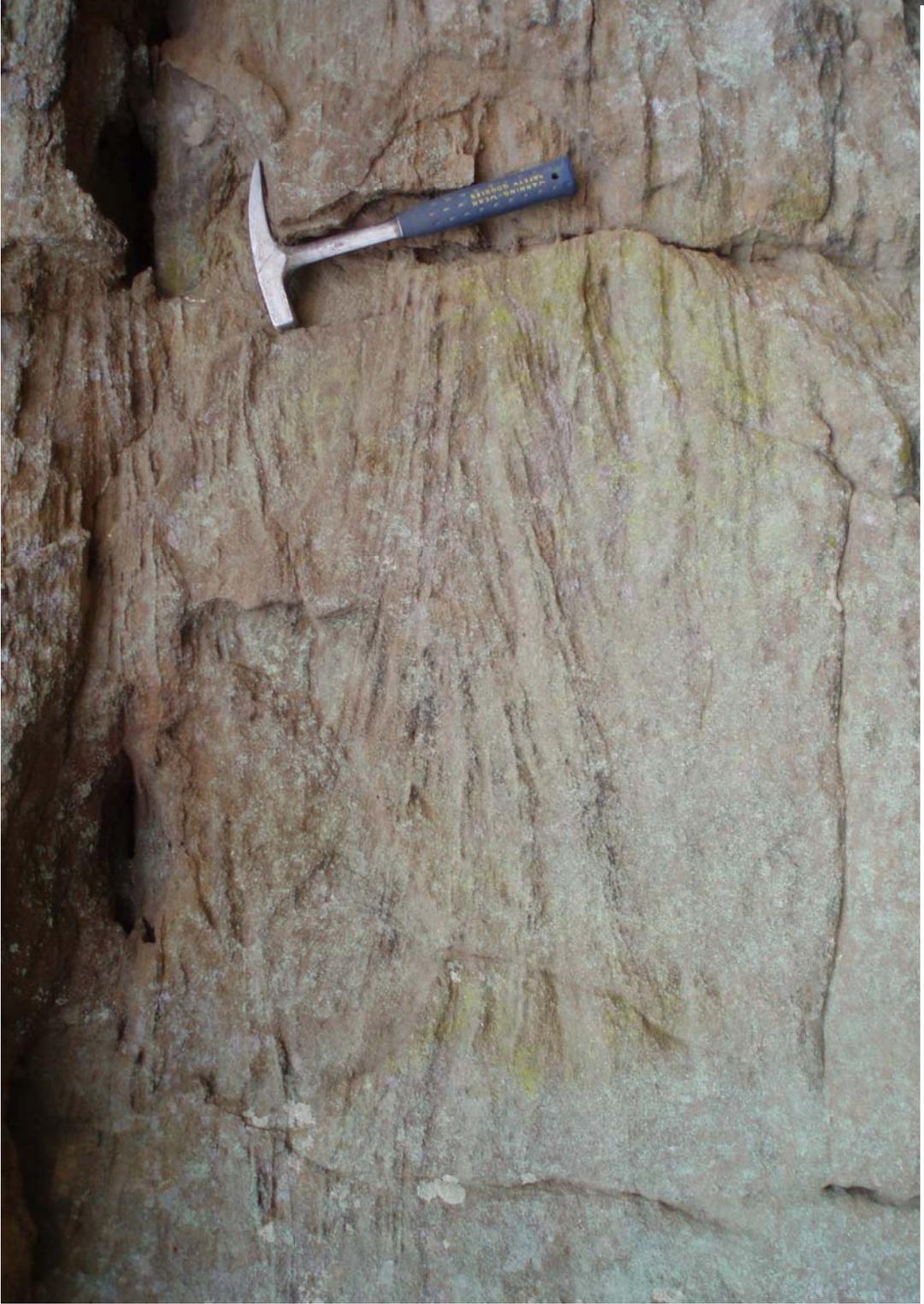
Figure 54 Bi-directional trough cross-beds. Bottom set of trough cross-beds dips S-SW. Upper set of trough cross-beds dips to the N-NE. Best exposed outcrop face in entire Alum Cove area.

Figure 55 Rippled sandstone with feeding tracks.

Parker Ridge

- Upper half of interval inaccessible

- Tan to brown sandstone with heavily weathered surface and excessive lichen growth

- Interval is characterized by trough cross-beds dipping in a dominantly N-NE direction

- Bi-directional trough cross-beds can be seen alternating from N-NE to S-SW dip directions

- Bottom of interval contains numerous clay pebbles and abundant muscovite flakes

- Wood fragments up to 1 m in length and 15 cm wide can be seen about 2 m above the base of interval

- Interval of thin sandstones and shales
- Sandstone has rippled top and flat bottom with pinstribe bedding visible in the shales where less weathered

- Horizontally bedded sandstone with scattered quartz pebbles
- Average pebble size 8.3 x 3.9 mm

- Gray ripple laminated siltstone

clay | silt | sand | gravel

Figure 56 Parker Ridge stratigraphic column.

Figure 57 Northerly dipping trough cross-bed sets seen at about 1 m and directly above scale. Scale in lower left is 2 m. Entire outcrop is approximately 20 m in thickness.

Figure 58 Best exposed trough cross-bed sets. Dip is in a N- NE direction. Small amounts of truncation may be seen.

Figure 59 Alternating beds of sandstone and shale. Sandstone beds have flat bottoms and rippled tops. The shale where not too weathered has orange and dark gray pin stripe bedding.

69

Figure 60 Dark gray siltstone underlying 1 m thick horizontally bedded sandstone with scattered quartz pebbles. Alternating beds of sandstone and shale (shown in Figure 59) overlie the 1 m thick sandstone.

Pedistal Rocks
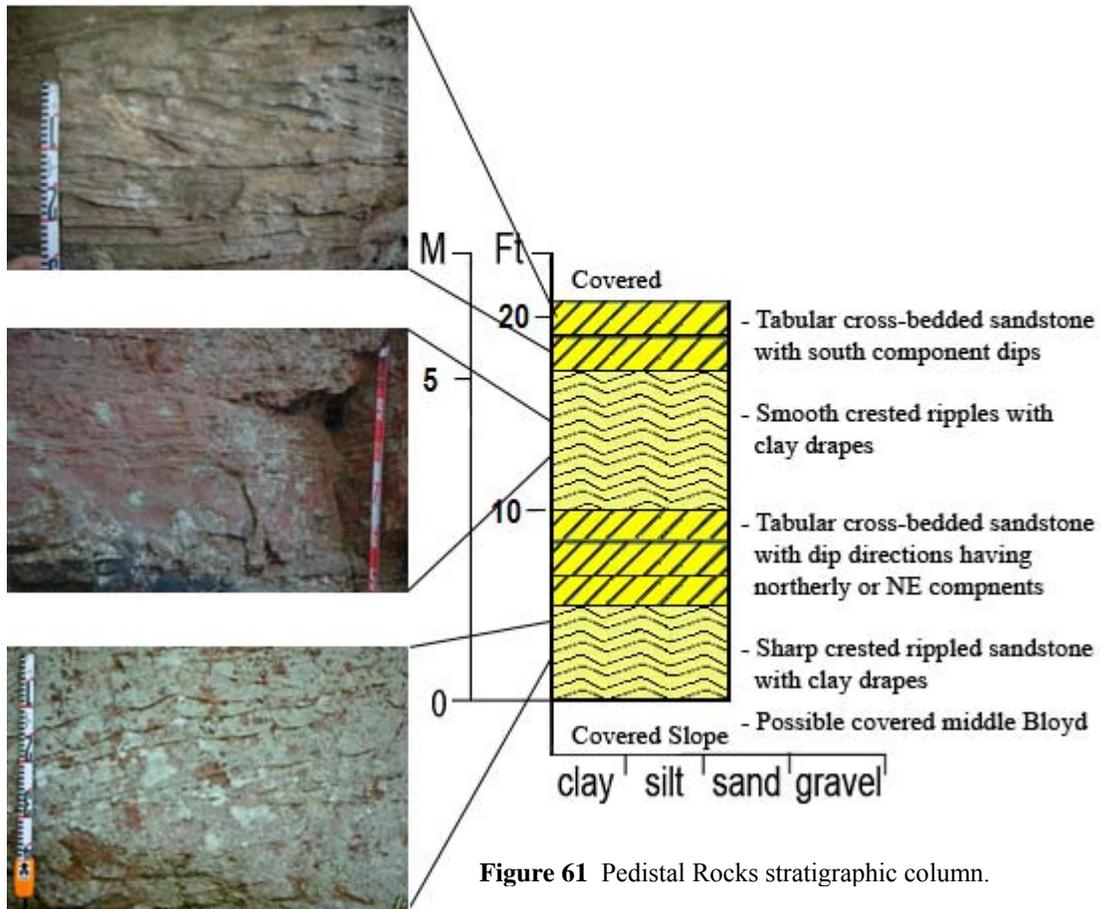
Figure 61 Pedistal Rocks stratigraphic column.

Figure 62 Low angle tabular cross-beds above rippled interval. Dips have a southerly component. Scale is inverted.

Figure 63 Rippled sandstone having smooth crests and mud drapes.

Figure 64 Rippled sandstone shown with upside down scale. Ripples appear to be mud draped, have sharp crests, and can be traced laterally through the outcrop for a distance.

Sugar Creek

- Interval of tan to brown trough cross-bedded sandstone with NE and SW dip directions
- Dominant dip direction is to NE

- Interval with truncation among trough cross-beds

- Interval of tan to brown trough cross-bedded sandstone with NE and SW dip directions
- Dominant dip direction is to NE

- Tabular cross-bed sets, difficult to see

- Dark gray shale/siltstone

clay | silt | sand | gravel

Figure 65 Sugar Creek stratigraphic section

Figure 66 Trough cross-beds typical of Sugar Creek outcrop. Trough cross-beds are dipping to the NE in photo. Dominant dip direction is NE but some beds dip to the SW. The entire outcrop face is highly weathered and covered with lichen growth.

