Stratigraphic Analysis with Respect to Aggregate Potential in the Duffield Quarry in Gum Log, Arkansas

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Stratigraphic Analysis with Respect to Aggregate Potential in the Duffield Quarry in Gum Log, Arkansas
Stratigraphic Analysis with Respect to Aggregate Potential in the Duffield Quarry in Gum Log, Arkansas

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology

by

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Arkansas Tech University
Bachelor of Science in Professional Geology, 2013

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This thesis is approved for recommendation to the Graduate Council.

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Abstract

The crushed stone mining industry is valued at nearly one billion dollars in Arkansas alone. Physical properties of the rock dictate whether or not an area may be suited for the establishment of an aggregate quarry. The Gum Log quarry located 10 miles northeast of Russellville, Arkansas is geographically well situated near areas in need of aggregate material, as well as physically competent rock. The rock mined in Gum Log is located in the Upper Atoka Formation, a Middle Pennsylvanian aged member of the Arkoma Basin. There are five different lithologic facies identifiable in the quarry (Facies 1-5 respectively): A shallow marine, fissile shale unit marks the oldest facies observable in the quarry; a distal bar sandstone with macerated plant debris; thick, highly cross-bedded distributary-mouth-bar sandstone; a tidal flat siltstone facies; and highly cross-bedded distributary channel sandstone, which is the youngest facies observed in Gum Log.

By using LA Abrasion test results on the different facies of Gum Log quarry the aggregate potential of the rock can be evaluated. Facies 1 is not well suited for aggregate mining and is unable to be tested with the LA Abrasion method because the process is not designed to test shale. Facies 2 has an average LA percentage of 47.6% and is not suitable for aggregate material. Facies 3 is separated into three units based on engineering properties, and have average LA percentages of 27.4, 31.6, and 43.1% from top to bottom in the section. This facies is the primary unit mined in Gum Log quarry and is well suited for aggregate material. Facies 4 has average LA percentages over 60% as is not suitable for aggregate material. Facies 5 has an average LA percentage of 27.3% and is very well suited for aggregate material; however current prices deem the unit uneconomic. Based on the results of this analysis, mining in Gum Log
quarry should continue north and east, following the thick sandstone of Facies 3 and avoiding the overlying siltstones of Facies 4.
Acknowledgments

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Introduction

The Aggregate Industry

In today’s society, crushing stone to create aggregate material is a common practice. The aggregate market is a much larger one than most would expect. In 2008, nonfuel raw mineral production in Arkansas alone was valued just short of one billion dollars (Minerals Yearbook, 2008). Humans rely on this material in order to enlarge cities, improve and expand highways, and to build and maintain our inhabitation on Earth. Using rock and aggregate materials has been the foundation of construction and development for thousands of years and will likely continue to be into the future.

Not all rock is suitable to become aggregate material. In the crushed stone mining industry properties, such as hardness and durability dictate the potential of a rock. In addition to testing physical properties, a site assessment must be conducted to determine if the source rock lies within an acceptable proximity to the need for aggregate material. Once an area is assessed for both rock quality and proximity of need, a quarry can be constructed. At this time, overburden is usually removed to gain access to the target bedrock beneath the surface. The bedrock is then blasted with explosives to fracture the rock and free it for use. Once this occurs, the shot rock is removed and transported to the crushing area of the quarry. Here the rock is fractured down through primary, secondary, and tertiary crushing methods and sorted out with screens to desired sizes. A correct physical assessment of rock quality, as well as proximity to need, is shown in the Duffield Gravel Quarry near Russellville, Arkansas which has been producing aggregate material in the region for over 20 years (Figure 1).
The Duffield Gravel Quarry in Gum Log, Arkansas is located approximately 10 miles northeast of Russellville on state highway 326 (Figure 2). The quarry spans approximately 2500 feet west to east and approximately 1100 feet from the northern to southern extent. The Gum Log quarry is well situated in the Arkansas River Valley near Interstate 40, Highway 124, and several other main roadways making it easy and relatively inexpensive to export aggregate from the quarry to locations in need.
In addition, the quarry is located in the most durable and competent bedrock in the area. The Arkansas River Valley near Russellville contains three major rock formations that could provide the means to establish a quarry. The McAlester Formation is composed chiefly of dark shale with fined grained sandstones and thin coal seams. The Hartshorne Formation is a high-constructive, tidally-influenced delta system containing blue-gray heavily channelized sandstones (Houseknecht, 1981). The Atoka Formation is predominantly a marine formation containing abundant shale, siltstones, and sandstones. The Atoka is the thickest of the River Valley formations, and can demonstrate significant lateral and vertical lithic variations.

Fig. 2. Map showing Gum Log quarry 10 miles NE of Russellville, AR with highway 124 to the W and state road 326 to the S as shown from Google Earth.
A major issue facing quarry operators today is the often rapid lithic transition within an area from high quality aggregate material to one of low quality aggregate material. Abrupt facies transitions can be very costly for a company, and if the operator is unable to locate better quality rock then the quarries existence may be in jeopardy. “Lateral changes in shale content through sedimentary facies are a concern in essentially the entire sedimentary rock terrain of Arkansas” (Kline 1999). To help account for this, quarries often send samples of rock to labs for analysis when moving to different locations of the mine. Members of the Arkansas Highway and Transportation Department (AHTD) also perform various tests on samples collected from the quarries to determine if the rock is compliant with state specifications. Some of these tests include the Los Angeles Abrasion as well as the sieve mechanical analysis tests which will be discussed in detail later in this study.

Determining facies relationships within a quarry allows an operator to forecast and better prepare for rapid lithic changes that may present problems. The intent of this study is to establish an understanding of the rock quality in the Gum Log quarry with respect to physical properties of the material, and deduce a correlation between rock quality and the stratigraphy of the rock within the quarry.
**Geologic History**

During the middle Pennsylvanian Period (approximately 320 million years ago) present day eastern Oklahoma and western Arkansas were inundated by a shallow marine seaway. This seaway was laterally extensive and bounded to the south by the Ouachita orogenic belt and to the north by the Ozark Dome, both primary sediment sources for the basin. It was during this time that the formations cropping out through the Russellville area were deposited in the Arkoma Basin (Perry Jr., 1995).

The Arkoma Basin Province includes portions of west-central Arkansas and southeastern Oklahoma and includes an area of about 33,800 square miles (Perry Jr., 1995). In Arkansas, the extent of the province is bounded to the north by the Ozark Uplift and south by the Ouachita Mountains (Figure 1). The Arkoma is one of a series of foreland basins that formed along the North American side of the Ouachita orogenic belt during the Carboniferous (Houseknecht, 1986). It lies due north of the Ouachita orogenic belt, to which the basin is related. Sediment feeding the Arkoma basin originated from three major dispersal systems: The Ozark Dome, the Illinois basin and eastern Arkansas, and also from the Ouachita orogenic belt. Based on the long, relatively narrow structure of the basin and paleocurrent data from Desmoinesian rocks, the sediments carried into the eastern part of the basin were transported west longitudinally to the sites of deposition (Houseknecht, 1986). It is in this way that sediments were carried into the tidally-influenced delta systems of the Arkoma during the Pennsylvanian, leading to the deposition of the Atokan sandstone mined in Gum Log quarry.
Arkansas River Valley Stratigraphy- Russellville Area

The stratigraphy of the Arkansas River Valley near Russellville consists of three prominent lithologic units: The Atoka, Hartshorne, and McAlester Formations from oldest to youngest (Figure 3). The Atoka Formation is essentially marine shale grading upward via increasing number and thickness of sandstone beds into sand dominated tidal flats, displaying a rich and diverse shallow marine trace fossil assemblage; although deltaic sandstone deposits similar to Desmoinesian systems can also be found in the Atoka, they are less common (Houseknecht, 1986). Houseknecht (1986) explains that the reason for this is in a prograding deltaic environment the distributary-channels destroy underlying prodeltaic and delta-front deposits. Above the Atoka lies the high-constructive, tidally influenced delta system sandstones of the Hartshorne Formation. Above the Hartshorne are the dark, iron rich, shale and sandstones of the McAlester Formation (Haley and Hendricks, 1968).

Atoka Formation

The Atokan Epoch (Pennsylvanian) Atoka is a thick formation in the Arkoma, reaching a maximum thickness of several thousand feet in the southern margin of the basin and is the oldest unit that crops out in the Gum Log quarry area. Due to its relatively great thickness and significant vertical facies changes the formation is usually sub-divided into three units: The Lower, Middle, and Upper Atoka. In addition to vertical facies changes through the Atoka there are significant lateral facies changes as well. Due to the thickness of the entire Atoka Formation, this study will focus solely on the Upper Atoka unit in the eastern and central Arkoma Basin. This is because the Upper Atoka is the only unit of the Formation to crop out within the Russellville area and Gum Log quarry.
**Fig. 3.** Stratigraphic Column of the Arkoma Basin during the Pennsylvanian Period. The 3 primary formations of interest are of the Atokan and Desmoinesian Epochs; Atoka, Hartshorne, and McAlester Formations (Mod. from Suneson, 2012).
The Atoka Formation is essentially marine shale grading upward via increasing number and thickness of sandstone beds into sand-dominated tidal flat facies (Chamberlain, 1978). The area of interest near Russellville is characterized by a large scale regression of the shallow seaway that once covered eastern Oklahoma and west-central Arkansas. The Upper Atoka is the transitional interval between the deeper marine deposits of the Middle-Lower Atoka and the shallower tidal and deltaic facies observed in the Russellville area. Houseknecht (1986) proposed two depositional models for the Upper Atoka in the Arkansas portion of the Arkoma Basin: Tidally dominated shoreline facies and a less common deltaic facies.

