

**DEPOSITIONAL AND EXPLORATION MODEL, GRAY SANDSTONE SERIES
(UPPER JURASSIC), COTTON VALLEY FIELD, NORTHERN LOUISIANA**

By

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INTRODUCTION

Oil and gas are produced from a set of closely related Upper Jurassic sandstones in northern Louisiana referred to collectively as the Gray Sandstone. Seven fields have been discovered in the play: South Sarepta, Ivan, Cotton Valley, Rocky Mount, Ruston, Sugar Creek and Terryville (Fig. 1). The reservoirs in the play lie in the deep subsurface at depths between 10,600 ft and 12,000 ft subsea in Cotton Valley field. The sandstones are the deepest producing clastic reservoirs in northern Louisiana. The first producing well in the play was the A. H. Gray #1 drilled in 1944. The Gray #1 was the discovery well for Cotton Valley field. Initial production was 120 barrels of distillate and 6 mmcf of gas per day, which was produced from 66 ft of perforations at depths of 10,615 ft to 10,681 ft subsea. The reservoirs in the trend produce condensate and natural gas from structural and stratigraphic traps in a narrow east-west-trending band immediately south and downdip from the North Louisiana Stateline fault system, just basinward of the Late Jurassic shelf edge (Fig. 1).

The Gray Sandstone reservoirs in Cotton Valley field are not well understood and need additional study in order to maximize oil and gas recovery from these generally low-permeability reservoirs. The reservoirs have been interpreted both as deep-water sediments deposited on a submarine fan basinward of the Smackover (Upper Jurassic) shelf edge (Judice and Mazzullo 1982) and as shallow-water, tidal flat deposits slumped off contemporaneously growing salt anticlines (Miciotto 1980). In this study, I constrain the depositional setting of the Gray Sandstone in Cotton Valley field and provide an exploitation and development model for the field.

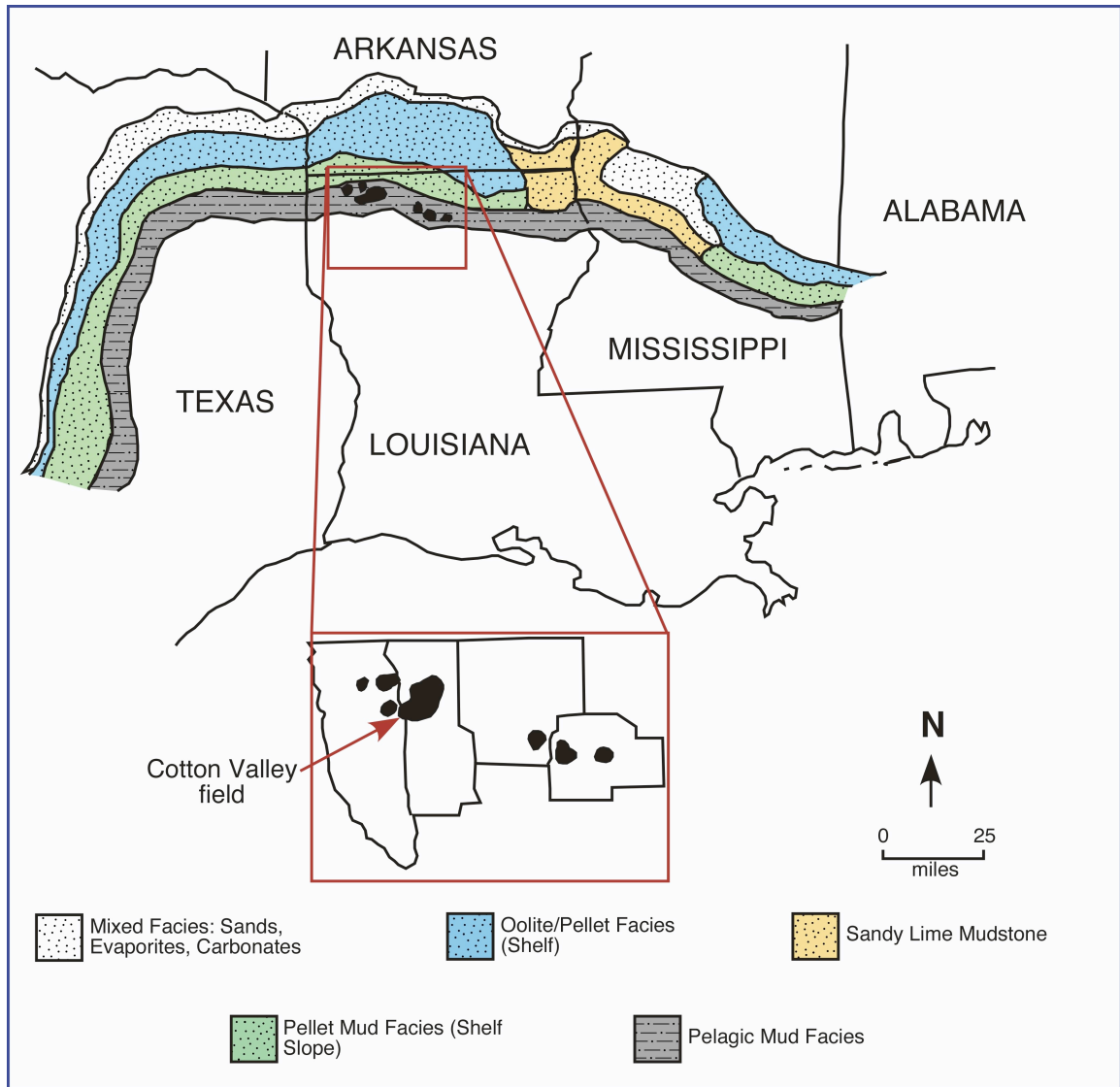


Figure 1. Location map showing Gray Sandstone fields, northern Louisiana. Fields trend parallel to Smackover (Upper Jurassic) shelf-edge. Modified from Judice and Mazzullo (1982).

REGIONAL GEOLOGY AND STRATIGRAPHIC RELATIONSHIPS

Accurate interpretation of the depositional setting of the Gray Sandstone series requires knowledge of the Late Jurassic paleogeography of the northern Gulf of Mexico. A clear understanding of the regional geologic setting is a prerequisite for constraining interpretation of the reservoirs in Cotton Valley field. The Mesozoic rocks of the Gulf of Mexico basin and its associated sub-basins, including the North Louisiana salt basin, record an episode of passive continental margin development. Rifting and initial segmentation of Pangea began in the Late Triassic and continued into the Late Jurassic (Goldhammer and Johnson 2001). Counterclockwise rotation and southerly drift of the Yucatan block away from the southeastern margin of the North American craton opened the proto-Gulf of Mexico and resulted in the flooding of the newly formed depression by marine waters. This influx of water from the Pacific took place during the Callovian and Early Oxfordian as determined by ammonite biostratigraphy.

At first, widespread evaporite deposition took place in an area extending from the northern Louisiana and east Texas salt basins well into south Texas. The evaporites unconformably overlie Triassic redbeds and Paleozoic basement. As marine transgression continued through the Middle Oxfordian and into the Kimmeridgian, carbonate ramps with high-energy, oolitic ramp-crests developed along the northern and western margins of the ancestral Gulf of Mexico (Fig. 2). The ramp-crests formed along a subtle break in slope located to the north of Cotton Valley field on the northern margin of the North Louisiana salt basin. The ramp-crest facies passed landward into mixed marginal marine facies deposited in tidal flat and lagoonal environments. Basinward the oolitic of the ramp-crest graded into lower energy, outer-ramp carbonate siltstones, calcareous oozes and deep-water shales (Goldhammer and Johnson 2001).

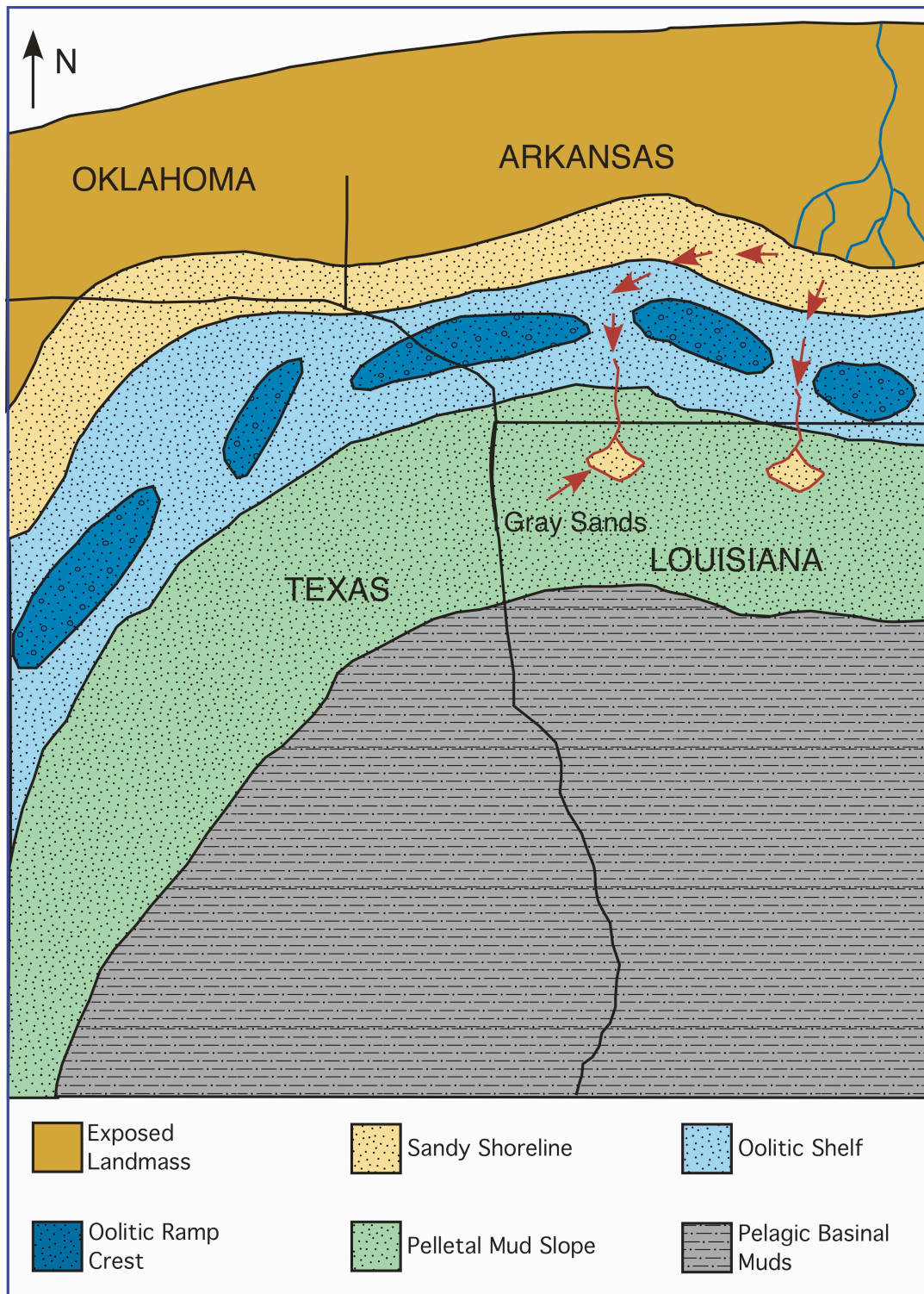


Figure 2. Paleogeographic map, northern Gulf of Mexico, during deposition of the Gray Sandstone (Upper Jurassic). Modified from Goldhammer and Johnson (2001).

