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Subsurface Stratigraphy and Carbon Sequestration Potential of Eastern Baldwin County,
Alabama

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ABSTRACT

Subsurface stratigraphy of eastern Baldwin County, Alabama, particularly the Upper Cretaceous section, exhibits a geologic framework favorable for carbon sequestration and is characterized by three critical attributes: a regionally extensive Upper Cretaceous chalk succession that provides an effective confining seal; a thick package of clastic formations with reservoir-quality properties (18-30% porosity, 100-1500 mD permeability); and relatively shallow burial depths that enhance both accessibility and the potential for injectivity. Stratigraphic correlation of the Tuscaloosa

Group and Eutaw Formation in the study area delineates two laterally continuous sequestration intervals bounded by confining units, herein designated the **Alpha** and **Beta** zones, separated by a middle confining unit. The **Alpha** and **Beta** zones are approximately 150 m (500 ft) and 90 m (300 ft) thick, respectively, with the intervening confining unit measuring about 150 m (500 ft). This vertically stacked system of reservoirs and seals provides multiple opportunities for long-term CO₂ storage within a single stratigraphic succession. The continuity, thickness, and reservoir quality of these intervals highlight eastern Baldwin County as a promising and regionally significant candidate for carbon storage, with implications for advancing carbon management strategies along the U.S. Gulf Coast.

INTRODUCTION

Several industries in Southwest Alabama and adjacent Florida are candidates for sequestering their carbon dioxide emissions. Local Alabama emitters that could sequester carbon in eastern Baldwin County include the coal and natural gas-burning Plant Barry and the natural gas-burning Cogen Facility at Theodore, both owned by Southern Company. In adjacent Florida, several non-power-generating facilities are candidate emitters that could engage in carbon sequestration in eastern Baldwin County.

Southwestern Alabama's subsurface stratigraphy is well-suited for carbon sequestration activities owing to the presence of porous sandstone formations below a thick section of relatively impermeable chinks. Figure 1 shows the study area and the five deep exploration wells used in this report, which have both subsurface logs and sample collections available at the Geological Survey of Alabama in Tuscaloosa. Well permit numbers (east to west) for these five wells are 1777, 1907, 3076, 3414, and 1845. As shown in Figure 1, the five wells described herein are

more or less equally spaced along a line about 19.3 km (12 mi) long spanning the study area. All five well logs penetrate the Upper Cretaceous stratigraphic interval, below the Selma Group chalks. These five closely spaced petroleum exploration wells in Baldwin County, Alabama, provide insights into the local carbon sequestration potential.

GEOLOGIC SETTING

The subsurface geology of formations in the study area of Baldwin County (Wilson and Tew, 1985) is shown in Figure 2. The upper group of formations (i.e., the Cenozoic section, which is not explicitly shown in Figure 2) consists of approximately 1460 m (4800 ft) of sandy, clayey (shaly), and carbonate sediments, which directly overlie the thick chalk deposits of the Upper Cretaceous Selma Group (the uppermost stratigraphic unit shown in Figure 2). In this area of Baldwin County, the lowermost limit of the USDW (i.e., underground source of drinking water) is located within the Cenozoic section, specifically within the undifferentiated sediments approximately at the middle of Oligocene strata (at a depth of about 900 m (3000 ft) in the study area; Robinson et al., 1996). The Cenozoic formations of the subsurface of Baldwin County are lithological units unsuitable for carbon sequestration because they are characterized by shallow depth, aquifers that are, or communicate with, underground source of drinking water, and a lack of thick confining or capping units that isolate sequestered CO₂ from potentially contaminating aquifers that source drinking water.

Formations of the Upper Cretaceous Selma Group that lie below the Cenozoic section include the Demopolis Chalk and the Mooreville Chalk, units with aggregate thicknesses of about 450 to 520 m (1500 to 1700 ft), composed of relatively impermeable fine sediment (Gonzalez, 1975).

These formations can serve to cap the underlying zones proposed for carbon sequestration.

Lithologic units with potential for carbon sequestration that underly the Upper Cretaceous Selma Group include the sandy units of the Eutaw Formation and the underlying Tuscaloosa Group (Fig. 2).

The Tuscaloosa Group is comprised of three main parts, including a lower sandy zone that is in part glauconitic, a middle marine shale (which is a confining or capping unit), and an upper sandy zone (Figure 2; Wilson and Tew, 1985). The sands of the younger Eutaw Formation and Tuscaloosa Group (both upper and lower) are considered saline reservoirs (Esposito et al., 2008), with the capacity to displace injected CO₂. Data on the chloride level in a well drilled into the lower Tuscaloosa sands in nearby Escambia County show approximately 91,200 mg/L and total dissolved solids of about 151,000 mg/L (Alverson, 1970).

It should be noted that the study area is located at least 16 km (10 mi) from the eastern limit of the structural effects of the Wiggins arch and is therefore in a zone of relatively minimal deformation. The geological formations of the study area are essentially flat-lying (dips less than a few degrees at most), and there are no known faults in or nearby the underlying area (Wilson and Tew, 1985). There is relatively low heat flow in the study area; values are about 1.4 deg F/30 m (or 100 ft) (Wilson and Tew, 1985), which is within the generally accepted range for carbon-sequestration practices.

