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Lithological Character and Sequence Stratigraphy of the Ste. Genevieve Limestone in Western Kentucky

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LITHOLOGICAL CHARACTER AND SEQUENCE STRATIGRAPHY OF THE STE. GENEVIEVE LIMESTONE IN WESTERN KENTUCKY

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LITHOLOGICAL CHARACTER AND SEQUENCE STRATIGRAPHY OF THE STE. GENEVIEVE LIMESTONE IN WESTERN KENTUCKY

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LITHOLOGICAL CHARACTER AND SEQUENCE STATIGRAPHY OF THE STE. GENEVIEVE LIMESTONE IN WESTERN KENTUCKY

Zachary D. Creech August 2019 118 pages

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The Ste. Genevieve Limestone is a Mississippian-aged, carbonate-dominated stratigraphic unit that is a prominent hydrocarbon producer in the Illinois Basin, and is widely distributed in states such as Missouri, Kentucky, Indiana, and Illinois. There has been relatively limited study focused on characterizing the Ste. Genevieve Limestone in terms of lithofacies, stacking patterns, and sequence stratigraphic context via analysis of roadcut exposures of the unit in western Kentucky.

The focus of this study is to use lithologic data collected from roadcuts and draft these data into cross sections for presentation of detailed stratigraphic columns that are locally correlative. Seven roadcuts were used in the study, five in Warren County Kentucky and two in Barren County Kentucky. The goal of this study is to characterize the lithofacies, stacking patterns, and sequence stratigraphy of the Ste. Genevieve Limestone. Another goal is to identify intervals in the unit that have a high potential to be hydrocarbon reservoirs and by extension, determine associated rocks that may function as seals or traps for reservoirs.

The results of this study show that the characteristics of the Ste. Genevieve Limestone in western Kentucky are:

- Roadcut consists of three stratigraphically distinct stacking patterns: 1) alternating coarse-grained units and fine-grained units, 2) a backstepping, retrogradational, shoal-building pattern, and 3) static, thick coarse-grained intervals.

- The roadcuts are dominated by limestone units, with coarse intervals consisting of mainly skeletal-ooid grainstones and fine-grained intervals representative of mudstones and wackestones.
- Dolomitized limestone is present, with dolomitized mudstone making up the majority of dolomitic units and fine-grain units in general.
- Oolitic and skeletal units are the most ideal hydrocarbon reservoir rocks in the roadcuts with paleokarst intervals such as brecciated limestone also being viable potential reservoirs.
- The presence of thick skeletal and skeletal-ooid grainstones are indicative of High Stand System Tracts (HSTs), which make up the majority of roadcut exposures and brecciated limestone in contrast, is indicative of a Falling Stage System Tract (FSST).
- Overall, the rocks exposed in the roadcuts are representative of shoal or shoaling upward environments yet possess localized partitioning of units based on identification of depositional and diagenetic facies changes.

1.0 INTRODUCTION

The Ste. Genevieve Limestone is a stratigraphic unit that is one of the most productive hydrocarbon reservoirs in the Illinois Basin (Bethke, Reed, and Olitz, 1991). Despite multiple studies that characterize the Ste. Genevieve Limestone at various localities (Short, 1962 and Stevenson, 1987), there has been limited study of the unit in western Kentucky that analyzes the lithofacies in the context of reservoir considerations in outcrop or in roadcuts. Additionally, there has been limited research conducted documenting lithofacies stacking patterns in a sequence stratigraphic context or minimally related to base-level changes in western Kentucky. Such information could aid in identifying potential hydrocarbon reservoirs that exist in the Ste. Genevieve Limestone in western Kentucky areas such as Warren, Butler, and Barren counties.

1.1 Problem Statement

In regard to the Ste. Genevieve Limestone in western Kentucky, there are many questions about the characteristics of these rocks in the region. Some of these questions include: which intervals comprise viable reservoir rock facies?, which units represent the seal or trap facies?, what are the stratigraphic stacking patterns?, what is the sequence stratigraphic context?, and in general, what is the lithological variation of the Ste. Genevieve Limestone in western Kentucky?

Hydrocarbon reservoirs in carbonate systems are differentiated from siliciclastic systems in that siliciclastic reservoir systems are predominately shale and sandstone (Galloway and Hobday, 1983), whereas carbonate-reservoir systems are mainly coarse-grained limestones. Sedimentary characteristics such as grain size, fossil/organic content, oolite abundance, etc. are lithostratigraphic parameters that aid in distinguishing between a viable hydrocarbon reservoir and nonviable unit (i.e. traps or seals) and thus, must be considered during exploration or field development. Such sedimentary characteristics are important in identifying hydrocarbon-reservoir potential. It is obviously important to understand the depositional environments responsible for the formation of viable reservoir units and their distribution. Furthermore, post-depositional or diagenetic features are also important to note in surface exposures as they can provide understanding of potential reservoir partitioning or boundary conditions such as exposure surfaces/unconformities and stylolites.

The identification of reservoir units is important, but additionally this information must be used in conjunction with documenting stacking patterns of the units. Stacking patterns of stratigraphic units refer to how these strata are positioned vertically within the overall geographic trend of the units. For example, identifying shoaling/coarsening upward, fining upward, and layering of mixed coarse- and fine-grained intervals is important. Study of such stacking patterns provides insight into the depositional environment and how they change over time and space. These stacking patterns in turn, can be placed in the context of "sequence stratigraphy" (e.g., Van Wagoner et al., 1988). Patterns in sequence stratigraphy represent the overall trend of depositional facies and are relatable to transgressive and regressive cycles or relative base-level changes in a given depositional system. Study of these sequence stratigraphic trends, coupled with lithofacies analysis, can be of great aid in hydrocarbon exploration and development.

1.2 Objectives of Thesis

The main objectives of this study are to: 1) identify the lithofacies that constitute the Ste. Genevieve Limestone, 2) identify units that have hydrocarbon reservoir potential, 3) analyze the stacking patterns, and by extension, the sequence stratigraphy of the Ste. Genevieve Limestone, 4) analyze the depositional environment of the subunits and how the environment changes over time and 5) identify salient diagenetic or other features that may be important for better understanding potential reservoir spatial limitations. To accomplish these objectives, a study was conducted that incorporates sedimentary, stratigraphic, and lithologic analysis. The main method for the study was the analysis of various roadcuts in western Kentucky (Figure 1.1) which included measuring stratigraphic sections, sampling, and describing and interpreting prepared slabbed hand samples retrieved from measured sections.

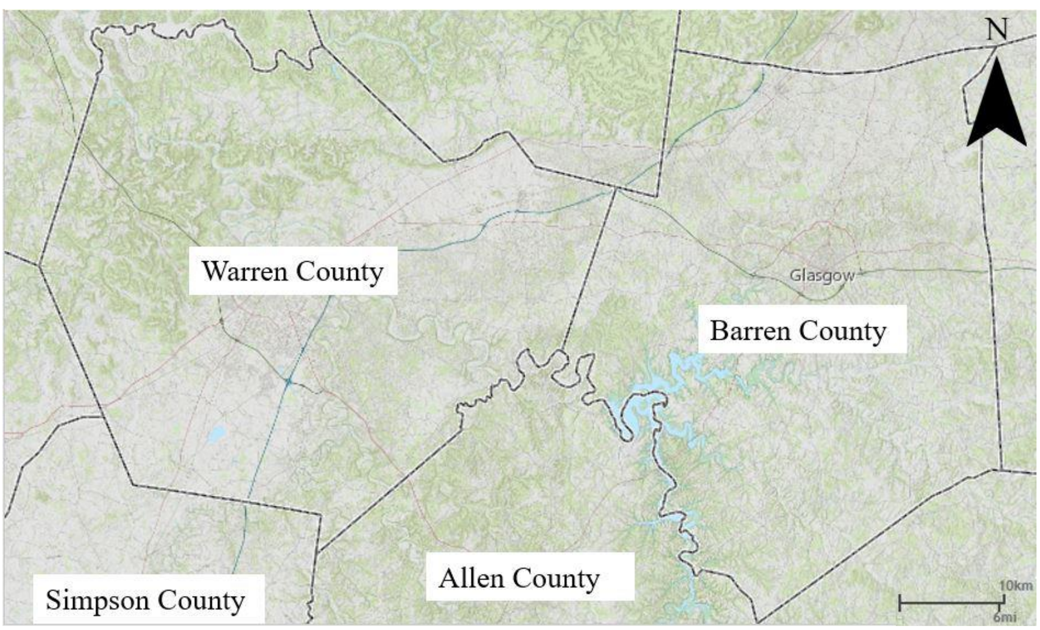

Figure 1.1. Map showing location of field study that was focused on two counties – Warren and Barren. Created using KGS map services (July 2019).

2.0 LITERATURE REVIEW

2.1 Illinois Basin

The Ste. Genevieve Limestone is a stratigraphic unit that was formed from sediments deposited in a shallow-marine environment in the Illinois Basin, a depositional basin that encompasses most of Illinois, southwestern Indiana, western Kentucky, eastern Missouri, and northwestern Tennessee (Figure 2.1). The Illinois Basin began as a failed rift concurrent with the breakup of a supercontinent during the Lower/Middle Cambrian. The basin eventually evolved into a cratonic embayment that subsided by the Upper Cambrian (Kolata and Nelson, 1990).

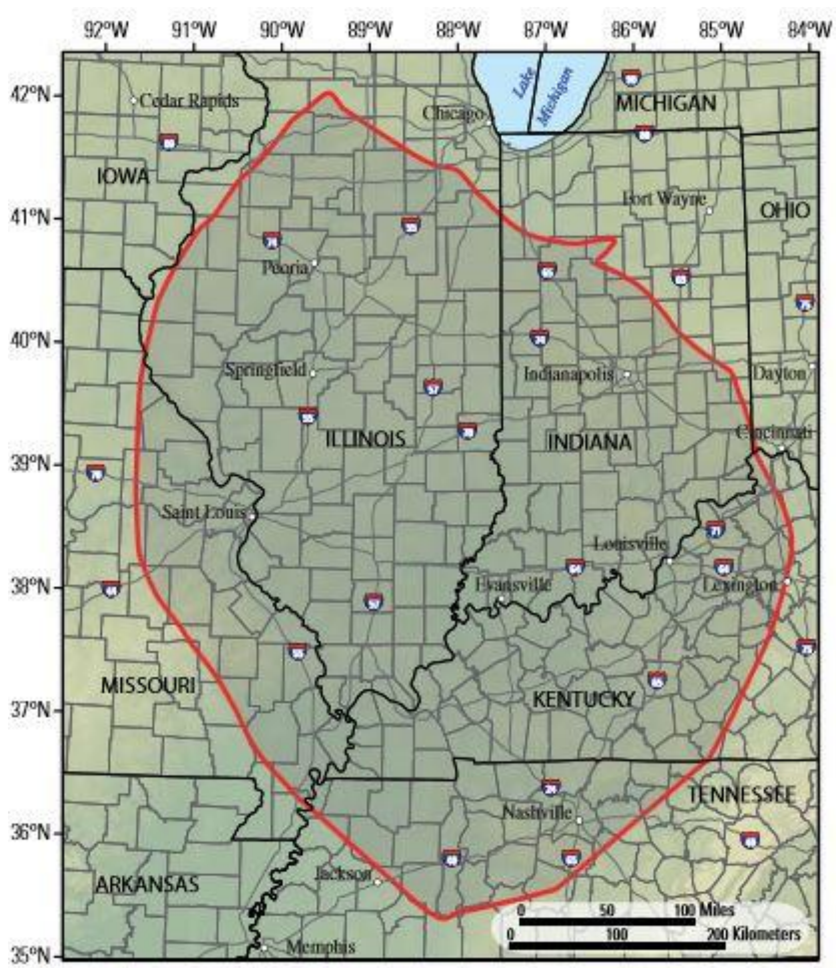

Figure 2.1. Map showing the extent of the Illinois Basin (after Swezey, 2007).

The Paleozoic Era was a time of major deposition and preservation of sediments within the Illinois Basin, with several depositional sequences accumulating during this time. During the Paleozoic, the Illinois Basin was connected to open ocean which resulted in a greater influence of fluctuating sea levels in the basin. Six primary sequences represent several complete transgressive-regressive cycles in the Paleozoic. These sequences in ascending stratigraphic order are the classic Sauk, Tippecanoe, Kaskaskia, Absaroka, Zuni and Tejas (Sloss, 1963).

The Illinois Basin is positioned near the New Madrid Rift Complex, a failed intercontinental rift system originating in the Precambrian that has influenced the geometry of the basin. The New Madrid Rift Complex is the primary control on sediment accumulation rates and depositional environments in the southern Illinois Basin. This resulted in episodic subsidence along normal faults that accommodated sedimentation and punctuated sedimentary sequences in the basin (Kolata and John, 1990). This complex can be subdivided into smaller failed rift or crustal extensional systems, with the main systems of interest in western Kentucky being the Reelfoot Rift system and the Rough Creek Graben system (Figure 2.2).

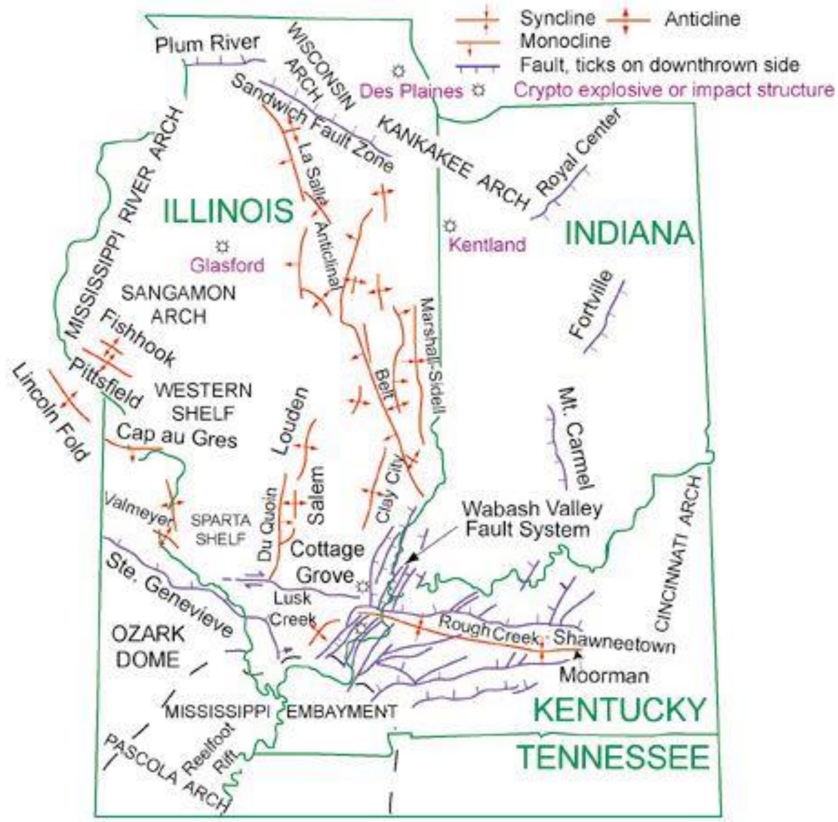

Figure 2.2. Major structural features of the Illinois Basin and bounding areas (after Buschbach and Kolata, 1991).

The dominant lithology of the geologic units in the Illinois Basin depends on which portion of the stratigraphy of the basin is inspected. The oldest rocks in the basin are predominantly granite and rhyolite basement rocks that are about 1,420 to 1,500 Ma old. As the basin transitioned into the Paleozoic, the lithology became dominated by carbonates with interbedded layers of siliciclastics resultant from tectonic activity (Swann, 1968).

In the study areas (Barren and Warren counties), the stratigraphy is mainly Mississippian-age rocks, with stratigraphic units mostly belonging to the Valmeyeran and Chesterian Series (Figure 2.3). The Valmeyeran Series makes up most of the units in the lowest part of the sections observed for this study. The main stratigraphic units of the Valmeyeran Series exposed are the St. Louis Limestone and the Ste. Genevieve Limestone. The Chesterian Series is commonly exposed in western Kentucky generally topographically above the karst areas such as in the Dripping Springs or Chester Escarpment areas with units such as the Girkin Limestone and the Big Clifty Sandstone. Lower to Middle Mississippian units are dominated by carbonates and in contrast, and the lithology becomes more siliciclastic rich as units approach the basal Pennsylvanian (Treworgy, 1991).

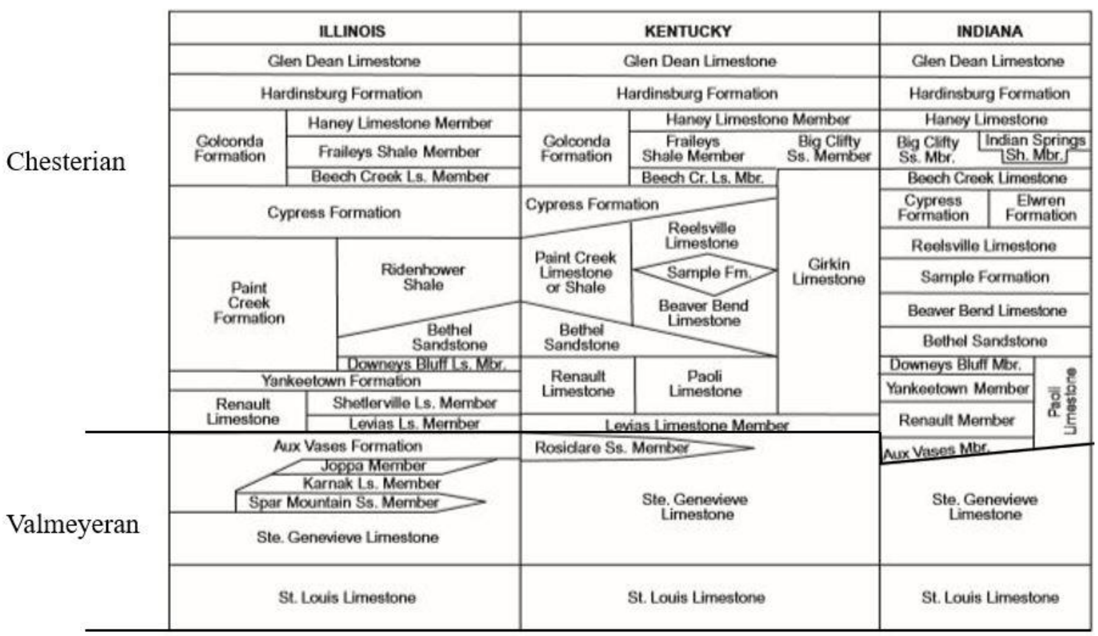

Figure 2.3. Stratigraphic columns of units in Illinois, Kentucky, and Indiana (after Nelson, Smith, and Treworgy, 2002).

2.2 Carbonate Depositional Environments

2.2.1 Standard Environments

Stratigraphic units such as the Ste. Genevieve Limestone were formed mainly by carbonate sediments being deposited in shallow-marine environments. It must be noted that there are numerous sub-environments and variations possible and thus, discussion of a series of detailed depositional models illustrating these sub-environments is warranted. A generalized depositional model for carbonates consists of sub-environments including a tidal flat region, lagoonal region, barrier/reef, a marine shelf, and a basin region (Figure 2.4). The differences between these subdivisions are basically a function of water depth and associated energy conditions. It should be noted that most of the Mississippian units are considered carbonate ramp deposits (Bachtel and Dorobek, 1998, and Smith and Read, 1999) but adjacent areas are tangentially discussed such as deep shelf to relatively deeper basinal areas.

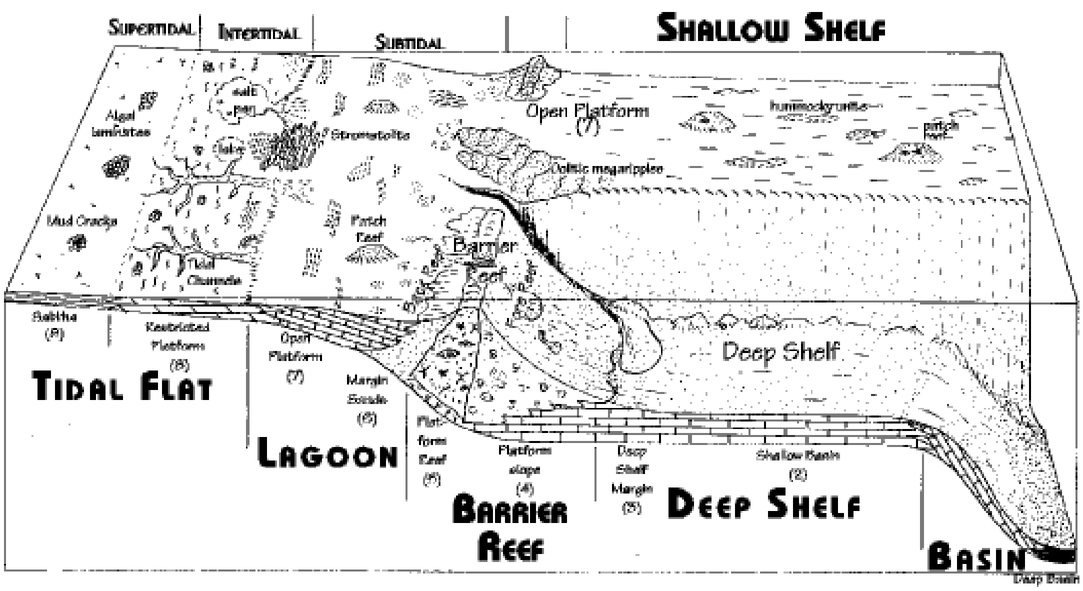

Figure 2.4. Standard model for a carbonate depositional environment and its subdivisions (after Harris, Moore, and Wilson, 1985)

2.2.1.1 Tidal Flats

The tidal flat region is the part of the environment that is closest to the terrestrial environment and thus is the most susceptible to terrestrial influence. A tidal flat is the most exposed of the carbonate environments, with tidal water waves being very small due to the shallow water and short fetch of the area (Fan, 2012). Tidal waters enter and leave a tidal flat through fairly straight, major channels, with minor channels serving as tributaries as well as distributaries (Murray et al., 2018; Desjardins, Buatois, and Mangano, 2012). Minor channels generally migrate and meander considerably over a period of several years. With the influence of both fresh terrestrial water and saline marine waters on the tidal flat, physical conditions such as temperature, salinity, and acidity tend to vary more widely than as are observed in other shallow-marine environments. Vegetation is minimal on a tidal flat and the biology of the environment consists of small marine animals such as crabs, burrowing organisms, shrimp, mollusks, encrusting foraminifera etc.

The tidal flat region is notable for the presence of both terrestrial and marine derived units which are associated with a great variety of lithofacies. Limestones and dolomites are common in this region, with limestones being relatively coarse grained, consisting of mostly packstones and grainstones with some small inclusions of muddier units, and dolomites consisting of fine-grained rocks (Matter, 1967). There are some deposits of quartz-rich sand in this region although these are usually fine grains deposited from bedload transport from terrestrial sources but with some influx of marine sands (Desjardins et al., 2012; Hantzschel, 1955). Sedimentary structures and other features that typify this region include laminations, mudcracks, burrows, pellets, and fossils (mainly brachiopods, gastropods, and ostracods). Overall, units in the tidal flat region are commonly thin and mixed with a few thicker units and significant intraclasts and inclusions (Daidu, Yuan, and Min, 2013).

2.2.1.2 Lagoons

The lagoon is the depositional environment that separates the tidal flat from the barrier reef or bioherm areas. A lagoon is best described as an area of relatively shallow, quiet water situated in a coastal environment and having access to the sea but separated from the open marine conditions by a barrier, usually a coral reef or a sandbar/barrier island. Lagoonal waters can possess a varying salinity, with brackish waters allowing for the growth of substantial vegetation and the formation of salt marshes, peat swamps and algal mats. Saline waters in contrast, allow for the deposition of evaporite minerals and stagnate anaerobic waters that may form black, organic-rich muds (Prothero and Schwab, 2004). Factors that control the formation and proliferation of lagoons are 1) sea-level fluctuation, with lagoons shifting landward as sea level transgresses and seaward as sea-level regresses, 2) shoreface dynamics, with the greater influence by terrestrial sediment as it is transported into a lagoonal setting (yielding significant sand deposits), and 3) tidal range, with the greater the influence by marine tides reflected in more marine sediments in the environment (Martin and Dominquez, 1994).

A lagoon is where marine influence starts to have a much greater effect on sedimentation and terrestrial influence begins to diminish. If a given lagoon is situated relatively far away from the shoreline, then any terrestrial sediments that are transported into the environment will be clay and silt from suspended load transport. Fine-grained, well sorted sands in contrast, will be deposited by tidal influence, and coarse sands will be deposited by high-energy storm events (Levy, 1974). Plentiful or dense vegetation and organic content of a lagoon results in dark organic-rich mud and peat. Due to the influence of organic and biologic components of the environment, sedimentary structures are rarely preserved in lagoonal facies (Brady, 1978).

2.2.1.3 Barrier/Reef

The depositional environment associated in a seaward direction from lagoonal facies usually falls within two categories, either a reef or a barrier. A reef is a ridge or hummock formed in shallow ocean areas by algae and the calcareous skeletons of certain coelenterates, of which corals are the most important. A barrier is a submerged or partly exposed ridge of sand or coarse sediment that is built by waves offshore from a beach, with buildup of barriers commonly growing to such an extent that they form barrier islands.

Depending on whether or not a reef or barrier develops, each depositional environment possesses a distinctive geological character that separates one from the other. Reefs are most distinctive for their extensive biological development, with coral reefs being a dominant expression of reefs or biological buildups on the sea floor. Reef deposits are characterized by very fossiliferous, skeletal carbonates (typically grainy deposits such as packstones and grainstones), with entire networks of coral being preserved in the geologic record (Boss and Liddell, 1987). A byproduct of coral-reef development is that the corals take in silica from the quartz sand in the environment, which results in the presence of silica concentration in the geological record (Perry, 2005). Additionally, silica-rich sediments can be contributed by sponges and similar organisms. These silica sources may be raw material for cherty intervals within the Ste. Genevieve Limestone.

A most distinctive characteristic of barrier environments is that their development is controlled by wave proliferation and thus result from a high-energy environment relative to other shallow-marine environments. With high-energy waves continually pounding, sand material is carried and eventually deposited where it encounters an area of relatively lower energy and if this happens continuously, then a barrier build up will result (Reynaud and Dalrymple, 2012). As a result of wave action, barrier deposition is dominated by sandy material such as fine-grained sandstones, but also grainy limestones (mostly grainstones), with the limestone units usually being oolitic (Colman, Berquist, and Hobb, 1988). The Ste. Genevieve Limestone is part of such a limestone unit, possessing skeletal and ooid intervals in the form of O'Hara and McClosky "sands." "Sands" are a driller's terms and are not to be confused with siliciclastic sand designations.

2.2.1.4 Marine Shelf

A marine shelf is a depositional setting composed of a broad, relatively shallow submarine terrace of continental crust forming the edge of a continental landmass. With the marine shelf being positioned so far from the shoreline, there is less influence from terrestrial sediment influx than in other marine environments and thus, deposition of units is dominated by marine processes. Marine shelves are subdivided into two parts: 1) shallow-marine shelf, where the water level is so shallow that marine waves have a great influence and 2) deep marine shelf, where water is so deep that marine tides have a relatively lesser influence on the deposition environment.

Deposits that characterize a marine shelf vary depending on whether they are associated with a shallow or deep shelf. In a shallow shelf environment, deposits are mainly fine-grained limestone units originating in the marine realm, with some fine silt and clay contributed by the terrestrial suspended load (Weimer, Porter, and Land, 1985). Typically, on a shallow shelf (such as along the Eastern Shelf of the Illinois Basin), there will be fine-grained sand deposits that are the result of waves scouring sand from the ocean floor and redepositing the material (Swift, 1974). In contrast to a shallow shelf, a deep shelf is not influenced by waves so there is a paucity of fine-grained sand deposits attributed to wave action however, submarine fans can develop at the slope break or at the edge of the shelf. Submarine fan deposits are typified by a mixture of fine- and medium-grained sand (Trumbull, Lyman, Pepper, and Thomasson, 1958). Similar to a shallow shelf, a deep shelf is dominated by limestone, but deep shelf limestones tend to be fine grained relative to the coarse-grained material typical of shallow shelf limestones.

2.2.1.2 Carbonate Ramp

Although the Harris and others' (1985) model is a good overview of the standard carbonate depositional environments (Figure 2.4), a more specific depositional model pertinent to the Ste. Genevieve Limestone is needed to be included in discussion to fully characterize the most typical environments expected or associated with deposition. With the Ste. Genevieve Limestone's depositional environments confined to shallow-marine environments, a carbonate-ramp model is the most appropriate for the unit.

A carbonate ramp is a type of carbonate platform where there is no major break in the slope between the shoreline and deep water. Carbonate ramps are typically characterized by sands in the inner ramp and muddy sands and mud in the outer ramp (Tucker, Calvet, and Hunt, 1993).

A carbonate ramp model can be divided into three parts (Figure 2.5) (Tucker, 1991): 1) back ramp, 2) shallow ramp, and 3) deep ramp. The back ramp is typically the closest to the shoreline and is thus close to sea level. Back ramp deposits are characterized by subaerial deposits such as lagoonal-tidal flat supratidal carbonates, evaporites, paleosols, and paelokarst modification. Dunham lithologies of back ramp deposits are most commonly wackestone and mudstone. The shallow ramp typically is positioned between the fair-weather wave base and sea level. Shallow-ramp deposits are characterized by wave-dominated deposits such as beach-barrier deposits, strandplain deposits, sand shoals, and patch reefs. Dunham Classification lithology of shallow ramp deposits are typically grainstones. The deep ramp is the most submerged of the ramp subdivisions, demarcating the area between the fair-weather wave base and the storm wave base. Deep-ramp deposits are characterized by thin bedded limestones, storm deposits, and mud mounds. Due to the variation in depositional environments, Dunham Classification of deep ramp deposits can range from mudstones to grainstones.