The Middle Jurassic through Lower Cretaceous section in the Gulf of Mexico has been subdivided into four second-order “supersequences” of approximately 15 Ma duration each (Goldhammer and Johnson 2001, their Fig. 6). Each supersequence is comprised of several third-order sequences of 1-3 Ma duration. The third-order sequences within a supersequence exhibit characteristic retrogradational, aggradational or progradational stacking patterns that can be correlated across the Gulf of Mexico region. The second-order cycles of change in relative sea level are superimposed on an overall first-order rise in sea level and marine transgression. Cycles of sedimentation recorded in the stratigraphy of the Middle Jurassic to Lower Cretaceous strata of the Gulf of Mexico basin reflect changes in eustatic sea level. Eustatic sea-level varied in response to changes in the volume of the Mid-Atlantic Ridge associated with the initiation of rifting and onset of sea-floor spreading (Goldhammer and Johnson 2001). Jackson and Vendeville (1994) suggested that salt upwelling is closely linked in time and space to regional extension. Differential sedimentary loading of a thick Jurassic clastic wedge onto the underlying Louann Salt, coupled with regional extension, may have mobilized the underlying salt. Regional extension thinned the brittle overburden by forming grabens and half grabens above the salt. Regional extension differentially loaded the salt by surface relief and weakened the overburden by fracturing and thinning (Jackson and Vendeville 1994).

The Gray Sandstone in Cotton Valley field represents a prograding submarine fan complex deposited basinward of the Upper Smackover shelf margin during a third-order fall in relative sea level (see below). This fall in sea level took place at the base of the second supersequence of Goldhammer and Johnson (2001) (Fig. 3), making the Gray Sandstone the basinal equivalent of the Buckner Formation. Some previous workers have placed the Gray Sandstone in the Smackover Formation (Ellison and Russo, 1976; Miciotto, 1980; Sartor and Howard, 1984). However, the present consensus is that the Gray Sandstone is part of the Buckner Formation.

PREVIOUS WORK

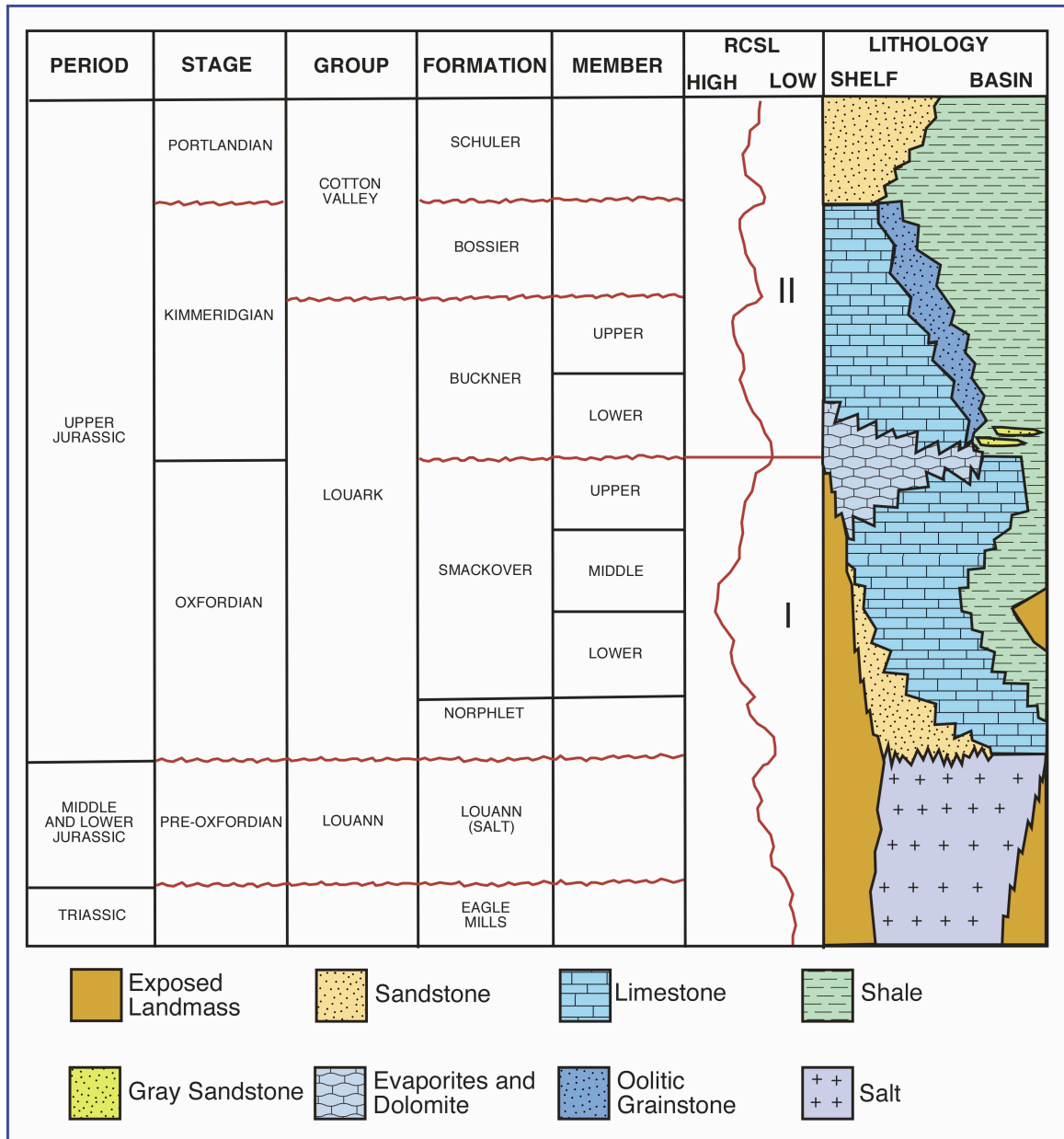


Figure 3. Chronostratigraphic and lithostratigraphic column showing placement of Gray Sandstone in lower Buckner. Relative change in sea level (RCSL) is also shown along with position of second-order supersequences I and II of Goldhammer and Johnson (2005). Modified from Miciotto (1980).

The environment of deposition of the Gray Sandstone in northern Louisiana is not well constrained. Previous interpretations range from shallow, proximal shelf deposits

encased in lagoonal and shelf muds to basinal turbidites resulting from dilute, low-density turbidity currents. Judice and Mazzullo (1982) recognized three distinct facies in the Gray Sandstone in Terryville field: 1) deep water, dark gray to black pelagic and hemipelagic sediments, locally pyritic and calcitic, containing crinoid columnals and fragments of red algae; 2) heavily bioturbated (*Arenicolites* and *Teichichnus*) shales and intercalated sandstones with load features, starved ripples, flaser and lenticular bedding, slump folds, cloud structures and partial Bouma sequences; 3) massive to diffusely planar-laminated sandstones and conglomeratic sandstones with pebbly rip-up clasts and partial Bouma sequences.

Based on the presence of vertically-stacked, amalgamated sand bodies with lobate geometries, Judice and Mazzullo (1982) interpreted the Gray Sandstone to be a progradational submarine fan complex with meandering upper-fan distributaries. They noted the Gray Sandstone in Terryville field is separated from other fields by basinal deposits, which suggested to them the presence of several feeder channels and entry points along the Upper Jurassic shelf edge. They also noticed that the lobes composing the sandstone were thickest on top of a deep-seated salt structure, which implies that halokinesis did not commence until after deposition of the Gray Sandstone.

Most of the effective porosity of the Gray Sandstone reservoirs in Terryville field is of secondary origin, resulting from the dissolution of unstable K-feldspar grains and dolomitic cements (Judice and Mazzullo 1982). The diagenetic sequence was dominantly one of porosity reduction involving four steps: 1) burial and compaction with

ductile deformation of shale clasts to form pseudomatrix; 2) precipitation of quartz overgrowths; 3) precipitation of pore-filling chlorite, illite, and smectite; 4) intergranular precipitation of and partial grain replacement by ferroan dolomite (Judice and Mazzullo 1982). Thick, conglomeratic sandstones deposited in the thalweg of distributary channels were found to have the best porosity and permeability, especially when draped over strong structural nosing (Judice and Mazzullo, 1982).

Miciotto (1980) proposed a mixed tidal flat to lagoonal depositional environment for the Gray Sandstone in South Sarepta, Ivan and Cotton Valley fields. His main evidence was the fact that the sands were oriented parallel to depositional strike (Fig. 4). He inferred that long-shore currents transported terrigenous sediment westward, depositing it unconformably over Norphlet strata and the Louann Salt. In this model, Swelling and uplift of the Louann Salt created barriers that restricted water circulation in lagoons isolated from the open sea. Miciotto (1980) believed that sediment slumped off an east-west trending, growing salt anticline into adjacent lagoonal muds. Other evidence cited by Miciotto (1980) in support of his interpretation include the presence of oolites, a flaser-bedded silty-shale facies and the dark gray to black color of the Gray Sandstone. Miciotto (1980) recognized three sandstone tongues, which he designated as the upper, middle and lower members of the Gray Sandstone.