Figure 67 Tabular cross-bed sets seen near the base of outcrop. Most cross-bed sets are difficult to see.
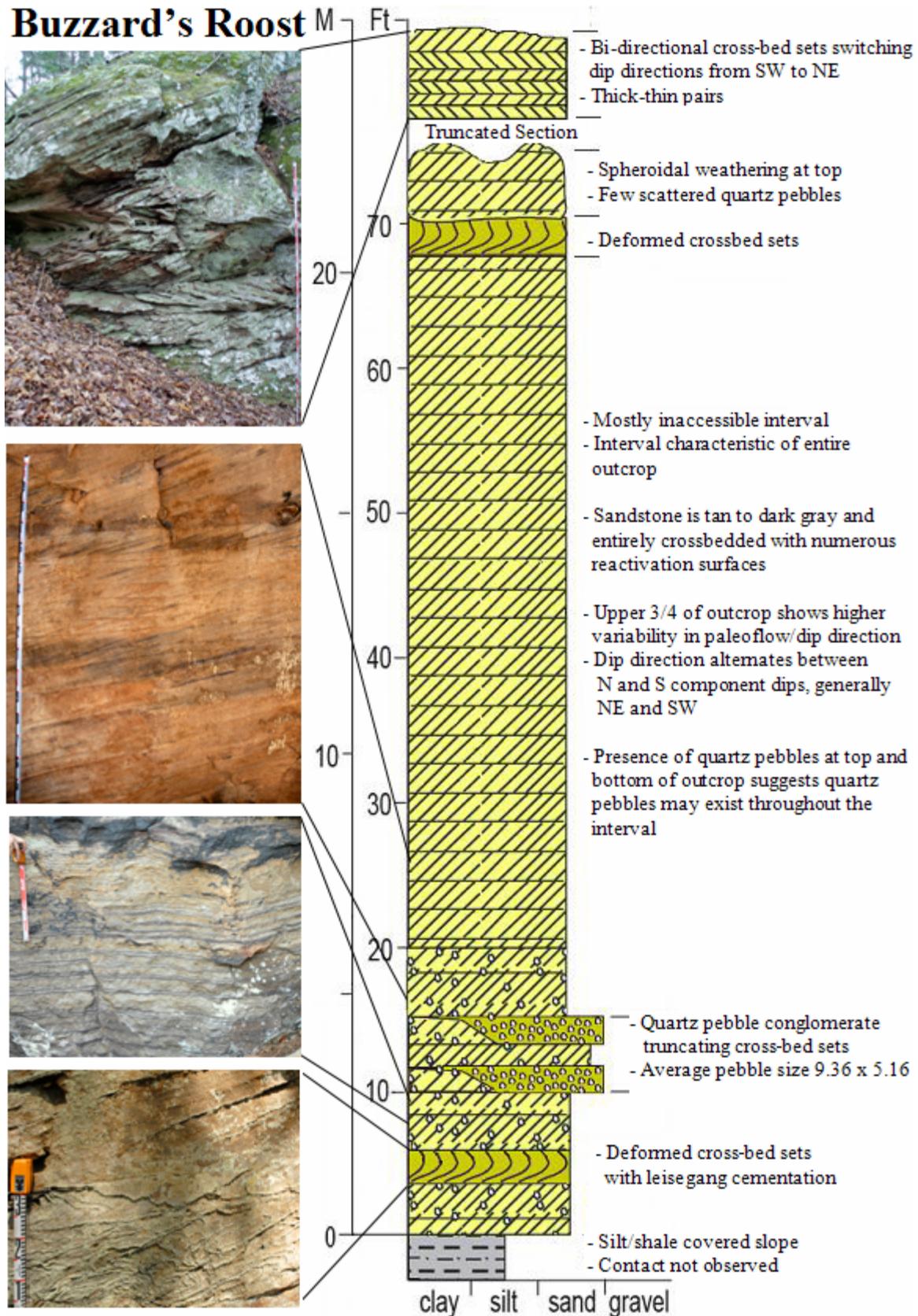
Figure 68 Buzzard's Roost stratigraphic section

Figure 69 Southwest outcrop showing bi-directional cross-bed sets alternating between NE and SW dips. Cross-bed sets also appear to contain some thick thin pairs. Cross-bed sets at 1 m and 1.65 m show NE dips. Remaining cross-bed sets show SW dips.

Figure 70 Cross-bed sets with numerous reactivation surfaces seen in small cave at central outcrop. Cross-bed sets in the outcrop range in thickness from 5 cm to 2 m. Average cross-bed sets measure from 0.4 to 1 m

Figure 71 Continuous 2 m thick cross-bed set at central outcrop. These continuous cross-bed sets were the thickest observed in the study area of the middle Bloyd. Pictured interval approximately 2.5 m above base of the outcrop. Thick-thin pairs may be present but weathered surface and lichens make for a difficult determination.

Figure 72 Thick-thin pairs seen at NE outcrop. Similar thick-thin pairs were seen at the central outcrop.

Figure 73 Cross-bed sets with liesegang cementation near base of outcrop. Cross-bed sets dip into deformed zone and become convolute. Locally flame like structures can be seen. It seems reasonable that the leisegang cementation followed the bedding structures because the cross-bed sets are leisegang cemented only at the boundaries.

83

Meadows Knob

- Bi-directional trough cross-beds with dominant northerly dip directions

- Interval of thinly interbedded sandstone and shale
- Shale is ripple bedded
- Sandstone has flat bottom, rippled top

- Bi-directional trough cross-bedded sandstone with highly weathered shale in between layers

Poorly Exposed or Covered

- 30 to 40 ft of poorly exposed or covered middle Bloyd

- Dark gray ripple laminated shale/ siltstone of the Brentwood Limestone Member

clay   silt   sand   gravel

Figure 74 Meadows Knob stratigraphic column

Figure 75 Top of Meadows Knob stratigraphic section. Section is exposed on a very steep slope covered with vegetation and loose rock. Overall the section is a poorly exposed due extensive weathering, lichen growth, and vegetative cover (Photo from Antia, 2006).

Figure 76 Sequence of thinly interbedded sandstone and shale. Sandstone beds have flat bottoms and rippled tops. Shale shows ripple bedding where not so weathered. Exposure appears identical to the Parker Ridge and Low Gap sections.
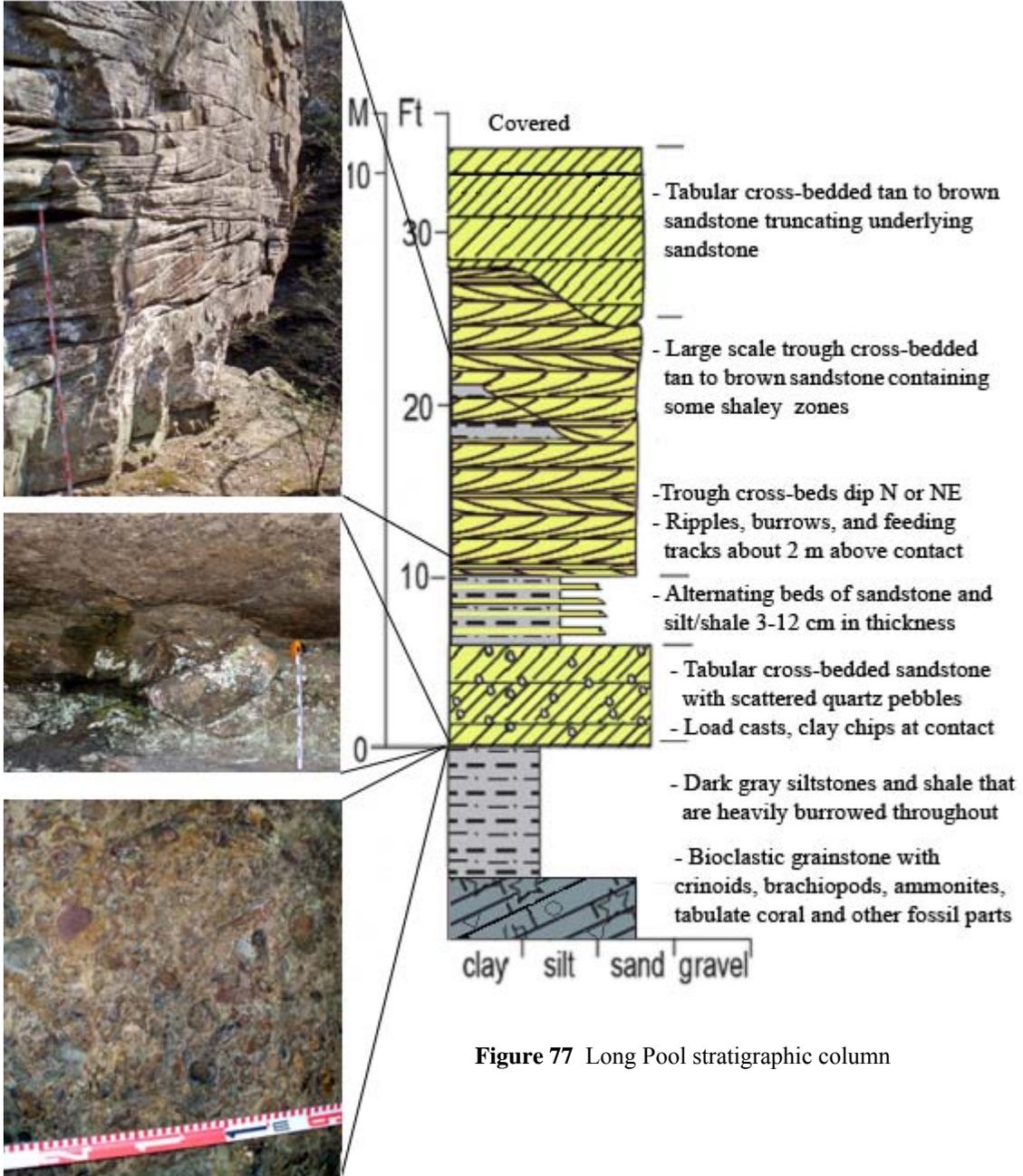
Figure 77 Long Pool stratigraphic column

Figure 78 Trough cross-beds dipping in a northerly direction. Most sets appear to dip to the northeast.

Figure 79 Strait on view of trough cross-beds dipping northward in the lower part of the outcrop.

Figure 80 Rippled sandstone from about 2 m above contact SW of main outcrop. Feeding trackways can be seen on surface.

Figure 81 Underside of erosional overhang at contact. Clay chips can be seen in abundance. Clay chips in numerous colors are similar in appearance to those seen at Parker Ridge.

Figure 82 Large load cast commonly found at the base of the middle Bloyd sandstone. Note pebbles and clay chips at top of photo.