Houseknecht (1986) described tidally dominated shoreline facies of the Upper Atoka as being largely characterized by fining upward sequences, and containing subfacies of sand-flat, mixed-flat, and mud-flat systems. Houseknecht (1986) describes each subfacies as follows: The sand-flat facies are composed almost entirely of sand and display various physical features including cross-bedding, swash bedding, and locally abundant U-shaped burrow casts. The subfacies channel-shaped beds displaying siderite pebble lags and epsilon cross-bedding likely represent meandering tidal channels. These sand-flat subfacies usually grade into mixed-flat subfacies containing abundant shale and sandstone interbedding. Sandstones contained within this subfacies often exhibit ripple-scale cross-bedding, flaser bedding, and mud-draped, asymmetric ripples. As mud content increases within the unit, the mixed-flat subfacies rapidly grade upward into mud-flat subfacies. This subfacies type is composed mainly of silty mudstone. Fining upward sequences within the Upper Atoka in Arkansas are usually 150-300 feet thick compared to only 15-30 feet in the Oklahoma portion of the basin. Vertical stacking of consecutive tidal flat sequences can result in sand-rich shoreline deposits in excess of 30 feet thick (Houseknecht, 1986).
Deltaic facies of the Atoka Formation are not as common in the Arkoma as the previously mentioned tidally dominated shoreline facies, although Houseknecht (1986) explains that they are more abundant in Arkansas than Oklahoma. In this type of depositional system, marine shales grade upwards relatively quickly into sand-rich delta front subfacies. Houseknecht (1986) describes the sandstones as having abundant ripple-scale cross-bedding and mud drapes, but are locally only a few inches thick. Distributary mouth bars or tidal reworking of bar sediment during low tide are responsible for these occurrences (Houseknecht, 1986). Within deltaic facies of the Atoka, delta front subfacies are typically overlain by distributary channel deposits which contain significant trough cross-bedding and extensive lateral bedding. Houseknecht (1986) also noted that Atoka delta front deposits are almost identical to Desmoinesian deltaic deposits of the Arkoma. He stated that the reason deltaic facies of the Atoka Formation are rarer than overthickened tidal flat facies is due to tidal processes effectively reworking shoreline sediment and subsequently destroying facies characteristics usually associated with deltaic facies (Houseknecht, 1986). Since deltaic facies of the Upper Atoka are virtually identical to the deltaic facies of the Hartshorne Formation, it is inferred that they were created under similar circumstances and can therefore be subjected to a similar depositional model.

Hartshorne Formation

Stratigraphically upward from the Upper Atoka is the Hartshorne Formation. The Hartshorne Sandstone and associated fine grained facies of the Arkoma were deposited in a high-constructive, tidally-influenced delta system (Houseknecht et al. 1981). From west to east within the Arkoma Basin, the Hartshorne Formation exhibits varying facies and depositional environments. This may cause the Hartshorne facies in Oklahoma to differ from the facies in the
Arkansas portion of the basin. Also the Hartshorne Formation crops out only in central and eastern Arkansas, plunging to depth westerward through the Arkoma Basin. The Arkansas Geologic Survey has mapped Hartshorne sandstone at the surface as far south as Little Rock and as far west as Fort Smith in Arkansas. The Hartshorne Formation is a primary ridge forming unit of the Arkansas River Valley area.

The Hartshorne Sandstone marks the onset of Desmoinesian Epoch (Pennsylvanian) deposition in the Arkoma Basin (Houseknecht, 1981). Within the Russellville area the Hartshorne overlies the Upper Atoka and is usually separated by an abrupt transition from fissile shale to heavily cross-bedded, massive sandstone (Kline, 1999). Facies of the Hartshorne can vary widely throughout the Arkoma, as well as the Russellville area, and therefore must be discussed at length for this study. Houseknecht et al. 1981 interprets seven distinct deltaic subenvironments recognized within the Hartshorne Formation: Prodelta facies, delta-front facies, distributary-channel facies, interdistributary-bay facies, crevasse-splay facies, marsh-swamp facies, and fluvial facies.

Hartshorne prodelta facies contain laminar and fissile shales that are dark gray to black in color. Abundant plant debris, horizontal burrowing, and absence of animal fossils all characterize this lithologic unit. Prodelta facies of the Hartshorne are easily mistaken for the Upper Atoka Formation, therefore it is impossible to determine the base of prodelta deposits or determine their entire thickness (Houseknecht et al. 1981). Prodelta facies appear to be laterally extensive throughout the entire Arkoma Basin.

Delta-front facies usually display a coarsening upward sequence throughout the Hartshorne Formation. Houseknecht et al. 1981 described several subfacies recognizable within
this facies type including; distal bars, distributary-mouth-bars, and frontal splay deposits. Distal bar subfacies of the Hartshorne are rich in macerated plant debris, contain laminated siltstones that grade upwards into flaser siltstones and fine-grained sandstone deposits, usually 3-30 feet thick. Flute molds, load structures, and siderite pebbles are commonly found near the base of thinly bedded micaceous sandstones of this subfacies. Distributary-mouth-bars usually contain fine to medium-grained sandstones and grade vertically from related distal bar subfacies. Within this subfacies, asymmetrical ripple-bedded sandstones with clay drapes are very common and represent a potential reworking of the sediment by marine or fluvial currents. Frontal-splay subfacies comprise lenses of sandstones similar to a channel usually up to 12 feet thick and in erosive contact with mouth-bar or distal bar deposits across a delta front (Houseknecht et al. 1981). Related splay deposits are usually created during the flooding stages of distributary channels (Prothero and Schwab, 2013).

Hartshorne distributary-channel facies are characterized primarily by fine to coarse-grained, well sorted sandstones. These deposits exhibit channel geometry and are usually in erosive contact with a more distal member of the Hartshorne system (Houseknecht et al. 1981). Channel stacking is usually common in this type of depositional system, along with physical features like trough cross-bedding. Houseknecht et al. 1981 noted that channel abandonment is a common occurrence within this facies of the Hartshorne, and is often evidenced by the abrupt appearance of shale atop cross-bedded channel sand. It is noted that the occurrence does not have to be sudden and that gradual abandonment can result in Hartshorne channel sand grading into shale. Overall Hartshorne distributary-channel deposits range from 60-120 feet thick, are linear, and decrease in width in the eastern and western most portions of the basin (Houseknecht et al. 1981).
Hartshorne interdistributary-bay facies typically contain dark, silty shale, abundant bioturbation, plant debris, and animal fossils (Houseknecht et al. 1981). Lenticular, wavey, flaser, rippled, very fine-grained sandstones are usually associated with this type of environment. Houseknecht et al. 1981 noted that physical features attributed to overbank flooding, tidal currents, or wind generated waves are present in interdistributary-bays today and are therefore a good analog for past examples. There is evidence that Hartshorne tidal flats occurred stratigraphically between bay and distributary-channel deposits in addition to bay and swamp deposits, suggesting that the margins of interdistributary bays were bordered by tidal flats. Interdistributary-bay facies range in thickness from 0-150 feet and generally overlie delta-front facies and underlie marsh-swamp facies (Houseknecht et al. 1981).

Crevasse-splay facies within the Hartshorne are usually characterized by coarsening upward sequences with shale comprising the base, flaser bedded sandstone in the middle, and cross-bedded sandstones at the top (Houseknecht et al. 1981). Crevasse-splay deposits can occur singularly or stacked in a sequence of many. In addition, uppermost beds of crevasse-splay deposits are usually capped by swamp facies (Houseknecht et al. 1981). Splays are usually characterized by a coarsening upward sequence and are closely associated with distributary-channel deposits. If these facies are stacked they can reach thicknesses in excess of over 70 feet in the Hartshorne (Houseknecht et al. 1981).

Hartshorne marsh or swamp facies are characterized by the appearance of an abrupt coal seam which often includes rooted underclay associated with the sequence (Houseknecht et al. 1981). Coal seams appear to be high grade bituminous and often contain pristine fossilized remains of plant and tree matter. Coal seams vary from 0-6 feet within the Arkoma Basin and are usually associated with an altered underclay layer that is usually several inches thick and
bleached white in appearance. Marshes and swamps colonized upon interdistributary-bays and crevasse splays as water prograded across the delta plain (Houseknecht et al. 1981).

Hartshorne fluvial facies suggest deposition in meandering and perhaps braided fluvial channels within the eastern portion of the basin (Houseknecht et al. 1981). These units are characterized by fining upward sequences between 15-25 feet thick and typically overlie distributary-channel deposits (Houseknecht et al. 1981). Within this type of depositional system, stacked point-bars are very prominent, indicated by planer cross-bedding and abundant scouring of previous channel deposits (Prothero and Schwab, 2013).

**McAlester Formation**

Lying conformably on the Hartshorne Formation is the younger Desmoinesian series of shale and sandstones of the McAlester Formation. Broad stratigraphy of the McAlester includes several hundred feet of shale with at least two distinct coal seams. The Lower Hartshorne coal seam marks the contact between deltaic Hartshorne deposits and the near shore fluvial McAlester. The McAlester Formation is predominately dark-gray to grayish-black shale and contains minor amounts of medium-gray siltstone and light-to medium-gray very silty fine grained sandstone to light-gray very fine grained sandstone (Haley and Hendricks, 1968). In Arkansas, the McAlester typically contains more sand than in the Oklahoma portion of the Arkoma Basin. In the Russellville area it is typically present on select mountain tops of eroded synclines or near the Arkansas River where rock is eroded enough to have reached the Formation. The McAlester is neither competent nor extensive enough to operate a quarry in the Russellville area; therefore it is discussed for stratigraphic significance but not for quarry purposes.
Previous Works

At year’s end in 2007, there were 123 permitted sites that produced sand and gravel in Arkansas (Minerals Yearbook, 2008). Several stratigraphic studies have been conducted on rock in the Arkansas River Valley. Chuck Stelting and Will Schweller, former geologist with Chevron and current instructors with Nautilus, have analyzed the stratigraphy of Duffield Gravel’s New Hope location. New Hope is the sister quarry to Gum Log, located south of Russellville near the Arkansas River. The New Hope location has been in operation for over 30 years, and is believed to target the same sandstone mined in Gum Log. Stelting and Schweller (2013) describe the quarry as having five principle lithologic facies types: cross-bedded sandstone, ripple-laminated sandstone, wavy-laminated to wavy-bedded sandstone with shale drapes, fissile shale, and interbedded sandstone and shale (undifferentiated). They describe the facies tracts of New Hope as being a meanderbelt depositional system, including many of the environments typical of the Hartshorne Formation similar to those described by Houseknecht et al. 1981.

Another location described by Stelting and Schweller (2013) is the Midway Quarry located 24 miles northwest of the New Hope quarry in Russellville, Arkansas. The Midway Quarry is slightly smaller than Duffield’s Gum Log location, but is mined to a depth of 100 feet in certain areas. Stelting and Schweller (2013) describe the quarry as being a braided fluvial deposit from the early Desmoinesian. They divide the quarry into three distinct lithologic facies: the lowest is a thickly bedded, fine-grained, chaotic-massive sandstone with locally abundant conglomerates; the middle unit is thick bedded, fine-grained sandstone with tabular bedsets; the upper facies consists of interbedded sandstone and interlaminated mudstones (Stelting and Schweller, 2013).
Not all rock quarries in the Arkansas River Valley lie in the Hartshorne Formation; the Atoka Formation contains more quarries than any other single unit in the state of Arkansas (Kline, 1999). Kline (1999) compiled LA Abrasion results from different quarries in the River Valley and determined that frequently, values less than 20% are observed in the sandstone portions of the formation. The average percentage is shifted downward slightly by two longstanding quarries that contain some fine-grained sandstone as compared to other quarries in the Atoka. This finer-grained sandstone is stratigraphically similar to facies described by Houseknecht et al. 1981 in the Hartshorne Formation. The Hartshorne is the best producer of aggregate material in the River Valley, especially when it is finer-grained sandstone as opposed to coarse-grained stone. It is likely that the finer-grained material was better cemented originally, and therefore is less susceptible to weathering. In cases where Atokan sandstones have poorer LA Abrasion values, research indicates that too much weathered rock was introduced into the test samples. Accidental mixing of poorer quality aggregate material in with higher quality materials can cause LA Abrasion test results to be negatively impacted (Kline, 1999).