PETROLOGY

The upper part of the Upper Cretaceous Tuscaloosa Group is composed of Coastal Plain sediments deposited primarily in alluvial plain environments, and the lower part is comprised of wave- and tide-dominated deltaic facies (Woolf, 2012). Sands of the Tuscaloosa Group are poorly sorted, ranging in grain size from fine to coarse sand. Two petrographic studies suggest a general Tuscaloosa sediment dispersal direction from the north (Tanner, 1955; Madeley, 1972), but these studies do not specify the types of rocks that were eroding at the hinterland. Pebbles are also found in some subsurface sections and suggest provenance from the inner Piedmont felsic crystalline terranes of the southern Appalachian fold and thrust belt (Sayers and Uddin, 2010).

Petrographic studies of the Tuscaloosa Group reveal that the sands are lithic arenites composed mostly of monocrystalline quartz and metamorphic and sedimentary lithic fragments. The high percentage of metamorphic lithic fragments supports a dominant metamorphic source with a short transport distance, as evidenced by poor sorting and relative angularity of the framework grains (Sayers and Uddin, 2010). The relative lack of feldspars indicates that the sediments experienced extensive chemical weathering as they were transported and deposited near the equator of that time. The presence of glauconite grains has been noted in some Tuscaloosa sands of southern Alabama, suggesting their deposition in a marine environment.

Quartz grains in Tuscaloosa sands commonly display chlorite coatings, which generally inhibit the development of quartz cements. Chlorite coatings are thought to be an important factor in the preservation of porosity and the higher-than-expected permeability in Tuscaloosa sands of both fluvial and deltaic origin in southern Louisiana (Dutton et al., 2018), and this may be true in southern Alabama as well.

Channel systems within the Tuscaloosa alluvial plain sediments are stacked deposits of both meandering and braided streams, including their associated, fine-grained overbank facies, which are organized in such a way that they might tend to retard the vertical movement of fluids in the carbon sequestration process (based on data in Stancliffe et al., 1986; Warren, 2018).

SUBSURFACE STRATIGRAPHY

Figures 3a-e show logs for the five wells and a data table of the tops of the main formations in each log. These logs show spontaneous potential on the left side and resistivity on the right. The red lines show the boundaries of the formations from the data table in each instance. Of note is that a very similar stratigraphy exists in each of these wells, and a summary is provided for each on the left. This summary includes, from top to bottom, as follows:

- An Upper Cretaceous (chalk) confining unit (only the lower few feet are shown; but the thickness of this confining unit is about 450 to 520 m (1500 to 1700 ft) in this area);
- An Upper Cretaceous sequestration zone **Beta** (Eutaw and upper Tuscaloosa sands), which averages about 90 m (300 ft) thick in this area and consists of porous and permeable micaceous quartz-rich sands;
- An Upper Cretaceous confining zone (the marine shale unit of the middle Tuscaloosa; John et al., 1997), which averages about 150 m (500 ft) thick in this area and consists of relatively impermeable shales and shaley sands;

- An Upper Cretaceous sequestration zone **Alpha** (lower Tuscaloosa sands, including glauconitic sands), which averages about 150 m (500 ft) thick in this area and consists of glauconitic quartz-rich sands; and
- A Lower Cretaceous confining zone, which is the Washita-Fredericksburg interval (shown as “undifferentiated interval” on Figure 1), a thick sequence of cemented sands, shales, and carbonates that generally acts as a local aquitard, and here as a lower confining zone.

Figure 4 shows the correlation of the five deep wells listed above, with units arranged west-to-east (left-to-right). The segments of the well logs in each instance are the same as in Figures 3a-e. The red lines are the boundaries between the five carbon sequestration-related units listed above. As the correlation shows, the proposed carbon-sequestration zones **Alpha** (above the Lower Cretaceous confining unit and below the marine shales) and **Beta** (below the Upper Cretaceous chalk confining unit and above the marine shales) persist across the area and maintain approximately the same thicknesses.

Carbon sequestration zones

Carbon sequestration zones **Alpha** and **Beta** are proposed here as preferred targets for carbon dioxide injection processes owing to their stratigraphic position relative to substantial confining units and their relatively shallow depth. Also, these units have the requisite porosity and permeability to be injected with supercritical carbon dioxide without induced fracturing.

The general averages for porosity and permeability for the **Alpha** zone (lower Tuscaloosa sands) are 18 to 30 % and 100 to 1500 mD, respectively (based on a regional study that includes the present study area; ARI, 2009). The general averages for porosity and permeability for the **Beta** zone (Eutaw and upper Tuscaloosa sands) are about 25% and 220 mD, respectively (Pashin et al., 2008). In a SECARB phase III report (ARI, 2009), the storage capacity for these two intervals (here referred to as **Alpha** and **Beta**) was estimated to be many tens of trillions of cubic feet in Alabama alone. These criteria are important for assessing the suitability of a geological formation for carbon sequestration, and in this instance, the Tuscaloosa Group is well-suited.

Theoretical storage capacity for these two zones in the Baldwin County area has been estimated using standard volumetric calculations based on effective porosity, thickness, and reservoir area, followed by application of NETL's recommended storage efficiency factors. These estimates yield a combined storage range of trillions of cubic feet (Tscf), which translates to millions of metric tonnes (MMt) of CO₂ (Levine et al., 2016). These estimates suggest the formation is capable of hosting multi-decade injection volumes at rates suitable for a commercial carbon capture and storage (CCS) hub (Levine et al., 2016).