Thin Sections and Photomicrographs

Through study of 17 thin sections, the middle Bloyd sandstone was found to be a quartz cemented quartzarenite based on the Folk (1974) classification. Quartz made up 96 to 98 percent of the sandstone grains in the thin sections. Most quartz grains were monocrystalline quartz with the occasional presence of polycrystalline quartz noted in about half of the samples. Often only a few polycrystalline grains could typically be found in a standard 1.5 x 3 inch thin section. Muscovite mica was commonly seen and made up 0.5 to 2 percent of the thin sections. Additionally clay was found to make up 0.5 to 1.5 percent of the thin sections. The clay was typically found on bedding planes and often associated with finer grained sandstones (Fig. 83, and 84). The presence of a few metamorphic rock fragments and biotite were noted in only thin sections from Gaither Mountain and Parker Ridge (Fig. 85). The fractured appearance of the quartz in many of the photomicrographs was due to the cutting process in the making of the thin sections.
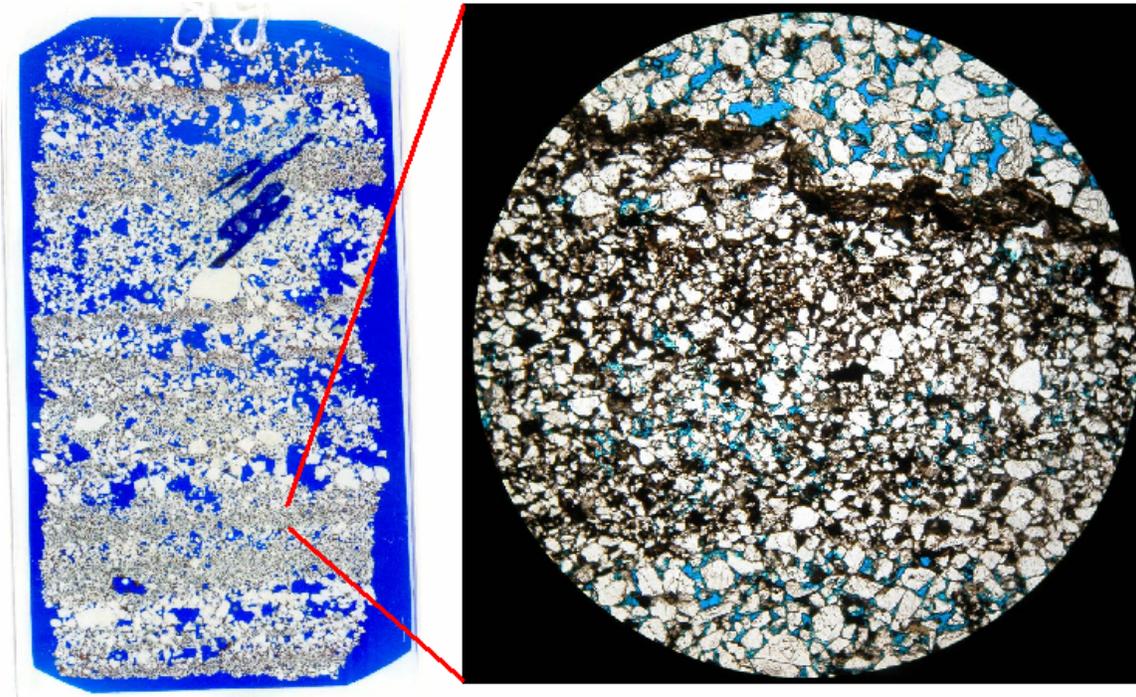
Figure 83 Graded bedding with alternating coarse/fine layers. Finer beds contain an abundance of clay. The middle finer layer in microscope view is overlain and underlain by a clean coarser sand. This graded bedding may have been deposited in a similar manner as the thick then pairs discussed earlier in this report. Thin section is 1.5 x 3 inches in size. Microscope view is 10x PPL. Sample collected from about 2 meters above convolute bedded zone in central portion of Buzzard's Roost Outcrop.

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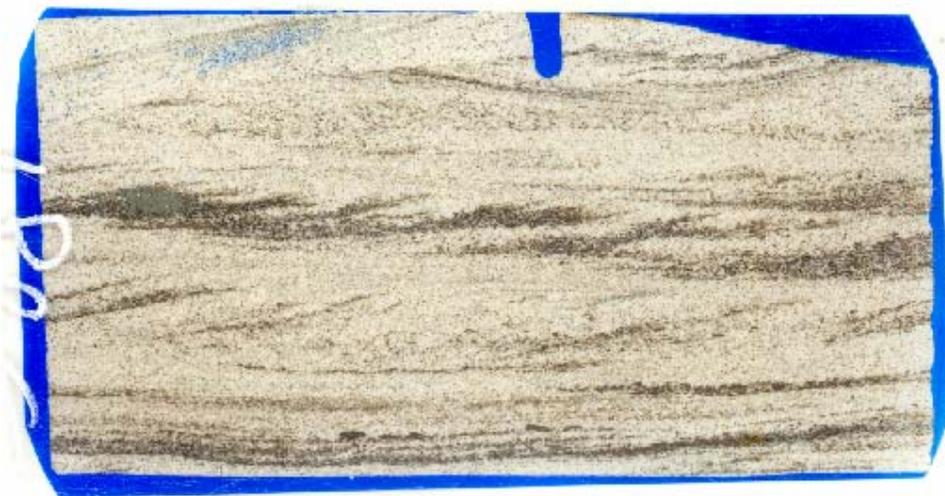
Figure 84 1.5 x 3 inch thin section showing abundant clay on boundaries in rippled interval collected from SW outcrop at Long Pool about 2.5 meters above the middle Bloyd/Brentwood contact.

94
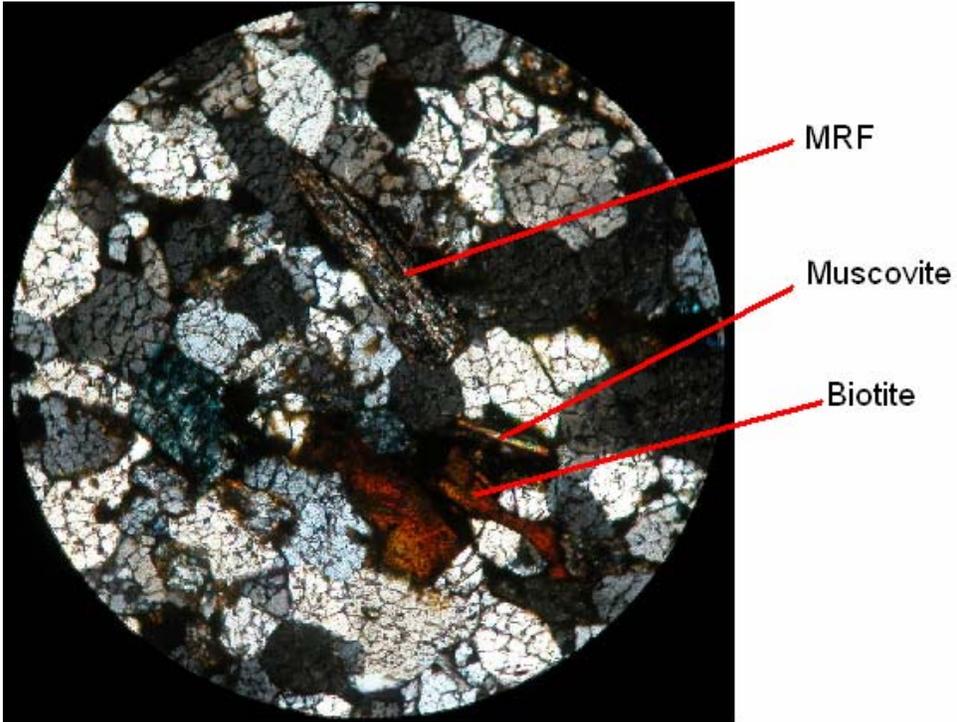
Figure 85 Microscope view at 20x XPL. Note biotite, muscovite and metamorphic rock fragment. Sample from 20cm above middle Bloyd/Brentwood contact in Parker Ridge Outcrop

Quartz Pebble Survey

When sufficiently common, quartz pebbles were measured from the outcrop face to determine if any size trends could be identified. Measurements were all in millimeters and consisted of a long and short axis measurement as the pebbles could not been seen in three dimensions (Table 1 and 2). Most pebbles appeared spherical or elliptical. Because pebbles could not be measured in three dimensions, cross sectional area of the pebbles was calculated as a way to compare size. As most pebbles were elliptical in shape the formula for an ellipse was used to calculate the cross sectional area (r1 x r2 x π). The radius (or half of each axis) is represented by r1 and r2.

From the measurements collected at each outcrop the average pebble size was calculated in order to compare pebble size among outcrops. Graphs were created with the cross sectional area of the average pebble at each outcrop on the Y axis and latitude and longitude on the X axis.

Trends shown by these graphs are unclear, but a westward coarsening can be seen in Figure 86 where pebble cross sectional area vs. longitude is graphed. In Figure 87 the Pebble cross sectional area (square mm) vs. latitude shows a very scattered pattern with no obvious trend. However, trends seen in the graphs may not show true trends. The measurements taken on the pebbles from the outcrop face may or may not have been the actual long and short axis measurements. The wide spacing of outcrops across the western part of the study area also may not represent trends that may be present if other outcrops were examined. Additionally a much larger number of outcrops would need to be studied to clearly identify any pebble size trends.

Buzzard's Roost	
long axis	short axis
3.5	2
8.5	2.5
2.5	2.5
3	2
4.5	2.5
4	2
2.5	2.5
8.5	5
5.5	1.5
4	3
4.5	3
5	3
6	2
5	5
3	2.5
2.5	1.5
3	1.5
4.5	2
3	2
6.5	1.5
9	3.5
2.5	2
7.5	5
5.5	3
7.5	4.5
3	2
7.5	2
3	1.5
2.5	2

Parker Ridge	
long axis	short axis
8.5	5
9.5	4.5
6	3
8.5	3
17.5	7.5
6	2
6.5	4.5
8	5
11	4.5
9	3.5
10	5
8	5
9.5	2
8	5.5
9	3
6	2.5
7.5	4.5
5	2
7	3
6	3

Sherman Mountain	
long axis	short axis
4	2
5	3
15	7.5
7	3
6	3.5
12	10
6	3
7.5	4
11	2
4	1.5
9	5
7.5	6
3.5	3
9.5	2.5
5	2.5
7.5	4.5
5.5	3.5
3	1.5
9	3
6.5	2.5
4	2
5.5	2
2	2
5	3
4.5	2.5
4.5	3
5.5	3
6.5	2.5
3	2

Average Pebble Size			Average Pebble Size			Average Pebble Size	
4.7	2.6		8.4	3.9		6.4	3.3

Table 1. Pebble measurements (in mm) for Buzzard's Roost, Parker Ridge and Sherman Mountain Outcrops.

