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MISCELLANEOUS PUBLICATION 24

A Model for Predicting Bedrock Failure in the Arkansas River Valley Region of Western Arkansas

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CONTENTS

TABLES

FIGURES

APPENDIX

Abstract

A rock strength classification system developed by New Zealander Michael J. Selby that assigns numerical values to stress resistance and outcrop features for crystalline igneous rocks, has been adapted to evaluate the strength and predict the stability of selected sedimentary formations in the Arkansas River Valley Region and closely adjoining sections of the Ozark Plateau and Ouachita regions of western Arkansas. Over 2,000 outcrops were viewed. Of these, 200 outcrops of the Hartshorne Sandstone, and Atoka and McAlester Formations have been analyzed for adaptation of Selby's Numerical Model.

Stability was assessed with this method by classifying and measuring several outcrop parameters. Features proven to have the most significant impact on stability of sedimentary strata of Arkansas River Valley Region include dip of bedding, dip (inclination) of fracture plane systems, rock hardness, and degree of weathering. Probably the most important factors in stability of sedimentary strata are dip of bedding and/or dip of persistent structural fracture planes (joints). One of the primary findings of the study is that sedimentary strata and persistent structural fractures behave in essentially the same manner in terms of rock failure. Almost all sandstones studied failed where bedding and/or joint planes dipped "out-of-the outcrop" at 26^{o} and more. In contrast, shale formations failed where bedding and/or joint planes dipped "out-of-the-outcrop" at 7^{o} and more.

Statistical analysis using Number Cruncher Statistical Software™ (NCSS) indicates an approximately 60% or greater reliability in failure prediction based solely upon rock hardness, degree of weathering, and dip/fracture inclination; however, other features have been shown to influence failure of rocks with borderline strength values. When aspects of bedding thickness, bedding plane width, fracture width, spacing of joints, and groundwater outflow were added to the model, a greater than 95% success rate in predicting failure was recorded for the 200 outcrops surveyed during the project.

The modified Selby strength model provides a reliable means of predicting failure and providing state and private agencies with an inexpensive screening tool for sedimentary bedrock of the Arkansas River Valley Region of western Arkansas.

Introduction

Failures of bedrock due to over-steepening of slopes by construction cost Arkansas state agencies and private organizations millions of dollars each year. Traditional rock strength evaluations upon which slope stabilities are determined are mainly based on rock-sample stress/strain laboratory analyses. These traditional rock sample analyses do not include outcrop features such as fracturing, layering thickness, and inclination of strata that can significantly reduce rock strength of large-scale sedimentary exposures.

Rock strength analysis models based on outcrop feature evaluation would be invaluable in slope failure prediction in western Arkansas; however, few outcrop-based strength-testing models are currently available. One rock strength classification has shown promise. Developed by New Zealander Michael J. Selby (Selby, 1980) the classification system assigns numerical values to stress resistance and outcrop features for crystalline igneous rocks (Table 1.) Although Selby's classification is strictly a strength classification and makes no claims as a failure prediction tool, rock strength and weakness could be used to indicate failure potential. Therefore, the Selby method of strength classification was chosen for testing of bedrock in the Arkansas River Valley Region.

Utilizing the Selby method involves compiling field observations of (see Table 1 for full description):

- intact rock strength using an *N-Style Schmidt Concrete Testing Hammer*
- degree of weathering
- spacing of joints
- joint or bedding orientation/orientations
- width of joints
- continuity of joints
- outflow of groundwater

Once compiled, the characteristics are assigned an "r" number value based on observed field features using parameters identified in Selby's classification (Table 1). As an example of utilizing Selby's classification to assess rock strength, an outcrop with the following features would be assigned the corresponding "r" values. A total "r" value of "70" would be considered moderately strong:

Outcrop features:	**r value**
- intact *N- Style Schmidt Hammer* reading of "35"	14
- moderately weathered	7
- joint spacing: average .44 m	21
- joint orientation: vertical; bedding orientation: horizontal	14
- width of joints: 1-3 mm	5
- joint continuity: vertically continuous; no infill	5
- slight outflow of groundwater	4
total rating:	70

To test the suitability of Selby's method for sedimentary sequences in the Arkansas River Valley Region, a preliminary evaluation of outcrop strength and failure potential was conducted on 25 outcrops. Formations common in the region were considered for study. Three Pennsylvanian age formations were chosen for investigation: the Atoka Formation, Hartshorne Sandstone, and McAlester Formation. These formations were chosen because they comprise most of the bedrock exposed throughout the region.

Four of the 25 outcrops initially evaluated had exhibited some degree of mass wasting indicating failure (such as rock falls and rock slides). However, Selby's unadjusted model, suggests that none of the outcrops would have been classified as weak and, therefore, likely to fail. It was clear after the preliminary screening of exposures in the region that Selby's model would need adaptation in order to be used as a reliable failure prediction tool.

Table 1. Michael J. Selby Field Classification of Rock Strength

	1	2	3	4	5
Parameter	**Very Strong**	**Strong**	**Moderate**	**Weak**	**Very Weak**
Intact rock strength (N-type Schmidt Hammer "R")	100-60 r = 20	60-50 r =18	50-40 r = 14	40-35 r = 10	35-10 r = 5
Weathering	unweathered r = 10	slightly weathered r = 9	moderately weathered r = 7	highly weathered r = 5	completely weathered r = 3
Spacing of Joints	> 3 m r = 30	3 - 1 m r = 28	1 - .03 m r = 21	300 – 50 mm r = 15	< 50 mm r = 8
Joint Orientations	very favorable steep dips into slope , cross joints intersect r = 20	favorable moderate dips into slope r = 18	fair horizontal dips or nearly vertical r = 14	unfavorable moderate dips out of slope r = 9	very unfavorable steep dips out of slope r = 5
Width of joints	< 0.1 mm r = 7	0.1-1 mm r = 6	1-5 mm r = 5	5-20 mm r = 4	> 20 mm r = 2
Continuity of joints	none continuous r = 7	few continuous r = 6	continuous, no infill r = 5	continuous, thin infill r = 4	continuous, thick infill r = 1
Outflow of Groundwater	none r = 6	trace r = 5	slight <25 l/min/10m^2 r = 4	moderate 25-125 l/min/10m^2 r = 3	great >125 l/min/10m^2 r = 1
Total Rating	**100 – 91**	**90 – 71**	**70 – 51**	**50 – 26**	**< 26**

Source: Selby (1980) from Zeitschrift für Geomorphologie. Used with permission of the publisher, E. Schweizerbart Science Publishers, Johannesstr. 3A D-70176 Stuttgart, Germany. www.borntraeger-cramer.de