In addition to these favorable attributes, it is noted that the sands of the **Alpha** zone are rich in the diagenetic clay mineral glauconite, which is an active donor for cations (e.g., Fe and Mg) in the mineral-forming, carbon-sequestration process (Tutolo et al., 2020; Zhang and Tutolo, 2021). These ions help fix carbon dioxide as Fe- and Mg-carbonate minerals in target injection formations. Further, it is noted that the **Beta** zone sands, which are not glauconitic, are good

carbon sequestration target rocks in experiments owing to carbon dioxide-mineral-brine interactions (Lu et al., 2011).

Figure 5 shows a thin-section view of glauconitic sands from a deep well in adjacent Mobile County, Alabama. These views are provided to illustrate the porosity and mineralogy expected in Tuscaloosa sands (Sayers and Uddin, 2010).

From a geologic containment perspective, the formations dip gently to the south and southwest, providing a favorable structural geometry for plume migration control. Combined with injection pressure management strategies, such a structural dip could be used to direct plume movement away from critical groundwater or ecological zones and toward optimal storage volumes, if that is an issue. Also of importance is that the study area lies in close proximity to existing infrastructure, including state and federal highways, and is within a feasible distance of major CO₂ pipelines and point-source emissions from industrial corridors in southern Alabama and nearby Mississippi. This accessibility enhances project economics by reducing right-of-way acquisition and pipeline construction costs (Esposito et al., 2009).

SUMMARY AND CONCLUSIONS

In eastern Baldwin County, Alabama, the subsurface stratigraphy appears to have properties suitable for carbon sequestration within the Upper Cretaceous clastic section, namely the Tuscaloosa Group and Eutaw Formation. The proposed **Alpha** and **Beta** carbon sequestration zones are approximately 150 and 90 meters (500 and 300 ft) thick, respectively, with a middle confining unit approximately 150 meters (500 ft) thick. These three zones are laterally

continuous across the study area and lie beneath a thick, relatively impermeable caprock formed by the Mooreville Chalk and the Demopolis Chalk, which in aggregate range from 450 to 520 meters (1,500 to 1,700 ft) in thickness.

Importantly, the study area lies within close proximity to existing infrastructure, including state and federal highways, and is within a feasible distance of major CO₂ pipelines and point-source emissions from industrial corridors in southern Alabama and nearby Mississippi. Given its geological suitability, thick confining intervals, proximity to high-volume point sources of CO₂, and favorable infrastructure access, the Baldwin County site represents a strong candidate for commercial-scale geologic carbon storage. In total, at least a dozen emitters within a 15-mile (24-km) radius of the study area could participate in carbon sequestration in eastern Baldwin County.

Additional work that could be performed in pursuit of more specific geological data regarding this carbon sequestration project include sampling of deep well drilled materials at the Geological Survey of Alabama, laboratory measurements of samples from deep wells at the Survey, more intensive literature review and synthesis of pertinent data from previous studies of this area and analogous areas regarding carbon sequestration, and assisting with well planning and siting operations.

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FIGURE CAPTIONS

Figure 1. Location of Baldwin County among counties in Alabama and a map (center) with an enlarged detail of Baldwin County, including main towns and cities. Right: Locations of permitted deep wells in Baldwin County; wells used in the present report are marked with red stars, and the line of correlation in Figure 4 is shown connecting those five wells (from Geological Survey of Alabama Oil and Gas Report 2; used with permission).

Figure 2. Stratigraphic column showing subsurface Cretaceous formations in the Baldwin County area, Alabama (modified from Wilson and Tew, 1985). The Selma Group consists mainly of Mooreville Chalk and overlying Demopolis Chalk. Lower Cretaceous formations are Washita-Fredricksburg (shown as “undifferentiated” in this diagram). G shows the approximate location of the sample shown in Figure 5.

Figure 3a. Detail of Well 1777 – Upper Cretaceous well-log stratigraphy below Selma Group chalks (Mooreville and Demopolis). Left side of log is S.P. (spontaneous potential in mVolts); Right side is resistivity in Ohms—Inset map from Figure 1. The inset table shows depth picks from the well-log. Details of sequestration zones and confining zones are given on the right.

Figure 3b. Detail of Well 1907 – Upper Cretaceous well-log stratigraphy, below Selma Group chalks (Mooreville and Demopolis). Left side of log is S.P. (spontaneous potential in mVolts); Right side is resistivity in Ohms—Inset map from Figure 1. The inset table shows depth picks from the well-log. Details of sequestration zones and confining zones are given on the right.

Figure 3c. Detail of Well 3076 – Upper Cretaceous well-log stratigraphy below Selma Group chalks (Mooreville and Demopolis). Left side of log is S.P. (spontaneous potential in mVolts); Right side is resistivity in Ohms—Inset map from Figure 1. The inset table shows depth picks from the well-log. Details of sequestration zones and confining zones are given on the right.