Gaither Mountain		Roadside Park		Cannon Creek	
long axis	short axis	long axis	short axis	long axis	short axis
9	4.5	12.5	5	19.5	11
7.5	5	12.5	4.5	14.5	8
12.5	5	7.5	5	12	5
7.5	3	9	3.5	8	5
11	2.5	11	7.5	12	5.5
5	4	7.5	5	14.5	6.5
7.5	3.5	7.5	7.5	8.5	4
5.5	2	9	7.5	8.5	3.5
2.5	2.5	6	3	8.5	4.5
5	3	11	4.5	13	5
10	3.5	5	5.5	18	5
3	2	11	4	9.5	4.5
5	3	9.5	5	8.5	7.5
5.5	2.5	9.5	4	8	5.5
3.5	2.5	6	3	12	7.5
4	1.5	7.5	2	11	6
4	2.5	10	10	11	6.5
3.5	2	7.5	5	11.5	9
4	2.5	10	5	11	5.5
7.5	3	7.5	4.5	8	5
4	3.5	10	3	7.5	7.5
7.5	2.5	11.5	5.5	6.5	5
5	5	10	3.5	11	4.5
8	3.5	8	2.5	9.5	8
6	5.5	9.5	7	11	6.5
4.5	2	9	3	11	7
7.5	2	6	4.5	11.5	3.5
5.5	3	7.5	6.5	13.5	5.5
5	3.5	7.5	5	8	5.5

Average Pebble Size		Average Pebble Size		Average Pebble Size	
6.0	3.1	8.8	4.9	10.8	5.9

Table 2. Pebble Measurements (in mm) for the Gaither Mountain, Roadside Park, and Cannon Creek outcrops.
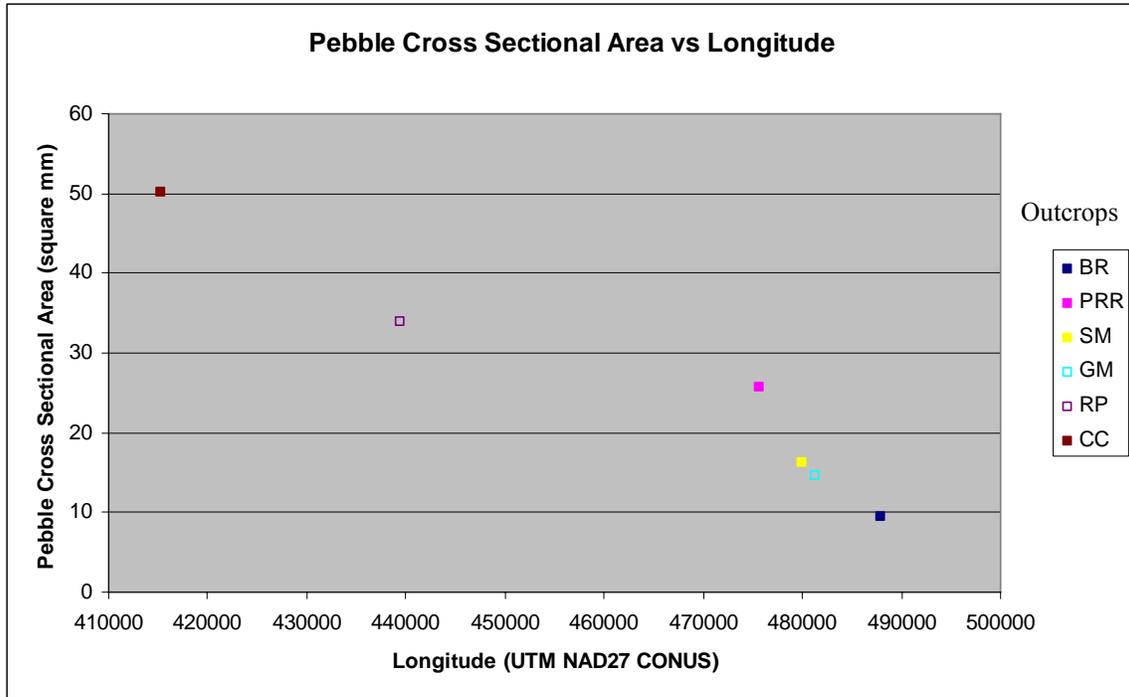
Figure 84 Pebble cross sectional area (square mm) vs. longitude. An increase in size to the west can be observed. Outcrop locations can be seen in Figure 1.
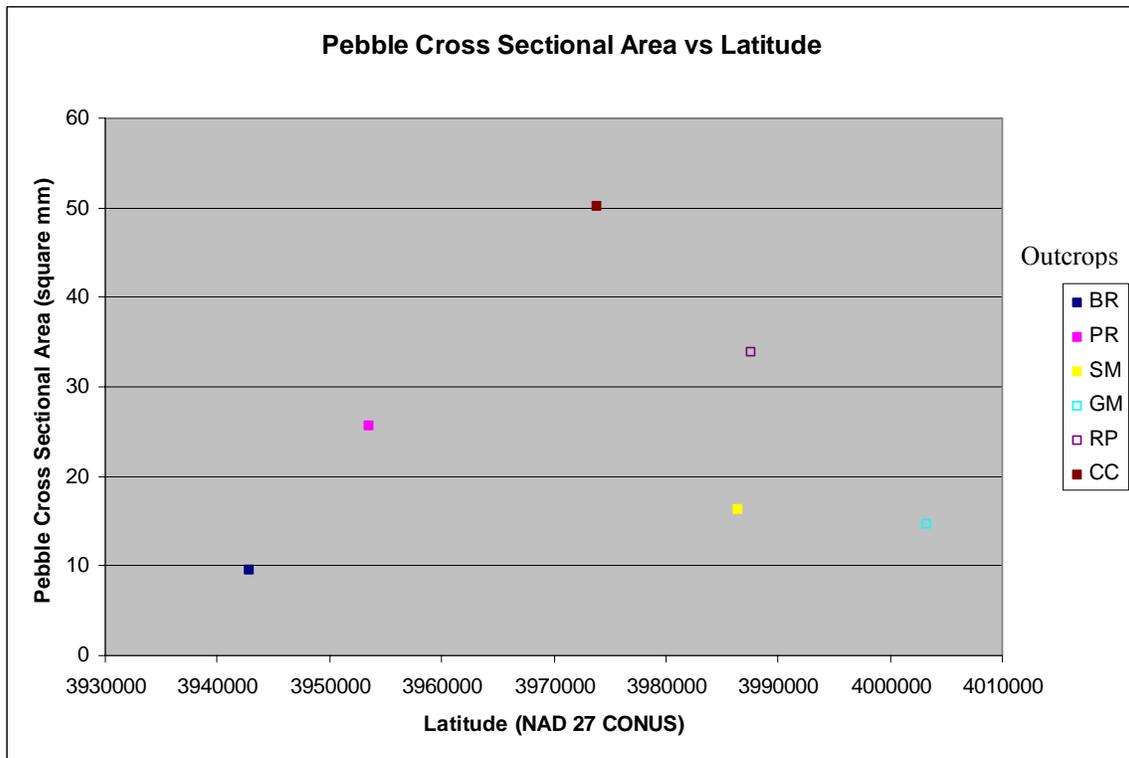
Figure 85 Pebble cross sectional area (square mm) vs. latitude. Outcrop locations can be seen in Figure 1.

Facies and Depositional Settings of the middle Bloyd

The middle Bloyd can be divided into three general facies across the study area. These facies consist of intervals of: horizontal bedding (HB), planar-tabular cross-bedding (PTCB), and trough cross-bedding (TCB). These three facies clearly vary in their characteristics across the study area especially in a north-south direction.

Horizontally Bedded Facies and Depositional Settings

The HB facies across the study area generally consists of wavy bedded sandstone and shale, ripple bedded sandstone with thin mud drapes, sandstone that appears to be thick bedded lacking physical sedimentary structures, and lenticular bedded shale and siltstone. The interbedded shale and sandstone is found only in the central part of the study area. Ripple bedded sequences lacking mud drapes were found in the northern and central parts. Mud drapes were found in only the Pedestal Rocks, Low Gap, and Witter outcrops in the central part of the study area.

Shale within the wavy bedded interval commonly displayed orange and blue-gray pinstripe bedding where there was a clean exposure (Fig. 34). Wavy bedding and Pinstripe bedded shales have been found to be characteristic of, but not solely restricted to, tidally influenced environments (Fig. 91) (Archer and Feldman 1995). A tidal environment would explain the cyclical natures of the bedding and consistencies in thicknesses between the shale and sandstone beds.

Wavy and pinstripe bedded sequences of rippled sandstone and shale were found at the Boxley South, Low Gap, Meadows Knob, and Parker Ridge outcrops. The thickness varied between outcrops but was between 1.5 and 5 meters. From top to bottom the

sandstones and shale maintained a cyclical nature in both thicknesses and lithofacies.

Typical thicknesses were 1-4 cm for the shales and rippled sandstones. These deposits have

been found to exist in tidal channels (possibly exhibited by the lateral pinchout at the Boxley

South outcrop) in the upper parts of Pennsylvanian incised valley fills, and in the middle

portions of estuaries, represented by mudflats and bars (Archer et. al, 1994; Archer and

Feldman, 1995). Bioturbation was found to be non-existent except for the Boxley South

outcrop (Fig. 45). This lack of bioturbation, common in early Pennsylvanian and modern

estuarine environments, has been explained by fluctuating salinity, high rates of deposition,

or a combination of the two (Archer and Feldman, 1995; Archer, in press). Additionally the

presence of coalified wood and pyrite at the base of the Boxley South outcrop suggests an

oxygen deficiency at the sediment-water interface.
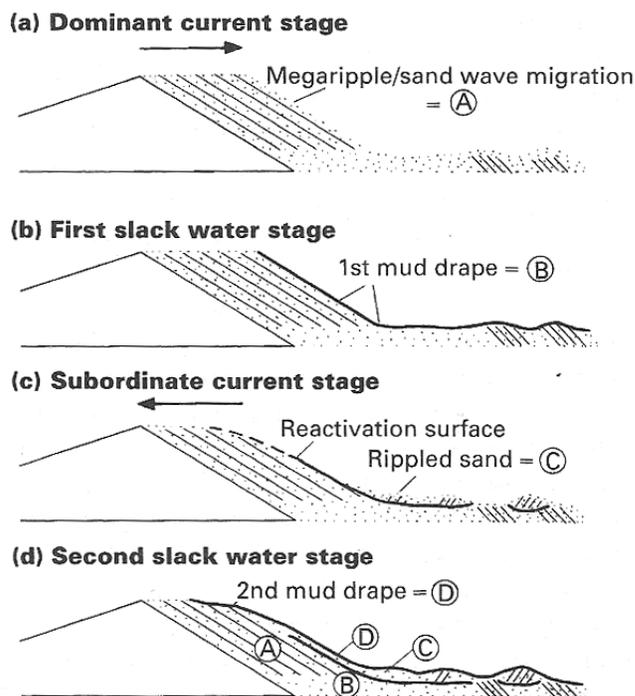
Figure 86 Formation of tidal rhythmites on planar-tabular cross-beds. Formation of horizontal rhythmites occurs in the same manner (Modified from Reading and Collinson, 1987 p. 165).

The ripple-topped sands in the wavy bedded interval exhibited either a northward or southward paleoflow, but on many ripple sets it was difficult to determine a paleoflow. Bi-directionality could also be observed, but the degree to which it exists is not clear as some rippled intervals did not display a clear paleoflow direction. It would seem reasonable that the ripple

topped sands were deposited in low water depths. The shales (mud) would then be deposited during stillstands after high tides had arrived creating deeper waters and a very low velocity flow. This stillstand would allow finer particles to fall out of suspension.