Rodgers Quarry is located 15 miles north of Morrilton, Arkansas in the Atoka Formation. The quarry was described stratigraphically in 2002 by Christine M. Wright, a then master’s candidate at Louisiana State University. Wright (2002) described the quarry walls being near 40 feet and composed of gray, quartz-rich sandstone with slight orange-tan discoloration (iron staining) on weathered surfaces. In addition, continuous horizontal bedding is observed in the quarry, along with ripple cross-lamination, load casts, and iron-oxide concretions throughout the shot rock in the quarry. The rock in Rodgers Quarry is interpreted to be sandstone deposited in a tidally influenced, deltaic depositional system (Wright, 2002).
Wright (2002) described several road cuts south of Morrilton along highway 9 towards Perry, Arkansas. Each road cut is exposed at the crest of an anticline and separated by valleys of nearly 1000 feet of shale (Kehler, 1988). The road cuts mainly exhibit alterations between fine-grained sandstone and thinly bedded siltstones with flaser sandstone interbeds (Wright, 2002). The thickest road cut, which Wright refers to as “Mor C,” is characterized by four identifiable units. At this location, over 60 feet of black shale and siltstone grade vertically into alternating silty sandstone layers approximately 20 feet thick (Wright, 2002). This unit grades into a 30 feet thick sandstone interval that becomes devoid of interbedded shale and siltstone upsection. This sandstone grades vertically into nearly 30 feet of interbedded black siltstone and shale, becoming more shale-rich upsection (Wright, 2002). This road cut lies in the Upper Atoka Formation, mapped by Boyd Haley of the USGS (Kehler, 1988). It is believed to be an uncommon deltaic facies of the Atoka Formation, with sandstone and siltstones that closely resemble the different lithologic units in the Gum Log quarry (Kehler, 1988).
Methods

*Gum Log Quarry Stratigraphic Analysis*

With a better understanding of the regional stratigraphy in the Arkansas River Valley area near Russellville this study will now outline the detailed stratigraphy of the Gum Log quarry itself. First, the formation where the quarry is located was determined (Figure 4). Following this the quarry was partitioned into four different sections based solely on geographic location and visual similarity of facies (Figure 5). These four sections were then classified according to differing vertical and lateral facies relationships within the quarry. The facies in each section were inspected visually and described, including a depositional interpretation for each facies.

Gum Log quarry is mined in a relatively thick sandstone unit that is underlain by dark, fissile shale and overlain by dark, silty shale. The area was mapped by the United States Geological Survey (Haley, 1962) as the Atoka Formation (Figure 4). The sandstone itself is cross-bedded throughout most of the quarry with rock layers striking almost entirely east/west and dipping about 15 degrees south. A more complete lithologic profile is exposed moving east in the quarry where five different facies were differentiated. Here the thick sandstone gradually grades vertically into dark, silty shale. The shale in Gum Log quarry does not resemble the shale of the McAlester Formation, nor is the Hartshorne Coal seam present at this contact. Furthermore sandstone beds are laterally continuous throughout the quarry, displaying little to no channel reworking like that expected in Hartshorne channel deposits. Therefore, it is determined that the Gum Log quarry lies within an uncommon deltaic section of the Upper Atoka Formation that very closely resembles the deltaic facies of the younger Hartshorne Formation. Due to the similarity between the facies of the two units, the deltaic model used by Houseknecht et. al
(1981) to describe the Hartshorne Formation will be used when describing the Atokan facies of the Gum Log quarry.

Section Locations-Gum Log Quarry

The different sections dividing Gum Log quarry are shown in Figure 5. Section 1 represents the western and northwestern portions of the quarry along with the area where the crushing of stone occurs today. Section 2 represents the northern high-wall, northeastern, and eastern portion of the quarry. Section 3 represents the central and east-central portions of the quarry. Section 4 represents the southern and southeastern extent of the quarry. It is important to remember that the Gum Log location is an active quarry, meaning that many of the stone surfaces and facies examples present one day could be excavated and no longer be present the next. This creates a unique level of difficulty when trying to document and classify the different stratigraphic units of the quarry.
Fig. 4. Russellville East 7.5 Minute Quadrangle showing the location of the Gum Log quarry with a star in the Atoka Formation (Pa) mapped by Boyd Haley. Hartshorne (Ph) McAlester (Pm) (Mod. from Haley Geologic Worksheets-Russellville East 7.5 Minute Quadrangle, 1962).
Fig. 5. Aerial map of Gum Log quarry north of Russellville, AR. Map depicts the 4 different geographic sections used for analysis. Section 1, 2, 3 and 4 (Shown by Google Earth, 2015).
Gum Log Quarry-Section 1

Section 1 of Gum Log quarry contains the western most high-wall as well as the northwestern extent of the mine itself (Figure 5). It also contains the area of the quarry where the crushing, sorting, and processing of stone for aggregate material occurs, known as the “crusher area.” The crusher area was once covered by nearly 30 feet of sandstone which was removed and processed several years ago. In Section 1, the visual appearances of the facies do not exhibit significant variation laterally or vertically making them ideal for categorization as a similar facies. The main focus in this section will be on facies of the western and northwestern quarry walls because they exhibit a complete Atokan sandstone interval. In addition, this area of the quarry has not been mined in over seven years (W. Langford, personal communication, January 2015).

Visual Description-Section 1

Section 1 of Gum Log contains several high sandstone walls in the western portion of the quarry. About 15 feet of wall is visible in southern portions of Section 1, rising to nearly 100 feet of exposure to the north in the section. Iron rich water percolating through rock walls has caused a distinct orange coloration, along with various other forms of staining. The walls of Section 1 are noticeably weathered. Freeze-thaw along with other erosional processes have wedged apart rock atop the walls, causing them to become unstable and fracture. The walls are also visually similar both vertically and laterally, exhibiting very little physical property changes throughout the entirety of Section 1. This location is heavily vegetated because Duffield Gravel has not mined this area for several years. The vegetation can cause obstruction issues when viewing the base of some of the stratigraphic intervals within Section 1. In addition the water
table works to further obscure the base of these stratigraphic intervals. This prevents the contact between the deeper shale and the target sandstone from being observed in this section of the quarry. However, due to the observed lateral similarities throughout the entire section, it is inferred that the parts of the section visible closely represent the parts of the section obscured by vegetation or water.

Facies Description-Section 1

Section 1 is composed entirely of one primary lithologic facies and exhibits little to no lateral variation throughout the unit (Figure 6). Nearly 80 feet of sandstone wall is visible in this section, with subtle differences in bedding and varying concentrations of cross-beds accounting for most of the vertical variation in the rock. Thin interbedded shale layers are observed throughout the entire facies, becoming increasingly prevalent vertically downward and west. The base of the unit is composed of fine-to-medium grained, massive sandstone with foreset cross-bedding indicating a southerly paleocurrent direction (Figure 7). Bedding in the lower portions of Section 1 is planer with thin 2-4 inch clay drapes defining bedding surfaces throughout the unit. Upward the sandstone becomes less planer and the amount of cross-bedding increases (Figure 8). Tabular cross-bed sets are noted inclining north/south in the section, indicating a paleocurrent flow direction to the south. Several bedding planes span the entire length of the section without pinching out or being truncated by other beds (Figure 6). The upper most portion of the sandstone wall in Section 1 transitions from planer to very tabular bedded with asymmetrical ripple marks defining bedding surfaces (Figure 9). Cross-bedding is not as prevalent in the upper portion of the section but ripple marks are very pronounced as shown in Figure 10. Bands of purple iron staining as well as occasional iron-oxide concretions are found in the sandstone throughout this entire section (Figure 11). Atop the sandstone wall is 2-3 feet of
orange, limonitic, heavily weathered sandy material.

**Fig. 6.** Display of the western most wall of Section 1. Notice the homogeneity of the sandstone both vertically and laterally as well as the continuous shale bedding throughout the section (Photo by Cecelia Hampton, 2014).

**Fig. 7.** Shows a 6 feet thick vertical section of the western wall in Section 1. Some small scale foreset cross-bedding is present within the massive, planer bedded sandstone at the base of the section (Photo by Cecelia Hampton, 2014).
Fig. 8. Shows a 25 foot thick dip direction viewing of tabular cross-bed sets in the western wall of Section 1. Notice the vertical transition from planer bedding to tabular bedding in the walls of the section (Photo by Cecelia Hampton, 2014).

Fig. 9. Shows strike direction viewing of 60 foot high northern wall of Section 1. Notice the lateral continuity of the rock across the section and the transition from planer, cross-bedding sandstone vertically into tabular, ripple bedded sandstone (Photo by Cecelia Hampton, 2014).
Fig. 10. Asymmetrical ripple marks in the tabular, upper portion of walls in Section 1 (Photo by Author, 2014).

Fig. 11. Large iron-oxide concretion shown in blast rock from walls of Sec. 1. Rock is not stratigraphically in place, but is good representation of observed iron concretions in Section 1 and throughout the quarry (Photo by Author, 2015).
Depositional Environment—Section 1

By applying Houseknecht’s (1981) deltaic depositional model for the Hartshorne to the deltaic sands of the Atoka, inferences are deduced about the depositional environment for each facies type in the quarry. Section 1 of Gum Log quarry contains one main lithologic facies; a thick sandstone unit with little variation vertically and little to no variation horizontally. When considering the sands in Section 1 the transition from massively bedded sandstone with small foreset bedding sets, to planner-tabular cross-bedded sandstones, and finally to tabular-ripple bedded sandstone is critical in determining the paleoenvironment. Distributary-mouth-bar deposits have several of the characteristics noted in Section 1. The vertical transitions observed in Gum Log quarry fit the ideal deltaic model for a distributary-mouth-bar deposit prograding out onto prodeltaic shale (Figure 12). The deeper sands stack seaward below the influence of currents or wave action creating the foreset cross-bedding present at the base of the wall in Section 1. Above this as sands prograde seaward, the bar thickens and comes into contact with the currents and wave base of the delta front. This sand becomes cross-bedded, aligning in the paleocurrent direction, forming tabular cross-bed sets like those observed in the wall of Section 1. Eventually the bar sand thickens enough that the top becomes influenced by deltaic distributary-channels, forming sands characterized by asymmetrical ripples marks. Sands in this portion of the bar are reworked by currents and wave action, eliminating the planer bedding associated with deeper portions of the bar. Temporary deepening events in the delta are responsible for the interbedded mud layers observed throughout the section. A mouth-bar typically exhibits lateral continuity of facies, similar to the facies observed in Gum Log quarry. This suggests the sandstone facies in Section 1 of Gum Log quarry was created in a delta-front, distributary-mouth-bar environment.
Fig. 12. Deltaic depositional model depicts the environment responsible for creating the differing facies observed in Gum Log quarry (Mod. from Houseknecht et al. 1981).
Gum Log Quarry—Section 2

Section 2 of Gum Log contains the northern, north-central, and northeastern most portions of the quarry (Figure 5). The northern wall is one of the highest in the quarry, reaching 120 feet in some areas. The north-central wall has not been blasted as deeply and is around 80 feet tall at its highest point. Portions of Section 2 display a nearly complete interval of Atoka sandstone, as well as the contact with underlying shale deposits. It is at this boundary that fossilized plant and tree remains can be located. The northeastern extent of the mine is also contained in Section 2 and remains the most active area of the mine in terms of blasting and excavation. Portions of the northeastern wall may reach as high as 100 feet, but depending on excavation, some portions of the wall may be obscured from observation by piles of blasted rock material.