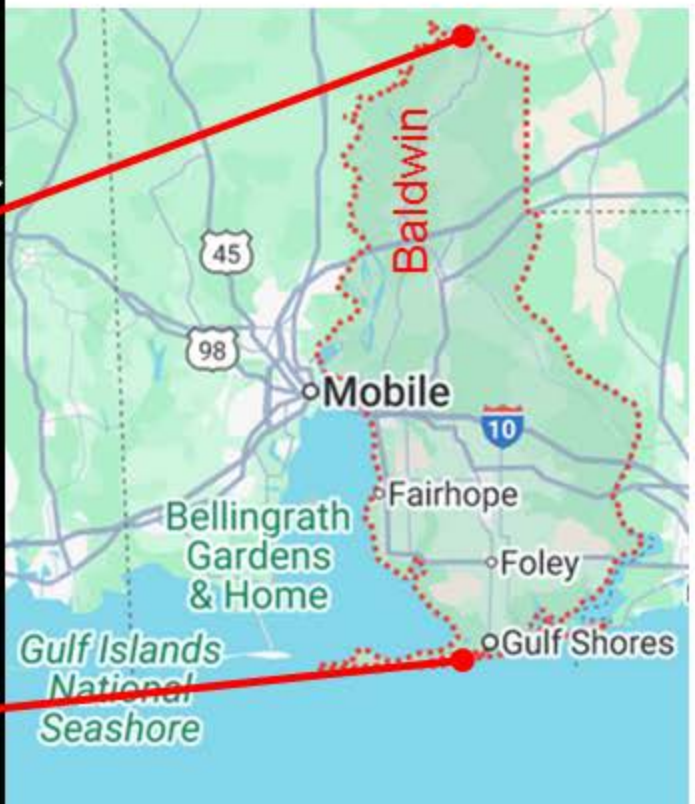
Figure 3d. Detail of Well 3414 – Upper Cretaceous well-log stratigraphy below Selma Group chalks (Mooreville and Demopolis). Left side of log is S.P. (spontaneous potential in mVolts);

Right side is resistivity in Ohms—Inset map from Figure 1. The inset table shows depth picks from the well-log. Details of sequestration zones and confining zones are given on the right.

Figure 3e. Detail of Well 1845 – Upper Cretaceous well-log stratigraphy below Selma Group chalks (Mooreville and Demopolis). Left side of log is S.P. (spontaneous potential in mVolts); Right side is resistivity in Ohms—Inset map from Figure 1. The inset table shows depth picks from the well-log. Details of sequestration zones and confining zones are given on the right.

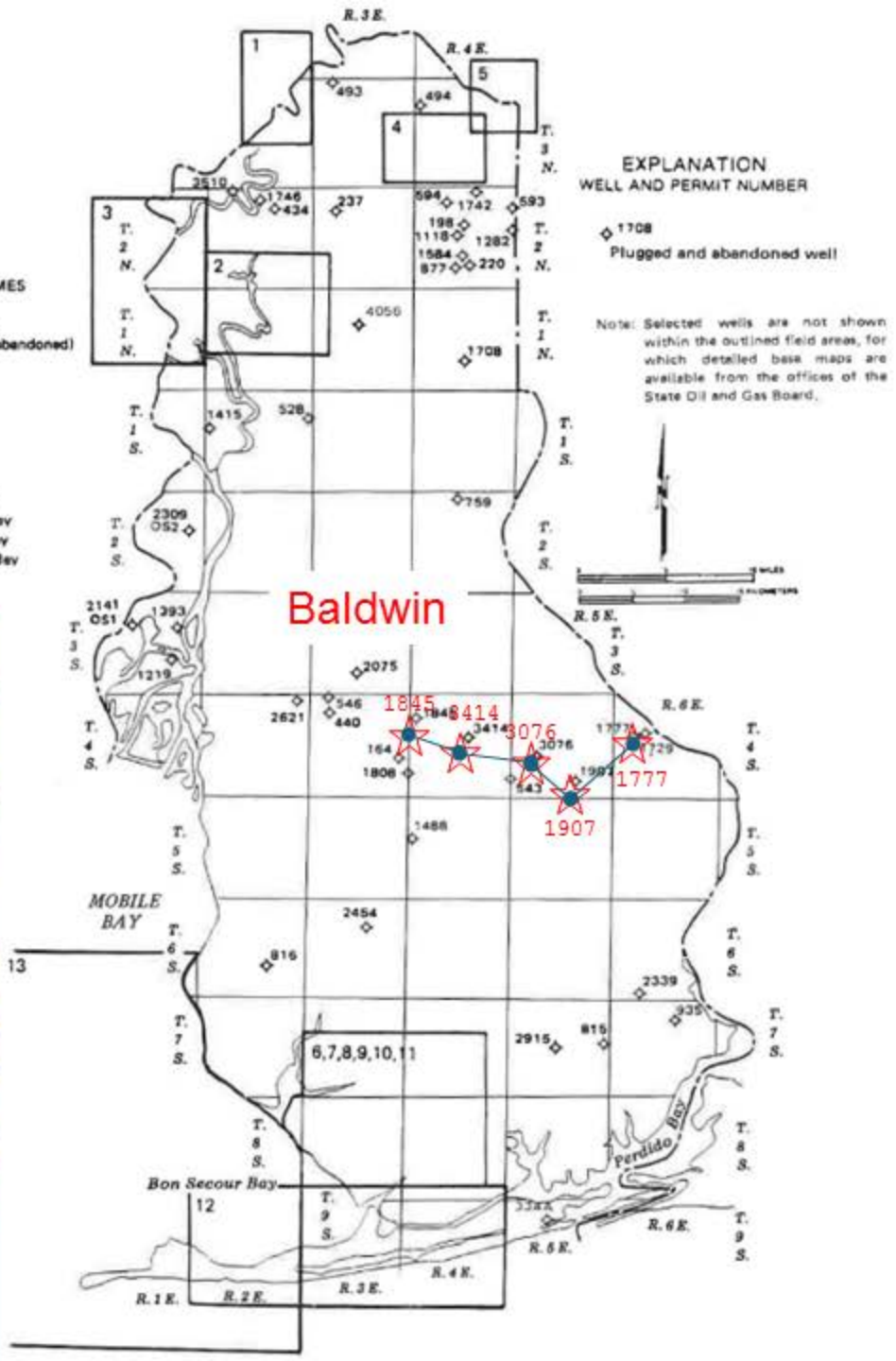
Figure 4. Correlation of the five permitted wells that are marked in Figure 1 and illustrated in detail in Figure 3a-e. Horizontal distance is about 12 miles. Vertical scale is marked in 100-ft intervals.