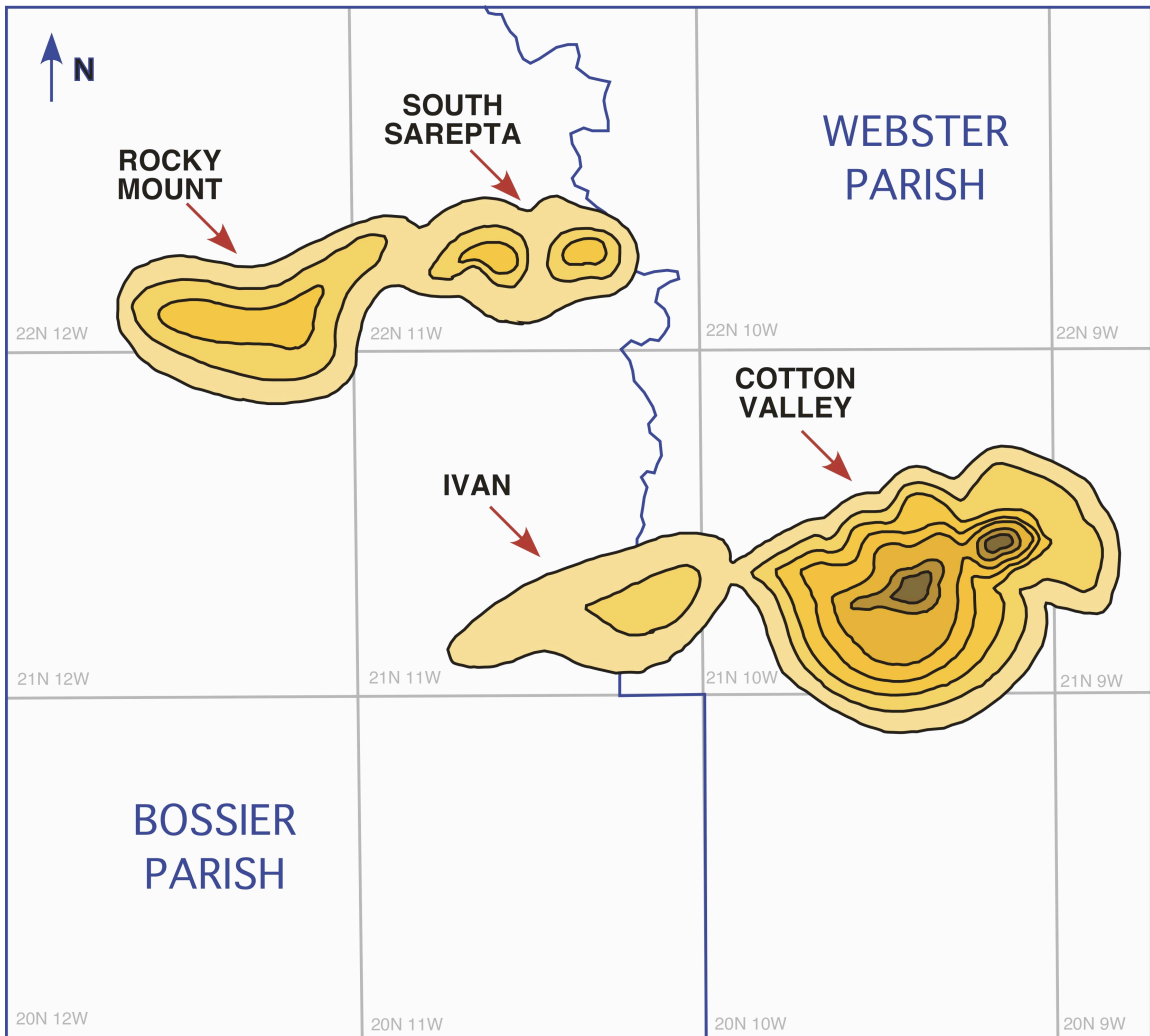


Figure 4. Composite net sand isopach of upper, middle and lower Gray Sandstone in Cotton Valley, South Sarepta, Ivan, and Rocky Mount fields. Contour interval, 5 ft. Modified from Miciotto (1980).

METHODOLOGY

Logs from 123 wells over an area of approximately 144 square miles were used to map the geometry and orientation of the sandstone lobes comprising the Gray Sandstone in Cotton valley field. Detailed lithologic descriptions of two conventional cores stored at the Texas Bureau of Economic Geology facility in Houston, Texas, show the texture, sedimentary structures, body fossils and trace fossils present in the Gray Sandstone. Graphic logs of core based on these descriptions were compared with electric logs to calibrate log response with lithology. Qualitative analysis of a suite of thin sections previously made from core from one of the cores revealed the textural and compositional maturity of the sandstones, as well as diagenetic events and the evolution of porosity during burial and compaction. Microfossils and small trace fossils not evident in the macroscopic description of the core were observed in the thin sections.

Six individual sandstone units within the Gray Sandstone interval were identified on logs. Following terminology used by geologists with XTO Energy, these were designated the lower and upper Gray “D”, the lower, middle, and upper Gray “C”, and the Gray “B” (Fig. 5). Each sandstone unit was correlated across the field. Isochore maps based on these correlations show the thickness and lateral extent of each unit. Considered in sequence the maps show the shifting positions and stacking pattern of the sandstone units in Cotton Valley field. Well logs and 2-D and 3-D seismic data were used to draw a structure map on the top of the upper Gray “C” Sandstone. Cross-sections were constructed both dip and strike oriented with regard to present-day structure.

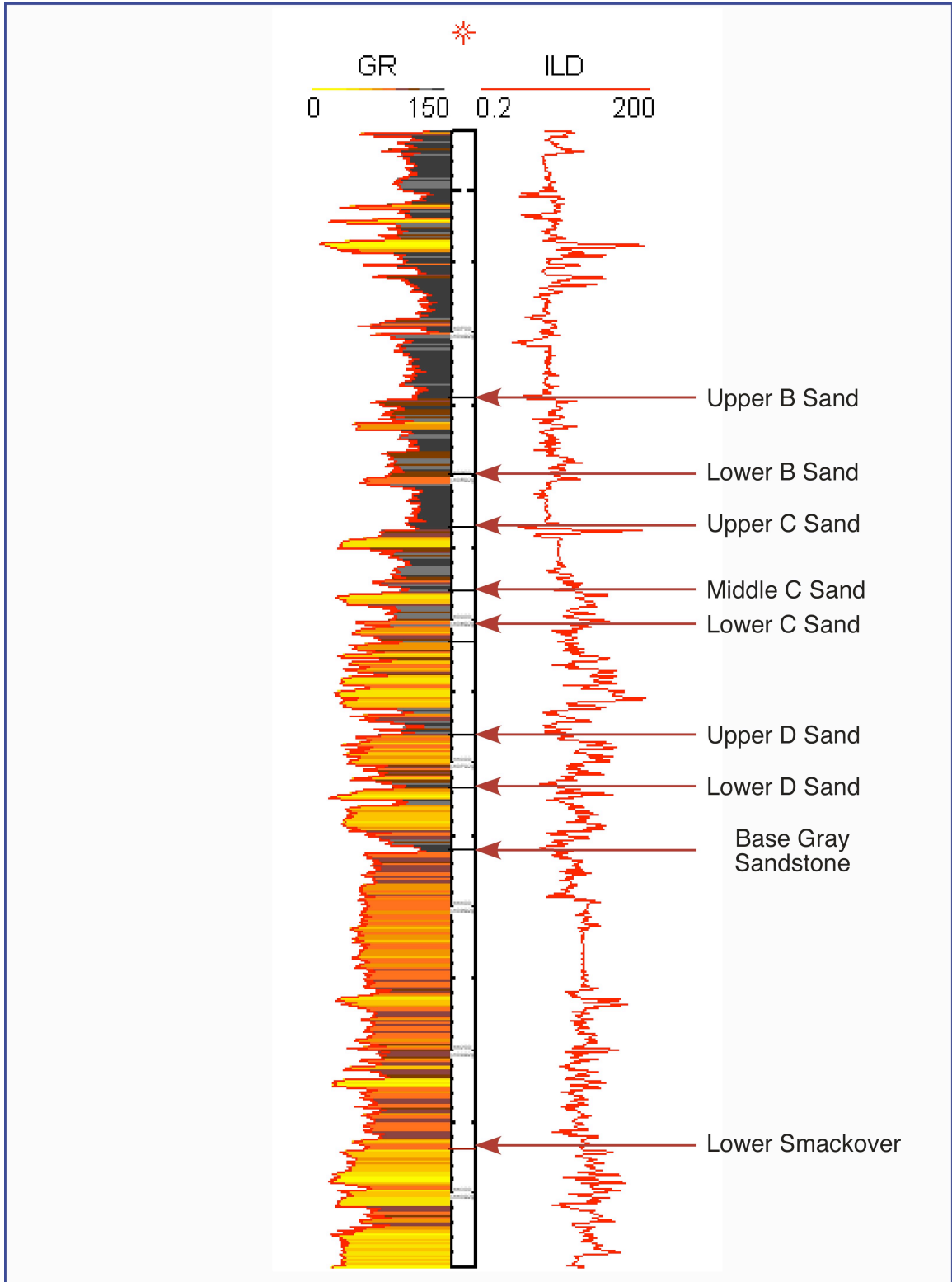


Figure 5. Type log from XTO 22 Cox showing tops of sandstone units in Gray Sandstone series in Cotton Valley field. The gamma ray (GR) and deep induction resistivity (ILD) logs are shown. Geocolumn shading has been applied to GR log.

RESULTS

Core Description

The CVOC Ohio Hodges #4 is near the center of Cotton Valley field and is in the southwest corner of S23 T21N R10W (Fig. 6). It was drilled and completed to a measured depth of 10,856 ft. Conventional core was taken from depths of 10,600 ft to 10,830 ft, recovering most of the Gray Sandstone interval. The graphic log for this core is shown in Figure 7, and typical sedimentary structures, facies and trace fossils are shown in Figures 8 and 9. The MOC Bodcaw #3 in S15 T21N R10W was drilled to a total depth 11,815 ft. Conventional core was taken from depths of 11,590 ft to 11,730 ft and represents the majority of the Gray Sandstone interval. The measured section for this well is shown in Figure 10, and representative sedimentary structures, facies and trace fossils are shown in Figures 9 and 11.

Rock in core from the CVOC Ohio Hodges #4 and MOC Bodcaw #3 can be divided into six facies based on color, texture, composition, sedimentary structures and trace fossils (Table 1). Two heterolithic facies (A, B) are present in the core. Facies A consists of siliceous gray siltstone and darker shale. The siltstone and shale are both heavily bioturbated. Facies B also contains both siliceous gray siltstone and shale. The siltstone, however, is finely laminated (<1 mm) and bioturbation may or may not be present. Three sandstone facies (C, D, and E) are present in the core. Facies C consists of light gray, very fine-grained, massive to faintly laminated, sublitharenitic sandstone. Pebbly sandstone containing containing rip-up clasts of black siltstone makes up facies D. Facies E consists of very fine-grained, calcareous sandstone. Facies F is thin, black, finely laminated shale lacking bioturbation. This facies makes up only a very small percentage of the core.