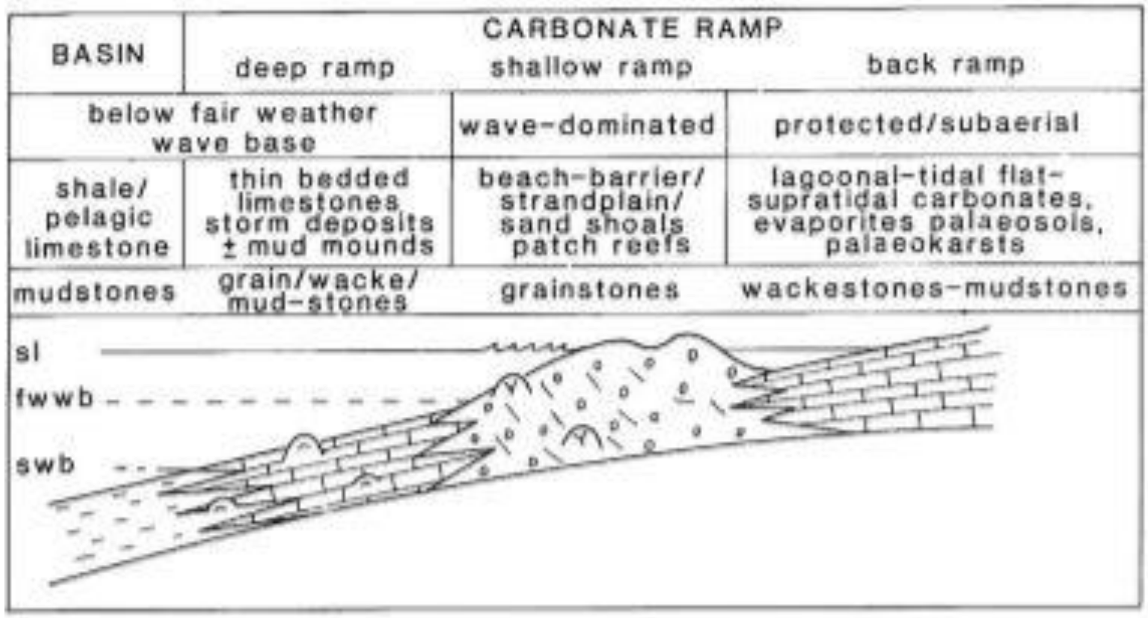

Figure 2.5. General model for a carbonate ramp. sl: sea level, fwwb: fair-weather wave base, and swb: storm wave base. (after Tucker, 1991)

2.3 Sequence Stratigraphic Concepts

Sequence stratigraphy is a branch of sedimentary geology that is focused on the punctuated order or sequence of depositionally related stratigraphic successions (time-rock) units that were laid down in the available space, termed accommodation. Sequence stratigraphy provides tools for interpreting the depositional origin and for predicting the heterogeneity, extent and character of lithofacies of interest (Catuneanu et al., 2011).

The idea behind sequence stratigraphy is based on the fact that successions of strata are bounded by a framework of major depositional and erosional surfaces (the latter termed sequence boundaries) and that successive strata have a characteristic depositional geometry. This depositional framework can be interpreted to be in part the result of relative sea-level change (termed relative coastal onlap, downlap, etc.), with depositional and erosional surfaces developing during the deposition and erosion of strata (Christie-

Blick and Driscoll, 1995). Transgressive surfaces are formed as a result of sea-level rise, with a maximum flooding surface (MFS) being the surface created when water in an environment attains its highest level in any given sea-level cycle, and a sequence boundary represents the lowest point in a sea-level cycle.

A sequence is best described as the collection of strata that are deposited (and partially eroded in some cases) in a complete sea-level rise and fall cycle. Strata in a sequence are divided into system tracts (STs) depending on which point in a sea-level cycle that the strata are deposited in and associated with as depositional units. The system tracts are (*sensu* Hunt and Tucker, 1995) (Figure 2.6):

1. Falling Stage System Tract (FSST): includes all the regressional deposits that accumulated after the onset of a relative sea-level fall and before the start of the next relative sea-level rise. A FSST rests directly atop a sequence boundary (SB).
2. Lowstand System Tract (LST): includes deposits that accumulate after the onset of relative sea-level rise. The LST lies directly on the upper surface of the FSST and is capped by a transgressive surface.
3. Transgressive System Tract (TST): comprises deposits that accumulated from the onset of coastal transgression until the time of maximum transgression of the coast, just prior to the renewed regression of the HST. The TST lies directly on the transgressive surface of the LST and is overlain by an MFS.
4. Highstand System Tract (HST): An HST constitutes the upper system tract of a stratigraphic sequence and lies directly on the MFS formed when marine sediments reached their most landward position. The HST is capped by a sequence boundary.

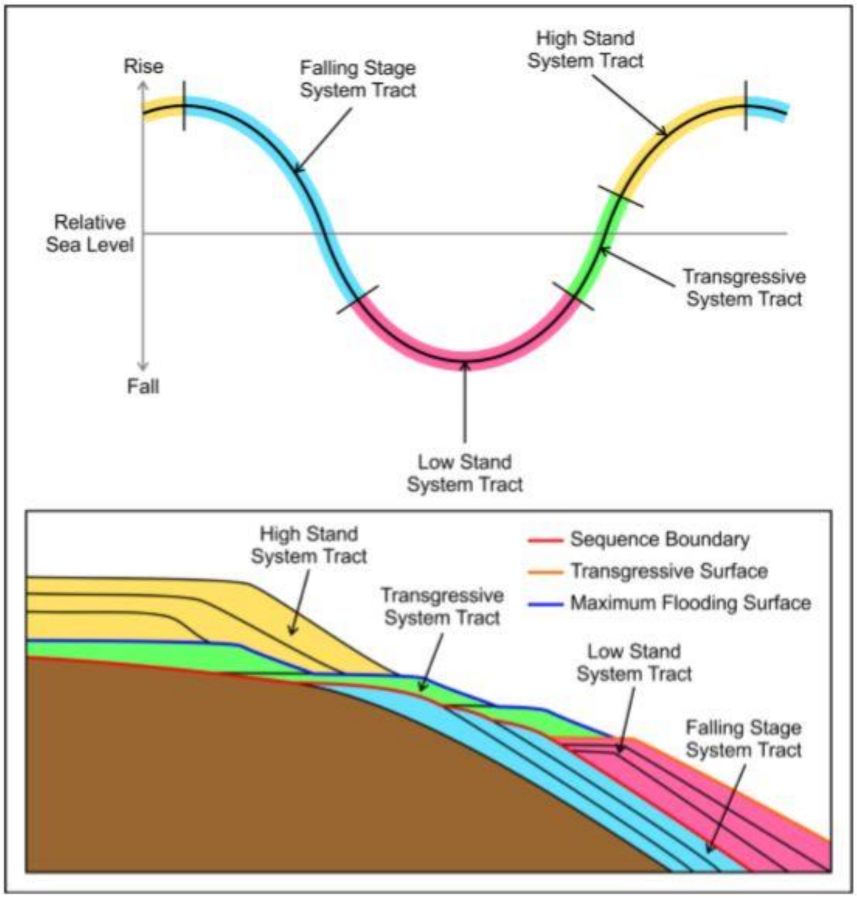

Figure 2.6. Diagram of a complete relative sea-level cycle, the corresponding system tracts, and bounding surfaces (after Wright et al., 2013).

Sequence stratigraphy is applicable to both siliciclastic- and carbonate-stratigraphic units, however, there are key differences between clastic- and carbonate-sequence stratigraphy. One of the main differences between siliciclastic- and carbonate-sequence stratigraphy is that carbonate units are formed via "*in situ* production" as opposed to siliciclastics that possess transported grains commonly deposited distally from a sediment source area in a given basinal setting (Wang, Shi, Cheng, and Zang, 2018).

Siliciclastic units are transported to their depositional setting through processes such as weathering, erosion, transportation and deposition and thus only respond to hydrodynamic thresholds and are limited by their physical accommodation space.

Carbonate rocks in contrast, result mainly from buildup of skeletal remains of marine organisms (such as phytoplankton, corals, mollusks, etc.) which reflects that the units are formed within their depositional environment. With carbonate formation being dependent on marine organisms, water depth is a substantial factor in carbonate production (e.g., such as those associated with the photic zone) and specific types of sediments. There of course can be many possible microfacies in carbonates (Flugel, 2010).

Carbonate production is described as being necessarily intrabasinal, with a generalized model of the depositional environment defined as a carbonate ramp. Carbonate production is mostly limited to the photic zone, with changing water level controlling the alternating facies (Pomar and Ward, 1995). As sea level lowers, the carbonate platform is exposed, resulting in erosion and karstification of the platform and simultaneously, formation of evaporites in the lower basin waters or restricted lagoons. Accommodation is generated for the carbonate ramp as sea level rises, however, if sea level rises too rapidly, this will drown the platform, resulting in carbonate production ceasing. Such a process in turn, can lead to siliciclastics being introduced into the environment (Pomar and Ward, 1994).

Carbonate-sequence stratigraphy uses the same system tracts as in siliciclastic-sequence stratigraphy but there are key differences between them (Figure 2.7). The HST is associated with the most favorable conditions for carbonate production on the platform and the deep-water setting, with carbonate formation outpacing accommodation. This results in excess carbonate sediment transferring to the basin. The HST is the case in which carbonate sand production is highest and thus most likely to produce grainy, high-porosity hydrocarbon reservoirs. In a carbonate system, the FSST and the LST are usually considered as a single systems tract (Plint and Nummedal, 2000). This is because any fall in base level, even of relatively low magnitude leads to rapid regression and subaerial exposure of the platform. The LST-FSST is a case in which carbonate production ceases and karstification of the platform occurs, generally being a function of global climate change that forces a change in base level (e.g., eustatic sea-level change). The TST in a carbonate system has sea level rising via two stages: slow transgression and rapid transgression. Slow transgression is associated with internal cycles of carbonate successions, which do not interrupt carbonate production. Rapid transgressions alternatively are associated with terminal cycles of carbonate successions, which leads to the drowning of carbonate platforms and a change from carbonate to clastic systems. The SB and MFS are present in a carbonate system; however, the stratigraphic sequences are commonly truncated and incomplete, thus these boundaries may not be present in a carbonate system that are under investigation (Petty, 2010).

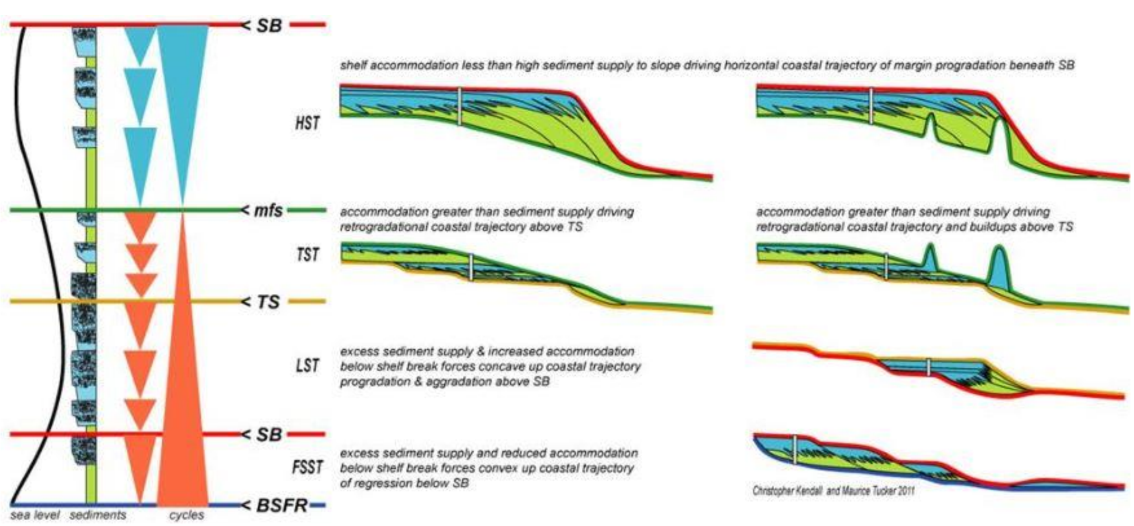

Figure 2.7. Diagram of system tracts in a carbonate system and their corresponding makeup of the carbonate platform (after Catuneau et al., 2011).

2.4 Ste. Genevieve Limestone

2.4.1 Stratigraphy

The Ste. Genevieve Limestone is a Mississippian-age unit named after the town of Ste. Genevieve, Missouri, where the unit was first documented at the type section established by Shumard (1859). The unit is present in outcrop or surface exposures in states such as Missouri, Illinois, Indiana, Kentucky, and Tennessee and in the subsurface of the Midcontinent such as in Kansas among others.

The Ste. Genevieve Limestone overlies the St. Louis Limestone, with the latter being dominated by limestone with a scattering of interbedded chert layers (Fielding, 1971; Marcher, 1962). The Ste. Genevieve Limestone is overlain by the Girkin Limestone, a carbonate unit with interbedded shales and sandstones (Craig and Conner, 1980) (Figure 2.8). A notable aspect of the stratigraphic relationship between various Mississippian units is that the shift from the St. Louis Limestone to the Ste. Genevieve Limestone is marked by a transitional environment that shares characteristics with both the underlying and overlying units (Fielding, 1971). The stratigraphy of the St Louis, Ste. Genevieve, and Girkin Limestones for example is dominated by carbonates, primarily limestones, with the main difference between the units being their lithology (fine to coarse limestone etc.), fossil content (biostratigraphic zonation), and other characteristics. The lithofacies that constitute these units tend to be grainstones, packstones and mudstones/wackestones, with the few non-carbonate units usually being shales (Metzger, Fike, Osburn, Guo, and Addison, 2015).

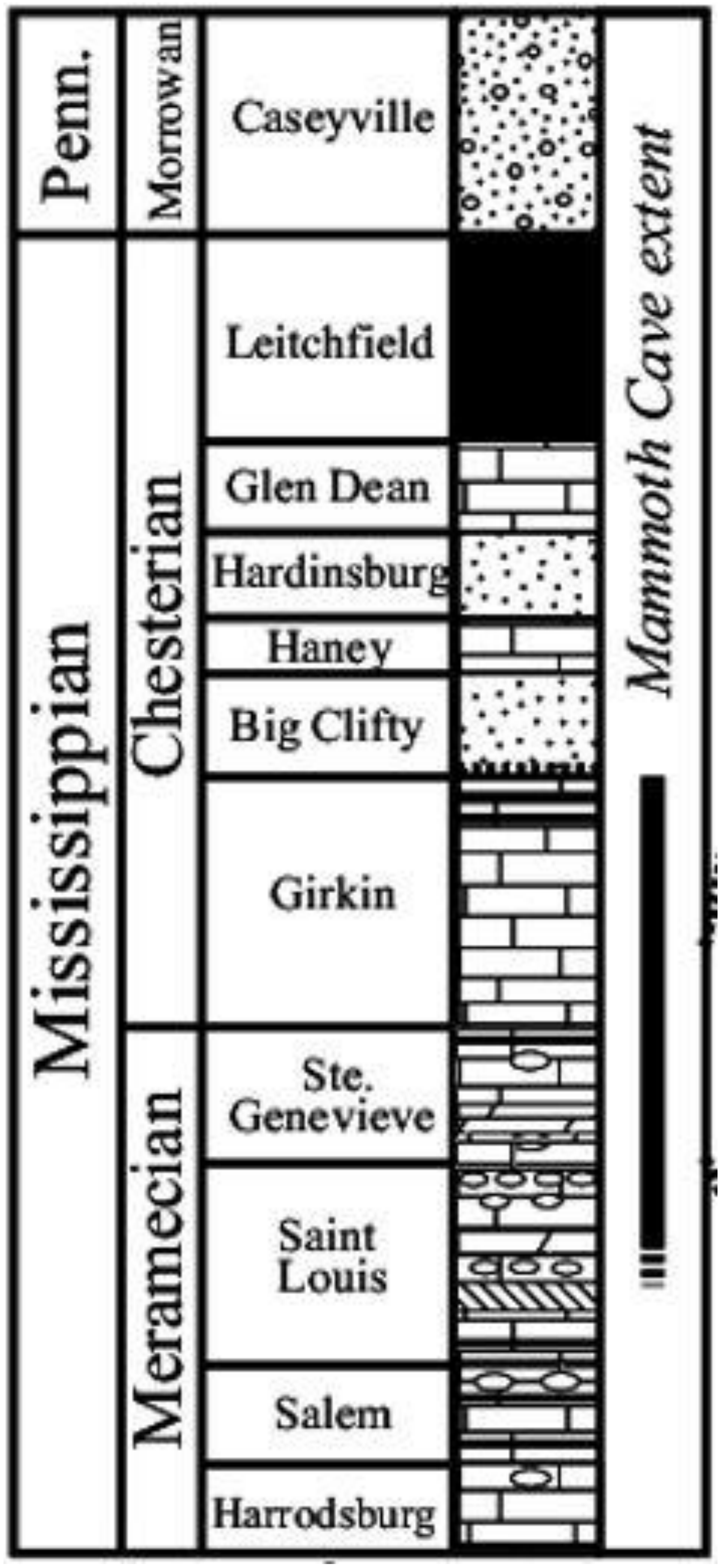

Figure 2.8. A stratigraphic column in the Mammoth Cave region in western Kentucky (after Metzger et al., 2015). Note that part of study area near Park City is close to Mammoth Cave.

2.4.2 Ste. Genevieve Limestone in Various Localities

Western Kentucky, specifically Warren County and Barren County, is the focus area for this study, however, it is important to note the differences in the Ste. Genevieve Limestone in other localities in order to account for regional differences. Table 1 below is a summation of different localities of the Ste. Genevieve Limestone and the dominant lithofacies determined by various researchers.

Equivalent Outcrops	**Dominant facies**	**References**
Missouri	Cross-bedded skeletal limestone, argillaceous limestone, shale, fine-grained sandstone	(Short, 1962)
Southern Illinois	Ooid grainstone, skeletal-ooid grainstone, skeletal grainstone, skeletal packstone, skeletal wackestone, lime mud	(Rao and Mann, 1972)
Southern Indiana	Cross-laminated bioclastic grainstone, bioclastic mudstone, fossiliferous grainstone, nonfossiliferous mudstone	(Hunter, 1993)
South-central Kentucky	Very fined to coarse grained cross-laminated bioclastic grainstone with very thin stingers of chert towards the base, mudstone containing very fined to very coarse bioclastic grains, very fine to very coarse fossiliferous bioclastic grainstone, nonfossiliferous grainstone and mudstone containing thin beds of chert	(Dever, 1999)
Western Kentucky	Brachiopod grainstones, oolitic and bioclastic grainstone, chert replacing limestone, dolostone, intraclastic conglomerate and breccia, supratidal limestone with typical fenestral porosity (birdseye vugs)	(May et al., 2007)
Southern Illinois and Eastern Missouri	21 distinct depositional environments, suggest numerous different facies	(Rao and Mann, 1972)

Table 1. Equivalent outcrops organized by state, dominant lithofacies and references.

2.4.3 Potential Hydrocarbon Reservoirs and Associated Traps/Seals

The Ste. Genevieve Limestone is classified as a carbonate reservoir that produces significant hydrocarbons in the Illinois Basin. The lithologic facies that are of great interest historically include oolitic shoals, dolostone units, and skeletal grainstones but many workers have concentrated solely on oolitic rocks (e.g., Keith and Zuppan, 1993, and Zuppan, 1989).

Oolitic shoals are carbonate rocks that are made up primarily of ooids, sand-sized carbonate particles that have concentric rings of $CaCO_3$, hence the “drillers” term “sands” for the O’Hara and McClosky reservoirs (Cliff, 1984). These concentric spherical bands are formed around grains of sand or shell fragments that were rolled around on the shallow sea floor, gathering layer after layer of carbonate material. This happens because as the shoal builds up in the shallow sea floor, CO_2 is released due to agitation by tidal currents and this in turn drives $CaCO_3$ precipitation. Oolitic shoals are primarily present in shallow-marine depositional settings that are typically proximal to tidal flats that are constantly impacted by the influence of tides. Such a repeated back and forth motion of the tidal current creates the optimal environment for the occurrence of ooids (Ball, 1967). Modern day examples of ooid shoals occur in parts of the Great Bahama Bank. The depositional environments for oolitic shoals are typified by prograding shorelines, lagoonal areas, tidal inlets, and open shelf areas of ocean (Figure 2.9). With oolitic shoals being deposited in wave influenced environments, they likely originate in association with HSTs.

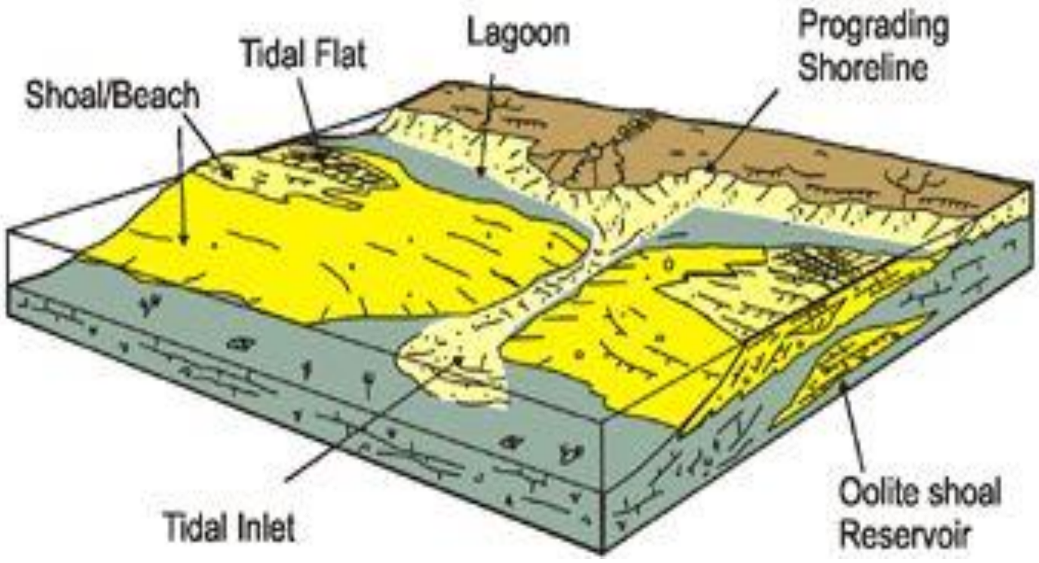

Figure 2.9. Typical ooid shoal depositional environment (after Hanford, 1988)

According to Carr (1973), oolitic shoals make up roughly 22% of the Ste. Genevieve Limestone in the Illinois Basin, with equivalent stratigraphic units present in southern Missouri, Kentucky, Illinois and beyond (e.g., in the subsurface of western Kansas) (Slamal, 1999). The oolitic shoal roadcuts studied originated as a sand belt with similar features as oolitic shoals in parts of the western side of the Great Bahama Bank. Oolitic shoals studied were observed to have a high porosity in both the central part of the oolite deposit as well as the exterior edge, which is very similar to other oolitic shoals researched in the Illinois Basin, suggesting these are significant petroleum reservoirs.

There are structural (i.e. fold and fault) trends that affect the orientation and formation of ooid shoals. Fouke and Gibson (2002) state that due to strong NW-SE tidal currents at the time of deposition, ooid shoals in the Ste. Genevieve Limestone in Lawrence County Indiana for example characteristically are oriented NW-SE. The result of this is that ooid shoals that are hydrocarbon reservoirs orient in these similar directions, showing how tidal currents affect the spatial distribution of ooid shoals. There are some overall structural trends associated with the orientation of ooid shoal hydrocarbon reservoirs. Productive hydrocarbon reservoirs tend to be oriented around faults and folds (Zuppan, 1989) (Figure 2.10).

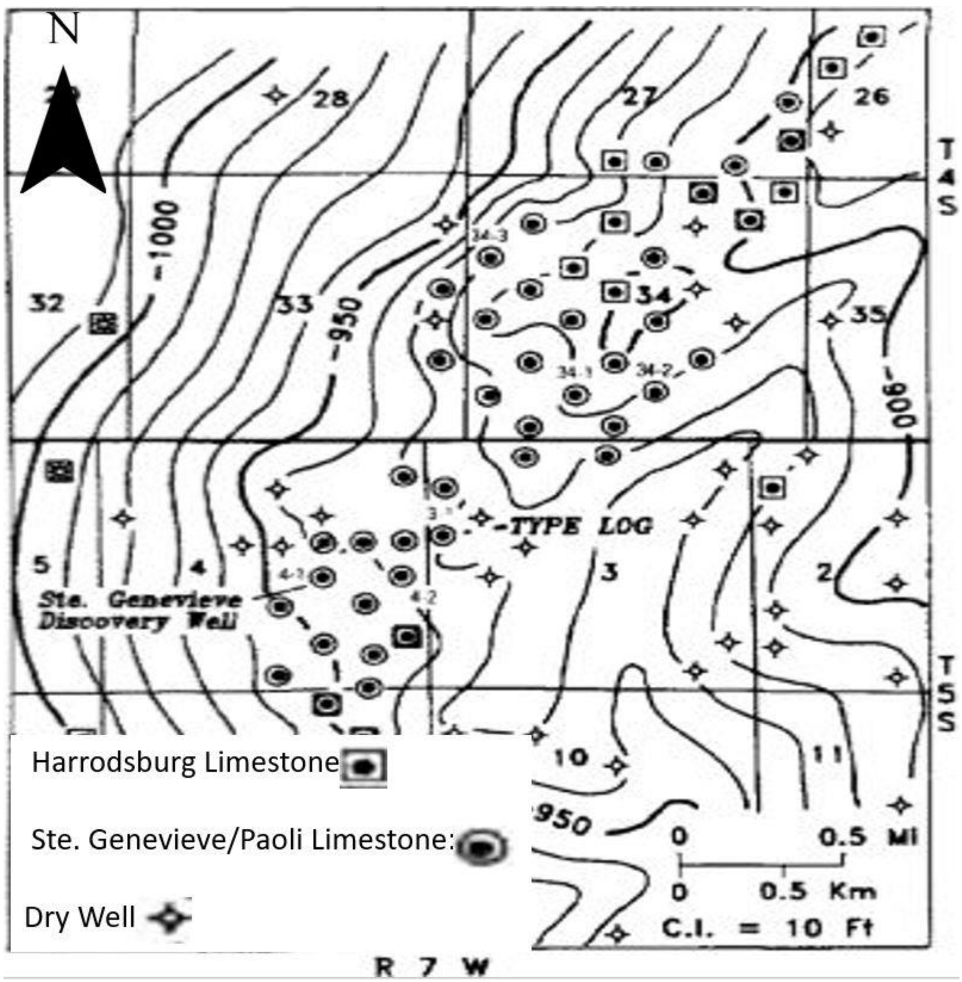

Figure 2.10. Structure contour and oil well map on top of Ste. Genevieve Limestone in the Folsomville, Warrick County, Indiana field area. The overall distribution pattern of wells in the area closely aligns with folds, particularly in the northeastern area. Note closure on structure drawn on top of an unknown Mississippian strata, defining the anticline in section 34 with a 10-ft contour interval shown (after Zuppan, 1989).

Oolitic shoals are commonly observed as the main hydrocarbon reservoir that appears in limestone stratigraphic units (Keith and Zuppan, 1993). However, there are other facies that can occur that have significant hydrocarbon reservoir potential. Other units of potential interest for hydrocarbon development in the Ste. Genevieve Limestone are dolomitic units and skeletal grainstones. Dolostone is a sedimentary rock that is composed primarily of the mineral dolomite [$CaMg(CO_3)_2$].

Sediments accumulating to form dolostone are deposited in an environment as calcium carbonate but are chemically transformed into dolostone by a process called dolomitization. Dolomitization occurs when calcite, ($CaCO_3$), the main mineral in limestone, is transformed by magnesium-rich water and then recrystallizes into a solid rock again through a process of dissolution and precipitation or by chemical "replacement." This influx of magnesium causes the calcite in the limestone to be changed into dolomite and thus the limestone becomes dolostone. Dolomitization can occur in varying degrees, with partially dolomitized limestone being classified as dolomitic limestone and limestone that has been completely dolomitized classified as dolostone (Choquette and Steinen, 1980). There have been numerous models proposed for dolomitization processes (Table 2). A relatively recent model is recrystallization, in which a favorable environment for calcite replacement by dolomite builds up into layers and then crystalizes to form dolomitic limestones through many cycles of deposition and recrystallization of previous units (Machel, 1997).