Figure 5. Thin-section view of a representative sand sample from the upper Tuscaloosa Group, which shows angular quartz grains (Qtz). This photomicrograph also shows abundant glauconite grains (Glc), which is typical of the upper Tuscaloosa in the study area, but not necessarily elsewhere. This field of view contains about 20-25% porosity. The scale bar (500 microns) is in the lower right.



FIELD NAMES

- 1 - South Carlton
- 2 - Tensaw Lake (abandoned)
- 3 - Movico
- 4 - Blacksher
- 5 - Little River
- 6 - Foley
- 7 - West Foley
- 8 - South Foley
- 9 - Skunk Bayou
- 10 - Pleasant View
- 11 - South Weeks Bay
- 12 - East Oysters Bay
- 13 - Lower Mobile Bay



CRETACEOUS

UPPER

LOWER

SELMA GROUP

EUTAW FORMATION

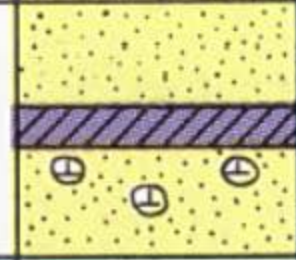
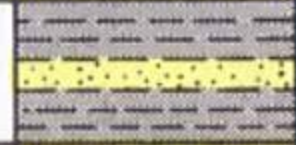
TUSCALOOSA GROUP

"Upper"

"Marine"

"Lower"

LOWER CRETACEOUS UNDIFFERENTIATED



Chalk, massive; chalky shale

Sandstone; glauconitic sandstone; shale

Sandstone, with shale and claystone interbeds

Shale, with sandy streaks and thin sandstone beds

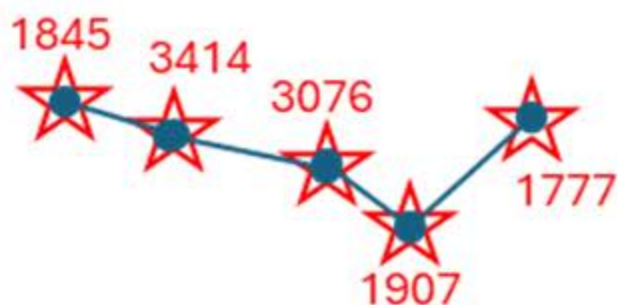
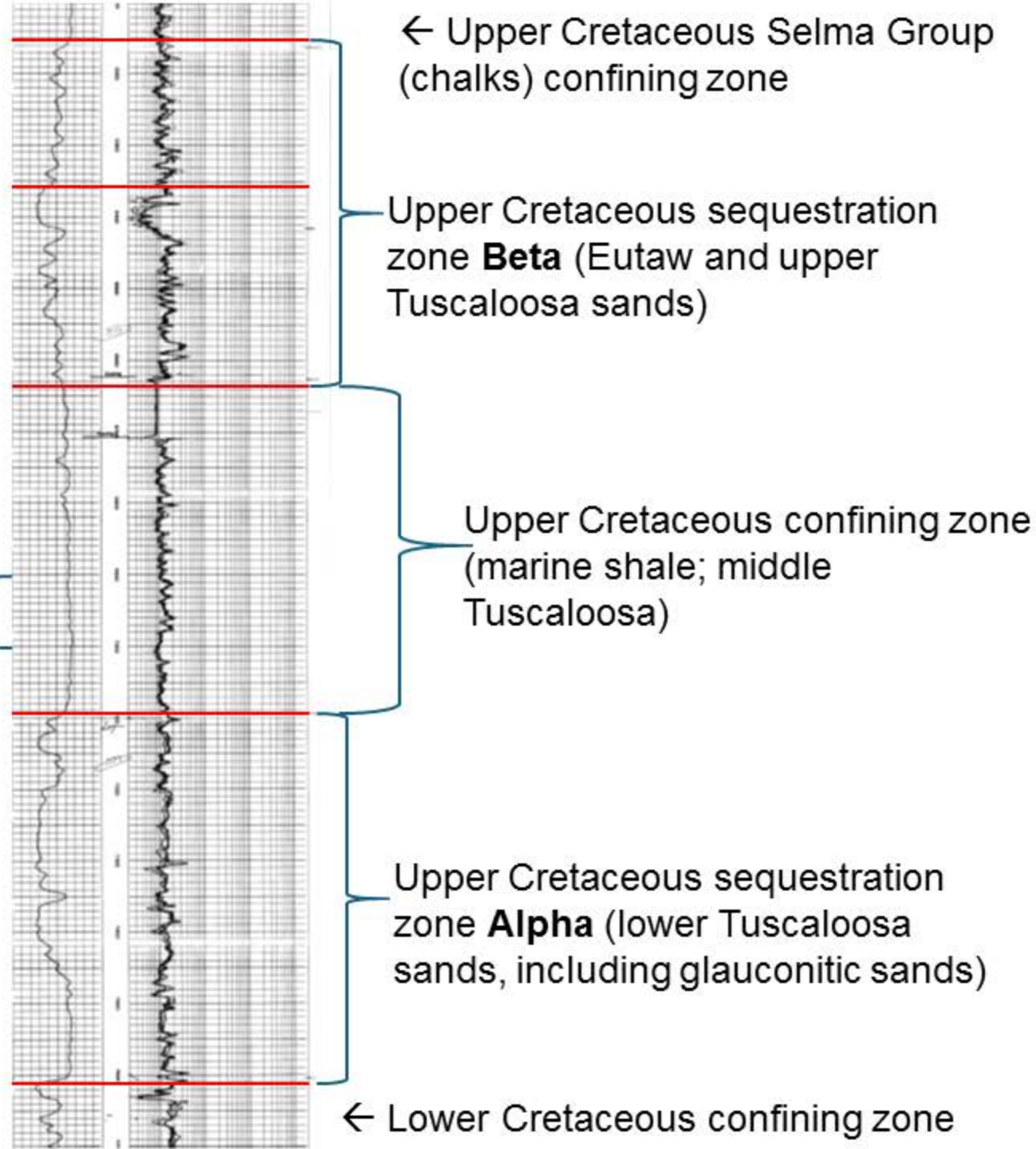
Sandstone, thin to massive, with shale interbeds