Visual Description—Section 2

Section 2 encompasses a large geographic region of the quarry. Upon observation, it becomes evident that there are few physical variations from west to east throughout the section, however some differences are noted. East through Section 2 reveals a change in color on the walls of the quarry. Orange, iron staining gives way to lighter, gray colored facies before transitioning to bluish-gray in the far eastern portions of Section 2. The level of weathering from west to east decreases in this section. Rock facies in the western portions of the section appear much like those of Section 1, before transition into more competent facies to the east. Moving vertically upward in Section 2 reveals some visual differences in the walls that are not observed in the previous section.
Several different lithofacies are present in Sections 2 that are not observed, at least at the surface, within the other sections of the quarry. However, one common problem when observing Section 2 of Gum Log quarry is that the base is often obscured by piles of quarry rock and remnants of the last blasting secession. To fully observe the section, a special effort was made by the quarry operator to remove excess piles of rock from the base of the section, allowing for a complete viewing of the target interval in Section 2.

Facies Description—Section 2

Section 2 of Gum Log quarry contains three distinctly different lithologic facies in vertical array through the section. At the base of the section lying just below the quarry floor is the light-gray to black, fissile shale of the Atoka Formation (Figure 13). Shale in this facies does not exhibit bioturbation or identifiable faunal remains. The shale is characterized by heavy iron staining as well as occasional thinly bedded iron stone deposits (Figure 14). Section 2 is the only location in the quarry where this shale unit can be observed and forms the lowest lithologic facies identifiable in Gum Log quarry. The shale facies is found at the base of the western and eastern portions of the section, but plunges to depth to the south in the quarry.

Upward from the dark, fissile Atoka shale is the second lithologic facies present in Section 2 of Gum Log quarry. The facies is only a few feet thick but it is one of the most unique and identifiable units in the quarry. The rock is extremely coarse-grained, chaotic-bedded, poorly-sorted sandstone with interbedded silty shale layers (Figure 15). Bedding planes can be deduced in this facies, but any form of bioturbation is presumed to be destroyed. The rock is heavily stained yellow-orange from limonite deposition at the base of the facies unit near the Atoka shale contact (Figure 16). Above this, the rock changes rather abruptly to grayish-white,
coarse-grained, well-sorted sandstone with abundant macerated plant debris and coal laminae (Figure 17). Large casts of trees as well as smaller ones have been removed from this facies of Section 2. The detail is preserved well enough in the plant remains that the lineation between wood fibers can be observed in the rock (Figure 18). No faunal remains are observed in this facies of the quarry.

Section 2 displays some subtle differences compared to Section 1 when moving farther east in the quarry. In the northeastern portion of the mine, Section 2 is characterized by dark, fissile shale grading upwards into coarse-grained sandstone with plant debris and then into 100 feet of sandstone. This is identical to the western part of the section; however the thick sandstone unit is slightly different in this portion of the quarry. The base of the sandstone facies now exhibits larger foreset cross-bedding (Figure 19). This foreset bedded unit spans the entire bottom third of the wall before being truncated vertically by a three feet thick channelloid deposit preserved in the eastern wall of Section 2 (Figure 20). Above the channelloid deposit the sandstone is planar bedded and continuous before transitioning vertically into the tabular, ripple-bedded sandstones like those in the upper portion of Section 1 (Figure 21). Essentially the stratigraphy of Section 1 and 2 are very similar within the thick sand unit, however the depositional features are more pronounced in the eastern portions of the quarry. In addition, there are fewer interbedded shale layers in this facies moving east through the section.
Fig. 13. Dark, fissile shale located at the base of Section 2. This Atoka shale facies represents the lowest stratigraphic unit viewable in Gum Log quarry (Photo by Author, 2015).

Fig. 14. Small banded iron concretion about the size of a quarter located in the fissile shale facies of Section 2 (Photo by Author, 2015).
Fig. 15. Piece of coarse-grained, chaotic bedded sandstone from the second facies described in Section 2. This facies is gradational with the dark Atoka shale below and the thick Atokan deltaic sand facies above in the quarry (Photo by Author, 2015).

Fig. 16. Limonitic staining in the coarse-grained chaotic bedded sandstone above the Atokan shale contact. Notice the thin, innerbedded silty shale layering in this facies (Photo by Author, 2015).
Fig. 17. Grayish-white, coarse-grained, well-sorted sandstone with macerated plant debris and coal laminae. Located in Section 2 above limonitic stained sandstones near the Atoka shale contact (Photo by Author, 2015).

Fig. 18. Detailed remains of plant material in gray sandstone of Section 2 (Photo by Author, 2015).
Fig. 19. Thick foreset cross-bedding at the base of eastern wall in Section 2. Cross-beds terminate into innerbedded shale layers throughout the bottom third of the wall (Photo by Author, 2015).

Fig. 20. Channelloid body (shown with arrow) appearing about 15 feet up eastern wall in Section 2. Notice how the channel body cuts off the lower foreset bedded sandstone and bedding changes above channelloid body. The top of the channel is capped by an 8in clay plug (Photo by Author, 2015).
Fig. 21. Shows the entire 80 feet tall eastern wall of Section 2. Facies appear less weathered and more detailed than western portion of Section 2 or sandstones of Section 1. Notice the vertical transition from foreset bedded sandstone, to planer bedded sandstone, to tabular ripple-bedded sandstones similar to the succession in Section 1 (Photo by Author, 2015).

Depositional Environment-Section 2

Section 2 of Gum Log quarry contains three distinctly different lithologic facies. The bottom most facies is the dark, fissile Atoka shale. The shale grades upwards into a coarse-grained, chaotic bedded, iron rich sandstone with plant debris. This layer is only a few feet thick before grading upwards into relatively thick, (~100 feet) cross-bedded sandstone section observed throughout the quarry. A prograding deltaic model is applied to the three facies present in Section 2 (Figure 12).
The dark, fissile shale observed in Section 2 is indicative of a shallow marine, prodeltaic deposit in the Arkoma Basin seaway. It is impossible to determine the thickness of the shale facies in the Gum Log quarry, but enough is exposed to observe the shale grading vertically into the coarse-grained, chaotic bedded, poorly-sorted sandstone with interbedded silty shale observed as the second facies in Section 2. The abrupt transition between dark, marine shale and coarse, poorly-sorted sandstone implies that sedimentation rates rapidly increased atop the previously quiet shallow marine deposits. Therefore the contact between the two facies represents the transition between shallow marine predeltaic and prodeltaic deposition. Prodeltaic facies in the deltaic depositional model are characterized by dark gray to black, laminated shales and silty shales grading into fine-grained sandstones. However, it is inferred that the sedimentation rates changed rapidly enough that coarse-grained material could have blanketed what was previously shallow marine deposits. This could occur in response to two large distributary-channels merging, significantly increasing the sediment load deposited into the prodelta area and potentially adding sediment to areas that were previously starved. In Section 2 of the quarry, this facies quickly transitions vertically into grayish-white, coarse-grained, well sorted sandstone with plant debris and coal laminae. This represents the transition from a prodeltaic setting to a shallower, delta-front environment (Figure 12). The sandstone in this facies is characteristic of a distal bar deposit. Houseknecht (1981) described the distal bar deposits as gradational with underlying prodelta shale, silty shale, and sandstones. Distal bars are characterized by macerated plant debris, coal laminae, and high sediment influx; all of which are observed in the second facies of Section 2. Vertically above the distal bar facies reveals thick, 100 feet cross-bedded distributary-mouth-bar facies described previously in Depositional Environment-Section 1. This sandstone package is inferred to be the same lithologic unit as the
sandstone facies of Section 1. The channellloid unit found within this mouth-bar facies in the eastern wall of the section is a frontal splay deposit (Figure 20). Frontal splay deposits, like the one depicted in Figure 12, are channellloid lenses of sandstone up to 12 feet thick and in erosive contact with distributary-mouth-bar deposits (Houseknecht et al. 1981). This feature located in the cross-bedded sandstone facies of Section 2 further illustrates the prograding deltaic system observed in Gum Log quarry. Shallow marine shale grades vertically into prodeltaic sandstones and shale, before transitioning into the delta-front facies associated with distal bar and distributary-mouth-bar deposits. Delta-front deposits are sometimes influenced by storm surge channels or distributary-channel environments, creating features similar to the channellloid body located in Section 2 of Gum Log quarry. Moving east in the quarry, this facies represents the proximal equivalent of the more distal facies described in Section 1.
**Gum Log Quarry-Section 3**

Section 3 of Gum Log quarry contains the central pit as well as the east-central wall of the mine (Figure 5). The walls of the central pit are shorter than many of the other sections in the quarry approaching only 30 feet in height. However, approximately 30 feet of rock was removed from atop the walls of the central pit during the initial expansion of the Gum Log quarry, and is therefore unable to be observed. The walls of the east-central portion of Section 3 are much taller, approaching 60 feet in some areas. This area constitutes a relatively active portion of the quarry and therefore vegetation and quarry rock piles are often not an issue when observing the sections walls.