Table 2. Modified Selby Model for Bedrock Failure Prediction

	1	2	3	4	5
Parameter	**Very Strong**	**Strong**	**Moderate**	**Weak**	**Very Weak**
Intact rock strength (N-type Schmidt Hammer "R"	100-50 r = 20	50-40 r =18	40-30 r = 17	30-10 r = 12	10 & below r = 5
Weathering	unweathered r = 10	slightly weathered r = 9	moderately weathered r = 7	highly weathered r = 5	completely weathered r = 3
Bed or Joint Orientation	very favorable steep dips into outcrop , cross joints intersect r = 45	favorable moderate dips into outcrop r = 42	fair horizontal dips; nearly vertical; or dips out of outcrop <10^o for ss or $\leq$5^o for sh; dips parallel to outcrop face r = 30	unfavorable moderate dips out of outcrop 11^o- 26^o for ss 6^o - 7^o for sh r = 23	very unfavorable steep dips out of outcrop >26^o for ss > 7^o for sh r = 6
Bedding Plane Thickness	< 1 mm r = 7	1-10 mm r = 6	10-30 mm r = 5	30-50 mm r = 4	> 50 mm r = 2
Bedding Thickness	> 3 m r = 3	1-3 m r = 3	10 cm -1m r = 2	1-10 cm r =2	<1 cm r = 1
Spacing of Joints	> 3 m r = 5	1 – 3 m r = 4	300 mm – 1 m r = 3	50 - 300 mm r = 2	< 50 mm r = 1
Width of Joints	< 1 mm r = 4	1 - 5 mm r = 3	5 - 10 mm r = 2	10 – 20 mm r = 2	> 20 mm r = 1
Outflow of Groundwater	none r = 6	trace r = 5	slight <25 l/min/10m^2 r = 4	moderate 25-125 l/min/10m^2 r = 4	great >125 l/min/10m^2 r = 1
Total Rating	**100 – 91**	**90 – 71**	**70 – 55**	**54 – 20**	**< 20**

Table 3. Sandstone Weathering Categories

Degree of Weathering	Outcrop Characteristics
unweathered	Outcrops lack staining; lack moss or lichen growth; have no detrital grains nor rock fragments present on the outcrop face or along base of outcrop.
slightly weathered	Some detrital grains and/or rock fragments present on the face of the outcrop or along the base of the outcrop; little to no mineral staining.
moderately weathered	Outcrops possess talus of rock fragments and sand at the base of the exposure; minor separation along bedding planes; pitting and corrosion along bedding plane surfaces; lichen growth; and staining by mineral oxides and organic acids.
highly weathered	Outcrops have large amounts of rock fragments and sand grains present on the exposure face; well-developed poorly sorted talus at the base of the outcrop; high degree of pitting and corrosion along bedding plane surfaces; and heavy staining by mineral oxides and organic acids.
almost completely weathered	little remaining "fabric" of bedding or sedimentary structures

Table 4. Shale Weathering Categories

Degree of Weathering	Outcrop Characteristics
unweathered	Shale retains original thinly bedded to laminar stratification. No shale fragments nor clay residue is present on the outcrop face nor at the base of the outcrop.
slightly weathered	Shale retains the original thinly bedded to laminar stratification. Minor talus consisting of platy shale fragments and minor clay in talus or clay coatings occurs on the outcrop.
moderately weathered	Outcrops have an accumulation of shale fragments and clay talus at the base of the outcrop. Some development of weathered joints infilled with platy fragments of shale with clay coatings may be present. Weathered joints may reach up to 20 mm in width. Iron oxide staining is common. Shale fragments are commonly leached and are lighter in color than unweathered strata.
highly weathered	Talus consisting of platy shale fragments covers most of the outcrop surface, masking most of the exposure. Joints are usually widened by weathering and possess significant amounts of infill of platy fragments of shale and clay. Weathered joints may reach one-third of a meter in width. Iron oxide staining may be pervasive. Shale fragments may be quite leached of color and appear almost “bleached”.
almost completely weathered	Exposures lack layering; small platy shale fragments are all that remain. Iron oxide staining may be pervasive. Clay is common. Color is usually a light tan or light gray from heavy leaching. Exposures appear as soil with small platy shale fragments.

Adaptation of Selby's Rock Strength Evaluation Model

To modify Selby's numerical model, additional features exhibited by sedimentary rocks were identified. These additional features of sedimentary rocks that influence strength, and were thus included in the adapted model, consist of: bedding thickness, bedding plane thickness, and orientation of strata (dip). These sedimentary features were added to Selby's model; adjustments for numerical values were made; and additional outcrops were evaluated. After over 2,000 outcrops screened, a total of 200 outcrops were fully assessed (Figure 1). Those 200 outcrops were chosen based on condition and accessibility of the outcrop. Individual criteria for distinguishing different weathering categories were defined in Tables 3 and 4; Figures 3 and 4. Photographic examples of each category are also included as a reference (Figure 3a-d and 4a-f).

A category for orientation of sedimentary bedding and persistent joints was added to the model. Failure clearly occurred along bedding plane surfaces dipping "out of the outcrop" (Figure 5). For sandstones, the critical angle for bedding failure was 26^{o} or greater. Shale strata failed along dips of $6\text{-}7^{o}$ and greater. Failure in sandstones also occurred along joint planes inclined at comparable angles to that of bedding. Surprisingly, it was found that failure in shales also occurred along joint planes inclined at angles analogous to failure along shale bedding planes. During the study it was assumed that tectonic fractures in sandstones tended to be more persistent and "regular" than fracturing in less competent shales; however, field reconnaissance has shown that tectonic fractures in shales of some formations in the study area are much more persistent and regular than previously believed (note failure along a joint system in silty shale facies of the Atoka Formation in Figure 4c). The competence of tectonic fractures in shales of the Atoka Formation is probably a function of the high silt content of the shales. Less regular fractures are identified from McAlester shales, probably a reflection of the lower silt content in much of the shale of the McAlester Formation.

The study was conducted over several years during which western Arkansas experienced unusually dry conditions. As a consequence of dry conditions, it was difficult to fully assess the contribution of groundwater seepage to overall failure; therefore, values comparable to those used in the original Selby method were retained.

The final categories for the Modified Selby Model Bedrock Failure Prediction include (Table 2):

- intact rock strength using an *N-style Schmidt Concrete Testing Hammer*
- degree of weathering
- bed or joint orientation/orientations
- bedding plane thickness
- bedding thickness
- spacing of joints
- width of joints
- outflow of groundwater

The adapted model (Table 2) was tested by using NCSS (Hintz, 2004). Statistical analyses indicate an approximately 60% or greater reliability in failure prediction based solely upon rock hardness, degree of weathering, and bedding or fracture inclination (dip); however, other features have been shown to influence failure of rocks with borderline strength values.

When aspects of bedding plane thickness, bedding thickness, spacing of joints, width of joints, and groundwater outflow were added to the model, the model proved to be greater than 95% reliable in predicting failure for the 200 outcrops surveyed during the project.

Utilizing the Modified Selby Model for Bedrock Failure Prediction

Equipment

To utilize the modified Selby model, little in the way of uncommon field equipment is necessary. Research by Arkansas Tech University faculty and students utilized a *N-style Schmidt Concrete Testing Hammer*, Brunton Compass, measuring tape, rock hammer, hand lens, and sediment comparator (pocket-size plastic grain-size indicator). Most equipment listed is a normal part of geologists' field "gear"; however, the concrete testing hammer is a piece of equipment that most model users would need to acquire. The *N-Style Schmidt Concrete Testing Hammer* was the instrument favored in Selby's research; so a Schmidt brand hammer was chosen. At the time of publication of this paper (2012), Schmidt hammers could be obtained for approximately $760.