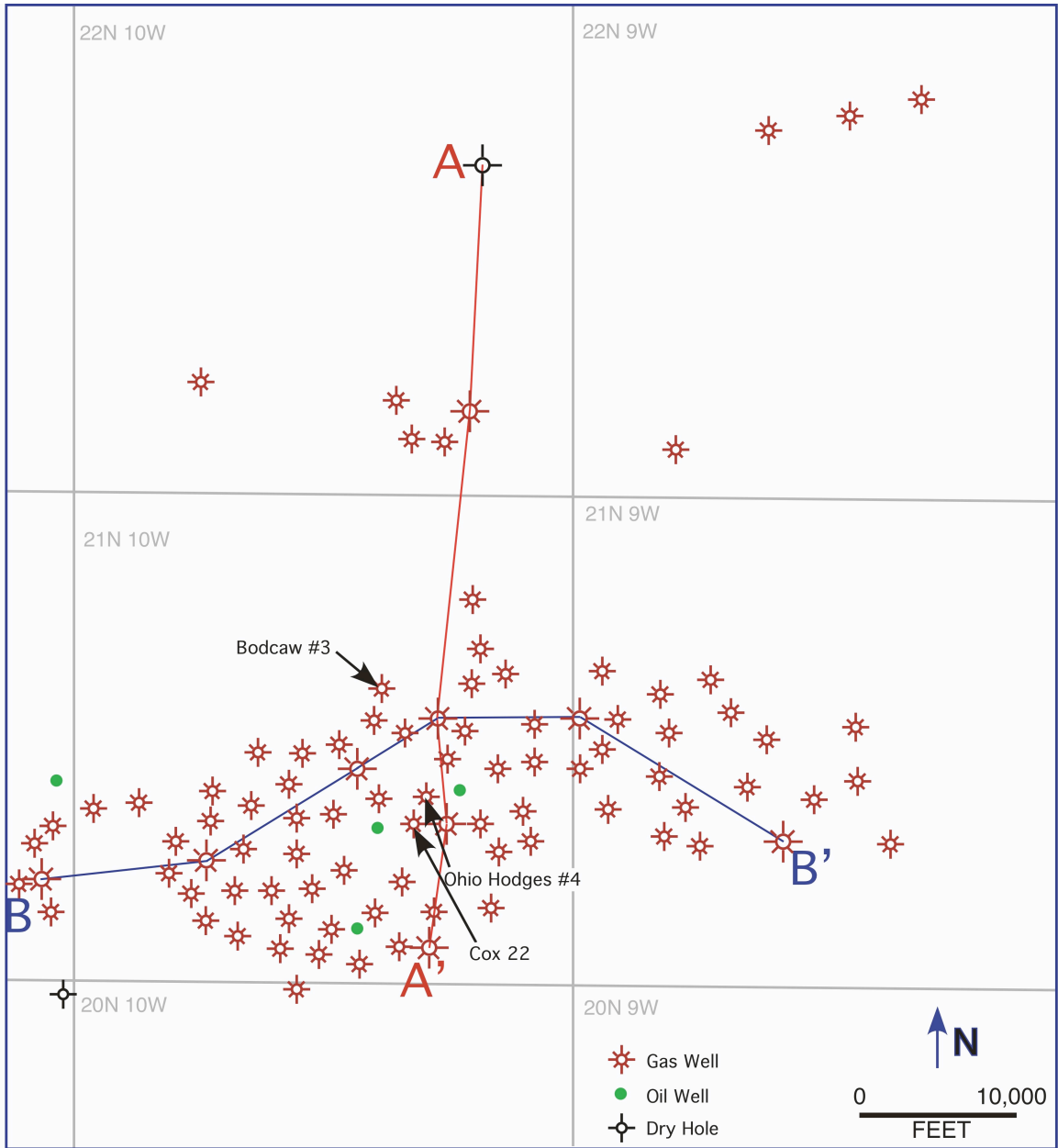


Figure 6. Map of Cotton Valley field showing well control, cross-section lines, wells from which core was examined (Bodcaw #3, Ohio Hodges #4) and location of type log (Cox 22).

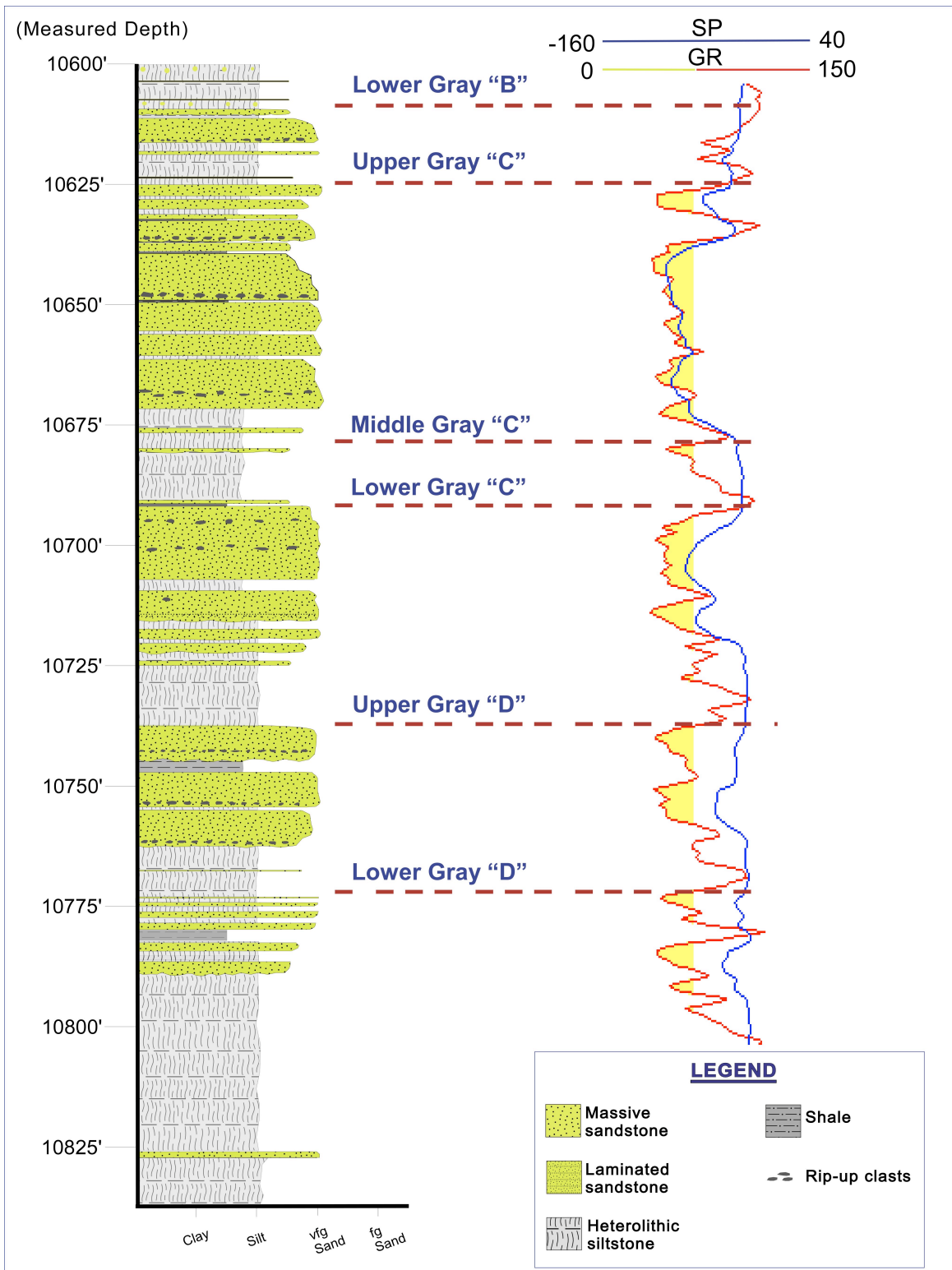


Figure 7. Graphic log of core from CVOC Ohio Hodges #4. Gamma ray (GR) and Spontaneous Potential (SP) logs shown along with tops of sandstone units in Gray Sandstone series.