Sandstone, fine- to medium-grained, with traces of nodular limestone; thin anhydrite unit near middle

Well no. | top of formation picked | ft depth

1777	top of Eutaw Formation	6155
1777	top of upper Tuscaloosa Group	6358
1777	top of marine shale, Tuscaloosa Group	6635
1777	top of lower Tuscaloosa Group	7090
1777	top of Washita-Fredericksburg, lower Cretaceous	7607

Vertical scale of 100 ft

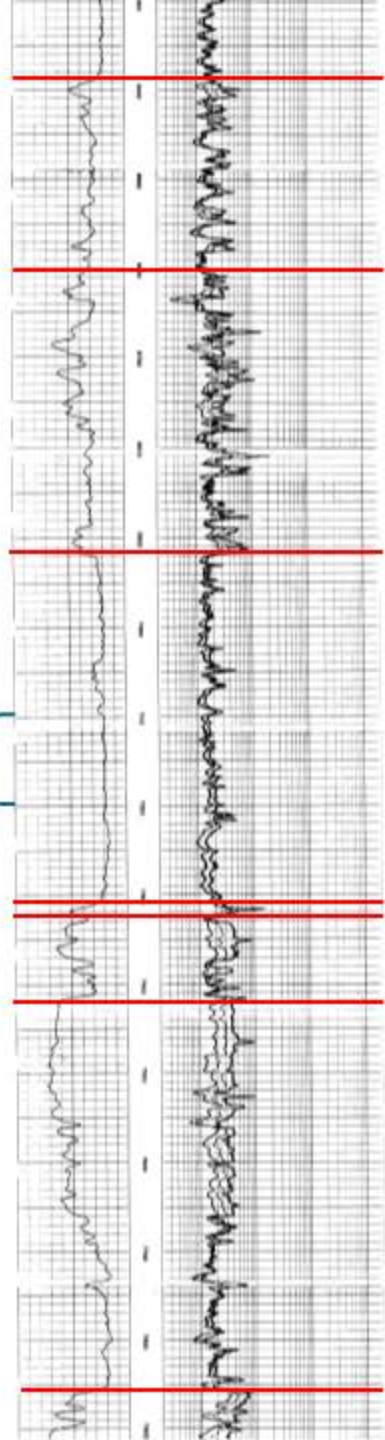


Well locations used in correlation

Well no. | top of formation picked | ft depth

1907	top of Eutaw Formation	6383
1907	top of upper Tuscaloosa Group	6599
1907	top of marine shale, Tuscaloosa Group	6913
1907	top of lower Tuscaloosa Group	7308
1907	top of Pilot sand, lower Tuscaloosa Group	7313
1907	top of Massive sand, lower Tuscaloosa Group	7417
1907	top of lower Cretaceous	7855

Vertical scale of 100 ft



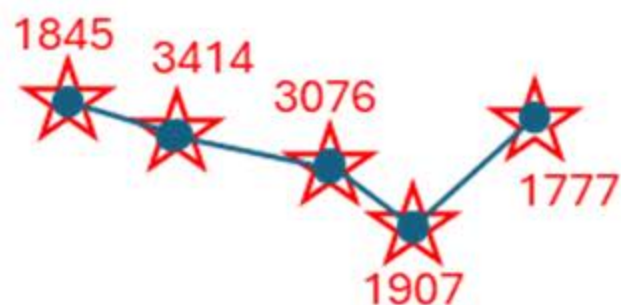
← Upper Cretaceous Selma Group (chalks) confining zone

Upper Cretaceous sequestration zone **Beta** (Eutaw and upper Tuscaloosa sands)

Upper Cretaceous confining zone (marine shale; middle Tuscaloosa)

Upper Cretaceous sequestration zone **Alpha** (lower Tuscaloosa sands, including glauconitic sands)