Gathering Field Observations

Rock Type

Formations of the study area considered in this study are dominated by sandstone, shale, claystone, and interbedded sandstone, and/or shale facies. In identifying rock type for analysis, no distinctions were made in sandstones with respect to grain size or cementing agents. Strength that would most likely be related to differences in grain size and cementation of grains was felt to be adequately addressed with hardness testing by the concrete testing hammer. Shale and claystone both lacked strength and in most cases failed to register hardness in concrete hammer testing. As a consequence, sandstone and shale or claystone distinctions were the only two rock type distinctions made during analysis of strength by the modified Selby method.

Hardness

Hardness as a component of rock strength is measured in the modified Selby method using a *Schmidt N-Style Concrete Testing Hammer*. The Schmidt brand hammer measures the rebound of a spring loaded mass impacting against the surface of a rock exposure. The test hammer strikes the rock face at a defined energy. The rebound is dependent on the hardness of the rock face. The Schmidt hammer scale is an arbitrary scale ranging from 10 to 100 (Figure 2a). *N-Style Schmidt Concrete Testing Hammer).* By reference to the conversion chart, provided by the Schmidt Company, the rebound value can be used to determine the compressive strength. In the Selby method, the arbitrary scale numbers are sufficient for a hardness determination. Determination of specific compressive strength is not necessary. For example, if the arbitrary reading derived from the *Schmidt Hammer* is "50", the corresponding "r" value of the modified Selby model is "18" (see Table 2.). When conducting the test, the hammer should be held at right angles to the rock faces which in turn should be flat, smooth, and lacking fracture (Figure 2b.).

During the research phase for adaptation of the Selby rock strength classification, three different sites along the outcrop were chosen for testing. Twenty different hardness readings in close proximity (within roughly a meter radius) were made at each site. The twenty readings were summed and averaged. The three resulting values were summed and averaged to produce a single hardness reading for the site. It is recommended that a minimum of three sites and twenty readings per site be used in a strength/failure analysis of an outcrop so that results of hardness testing will be consistent with conditions used in developing the model.

Weathering

Selby's original strength classification defined degrees of weathering with respect to crystalline rocks (Selby, 1993, Table 6.3, page 96). For this study, it was necessary to define levels of weathering with respect to sedimentary rocks. The nature of the levels of weathering and corresponding "r" values for sedimentary rocks are defined in tables 3 and 4 and illustrated in figures 3a-f and 4a-f. Levels of weathering are obtained by visual inspection. Aspects of weathering compiled include:

- staining (mineral oxides, organic acids, and mineral salts)
- lichen/moss growth
- fragments (sand particles, shale fragments, clay)
- talus (presence, amounts, sizes, and kinds of talus)
- outcrop, joint, or bedding plane surface corrosion (pitting, ribs, grooves)
- joint presence, orientation, and width

Staining levels increase with weathering. Iron oxides and hydroxides are among the most widespread stains in sedimentary formations of the Arkansas River Valley. Hematite (iron oxide) tints rocks a dark blood-red color. Limonite is a hydrated variety of iron oxide that stains rocks a reddish-orange or yellowish-orange color. Hematite usually is present as a cementing agent in sandstones and commonly hydrates to limonite on exposure. Increasing levels of limonite staining are indicative of increasing levels of weathering.

Other oxides and hydroxides such as manganese oxide and organic acids form dark gray to black stains in rocks of the Arkansas River Valley. Occasionally, other mineral species can be precipitated along surfaces of both shales and sandstones. Carbonate residues may leave light colored to white deposits, especially in more porous facies. Higher amounts of black staining and light-colored precipitated mineral species are indicative of higher levels of weathering.

Lichen and moss growth is a function of rock type and exposure to weathering. Heavy lichen and moss growth suggest long periods of exposure of an outcrop, and therefore, signal greater degrees of weathering. Moss growth can be common on highly porous and permeable rocks such as sandstones. Lichen can survive on less porous and permeable rock; however, lichen most commonly flourish on rocks of the sandy facies of Arkansas River Valley formations.

Talus accumulation is a function of rock type, length of exposure time, and slope management practices. Large amounts of talus indicate high amounts of weathering. Fresh talus implies recent instability. Talus with iron oxide staining, moss or lichen growth and growth of plants suggests past instability. Absence of talus may indicate a stable slope with little weathering, but can also indicate a highly weathered unstable slope that has been cleared. Since absence of talus in itself is not necessarily indicative of low levels of weathering, basing stability judgments on absence of talus alone is not advisable.

Silica is common in all rocks studied in the study area. Silica is common in the sands of the Hartshorne Sandstone and in the sands, silts, and clays of the Atoka Formation. Mobilization of silica during weathering produces fluids high in silica that often precipitate along bedding planes and joints. Precipitated silica can produce hard "veneers" known as "case hardening" (Figure 6a). The combination of silica and iron oxides accumulated along bedding planes and joint surfaces results in differential weathering and erosion that creates a distinctive rusty-colored "waffle-iron" pattern upon weathering known as "liesegang banding" (Figure 6b). Silica and iron oxide concentrations can produce zones of higher cementation and greater hardness. Surfaces with pervasive case hardening and/or liesegang banding are highly weathered surfaces; however, the rock surfaces are likely to be hard and yield higher "r" values for hardness than rocks with low amounts of silica and iron oxides.

Rock fragments and their abundance on exposures are suggestive of increasing amounts of weathering. Sandstones produce large blocks and sand-sized grains upon disintegration. The greater the number of sand grains along the face of a sandstone outcrop and the greater the number of blocks and sand grains accumulated at the outcrop base, the higher the level of weathering. Shales chemically and mechanically weather to produce plate-like fragments. The greater the silt content, the higher the percentages of plate-like shards. Clay shales and claystones produce clay in abundance. Small amounts of platy fragments and clay along the face of an outcrop indicates low levels of weathering while greater numbers of fragments and clay at the base of the outcrop indicate greater extent of weathering.

Evidence of corrosion on the surface of an outcrop can be significant. As sandstones weather, preferential weathering can occur along the following rock fabrics: bedding planes, cross-bed sets, and along joint and fault surfaces. Ridges, grooves, and pits can develop along differentially weathering rock fabrics (see uneven surface due to corrosion of a sandstone in Figure 3d.). Differential compaction, cementation, and zones of mineralization can produce zones of weakness or strength. Heavy weathering of sandstones with abundant ironstone nodules or concretions and clay balls may develop a highly pitted or indented surface.

Joint planes with shale fragment infill and clay infill are especially obvious features that signify higher levels of weathering. In the Arkansas River Valley Region, infilled joints are almost exclusively developed in shales, both in the Atoka and McAlester formations. Tectonic joints tend to be persistent throughout silty shale facies of the Atoka Formation and the McAlester Formation. Mechanical hydration or dehydration and chemical hydrolysis have produced small platy fragments of silty shale and clay along tectonic fractures. Continued hydration, dehydration and hydrolysis accompanying groundwater seepage along tectonic fractures recrystallize the grains into a parallel alignment with the joint surfaces (see Figure 4e.). Moderately weathered silty shales may contain joint infill of up to 20 mm in width; whereas more highly weathered silty shales may possess joint infill zones that reach one-third of a meter in width.