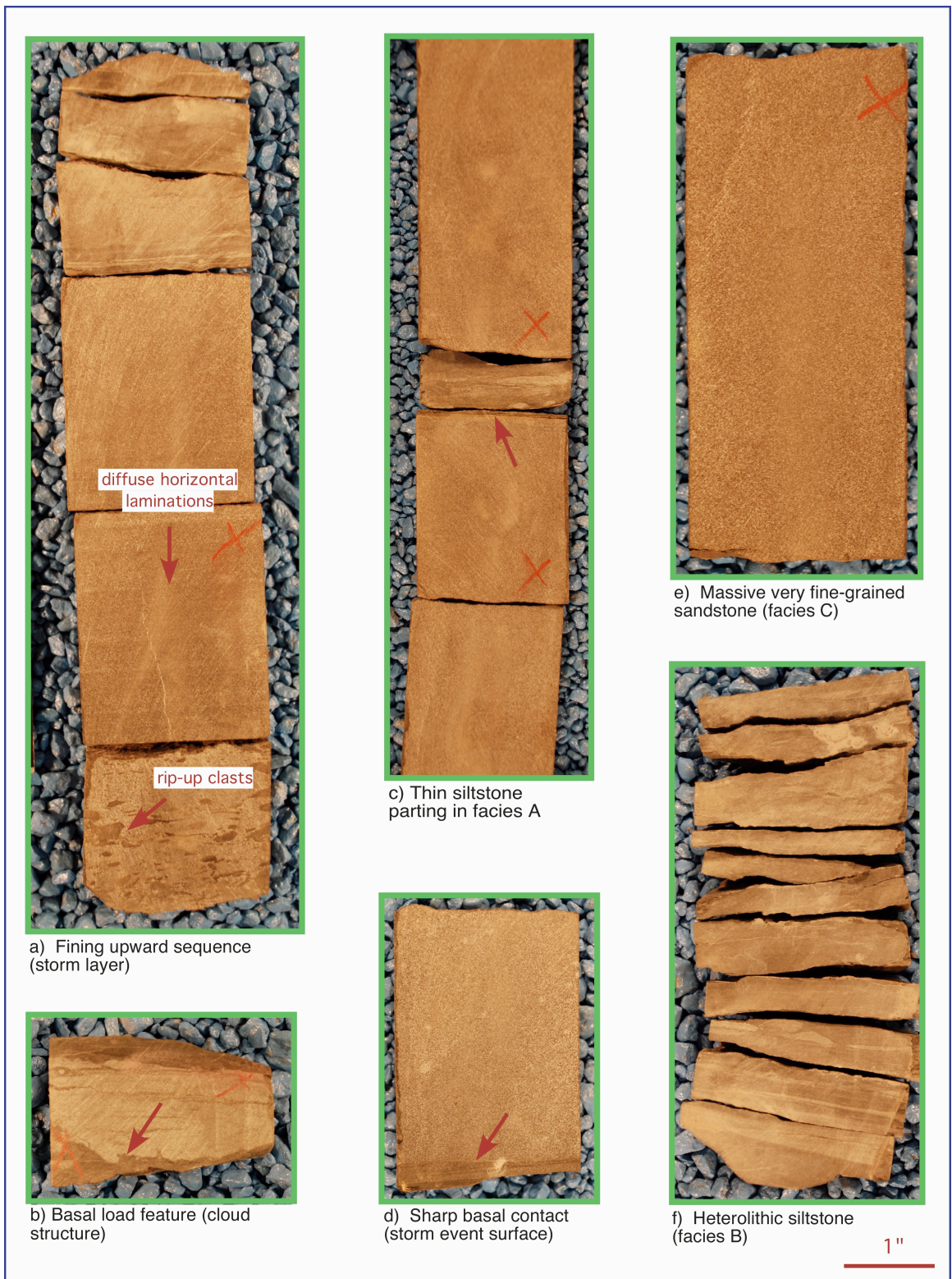


Figure 8. Photographs of common sedimentary features and facies in core from CVOC Ohio Hodges #4.

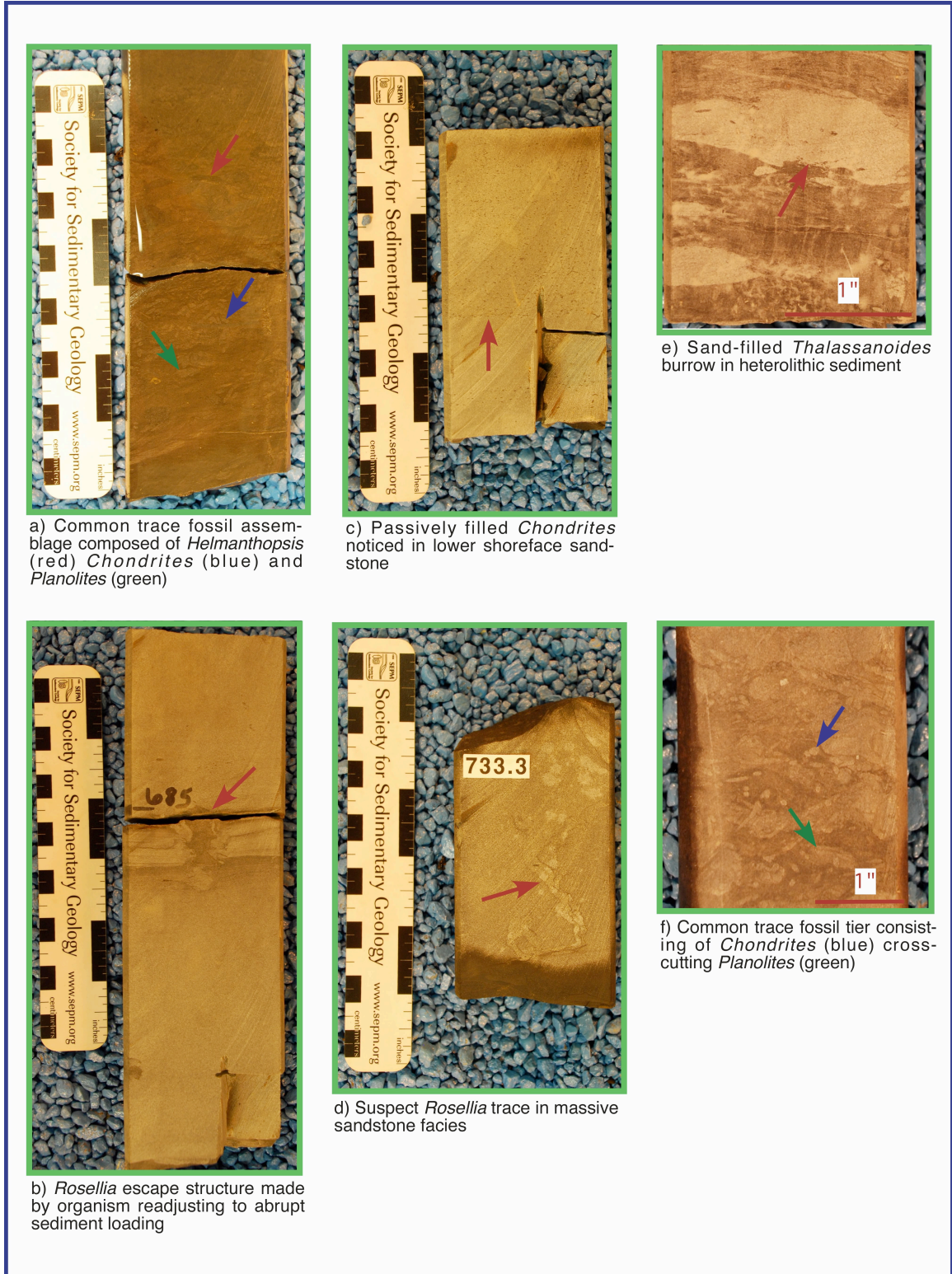


Figure 9. Photographs of trace fossils in core from Gray Sandstone in Cotton Valley field. Trace fossil assemblage composed of *Chondrites*, *Planolites*, *Thalassanoides*, *Helmanthopsis*, *Phycosiphon* *isp.*, and *Rosellia*.

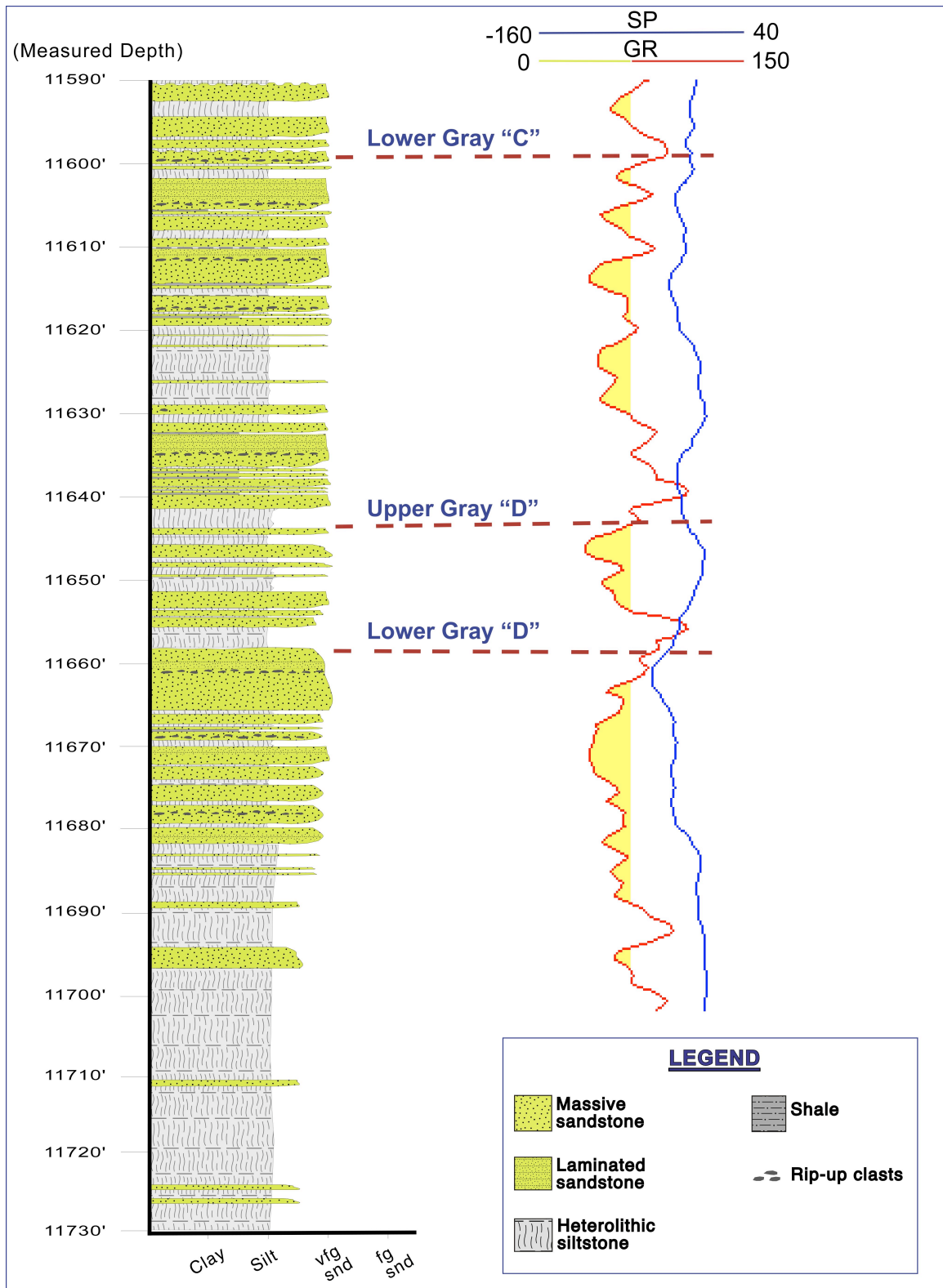


Figure 10. Graphic log of core from MOC Bodcaw #3. Gamma ray (GR) and Spontaneous Potential (SP) logs shown along with tops of sandstone units in Gray Sandstone series.



Figure 11. Photographs of common sedimentary features and facies in core from MOC Bodcaw #3.

FACIES	DESCRIPTION
A	Siliceous gray siltstone and darker shale
B	Finely laminated siliceous gray siltstone and darker shale
C	Light gray, very fine-grained, massive to finely laminated, sublitharenitic sandstone
D	Pebble sandstone containing rip-up clasts of dark gray siltstone
E	Very fine-grained calcareous sandstone
F	Thin, black, finely laminated shale

Table 1. Facies observed in core.