Horizontally bedded sand/shale thick-thin pairs were formed in a similar manner and setting to the wavy bedded intervals. Horizontally bedded thick-thin pairs were found only at the Buzzards Roost outcrop; however thick thin pairs were found in other outcrops in the PTCB facies. The mechanism for horizontal and inclined bedded thick thin pairs and mud draped ripples are the same. The first stage of formation called the dominant current stage is a time of sand migration leading to deposition of a sandy foreset (Fig. 88). Following this stage a stillstand (slack water) stage where currents are very low and result in mud falling out of suspension depositing a muddy (clay) drape. This may also be influenced by saline waters moving inland from tides causing clays to flocculate and fall out of suspension rapidly (Reading and Collinson, 1987). The third stage, the subordinate stage, is weaker than the dominant stage. However, it may or may not be strong enough to deposit sand on top of the previous mud drape. Following the subordinate stage a second stillstand (slack water) stage may or may not occur depositing another mud drape (Nio and Yang, 1991; Reading and Collinson, 1987).

All four stages of rhythmite formation would form a four-element rhythmite in ideal conditions (Fig. 89). Often all four stages are not strong enough and lead to formation of other types of rhythmites. Two and three-element rhythmites are also possible. The three-element rhythmites will form when the subordinate flow is not followed by a stillstand. The two-element rhythmites occur when the subordinate flow is very weak and is also not followed by a stillstand. These two-element rhythmites are common in the Pennsylvanian

and indicate that there was little to no deposition during the subordinate flow. This would

indicate inequality (in terms of velocity and/or vertical range) between the high and low tides

(Archer 1998).
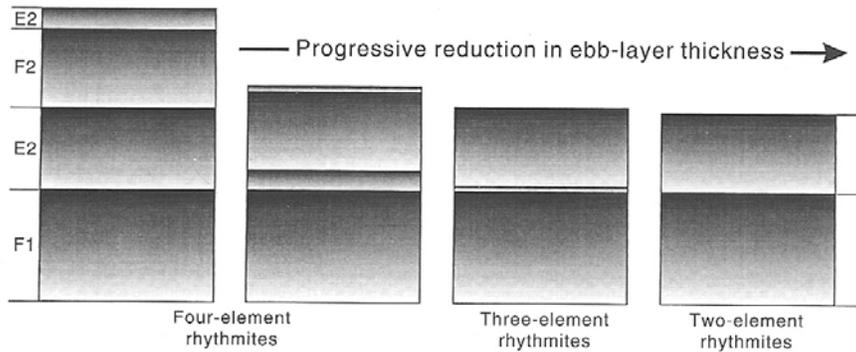
Figure 87 Multi-element rhythmites. F= Flood (High tide), E= Ebb (low tide) (Archer, 1998).

A complete tidal cycle will be made up of 29 rhythmite pairs, due to 29 days in a tidal

cycle (Reading and Collinson, 1987). The deposits may be inclined (cross-bedded) or

horizontal. Spring tides are the highest of all tides and are 20% higher than normal. Neap

tides are 20% lower than normal and occur when the sun and moon are at right angles

relative to the earth. For this reason a complete tidal cycle will show thinner (neap)

rhythmites transitioning to thicker (spring) rhythmites, and then into another interval of thin

(neap) rhythmites (Fig. 90) (Reading and Collinson, 1987).
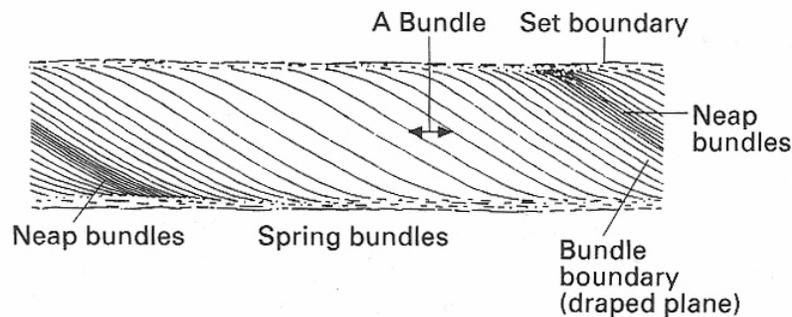
Figure 88 Typical appearance of a 29 day tidal cycle with rhythmites thickening at the spring bundles
(Modified from Prothero, 1987).

The middle Bloyd shows a nearly complete tidal cycle in horizontal beds at the Buzzard's Roost outcrop (Fig. 72). These thick thin pairs do not show a mud layer but show what appears to be replacement by iron cements. This was seen in the Pennsylvanian Abbot Sandstone in the Illinois Basin as well (Kvale and Archer, 1991). A similar feature was observed at the Pedestal Rocks and Witter Outcrops where mud drapes appeared to be replaced by iron cements or smaller sand grains were better cemented resulting in differential weathering.

The mud draped ripples (Fig. 37, 52, 63, and 64) likely formed in settings similar to the interbedded sandstone and shales. When the stillstands did not occur, either due to greater fluvial discharge not allowing tidal influences to extend further inland or in areas not influenced by tides, the mud drapes were not deposited and left behind a vertical sequence of ripple-bedded sandstone seen in many outcrops. Many of the ripple bedded sandstones were likely deposited in environments with little to no tidal influence. This was commonly observed in the northern parts of the study area where very thin ripple beds were located in close proximity to PTCB facies. These ripples could have been deposited anywhere in the channel including on top of bars submerged in shallow water.

Mud drapes could also have been destroyed as the tide went out leaving behind evidence as flaser bedding (Fig. 91). The latter seems unlikely as the sandstones and shales seem to maintain regular and consistent thicknesses with rippled sands that do not have scoured or flattened ripple tops. Flaser bedding might also be shown if mud drapes were partially removed. However, rip up clay clasts were commonly found through the middle Bloyd. This was seen especially when cutting slabs or billets for thin sections.
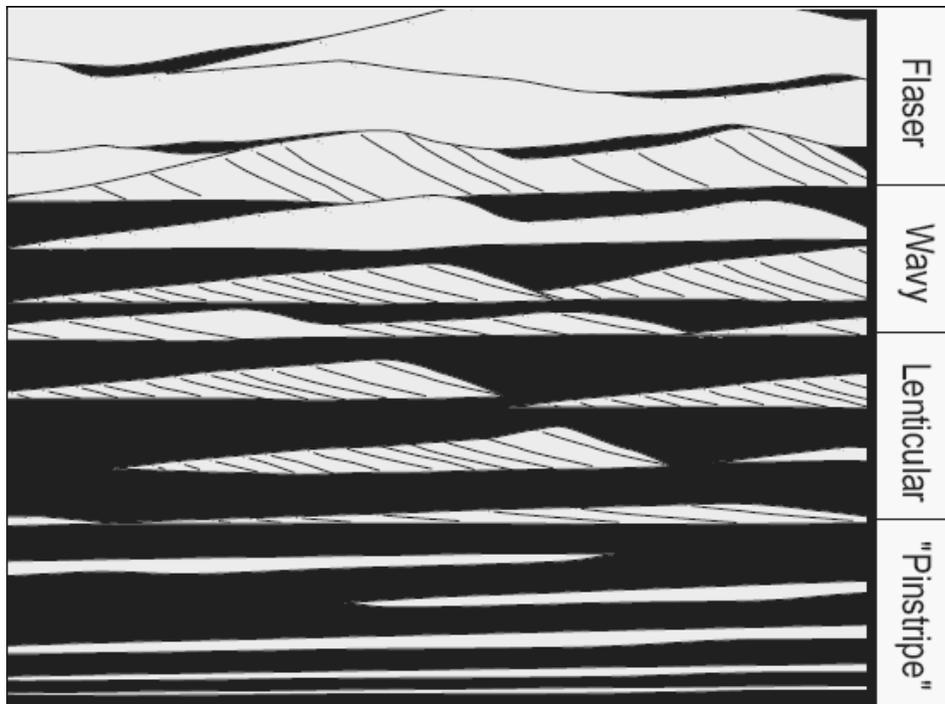
Figure 89 Comparison of bedding types characteristic of, but not solely restricted to, tidally influenced environments (Modified from Archer and Feldman 1995).

Horizontally deposited sandstone apparently lacking any type of cross-stratification was also seen in the study area. This structureless sandstone was seen at the Boxley, Boxley South, and the Parker Ridge outcrops. Additionally the Gaither Mountain and Sherman Mountain outcrops had an interval of slightly inclined beds lacking cross-stratification which appeared to have some curved channel boundaries filled with a structureless sand. Commonly an abundance of small wood pieces, more than any other outcrops in the study area, were found in these sands. The Boxley outcrop even had an interval at the base which was marked by coalified wood (Fig. 31).

The horizontal beds likely formed at the upper flow regime (Fig. 92) where sedimentation occurred rapidly burying wood fragments and filling in small channels. A similar facies was described by Plink-Bjorklund (2005) in an Eocene estuarine system. Scattered yet abunadant quartz pebbles were also found in this interval, most notably at

Parker Ridge. The abundant scattered quartz pebbles would also suggest upper flow regimes where high flow can move the larger quartz pebbles and scatter them from a concentrated area such as a sand/quartz pebble bar.

The Low Gap outcrop also contained a horizontally bedded interval of shale and siltstone with lenticular bedding (Fig. 38). This outcrop, which was in the upper part of the middle Bloyd, exposes an interval that was not commonly seen in the study area. The upper portions of many outcrops in the study area consisted of shale to siltstone covered slopes with scattered blocks of middle Bloyd sandstone. This suggests that the upper portions of many of the outcrops contained sequences of shales and siltstone, which do not keep a vertical face unlike the thick sandstone of the middle Bloyd. The lenticular bedded siltstone and shale would indicate that deposition likely occurred in a mid-estuarine mud flat similar to other Pennsylvanian settings (Archer and Feldman, 1995; Lanier et al., 1993).

Planar-tabular Cross-bedded Facies and Their Depositional Settings

The PTCB facies of the middle Bloyd is dominant in the Buzzard's Roost, Cannon Creek, Gaither Mountain, Roadside Park, and Sherman Mountain outcrops. The Boxley South, Long Pool, and Pedestal Rocks outcrops also contain intervals of planar-tabular cross-bedding but it is not the dominant facies. PTCB facies has been observed in many modern river systems (Miall 1972, 1992). This common facies is generally attributed to the formation of different types of bars. To a geologist studying outcrop faces, identifying the type of bar or identifying the size of a bar would be difficult if not impossible under most circumstances.

Modern analogs have shown that point bars, mid-channel bars and side bars are some of the most common types of bars found in the fluvial system (Miall 1972, 1992; Coleman, 1969).   It would be reasonable to expect these bars throughout much of the fluvial system in the study area. In this investigation the cross-beds were observed to be continuous throughout the outcrops until running into covered slopes where they were no longer visible. For this reason a size range for potential bars could not be determined. Sand waves and ripples have been attributed to bars forming in the lower flow regime for the PTCB facies (Fig. 92). It is also important to point out that PTCB can be found from the mid-channel (thalweg) up to the margin of a fluvial channel (Sambrook-Smith et.al, 2005). Coleman (1969) found that this facies was often preserved due to high bed loads burying the bars in a rapidly aggrading fluvial system. Studies of modern analogs have shown these bars may migrate rapidly during times of high flow. At times of low flow the bars were left much higher than the water surface leading to formation of a braided channel pattern with low sinuosity (Miall 1972, 1992; Coleman, 1969).