Dolomitization Model	Source of Mg^{2+}	Delivery Mechanism	Hydrologic Model	Predicted Dolomite Patterns
A. Reflux Dolomitization	seawater	storm recharge, evaporative pumping density-driven flow		
B. Mixing Zone (Dorag) Dolomitization	seawater	tidal pumping		
C1. Seawater Dolomitization	normal seawater	slope convection ($K_V > K_H$)		
C2. Seawater Dolomitization	normal seawater	slope convection ($K_H > K_V$)		
D1. Burial Dolomitization (local scale)	basinal shales	compaction-driven flow		
D2. Burial Dolomitization (regional scale)	various subsurface fluids	tectonic expulsion topography-driven flow		
D3. Burial Dolomitization (regional scale)	various subsurface fluids	thermo-density convection		
D4. Burial Dolomitization (local and regional scales)	various subsurface fluids	tectonic reactivation of faults (seismic pumping)		

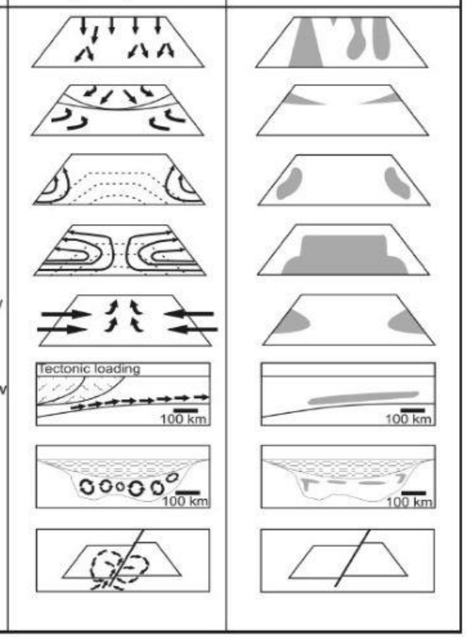

Table 2. Models of dolomitization organized by Mg^{2+} source, delivery mechanism, hydrologic model and predicted patterns (after Machel, 2005).

Dolostone acts as a hydrocarbon reservoir in a geologic unit under very specific circumstances. When a limestone is dolomitized, the skeletal grains that are contained in the limestone are not removed from the unit and the resulting dolostone is of less volume than the original limestone. As a result, grains and matrix material in the dolostone are concentrated in a much smaller volume. An ideal dolostone reservoir will possess fine-grained limestone overlaying and underlying it, with the relatively fine-grained limestones units acting as a “trap” that seals the dolostone layer, preventing emplaced hydrocarbons from moving laterally (Ray, Sharma, and Chopra, 2014).

Dolostone units have been shown to be productive hydrocarbon reservoirs in various localities ranging from Ohio (Miken and Castagna, 2003) to China (Xiao et al. 2017). Choquette and Steinen (1985) conducted research on hydrocarbon reservoirs in the

Ste. Genevieve Limestone at North Bridgepoint, Illinois. They discovered that the two prominent hydrocarbon reservoir facies at this location were oolitic limestones and microbial dolostone (dolomitization resulting from microbial action). Their research shows that there are productive dolostone reservoirs in the Ste. Genevieve Limestone.

Skeletal grainstones are stratigraphic units of interest that have some commonality with dolostone/dolomitic units. Skeletal grainstones are carbonate units that were deposited in relatively high-energy marine environments that led to the deposition of coarse grains. Skeletal grainstones are defined by their abundant fossil content. Similar to dolostone units, skeletal grainstone units are ideal hydrocarbon reservoirs in the case in which these rocks are enclosed by fine-grained units, such as mudstone/wackestone or shales. In the case of skeletal grainstone, when the unit is positioned like this, hydrocarbon material is prevented from migrating outward. The enveloping fine-grained units may act as a “trap” and this permits hydrocarbon accumulation as in the case of dolomite reservoirs. Skeletal grainstones appear to have some overlap with ooid shoals, with studies showing hydrocarbon reservoirs consisting of skeletal grainstones with high ooid content and ooid shoals comprising grainstones (Bebout, Major, and Harris, 1994).

It must be noted that an important parameter for identifying potential hydrocarbon reservoirs is the enveloping stratigraphic layers that underlay and overlay the potential reservoir. As previously referenced in regard to dolomitic and grainy limestone reservoirs, the ideal stratigraphic setting for a potential hydrocarbon reservoir is one in which the reservoir is enclosed by fine-grained material with low porosity and permeability such as by either siliciclastic or carbonate mudstone (Ray et al., 2014). Within such a scenario, hydrocarbons will be confined into the reservoir unit and thus will not migrate out unless the confining layers are penetrated. A notable aspect of this is that with a confining layer necessarily possessing low permeability and porosity, units that have traditionally been considered as reservoir units can instead act as confining units, such as shales (Downey, 1984). An example of this is fine-grained dolostone, with dolostone units behaving as if comparable to mudstone and wackestone limestone units in the sense of a stratigraphic trap (Lan and Lu, 2013).

Diagenetic controls are important characteristics to consider in reservoir rocks, with examples such as stylolites and paelokarst. Stylolites are serrated surfaces within a rock mass at which minerals have been removed by pressure dissolution, resulting in a decrease in total rock volume (Toussaint et al. 2018). Insoluble minerals or material, such as clays, pyrite and sequioxides, remain within the stylolites and make them visible. This process commonly results in the formation of thin layers of low permeable material that impede fluid flow and thus act as confining layers (Padmanabhan, Sivapriya, Huang, Askury, and Chow, 2015; Tada and Siever, 1989).

Paelokarst is karst (limestone) features that represent ancient exposure and dissolution surfaces that are subsequently buried in sediment that becomes lithified. The result of such preservation of paleokarst features results in an increase in porosity of the affected unit while largely maintaining their mineral/hydrocarbon content (Hollis, 2011). An example of a paelokarst unit is brecciated limestone. Brecciated limestone is a unit composed of eroded limestone clasts reincorporated or included into a geologic unit. Studies have shown that paelokarst lithologies such as breccia are key reservoirs in numerous locales such as west Texas (Kerans, 1988), the Middle East (Hollis, 2011), and China (Tian et al., 2017).

3.0 METHODS

The methods that were used to analyze the lithological character of the Ste. Genevieve Limestone are typical of other field focused studies. At each of the roadcuts, exposed rocks were measured and the different lithologies encountered were analyzed and classified by their grain size, mineralogy, fossil content, sedimentary structures, sedimentary facies, color and other characteristics. These data were placed within the graphics, photographs and text descriptions generated as part of the stratigraphic section measurement effort. With the Ste. Genevieve Limestone being composed of primarily carbonates, it is important to differentiate the types of carbonates in the roadcuts to better understand their characteristics. To accomplish this, the carbonates in roadcuts were classified using the modified Dunham Classification (Dunham, 1962, and Embry and Klovan, 1971). In this system, carbonates are classified primarily on the basis of being mud-supported versus grain-supported or by what is referred to as depositional texture. The classification used for this study uses only the mudstone, wackestone, packstone, and grainstone monikers because the other distinctions are not pertinent to this study (such as boundstone, bindstone etc.). This classification is used because it is the standard for classifying carbonates in the field since it conveys the original depositional texture of rocks at a hand-sample scale (Table. 3). In order to make descriptions of the lithofacies more systematic and consistent, the Munsell soil color chart (Macbeth, 1998) is used to describe the colors of the lithofacies.

<table>
<tr><td colspan="6">Allochthonous carbonates
original components not organically bound during deposition</td><td colspan="3">Autochthonous limestones
original components organically bound during deposition</td></tr>
<tr><td colspan="4">Less than 10% >2-mm components</td><td colspan="2">Greater than 10% >2-mm components</td><td colspan="3">Boundstone</td></tr>
<tr><td colspan="3">Contains lime mud (<0.03 mm)</td><td>No lime mud</td><td rowspan="3">Matrix supported</td><td rowspan="3">>2-mm component supported</td><td rowspan="3">By organisms that act as bafflers</td><td rowspan="3">By organisms that encrust and bind</td><td rowspan="3">By organisms that build a rigid framework</td></tr>
<tr><td colspan="2">Mud supported</td><td colspan="2" rowspan="2">Grain supported</td></tr>
<tr><td>Less than 10% grains (>0.03 mm to <2 mm)</td><td>Greater than 10% grains</td></tr>
<tr><td>Mudstone</td><td>Wackestone</td><td>Packstone</td><td>Grainstone</td><td>Floatstone</td><td>Rudstone</td><td>Bafflestone</td><td>Bindstone</td><td>Framestone</td></tr>
</table>

Table 3. Modified Dunham Classification (after Embry and Klovan, 1971).

To understand the characteristics of the Ste. Genevieve Limestone in study areas, roadcuts were analyzed in both vertical and horizontal dimensions. Using whatever tools were convenient to measure the units (in the case of this study, a yard stick or Jacob's staff for the roadcuts that are few feet high and a tape measure for the larger roadcuts and a ladder), the vertical dimension was measured for stacking patterns and horizontal extent was studied for facies changes in units. By understanding the vertical and horizontal transitions in the Ste. Genevieve Limestone roadcuts, this aids understand of the depositional environments and how depositional processes changed over time. This was accomplished with study of seven roadcuts to reduce uncertainly in the characterization of the Ste. Genevieve Limestone. These roadcuts are typically eight hundred to one-thousand feet long and ten- to thirty-feet high, with a few larger roadcuts. Each roadcut was in turn subdivided into three different measured stratigraphic sections, for a total of twenty-one for the entire study. With a key aspect of this study focusing on the hydrocarbon potential of certain stratigraphic intervals, it is imperative that results are comparable to existing databases (such as the Kentucky Geological Survey well log database). To accomplish this, the roadcuts were measured in feet, as were the stratigraphic column cross sections instead of the SI or metric standard. This fieldwork was conducted to make it easier to compare the lateral and vertical transition between the roadcuts. An alphabetical naming scheme is used to identify units in the roadcuts, with A being the lowest in a given roadcut and subsequent units named in ascending order (A, B, C, D, etc.). This scheme is used individually in each roadcut, meaning that a given unit A in one roadcut doesn't necessarily correlate to a designated unit A in another roadcut.

In order to adequately analyze the lithofacies in the roadcuts, samples were retrieved to be cut into slabs. At each roadcut, a sample was taken from each of the identified stratigraphic units, with the samples marked for their stratigraphic unit context and vertical orientation. Samples collected were then taken to the WKU Geography & Geology rock prep lab where they were cut into slabs. Once the slabs were cut, they were then hand sanded first using 200 grit and then 400 grit. This was done to remove any saw blade cutting marks and overall just to make the slabs more presentable. This cutting and grinding work on the slabs was conducted in order to study the internal structure of the rocks and for observing, describing and interpreting details such as fossil content, grain size, Munsell color, and to provide a Dunham Classification name. Finally, for photographing the slabs, each was sprayed with two layers of clear acrylic or shellac spray in order to make the details of the slabs easy to identify providing a pseudo-polished look.

4.0 STUDY AREA

This study focuses on roadcuts in Warren and Barren counties in Kentucky, with the intent that these exposures could be correlated and placed in stratigraphic context within this portion of the Illinois Basin. Originally, this study was to focus solely on roadcuts in Warren County however, it was eventually decided based on initial field work that there are too few roadcuts available for study of the Ste. Genevieve Limestone in Warren County. As a consequence, roadcuts in the Barren County were also included to create a better analysis of the studied stratigraphic unit.

4.1 Warren County Roadcuts

A total of five roadcuts were analyzed as part of this study. These roadcuts are found in three primary locations: 1) Kentucky State Highway (Hwy) 1435, Barren River Road, 2) Kentucky State Highway 185 (Hwy 185), north of Bowling Green, and 3) US Interstate 65 (I-65) (Figure 4.1).

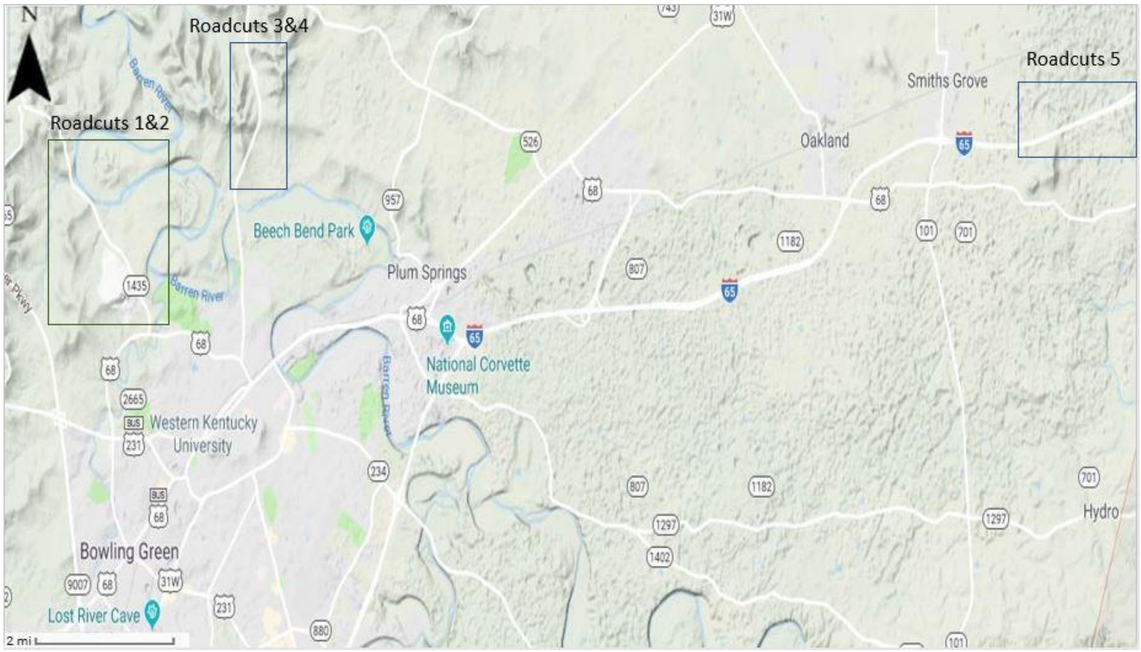

Figure 4.1. Map of Warren County with general locations of roadcuts shown within rectangles. Map created by author using Google Maps (March 2019).

4.1.1 Barren River Road Roadcuts

The Barren River Road area is located in the northwestern outskirts of Bowling Green, with the road following its namesake, the Barren River. Stratigraphically, the area is dominated by the Ste. Genevieve Limestone, with the Girkin Limestone and Big Clifty Sandstone becoming pronounced further northwest of the area and Quaternary alluvium (not part of this study) present along the Barren River (Figure 4.2). There are two roadcuts that were studied in this area, one at mile marker 2 and the second near Belle Rive Circle (approximately mile marker 3). The Mile 2 Roadcut is a moderate sized roadcut at roughly 20 feet high, but the Belle Rive Circle Roadcut is notable for being the largest of the roadcuts analyzed for this study at approximately 70 feet in height cut along several benches.

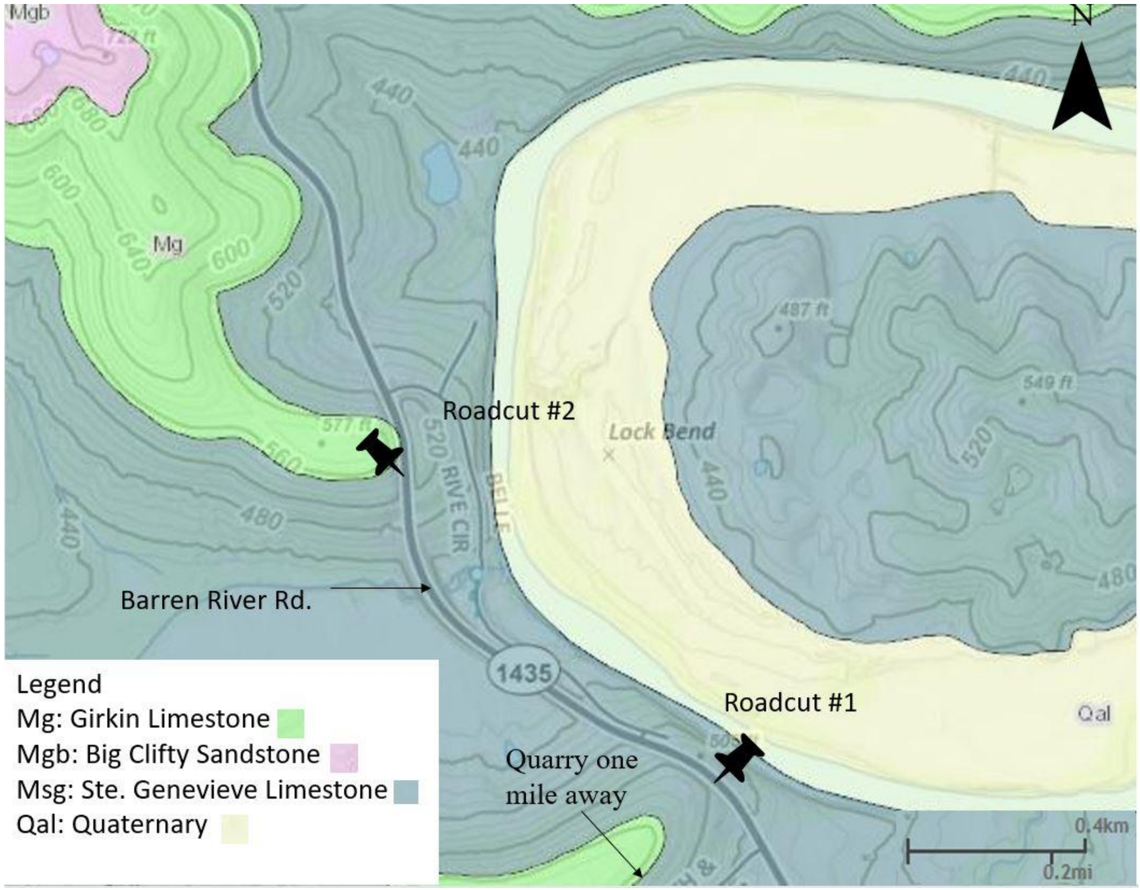

Figure 4.2. Geologic map of the Barren River Road area. The subdivisions for geologic material in the area are: Msg (dark blue) Ste. Genevieve Limestone, Qal (light yellow) Quaternary Alluvium, Mg (green) Girkin Limestone, and Mgb (magenta) Big Clifty Sandstone. Map was created by the author using the KGS (Kentucky Geological Survey) map information service accessed March 2019.

Structurally, the stratigraphic units of the Barren River Road area dip toward the northwest, expressed as structural contours declined to the northwest (Figure 4.3). The contours represent the elevation at the base of the Big Clifty Sandstone, which decrease to the northwest with an elevation high of less than 720 feet. There is an abrupt break southeast of the area where the contours change from positive to negative values (i.e. from above sea level to subsea elevations) ranging from -260 feet to -300 feet, with these contours (red lines on map) being drawn on the top of the Chattanooga Shale as the structural datum.

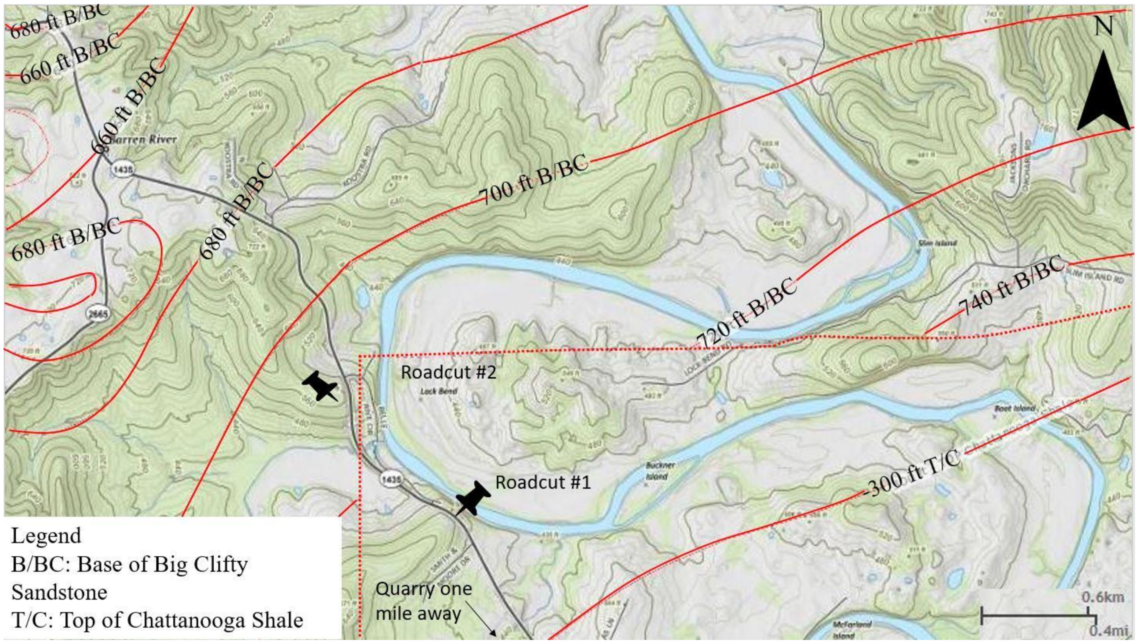

Figure 4.3. Structural contour map of the Barren River Road area (March 2019). Chattanooga Shale contours occupy the southeastern part of the map and the Big Clifty Sandston contours are in the northwestern part of the map. There is an abrupt change from the Chattanooga Shale to the Big Clifty Sandstone contours halfway along Barren River Road in this view. With the KGS map information service data (such as structural contours and scale) being in English measurement units, these units were not converted to metric to make the figures comparable to the database. Map was created by the author using the KGS map information service.

A helpful feature of the Barren River area is that there is a large limestone quarry near the studied roadcuts (one mile to the southeast of bottom of Figure 4.3). The Martin Marietta Materials, Bowling Green South Quarry is a quarry that shares data with Kentucky Geological Survey (KGS) which allows data collected from the site to be accessed by the public through the KGS map information service. The data analysis of the quarry shows that there are samples from the Ste. Genevieve Limestone that have a range of mineralogical compositions. Some intervals have a high percentage of $MgCO_3$, which suggests the presence of dolostone, and SiO_2, which is indicative of chert deposits (Table 4). While it is unfortunate that these are bulk (i.e. whole rock analysis) samples, these data however, provide some insight into the detailed potential lithology that can be observed in roadcuts.

Section ⓘ	Ledge ⓘ	Unit	Bottom (ft)	Top (ft)	No. of Samples	CaCO3	MgCO3	Al2O3	Fe2O3	SiO2	P	S
1	4	Ste. Genevieve Limestone	9	27	18	93.56	3.72	0.12	0.19	1.73	0	0
1	3	Ste. Genevieve Limestone	7	9	2	63.65	24.7	2.46	0.88	7.68	0	0
1	2	Ste. Genevieve Limestone	5	7	2	93.9	1.81	0.3	0.31	2.28	0	0
1	1	Ste. Genevieve Limestone	0	5	5	96.9	1.79	0.06	0.13	1.11	0	0

Table 4. Chemical analysis of Ste. Genevieve Limestone quarry samples from the Martin Marietta Materials Bowling Green South Quarry. Data table acquired directly from KGS Limestone and Dolostone resources database (accessed March 2019).

4.1.2 Kentucky State Highway 185 Roadcuts

The Hwy 185 roadcuts are located in the northern outskirts of Bowling Green. The stratigraphy of the area is dominated by the Ste. Genevieve Limestone in the south, but further north the Girkin Limestone and Big Clifty Sandstone are exposed, mainly a result of the increase in elevation as one traverses out of the karst plain and up the Chester Escarpment (Figure 4.4). There are two roadcuts analyzed from this area, the Eversole Rd. Roadcut and another about half a mile down the road by a Crossroads (IGA) fuel station. The Eversole Rd. Roadcut is the larger of the two with the roadcut being 25 feet high, and the Crossroads Roadcut is roughly 10 feet in vertical extent. A notable aspect of both roadcuts is the dramatic change in elevation from one end of one roadcut to another. The Eversole Rd. Roadcut goes from 551 feet to 571 feet whereas the crossroads roadcut extends from 522 feet to 591 feet in elevation.

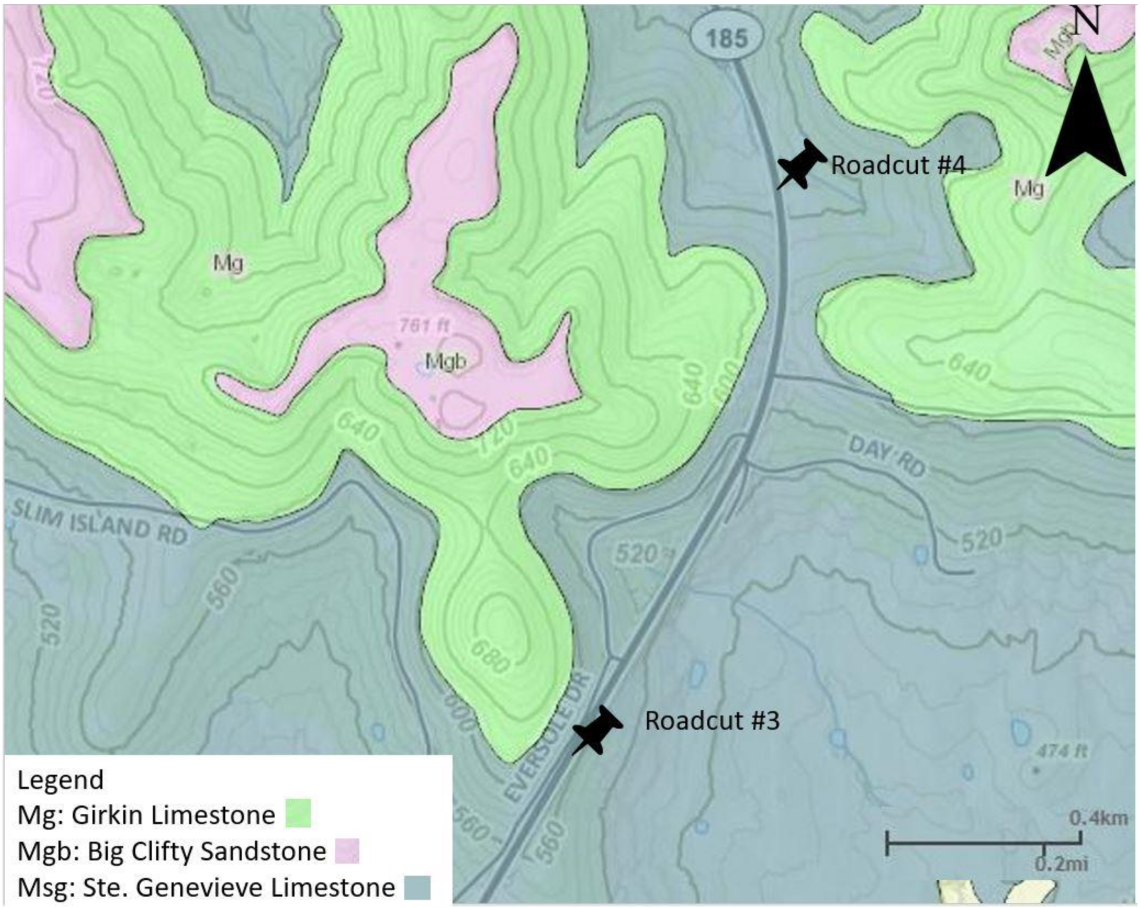

Figure 4.4. Geologic map of the Hwy 185 area. Subdivisions are the same as the Barren River Road map (Fig 4.3). Map was created by the author using the KGS map information service accessed in March 2019.

Structurally, the Hwy 185 area is similar to the Barren River Road area. The bedrock of the area dips to the north to slightly northwest, with the structurally highest contour being 740 feet (with Big Clifty Sandstone as the structural datum). The structural datum shift from one datum to another previously mentioned also applies to this area, with the lowest elevation contour being at -300 feet with the top of the Chattanooga Shale as the datum (Figure 4.5).

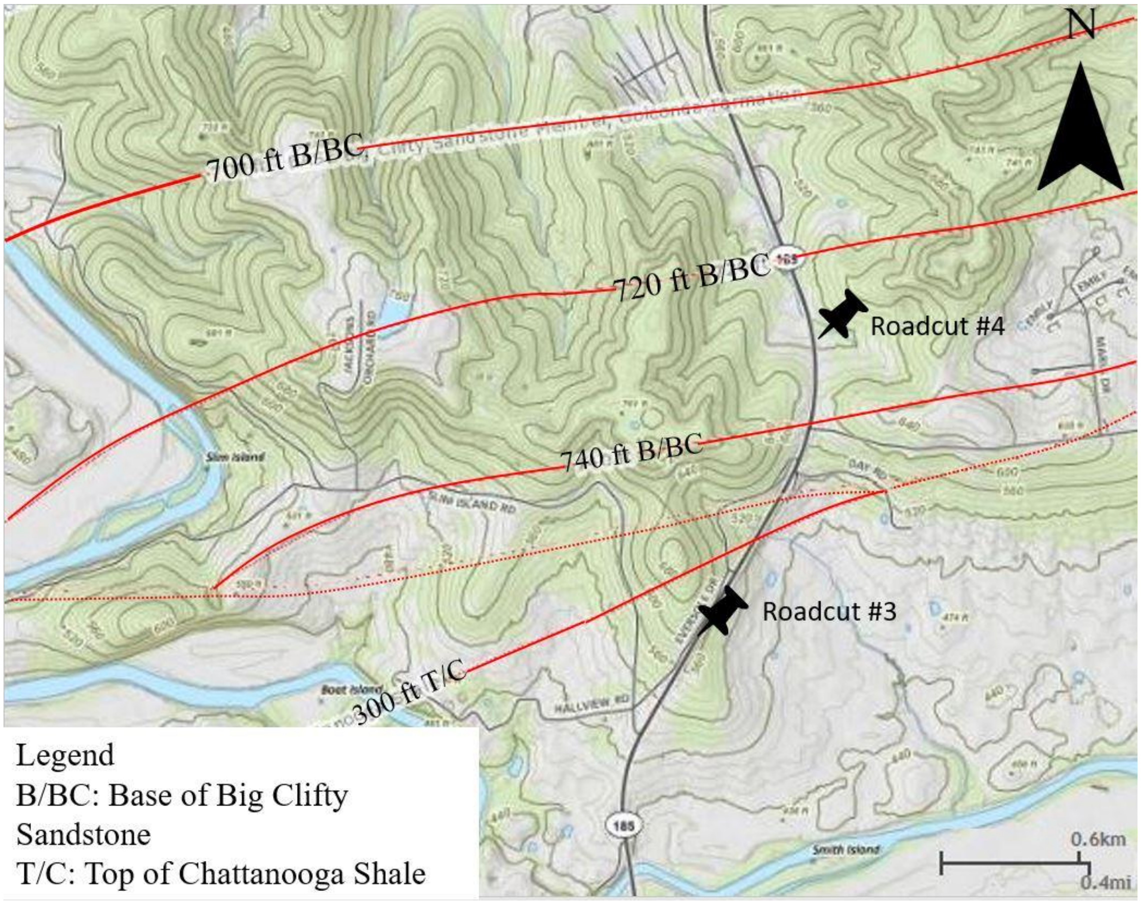

Figure 4.5. Structural contour map of the Hwy 185 area. Map was created by the author using the KGS map information service accessed March 2019.