To illustrate the assessment of an exposure with respect to weathering, a photograph of an exposure of a shale can be used (Figure 4c.). The outcrop consists of very thinly-bedded layers of silty shale. Weathering has resulted in some disintegration along the bedding planes, producing numerous platy fragments and some clay residue on the exposure surface. The base of the outcrop has a small talus pile of shale fragments containing minor amounts of clay. Staining by iron oxide and hydroxides is clearly visible. Limonitic stains predominate. Shale layers still in place are very dark gray to black in color. Weathered platy fragments are somewhat "bleached" to a lighter gray color. Weathered persistent joints with thin infill are common. Based on the collective nature of weathering, the level of weathering would be considered "moderately weathered" and receive an "r" rating of "5".

Bed or Joint Orientation

Orientation and occurrence of bedding planes of strata and joint planes in rocks of the study area have been shown to strongly influence overall strength of outcrops. Where bedding planes and joints are laterally persistent and dipping, the planes can act as gliding surfaces, greatly increasing the likelihood of failure.

Joints, fractures along which no displacement has occurred, are common in the Arkansas River Valley Region. Because the area lies north of the strongly deformed Ouachita Mountain Province, joint systems that are predominantly tectonic in origin and laterally persistent are common. A system of major "lineaments" and persistent joints believed to be tectonic in origin trend northeast-southwest across the Ozark Plateaus, including the Boston Mountains, and into the Arkansas River Valley Region as well. Randomly trending fractures occur in the area, but are less common and less persistent than the tectonic joints. Most joints, therefore, usually occur trending primarily north-south, east-west, or northeast-southwest. Joint planes may be vertical, horizontal, or tilted.

Bedrock of the Arkansas River Valley Region is almost exclusively sedimentary and, therefore, layered. The attitude of the strata of the area, like joint orientation, can be quite variable: vertical, horizontal, or tilted. Research for this study has shown that failure along bedding planes and failure along joint planes occurs under the same conditions. For example, this study shows that sandstones begin to slide at approximately 26^o of dip whether the plane is a bedding plane or a persistent joint plane. Dip of bedding and orientation of persistent joints therefore, are treated as synonymous in the adapted Selby method. In addition to being vertical, horizontal or inclined, planes may parallel the outcrop slope face, or may intersect the outcrop at an angle. Planes may dip "into" the outcrop slope face or dip "out" of the outcrop (Figure 5).

In this study bedding and joint planes that are horizontal or vertical were shown not to significantly increase failure potential. Bedding and joint planes that dip "out" of the outcrop have the greatest weakening affect on bedrock. Almost all sandstones analyzed in this study failed where bedding and/or joint planes dipped "out-of-the-outcrop" at 26^o or greater. In contrast shale formations failed where bedding and/or joint planes dipped "out-of-the-outcrop" at 7^o and greater.

Several faults were encountered during the course of the study. Failure with respect to dip of the fault plane appears to be consistent with failure patterns observed for bedding and joint planes; however, too few faults were examined to statistically substantiate conclusions relating faulting and failure. Only values for dip of bedding and dip of persistent joint planes were selected for inclusion into the adapted Selby model.

In determining the "r" value of bed or joint orientation, information on the strike and dip of all joint planes and bedding planes were collected and recorded. The feature/features with the lowest strength rating are those suitable for assessing failure. For example, selection of the bedding or joint orientation feature with the lowest strength value is illustrated by the exposure shown in Figure 7. The photograph features sandstone strata of the Atoka Formation dipping "into" the outcrop face. Also visible are joint planes which dip "out" of the outcrop face. The bedding dip "into" the outcrop was recorded as 33^{o}. The joint planes dip "out" of the outcrop at a measured angle of 60^{o}. The joint planes are the weakest structural feature; therefore, the "r" value for bed or joints dipping out of the outcrop at 60^{o} was used in assessing the outcrop.

Assessment Example

Figure 8 illustrates a typical outcrop that was assessed using the Modified Selby Model for Bedrock Failure Prediction (Table 2). The outcrop consists of a slightly sloping bedrock exposure created during the construction of an interchange of I-40 west of Conway, Arkansas (Appendix: site 167). Atoka Formation sandstones with minor shale partings comprise the road cut. All criteria used in the evaluation are listed as follows:

Intact Rock Strength	Schmidt Hammer value: 37	r = 17
Weathering	moderate: minor staining; talus	r = 7
Bedding or Joint Plane Orientation	Joints dip "out-of-the-outcrop" at 60 ^{o}	r = 6
	Bedding planes dip "into-outcrop" at 33^{o}	
Bedding Plane Thickness	1-10 mm	r = 6
Bedding Thickness	1-10 cm	r = 2
Spacing of Joints	roughly averaging 20 cm	r = 2
Width of Joints	5-10 mm	r = 2
Outflow of Water	none	r = 6
		48 total

The total "r" value of 48 ranks the exposure as "weak" and likely to fail. Examination of the photograph of the outcrop (Figure 7) reflects catastrophic failure.

Conclusions

The Modified Selby Model for Bedrock Failure Prediction is a reliable, cost-effective, and relatively simple method for predicting bedrock failure that can be used in the Arkansas River Valley Region of western Arkansas. The study did not attempt to evaluate strata in the Ouachita Mountain Region because of the complex nature of structural fracturing and fracturing pattern relationships. The study did not attempt to evaluate strata in the northern tier of counties of Arkansas because strata is essentially flat-lying and would not normally be expected to fail unless undercut. This Modified Selby Model should be used only for assessing bedrock failure in the Arkansas River Valley Region and closely adjoining sections of the Ozark Plateau and Ouachita regions where rocks have not been exposed to alteration and do not possess complicating metamorphic rock fabrics. When outcrops border between weak and moderate in strength, the model can be especially helpful in distinguishing failure potential.

During the study additional observations and correlations of a general nature were drawn. In many cases, observations of only a few features can be used to reliably predict failure and/or nature of failure without computation of "r" values. The following conditions usually produce failure:

- undercutting of almost any outcrop (some sandstones that are massively bedded and dip "into" the outcrop face may stabilize and support some degree of overhang).
- 26^{o} appears to be the critical angle for dip of bedding planes AND joint fracture surfaces for sandstone failure.
- $6\text{-}7^{o}$ appears to be the critical angle for dip of bedding planes AND joint fracture surfaces for shale failure.
- heavily weathered joints with shale and clay infill serve as significant zones of weakness and failure when orientation of the joint is, "out-of-the-outcrop".
- when outcrops consist of more than one rock-type, failure is determined on the characteristics of the weaker rock type. For example, when shales and sandstones are interbedded, the critical dip angles are drawn from the shales rather than sandstones.
- extent of failure is usually related to the bedding/joint plane failure orientation. For example, sandstones and shales with steep dip/joint orientation strongly "out-of-the-outcrop" tend to have failures that extend limited distances into the outcrop; whereas, sandstones and shales with low dip/joint "out-of-the-outcrop" orientation may have failures that extend greater distances back into the outcrop.
- where bedding is uneven, such as in areas with differential compaction and large-scale bulges and troughs, the dip of the bedding planes may locally be high enough to cause small scale failures.