Cross-bed sets across the study area typically range from 0.4 to 1 m in thickness and have a dominant paleoflow to the south-southwest. At the Buzzard's Roost outcrop planar-tabular sets could be found as thin as 4-10 cm (Fig. 70), and as thick as 2 m (Fig. 71), the thickest observed in the study area. The thinner cross-bed sets contained numerous reactivation surfaces (more than any other outcrop in this study) and could likely be mid-channel deposits which would often be scoured and reworked due to the channel aggrading and degrading at different times. These thin sets were slightly variable in paleoflow but displayed a dominant dip direction to the southwest. This variation may be due to a braided channel pattern.
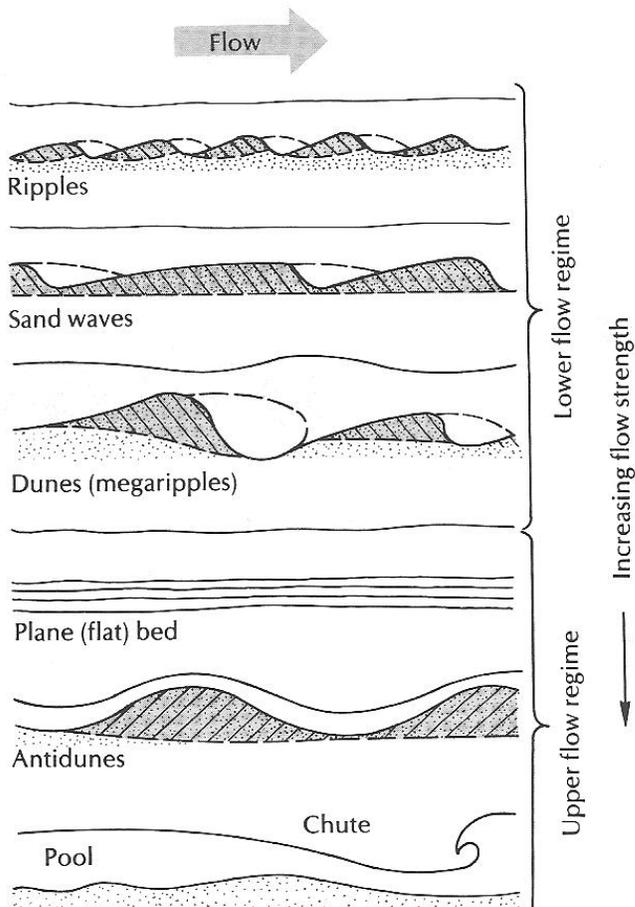
Figure 90 Bedforms in a unidirectional flow regime (Modified from Prothero 1990).

It was observed that across the study area the PTCB facies locally contained thick-thin pairs. These pairs are strong indicators of tidal influences which can extend inland for hundreds of kilometers (Archer and Feldman, 1995; Lanier, Feldman and Archer, 1993; Archer, 2004; Kvale and Archer, 1991; Archer et. al, 1996). The thick-thin layers consist of a thicker sandy layer and a thinner mud drape layer. One of the best documented occurrences of these features was seen in the Pennsylvanian Abbott Sandstone in the Illinois Basin. Entire 29 day tidal cycles are preserved in this unit (Kvale and Archer, 1991).

In the middle Bloyd the high-angle cross stratification lacks mud drapes (or appears to). Differential weathering and parting surfaces often make these features stand out, otherwise they might have been overlooked. It is possible however that muds may be preserved in the thick thin pairs, but have been weathered deeply back into the outcrop face. Extensive rock removal would need to be done to confirm whether clay is present. Very large clay chips were found in the middle Bloyd near the contact as previously mentioned, but small clay chips (0.5 cm or smaller) were also found tens of meters or more above the

contacts. Often these small clay chips were found in abundance when cutting or removing samples for use in making thin sections. Upon cutting rocks up in the lab an even greater abundance of these small clay chips were found in samples from most of the outcrops. This may suggest that clay drapes were ripped up by tidal or fluvial action and destroyed in transport with some buried within the sand and preserved.

The upper portions of the middle Bloyd outcrops also contained PTCB facies with thin bi-directional cross-beds which locally may contain thick-thin pairs. The best example of this was found at the Buzzard's Roost outcrop (Fig. 69). Again mud drapes appear absent but the reactivation surfaces are weathered far into the surface so it is difficult to tell for sure. The bi-directional sets have clear northeast-southwest shifts in paleoflow. This bi-directional nature of PTCB in upper portions of outcrops has been reported in similar early Pennsylvanian settings in central North America. These were interpreted to be indicative of shallow water estuarine depositional settings where fluvial and tidal flow would vary causing changes in flow direction (Archer and Greb, 1995).

Also included in the PTCB facies are overturned (deformed) cross-beds. These are best seen at Buzzard's Roost, Cannon Creek and Gaither Mountain. Overturned cross-bedding has been seen in modern analogs to have been caused by planar-tabular cross-beds being influenced by drag. Drag is said to be induced by strong sediment-laden currents which will overturn the foresets (Coleman, 1969). Also included in the PTCB facies is convolute bedding. This was seen in several outcrops often near the base where cross-beds were deformed through liquefaction and locally flame like structures could be seen (Fig. 73).

Trough Cross-Bedded Facies and Depositional Settings

Trough cross-bedding was found in outcrops in the southern portion of the study area. The TCB facies were dominant in the Parker Ridge, Alum Cove, and Sugar Creek outcrops. The Long Pool and Meadows Knob outcrops also had a large portion of TCB facies. Both small scale and large scale cross-beds occur in the study area. The small scale trough cross-beds sets are less than 35 cm thick with the large scale sets being greater than 35 cm thick. The scale was chosen to differentiate between the size of the trough cross-beds at Long Pool (large scale) and the trough cross-beds in the other outcrops (small scale).

Trough cross-beds can form in both fluvial and marine environments. To form the trough cross-beds there must be a scoured surface in the downstream direction. Due to the scoured out area, deposition will lead to curved (trough shaped) beds. If no scours were present deposition would result in planar-tabular cross-bedding. The Long Pool outcrop exhibits both intricately interwoven and truncated trough cross-bed sets up to 70 cm in height. This, along with a change in paleoflow to a northward direction, suggests that a tidal influence may have formed these dune (formerly termed megaripple) scale features at the boundary between the upper and lower flow regime (Fig. 92). Wave influence would also be a possibility as it has been attributed to cause interwoven dune scale trough cross-bedding (Reading and Collinson, 1978). The other small scale northward dipping trough cross-beds may also have been influenced by tides but to a smaller degree as they would be further upstream.

Incised Valley Fill in the Middle Bloyd

Accommodation space for the middle Bloyd was necessary for deposition to occur. Incised valley systems common in the Pennsylvanian (Archer and Greb, 1995; Archer and Feldman, 1995) would allow for this accommodation space. Clast (and to a small degree matrix) supported quartz pebble conglomerate at the contact between the middle Bloyd and the Brentwood is nearly identical to those in many of the Early Pennsylvanian incised valley fills in the Midcontinental U.S. (Archer and Greb, 1995). The facies of the middle Bloyd also closely mirror these incised valley fills.

The middle Bloyd lies on either the Brentwood Limestone or the Brentwood Shale/Siltstone across the study area. The western portion of the study area lies on the fossiliferous Brentwood Limestone and typically shows local incision (erosional step-downs) on the order of one meter (Cannon Creek, Fig. 40). Tabulate corals and crinoid parts can be found in the middle Bloyd about two meters above the contact. These fossils were derived from the underlying Brentwood Limestone. Moving eastward, regional incision cuts deeper into the Brentwood Limestone and Brentwood Shale. At the Boxley South outcrop a steeply sloped locally incising channel over two meters in depth can be seen (Fig. 49). It is expected that further incision is present as this channel bottom cannot be seen. Many of the outcrops in the study area were seen to have between 2 and 3.5° of dip at the contact suggesting the paleovalley may be deep yet broad.

Eastward from the base of the Cannon Creek outcrop to the base of the Boxley outcrop there is just over 12 meters of incision (Zachry, 1979). This distance covers only the western one half of the study area. It would be expected that incision increases further south and east due to outcrops resting on intervals of siltstone in those directions. The Gaither

Mountain, Boxley, Buzzard's Roost, and Meadows Knob outcrops are all over 30 meters in thickness when counting poorly exposed intervals above the outcrops containing middle Bloyd blocks. The thickest outcrops observed in the study area are the Meadows Knob and Buzzard's Roost outcrops which are approximately 35 meters in thickness. However the Buzzards Roost outcrop may be considerably thicker as the contact was not observed. Decompacting the incised valley fill would also increase this thickness. When estimating the thickness, 30 percent or so can be added to the thickness of the shale intervals (Archer and Feldman, 1995). A reasonable depositional thickness would put the Meadows knob outcrop at around 38 meters in total thickness. This range fits into the 20-70 meter range of other Pennsylvanian incised valley fills.

Depositional Model of the Middle Bloyd

Modern and ancient analogs in fluvio-estuarine settings have been extensively studied leading to a commonly accepted tripartite facies depositional model (Allen, 1991; Archer, 2004; Archer and Feldman, 1995; Archer et. al, 1994; Plink-Bjorklund, 2005; Archer et al., 1996; Lanier et al., 1993). The typical tripartite model consists of an outer estuarine zone dominated by sandy deposition, an inner estuarine zone dominated by muddy deposition, and an upper estuarine zone with sandy deposition (Fig. 93).
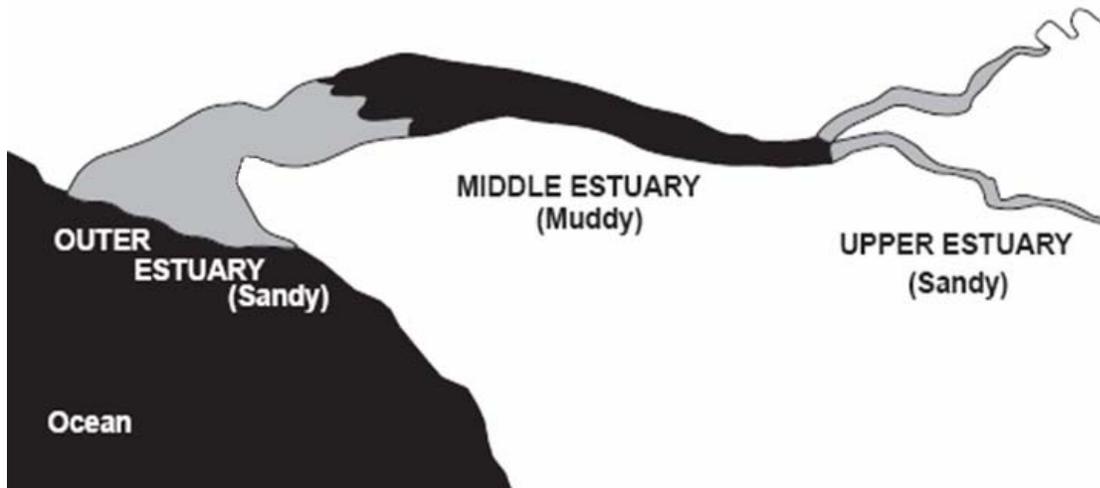
Figure 91 Tripartite estuarine model. Modified from Archer and Feldman (1995) Figure 5 p. 122

The estuarine facies model is typically funnel shaped and reflects the shape of the drowned incised valley system it fills. As marine transgressions or regressions occur, these zones may shift position and be preserved in the rock record. These changes in base level are especially useful for paleogeographic reconstructions (Archer and Feldman, 1995).