← Lower Cretaceous confining zone



Well locations used in correlation

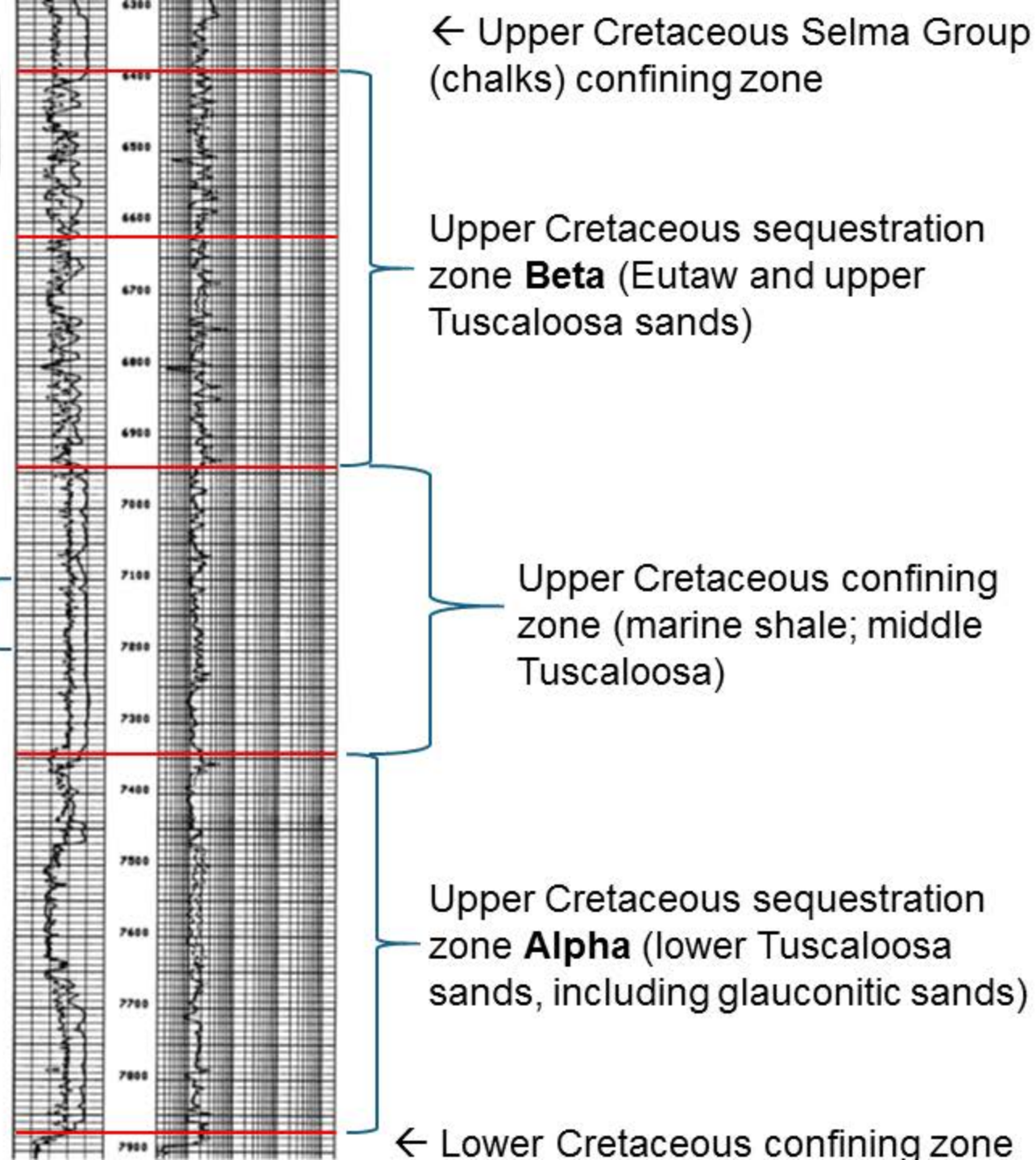
Well no. | top of formation picked | ft depth

3076	top of Eutaw Formation	6392
3076	top of upper Tuscaloosa Group	6621
3076	top of marine shale, Tuscaloosa Group	6941
3076	top of lower Tuscaloosa Group	7340
3076	top of Washita-Fredericksburg, lower Cretaceous	7871