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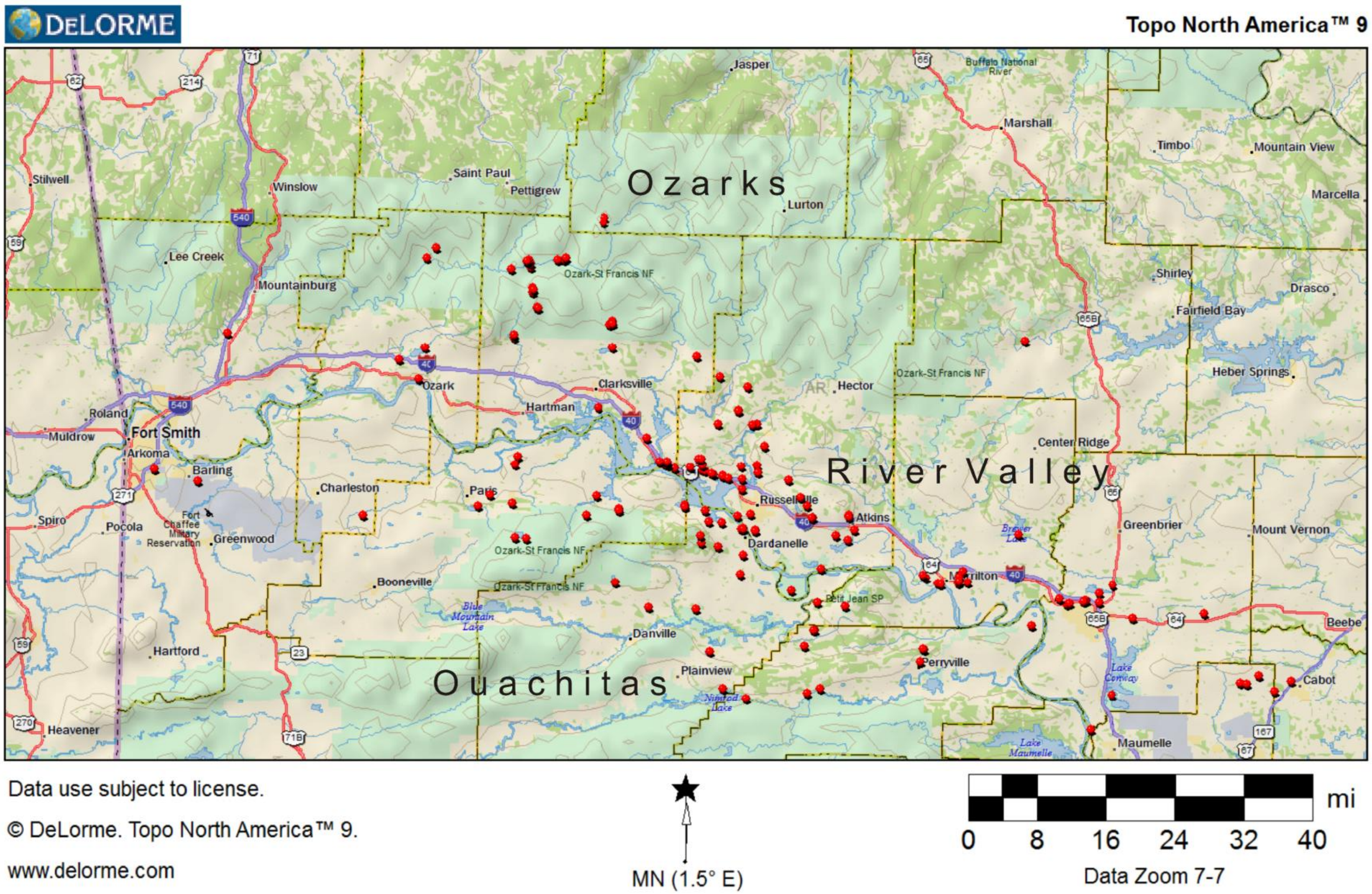

Figure 1. Locations of study sites in the Arkansas River Valley Region. Individual GPS locations are included in the Appendix.

Figure 2a. *N-Style Schmidt Concrete Testing Hammer*.

Figure 2b. Demonstration of use of *N-Style Schmidt Concrete Testing Hammer*.

Figure 3a. Unweathered sandstone: Hartshorne Sandstone at the I-40 Interchange #78 west of Russellville.

Figure 3b. Slightly weathered sandstone: Hartshorne Sandstone at the I-40Interchange #78 west of Russellville.

Figure 3c. Moderately weathered sandstone: Hartshorne Sandstone on I-40 approximately one-half mile east of Interchange #74 at London.

Figure 3d. Moderately weathered sandstone: Hartshorne Sandstone near Mather Lodge at Petit Jean State Park located approximately 14 miles east of Centerville on AR Hwy. 154.

Figure 3e. Heavily weathered sandstone: Hartshorne Sandstone at Cove Mountain and AR Hwy. 247 approximately 3.6 miles south of Pontoon.

Figure 3f. Almost completely weathered sandstone: Hartshorne Sandstone at Cove Mountain and AR Hwy. 247 approximately 3.6 miles south of Pontoon.

Figure 4a. Unweathered to slightly weathered shale: Atoka Formation along AR Hwy. 9 roughly 1.75 miles south of I40 Interchange #108 at Morrilton.

Figure 4b. Moderately weathered shale: McAlester Formation at the spillway of Horsehead Lake approximately 2.7 miles north of Hunt on AR Hwy. 164.

Figure 4c. Moderately weathered shale: Atoka Formation along AR Hwy.7 nearly two miles north of the I-40 Interchange #81 at Russellville.

Figure 4d. Heavily weathered shale: McAlester Formation at Robertsons Lane off US Hwy. 64 nearly two miles west of I-40 Interchange #78 west of Russellville.

Figure 4e. Heavily weathered joint plane in shale: Atoka Formation along AR Hwy. 22 nearly two miles west of Dardanelle, Arkansas. The photograph illustrates development of platy shale fragments aligned along the joint plane.

Figure 4f. Nearly completely weathered shale: McAlester Formation at Round Mountain on Milky Way Lane near Arkansas Nuclear One west of Russellville.

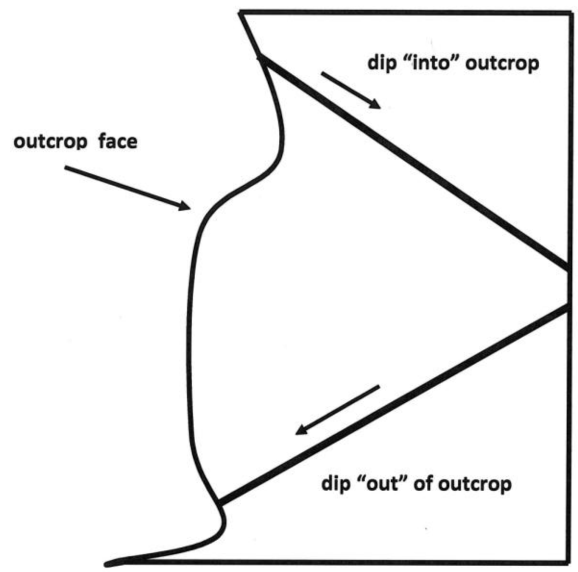

Figure 5. Illustration of joint and dip orientation terminology.