The outer estuarine zone is dominated by wave action and strong tidal currents which do not allow for muddy sediments to fall out of suspension. For this reason the outer estuarine zone consists of clean sands devoid of mud. These sand bodies are represented in the middle Bloyd as northward dipping trough cross-beds that increase in scale southward (seaward) where intricately interwoven dune scale trough cross-beds up to 70 cm in height can be found. This records a strong wave and tidal influence as previously mentioned in this report.

In the upper parts of the middle Bloyd horizontally interbedded sandstones and shale exhibiting wavy, lenticular, and pinstripe bedding typical of middle estuarine deposits where marine and fluvial influences merge. This merging creates a current velocity stillstand where rapid deposition of fine muddy sediments can fall out of suspension. These sediments

generally lack bioturbation likely indicating rapid deposition and/or salt/freshwater fluctuations that organisms do not tolerate well.   Biogenic sedimentary structures seen as trackways on rippled surfaces in the middle Bloyd, though rare, also indicate inner estuarine zones (Archer, 2004) This inner estuarine interval is also represented in the middle Bloyd by strong bi-directional paleoflow in cross-bedded sandstone which has possible preserved rhythmites. Mud draped ripples found in the middle Bloyd are also common in mid estuarine zones (Archer and Feldman, 1995).

The upper estuarine zone is dominated by sandy fluvial depositional settings. In the middle Bloyd this is represented by intensely cross-stratified (planar-tabular) sandstone with abundant quartz pebbles. Paleoflow in this fluvial upper estuarine zone is strongly uni-directional to the southwest. Locally, rhythmites on the cross-stratified sets record strong tidal influences moving far inland. This influence extending far inland is likely due to amplification from the funnel shaped estuary (Archer, 2004; Kvale and Mastalerz, 1998).

The transition from sandy fluvial deposition at the base of the middle Bloyd to muddy inner estuarine deposition with bi-directional paleoflow higher in the outcrops, suggests the middle Bloyd records a marine transgression and a flooding estuarine system. Marine sandstone found in the upper meter of the middle Bloyd containing bryozoan and crinoid fossils also suggests the transition to marine settings. The shift from the terrestrial middle Bloyd to the marine Dye Shale is also evidence of a marine transgression. A model of this process can be seen in Figure 95. Following the early highstand stage the incised valley system would be overtopped where the marine Dye would then be deposited.

An ideal depositional model of the middle Bloyd during an early transgression is shown in Figure 94. This model contains an estuarine funnel which allows tidal influence to extended far inland, amplified by the funnel shape. Sand and quartz pebble bars are also represented in the upper and mid-estuarine zones, and would be common due to the widespread cross-bedding. Mudflats with heterolithic bedding are represented at the margins (and would be present below water in the middle estuary) as has been noted in modern analogs (Allen, 1991; Archer, 2004). Additionally swamp like areas are also represented. These areas overtime became thin coal beds which can be found in some middle Bloyd outcrops (Berrry, 1978; Crowder, 1982).
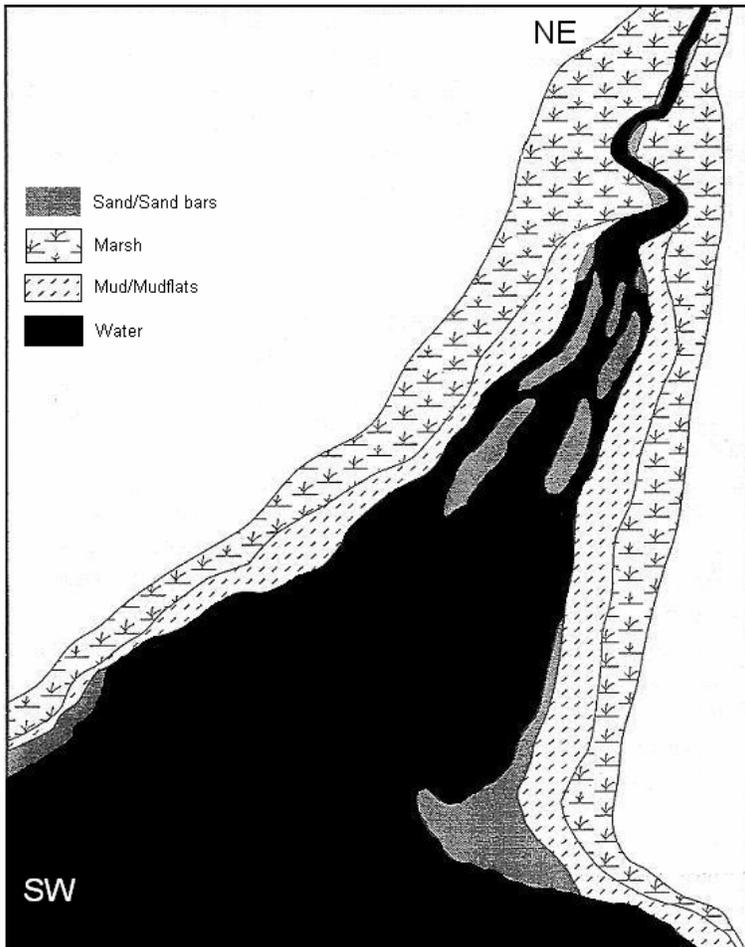
Figure 92 Ideal paleogeographic model of the middle Bloyd sandstone (Modified from Archer et al., 1994).

Lowstand systems tract

Early transgressive systems tract

Late transgressive systems tract

Early highstand systems tract

Alluvial plain and river channels
Tidally-influenced fluvial channel
High- and low-sinuosity tidal channels
Tidal sand bars and UFR tidal flats
Mixed to muddy tidal flats and marshes

Figure 93 Early to late transgression in an incised valley fill (Modified from Plink-Bjorklund, 2005).

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Conclusions

The middle Bloyd sandstone exhibits strong evidence for a fluvial to estuarine transition within an incised valley fill similar to many Early Pennsylvanian systems in the U.S. Midcontinent. Fluvial deposition is marked by intensely cross-stratified sandstone with a dominant southwest paleoflow. Locally the cross-stratification preserves tidal rhythmites as thick-thin pairs, indicating tidal influences extended far inland. A transition from fluvial to estuarine deposition is seen in several respects. Sequences of interbedded sandstone and shale/siltstone that are wavy, lenticular and pinstripe bedded, attributed to mid-estuarine deposition, were found in the upper parts of outcrops. Commonly the sandstone beds that overlie and underlie these estuarine deposits have recorded tidal influence marked by bi-directional northeast-southwest paleoflow typical of fluvio-estuarine deposition. One outcrop (Long Pool) preserved intricately interwoven dune scale trough cross-stratification with northerly paleoflows. The strong northerly paleoflow and intricately interwoven trough cross-stratification is a good indicator of wave and tide influence seen in outer estuaries.

Following the fluvio-estuarine deposition, sea level continued to rise. Horizontally deposited marine sandstones reported in the uppermost meter of several outcrops (Cannon Creek, Meadows Knob, and Boxley) contain bryozoan and crinoid parts. Gradationally overlying the middle Bloyd is the marine deposited Dye Shale. This member of the Bloyd Formation marks the return to marine deposition. The middle Bloyd-Dye Shale interval marks a transition from terrestrial to marine deposition and records one of many transgressional periods in the Pennsylvanian.

A tripartite estuary model appears to fit the middle Bloyd well. A fluvial dominated facies locally containing rhythmites and mud draped ripples represents a sandy upper estuarine setting. The middle estuarine interval is represented by interbedded sandstone and shale/siltstone with wavy, lenticular and pinstripe bedding typical of tidal flats and bars. The outer estuary is represented by the trough cross-stratified sandstone with northerly paleoflow.

References Cited

Allen, G.P., 1991, Sedimentary Processes and Facies in Gironde Estaury; A Recent
     Model for Macrotidal Estuarine Environments, *in* Clastic Tidal Sedimentology,
     Smith, D.G., ed. Canandian Society of Petroleum Geologists Memoir 16, p.

Antia, J., 2006, Stratigraphic Coorelation and Facies Interpretation of the "Middle Bloyd
     Sandstone" in Outcrop, Johnson and Pope Counties, Arkansas, Arkansas [M.S.
     Thesis]: Fayetteville, University of Arkansas, 49 p. 29-40.

Archer, A.W., 2004, Recurring Assemblages of Biogenic and Physical Sedimentary
     Structures in Modern and Ancient Extreme Macrotidal Estuaries: Coastal Research
     v. 43, p. 4-22.

Archer, A.W., 1998, Hierarchy of Controls on Cyclic Rhythmite Deposition:
     Carboniferous Basins Eastern and Mid-Continental U.S.A., *in* Dalrymple, R.W.,   ed.,
     Tidalites: Processes and Products, SEPM Special Publication No. 61, p. 61-67.

Archer, A.W., Feldman, H.R., Lanier, W.P., and Tessier, B., 1996, Relationships of
     Fluvio-Deltaic and Tidal-Estuarine Facies Within the Douglas Group
     (Missourian-Virgillian) of Eastern Kansas, *in* Oklahoma Geological Survey
     Circular 98, p. 229-235.

Archer, A.W., and Greb, S.F., 1995, An Amazon-Scale Drainage System in the Early
     Pennsylvanian of Central North America: Geology, v. 103, p. 611-628.

Archer, A.W., Lanier, W.P., and Feldman, H.R., 1994, Fluvio-estuarine transitions within
     incised paleovalley fills, Douglas Group (Stephanian); Upper Carboniferous of
     Kansas, U.S.A., *in* Dalrymple, R.W., Boyd, R., and Zaitlin, B.A., eds., Incised
     Valley Fill Systems: Tulsa Society for Sedimentary Geology Special Paper v. 51, p.
     175-190.