4.1.3 Interstate Highway 65, Mile 40 Roadcuts

The Interstate 65 Mile 40 Roadcut is the easternmost roadcut from Warren County used in this study. The roadcut is located in the far eastern part of the county, near the borders of Barren, Warren, and Edmonson counties. The stratigraphy is dominated by the St. Louis Limestone, with deposits of Ste. Genevieve Limestone and Girkin Limestone representing the very few higher elevations in an otherwise relatively flat area (Figure 4.6). The I-65 roadcut is approximately 17 feet high, with a relatively constant elevation throughout the exposure. It must be noted that this roadcut has been weathered extensively by water dissolution.

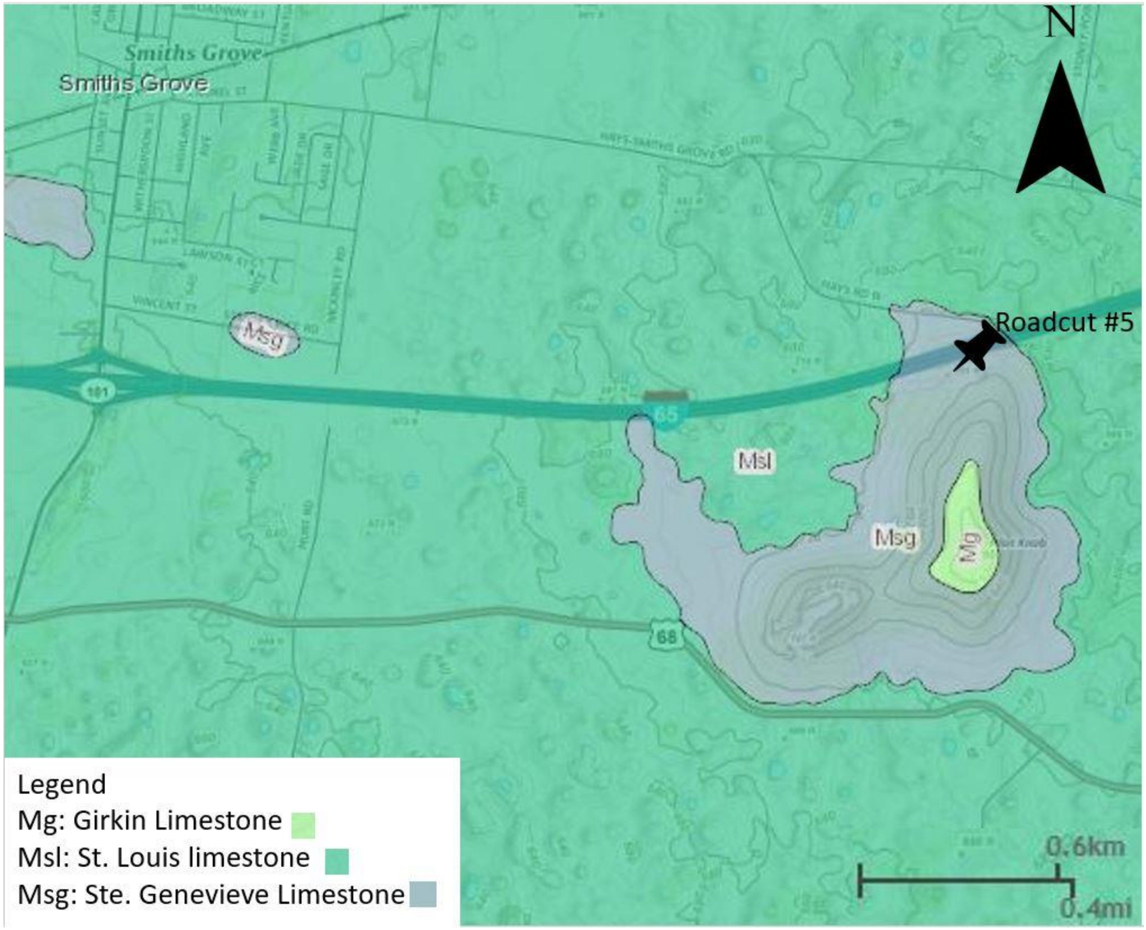

Figure 4.6. Geologic map of I-65 area near Mile Marker 40. Subdivisions are the same as the Barren River Road map, with Msl (Green) representing the St. Louis Limestone. Map was created by the author using the KGS map information service accessed March 2019.

Structurally, the area dips toward the west to northwestern part of the map (Figure 4.7). Contours of the area range from a high of 180 feet to negative values such as -20 feet and -40 feet. The contours of the area are tightly compacted compared to the other areas, representing the relatively uniform bedrock topography of the region.

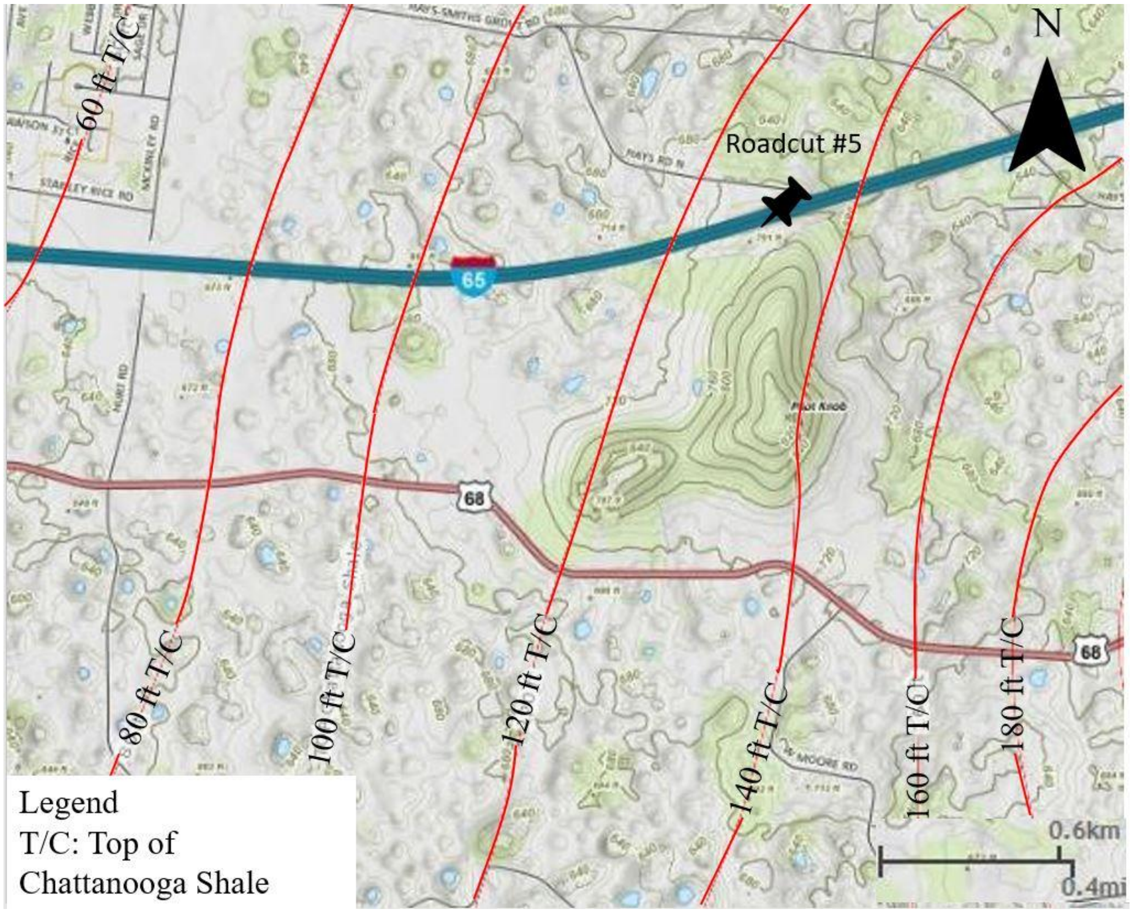

Figure 4.7. Structural contour map of I-65 area near Mile Marker 40. Map was created by the author using the KGS map information service accessed March 2019.

4.2 Barren County Roadcuts

The Barren County Roadcuts are located along I-65 off of US Exit 48, near Park City, KY. There are two roadcuts in this area, one on the southwestern part of the exit and the other on the northeastern part of the exit. Although these roadcuts are very close to each other, they represent two different sets of lithologies so for clarity, they are discussed separately. The area's stratigraphy is dominated by the Ste. Genevieve Limestone, but the Girkin Limestone and Big Clifty Sandstone are observable in the northern part of the area and the St. Louis Limestone is exposed to the south (Figure 4.8).

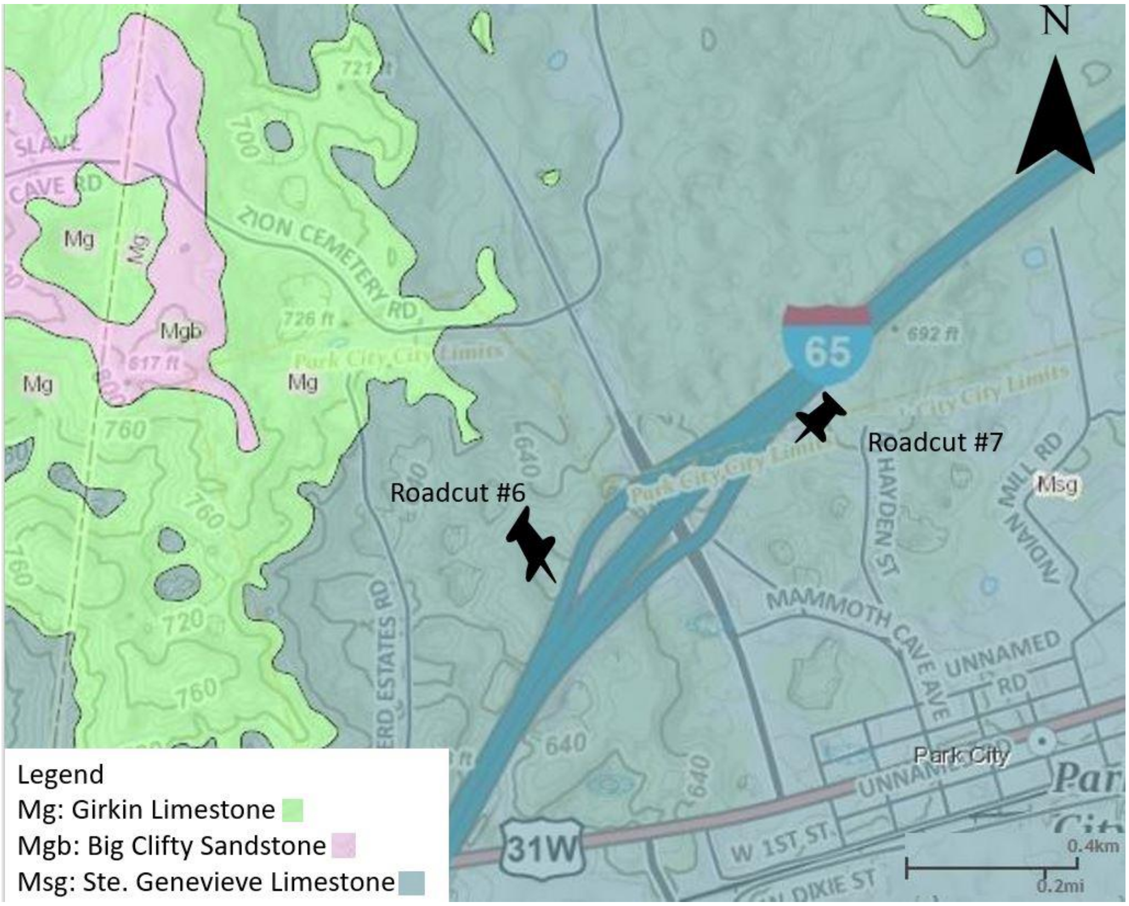

Figure 4.8. Geologic map of the Barren County area at Exit 48 on I-65 (Park City, KY). Subdivisions are the same as the Barren River Road map (Fig 4.3). Map was created by the author using the KGS map information service accessed March 2019.

The area is structurally positioned very close to the l break between the top of the Chattanooga Shale and base of the Big Clifty Sandstone contours in the north and the south (Figure 4.9). The contours in the south are very close to each other, with contour values ranging from -40 feet to 140 feet in a span of less than a mile with bedrock dipping toward the north. The contours in the north are substantially more spread apart in comparison, ranging from 920 feet to 720 feet over a few miles, with rock dipping toward the northwest which is consistent with regional dip in this portion of the Illinois Basin.

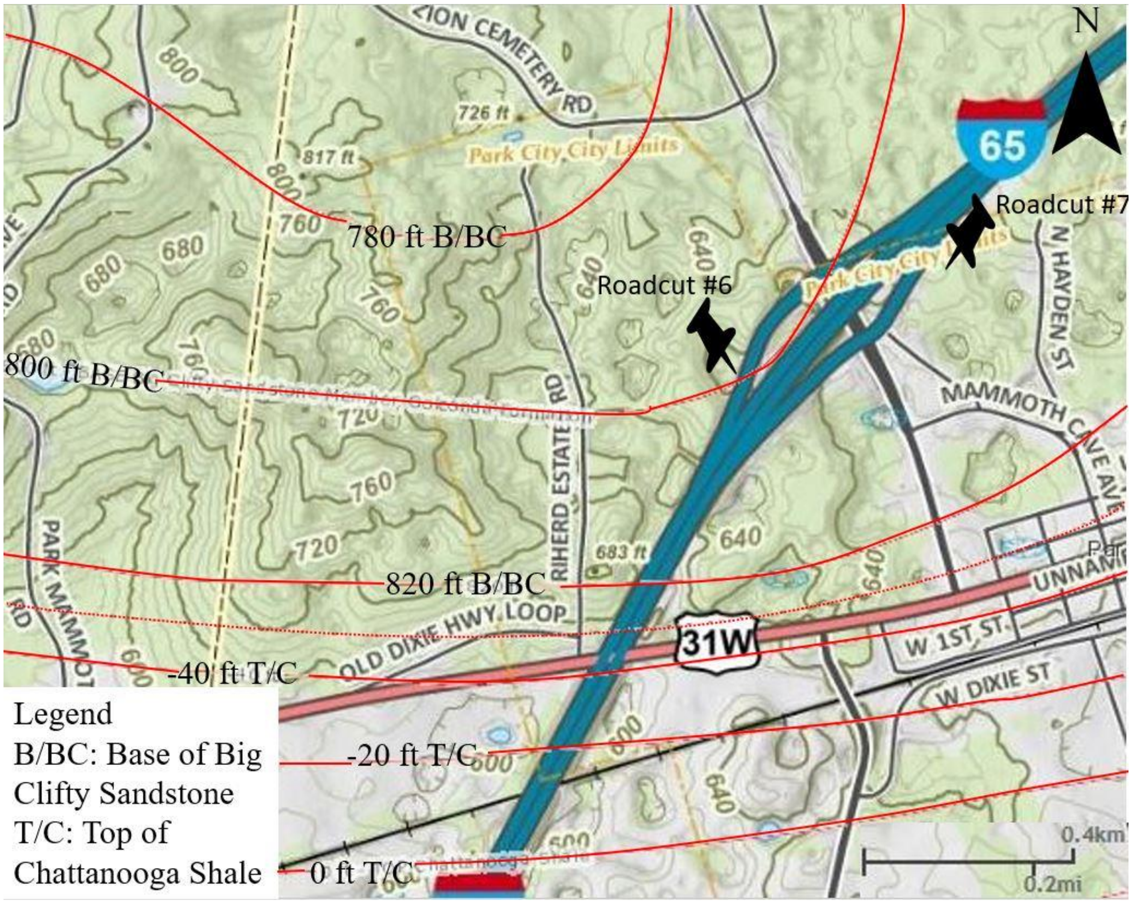

Figure 4.9. Structural contour map of the Barren County area at Exit 48 on I-65 (Park City, KY). Map was created by the author using the KGS map information service accessed March 2019.

4.3 Roadcut Locations in Regional Stratigraphic Context

The focus of this study is to analyze the Ste. Genevieve Limestone in western Kentucky, and thus the roadcut locations (i.e. seven main areas discussed above) must be known in regional stratigraphic context rather than merely as disparate, physically separated measured sections. Using the base of the Big Clifty Sandstone as a structural datum and determining the elevation of the base of the roadcuts, one can discern any given individual roadcut's measured section placement into the regional stratigraphy. Furthermore, the thickness of roadcuts can be used to document vertical extent. Based on their contextual placement in the stratigraphy (Figure 4.10), most of the roadcuts are positioned in the middle to upper part of the Ste. Genevieve Limestone, with the I-65 Mile 40 Roadcut (roadcut #5) representing the lower part of the unit.

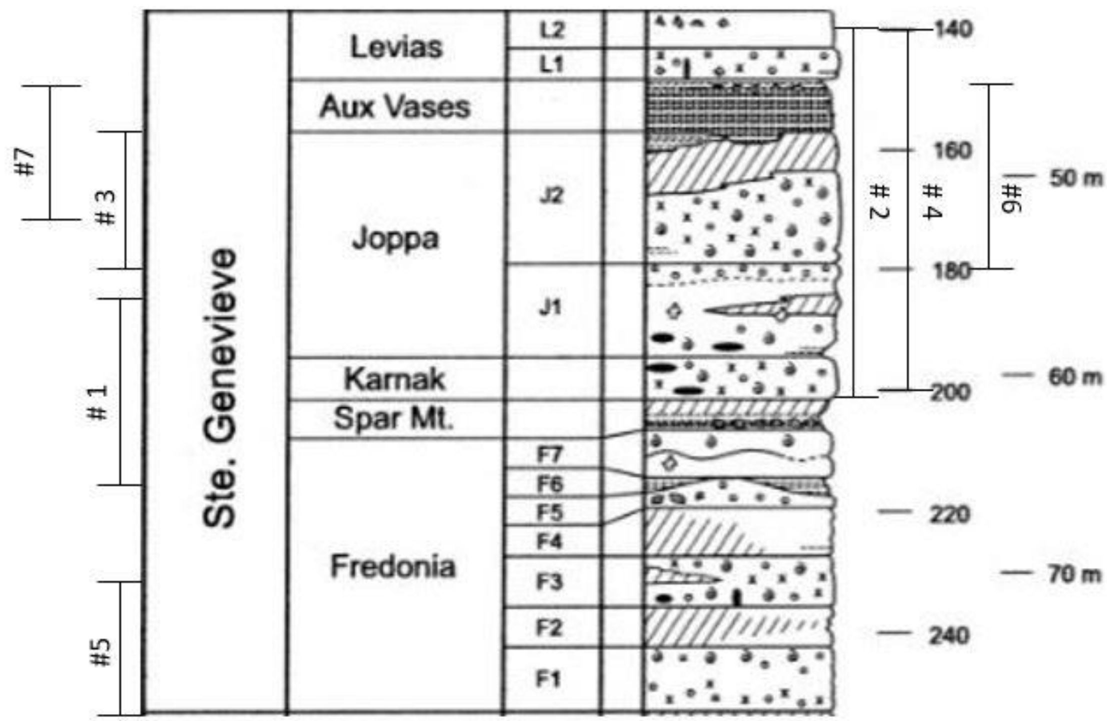

Figure 4.10. Roadcut locations (numbered after #) studied in stratigraphic context of the Ste. Genevieve Limestone. The numbers on the right represent the distance from the base of the Big Clifty Sandstone. On left-hand side of scale, units are in feet (e.g., 240, 220 etc.) and meters on right-hand side of scale (e.g., 70, 60 etc.). (Stratigraphic framework modified from Palmer, 1998).

5.0 RESULTS

5.1 Barren River Road, Mile 2 Roadcut

5.1.1 Lithofacies

The Mile 2 Roadcut reveals six distinct stratigraphic units. These lithofacies (Figure 5.1) constitute the exposure in ascending stratigraphic order as follows:

- A. Chert-Bearing Dolomitic Mudstone: A light olive brown (2.5Y 5/3) dolomitic mudstone with sparse deposits of chert with little to no fossils or skeletal content, and little to no preserved sedimentary structures. Overall, the unit is very fine grained, almost entirely mud, with few nodular chert deposits. There are numerous calcite veins in the unit (fracture filled in exposures).
- B. Skeletal Grainstone: A light gray (2.5Y 6/2) skeletal grainstone unit with bryozoans, crinoids, and brachiopods. Skeletal fragments make up the vast majority of grains. There is a minor tint of orange coloring that is likely the result of iron-oxide replacement.
- C. Chert-Bearing Dolomitic Mudstone: A light yellowish brown (2.5Y 6/3) unit with sparse deposits of chert. Very similar to unit A, and most likely the same unit with the only difference being light gray (2.5Y 6/2) deposits.
- D. Packstone: A gray (2.5Y 6/1) packstone unit with little to no fossils and no sedimentary structures. In the upper part of the unit, laminations of grainy material become prevalent.

- E. Dolomitic Mudstone: A light gray (2.5Y 7/1) mudstone with sparse deposits of brachiopods and a few small sedimentary structures present such as ripples. Unit is dolomitized somewhat.
- F. Skeletal-Ooid Grainstone: A light brownish gray (2.5Y 6/2) skeletal grainstone unit with the dominant feature being ooids. Fossil content includes bryozoans, crinoids, and brachiopods. Ooids are not distributed throughout but occur in concentrated pockets.

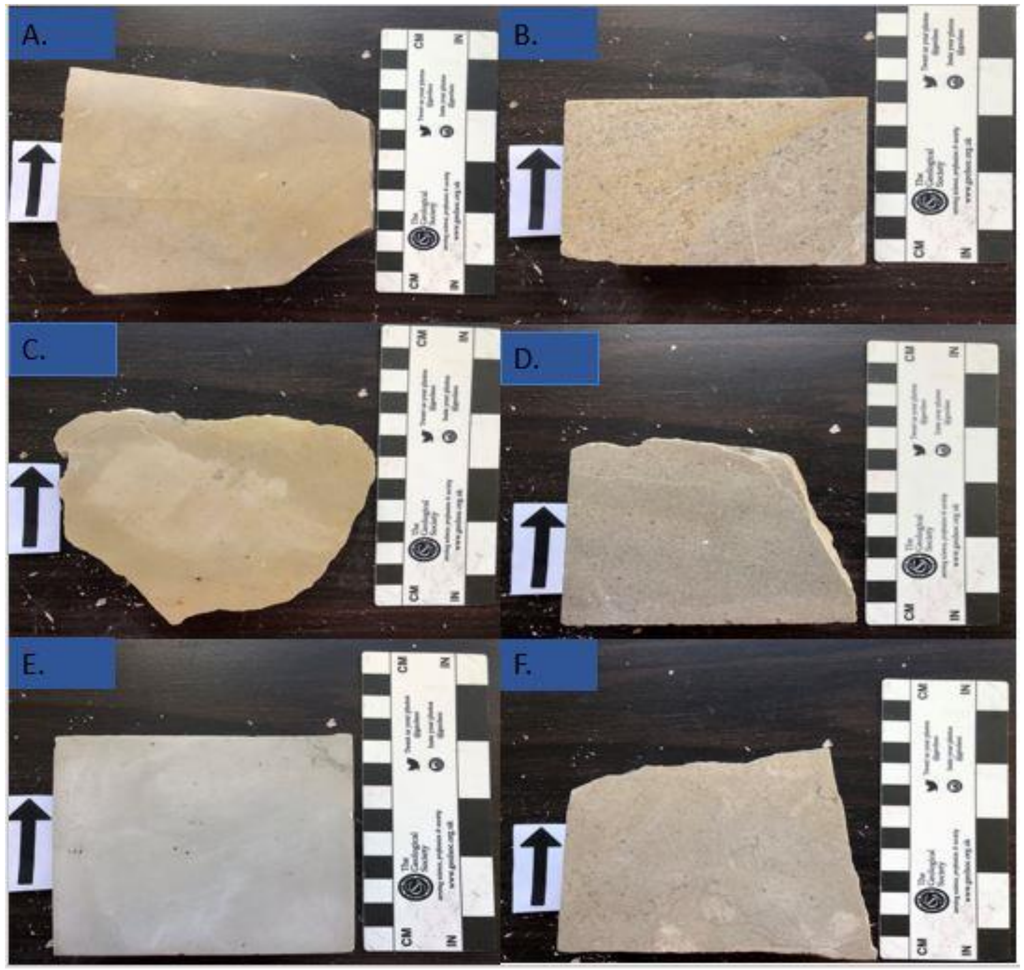

Figure 5.1. Lithofacies (A through F) of the Barren River Road, Mile 2 Roadcut. Arrows show stratigraphic up and scale bars are in centimeters (left side of scale) and inches (right side of the scale). A. Chert-Bearing Dolomitic Mudstone, B. Skeletal Grainstone, C. Chert-Bearing Dolomitic Mudstone, D. Packstone, E. Dolomitic Mudstone, and F. Skeletal-Ooid Grainstone

5.1.2 Stratigraphy

The stratigraphy of the Barren River Road, Mile 2 Roadcut can be best described as a coarsening upward sequence (Figure 5.2). Unit A is the lowest stratigraphic unit, measuring on average three feet thick, but is only present on the southern part of the roadcut (Figure 5.3). The stratigraphy transitions into coarse-grained unit B but is only present along the edges of the roadcut, averaging two feet thick on the southern part of the roadcut and three feet thick along the north (Figure 5.4). Unit B transitions into the dolomitic unit C, which is present along the edges of the roadcut, averaging three feet in thickness on the south and seven feet thick on the north. This transitions into unit D, the most dominant unit in the roadcut. The thickness of the unit varies, averaging six feet on the edges of the roadcut and 11 feet in the center. In the center of the roadcut, there are remnants of unit E, with the thickest the unit being observed at two feet, with shale mantling the rest of the roadcut at this stratigraphic level. The roadcut is capped by unit F which is only present in the center (Figure 5.5), where it averages 13 feet in thickness.

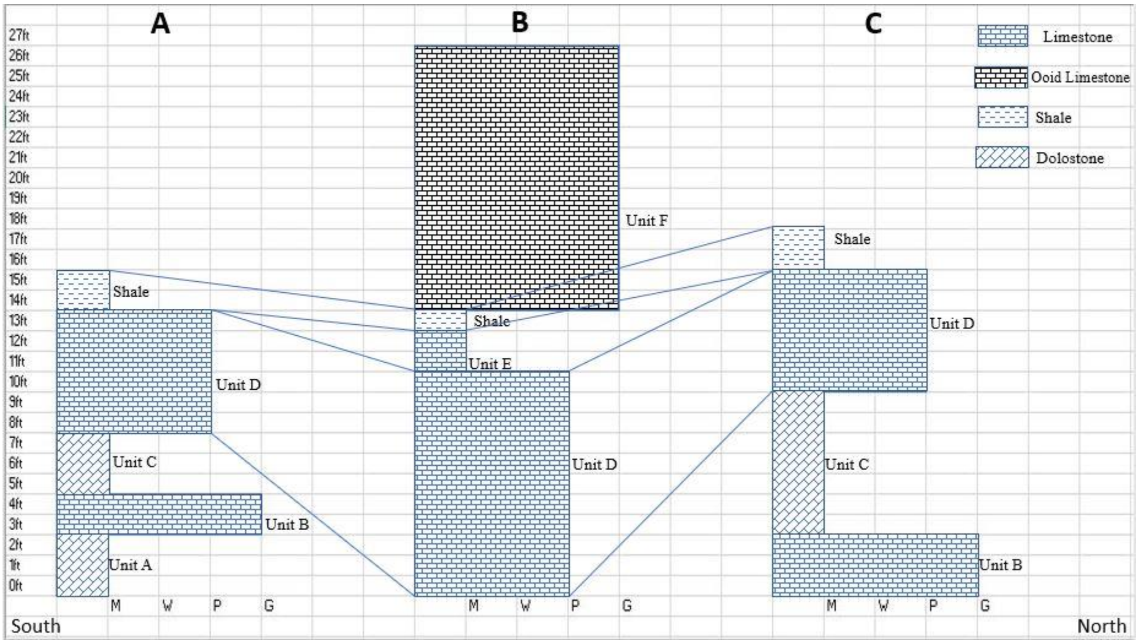

Figure 5.2. Stratigraphic cross section of the Barren River Road, Mile 2 Roadcut. Designations of M, W, P and G correspond to Dunham Classification names (mudstone, wackestone, packstone, and grainstone).