Figure 6a. Silica case hardening: Hartshorne Sandstone at Mount Nebo State Park in Yell County, roughly seven miles west of Dardanelle, Arkansas.

Figure 6b. Liesegang: Hartshorne Sandstone along Rim Rock Road roughly one-half mile upstream from Dardanelle Lock and Dam at Dardanelle.

Figure 7. Failure along persistent structural fracture planes: Atoka Formation (sandstone facies) at Interchange #124 on I-40 approximately two miles west of Conway. Strata dip "into" the outcrop. Joint planes dip "out" of the outcrop.

Figure 8. Assessment Example*:* Atoka Formation (sandstone facies) at Interchange #124 on I-40 approximately two miles west of Conway.

Appendix 1 – Research Site Locations and Strength Values

Site # and Name	Numerical Rating	Latitude/Longitude Location	
	F is for visible failure	N for North; W for West	
1. Dardanelle Rock SW – sandstone – Hartshorne	88	35.23733° N	93.16750° W
2. Dardanelle Rock SW – shale – Atoka	68	35.23733° N	93.16750° W
3. Dardanelle Rock NE – sandstone – Hartshorne	54F	35.23850° N	93.16517° W
4. River Ridge – Land's End – sandstone – Hartshorne	81	35.25950° N	93.17550° W
5. Sweden Island – shale and silty shale – Atoka	73	35.17033° N	93.00333° W
6. Moore Hill Cemetery – shale – Atoka	57	35.16117° N	93.17083° W
7. *Jones Mountain Foothill – shale – Atoka	57	35.20733° N	93.21500° W
8. Walker Mountain North Dardanelle Hwy. 7 – McAlester	34F	35.23500° N	93.14000° W
9. Washburn Park– silty/shaly sandstone – Hartshorne	86	35.30433° N	93.16617° W
10. Mount Nebo Sunrise Point – sandstone – Hartshorne	87	35.21383° N	93.25067° W
11. Mount Nebo East Bench – shale & silty shale – Atoka	35F	35.22600° N	93.25183° W
12. Western Hills Pluto Driver – shale – Atoka	69	35.26233° N	93.14833°W
13. High Knob-south – Petit Jean – sandstone – Atoka	86	35.10267° N	93.26033° W
14. High Knob-north – Petit Jean – sandstone – Atoka	67	35.10267° N	93.26033° W
15. Pontoon Park – Pontoon – shale – Atoka	75	35.11417° N	93.01133° W
16. *Casa Cutoff A – sandstone – Hartshorne	80	35.06783° N	93.01633° W
17. *Casa Cutoff B – sandstone – Hartshorne	54F	35.06733° N	93.01850° W
18. *Casa – Casa Mountain Road – sandstone – Hartshorne	89	35.04167° N	93.03667° W
19. *Neeley Farm Quarry – silty shale/sandstone – Atoka	68	35.15600° N	92.78933° W
20. Allison Farm SW – silty shale/sandstone – Atoka	68	35.16050° N	92.79433° W
21. *Cherokee Road Morrilton – sandstone – Atoka	62	35.14500° N	92.76067° W
22. *Cherokee Road Morrilton – sandstone – Atoka	70	35.14500° N	92.76067° W
23. Petit Jean SW – sandstone – Hartshorne	75	35.10733° N	92.95317° W
24. Spring Lake Dam – sandstone – Atoka	91	35.14833° N	93.42533° W
25. Spring Lake Dam – sandstone – Atoka	89	35.14833° N	93.42533° W
26. Crow Mountain – Sherman – sandstone – Hartshorne	76	35.31850° N	93.07000° W
27. * Russellville Hwy. 7 So. – sandstone/shale – Hartshorne	76	35.23500° N	93.1400° W
28. * Russellville Hwy. 7 So. – sandstone/shale – Hartshorne	94	35.23483° N	93.14067° W
29. *Tater Hill – shale and silty shale – McAlester	31F	35.29283° N	93.46650° W
30. *Paris south- sandstone – ?McAlester	79	35.27633° N	93.70900° W
31. Shrives Crow Mt. – shale and silty shale – Atoka	86	35.27650° N	93.03200° W
32. Shrives Crow Mt. – shale and silty shale – Atoka	82	35.27650° N	93.03200° W
33. *Dover Illinois Bayou – north – shale – Atoka	60	35.41317° N	93.13600° W
34. *Linker Mountain – east – shale – Atoka	36F	35.37567° N	93.12117° W
35. *Spring Lake Road – sandstone – Hartshorne	89	35.27150° N	93.41917° W
36. Spring Creek – shale – Atoka	73	35.26833° N	93.41917° W
37. *Mill Creek I40 Roadcut #1 – shale – Atoka	61	35.32750° N	93.20550° W
38. *Mill Creek I40 Roadcut #2 – sandstone – Hartshorne	77	35.32467° N	93.20600° W