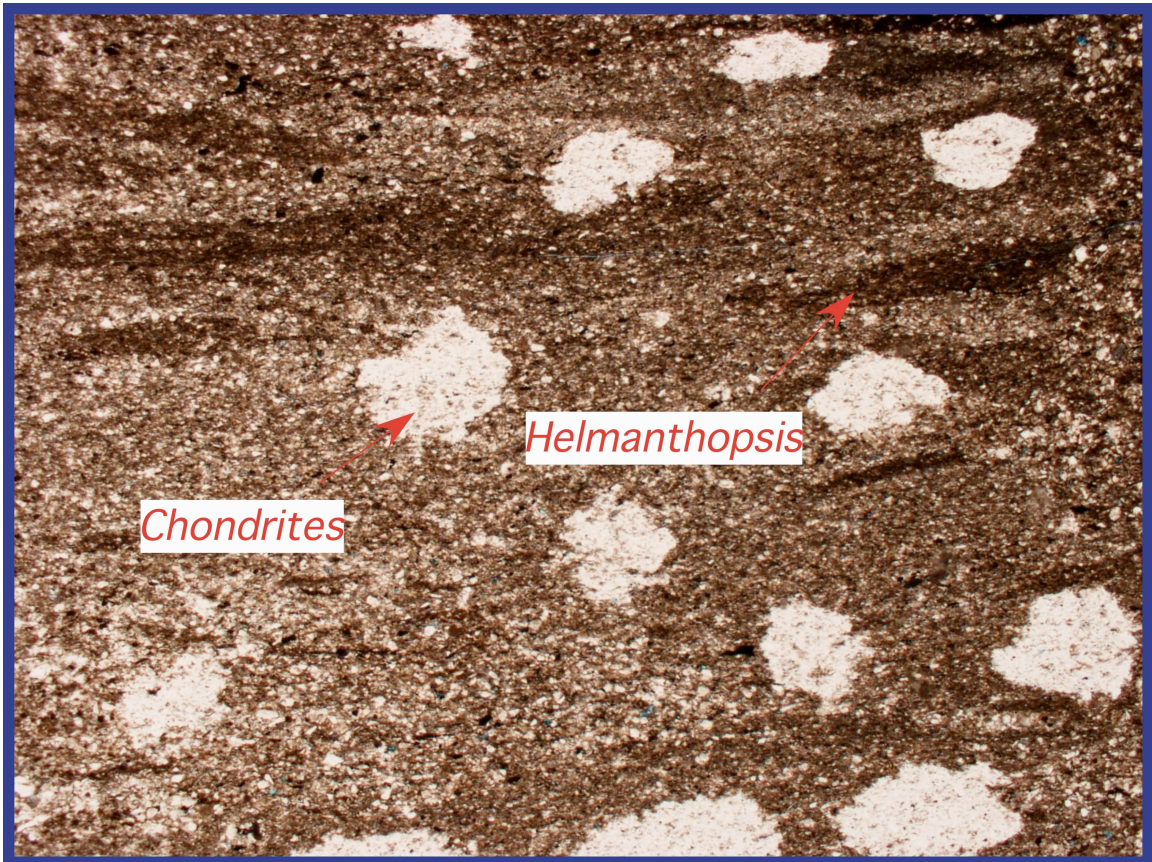


Figure 12. Photomicrograph of *Helmanthopsis* horizontals and *Chondrites* burrows. Plane polarized light, field of view is 8.5 mm across.

Rip-up clasts in facies D generally occur as lag conglomerates at the base of sandstone beds (Fig. 8a). Isolated rip-up clasts may also occur higher in the beds. Individual sandstone beds fine upward in all three sandstone facies. The lower contact of most sandstone beds is sharp (Figs. 8d and 11f), and load features such as cloud structures and flame structures may be present (Fig. 8b). The upper contacts may be abrupt or the sandstone may grade upward into overlying, finer grained sediment of the heterolithic facies (Fig. 11d). Symmetrical wave ripples with 1 cm tall crests are found at the upper contacts of a few sandstone beds (Fig. 11a, b). Low-angle laminations are observed in facies C and most likely represent hummocky cross-stratification in three dimensions (Fig. 11b). Thin partings of the heterolithic facies may be found within otherwise structureless sandstone (Fig. 8c).

The massive and faintly laminated sandstones of facies C, D and E are interbedded with the siltstones and shales of facies A and B (Figs. 7 and 10). The siltstone in facies A is heavily bioturbated and has a churned appearance (Fig 9e, f). The thickness of the siltstone and shale units decreases upward in the core and sandstone beds become thicker and more abundant, forming a well-defined thickening- and coarsening-upward sequence.

Common trace fossils seen in the core include *Planolites*, *Chondrites*, *Rosellia*, *Helminthopsis*, *Tiechichnus* and *Phycosiphon insertum* (Fig. 9). Almost all trace fossils were found in the heterolithic facies (A and B). The traces are commonly filled with coarser grained sediment, except for *Helminthopsis*, which is generally filled with fine-grained sediment (Fig. 12). *Chondrites* burrows with passive silt filling were found in the very fine-grained calcareous siltstone facies in the MOC Bodcaw #3 core below the Gray Sandstone.

Thin-Section Analysis

A set of thin sections previously made from the MOC Bodcaw #3 core by Marathon Operating Company was analyzed to determine compositional and textural maturity of these generally very-fined grained sediments. Also an attempt was made to elucidate the paragenetic sequence during burial and diagenesis and to determine the effects this had on the evolution of porosity in the Gray Sandstone.

The sandstones are moderately to poorly sorted with angular to sub-angular grains. Common detrital grains include mono- and polycrystalline quartz, chert, K-feldspar, muscovite, argillaceous sedimentary rock fragments, intraclasts and ooids (Fig. 13). Quartz grains make up approximately 90% of the rock in thin section. K-feldspar grains are partially altered to clay along twin planes, exhibit corroded grain boundaries, and make up approximately 5% of the total rock. Slightly altered plagioclase grains are present in small amounts (Fig.14). Chert, argillaceous rock fragments, carbonate grains (intraclasts/ooids) and muscovite make up the remaining 5% of the rock. Intraclasts and ooids are generally micritized and replaced by authigenic calcite (Fig. 15). Pseudomatrix resulting from the plastic deformation of labile grains during burial and compaction has been squeezed into primary pore spaces around more rigid grains (Fig. 16).

Both siliceous and calcareous cements are present and completely fill primary porosity. Authigenic anhydrite cement is also present. Syntaxial quartz overgrowths rim detrital quartz grains and grew into primary pore spaces during diagenesis (Fig. 16).

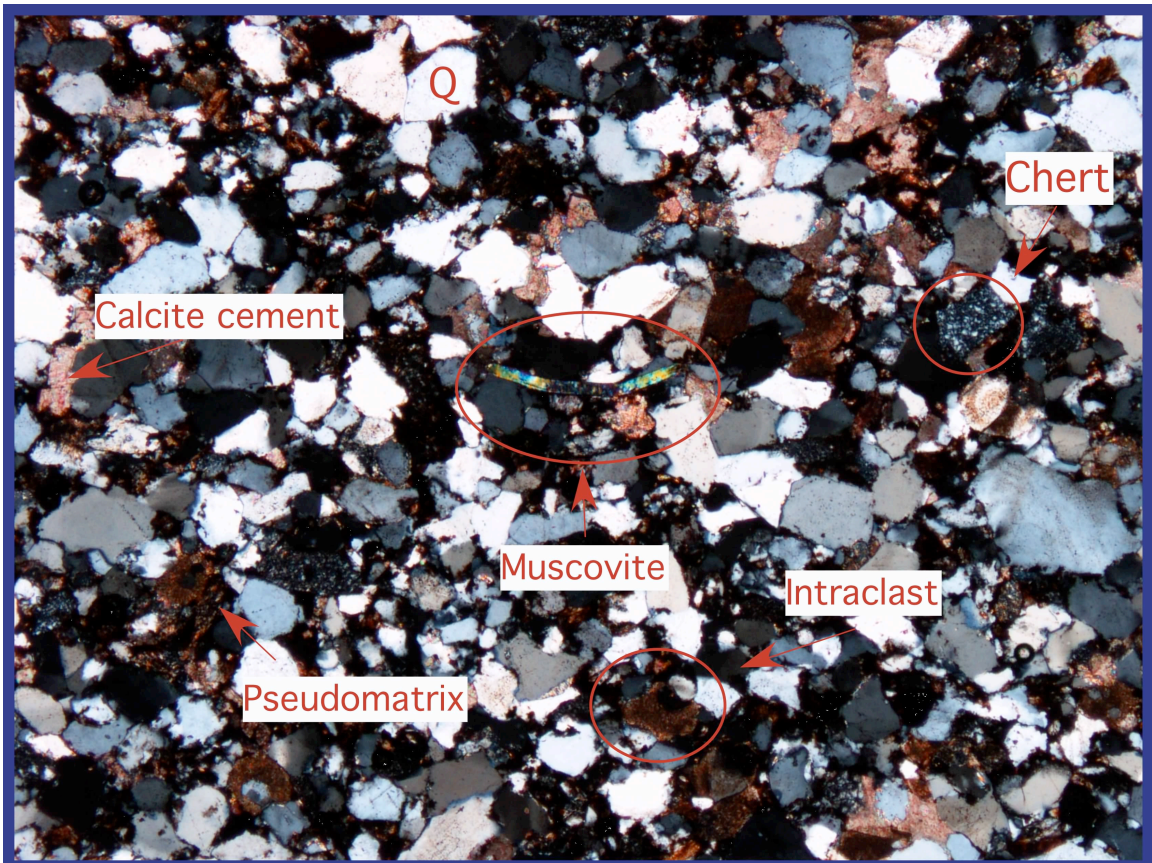


Figure 13. Photomicrograph of very fine-grained, angular to subangular, poorly sorted, intraclast bearing, micaceous sublitharenite (facies C). Q=Quartz. Crossed polars, field of view is 4.25 mm across.