Figure 5.3. Annotated view of the southern edge of the Barren River Road, Mile 2 Roadcut. Carbonate units are lettered and interbedded clastics are not lettered (e.g. shale).

Figure 5.4. Annotated view of the northern edge of the Barren River Road, Mile 2 Roadcut. Carbonate units are lettered and interbedded clastics are not lettered (e.g. shale).

Figure 5.5. Annotated view of the center of the Barren River Road, Mile 2 Roadcut. Carbonate units are lettered and interbedded clastics are not lettered (e.g. shale).

5.2 Barren River Road, Belle Rive Circle Roadcut

5.2.1 Lithofacies

The Belle Rive Circle Roadcut investigated consists of ten distinct stratigraphic units. The lithofacies that constitute the exposure (Figure 5.6), in ascending stratigraphic order are (with the exception of units B1 and B2 due to the close proximity in the roadcut):

- A. Chert-Bearing Dolomitic Mudstone: A grayish brown (2.5Y 5/2) unit with beds of chert. There are a few deposits of skeletal material, consisting of fragmentary fossils.
- B1. Partially-Dolomitic Wackestone: A greenish gray (GLEY 1 6/1) unit with a mix of very muddy material and slightly coarser material. HCl acid tests show that the coarse material is non-dolomitic whereas the muddy material is dolomitic.
- B2. Skeletal Grainstone: A light gray (2.5Y 7/1) fragmentary skeletal unit. There are a few clay laminations in the lower part. Identifiable fossils consist of mostly brachiopods.
- C. Skeletal Grainstone: A greenish gray (GLEY 1 6/2) fragmentary skeletal unit. There are a few layers of less coarse material, but overall, the unit becomes progressively coarser upwards. It is very similar to unit B2 and is possibly the same unit.
- D. Skeletal-Ooid Grainstone: A pale yellow (2.5Y 8/2) unit made up primarily of ooids. There are dark gray (2.5Y 4/1) layers that represent purely skeletal material, with the layers characterized by their disarticulated or broken skeletal grains.

- E. Brecciated Limestone: A very dark grayish brown (2.5Y 3/2) consisting of large fragments of limestone. Rock fragment sizes range from >1 cm to 2 cm or larger in diameter.
- F. Mudstone: A greenish gray (GLEY 1 6/2) unit consisting of mainly mud with a few deposits of coarse grains sparsely distributed in the unit. Little to no skeletal content and no identifiable fossils.
- G: Skeletal Wackestone: A light brownish gray (2.5Y 6/2) unit, mainly mud supported with skeletal material evenly distributed. Most of the skeletal materials are fragments, with the few identifiable fossils consisting of crinoids.
- H: Skeletal-Ooid Grainstone: a light-gray (2.5Y 7/1) unit consisting mostly of ooids. There are beds of concentrated skeletal material in the form of fragmentary skeletal grains.
- I: Skeletal Wackestone: A light-gray (2.5Y 7/1) unit, mainly mud supported with well distributed skeletal material. Unit I is very similar to unit G, however, unit I has a greater skeletal content, with identifiable fossils including crinoids, horn corals, and bryozoans.

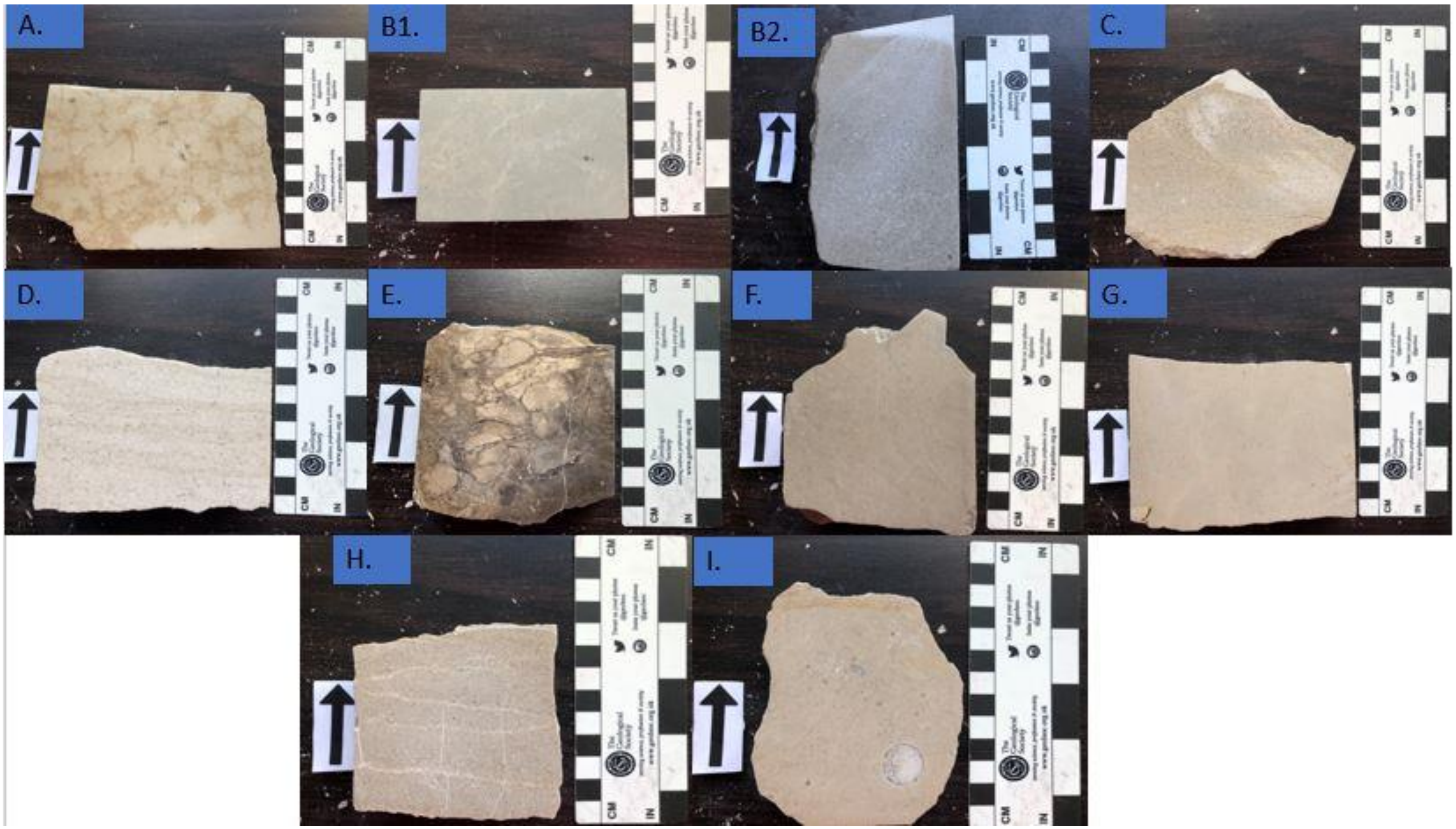

Figure 5.6. Lithofacies (A through I) of the Belle Rive Circle Roadcut. Arrows show stratigraphic up and scale bars are in centimeters (left side of scale) and inches (right side of the scale). A. Chert-Bearing Dolomitic Mudstone, B1. Partially-Dolomitized Wackestone, B2. Skeletal Grainstone, C. Skeletal Grainstone, D. Skeletal-Ooid Grainstone, E. Brecciated Limestone, F. Mudstone, G. Skeletal Wackestone, H. Skeletal-Ooid Grainstone, and I. Skeletal Wackestone.

5.2.2 Stratigraphy

The stratigraphy of the Belle Rive Circle Roadcut can be best described as a static sequence (relative to base-level), with the roadcut not fitting the profile of a definitive fining or coarsening upward trend or stacking pattern (Figure 5.7). The lowest unit is Unit A with a thickness ranging from four feet on the southern and northern edges to nine feet in the center, with a small area in the roadcut near the center measuring two feet. Unit A transitions into units B1 and B2, with units B1 and B2 found in the similar locations in the roadcut and thus it cannot be adequately determined which unit is the older. Units B1 and B2 are present only along the northern edge of the roadcut (Figure 5.8), suggesting that they are localized units.

Units A, B1, and B2 are separated from the overlying units by a scour (or potential exposure) surface, with the surface having a wavy character that suggests it is an erosional surface that certainly has been modified by post-depositional pressure dissolution. The surface is lined with a thin claystone layer in the northern edge of the roadcut. The interpretative exposure surface shows distinct evidence of being modified by pressure dissolution with the claystone layer being contorted and twisted relative to horizontal. In some locations, this claystone may be vertical, but in other locations it is obliquely inclined and subhorizontal, suggesting similarity to stylolites (Figure 5.9).

The next depositional event ascending the roadcut is unit C, with thickness of the unit measuring nine feet along the southern edge (Figure 5.10) of the roadcut, eight feet on the northern edge, and 16 feet in the center (Figure 5.11) of the roadcut. Unit C transitions into units D and E with the units being fairly consistent in the roadcut, with unit D measuring eight feet thick except along the southern edge where it measured six feet and unit E measures 10 feet throughout the roadcut. Unit E is followed by a very thin shale unit, measuring only one-foot thick and this shale and all units deposited after it are not present in the western edge of the roadcut. Unit E transitions to the muddy unit F, with the unit's thickness consistently measuring seven feet throughout the roadcut. The roadcut then transitions into units G, H, and I, with these rocks only being exposed in the center of the roadcut. The thickness of unit G was measured to be four feet, unit H measured six feet, and unit I measured nine feet. The only ideal potential hydrocarbon reservoir is unit H, a skeletal-ooid grainstone, enclosed by two muddy units (i.e. units G and I).

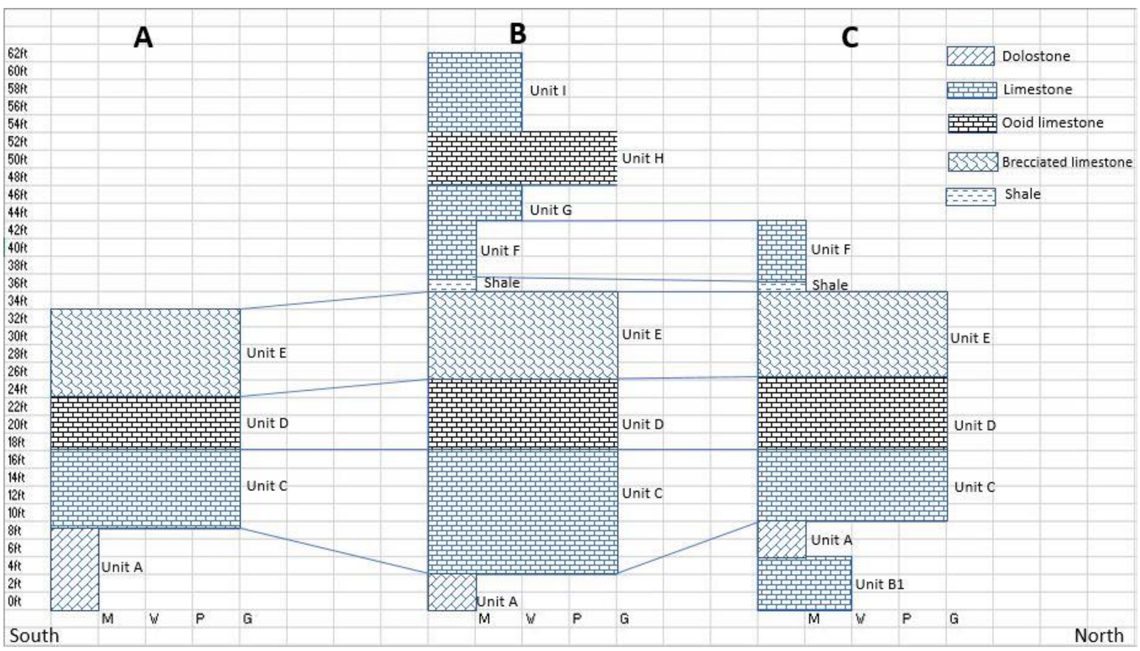

Figure 5.7. Stratigraphic cross section of the Belle Rive Circle Roadcut. Dunham Classification as previously noted in Figure 5.2.

Figure 5.8. Annotated view of the northern edge of Belle Rive Circle Roadcut.

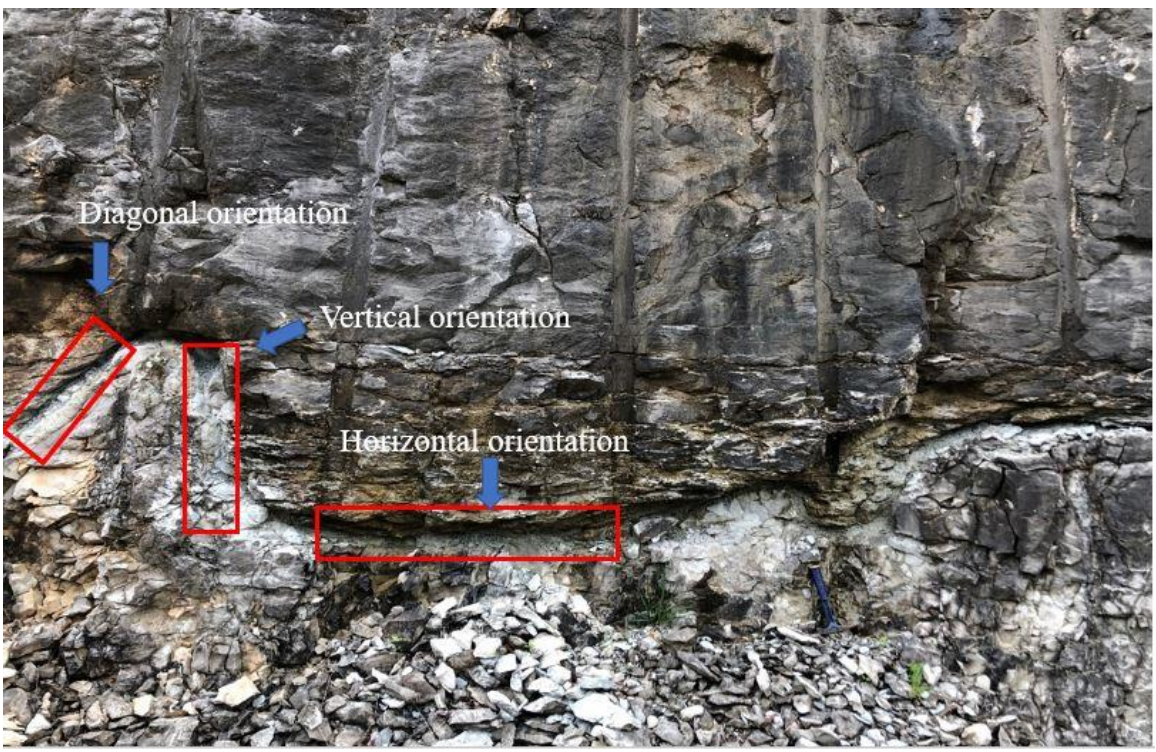

Figure 5.9. View of claystone layer and its different orientations in the northern edge of the road cut.

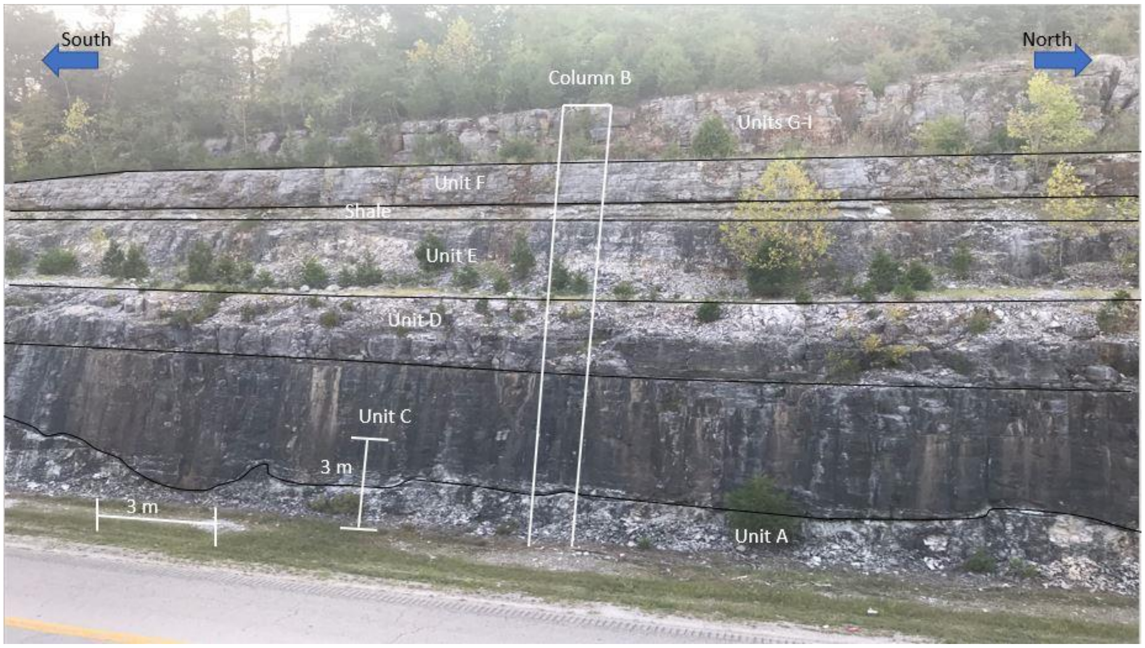

Figure 5.10. Annotated view of the southern edge of Belle Rive Circle Roadcut.

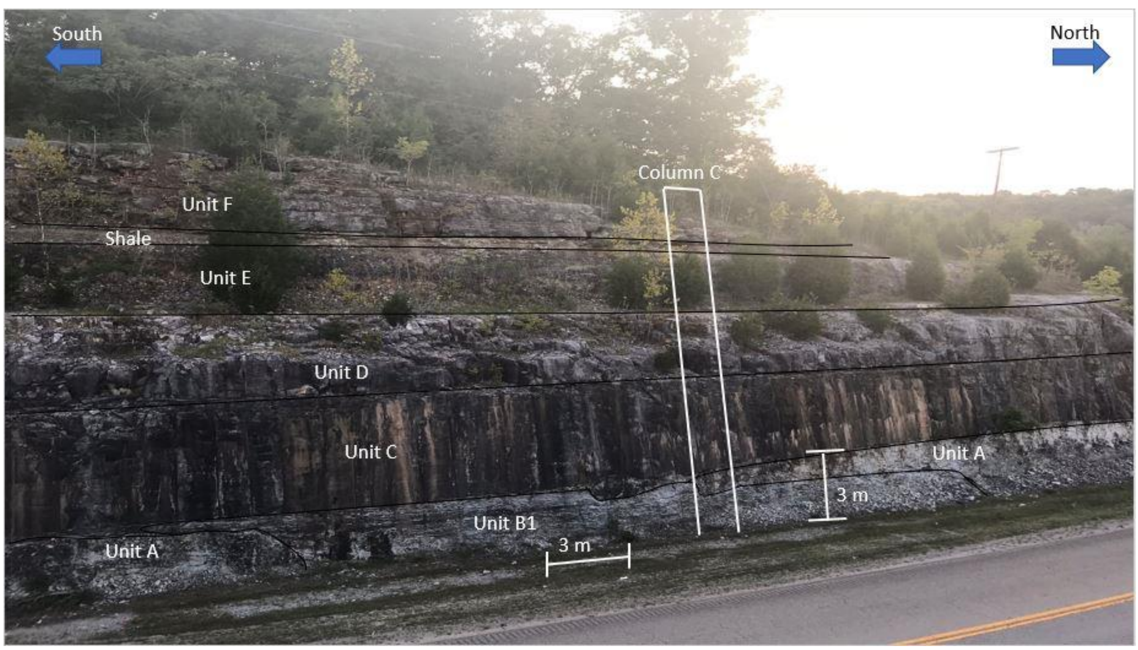

Figure 5.11. Annotated view of the center of Belle Rive Circle Roadcut.

5.3 Hwy 185, Eversole Road Roadcut

5.3.1 Lithofacies

The Hwy 185, Eversole Road Roadcut, consists of nine distinct stratigraphic units. The lithofacies (Figure 5.12) that constitute these layers are, in ascending stratigraphic order:

- A. Skeletal-Ooid Grainstone: A unit composed of skeletal fragments and ooids. Grains deposited are interbedded, with alternating layers of lighter, white (2.5Y 8/1) colored fragments and gray (2.5Y 6/1) ooid layers. The defining characteristic of the unit is the presence of stylolites, serrated surfaces within a rock mass within which minerals have been removed by pressure dissolution (via-post depositional processes).
- B. Chert-Bearing Dolomitic Mudstone: A light olive brown (2.5Y 5/2) dolostone unit with sparse deposits of chert. There are small deposits of light gray (2.5Y 7/1) material that are differentiated from the rest of the unit by the lack of chert.
- C. Skeletal-Ooid Grainstone: A light gray (2.5Y 7/1) grainstone unit composed of skeletal fragments and ooids. The unit is composed of mainly ooids, with few deposits of skeletal fragments and fossils. Fossils consists of mainly brachiopods and bryozoans.
- D. Dolomitic Mudstone: A light greenish gray (GLEY 1 7/1) dolostone unit. There is a small quantity of skeletal material with a few brachiopods.

- E. Skeletal Wackestone: A light brownish gray (2.5Y 6/2) wackestone unit. The unit is composed of mostly mud, but there are fragmental skeletal materials. There are a few identifiable fossils such as brachiopods.
- F. Skeletal Packstone: A gray (2.5Y 6/1) packstone unit. The unit is composed of mostly skeletal fragments, with some mud deposits. Skeletal content is mostly skeletal fragments with the identifiable fossils consisting of brachiopods.
- G. Skeletal Grainstone: A grayish-brown (2.5Y 5/2) grainstone unit. The unit is mostly composed of skeletal fragments, with identifiable fossils consisting of brachiopods and bryozoans.
- H. Skeletal-Ooid Grainstone: A white (2.5Y 8/1) grainstone unit. The lowest part of the unit is white and composed of mostly ooids. Further up stratigraphically, the unit becomes darker with a greater presence of skeletal fragments. In the top part of this unit, there are muddy deposits. Fossils consist of mainly brachiopods.
- I. Brecciated Limestone: A very dark-gray (2.5Y 3/1) brecciated limestone unit. The unit is composed of large limestone fragments, with breccia fragments ranging from >1 cm to 2 cm or more in diameter, with there being significantly less fragments than as observed in Belle Rive Circle unit E. Sedimentary structures are limited to distinctive planar beds best defined by chert layers.

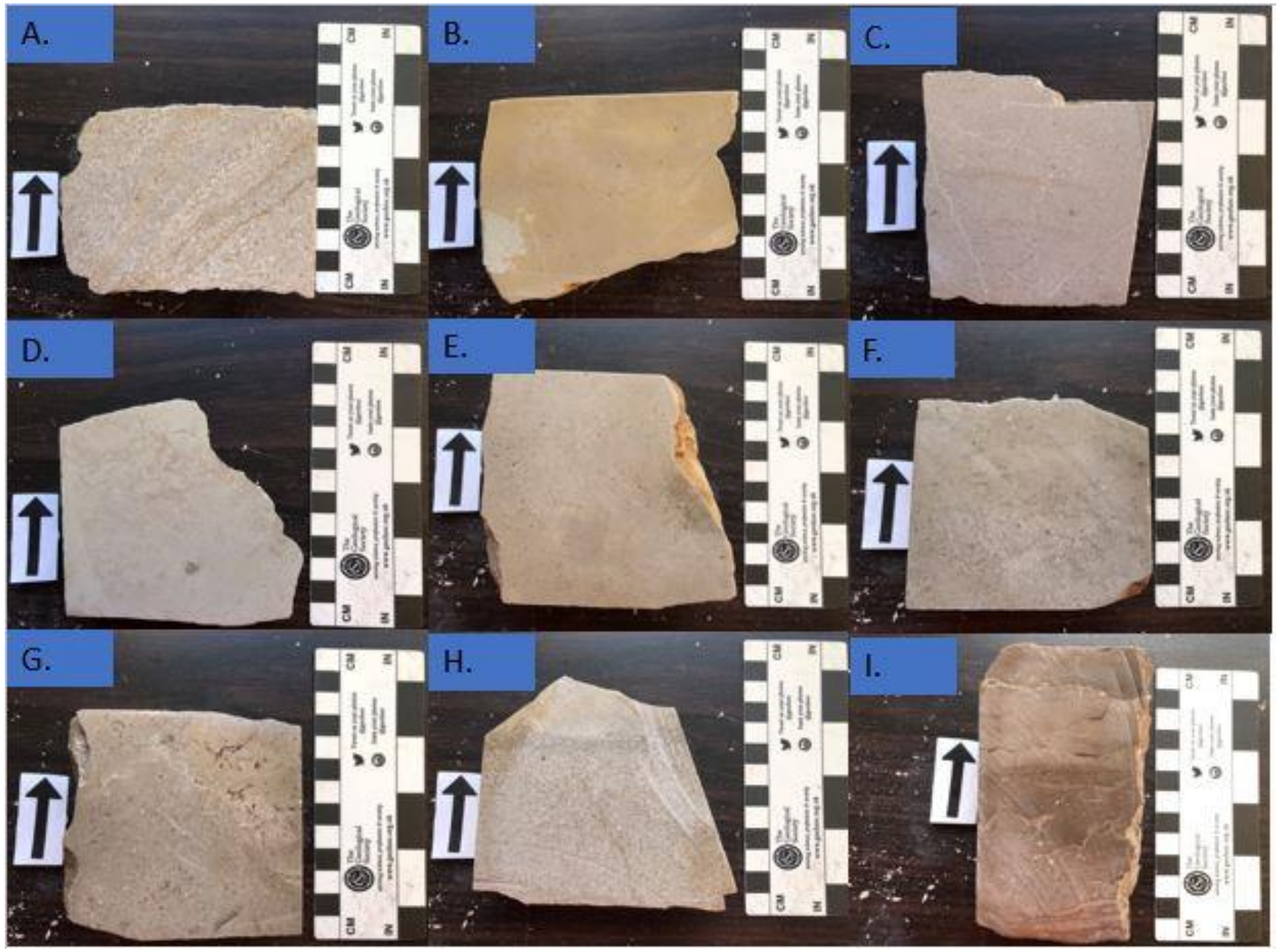

Figure 5.12. Lithofacies (A through I) of the Eversole Road Roadcut. Arrows show stratigraphic up and scale bars are in centimeters and inches. A. Skeletal-Ooid Grainstone, B. Chert-Bearing Dolomitic Mudstone, C. Skeletal-Ooid Grainstone, D. Dolomitic Mudstone, E. Skeletal Wackestone, F. Skeletal Packstone, G. Skeletal Grainstone, H. Skeletal-Ooid Grainstone, and I. Brecciated Limestone.

5.3.2 Stratigraphy

The stratigraphy of the Eversole Road Roadcut consists of three different stacking patterns: 1) alternating skeletal-ooid grainstone units and dolostone units from units A to D, 2) a backstepping pattern from units D to G, and 3) a static, coarse-grained sequence from units G to I (Figure 5.13).

Units A through D are present only on the southwestern edge of the roadcut (Figure 5.14), units E and F are only present on the southwestern edge and center of the roadcut (Figures 5.14 and 5.15), and units G through I are only present in the center and northeastern edge of the roadcut (Figures 5.15 and 5.16). Unit A is the lowest unit in the roadcut, only measuring one feet thick. Unit A transitions into unit B, with a thickness of four feet. Unit B transitions into unit C, which measures five feet in thickness. Unit C transitions into unit D, which measures six feet in thickness. The next unit in the stratigraphy is unit E, which measures five feet on the southwestern edge and four feet in the center of the roadcut. Unit E transitions into unit F, with the latter measuring four feet in thickness on the southwestern edge and in the center of the roadcut. Unit F transitions into unit G, along which measures four feet on the southwestern edge of the roadcut, seven feet in the center, and five feet along the northeastern edge of the roadcut. Unit G transitions into unit H, which measures 11 feet in the center and also along the northeastern edge. The stratigraphy of the roadcut is capped by unit I, which measures four feet in both the center and northeastern edge of the exposure.