Archer, A.W., and Feldman, H.R., 1995, Incised Valleys and Estuarine Facies of the
     Douglas Group (Virgilian): Implications for similar Pennsylvanian Sequences in   the
     U.S. Mid-Continent, *in* Hyne, N., eds., Sequence Stratigraphy of the Mid- Continent,
     Tulsa Geologic Society, p. 119-145.

Archer, A.W., and Greb, S.F., Depositional Zonation and Hypertidal Sedimentation
     within Turnagain Arm, Cook Inlet, Alaska, USA, Kansas: Kansas State   University,
     Manuscript in preparation for Sedimentary Geology.

Berry, R.A., 1978, Stratigraphy and Petrology of the Middle Bloyd Sandstone
     (Morrowan) Southeast Madison County, Arkansas [M.S. Thesis]: Fayetteville,
     University of Arkansas, 102 p.

Coleman, J.M., 1969, Brahmaputra River: Channel Processes and Sedimentation, Geology, v. 3, p. 129-329.

Crowder, R.K., 1982, Anatomy of a Pennsylvanian Fluvial Sheet Sandstone, Northwest Arkansas [M.S. Thesis]: Fayetteville, University of Arkansas, 111 p.

Folk, R. L., 1974, Petrology of Sedimentary Rocks: Austin, Texas, Hemphill Publishing Company, 182 p.

Glenn, J.M., 1973, Stratigraphy and Depositional Environment of a Middle Bloyd Sandstone, Madison and Washington Counties, Arkansas [M.S. Thesis]: Fayetteville, University of Arkansas, 60 p.

Glick, E.E., 1975, Arkansas and Northern Louisiana, *in* McKee, E.D. and Crosby, E.J., eds., Paleotectonic Investigations of the Pennsylvanian System in the United States. United States Geologic Survey Professional Paper 853, p. 157-175.

Greb, S.F., and Archer, A.W., 1998, Annual Sedimentation Cycles in Rhythmites of Carboniferous Tidal Channels, *in* Dalrymple, R.W., ed., Tidalites: Processes and Products, SEPM Special Publication No. 61, p. 75-83.

Haley, B.R., Glick, E.E., Bush, W.V., Clardy, B.F., Stone, C.G., Woodward, M.B., Zachry, D.L., 1993, Geologic Map of Arkansas, U.S. Geological Survey and Arkansas Geological Commission, Scale 1:500,000.

Henbest, L.G., 1962, New Members of the Bloyd Formation of Pennsylvanian Age: U.S. Geological Survey Professional Paper 450-D, article 131, p. D 42-44.

Houseknect, D.W., and Kacena, J.A., 1983, Tectonic and Sedimentary Evolution of the Arkoma Foreland Basin, *in* Houseknect, D.W., ed., Tectonic – Sedimentary Evolution of the Arkoma Basin, SEPM Midcontinent Section, v. 1, p. 3-33.

Hudson, M.R., Murray, K.E., and Pezzutti, D., 2001, Geologic Map of the Jasper Quadrangle, Newton and Boone Counties, Arkansas: U.S. Geological Survey Miscellaneous Field Studies Map MF-2356, scale 1:24000.

Kvale, E.P., and Mastalerz, M., 1998, Evidence of Ancient Freshwater Tidal Deposits, *in* Dalrymple, R.W., ed., Tidalites: Processes and Products, SEPM Special Publication No. 61 p. 95-108.

Kvale, E.P., Fraser, G.S., Archer, A.W., Zawistoki, A., Kemp, N., McGough, P., 1994, Evidence of Seasonal Precipitation in Pennsylvanian Sediments of the Illinois Basin: Geology, v. 22, p. 331-334.

Kvale, E.P., and Archer, A.W., 1991, Characteristics of two, Pennsylvanian-age, Semidiurnal Tidal Deposits in the Illinois Basin, *in* Clastic Tidal Sedimentology, Smith, D.G., ed. Canandian Society of Petroleum Geologists Memoir 16, p. 179-188.

Lanier, W.P., and Tessier, B., 1998, Climbing-Ripple Bedding in the Fluvio-Estuarine Transition: A Common Feature Associated with Tidal Dynamics (Modern and Ancient Analogues), *in* Dalrymple, R.W., ed., Tidalites: Processes and Products, SEPM Special Publication No. 61, p. 109-118.

Lanier, W.P., Feldman, H.R., and Archer, A.W., 1993, Tidal Sedimentation from a Fluvial to Estuarine Transition, Douglas Group, Missourian-Virgillian, Kansas: Sedimentary Petrology, v. 63, No. 5, p. 860-873.

Manger, W.L., and Sutherland, P.K., 1992, Analysis of Sections Presumed to be Complete Across the Mississippian-Pennsylvanian Boundary, Southern Midcontinent, *in* Oklahoma Geological Survey Circular 94, p. 69-79.

Miall, A.D., 1977, Fluvial Sedimentology, Canadian Society of Petroleum Geologists, Parts 1-2.

Miall, A.D., 1992, Alluvial Deposits, *in* Walker, R.G., and James, N.P., eds. Facies Models: Response to Sea Level Change, Geolgical Association of Canada, p. 179-194.

Nio, S.D., and Yang, C.S., 1991, Diagnostic Attributes of Clastic Tidal Deposits: A Review, *in* Clastic Tidal Sedimentology, Smith, D.G., ed., Canadian Society of Petroleum Geologists, Memoir 16, p. 3-28.

Plink-Bjorklund, P., 2005, Stacked Fluvial and Tide-Dominated Estuarine Deposits in High Frequency (Fourth-Order) Sequences of the Eocene Central Basin, Spitsbergen, Sedimentology, v. 52, p. 391-428.

Potter, P.E., and Siever, R., 1956, Sources of Basal Pennsylvanian Sediments in the Eastern Interior Basin, Crossbedding: Geology, v. 64, p. 225-244.

Potter, P.E., and Glass, H.D., 1958, Petrology and Sedimentation of the Pennsylvanian Sediments in Southern Illinois: A Vertical Profile, Illinois State Geological Survey Report of Investigation 204, 60 p.

Potter, P.E., and Pryor, W.A., 1961, Dispersal Centers of Paleozoic and Later Clastics of the Upper Mississippi Valley and Adjacent Areas, Geological Society of America Bulletin, v. 72, p. 1195-1250.

Prothero, D.R., 1990, Interpreting the Stratigraphic Record, Freeman, New York, p. 30.

Reading, H.G., and Collinson, J.D., 1987, Clastic Depositional Settings, *in* Sedimentary Environments: Processes, Facies, and Stratigraphy, Reading, H.G., ed. Blackwell, London, p. 262.

Sambrook-Smith, G.H., Ashworth, P.J., Best, J.L., Woodward, J., and Simpson, C.J., 2005, The Morphology and Facies of Sandy Braided Rivers: Some Considerations of Scale Invariance. *In* Blum, M.D., Marriott, S.B, and Leclair, S.F. eds., Special Publication Number 35 of the International Association of Sedimentologists: Fluvial Sedimentology VII, p. 135-144.

Schoff, J.M. 1975, Pennsylvanian Climate in the United States, *in* McKee, E.D. and Crosby, E.J., eds., Paleotectonic Investigations of the Pennsylvanian System in the United States. United States Geologic Survey Professional Paper 853, p. 23-31.

Snyder, F.G., 1968, Tectonic History of the Midcontinental United States: University of Missouri Rolla Journal, v. 1, p. 65-77.

Sutherland, P.K., and Manger, W.L., 1979, Comparison of Ozark Shelf and Ouachita Basin Facies for Upper Mississippian and Lower Pennsylvanian Series in Eastern Oklahoma and Western Arkansas, *in* Sutherland, P.K., ed., Oklahoma Geological Survey Guidebook 19, p. 1-13.

Sutherland, P.K., 1988, Late Mississippian and Pennsylvanian Depositional History in the Arkoma Basin Area, Oklahoma and Arkansas: Geological Society of America Bulletin, v. 100, p. 1187-1802.

Sutherland, P.K., Grayson, R.C., and Zimbrick, G.D., 1978, Reevaluation of Morrowan-Atokan Series Boundary in Northwestern Arkansas and Northeastern Oklahoma, American Association of Petroleum Geologists Bulletin, v. 62 No. 3, p. 566.

Thomas, W.A., 1984, Carboniferous Tectonic Framework of the Continental Margin of Southeastern North America, *in* Ninth International Congress on Carboniferous Stratigraphy and Geology, v. 3, p. 291-301.

Webb, G.E., 1994, Paleokarst, Paleosol, and Rocky-Shore Deposits at the Mississippian-Pennsylvanian Unconformity, Northwestern Arkansas: Geological Society of America Bulletin, v. 106, p. 634-648.

Zachry, D.L., and Haley, B.R., 1975, Stratigraphic Relationships Between the Bloyd and Atoka Formations (Pennsylvanian) of Northern Arkansas, *in* Headrick, K.N., and Wise, O.A., eds., Contributions to the Geology of the Arkansas Ozarks: Little Rock, Arkansas, Arkansas Geologic Commission, p. 96-106.

Zachry, D.L., Jr., 1979a, Early Pennsylvanian Braided Stream Sedimentation, Northwest Arkansas: *in* Hyne, N.J., Pennsylvanian Sandstones of the Midcontinent: Tulsa, Tulsa Geologic Society, p. 269-82.

Zachry, D.L., Jr., 1979b, Stratigraphy of Middle and Upper Bloyd Strata (Pennsylvanian, Morrowan) Northwestern Arkansas, *in* Sutherland, P.K., ed., Upper Chesterian-Morrowan Stratigraphy and the Mississippian-Pennsylvanian Boundary in Northeastern Oklahoma and Northwestern Arkansas: Oklahoma Geological Survey, Guidebook 18, p. 61-66.

Appendix

Informal Outcrop Name	UTM Coordinates NAD 27 CONUS	Quadrangle
Cannon Creek (CC)	15 S 415359 3973867	Durham
Roadside Park (RP)	15 S 439431 3987632	Huntsville
Boxley (B)	15 S 462068 3983430	Boxley
Boxley South (BS)	15 S 465354 3975917	Boxley
Gaither Mountain (GM)	15 S 481359 4003202	Gaither
Long Pool (LP)	15 S 486213 3933782	Treat
Sugar Creek (SC)	15 S 479116 3948391	Fort Douglas
Parker Ridge (PR)	15 S 475740 3953496	Rosetta
Alum Cove (AC)	15 S 478693 3968390	Deer
Sherman Mountain (SM)	15 S 479977 3986410	Jasper
Witter (W)	15 S 438593 3975857	Witter
Low Gap (LG)	15 S 471223 3983370	Ponca
Pedestal Rocks (PRX)	15 S 498053 3951592	Sand Gap
Meadows Knob (MK)	15 S 480133 3942777	Fort Douglas
Buzzard's Roost (BR)	15 S 487942 3943136 15 S 487784 3942917 15 S 488041 3943292	Fort Douglas

Outcrop Locations recorded near outcrops with a Garmin Rino 130 GPS.