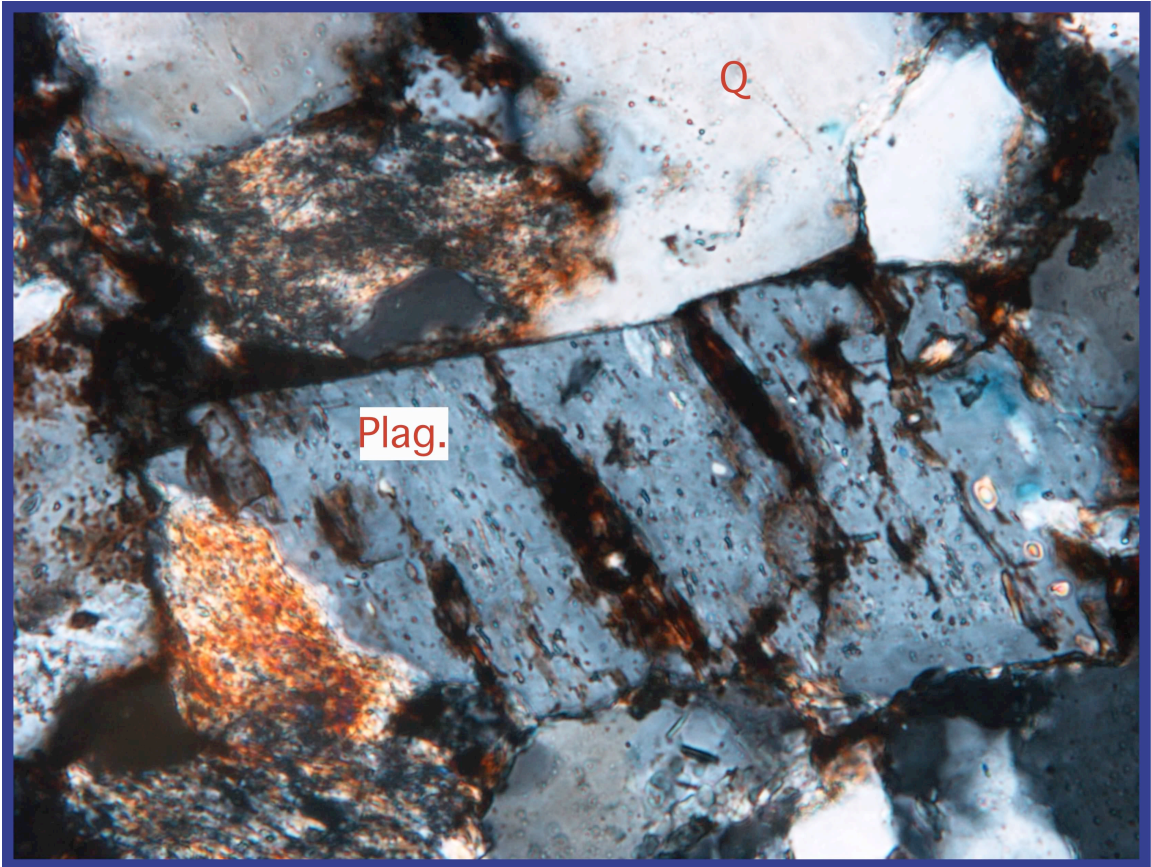


Figure 14. Photomicrograph of slightly altered detrital plagioclase feldspar. Plag=Plagioclase; Q=Quartz. Crossed polars, field of view is 1.9 mm.

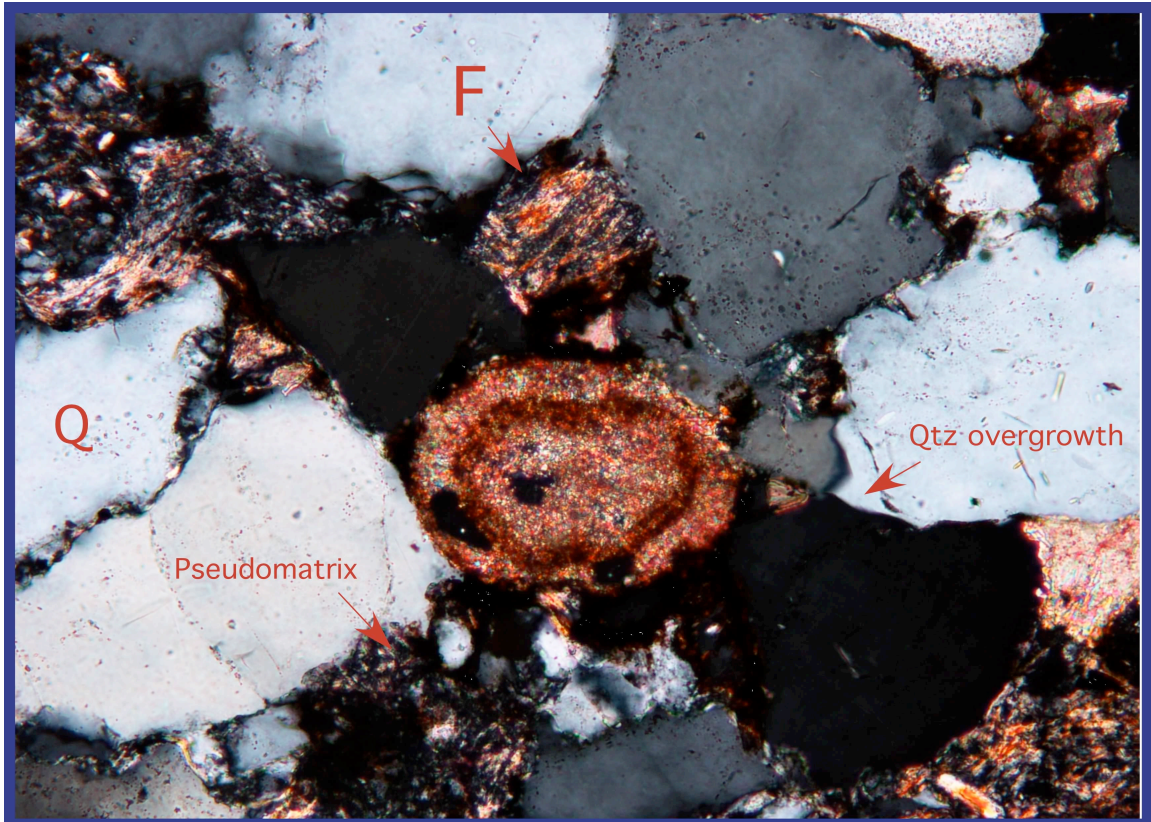


Figure 15. Photomicrograph showing ooid partially replaced by authigenic calcite. Notice euhedral quartz overgrowth and feldspar grain (F) altering to carbonate along twin planes (facies C). F=Feldspar; Q=Quartz. Crossed polars, field of view is 1.9 mm

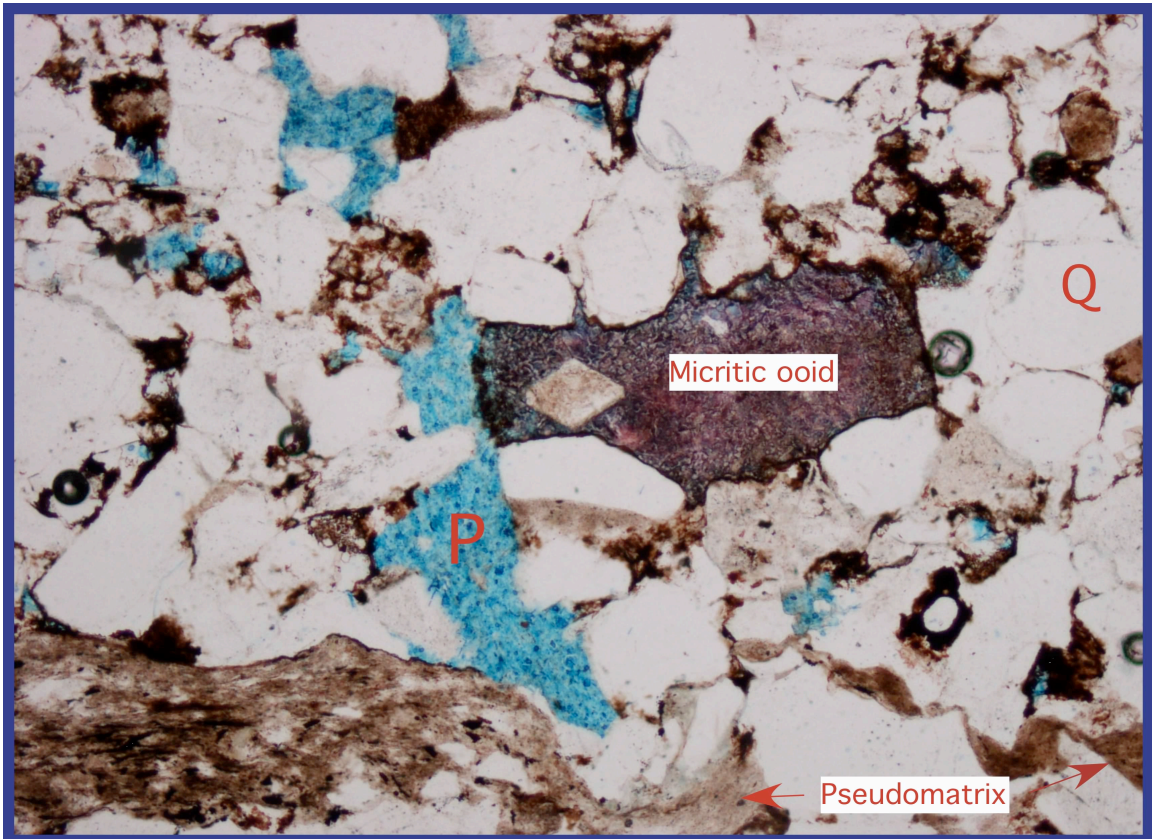


Figure: 16. Photomicrograph of secondary porosity (blue epoxy) resulting from partial dissolution of authigenic carbonate cement. Notice micritic ooid containing euhedral dolomite crystal and replaced along margins by quartz overgrowths. Quartz overgrowths also extend into primary pore spaces. Compactional deformation of labile framework grains to form pseudomatrix is visible in lower left. Q=Quartz; P=Porosity. Plane polarized light, field of view is 2.18 mm across.

Porosity is low, averaging less than 10%. Most of the porosity is secondary porosity from the dissolution of carbonate cements. Secondary porosity from dissolution of feldspar and dolomitic cements accounts for most of the porosity in the Gray Sandstone in Terryville field (Judice and Mazzulo, 1982).

Calibration of Core with Electric Logs

The responses for spontaneous potential (SP), gamma ray (GR) and resistivity logs show a strong correlation with the lithologies recognized in core. The sandstones generally have cylindrical to bell-shaped, serrated GR responses with sharp bases and slightly rounded tops. The heterolithic siltstone and shale facies is represented by an irregular GR response and is generally associated with a lower resistivity reading. Maximum deflection of the SP curve from the shale baseline occurs in the thicker sandstones. No SP excursions are recorded in the interval below the Gray Sandstone even though very fine-grained calcareous sandstones interbedded with calcareous siltstones were seen at this depth in core. The absence of an SP excursion indicates that the sandstones and siltstones have no permeability.