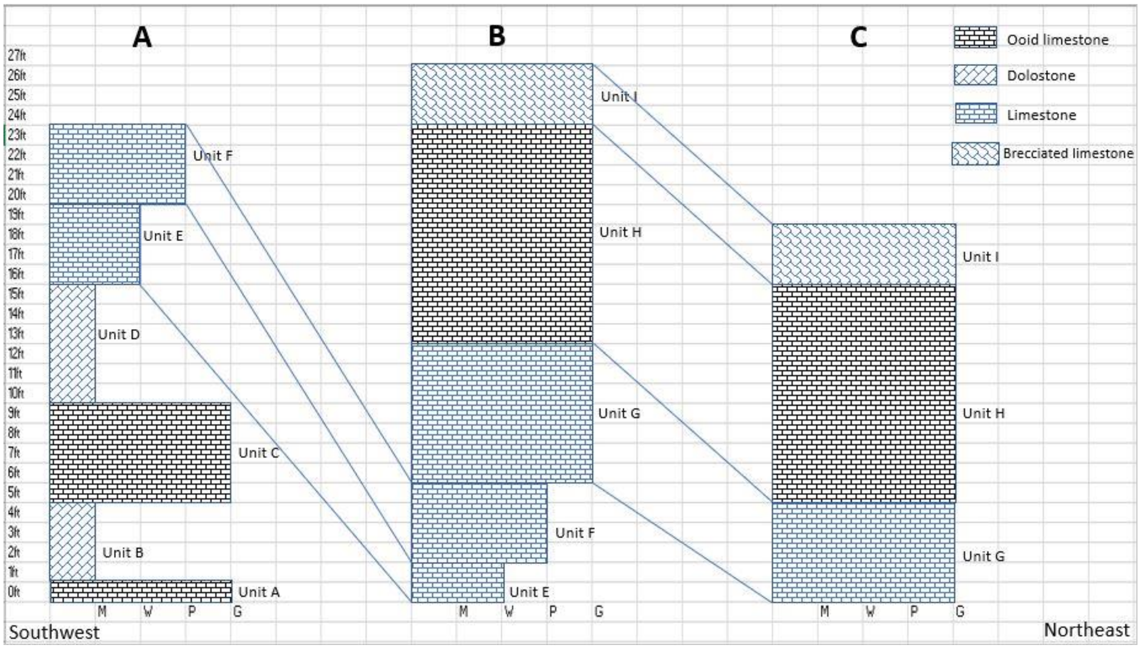

Figure 5.13. Stratigraphic cross section of the Eversole Road Roadcut. Dunham Classification as in Figure 5.2.

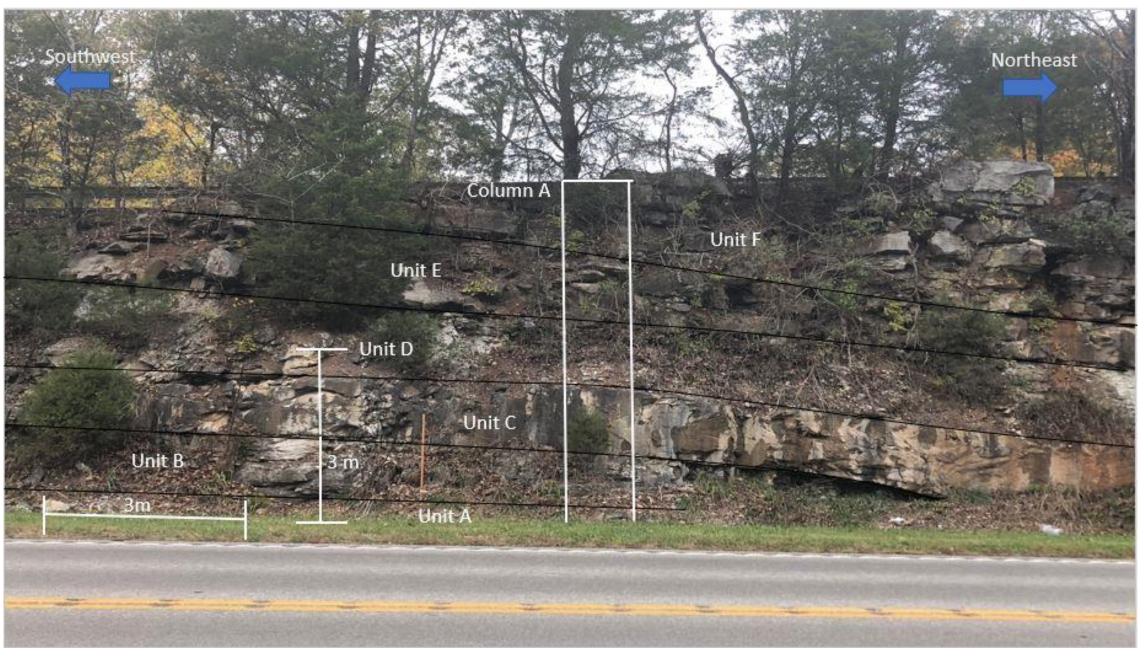

Figure 5.14. Annotated view of the southwest wing of the Eversole Road Roadcut.

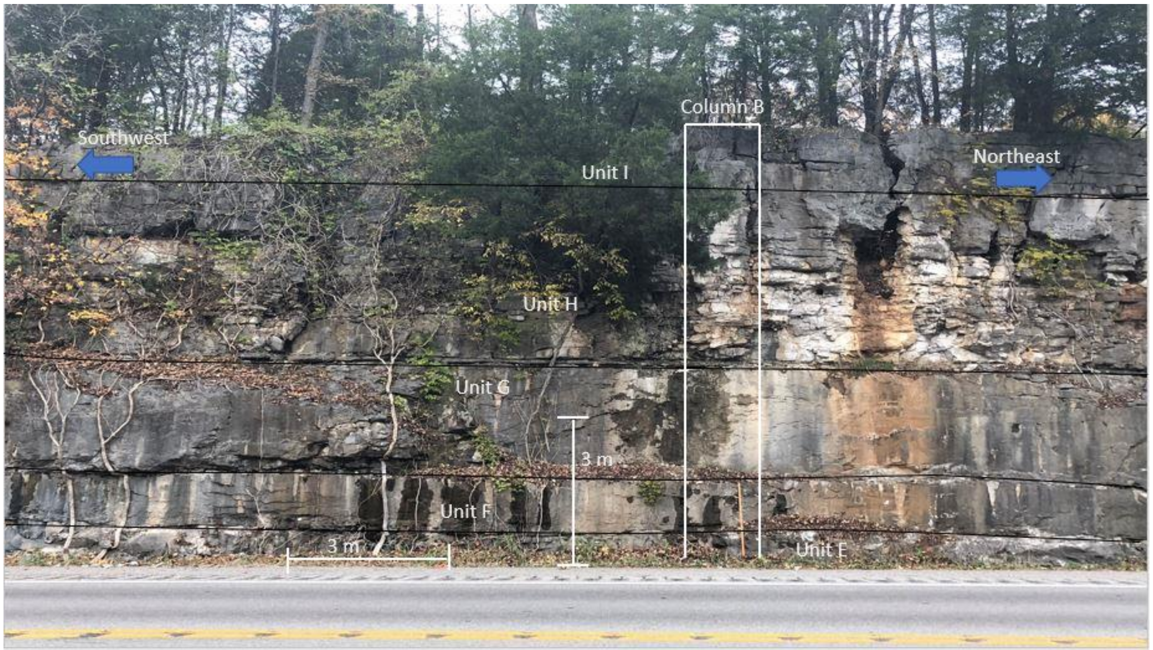

Figure 5.15. Annotated view of the center of Eversole Road Roadcut.

Figure 5.16. Annotated view of the northeast wing of Eversole Road Roadcut.

5.4 Hwy 185, Crossroads Roadcut

5.4.1 Lithofacies

The Hwy 185, Crossroads Roadcut investigated consists of seven distinct stratigraphic units. The lithofacies that constitute these layers are, in ascending stratigraphic order (Figure 5.17):

- A. Skeletal Mudstone: A light brownish-gray (2.5Y 6/2) mudstone unit. The unit is composed of mostly mud, with the few observable grains consisting of skeletal material. Skeletal materials are brachiopods and fragments. A notable feature is the presence of fractures that are filled with calcite veins.
- B. Skeletal Wackestone: A grayish-brown (2.5Y 5/2) wackestone unit. The unit is composed of mud and skeletal material in roughly equal proportions. Skeletal material is mostly fragments, with identifiable fossils consisting of brachiopods.
- C. Tidally-Influenced Skeletal Packstone: A grayish-brown (2.5Y 5/2) packstone unit. Skeletal fragments make up the majority of material in the unit, with little to no identifiable fossils. Notable are rhythmic beds (termed rhythmites or tidalites) o) capped with "supratidal" limestone replete with "birdseye vugs" or fenestral-porosity networks.
- D. Partially-Dolomitized Skeletal Wackestone: A wackestone unit with alternating light gray (2.5Y 7/2) and brownish-gray (2.5Y 6/2) material. Skeletal material consists of fragments and identifiable fossils such as bryozoans and brachiopods. HCl acid tests show that the light gray material is dolomitic and dark brownish-gray material is calcite.

- E. Skeletal-Ooid Grainstone: A grayish-brown (2.5Y 5/2) grainstone unit. Skeletal material is mostly composed of skeletal fragments with little to no identifiable fossils. Ooids are present throughout in roughly equal proportions.
- F. Skeletal Wackestone: A light-gray (2.5Y 7/2) wackestone unit. The unit is mainly composed of mud, with skeletal material scattered throughout. Skeletal material in the unit is mostly fragments, with some identifiable brachiopods.
- G. Skeletal Packstone: A light brownish-gray (2.5Y 6/2) packstone unit. The unit is mainly composed of skeletal fragments with little to no identifiable fossils, with deposits of mud material. Further up stratigraphically, mud becomes more common, with planar cross bedding also exhibited.

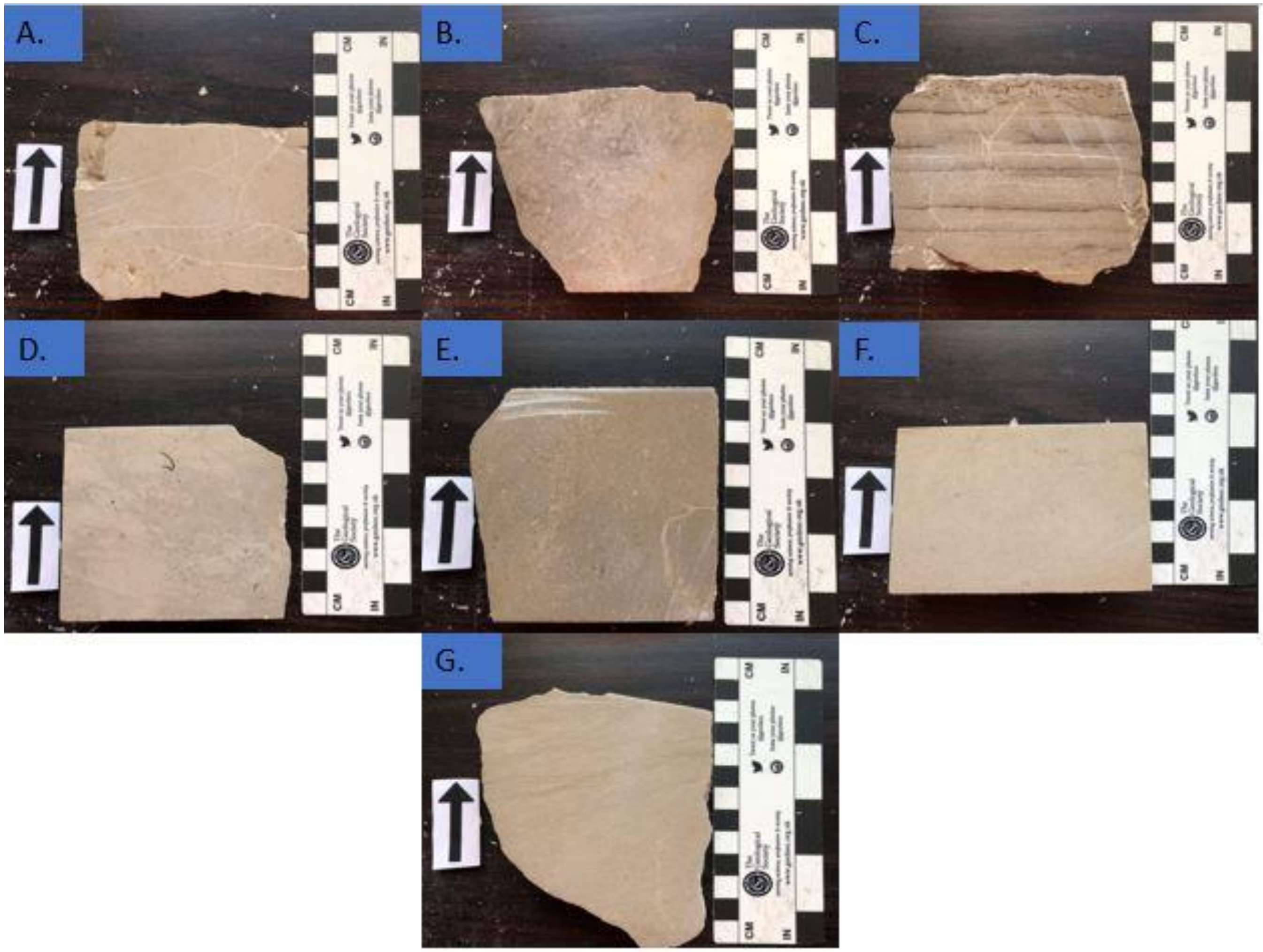

Figure 5.17. Lithofacies (A through G) of the Crossroads Roadcut. Arrows show stratigraphic up and scale bars are in centimeters and inches. A. Skeletal Mudstone, B. Skeletal Wackestone, C. Tidally-Influenced Skeletal Packstone, D. Partially-Dolomitized Skeletal Wackestone, E. Skeletal-Ooid Grainstone, F. Skeletal Wackestone, and G. Skeletal Packstone.

5.4.2 Stratigraphy

The stratigraphy of the Crossroads Roadcut can be best described as a back stepping, retrogradational pattern, with two separate identifiable stacking patterns (Figure 5.18). Unit A is the lowest unit in the stratigraphy, documented only on the northern edge of the roadcut (Figure 5.19), and measures two feet in thickness. Unit B is found on the northern edge, measuring four feet in thickness. Unit C is found on the northern edge and center of the roadcut, measuring four feet and five feet respectively. Unit D and Unit E are only present in the center of the roadcut (Figure 5.20), with Unit D measuring five feet in thickness and Unit E measuring four feet. Unit F and Unit G are only present on the southern edge of the unit (Figure 5.21), with Unit F measuring four feet in thickness and Unit G measuring three feet.

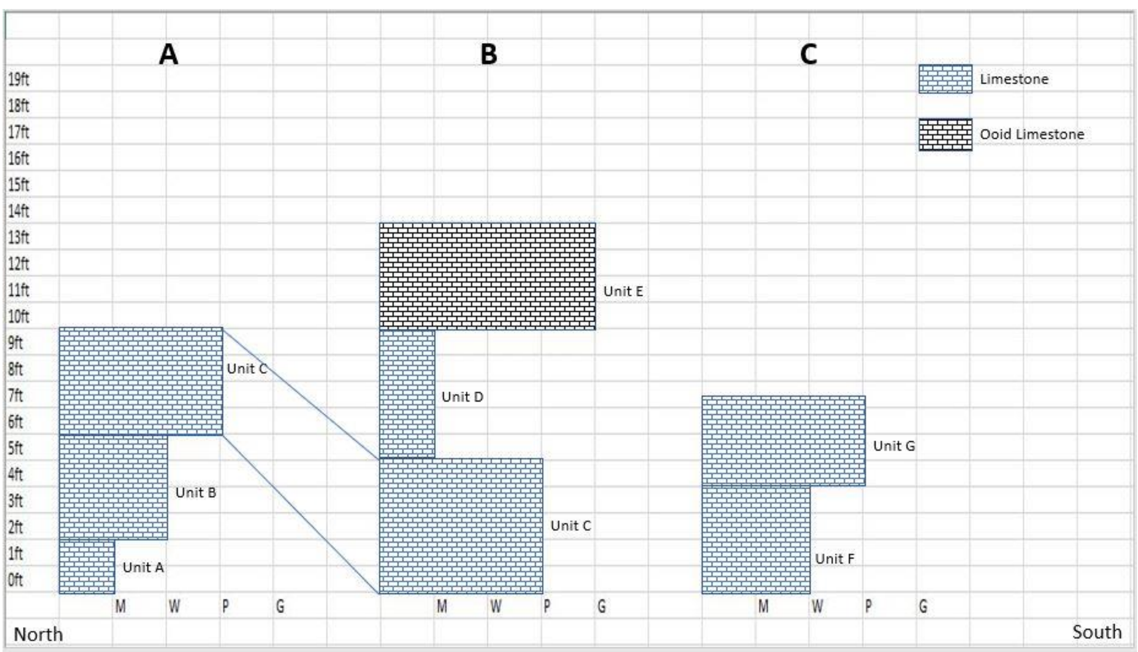

Figure 5.18. Stratigraphic cross section of the Crossroads Roadcut. Dunham Classification as in Figure 5.2.

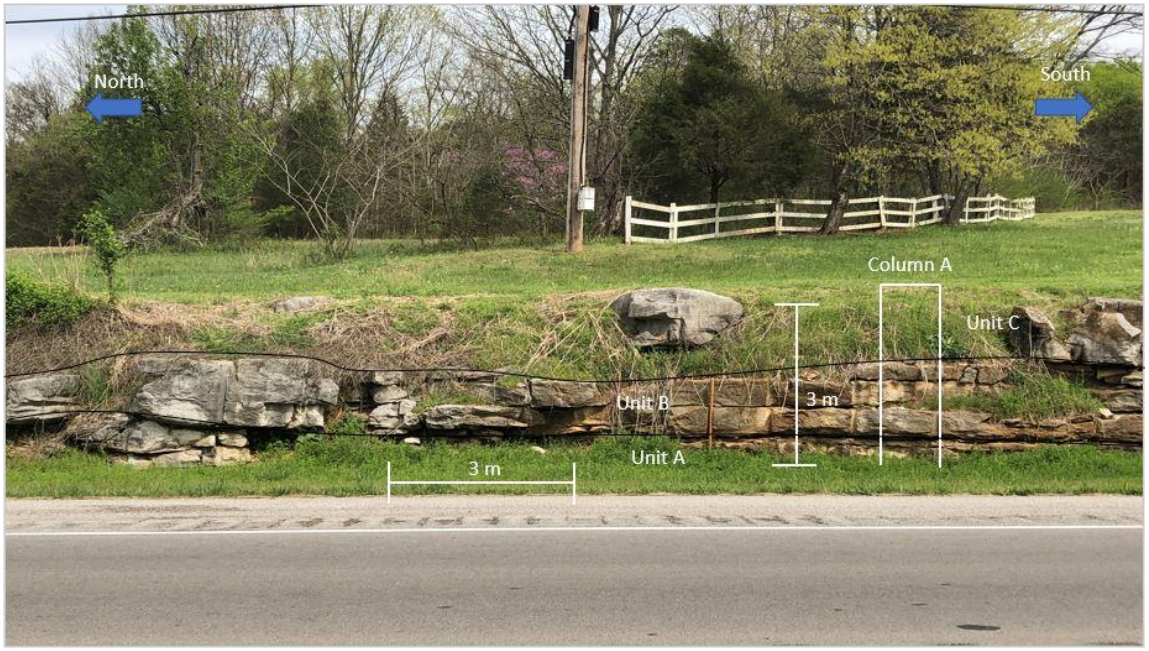

Figure 5.19. Annotated view of northern edge of Crossroads Roadcut.

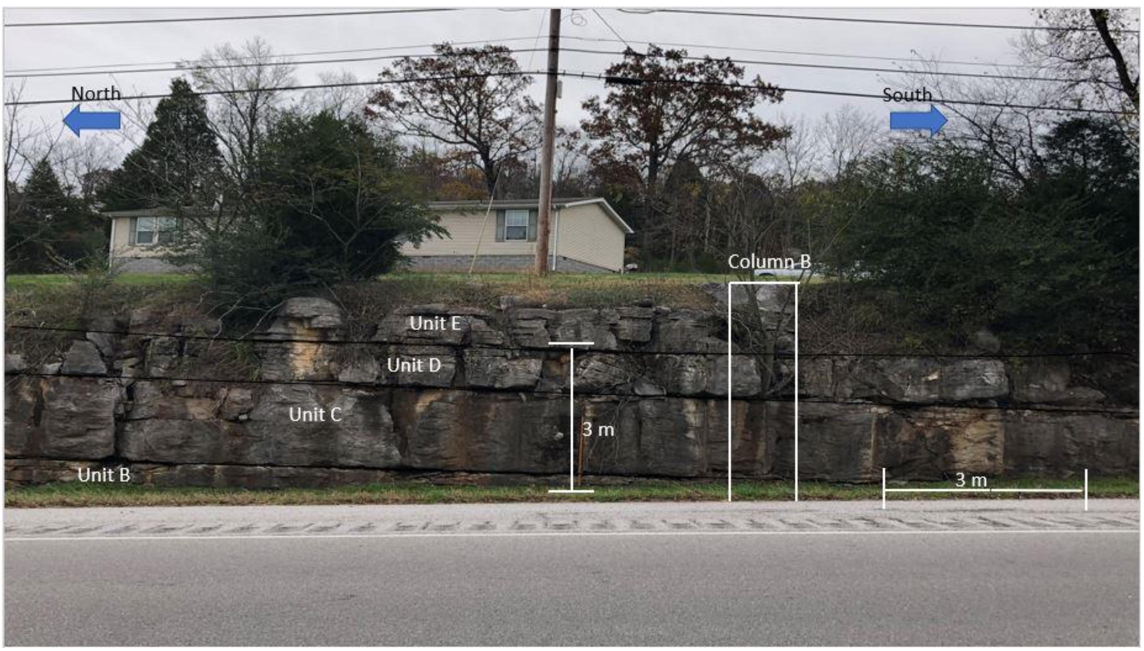

Figure 5.20. Annotated view of the center of the Crossroads Roadcut.

Figure 5.21. Annotated view of southern edge of the Crossroads Roadcut.

5.5 Interstate 65, Mile 40 Roadcut

5.5.1 Lithofacies

The I-65, Mile 40 Roadcut possesses six distinct stratigraphic units. The lithofacies (Figure 5.22) that constitute these layers are, in ascending stratigraphic order:

- A. Skeletal Packstone: A dark gray (2.5Y 4/1) packstone unit. The unit is dominated by skeletal material with notable deposits of carbonate mud throughout. A large portion of skeletal material possesses recognizable fossils, mostly brachiopods and bryozoans.
- B. Wackestone: A grayish-brown (2.5Y 5/2) wackestone unit. The unit is composed of mostly mud, with a few skeletal deposits. The skeletal material is mostly bryozoans. The lower part of the unit is muddier, and the upper part is

relatively coarse grained. A notable feature is the presence of a thin chert layer, roughly 0.4 feet to 0.6 feet (12 cm to 18 cm) thick in the middle of the unit.

- C. Packstone: A dark grayish-brown (2.5Y 4/2) packstone unit. There is fracturing throughout the unit, with calcite veins in the fractures. A notable feature is muddy material in the center, roughly 0.33 feet to 0.4 feet (10 to 12 cm) thick, characterized by laminar bedding.
- D. Skeletal Grainstone: A gray (2.5Y 6/1) grainstone unit. The unit is dominated by skeletal material in the form of skeletal fragments, with little to no recognizable fossils. There are few deposits of light gray (2.5YR 7/1) muddy material, but these are rare.
- E: Mudstone: A dark-gray (2.5Y 4/1) mudstone unit. The unit is composed of almost entirely of dark mud. There is significant fracturing, with calcite veins filling fractures.
- F. Grainstone: A grayish-brown (2.5Y 5/2) grainstone unit. The unit is dominated by coarse material, with thin layers of orange indicative of Fe-oxide with chert replacement. Coarse-grained material is present throughout, however, toward the top there are concentrated deposits of comparably coarse skeletal material.

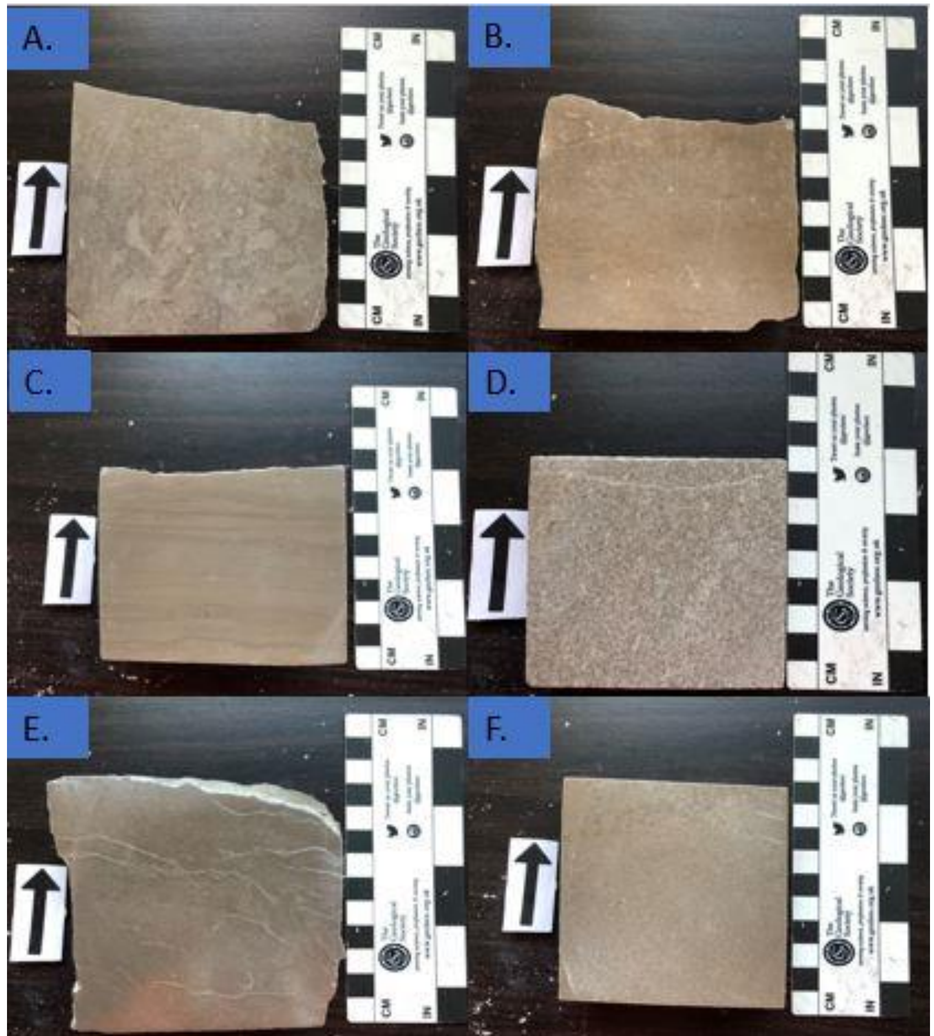

Figure 5.22. Lithofacies (A through F) of the I-65, Mile 40 Roadcut. Arrows show stratigraphic up and scale bars are in centimeters and inches. A. Skeletal Packstone, B. Wackestone, C. Packstone, D. Skeletal Grainstone, E. Mudstone, and F. Grainstone.

5.5.2 Stratigraphy

The stratigraphy of the I-65, Mile 40 Roadcut can be best described as a backstepping, retrogradational stacking pattern with some deviations from such a model in the lowest and highest units (Figure 5.23). Unit A is the lowest unit of the exposed the stratigraphy, measuring only one foot. Unit A transitions to unit B, measuring four feet in thickness. Both units A and unit B are only found in the western edge of the roadcut (Figure 5.24). The next unit in the stratigraphy is unit C, measuring five feet in thickness and is only present in the center of the roadcut (Figure 5.25). Unit C transitions into units D, E, and F, with these units are found in both the center and eastern edge of the roadcut (Figures 5.25 and 5.26). The thickness of these units vary, with unit D measuring seven feet in the center of the roadcut and three feet in the eastern edge, unit E measuring four feet in the center and six feet in the eastern edge, and unit F measuring two feet in the center and three feet along the eastern edge.

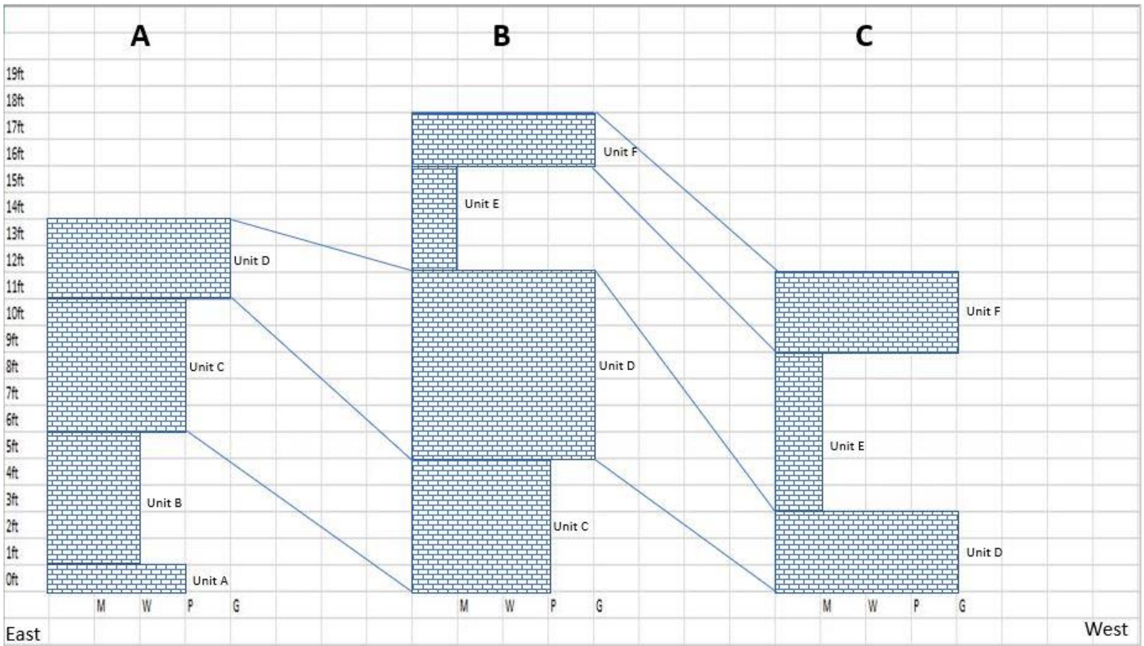

Figure 5.23. Stratigraphic cross section of the I-65, Mile 40 Roadcut. Dunham Classification as in Figure 5.2.