**Visual Description-Section 3**

Section 3 displays some of the same trends that were noted in previous sections. While moving west to east throughout the section the rock transitions from orange and iron stained to bluish-gray in color. In addition to a change in color, the rock also appears more weathered in western portions of Section 3 than it does in the east. This section differentiates itself from the other sections by housing a lithofacies transition in the dip-direction as well as the strike-direction of the quarry. This is the first section of the quarry described where there is an obvious lateral facies transition within the rock. In the southern portion of Section 3 there are significant vertical lithofacies changes that are noticed in addition to lateral transitions mentioned previously. In this portion of the quarry, water often obscures the base of the formation, preventing the observation of a complete vertical profile in the section.
Facies Description-Section 3

Section 3 of Gum Log quarry contains two distinctly different lithologic facies vertically throughout the section. Section 3 is also the only location in the quarry where lateral (strike-direction) facies variation is observed (Figure 22). The lowest unit visible in Section 3 is the cross-bedded, relatively thick sandstone described previously in Section 1 and Section 2. In Section 3 the sandstone appears identical to the facies described in Section 2, and is inferred to be the same lithologic unit. For a complete description of this facies refer to Facies Description-Section 2.

Upward in Section 3 reveals a gradational change from tabular, ripple-bedded sandstone to interbedded sandstone and fissile, black siltstone (Figure 23). The sandstone in this transition zone exhibits ripple-scale cross-bedding, flaser bedding, and asymmetric ripple marks (Figure 24). South in the dip-direction of the quarry the siltstone becomes increasingly thicker, transitioning into a section of siltstone over 30 feet thick and containing thin, lenticular sandstones (Figure 25). This unit is the second facies observed in Section 3 of the quarry. It is characterized by thinly bedded, fissile, black siltstone with abundant horizontal burrows (Figure 25A), load casts (Figure 25B), and thin lenticular sandstones. In the southern wall of Section 3, a lenticular sandstone body appears to be in erosive contact with the underlying siltstone and pinches out in the strike-direction of the quarry (Figure 26). The sandstone is only a few feet thick and characterized by tabular bedding with slight internal cross-bedding. Aside from heavy bioturbation, no faunal or plant remains are located within the siltstone facies of Section 3.
Fig. 22. Illustrates vertical and lateral facies transition (shown with arrow) in eastern wall of Section 3 between tabular-ripple bedded sandstone, innerbedded sandstone and siltstone, and fissile siltstone. Notice how the siltstone facies thickens to the south in the dip-direction (Photo by Cecelia Hampton, 2014).

Fig. 23. Illustrates gradational change vertically from tabular, ripple-bedded sandstone to interbedded sandstone and fissile, black siltstone in eastern wall of Section 3 (Photo by Author, 2015).
Fig. 24. Shows ripple scale cross-bedding and flaser bedding in the interbedded sandstone and siltstone facies of Section 3 (Photo by Author, 2015).

Fig. 25. Southern wall of Section 3 showing around 30ft of dark, fissile siltstone with interbedded lenticular sandstones present. Notice the gradational contact between the tabular ripple-bedded sandstone facies and the siltstone facies near the base of the wall (Photo by Cecelia Hampton, 2014).
Fig. 25A. Horizontal burrows present throughout the entire siltstone facies of Section 3 (Photo by Author, 2015).

Fig. 25B. Load casts present throughout the siltstone facies of Section 3 (Photo by Author, 2015).
Section 3 of Gum Log quarry contains two different lithologic facies: The lower facies is the distributary-mouth-bar sandstone described previously in Sections 1 and 2. For a complete description of the depositional environment of the distributary-mouth-bar facies see Depositional Environment-Section 1 of this study. The facies above that is a dark, fissile siltstone unit with interbedded flaser and lenticular sandstones. The deltaic depositional model is applied to the siltstone facies of Section 3 to determine the environment of deposition (Figure 12). Interdistributary-bay facies comprise dark gray to black silty shale which contain abundant horizontal burrows (Houseknecht et al. 1981). Tidal flat deposits within an interdistributary-bay
typically comprise ripple and flaser-bedded sandstones overlain by rhythmically alternating layers of sandstone and dark siltstones (Houseknecht et al. 1981). In Section 3 of Gum Log quarry a gradual transition between a distributary-mouth-bar and an interdistributary-bay, tidal flat environment is observed (Figure 12). Sand from the distributary-mouth-bar fines upward into rhythmic alterations of sand and mud as the distributary-channel previously feeding the delta-front is abandoned or altered. During this time, tidal process begin to influence deposition. Currents between tidal cycles separate the muddy from the sandy fraction, forming flaser and lenticular bedding in the sediments (Prothero and Schwab, 2013). Flaser bedding is more prevalent in areas with higher sand content but as the abundance of mud increases, wavy and eventually lenticular bedded sediments result (Prothero and Schwab, 2013). Eventually the tidal flat becomes mud dominated with little sediment influx, forming the siltstone package observed in Section 3 of Gum Log quarry. Lenticular sand deposits like those observed in Figure 26 are common occurrences in tidal flat environments. Channelloid sand bodies are created in tidal flats through processes like storm surge, tidal creek channels, or crevasse-splay deposits (Figure 12). Houseknecht (1981) describes crevasse-splay deposits as appearing gradationally with underlying interdistributary-bay shale or siltstone and characterized by lenticular to flaser bedded appearance. He also mentions how splay deposits grade laterally into interdistributary-bay facies.
**Gum Log Quarry-Section 4**

Section 4 contains the southern and southeastern extent of the mining area in Gum Log quarry (Figure 5). The walls within the southern section of the quarry are only visible for about 15 feet before encountering the water table and plunging south to depth. The northern extent of the section contains rock walls around 40 feet high. The southeastern portion is similar in terms of height and distribution to the southern portion, displaying over 40 feet of section before plunging to depth moving south in the section. Section 4 constitutes the smallest geographic division of the Gum Log quarry.

**Visual Description-Section 4**

Section 4 contains rocks that are dark gray to black in color, transitioning to bluish-gray and almost white south through the section. There is very little variation in color laterally in this section. The walls do not appear to be heavily weathered or stained unlike several of the sections previously mentioned. The rock face in the southern most portion of Section 4 reflects a considerable amount of light, enough that the entire unit appears to sparkle during the day. This is a visual feature unlike any other in the quarry. This section also contains the most easily distinguishable lithofacies of the quarry with often abrupt boundaries separating the different rock types. Moving south in the section there is a significant increase in overburden material atop the target sandstone. The material is orange with iron staining coloration, similar to the weathered facies of Sections 1 and 2, and appears to be unconsolidated.
Section 4 of Gum Log quarry contains two different lithologic facies. The lowest facies observable in Section 4 is the dark, fissile siltstone and flaser bedded sandstones discussed previously. For a full description of this facies refer to *Facies Description-Section 3*. The uppermost facies in Section 4 is the youngest stratigraphic interval present in Gum Log quarry. The contact between the two facies is characterized by a coarsening upward sequence from dark, fissile siltstone into interbedded siltstone and tabular sandstones (Figure 27). The transition is relatively abrupt compared to gradational changes between facies in other sections of the quarry. A 15 feet thick wall displaying heavily cross-bedded, tabular, medium-grained, well sorted sandstone is visible in the southern wall of Section 4 (Figure 28). The sandstone displays thick trough and tabular cross-bedding at the base of the wall (Figure 29) and transitions to massive-bedded sandstone moving vertically through the section. Cross-bedding indicates a paleocurrent flow direction to the east in this facies, differing from other cross-beds in the quarry which indicate a southerly flow. At the top of the sandstone there is a 1-2 feet thick, clay plug capping off the facies (Figure 30). The plug is fissile, dark, silty shale and appears abruptly above the sandstone facies of Section 4. Heavily weathered, yellow-orange limonitic material, or overburden, thickens in this part of the quarry and continues to thicken in the dip-direction moving south (Figure 31).
**Fig. 27.** Illustrates the transition between the dark, siltstone facies and the tabular sandstone facies (shown with arrow) in the western wall of Section 4 (Photo by Cecelia Hampton, 2014).

**Fig. 28.** Shows the 15 feet high southern wall of Section 4. The base of the wall is heavily trough cross-bedded before transitioning upward into more massive-bedded sandstone (Photo by Cecelia Hampton, 2014).
**Fig. 29.** Trough cross-bedding (shown with arrow) at the base of sandstone facies in Section 4 (Photo by Cecelia Hampton, 2014).

**Fig. 30.** Shows clay plug at the top of the sandstone facies in Section 4 (shown with arrow). Also displays tabular cross-bedding at the base of the wall (Photo by Cecelia Hampton, 2014).
Fig. 31. Shows the heavily weathered, yellow-orange limonitic material removed in the quarry as overburden. The material is about 6 feet thick in Section 4 and continues to thicken south in the dip-direction throughout the quarry (Photo by Cecelia Hampton, 2014).

Depositional Environment-Section 4

Section 4 of Gum Log quarry contains two different lithologic facies: The lower of the two is the dark, siltstone facies that is interpreted to have been deposited in an interdistributary-bay tidal flat environment. For a complete description of the environment of this facies refer to Depositional Environment-Section 3 of this study. The second is cross-bedded, medium grained, well-sorted sandstone that represents the youngest stratigraphic interval present in Gum Log quarry. By applying the deltaic depositional model to this facies, a distributary-channel environment is interpreted to have been present during the deposition of the sands in Section 4 (Figure 12). The sandstone in this facies contains abundant trough-cross bedding as well as some tabular cross-bed sets. Many of the cross-beds sets in this section are truncated by others, indicative of multiple episodes of erosion within a braided channel system. Distributary-channel
deposits are usually truncated by younger channel deposits, predominantly trough cross-bedded with tabular and horizontal bedding occurring less frequently, and a decrease in cross-bed thickness upsection (Houseknecht et al. 1981). Sediment deposition in this area of the delta was drastically reduced during the creation of the tidal flat environment described in Section 3 (Figure 12). During this time mud accumulated along the tidal flat until sediment deposition resumed. This could have occurred through the merger and creation of new channels near shore, causing a shift in sediment deposition back onto the tidal flat. The mud on the tidal flat was quickly covered with channelized sand. As the sand began to accumulate, channel erosion destroyed many of the underlying facies characteristics, causing planer and cross-bedded sands to become more massive vertically. This created a profile of tidal flat mud transitioning into cross-bedded sands at the base of the unit, grading vertically into massive-bedded sands. Houseknecht et al. (1981) also mentioned that beds of shale or silty shale abruptly appear above the cross-bedded sandstone facies. Avulsion occurs when a segment of a channel is abruptly abandoned (Prothero and Schwab, 2013). This leads to the channel being filled in with fine grained material, creating a clay plug layer like the one observed above channel deposits in Section 4 (Figure 30).
Discussion and Results

Gum Log Stratigraphic Column and Cross-Section

A stratigraphic column (Figure 32) and cross-section (Figure 33) were constructed to display the five different lithologic intervals observed in Gum Log quarry. The stratigraphic column allows for quick reference to the different facies in the quarry and is used in this study to illustrate which lithologic unit is being tested for aggregate potential. The cross-section provides a dip-direction perspective of the five lithologic units in Gum Log quarry, in addition to demonstrating the current mining surface of the quarry.