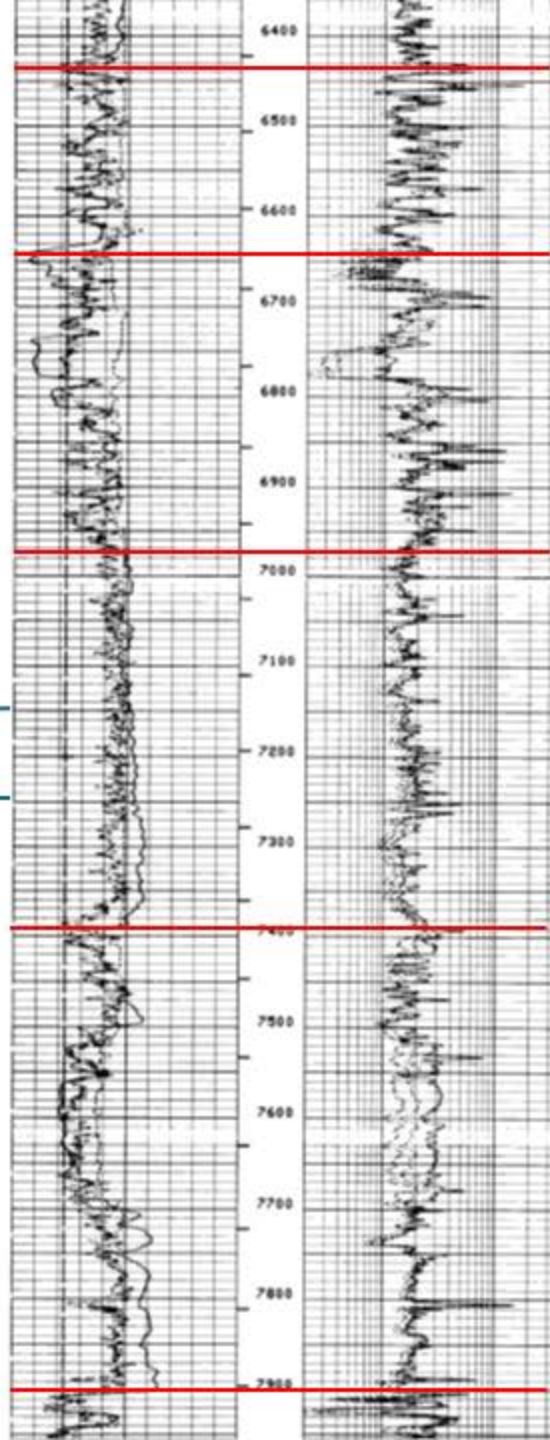
Vertical scale of 100 ft



Well locations used in correlation



Well no.	top of formation picked	ft depth
3414	top of Eutaw Formation	6434
3414	top of upper Tuscaloosa Group	6639
3414	top of marine shale, Tuscaloosa Group	6974
3414	top of lower Tuscaloosa Group	7389
3414	top of Washita-Fredericksburg, lower Cretaceous	7900



← Upper Cretaceous Selma Group (chalks) confining zone

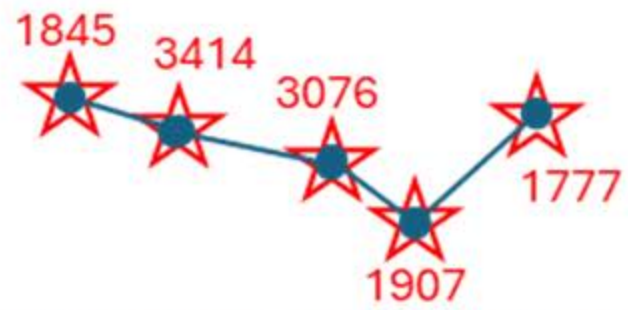
Upper Cretaceous sequestration zone **Beta** (Eutaw and upper Tuscaloosa sands)

Upper Cretaceous confining zone (marine shale; middle Tuscaloosa)

Upper Cretaceous sequestration zone **Alpha** (lower Tuscaloosa sands, including glauconitic sands)

← Lower Cretaceous confining zone

Vertical scale of 100 ft



Well locations used in correlation

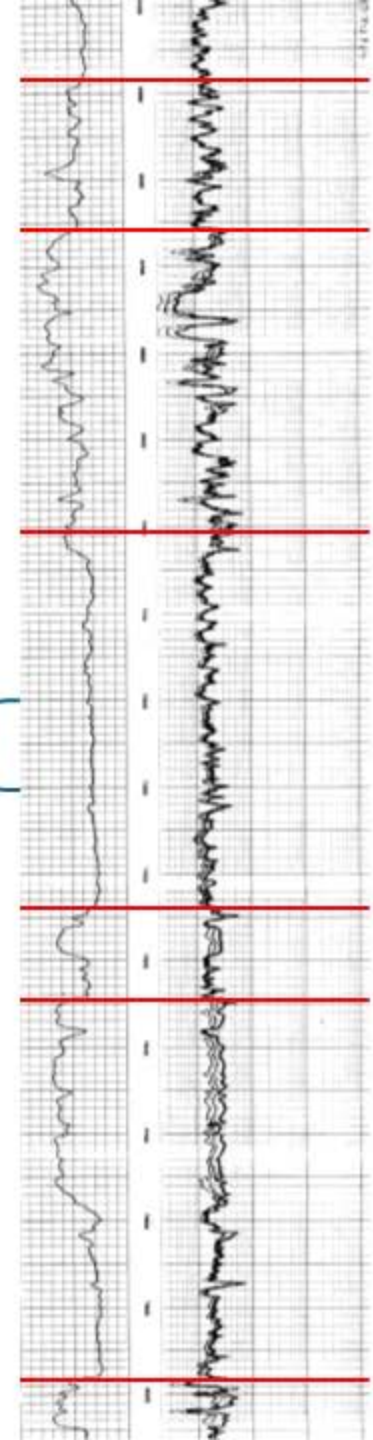
Well no. | top of formation picked | ft depth

1845	top of Eutaw Formation	6483
1845	top of upper Tuscaloosa Group	6655
1845	top of marine shale, Tuscaloosa Group	7030
1845	top of lower Tuscaloosa Group	7438
1845	top of Pilot sand, lower Tuscaloosa Group	7438
1845	top of Massive sand, lower Tuscaloosa Group	7543
1845	top of Washita-Fredericksburg	7981

Vertical scale of 100 ft



Well locations used in correlation



← Upper Cretaceous Selma Group (chalks) confining zone

Upper Cretaceous sequestration zone **Beta** (Eutaw and upper Tuscaloosa sands)

Upper Cretaceous confining zone (marine shale; middle Tuscaloosa)

Upper Cretaceous sequestration zone **Alpha** (lower Tuscaloosa sands, including glauconitic sands)

← Lower Cretaceous confining zone