Figure 5.24. Annotated view of western edge of I-65, Mile 40 Roadcut.

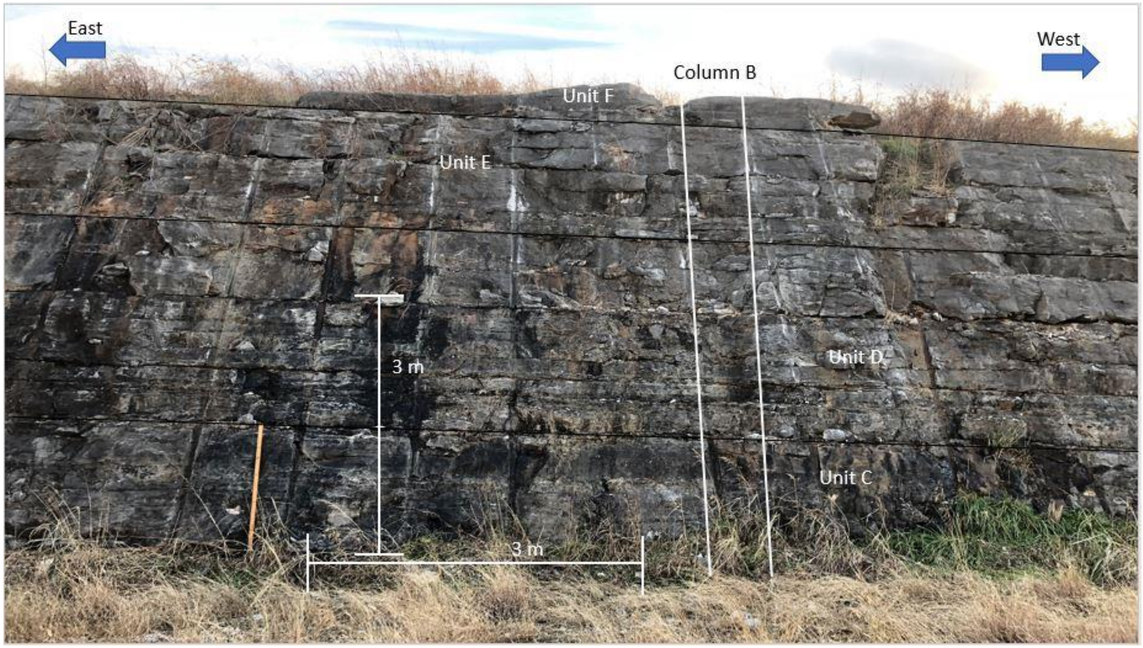

Figure 5.25. Annotated view of center of I-65, Mile 40 Roadcut.

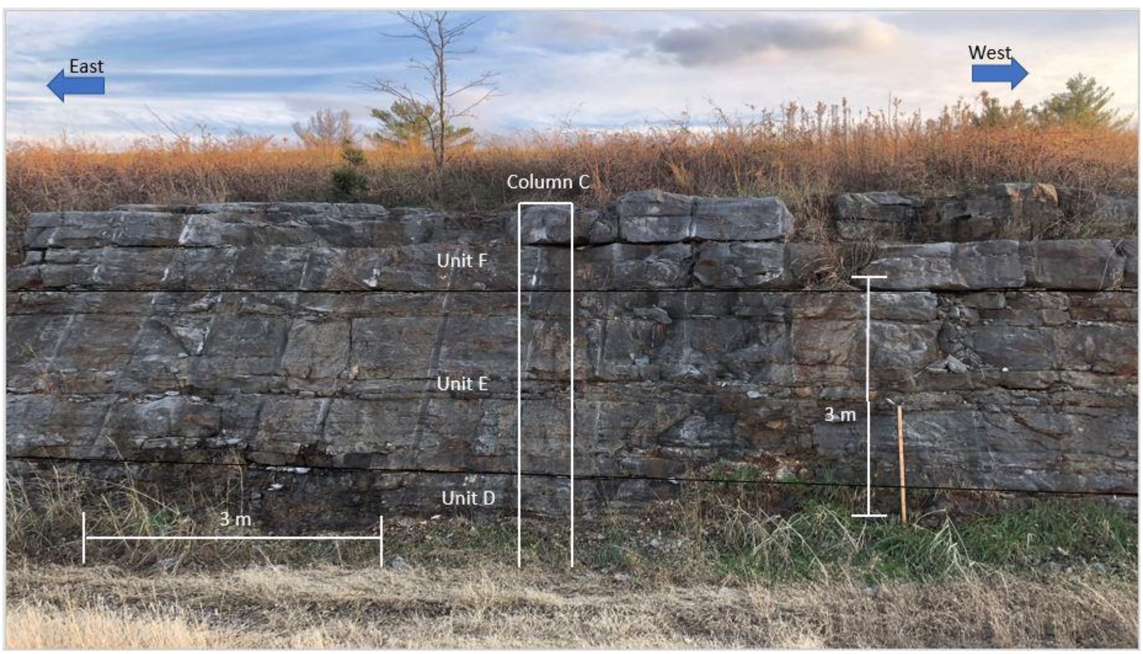

Figure 5.26. Annotated view of the eastern edge of the I-65, Mile 40 Roadcut.

5.6 I-65 Southwest Exit 48 Roadcut

5.6.1 Lithofacies

The Southwest Exit 48 Roadcut investigated consists of ten distinct stratigraphic units. The lithofacies (Figure 5.27) that constitute these layers are, in ascending stratigraphic order:

- A. Dolomitic Mudstone: A light-gray (2.5Y 7/1) dolostone unit. Unit is mostly composed of light-gray dolomitic material, however, there is a significant presence of dark mud material. HCl acid test shows that the dark material is calcite.
- B. Ooid Grainstone: A gray (2.5Y 5/1) grainstone unit. The unit is composed of almost exclusively ooids, with little other material in the unit. The only other notable feature is the presence of small (less than 0.3 meters or 1 foot) amplitude stylolites.
- C. Skeletal-Ooid Grainstone: A dark-gray (2.5Y 4/1) grainstone unit. The unit is composed of mostly skeletal fragments, with sparse ooids throughout.
- D. Mudstone: A light brownish-gray (2.5Y 6/2) mudstone unit. The unit is mostly composed of muddy material, with a few skeletal deposits. Skeletal material is made up of recognizable fossils in the form of brachiopods. There is significant fracturing in the unit.
- E. Dolomitic Mudstone: A light-gray (2.5Y 7/2) dolostone unit. The unit is composed of almost entirely dolomitic material, with some thin, light orange layers most likely the result of Fe-oxide stained chert replacement.

- F: Mudstone: A dark grayish-brown (2.5Y 4/2) mudstone unit. The unit is mostly composed of mud, with a few skeletal grains. There are thin, light orange layers present, most likely the result of Fe-oxide stained chert replacement.
- G: Packstone: A grayish-brown (2.5Y 5/2) packstone unit. The unit is mostly composed of skeletal fragments in layers, with thin layers of fine-grained material in between coarse-grained layers. Toward the upper part of the unit, thicker layers of larger fragments become more evident.
- H: Skeletal-Ooid Grainstone: light gray (2.5Y 7/2) grainstone unit. The unit is composed of equal amounts of ooids and skeletal material. Skeletal material in the unit has a significant amount of identifiable fossils, mostly brachiopods, bryozoans, and crinoids.
- I: Supratidal Wackestone: An olive-yellow (2.5Y 6/6) wackestone unit. The unit is mostly composed of mud with significant fossil content. Fossils include bryozoans and brachiopods. The unit contains fenestral porosity, informally known as “birdseye vugs”, typical of supratidal limestones.
- J. Skeletal-Ooid Grainstone: A light-gray (2.5Y 7/2) grainstone unit. The unit is mostly composed of skeletal fragments with ooids present throughout.

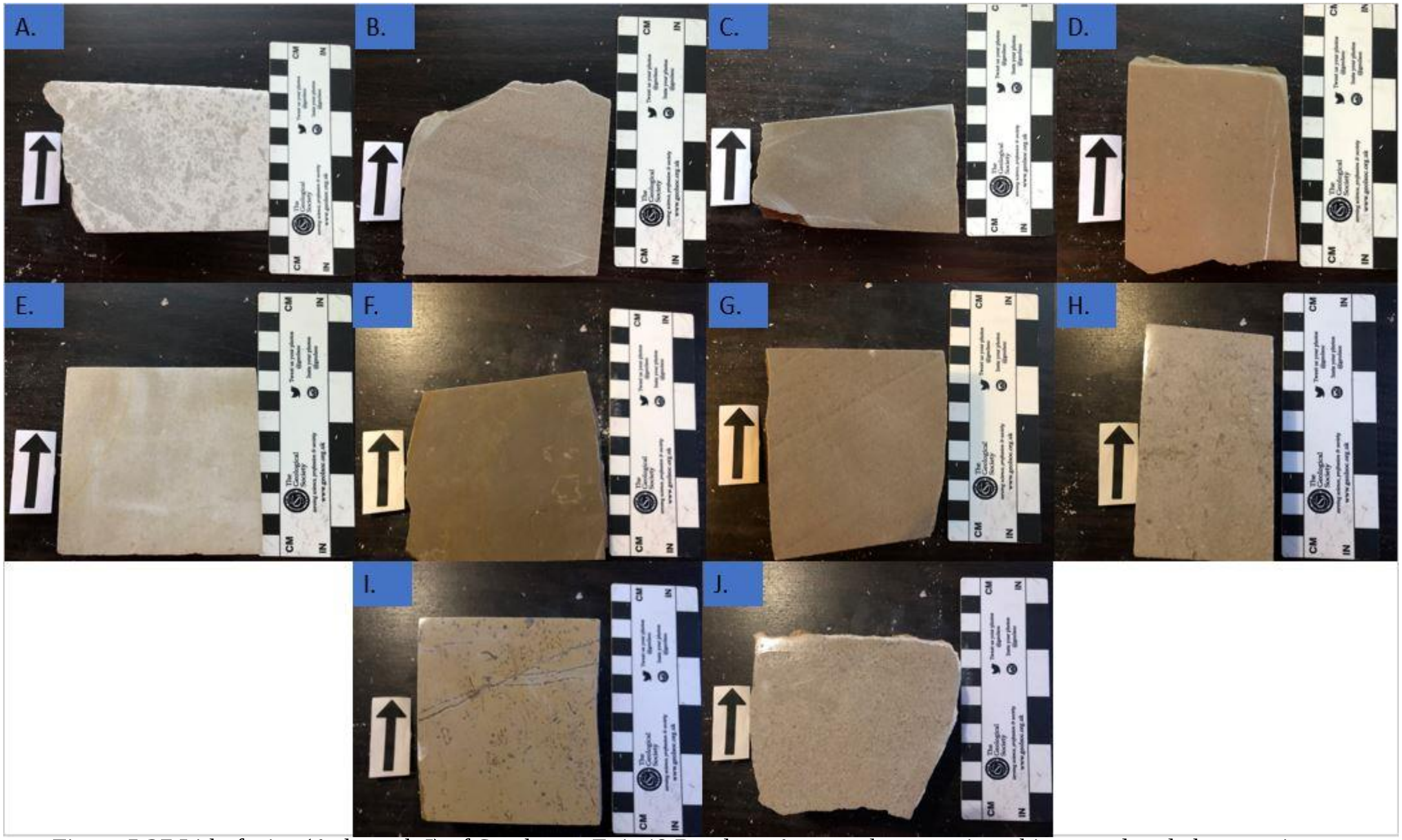

Figure 5.27 Lithofacies (A through I) of Southwest Exit 48 Roadcut. Arrows show stratigraphic up and scale bars are in centimeters and inches. A. Dolomitic Mudstone, B. Ooid Grainstone, C. Skeletal Grainstone, D. Mudstone, E. Dolomitic Mudstone, F. Mudstone, G. Packstone, H. Skeletal-Ooid Grainstone, I. Supratidal Wackestone, and J. Skeletal-Ooid Grainstone.

5.6.2 Stratigraphy

The stratigraphy of the Southwest Exit 48 Roadcut can be best described as alternating thick layers of fine-grained units and coarse-grained units (Figure 5.28). Units A and B are only present on the western edge of the roadcut (Figure 5.29), with both units measuring four feet in thickness. Units C through H are present throughout the roadcut, with varying thickness depending on the location. Unit C measures five feet on the western edge and center of the roadcut, and two feet on the eastern edge. Unit D measures five feet on the western edge and center, and four feet along the eastern edge. Unit E measures five feet on the western and eastern edges, and four feet in the center of the roadcut. Unit F measures two feet on the western and eastern edges, and three feet in the center. Unit G measures five feet on the western edge and four feet in the center and eastern edge of the roadcut. Unit H measures two feet on the western edge, five feet in the center, and six feet along the eastern edge. Unit I is only present in the center (Figure 5.30) and eastern edge of the roadcut, measuring three feet and three and a half feet respectively. Unit J is only present on the eastern edge of the roadcut (Figure 5.31), and measures six and a half feet in thickness.

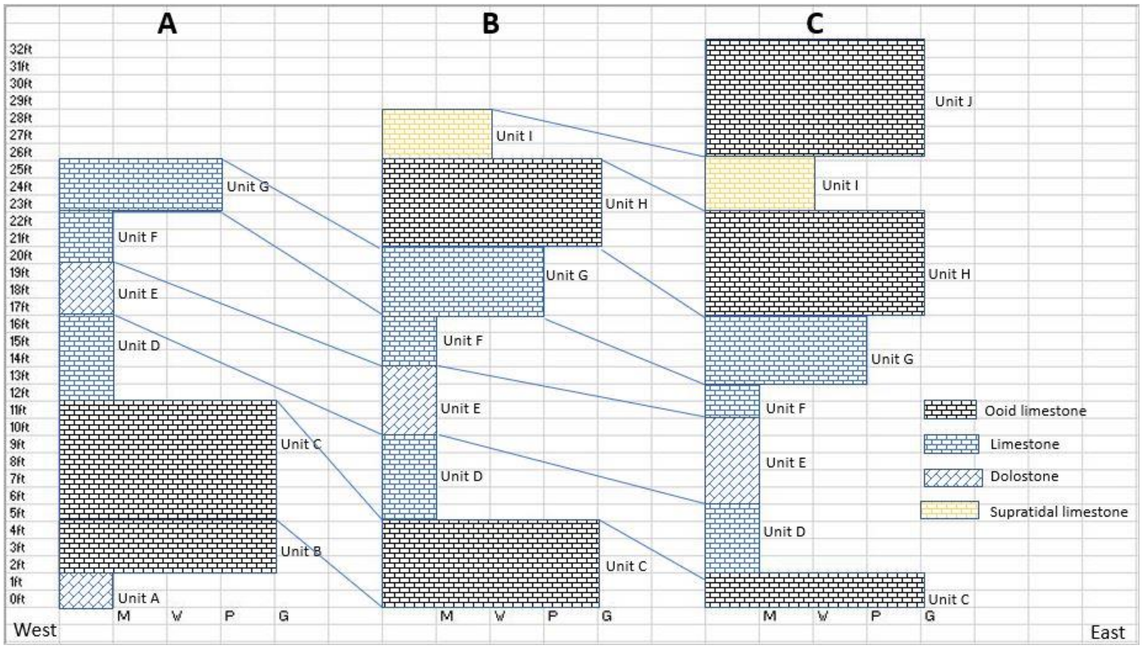

Figure 5.28. Stratigraphic cross section of the Southwest Exit 48 Roadcut.

Figure 5.29. Annotated view of the western edge of Southwest Exit 48 Roadcut.

Figure 5.30. Annotated view of the center of Southwest Exit 48 Roadcut.

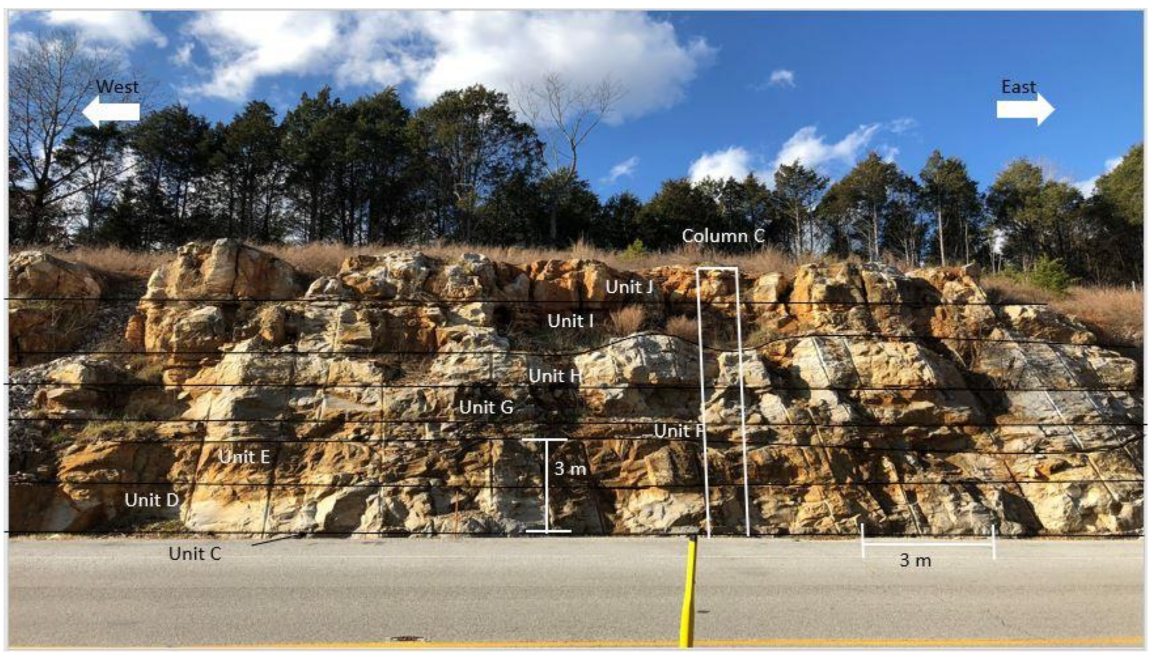

Figure 5.31. Annotated view of the eastern edge of Southwest Exit 48 Roadcut.

5.7 I-65 Northeast Exit 48 Roadcut

5.7.1 Lithofacies

The Northeast Exit 48 Roadcut investigated consists of five distinct stratigraphic units. The lithofacies that constitute these layers are, in ascending stratigraphic order (Figure 5.32):

- A. Chert-Bearing Mudstone: A dark grayish-brown (2.5Y 4/2) mudstone unit. The unit is composed almost entirely of dark grayish-brown material, with small orange/brown deposits in the unit representative of chert replacement. There is fracturing in the unit, with calcite veins precipitating in the fractures.
- B. Partially-Dolomitic Chert-Bearing Mudstone: A light-gray (2.5Y 7/1) mudstone unit. The majority of the unit is composed of light-gray material, however, there are layers of white material that HCl acid tests shows are at least partially dolomitic. Small orange/brown deposits are present that are representative of Fe-oxide stained chert deposits.
- C. Chert-Bearing Wackestone: A light brownish-gray (2.5Y 6/2) wackestone unit. The unit is mainly composed of mud with sparse coarse material, with chert present throughout. There are crinoid-stem molds present that have a gray (2.5Y 6/1) coloring.
- D. Skeletal-Ooid Grainstone: A white (2.5Y 8/1) grainstone unit. The unit is composed of skeletal material and ooids in roughly equal proportions. Skeletal material is mostly fragments, but there are identifiable fossils, mostly brachiopods.

- E. Skeletal Packstone: A gray-brownish (2.5Y 5/2) packstone unit. The unit is composed mostly of skeletal material with sparse deposits of mud. The skeletal material is mostly fragmentary with the few identifiable fossils consisting of brachiopods.

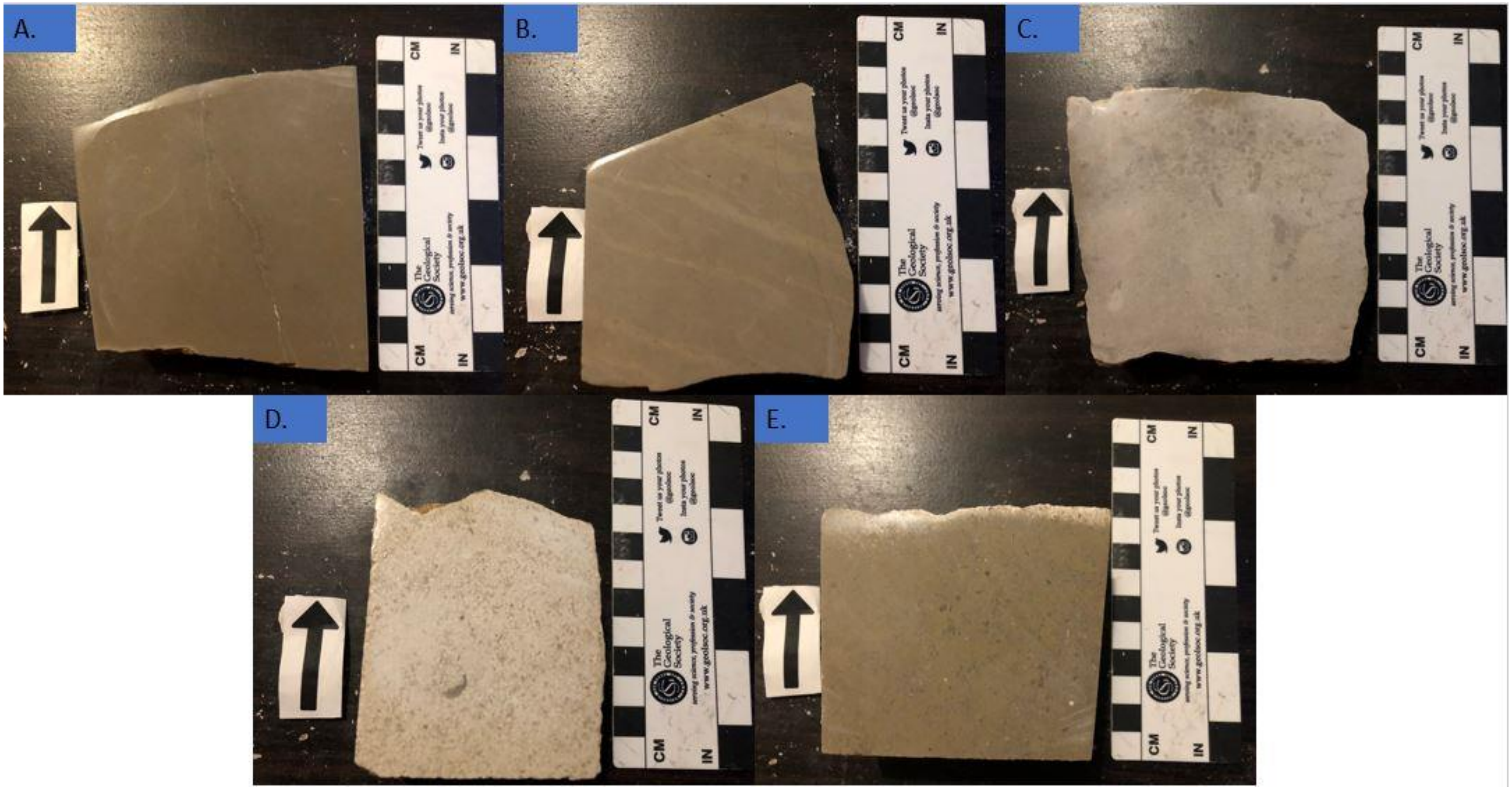

Figure 5.32 Lithofacies of Northeast Exit 48 Roadcut. Arrows show stratigraphic up and scale bars are in centimeters and inches. A. Chert-Bearing Mudstone, B. Partially-Dolomitized Chert-Bearing Mudstone, C. Chert-Bearing Wackestone, D. Skeletal-Ooid Grainstone, and E. Skeletal Packstone.

5.7.2 Stratigraphy

The stratigraphy of the Northeast Exit 48 Roadcut (Figure 5.33) are described as a shoaling upward sequence. Unit A is presently exclusively along the western edge of the roadcut, measuring two and a half feet thick (Figure 5.34). Unit B occurs on the western edge and center of the roadcut (Figure 5.34 and 5.35), measuring seven feet on the western edge and six feet in the center. Unit C is present throughout the unit, measuring roughly eight feet on each section of the roadcut. Unit D occurs in the center and eastern edge of the exposure (Figures 5.35 and 5.36), measuring five feet on both sections where it occurs. Unit E is only found on the eastern edge of the roadcut, measuring four feet.

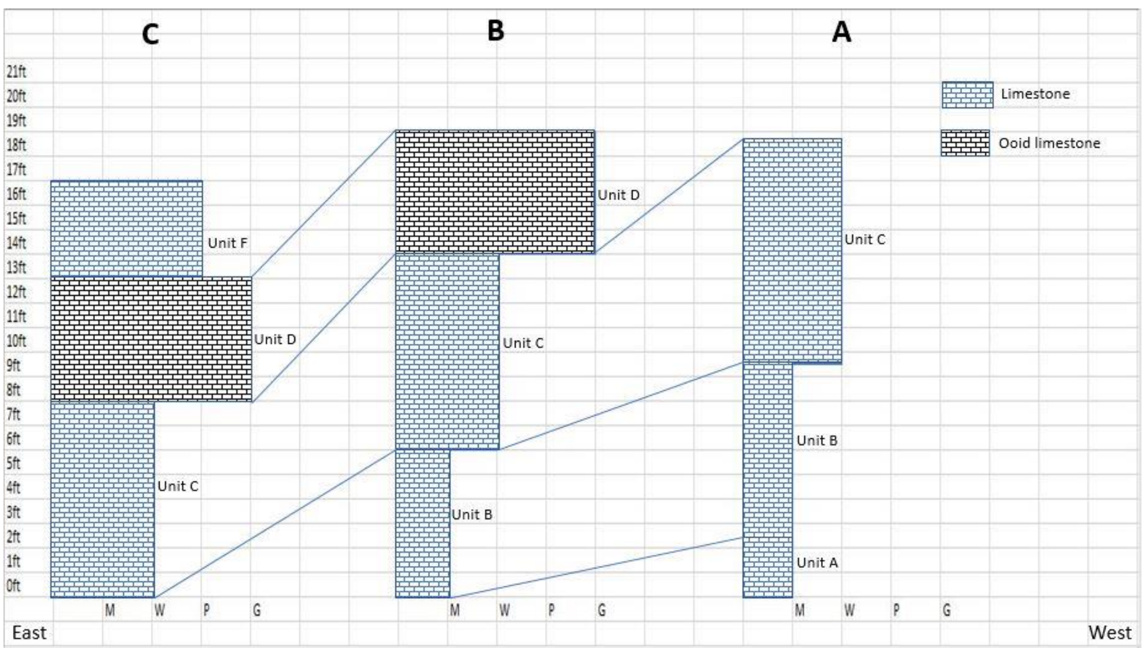

Figure 5.33. Stratigraphic cross section of the Northeast Exit 48 Roadcut. Dunham Classification as in Figure 5.2.

Figure 5.34. Annotated view of eastern edge of the Northeast Exit 48 Roadcut.

Figure 5.35. Annotated view of center of Northeast Exit 48 Roadcut.

Figure 5.36. Annotated view of western edge of Northeast Exit 48 Roadcut.

6.0 DISCUSSION

Based on the data compiled for this study, the general trends and characteristics of the Ste. Genevieve Limestone in western Kentucky become apparent, with variation exhibited via specific roadcut location as well as stratigraphic position. These trends and variations from established generalizations are discussed in detail in the following sections.

6.1 Barren River Road, Mile 2 Roadcut

The Mile 2 Roadcut overall has a coarsening upward stacking pattern, but the roadcut is characterized by alternating layers of coarse-grained and fine-grained units. In the stratigraphic sequence from unit A to unit D, the roadcut alternates from dolostone to grainstone to dolostone to packstone (Figure 5.2). This suggests that the depositional setting experienced drastic changes from relatively low-energy environments to high-energy environments in a relatively short period of geologic time. This pattern persists for units E through F; however, the difference is that whereas unit E (and the correlating shale layer) represents a similar time period as do the other fine-grained units, unit F is a much thicker and a coarse-grained unit and may represent a much longer period of high-energy deposition. With Unit F being characterized by oolitic deposits, such a deposit represents the peak in high-energy level in the stratigraphy of this roadcut.

A salient feature of this roadcut is that the deposition of the units resulted in the formation of a channel with “wings” near the edges of the roadcut (Figures 6.1 and 6.2). The roadcut is dominated by unit D in the center (due to channeling into older depositional units), with units B and C best exposed toward the edges of the roadcut.

Such depositional geometry produces a superficial synform-like pattern with younger units in the center and older ones on the edges. This suggests that the rocks in this roadcut are the result of deposition in a marine channel, with the channel incising into the pre-existing stratigraphic units with sediments in turn, being deposited into the low spots of the scoured or incised strata.