Facies 1 is dark, fissile marine shale representing the oldest lithologic unit in the quarry. Facies 2 is chaotic bedded, poorly-sorted, gray distal-bar sandstone with plant debris. Facies 3 is relatively thick, cross-bedded, well-sorted, ripple-marked distributary-mouth-bar sandstone. Due to the thickness of this facies, it is divided into a lower, middle, and upper portion so that the aggregate potential can be more accurately described. Facies 4 is dark, fissile, bioturbated, interdistributary bay siltstone with interbedded flaser sandstones. Facies 5 is highly cross-bedded, well-sorted distributary-channel sandstone representing the youngest lithologic unit in Gum Log quarry. Overburden is illustrated in the figures for reference purposes.
**Fig. 32.** Stratigraphic column representing the five different lithologic facies present in Gum Log quarry. Facies 3 separated into Upper, Middle, and Lower based on changing LA abrasion percentage results (Figure by Author, 2015).
Fig. 33. Provides a dip-direction profile of the Gum Log quarry. The mine spans over 1100 feet in this direction and is over 120 feet deep at certain locations in Section 2. The dashed line represents a gradational change between facies. Vertical Scale (1 in:25 ft) Horizontal Scale (1 in:125 ft) Dips of facies become exaggerated at depth. (Figure by Cecelia Hampton and Author, 2015)
Testing for Aggregate Potential

For construction applications, stone used in aggregates must be sufficiently durable to meet the rigors placed on the aggregate by its intended use (Kline, 1999). There are several techniques used today to test the suitability of stone. The Arkansas State Highway and Transportation Department (AHTD) frequently uses the LA abrasion method in order to determine the suitability of rock for aggregate material. The LA abrasion test is designed to measure an aggregate’s resistance to degradation by abrasion and impact (Marek, 1991). The test is useful in determining how the aggregate material will behave when exposed to the compacting, mixing, and heavy machinery indicative of a construction environment. The test involves placing a sample of crushed stone with a prescribed grading in a drum with steel balls and rotating the drum for a prescribed time period (Kline, 1999). The Materials Division at AHTD specifies that the drum is usually loaded with 5000 grams of a sample, 11 steel balls, and rotated between 30-33 revolutions per minute. The sample is dried in an oven for several hours before testing and is washed and dried again when testing is complete. Stone that is more durable degrades less during the test. Analyzing the amount of material passing a prescribed sieve at the end of the trial reveals a percent loss as a result of degradation (Kline, 1999). A lower percent loss indicates a superior aggregate material. The acceptable limit allowed by AHTD for LA abrasion percent loss varies depending on the intended use of the aggregate. Section 300 of the 2003 edition of Standard Specifications for Highway Construction states that 45% loss is the maximum percentage allowed when using aggregate for construction, while asphalt is allowed a 35% loss (AHTD, 2003).

Sampling is an important component when testing the potential of a stone for aggregate material. The Materials Division of AHTD specifically addresses how samples meant for testing
are to be procured in a quarry. Samples can be collected from quarry ledges, unworked deposits, conveyor belts, and stockpiles. When collecting a sample, the authorized person performing the task is required to inspect quarry walls for visual variations in differing layers including variations in color, texture, structure, etc. This is done in order to achieve a sample that closely represents the lithologic strata present in the quarry. This is very important for testing purposes because an incorrect sample could create issues for quarry operators. Various different processes are required for sampling depending on the location of the quarry; for a full viewing of AHTD sampling procedures refer to page 48 in the 2012 edition of the *Manual of Field Sampling and Testing Procedures* by the AHTD Materials Division (AHTD, 2012).
**Aggregate Potential-Gum Log Quarry**

The aggregate potential of Gum Log quarry is discussed by partitioning the mine into four different sections (Figure 5). This is the same method used earlier to describe the facies of the quarry and allows for a direct comparison between the stratigraphy and rock quality in each section. LA abrasion data, compiled from various facies of the quarry, are used to identify trends in aggregate quality throughout the different sections of the mine. Consideration is given to how the rock material was sampled as well as how many times the sample has been crushed.

**Aggregate Potential-Section 1**

Section 1 of Gum Log quarry contains one lithologic facies (Figure 33). Facies 3 (Figure 32) is the thickest unit described in the quarry and is the target facies for most of the mining at Gum Log. Facies 3 is sub-divided into three sections which are all observed in Section 1: Upper, Middle, and Lower. There are eleven different LA abrasion tests available for Section 1 (Table 1). Table 1 illustrates the date each sample was tested, the section of the quarry where the sample was taken, the facies targeted, sample area, sample size, how many times the sample was crushed, and the LA abrasion test result for the sample.

**Table 1.**

<table>
<thead>
<tr>
<th>Test Date (mm/yr)</th>
<th>Quarry Section</th>
<th>Target Facies</th>
<th>Sample Area</th>
<th>Sample Size (Inches)</th>
<th>Crushed</th>
<th>LA Abrasion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>07/97</td>
<td>Section 1</td>
<td>Facies 3 “Upper”</td>
<td>Shot Rock</td>
<td>N/A</td>
<td>0</td>
<td>26.0</td>
</tr>
<tr>
<td>06/98</td>
<td>Section 1</td>
<td>Facies 3 “Upper”</td>
<td>Shot Rock</td>
<td>N/A</td>
<td>0</td>
<td>26.0</td>
</tr>
<tr>
<td>04/99</td>
<td>Section 1</td>
<td>Facies 3 “Low-Mid”</td>
<td>Shot Rock</td>
<td>N/A</td>
<td>0</td>
<td>35.0</td>
</tr>
<tr>
<td>04/00</td>
<td>Section 1</td>
<td>Facies 3 “Upper”</td>
<td>Shot Rock</td>
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<td>0</td>
<td>29.0</td>
</tr>
</tbody>
</table>
Table 1. Cont.

<table>
<thead>
<tr>
<th>Test Date (mm/yr)</th>
<th>Quarry Section</th>
<th>Target Facies</th>
<th>Sample Method</th>
<th>Sample Size (Inches)</th>
<th>Crushed</th>
<th>LA Abrasion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/01</td>
<td>Section 1</td>
<td>Facies 3 “Middle”</td>
<td>Stockpile</td>
<td>½</td>
<td>3</td>
<td>32.7</td>
</tr>
<tr>
<td>09/01</td>
<td>Section 1</td>
<td>Facies 3 “Low-Mid”</td>
<td>Stockpile</td>
<td>¾</td>
<td>≥2</td>
<td>45.6</td>
</tr>
<tr>
<td>09/01</td>
<td>Section 1</td>
<td>Facies 3 “Low-Mid”</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
<td>44.4</td>
</tr>
<tr>
<td>01/02</td>
<td>Section 1</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
<td>26.1</td>
</tr>
<tr>
<td>01/02</td>
<td>Section 1</td>
<td>Facies 3 “Mid-Up”</td>
<td>Stockpile</td>
<td>¾</td>
<td>≥2</td>
<td>29.4</td>
</tr>
<tr>
<td>02/02</td>
<td>Section 1</td>
<td>Facies 3 “Middle”</td>
<td>Stockpile</td>
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<td>≥1</td>
<td>30.5</td>
</tr>
<tr>
<td>01/06</td>
<td>Section 1</td>
<td>Facies 3 “Low-Mid”</td>
<td>Stockpile</td>
<td>¾</td>
<td>≥2</td>
<td>52.6</td>
</tr>
</tbody>
</table>

Observations - Section 1

Section 1 of Gum Log quarry displays a relative increase in LA abrasion percentage moving west through the section. This means that the aggregate quality of the rock is becoming poorer to the west. Between years 1997 and 2006 the operator of Gum Log quarry mined in an overall western direction through Section 1. During this time the amount of interbedded shale layers increases moving west in Section 1, thereby leading to poorer results from the LA abrasion test. By 2006, Facies 3 in Section 1 had become interbedded with enough shale to drop the LA test percentages below acceptable limits. Figure 6 illustrates the western most extent of Section 1 as well as the continuous, interbedded shale layers responsible for lowering LA test percentages in this section.
Fig. 34. Shows average LA Abrasion percentages for the different portions of Facies 3 located in Section 1 and 2. The facies was sectioned into an upper, middle, and lower portion based on test results only, not stratigraphic principles (Figure by Author, 2015).

Vertical variation of rock quality in Section 1 is illustrated by the LA abrasion test results in Table 1. Samples taken from the upper portion of Facies 3 have LA test percentages in the mid- to upper –twenties (Figure 34). Samples taken in the middle portion of Facies 3 have percentages in the low thirties, while samples from lower in the section have percentages in the mid- and upper- thirties (Figure 34). Interbedded shale layers appear to be more prevalent lower in the facies, attributing to the lower LA test percentages experienced vertically downward in the section.
Crushing the sample prior to testing appears to have a slight result on the LA abrasion test percentage. By observing the size and location of test samples it is possible to determine how many times the samples have been crushed. Usually the smaller rock samples are more processed than the larger ones. LA tests from the same location in Facies 3, and the same area of Section 1, display varying results depending on how many times the sample was crushed before testing. The shot rock, which has not been crushed, appears to have lower LA test percentages when compared to the same rock that has been crushed 1, 2, or 3 times. Aggregate quality appears to be directly proportional to the processing of the rock; the more times the rock is crushed the higher the percent lost in the LA abrasion test.

*Stratigraphy and Rock Quality-Section 1*

The distributary-mouth-bar sandstone located in Section 1 was initially an excellent source of aggregate material for the Gum Log quarry. As mining moved further west, LA test percentages began to rise and rock quality slowly decreased. This is due largely to the thin, shale interbeds that become more numerous moving west through Facies 3. Shale interbeds also increase in number moving vertically downward in the section. Mud accumulated in the distributary-mouth-bar due to temporary sea-level transgressions or a shortage of sediment input from the delta (Figure 12). Moving west through Section 1 is likened to moving deeper into the shallow marine seaway of the Arkoma Basin. The sandstone of Facies 3 in Section 1 is the more distal equivalent of Facies 3 sandstone located in the eastern sections of the quarry. In a deeper environment the mouth-bar sandstones are prone to changes in sea-level and sediment fluctuations, making them more susceptible to mud accumulation and therefore lowering the aggregate potential.
Section 2 of Gum Log quarry contains three different lithologic facies (Figure 33). Facies 1 is the lowest lithologic unit in the quarry and is not mined at this location. Facies 2 is only 3-5 feet thick in Gum Log quarry, making it too thin to target exclusively. Therefore Facies 2 usually gets grouped in with Facies 3 during blasting. Facies 3 is very thick in Section 2 and is the main lithologic unit targeted for mining in this section. There are fifteen LA abrasion test results available for the facies of Section 2 (Table 2).