39. *Pleasant View Mt. – shale & silty shale – Atoka	72	35.34267° N	93.16800° W
40. *Bay Ridge Hwy. 7– shale/sandstone inter. – Atoka	68	35.24833° N	93.20783° W
41. *Dardanelle Rock – sandstone – Hartshorne	80	35.23733° N	93.16367° W
42. *Hickerson Hollow – sandstone –Hartshorne	87	35.26800° N	93.24267° W
43. Linker Mountain – sandstone – Hartshorne	88	35.34367° N	93.13600° W
44. *Crow Mt. Pottsville – sandstone – Hartshorne	87	35.25617° N	93.02100° W
45. *Crow Mt. Pottsville – shale – Atoka	74	35.25617° N	93.02100° W
46. *Crow Mt. Pottsville – shale – Atoka	74	35.25567° N	93.02133° W
47. *Crow Mt. Bradley Cove Rd. – sandstone – Hartshorne	88	35.28917° N	93.04550° W
48. *Crow Mt. Bradley Cove Rd. – shale – Atoka	72	35.28917° N	93.04550° W
49. *Crow Mt. Atkins – sandstone – Hartshorne	89	35.25983° N	92.94617° W
50. *Crow Mt. Atkins – shale – Atoka	71	35.25800° N	92.94600° W
51. *Pleasant View Mt. I40A – sandstone – Hartshorne	78	35.32300° N	93.19433° W
52. *Pleasant View Mt. I40B– sandstone – Hartshorne	73	35.24950° N	93.23467° W
53. *Pleasant View Mt. I40C – sandstone – Hartshorne	71	35.33667° N	93.24850° W
54. *Pleasant View Mt. I40D – sandstone – Hartshorne	73	35.33500° N	93.24283° W
55. *Pleasant View Mt. I40E – sandstone -- Hartshorne	75	35.33067° N	93.22933° W
56. *Pleasant View Mt. I40E – shale – Atoka	35F	35.33067° N	93.22933° W
57. *Pleasant View Mt. I40F – sandstone – Hartshorne	76	35.32917° N	93.22467° W
58. *Pleasant View Mt. 40-acre – sandstone – Hartshorne	79	35.32017° N	93.16650° W
59. *OarkA – sandstone – Atoka	60	35.68900° N	93.53200° W
60. *OarkA – shale – Atoka	76	35.68900° N	93.53200° W
61. *OarkB – shale mixed siltstone, sandstone – Atoka	72	35.68767° N	93.54517° W
62. *OarkC – sandstone – Atoka	60	35.67550° N	93.60000° W
63. *OarkC – shale – Atoka	69	35.67550° N	93.60000° W
64. *OarkD – shale mixed siltstone, sandstone – Atoka	54F	35.64167° N	93.59650° W
65. *OarkE – sandstone – Atoka	71	35.63843° N	93.95683° W
66. *OarkF – sandstone – Atoka	76	35.60883° N	93.58817° W
67. *Oark G – sandstone – Atoka	79	35.60983° N	93.58667° W
68. *OarkH – sandstone – Atoka	59	35.60867° N	93.58600° W
69. *OarkI – shale mixed siltstone, sandstone – Atoka	58F	35.68250° N	93.59967° W
70. *OarkJ – sandstone – Atoka	75	35.63883° N	93.59550° W
71. *FallsvilleA – shale mixed siltstone, sandstone – Atoka	65	35.75917° N	93.44950° W
72. *FallsvilleB – sandstone – Atoka	77	35.75250° N	93.45117° W
73. *OzoneA – shale mixed siltstone, sandstone – Atoka	77	35.58033° N	93.43717° W
74. *OzoneB – sandstone – Atoka	78	35.58700° N	93.43267° W
75. *OzoneC – sandstone – Atoka	76	35.38317° N	93.43150° W
76. *OzoneD – sandstone – Atoka	58F	35.58200° N	93.43133° W
77. *LudwigA – sandstone – Atoka	50F	35.54150° N	93.43217° W
78. *LudwigB – sandstone – Atoka	71	35.54150° N	93.43217° W
79. *CatalpaA – shale – Atoka	34	35.69117° N	93.52850° W
80. *CalalpaB – shale – Atoka	37	35.69117° N	93.52850° W
81. *Wolf PenA – sandstone – Atoka	76	35.67317° N	93.63983° W
82. *Wolf PenB – sandstone – Atoka	87	35.68600° N	93.60833° W
83. *Wolf PenC – sandstone – Atoka	85	35.68733° N	93.60733° W
84. *Wolf PenD – sandstone – Atoka	71	35.68767° N	93.60517° W
85. *Pleasant View Mt. I40G – sandstone – Hartshorne	77	35.33883° N	93.30533° W
86. *Pleasant View Mt. I40H – sandstone – Hartshorne	78	35.34417° N	93.31750° W
87. *Pleasant View Mt. I40I – sandstone – Hartshorne	53F	35.34583° N	93.32417° W

88. *Pleasant View Mt. I40I – sandstone – Hartshorne	68	35.34583° N	93.32417° W
89. *Pleasant View Mt. I40J – sandstone – Hartshorne	75	35.34833° N	93.31983° W
90. *Pleasant View Mt. I40K – sandstone – Hartshorne	76	35.35017° N	93.33433° W
91. *Sims Hollow RoadB – shale – Atoka	36F	35.34367° N	93.24783° W
92. *Dug RoadA – shale – Atoka	71	35.35500° N	93.25567° W
93. *Dug RoadB – shale – Atoka	59	35.35450° N	93.24983° W
94. *Lee Mountain RoadA – sandstone – Atoka	90	35.43617° N	93.17350° W
95. *Lee Mountain RoadB – shale – Atoka	33F	35.43550° N	93.17383° W
96. *Nimrod Dam – sandstone – Atoka	54F	34.95283° N	93.15950° W
97. *Nimrod Dam West – sandstone – Atoka	90	34.97000° N	93.20667° W
98. *Nimrod Community East-A – sandstone – Atoka	54F	34.96283° N	93.03167° W
99. *Nimrod Community East-B – sandstone – Atoka	54F	34.96950° N	93.00578° W
100. *Lee's ChapelA – fine grained sandstone – Atoka	32F	35.53633° N	93.26017° W
101. *Augsburg EastA – sandstone – Atoka	75	35.41350°N	93.21633° W
102. *Augsburg EastB- shale – Atoka	59	35.41133° N	93.14633° W
103. *Danville Golf Course – sandstone – Atoka	52F	35.01567° N	93.35800° W
104. *Baker's Creek – shale – Atoka	32F	35.33117° N	93.13350° W
105. *Morrilton Hwy. 9-A – sandstone – Atoka	90	35.16650° N	92.70183° W
106. *Morrilton Hwy. 9-A – sandstone – Atoka	78	35.16650° N	92.70183° W
107. *Morrilton Hwy. 9-B – shale – Atoka	61	35.16650° N	92.71083° W
108. *Morrilton Hwy. 9-C – shale – Atoka	59	35.15650° N	92.71900° W
109. *Morrilton Hwy. 9-D – shale – Atoka	72	35.14933° N	92.72050° W
110. *Morrilton Hwy. 9-E – sandstone – Atoka	81	35.14933° N	92.72050° W
111. *Morrilton Hwy. 9-F – shale – Atoka	75	35.14683° N	92.72033° W
112. *Morrilton Hwy. 9-G – sandstone – Atoka	91	35.14683° N	92.72017° W
113. *Perry South – sandstone – Atoka	83	35.03433° N	92.79267° W
114. *Perry South 2 – sandstone – Atoka	48F	35.03650° N	92.79433° W
115. *Morrilton Hwy. 64A – shale – Atoka	62	35.14967° N	92.71867° W
116. *Menifee East – sandstone/shale – Atoka	42F	35.13317° N	92.53017° W
117. *Hogan Lane A – sandstone/shale – Atoka	76	35.01983° N	92.49933° W
118. *Hogan Lane B – sandstone/shale – Atoka	46F	35.01983° N	92.49933° W
119. *Conway US 65McDonalds – sandstone/shale – Atoka	43F	35.11317° N	92.43150° W
120. *Sardis Road – sandstone – Atoka	54F	35.14700° N	92.70150° W
121. *Comfort Inn Conway – sandstone/shale – Atoka	32F	35.12967° N	92.43183° W
122. *Subway Conway – sandstone/shale – Atoka	32F	35.11317° N	92.43217° W
123. *Toad Suck A – sandstone – Atoka	52F	35.07533° N	92.57150° W
124. *Ola Dale Lake Spillway A – sandstone/shale – Atoka	87	35.03117° N	93.23267° W
125. *Ola Dale Lake Spillway B – sandstone – Atoka	53F	35.03117° N	93.23267° W
126. *Hot Shot Trucking Atkins – sandstone – Atoka	53F	35.23500° N	92.93550° W
127. *London Mt. Co. Quarry A – sandstone – Hartshorne	90	35.34083° N	93.27317° W
128. *London Mt. Co. Quarry B – sandstone – Hartshorne	78	35.34083° N	93.27317° W
129. *Point Remove Park Quarry – sandstone – Atoka	50F	35.14583° N	92.76433° W
130. *Pickles Gap Shale Pit – sandstone/shale – Atoka	36F	35.14250° N	92.40300° W
131. *Horsehead Lake Spillway – sandstone – Hartshorne	54F	35.55867° N	93.63500° W
132. *Knoxville North – shale – Atoka	59	35.39083° N	93.36167° W
133. *Keener Quarry A – sandstone – Atoka	59	35.22700° N	92.97283° W
134. *Willcutt Quarry A – sandstone – Atoka	38F	35.21817° N	92.94833° W
135. *Willcutt Quarry B – shale – Atoka	61	35.21850° N	92.94750° W
136. *Morrilton City Quarry A – sandstone – Atoka	77	35.14467° N	92.75650° W