An alternative explanation for the "channel" deposits found in the Barren River Road, Mile 2 Roadcut can be found in a seminal paper on the sequence stratigraphy of the Mississippian age strata in the Illinois Basin. Nelson and others (2002) described how sequence boundaries in the Mississippian strata are typically categorized by incised valleys (with the valley fills characterized by coarse quartz sands) and paleosols. They state that "incised valleys can be confused with local tidal and fluvial channels", raising the possibility that these "channel" deposits are evidence of a sequence boundary. However, these incised valleys as Nelson and others (2002) studied are typically classified as measuring in the tens of kilometers and contain paleosols. The Barren River Road, Mile 2 Roadcut is significantly smaller and possesses no evidence of paleosols; however, with my study focusing on reservoirs, fine-grained rocks were not the focus of this study and thus fine-grained paleosols could be present but not seen. Based on the evidence available, it can be suggested that the Barren River Road, Mile 2 Roadcut is characterized by "channel" deposits and not a sequence boundary.

The only unit in the roadcut possessing hydrocarbon reservoir potential is unit B, with the skeletal grainstone acting as an ideal reservoir rock. The muddy dolostone units overlying (unit C) and underlying (unit A) the potential reservoir unit (unit B) act as ideal confining layers or seals. Unit F is also a potential hydrocarbon reservoir, with the underlying shale acting as a confining layer; however, with the overlaying layer eroded off or blasted off during road construction, it is not possible to discern regarding the viability of the unit's potential as a hydrocarbon reservoir or aquifer.

Figure 6.1. Annotated view of the south "wing" of the Barren River Road, Mile 2 Roadcut. View to the northwest.

Figure 6.2. Annotated view of the north "wing" of the Barren River Road, Mile 2 Roadcut. View to northwest.

6.2 Barren River Road, Belle Rive Circle Roadcut

A distinct characteristic of the Belle Rive Circle Roadcut is a scour surface that separates Units A, B1, and B2 from the upper units. The scour surface is described as a wavy, continuous surface that is present throughout the roadcut. Along the scour surface in the northern edge of the roadcut there is a very thin, pale green (GLEY 2, 8/1) claystone. It must be noted that there is a point in the roadcut where the claystone layer encloses a lower part of unit C (Figure 6.3), which suggests that the claystone layer is the result of pressure dissolution along the scour or diastem/unconformity surface.

Based on the characteristics of the scour surface, it is possible that the surface is an unconformity. However, this feature is not solely an erosional surface and characterization beyond a mere scour surface is supported by available data. There are also for example, indications that this surface or contact has been modified by pressure dissolution (i.e. mega stylolitization). Evidence for this is that the claystone layer's orientation varies from horizontal to oblique to vertical (Figure 5.9). This shows that the original horizontality of the layer or surface was locally disturbed. Additionally, evidence presented by May and others (2007) shows calcite veinlets being terminated by this surface. Such mineralogic terminations are suggestive of a "fractured and solutioned surface" formed during exposure in the Mississippian and then in turn, deposition of marine units above this surface that lack such calcite veins in fractures. These observations are suggestive that these features (i.e. fractures) were present before the formation of the scour surface. Based on the extent of the scour surface and the presence of the clay layer, it is surmised that the surface acts as a confining layer in the roadcut exposure (Padmanabhan et al., 2015; Tada and Siever, 1989).The pressure-dissolution modified scour surface covers the entire extent of the Belle Rive Circle Roadcut (Figures 5.8, 5.10, and 5.11), with the claystone layer covering the entire extent.

Figure 6.3. View of enclosed unit C in the Belle Rive Circle Roadcut. View is to the northwest.

Two distinct units in the Belle Rive Circle Roadcut are units B1 and B2. These units are located only in the northern part of the roadcut and occupy a similar stratigraphic position of the roadcut, suggesting that they are coeval localized units. Unit B1 is a partially-dolomitized wackestone unit and unit B2 is a skeletal grainstone unit. Unit B2 is of importance to this study because its location in the stratigraphy of the roadcut makes it a near textbook example of an ideal hydrocarbon reservoir unit, being enclosed by the dolomitic unit A (Figures 6.4 and 6.5).

Figure 6.4. Annotated view of unit B2 enclosed by unit A in east side of Belle Rive Roadcut. Jacob staff for scale is approximately five feet, view to the east side of the roadcut.

Figure 6.5. Annotated view of unit B2 enclosed by unit A in west side of the Belle Rive Circle Roadcut. Jacob staff for scale is approximately five feet. Unit B2 shown is correlative to unit B2 shown in Figure 6.4. Distance between the two roadcut exposures is approximately 75 feet.

Another distinct unit in the Belle Rive Circle Roadcut is a brecciated limestone unit, unit E. The size of brecciated fragments in the unit range from less than a centimeter to two centimeters or more (cobble size), with the fragments being karstified or showing evidence of dissolution. Since the Belle Rive Circle Roadcut represents the upper part of the Ste. Genevieve Limestone, it is likely that this unit is correlative with the Bryantsville Breccia, named after a well exposed locality in Indiana (Hunter, 1993). With the brecciated limestone (Figure 5.11) being the result of exposure and weathering of a previous carbonate unit, it is likely that this rock was formed during a regressive cycle and thus is indicative of a Falling Stage System Tract (FSST).

There are characteristics of the Belle Rive Circle Roadcut that reflect deposition in an HST environment. The stacking pattern of units C and D is suggestive of carbonate depositional processes associated with an HST and are characterized by high-energy, coarse-grained units, with ooid grainstones being especially indicative of an HST (Tucker et al., 1993). Units C through E constitute roughly one-half of the stratigraphy in the roadcut, with these units measuring 25 feet to 32 feet in thickness (Figure 5.8). All of these units consist of coarse-grained lithofacies (skeletal grainstones and skeletal-ooid grainstone), indicating that they were deposited in a relatively high-energy, shallow-marine setting consist with an HST.

The stacking pattern for units F through I represents a stratigraphic sequence distinct from the rest of the roadcut (Figure 5.7). From the shale layer underlying unit F to unit G, there is approximately 12 feet of fine-grained material indicative of a low energy, shallow-marine setting. In unit H, the depositional setting changes to a shallow, high-energy setting similar to that of units C through. Finally, within unit I, the roadcut exposes a setting similar to units F through G, indicating a relatively dynamic setting in comparison to the lower stratigraphic units (units A and B).

Overall the units in the Belle Rive Circle Roadcut that have the greatest hydrocarbon reservoir potential are units B2, C, D, E, and H. Unit B2 is enclosed by the dolomitic unit A, representing an ideal reservoir. The skeletal unit C, oolitic unit D, and brecciated unit E are enclosed by the shale layer above the units and the stylolitic scour surface below. The oolitic unit H is enclosed by wackestone units G and I.

6.3 Hwy 185, Eversole Road Roadcut

The Eversole Road Roadcut is an approximately 27-feet thick exposure, with the roadcut being one of the larger exposures used in this study. The roadcut shares certain characteristics with the Belle Rive Circle Roadcut (Figures 5.7 and 5.13).

The Eversole Road Roadcut consist of three differentiable units: 1) alternating skeletal-ooid grainstone and dolostone from units A to D, 2) a backstepping, retrogradational pattern from units D to G, and 3) a static, coarse-grained sequence from units G to I. Each of these stacking patterns represents three distinct phases in the depositional environment exposure at this roadcut (Figure 5.13). The alternating ooid skeletal grainstone and dolostone layers of the first stacking pattern represents a dynamic depositional setting, alternating between shallow, high-energy shallow-marine settings and relatively more protected, low energy, static marine settings. The backstepping setting of the second stacking pattern is indicative of a shoaling upward, with a shallowing of the setting and/or a transition into a relatively high-energy environment. The third stacking pattern, characterized by substantial layers of coarse-grained material, is suggestive of a high-energy, shallow-marine setting, most likely a shoal environment. The unit with the most ideal hydrocarbon reservoir potential is the skeletal-ooid limestone, unit C, with dolostone units B and D acting as confining layers around the grainy reservoir rock.

One of the most distinctive units found at Eversole Road is the brecciated limestone represented by unit I. Unit I is the stratigraphically highest in the roadcut (Figure 5.13) and it is at the stratigraphic level correlative to the upper part of the Ste. Genevieve Limestone (Figure 4.10). It is likely that unit I can be correlated to unit E from the Belle Rive Circle Roadcut and thus, unit I is a local stratigraphic equivalent of the Bryantsville Breccia.

Similar to the depositional characteristic found in the Mile Marker 2 Barren River Road Roadcut, there is indication of “channel” deposits in the Eversole Road Roadcut. In the southwestern edge of the roadcut (Figure 6.6), there is portion of unit 3C that exhibits a synform-like channel form but not to the extent as is observable in the Mile Marker 2 Barren River Road Roadcut. With the increase in elevation that occurs between the southwestern edge and northeastern edge of the cut, it is possible that part of the channel is covered. Similar to the Mile Marker 2 Roadcut, the extent of this channel body is limited and thus is most likely the result of channelization and not a sequence boundary.

Figure 6.6. Annotated view of channel “wing” in the Eversole Road Roadcut. View is to the northwest.

The third stacking pattern of the Eversole Road (thick units of coarse-grained material) is very similar to units C, D, and E stacking pattern present in the Belle Rive

Circle Roadcut. The Belle Rive Circle vertical stacking pattern consists of a skeletal grainstone, skeletal-ooid grainstone, and brecciated limestone in ascending stratigraphic order. The third Eversole Road stacking pattern exhibits the same pattern in similar units' thickness as the Belle Rive Circle section, suggesting that these units can be correlated with each other (Figures 5.7 and 5.13). In both cases, the staking patterns represent a profile that is typical of deposition consistent with an HST.

6.4 Hwy 185, Crossroads Roadcut

The Crossroads Roadcut is the shortest exposure analyzed for this study, measuring only 14 feet at its thickest and seven feet at its thinnest. A notable feature of this roadcut is that the northern and center stratigraphic columns are positioned much lower in the Ste. Genevieve Limestone in comparison to the southern stratigraphic column which is much higher in the unit, with there being about a 70-feet difference in elevation from the base of the units (Figure 5.18).

The Crossroads Roadcut is representative of an overall backstepping, retrogradational pattern series of facies, however, there are some minor deviations that must be noted. From units A to C there is a typical retrogradation stacking pattern, transitioning from mudstone (unit A) to wackestone (unit B) and finally packstone (unit C), indicative of a shoaling upward depositional setting. However, unit D, a wackestone unit, exhibits a break in this pattern, representative of a change to a low-energy marine setting. The transition to unit E shows a transition back to a shallow, high-energy environment represented by a skeletal-ooid grainstone. Units F and G in turn, reflect a change back to a shoaling-upward setting.

6.5 Interstate 65, Mile 40 Roadcut

The Mile 40 Roadcut is a medium-sized roadcut for this study, ranging from 12 feet to 18 feet in height. The analysis of the stacking patterns of the lithofacies indicates the depositional environment of the roadcut and how it changed over time. This cut is especially useful in my field investigation as the exposure is one of the few representatives of the lower stratigraphic intervals of the Ste. Genevieve Limestone (Figure 4.10).

Unit A represents the depositional setting of the roadcut initially in a shallow, high-energy environment indicated by the coarse-grained material. The transition from unit A to unit B represents a depositional setting with increasing water depth and thus a decrease in energy. Study of the sequence from units B through D suggests a shoaling upward setting, transitioning from a relatively low-energy, static marine setting to a high-energy environment. The transition from unit D to unit E reflects a similar change to that of unit A to unit B, albeit to a greater degree due to the transition from grainstone to mudstone (in units D and E), relative to the packstone to wackestone lithologic change represented by units A and B. The transition from unit E to unit F represents a deep, low-energy environment to a much shallower, high-energy environment.

A characteristic that differentiates the Interstate 65 Mile 40 Roadcut from the rest of the roadcuts studied is the lack of oolitic limestone (Figure 5.23). Most of the other roadcuts are located in the upper-middle to upper stratigraphic intervals of the Ste. Genevieve Limestone (Figure 4.10), with oolitic limestone units and especially skeletal-ooid limestone being present in the other roadcuts. This suggests that oolitic units are more prevalent in the middle/upper Ste. Genevieve Limestone as opposed to the lower portion, which is consistent with the literature on the Ste. Genevieve Limestone (Zuppan, 1989; Cooper, 2004).

6.6 I-65 Southwest Exit 48 Roadcut

The I-65 Southwest Exit 48 Roadcut is one of the larger roadcuts that were used in this study, measuring 33 feet at the roadcut's thickest and 26 feet at its thinnest (Figure 5.28). The I-65 Southwest and Northeast Exit 48 roadcuts are important in this study due to the great distance that separates them from the rest of the roadcuts and thus indicate the regional differences between the roadcuts.

Unit A represents the lowest unit exposed in the roadcut, with the unit representing deposition within a relatively low-energy environment. The transition into units B and C shows the depositional setting being a much shallower, high-energy shoal setting. Units D, E, and F shows the roadcut's depositional setting reverting back to an environment similar to that of unit A but with the substantial increase in the units' thickness, possibly reflecting a depositional setting that was maintained for a much larger period of time. The transition into units G through J suggests the depositional setting changing back into a shallow, high-energy environment. The units that are the most ideal hydrocarbon reservoirs are B and C, with A and D functioning as confining layers or seals.

The Southwest Exit 48 Roadcut is mainly dominated by coarse-grained units, with skeletal-ooid limestones making up the majority (Figure 5.28). This suggests that the depositional environment associated with rocks at this roadcut was mainly a shoal, indicative of an HST. The thick, fine-grained stratigraphy represented by units D through F show a substantial deviation from this trend.

6.7 I-65 Northeast Exit 48 Roadcut

The I-65 Northeast Exit 48 Roadcut is a roadcut measuring 19 feet at its thickest and 17 feet at its thinnest (Figure 5.33). Although the I-65 Northeast Exit 48 Roadcut is very close to the I-65 Southwest Exit 48 roadcut, both cuts each have a distinct set of lithofacies that and thus, are treated as entirely separate.

The I-65 Northeast Exit 48 Roadcut is a shoaling upward sequence and thus the roadcut's depositional setting is indicative of this entire sequence. Units A and B show that the initial environment is a relatively low-energy setting due to units consisting almost entirely of mud. This depositional setting was maintained for a relatively long time due to the thickness of the units (assuming relatively constant accommodation and sedimentation rates for all units). Unit C shows the depositional setting somewhat shallowing and/or increasing in energy. Units D and E shows the roadcut's depositional setting transitioning into a shoal environment, indicated by the coarseness of the units and the presence of ooids in unit D.

In comparison to the I-65 Southwest Exit 48 Roadcut (Figures 5.28 and 5.29), the study of the I-65 Northeast Exit 48 Roadcut (Figures 5.33 and 5.34) exhibit key differences. The Southwest Exit 48 Roadcut consists of a much greater variety of lithofacies contained within a thick exposure. Although the two roadcuts are in close proximity, they consist of two different sets of lithofacies, with the Northeast Exit 48 Roadcut possessing a shoaling upward pattern and the Southwestern Exit 48 Roadcut is represented by a more dynamic depositional environment. This is likely the result of the difference in elevation and facies transition of the units.

6.8 Lithofacies Variation

The roadcuts included in this study of the Ste. Genevieve Limestone were found to be composed of several different lithofacies individually. Based on the fieldwork conducted for this study, it was discovered that there are a total of 53 distinct lithofacies in the seven roadcuts studied. A breakdown of the classifications of the lithofacies are presented based on these data (Table 5).

Lithofacies Classification	
Mudstone	1A, 1C, 1E, 2A, 2F, 3B, 3D, 4A, 5E, 6A, 6D, 6E, 6F, 7A, 7B
Wackestone	2B1, 2G, 2I, 3E, 4B, 4D, 4F, 5B, 6I, 7C
Packstone	1D, 3F, 4C, 4G, 5A, 5C, 6G, 7E
Grainstone	1B, **1F,** 2B2, 2C, **2D, 2H, 3A, 3C,** 3G, **3H, 4E,** 5D, 5F, **6B, 6C, 6H, 6J, 7D**
Brecciated limestone	2E, 3I

Table 5. Table of lithofacies present in roadcuts subdivided based on their respective Dunham Classifications. Brecciated limestone is not a Dunham Classification moniker but is included for completion of observed lithologic variety. Blue units are representative of dolomitic lithofacies and **Bolded units** are representative of oolitic units.

Based on this subdivision of the lithofacies classification, the general trends of the lithofacies are reportable. Mudstones make up fourteen of the lithofacies present in the roadcuts, constituting roughly 28% of the total number of lithofacies. Ten out of the fourteen mudstone units are dolomitic, or approximately 73% of the mudstone present, meaning that dolomitic units make up the vast majority of mudstone lithofacies encountered.

Wackestones make up eleven of the lithofacies present in the roadcuts, constituting about 19% of the total number of lithofacies. Three out of the eleven wackestone units present are dolomitic, making up only 20% of the total wackestone units, with non-dolomitic units comprising the vast majority of wackestone units.

Packstone units represent eight of the lithofacies present in the roadcuts, constituting roughly 15% of the total number of lithofacies. Packstone units in the roadcuts have no distinguishing characteristics such as oolitic deposits and dolomitic replacement.

Grainstone units constitute eighteen of the lithofacies present in the roadcuts, constituting roughly 34% of the total number of the lithofacies. Twelve out of the eighteen grainstone units are oolitic grainstones, making up about 67% of the grainstone units, and this translates into oolitic grainstones constituting the vast majority of grainstone units.

Brecciated limestone units contribute to only two of the lithofacies present in the roadcuts, constituting roughly 4% of the total number of the lithofacies. The two brecciated limestone units occupy similar stratigraphic positions, with the units likely being the same unit.

Key conclusions on the lithofacies in the roadcuts can be made based on these general trends of the lithofacies discussed above. These conclusions include: 1) The majority of lithofacies present are grainstones, with most of these being skeletal-ooid grainstones, 2) The second most prominent lithofacies are mudstones, with the vast majority of these being dolomitic (i.e. dolomitized) mudstones, 3) Wackestone units are the third most abundant lithofacies, with only a small minority of these being dolomitic, 4) Packstones are the fourth most abundant of the lithofacies, with the packstones present having no distinguishing secondary characteristics (i.e. dolomitic replacement and diagenetic features) and 5) Brecciated limestone units are the least abundant lithofacies, with the two units encountered in the field most likely being the same stratigraphic unit.

6.9 Stacking Patterns and Sequence Stratigraphy

Based on the data compiled from the results of this study, stacking patterns and sequence stratigraphic characteristics of the roadcuts studied become apparent. Lithofacies of the roadcuts represent three stacking patterns (with minor variations): 1) static, thick coarse-grained intervals, 2) backstepping, shoal-building patterns, and 3) alternating coarse-grained and fine-grained units.

The static, coarse-grained intervals range in thickness from as little as 10 feet to approximately 22 feet, with lithofacies being dominated by grainstones and packstones. These coarse-grained intervals typically have abundant ooids, with the oolitic material usually making up at least one-half of the lithofacies in the interval. This interval, with the presence of oolitic shoals is likely a representation of an HST. Nelson and others (2002) state that the HST is the most common systems tract in the Ste. Genevieve Limestone, making up the bulk of most sequences.

The backstepping, shoal-building pattern primarily consists of stacking of progressively coarsening units, typically starting with mudstones and wackestones, then transitioning upward into packstones and grainstones. Within these intervals, they precede a static, coarse interval, suggesting that the shoal-building intervals were deposited in a similar time frame and environment as were the coarse intervals. The presence of mudstones and wackestones suggest that the intervals were initially deposited in a comparably deeper water or low-energy environment. These intervals overall likely encompass the late part of a TST and the beginning of an HST.

Alternating fine-grained and coarse-grained intervals are the most important in regard to hydrocarbon reservoir potential. Potential reservoir intervals are typically characterized by a coarse-grained unit, usually an ooid or skeletal-ooid grainstone, with brecciated and solely skeletal units also being possible reservoirs. Confining layers consist of fine-grained units, usually mudstones (both calcitic and dolomitic) but in some cases wackestones. The coarse-grained units act as ideal reservoirs and the fine-grained units act as ideal confining layers for potential hydrocarbon reservoirs.

Based on the data available, the roadcuts studied are dominated by HST deposits. Nelson and others (2002) stated that the Ste. Genevieve Limestone is made up of two sequences, with each measuring roughly 50 m each. In the case of both sequences, the HST and TST are the only systems tracts that are adequately preserved in the geological record, with HST deposits being substantially more common. The HST is typically characterized by limestone units and shoal deposits whereas the TST is characterized by sandstone and shale deposits with thin limestone intervals. The lack of sandstone deposits and the few shale deposits in the stratigraphy studied suggest HST deposits dominate roadcuts.

7.0 CONCLUSIONS

The Ste. Genevieve Limestone in western Kentucky has several characteristics that are best represented by the roadcuts that are found throughout the area. These characteristics include:

- Lithofacies tend to represent three stacking patterns (with minor variations): 1) alternating coarse-grained units and fine-grained units (characterized by hydrocarbon reservoir potential and confining layers) (Figures 5.2, 5.13, and 5.28), 2) backstepping, retrogradational, shoal-building pattern (indicative of the beginning of HSTs and the late portion of TSTs) (Figures 5.13, 5.18, 5.23, and 5.33), and 3) static, thick coarse-grained intervals (indicative of HSTs) (Figures 5.7, 5.13, 5.28 in upper and lower parts).
- The stratigraphy is dominated by limestone units, with other common lithofacies consisting of dolomitic units, with a few intercalated shales, and little to no coarse siliciclastic units, suggesting a shallow-marine environment (Table 5).
- Dolomitic units in the stratigraphy are dominated by fine-grained rocks (mudstones), with a few comparably coarser (wackestone) units consisting of partially dolomitized intervals, suggesting dolomitic replacement (Table 5).
- Coarse-grained units in the stratigraphy are dominated by skeletal grainstones, with skeletal-ooid grainstone intervals making up more than half of these units, suggesting extensive shoal build ups (Table 5).
- Fine-grained material tends to be dominated by mudstones, primarily dolomitic, with wackestones (primary calcitic) making up the remainder (Table 5).

- Ooid units tend to be present more in the upper most part of the Ste. Genevieve Limestone than in the lowermost stratigraphic intervals, suggesting that shoal development is more prominent in the upper stratigraphy (Figures 2.8 and 5.23).
- The units present in the stratigraphy with the greatest hydrocarbon reservoir potential tend to be skeletal-ooid grainstones (Figures 5.1F, 5.6D, 5.6H, 5.12A, 5.12C, 5.17E, 5.27B, 5.27H, 5.27J, and 5.32D), with skeletal grainstones (Figures 5.1B, 5.6B2, 5.6C, 5.12G, and 5.22D) and brecciated limestones (Figures 5.6E and 5.12I) also having potential.
- The units that act as confining layers to reservoir units are fine-grained dolomitic units (Figures 5.1A, 5.1C, 5.6A, 5.12B, 5.12D, and 5.27A), with other confining layers including shales (Figures 5.2, 5.3, 5.7 and 5.8) and non-dolomitic fine-grained rocks (Figure 5.6G, 5.6B1, 5.6I, and5.27D).
- The pressure-dissolution modified scour surface (megastylolite) and its corresponding clay layer act as a confining layer in the Belle Rive Circle Roadcut, and such surfaces may be important as reservoir partitions throughout the Illinois Basin (Figures 5.8, 5.9, 5.10, 5.11, and 6.3).
- The depositional environments for the roadcuts are either a shoal environment, dominated by coarse-grained limestone (Figures 5.7, 5.13, 5.28), or a shoaling upward environment, characterized by fine-grained material transitioning into coarse-grained material (Figures 5.13, 5.18, 5.23, and 5.33).
- The presence of thick sections of coarse-grained units in the stratigraphy of roadcuts suggests that they were deposited in an HST (Figures 5.7, 5.13, and

5.28), with the exception of brecciated limestone intervals (representative of the Bryantsville Breccia) (Figures 5.7 and 5.13) which are indicative of an FSST.

- Study of the roadcuts indicates that the units were deposited in tidally influenced depositional environment with siliciclastic intervals not becoming prominent until the upper part of the unit (Figures 2.8, 5.2, and 5.7), similar to what is described in Smith and Read (1999).

7.1 Study Limitations and Future Research

Information gained from this study overall is valuable for the continuing investigation of the Ste. Genevieve Limestone; however, it must be noted that there are limitations to this study. The main limitation of this study is the relatively small number of roadcuts used for data collection and interpretation. Seven roadcuts from Warren and Barren counties were analyzed to characterize the Ste. Genevieve Limestone. While this does create an adequate localized profile for the Ste. Genevieve Limestone, if additional roadcuts were included from different areas as well as cores, this would permit a more detailed study and also would also enhance discovering characteristics that are unique to a specific locality.

A limitation that is intrinsic to the nature of my study is that it focuses almost exclusively on roadcuts. Roadcuts are an important avenue for analysis of lithology and stratigraphy, but they are limited in the amount of the stratigraphy that is exposed. Future studies of the Ste. Genevieve Limestone in western Kentucky should consider data from different sources in order to better characterize the unit on a more regional basis. An example of this would be to study subsurface data from geophysical well logs from oil and gas wells in the area (e.g., Figure 7.1). When a well is drilled, geophysical well logs and drillers sample logs are generated for a given well. A well log is a detailed diagram or vertically plotted graphic of the units that constitute the subsurface geology encountered by drilling and the characteristics of the units. Well logs cover substantially more of the stratigraphy than do roadcuts. Such logs also have associated measuring parameters such as gamma ray (radiation) and neutron porosity, density porosity, and resistivity that all provide a greater insight into the hydrocarbon potential of units.

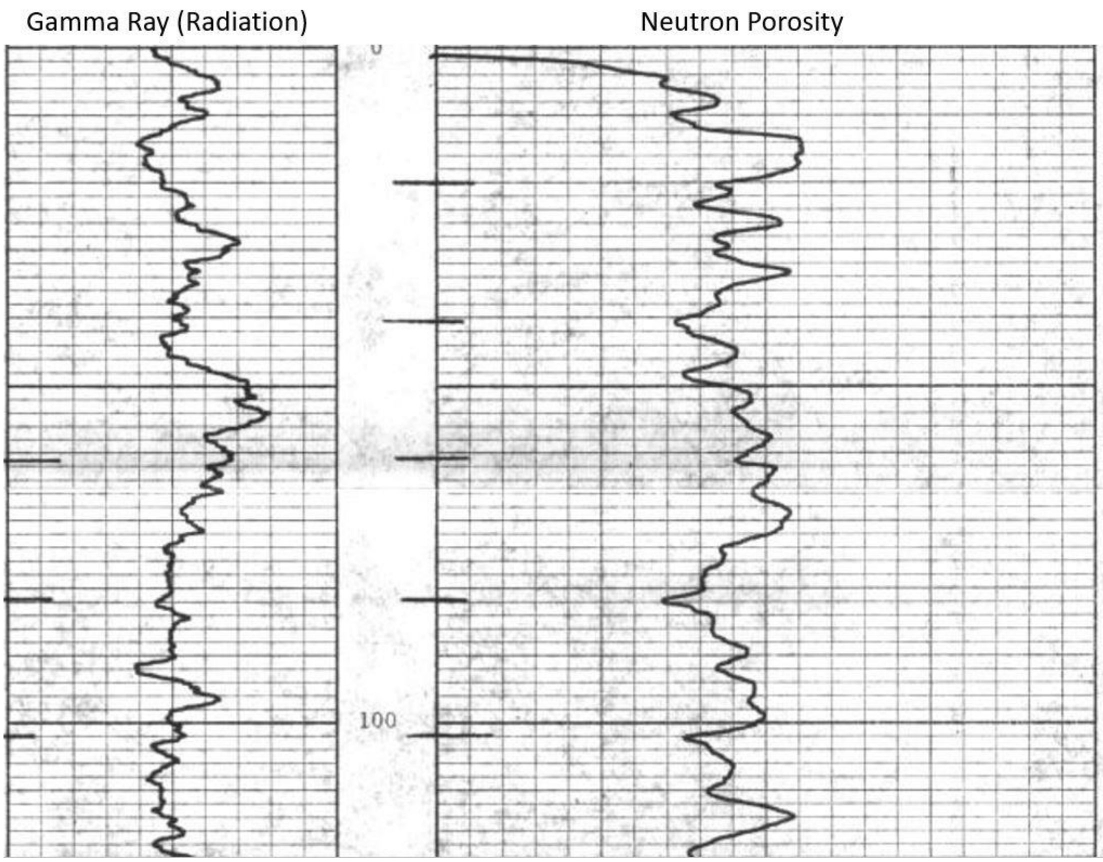

Figure 7.1. Example of a typical well log. The measurement in the middle is in feet (each rectangle represents two feet). Well number 3, permit number 48026, and KGS record number 17395. Accessed from the KGS (June 2019).

The downside of using drillers' sampling logs or verbal description well logs is that they may not provide sufficiently detailed descriptions of the lithology. However, when an exploration or development well is drilled, there may be a core available for study such as which are available from the KGS Core Library in Lexington. A core is a part of the subsurface that presents an avenue for conducting a detailed analysis of subsurface lithofacies tantamount to analysis as can be conducted in roadcuts or other surface exposures.

Another example of different data sources is petrofacies analyses using petrographic thin sections. An example of this is a study conducted to document more details of facies relationships not possible with just surface study and observation, description and interpretation of rock slabs.

A future study of the Ste. Genevieve Limestone in western Kentucky could take well-log data from wells and cores in the area and correlate them to create profiles. Well logs from wells are usually open for academic research from sources such as the KGS and the core samples can be requested if available from core libraries. If one was to take ¨ few tens of wells and correlate them this would allow for a more detailed analysis of the hydrocarbon potential of units in the Ste. Genevieve that could be tied or correlated to my presented roadcut study. It would also form the basis for a more complete characterization of the sequence stratigraphy of the unit and analyze a much wider scope of the Ste. Genevieve Limestone.

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