**Table 2.**

<table>
<thead>
<tr>
<th>Test Date (mm/yr)</th>
<th>Quarry Section</th>
<th>Target Facies</th>
<th>Sample Method</th>
<th>Sample Size (Inches)</th>
<th>Crushed</th>
<th>LA Abrasion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/00</td>
<td>Section 2</td>
<td>Facies 3 “Upper”</td>
<td>Shot Rock</td>
<td>N/A</td>
<td>0</td>
<td>29.0</td>
</tr>
<tr>
<td>09/01</td>
<td>Section 2</td>
<td>Facies 3 “Mid-Up”</td>
<td>Stockpile</td>
<td>½</td>
<td>3</td>
<td>31.4</td>
</tr>
<tr>
<td>09/01</td>
<td>Section 2</td>
<td>Facies 3 “Mid-Up”</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
<td>30.3</td>
</tr>
<tr>
<td>10/01</td>
<td>Section 2</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
<td>½</td>
<td>3</td>
<td>32.9</td>
</tr>
<tr>
<td>10/01</td>
<td>Section 2</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
<td>23.3</td>
</tr>
<tr>
<td>10/01</td>
<td>Section 2</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
<td>¾</td>
<td>≥2</td>
<td>25.4</td>
</tr>
<tr>
<td>01/02</td>
<td>Section 2</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
<td>22.8</td>
</tr>
<tr>
<td>01/02</td>
<td>Section 2</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
<td>¾</td>
<td>≥2</td>
<td>23.9</td>
</tr>
<tr>
<td>Test Date (mm/yr)</td>
<td>Quarry Section</td>
<td>Target Facies</td>
<td>Sample Method</td>
<td>Sample Size (Inches)</td>
<td>Crushed</td>
<td>LA Abrasion (%)</td>
</tr>
<tr>
<td>------------------</td>
<td>----------------</td>
<td>---------------</td>
<td>---------------</td>
<td>----------------------</td>
<td>---------</td>
<td>----------------</td>
</tr>
<tr>
<td>04/07</td>
<td>Section 2</td>
<td>Facies 3 “Middle”</td>
<td>Shot Rock</td>
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<td>0</td>
<td>33.0</td>
</tr>
<tr>
<td>04/09</td>
<td>Section 2</td>
<td>Facies 3 “Middle”</td>
<td>Shot Rock</td>
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<td>0</td>
<td>32.0</td>
</tr>
<tr>
<td>07/09</td>
<td>Section 2</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
<td>3</td>
<td>1</td>
<td>29.3</td>
</tr>
<tr>
<td>02/12</td>
<td>Section 2</td>
<td>Facies 3 “Lower”</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
<td>37.9</td>
</tr>
<tr>
<td>03/14</td>
<td>Section 2</td>
<td>Facies 2</td>
<td>Stockpile</td>
<td>¾</td>
<td>≥2</td>
<td>49.9</td>
</tr>
<tr>
<td>03/14</td>
<td>Section 2</td>
<td>Facies 2</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
<td>45.2</td>
</tr>
<tr>
<td>03/14</td>
<td>Section 2</td>
<td>Facies 3 “Low-Mid”</td>
<td>Stockpile</td>
<td>3</td>
<td>1</td>
<td>33.4</td>
</tr>
</tbody>
</table>

**Observations - Section 2**

Section 2 of Gum Log quarry displays a relative increase in LA abrasion test percentages moving west through the section. There is also an increase in LA percentage moving vertically downward through the section similar to the trend observed in Section 1 (Figure 34). The number of times the sample has been crushed plays a role in LA abrasion test percentages in Section 2 as well. Since approximately 2006, Gum Log operators have mined in an easterly direction through Section 2, following Facies 3. Facies 3 is devoid of interbedded shale layers in the eastern direction and therefore yields lower LA abrasion test percentages. Samples taken in the lower and middle portions of Facies 3 yield LA percentages in the low to mid-thirties while the upper portion of Section 2 yields percentages in the low to mid-twenties (Figure 34). Facies 2 is relatively thin and is not purposely targeted during mining operations in Gum Log quarry. However, the unit can play a role in lowering the overall quality of rock tested in Section 2. Samples tested from Facies 2 yield LA test percentages ranging from the middle forties into the
lower fifties (Figure 35). If quarry operators are targeting the sands of Facies 3 and unintentionally blast too deep and encounter Facies 2, the aggregate quality will be negatively impacted. Facies 1 is present at the base of the quarry or the “quarry floor” throughout northern portions of Section 2. Facies 1 has never been tested in Gum Log quarry because the LA abrasion method is not designed to test shale. Facies 1 is commonly used to mark the bottom boundary for productive mining; therefore it has never been mined or processed in Gum Log quarry.

**Fig. 35.** Shows average LA Abrasion percentage of Facies 2 located in Section 2. (Figure by Author, 2015).
Stratigraphy and Rock Quality-Section 2

The distributary-mouth-bar sandstone of Facies 3 has proven to be an excellent source of aggregate material. It is the primary source of crushed stone in Gum Log quarry and exhibits little lateral variation in LA test percentages throughout the section. Vertical variation within 10 percent is observed through Facies 3, largely due to the slight increase in shale interbeds vertically downward in the section. There are fewer interbedded shale layers in the sandstone eastward in the quarry. This is because the eastern portion of the quarry represents a more proximal setting in the deltaic environment where mud is eliminated due to tidal currents and wave action. With lower mud content the sand in Facies 3 produces rock with low LA abrasion percentages and high aggregate potential.

The distal bar sandstone of Facies 2 marks the transition interval between shallow marine, prodeltaic shale of Facies 1 and delta-mouth-bar sandstones of Facies 3 (Figure 12). Distal bar sandstone is characterized by numerous interbedded silty shale layers containing fossilized plant material. These muddy intervals are a result of sediment fluctuations in the deltaic environment of the shallow Arkoma seaway and cause aggregate potential to drop dramatically in the distal bar sands. Facies 2 is not purposely targeted for aggregate material in Gum Log quarry, but occasionally the rock is accidentally incorporated into the processing of Facies 3 sandstone. When this happens, the overall LA abrasion test percentage increases and the aggregate quality of the rock diminishes.

Aggregate Potential-Section 3

Section 3 contains two different lithologic facies (Figure 33). Nearly twenty feet of the upper portion of Facies 3 is visible before plunging to the south while the middle and lower
portions of Facies 3 are not present at the surface of this section. Facies 3 “upper” has been mined successfully throughout the section but is being truncated by Facies 4 to the east (Figure 22). Facies 4 is characterized by dark siltstones that are not intentionally mined in the quarry. However, due to the relative abundance in Section 3, and lateral and vertical proximity to the high quality sandstones of Facies 3, Facies 4 siltstone is sometimes incorporated into the blasting and processing of the high quality target facies unintentionally. There are seven LA abrasion test results available for analysis of the facies in Section 3 (Table 3).

Table 3.

<table>
<thead>
<tr>
<th>Test Date (mm/yr)</th>
<th>Quarry Section</th>
<th>Target Facies</th>
<th>Sample Size (Inches)</th>
<th>Crushed</th>
<th>LA Abrasion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/05</td>
<td>Section 3</td>
<td>Facies 3 “Upper”</td>
<td>Shot Rock</td>
<td>N/A</td>
<td>25.0</td>
</tr>
<tr>
<td>03/06</td>
<td>Section 3</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
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<td>28.4</td>
</tr>
<tr>
<td>04/07</td>
<td>Section 3</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
</tr>
<tr>
<td>01/08</td>
<td>Section 3</td>
<td>Facies 4</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
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<tr>
<td>01/08</td>
<td>Section 3</td>
<td>Facies 3 “Upper”</td>
<td>Stockpile</td>
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<td>3</td>
</tr>
<tr>
<td>01/08</td>
<td>Section 3</td>
<td>Facies 4</td>
<td>Stockpile</td>
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<td>3</td>
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<tr>
<th>Test Date (mm/yr)</th>
<th>Quarry Section</th>
<th>Target Facies</th>
<th>Sample Method</th>
<th>Sample Size (Inches)</th>
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<tr>
<td>01/08</td>
<td>Section 3</td>
<td>Facies 4</td>
<td>Stockpile</td>
<td>½</td>
<td>3</td>
<td>61.6</td>
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</table>

Observations - Section 3

Section 3 displays LA abrasion test percentage trends similar to those observed in other sections of the quarry. Facies 3 produces high quality aggregate material with LA percentages in the mid- to upper- twenties. It appears that the tests are slightly impacted by the number of times the sample has been crushed, behaving similar to facies described previously. Section 3 does pose two major concerns for the quarry: Facies 3 grades vertically into Facies 4 and plunges to the south (Figure 33). This means that the quarry operator can no longer mine Facies 3 to the south due to the facies plunging to depth under several feet of overburden and siltstone. The operator is also limited in mining to the east because of the vertical gradation to Facies 4. As shown in Table 3, Facies 4 causes relatively high LA abrasion test percentages, leading to poor quality aggregate material. This prevents the high quality material in Facies 3 from being blasted and processed without incorporating large volumes of overlying Facies 4 (Figure 36). The siltstone facies itself cannot be directly tested with the LA abrasion method; however the sandy transition intervals between the two facies yield LA test percentages ranging from the mid-forties upwards into the sixties (Figure 36). The percentages appear to vary based on how much Facies 4 siltstone is present in the sample.
Fig. 36. Shows the average LA Abrasion percentages near the transition between the upper portion of Facies 3 and Facies 4 located in Section 3. Most LA Abrasion percentages were taken near the boundary between the two lithologic units; therefore LA results increasingly diminish moving vertically through Facies 4 (Figure by Author, 2015).
**Stratigraphy and Rock Quality-Section 3**

The distributary-mouth-bar sandstone of Facies 3 has been a prolific aggregate producer in Section 3 of Gum Log quarry. However, as quarry operators mine farther east the high quality mouth-bar sandstone begins to grade vertically into the interdistributary bay, tidal flat siltstones of Facies 4 (Figure 12). The transition between the two facies likely occurred during a period of sea level transgression or avulsion of a distributary-channel. During this time sandy mud began to gradationally blanket the mouth-bar sands until finally the tidal flat environment dominated deposition. The addition of mud from the tidal flat environment dramatically changed the lithology present in Gum Log quarry. High quality sandstones, historically producing good aggregate material, are now being truncated to the east by poor quality, high LA test percentage siltstones. Mining Facies 3 sandstone to the south is not an option due to the sand plunging to depth under increasing overburden material. It is therefore concluded that mining high quality aggregate material, without removing tremendous amounts of siltstone and overburden, is no longer possible in Section 3 due to the gradation of poor quality siltstones of Facies 4.