137. *Morrilton City Quarry B – sandstone – Atoka	53F	35.14467° N	92.75650° W
138. *Lake Brewer Spillway – sandstone – Atoka	76	35.22783° N	92.59667° W
139. *Lake Brewer Spillway – sandstone – Atoka\	85	35.22783° N	92.59667° W
140. *Lake Brewer Spillway – sandstone – Atoka	60F	35.22783° N	92.59667° W
141. *Lake Brewer Spillway – sandstone – Atoka	72	35.22783° N	92.59667° W
142. *Carmichael Gap A – sandstone – Atoka	52F	35.09550° N	92.21600° W
143. *Carmichael Gap B – shale – Atoka	35F	35.09550° N	92.21600° W
144. *Mt. Zion Church – sandstone – Atoka	53F	34.97850° N	92.14217° W
145. *Mt. Zion Church – shale – Atoka	36F	34.97850° N	92.14217° W
146. *Conway County Landfill A – sandstone – Atoka	51F	35.11917° N	92.51317° W
147. *Conway County Landfill B – shale – Atoka	35F	35.11917° N	92.51317° W
148. *Conway County Landfill C – sandstone – Atoka	51F	35.11917° N	92.51317° W
149. * Palarm 1 – shale – Atoka	37F	34.90033° N	92.44900° W
150. *Conway US64 East – sandstone – Atoka	54F	35.08800° N	92.36267° W
151. * Palarm 2 – sandstone – Atoka	52F	34.90033° N	92.44900° W
152. *Mount Zion Church C – sandstone – Atoka	54F	34.97717°N	92.12983° W
153. *Cabot A – sandstone – Atoka	53F	34.96567° N	92.07183° W
154. *Keener Lake – sandstone/shale – Atoka	49F	34.99150° N	92.10467° W
155. *Cabot B – sandstone/shale – Atoka	54F	34.98217° N	92.03567° W
156. *Perryville Hwy 9/60 – shale/sandstone – Atoka	35F	35.01433° N	92.80017° W
157. *Clarksville Jamestown – shale – McAlester	71F	35.44133° N	93.46267° W
158. *Conway Lake Spillway A – sandstone – Atoka	37F	34.95933° N	92.40517° W
159. *Conway Lake Spillway B – shale – Atoka	75	34.95933° N	92.40517° W
160. *Shoal Creek Horsecamp – shale – Atoka	37F	35.26050° N	93.48767° W
161. *Subiaco Reservoir – sandstone – Atoka	53F	35.28033° N	93.63783° W
162. *Magazine Hwy. 309 – sandstone – Hartshorne	87	35.22333° N	93.63300° W
163. *Magazine Hwy. 309 – shale – Hartshorne	68	35.22333° N	93.63300° W
164. *Subiaco North – shale – McAlester	72	35.35883° N	93.62633° W
165. *Cabot C – sandstone – Atoka	76	34.96567° N	92.07183° W
166. *Cabot C – sandstone – Atoka	76	34.96567° N	92.07183° W
167. *Conway I40A – sandstone – Atoka	70	35.11733° N	92.46250° W
168. *Conway I40B – shale /sandstone – Atoka	48F	35.11750° N	92.46250° W
169. *Conway I40C – sandstone – Atoka	53F	35.11733° N	92.46100° W
170. *Conway I40C – sandstone – Atoka	72	35.11733° N	92.46100° W
171. *Conway I40D – sandstone – Atoka	49F	35.11733° N	92.46100° W
172. *Horsehead Lake – shale – Atoka	70	35.19383° N	93.16400° W
173. J. Wood Farm – shale – Atoka	63	35.27700° N	93.28300° W
174. *Wood Shale Pit-A – shale – Atoka	73	35.27417° N	93.28467° W
175. *Wood Shale Pit-B – shale – Atoka	53	35.27417° N	93.28467° W
176. *Short Mountain South – shale – Atoka	58	35.29517° N	93.68450° W
177. Shaver Road – shale – Atoka	75	35.25467° N	93.90117° W
178. Rich Mountain Forest Service (#4) – shale – Atoka	71	35.22217° N	93.60967° W
179. Sheepskin Road A – shale – Atoka	35F	35.24850° N	93.20750° W
180. Sunnyside Road – A: shale/sandstone – Atoka	64	35.34500° N	93.63200° W
181. Sunnyside Road – B: shale/sandstone – Atoka	28	35.34500° N	93.63200° W
182. *Clinton SW – sandstone – Atoka	64	35.55217° N	92.58417° W
183. *Hogan Road East –sandstone/shale – Atoka	43F	35.11267° N	92.49267° W
184. *Salem Lane A – sandstone – Atoka	52F	35.11533° N	92.46283° W
185. *Salem Lane A – shale – Atoka	39F	35.11533° N	92.46283° W

186.	*Salem Lane B – shale – Atoka	39F	35.11483° N	92.46417° W
187.	*Rushing Silex Road – shale – Atoka	38F	35.49183° N	93.21200° W
188.	*Bogger Hollow A – shale – Atoka	61	35.47483° N	93.15433° W
189.	*Bogger Hollow B -- shale – Atoka	33F	35.47483° N	93.15433° W
190.	*Lone Oak Road – shale – Atoka	33F	35.70883° N	93.79333° W
191.	*Woolsey Seeco #5 – shale – Atoka	32F	35.54200° N	93.81833° W
192.	*Timber Ridge Road – shale – Atoka	32F	35.48883° N	93.83217° W
193.	*Mt.burg I40A – shale – Atoka	33F	35.52167° N	93.87167° W
194.	*Mt.burg I40B – shale – Atoka	33F	35.56667° N	94.22417° W
195.	*Massard Road – shale – Atoka	35F	35.33783° N	94.37383° W
196.	*Oark K – shale – Atoka	33F	35.68617° N	93.60800° W
197.	*Oark L – shale – Atoka	33F	35.68667° N	93.60750° W
198.	*Cass Co. Rd. – shale – Atoka	32F	35.69200° N	93.81550° W
199.	*Ft. Chaffee I49 – shale – Atoka	36F	35.31800° N	94.29617° W
200.	*Horsehead Dam – shale/sandstone – Atoka	35F	35.56300° N	93.63533° W

*** denotes outcrops that are artificial or "man-made" or natural outcrops that have been altered**