**Aggregate Potential-Section 4**

Section 4 of Gum Log quarry contains two different lithologic facies (Figure 33). Facies 4 is the siltstone unit that is not purposely targeted in the quarry. However, it has caused issues when trying to mine Facies 3 to the south in Section 4. Due to the inclination of the strata in Gum Log quarry, the sandstones of Facies 3 are too deep beneath the siltstones of Facies 4 to be mined in this section. Abruptly above the siltstone facies is Facies 5, the main united targeted for mining in Section 4. Facies 5 is nearly 20 feet thick in some areas and appears to thicken down section to the east. It is the youngest lithologic unit cropping out in Gum Log quarry and
produces some of the highest quality aggregate materials. There are eight LA abrasion test results available for the facies of Section 4 (Table 4).

Table 4.

<table>
<thead>
<tr>
<th>Test Date (mm/yr)</th>
<th>Quarry Section</th>
<th>Target Facies</th>
<th>Sample Method</th>
<th>Sample Size (Inches)</th>
<th>Crushed</th>
<th>LA Abrasion (%)</th>
</tr>
</thead>
<tbody>
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<td>10/03</td>
<td>Section 4</td>
<td>Facies 5</td>
<td>Stockpile</td>
<td>1 ½</td>
<td>≥1</td>
<td>27.1</td>
</tr>
<tr>
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<td>Section 4</td>
<td>Facies 5</td>
<td>Stockpile</td>
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<td>≥1</td>
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</tr>
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</table>

Observations - Section 4

Section 4 is characterized by a rapid lithologic transition from low quality to high quality aggregate material shown in the LA abrasion percentages of Table 4. The poor quality siltstones of Section 3 transition vertically into high quality sandstones to the south in Section 4. Facies 5 sandstone in this section yields LA test percentages ranging from the mid- to upper twenties (Figure 37). These numbers are consistent, displaying little variation throughout the facies. Facies 5 is devoid of nearly all shale or siltstone material throughout the entire lateral and vertical extent of the unit, contributing to the high LA test percentages associated with the facies.
Crushing and processing do appear to negatively impact the LA percentages as observed in all other facies of Gum Log quarry.

Despite the high quality nature of the sandstone in Facies 5, Gum Log quarry has not mined the unit in over five years. There are three significant issues when attempting to mine Facies 5 sandstone: Overburden, water, and abrasiveness. Due to the inclination of strata in Gum Log quarry, Facies 5 plunges to the south quickly in Section 4. This requires quarry operators to remove increasing amounts of overburden in order to mine the sandstone. By doing this, the quarry is required to spend significantly more capital to process the rock, potentially rendering Facies 5 unprofitable. Therefore, aggregate prices dictate whether it is feasible to mine Facies 5 to the south in Section 4 or not. During the time of this study, Duffield Gravel officials have determined mining Facies 5 is not economically viable.

Water poses some issues when trying to mine the high quality sandstones of Section 4. Gum Log quarry is engineered in such a way that surface and groundwater passing through the mine “drain” south and east through Section 4. The water table is near the mine floor surface, enveloping intervals of Facies 5 in water. This is a problem for the exhumation and processing of the material. Wet material is heavy, making it more expensive to transport within the quarry and also creating problems during the crushing process. Material that is too highly saturated during processing can cause conveyor belts to slip, segregation screens to clog, and other costly mechanical failures. In order to process the aggregate material in Facies 5, pumping would be required to lower the water table in Section 4.

The sandstone of Facies 5 is very hard and durable as shown in the LA test percentages in Table 4. However, this creates an issue unique to this facies in Gum Log quarry. The aggregate
material is so hard and abrasive that is wears the crushing and processing equipment out much faster than other facies in the mine. “The rock [Facies 5] in the southeast pit [Section 4] has a much higher abrasion factor and pulls the crushing equipment 15-20 amps higher on motor current draw” (W. Langford, personal communication, January 2015). By mining and processing the sandstone of Facies 5, quarry operators face the issue of having to replace worn-out equipment more often. This cost Duffield Gravel Company capital that, with the current price of aggregate material, may or may not be feasible. At the time of this study Duffield Gravel officials have determined that mining Facies 5 sandstone is not economic, despite the high LA abrasion test percentages associated with the facies.

**Fig. 37.** Shows the average LA Abrasion percentage for Facies 5 located in Section 4. Overburden materials lie in contact with Facies 5 and increase in thickness south (Figure by Author, 2015).
Stratigraphy and Rock Quality-Section 4

Section 4 is characterized by interdistributary bay siltstone transitioning vertically into highly cross-bedded distributary-channel sandstones (Figure 12). The channel sands of Facies 5 produce exceptional aggregate material and are devoid of interbedded mud layers that would increase the LA abrasion test percentages. The sands are well sorted and intensely cross-bedded, indicative of an active environment in which mud deposition would not occur. This is critical to the formation of a high quality aggregate deposit like Facies 5, which exhibits little lateral and vertical variation in LA test percentages throughout the section. Therefore, the active environment associated with a distributary-channel produces consistently high quality aggregate material in Gum Log quarry.

The facies transition observed in Section 4 is interpreted to be a critical aspect in the existence of Gum Log quarry. Houseknecht et al. (1981) explained that prodeltaic and delta front facies of the Atoka Formation are rarely observed in a prograding delta system because the distributary-channel environment usually destroys the underlying facies (Figure 12). The deposition of Facies 4 is critical to the preservation of the lower facies in the quarry. During Facies 4 deposition, sea-level rise or sediment fluctuations altered the depositional environment responsible for creating the deltaic facies in Gum Log quarry, blanketing the prodeltaic and delta front deposits with interdistributary bay, tidal flat mud (Figure 12). The tidal flat environment continued depositing mud on the deltaic facies until sea-level or sediment fluctuations renewed deltaic deposition. In Gum Log quarry, the distributary-channel sand of Facies 5 is observed abruptly above the tidal flat siltstones of Facies 4. Therefore, the tidal flat mud associated with Facies 4, and any subsequent overlying facies that have since been eroded away, are responsible for preserving the underlying prodeltaic and delta front facies mined in Gum Log quarry. Had
Facies 4 deposition never occurred, the depositional environment associated with Facies 5 would have partially or entirely destroyed the underlying sediment. By destroying the sediments responsible for creating Facies 3, Gum Log quarry could not exist today.
Conclusion

The crushing of stone for aggregate material is a process necessary to support and maintain human inhabitance on Earth. Not all rock is suitable to become aggregate material and careful consideration must be given when selecting the location of a rock quarry. Adequate physical rock properties, such as hardness and durability, as well as rock location are all critical to establishing a successful quarry. The Duffield Gravel Quarry in Gum Log, Arkansas has successfully assessed the aggregate potential of the area and has been a prolific crushed stone producer in the Arkansas River Valley for over 20 years.

The rock mined in Gum Log quarry was deposited in the Arkoma Basin during the Atokan Epoch of the Pennsylvanian Period. The rock is interpreted to be part of a prograding deltaic deposit within the Upper Atoka Formation and is lithologically similar to the overlying deltaic Hartshorne sandstones deposited during the Desmoinesian Epoch. There are five different lithologic facies defined in the different sections of Gum Log quarry. Facies 1 is dark, fissile marine shale representing the oldest lithologic unit in the quarry. This facies is only observed in Section 2 of the quarry. Facies 2 is chaotic bedded, poorly sorted, gray distal-bar sandstone with plant debris and limonitic staining. This facies is observed exclusively in Section 2 of the quarry. Facies 3 is relatively thick, cross-bedded, ripple-marked distributary-mouth-bar sandstone. This facies is observed in Sections 1, 2, and 3 of the quarry. Facies 4 is dark, fissile, bioturbated siltstone with interbedded flaser sandstones. This facies is observed in Sections 3 and 4 of the quarry. Facies 5 is highly cross-bedded, well sorted distributary-channel sandstone.
and is the youngest lithologic unit in Gum Log quarry. This facies is only observed in Section 4 of the quarry.

To evaluate the aggregate potential of the different facies in Gum Log quarry LA abrasion test results were utilized. The LA abrasion test is designed to simulate a weathering environment in order to measure the materials resistance to degradation. The Arkansas Highway and Transportation Department uses LA abrasion to set acceptable limits of degradation depending on the intended use of the aggregate. A 45% loss is acceptable in construction aggregate while asphalt and other uses allow only a 35% loss in LA abrasion test percentage. A smaller percentage after an LA abrasion test means the rock is more competent.

Facies 1 is not mined in Gum Log quarry, and is unable to be tested by the LA abrasion method, because it is shale and not useful for crushed stone aggregate. Facies 2 has been mined in Section 2 and produced LA abrasion test results ranging from 45.2-49.9% with an average LA abrasion percentage of 47.6%. Facies 3 has been mined in Sections 1, 2, and 3 of the quarry and produced LA abrasion test results ranging from 22.8-52.6%. The upper portion of the facies resulted in an average percentage of 27.4%. The middle portion resulted in an average percentage of 31.6%. The lower portion of Facies 3 resulted in an average percentage of 43.1%. Facies 4 is avoided during mining if possible, with LA abrasion results ranging from 47.0-61.6% depending on the amount of siltstone in the sample. The average LA test percentage is 54.7% in this facies. Facies 5 yields LA abrasion percentages ranging from 25.0-29.1% with an average percentage of 27.3%. Within all sections and facies, the amount of crushing and processing rock samples had experienced prior to testing appeared to negatively impact the LA test percentages.
The shallow marine deposits of Facies 1 are not mined in the quarry and mark the lowest boundary of productive mining in Gum Log. The distal-bar sandstone of Facies 2 is characterized by numerous interbedded shale and plant debris layers that cause the aggregate quality of the sandstone to be diminished. Because of this Facies 2 is avoided during mining in the quarry. The distributary-mouth-bar sandstone of Facies 3 is the most prolific source of aggregate material in the quarry. The amount of interbedded shale layers diminish upward and proximally to the east, producing higher quality aggregate material. High quality rock in Facies 3 is being truncated to the east by Facies 4, this will force mining operations to proceed north in the dip-direction in order to continue mining Facies 3. The tidal flat siltstones of Facies 4 are not purposely mined in the quarry. However they can be accidently incorporated into the material of Facies 3 and act to severely lower the overall sample quality. Deposition of Facies 4 was critical to the existence of Gum Log quarry. The interdistributary bay deposits acted as a barrier to erosion from the prograding deltaic channels of Facies 5. This preserved the underlying prodeltaic and delta front deposits mined in Gum Log quarry today. The distributary-channel sandstone of Facies 5 is the most competent and high quality material in the quarry. However, overburden complications, water table level, and machine wear prevent Facies 5 sandstone from being economic to mine during the time of this study.
References