Siltstones below the Gray Sandstone interval react more readily with dilute HCL than the siltstones and sandstones within the Gray Sandstone. The siltstones below the Gray Sandstone show a higher resistivity and lower GR than the siltstones in the Gray sandstone interval, indicating a higher quartz content or more complete cementation.

Structure Map and Cross-Sections

The top of the upper Gray "C" sandstone was used to construct a structure map for the Cotton Valley field area. The dominant structural element is a NE-SW-trending, salt-cored anticline (Fig. 17). The Gray Sandstone is draped over this deep-seated salt structure. The structure plunges both to the northeast and to the southwest. The northern margin of the anticline is bounded by a prominent graben set up by large, down-to-the-south growth fault. This fault is clearly visible on 3-D seismic sections. Smaller antithetic faults are hard to discern on 3-D seismic sections and were inferred from contour patterns.

Cross section A-A' (Fig. 18) extends across the field from north to south and is perpendicular to regional present-day structural strike. The datum is the top of the Lower Smackover. The northernmost well penetrates the oolitic deposits of the ramp crest. The remaining wells are basinward of the shelf. The interpretive color fill on the cross section is based on log responses. The upper and lower "D" sands are thickest in wells #2 and #3. These sands pass into shale and siltstone both to the north, toward the shelf, and to the south, out into the basin. The "C" sands are thickest in wells #4 and #5, which are farther to the south, suggesting the site of sand deposition had prograded basinward. On this cross section, the "B" sands are best developed in shelfal and proximal slope areas to the north and pass basinward into shales above the thicker parts of the "D" and "C" sands.

Cross section B-B' (Fig. 19) extends across the field from east to west, following the crest of the structure and is parallel to present-day structural strike. Well D in this cross section corresponds to well #3 in the previous cross section. The upper and lower "D" sands maintain a fairly uniform thickness across the entire section, presenting a sheetlike appearance. The upper and lower "C" sands are not as continuous as the "D" sands. The

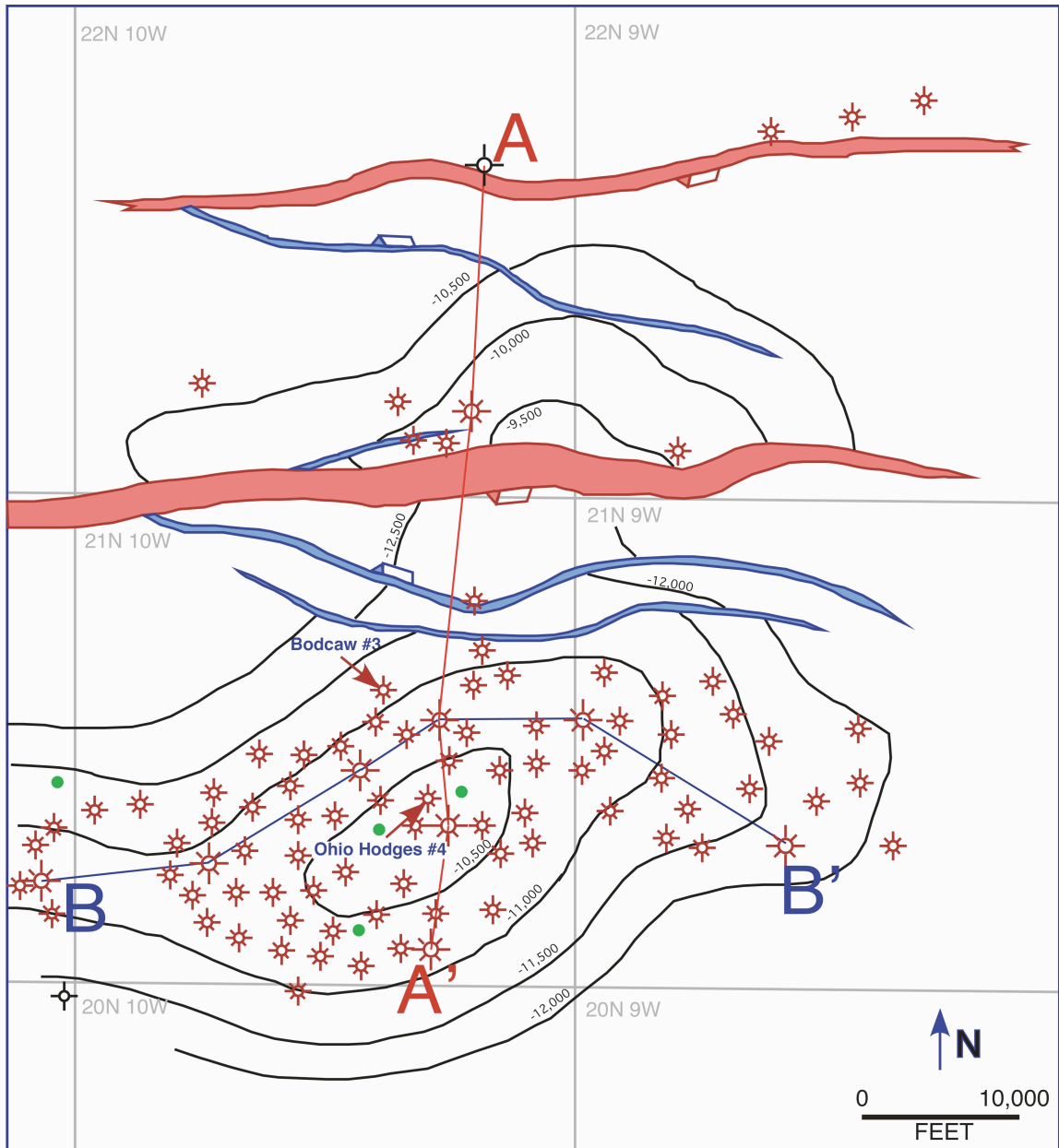


Figure 17. Structure map of top of upper Gray "C" sand, Cotton Valley field showing location of two cross sections and wells from which core was described. The thick red lines represent down-to-the-south growth faults and thick blue lines represent down-to-the-north antithetic faults. Well symbols are the same as in figure 6. Contour interval, 500 feet.

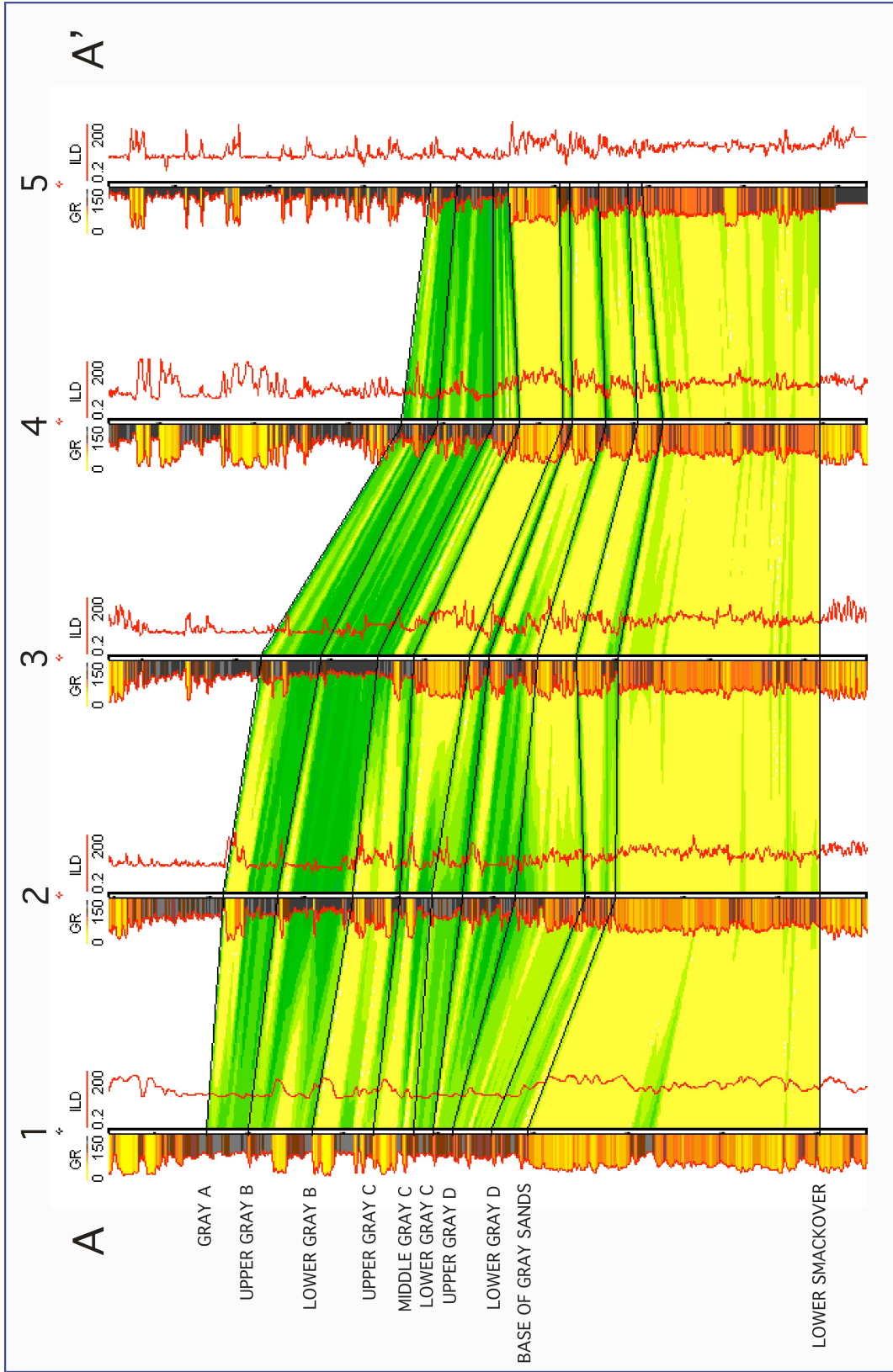


Figure 18. Stratigraphic cross-section A-A'. Datum is top of lower Smackover. Geocolumn shading has been applied to the GR log. Interpretative color fill is based on the magnitude of the GR response (yellow = sand, green = shale). See figures 6 and 17 for location of cross section.

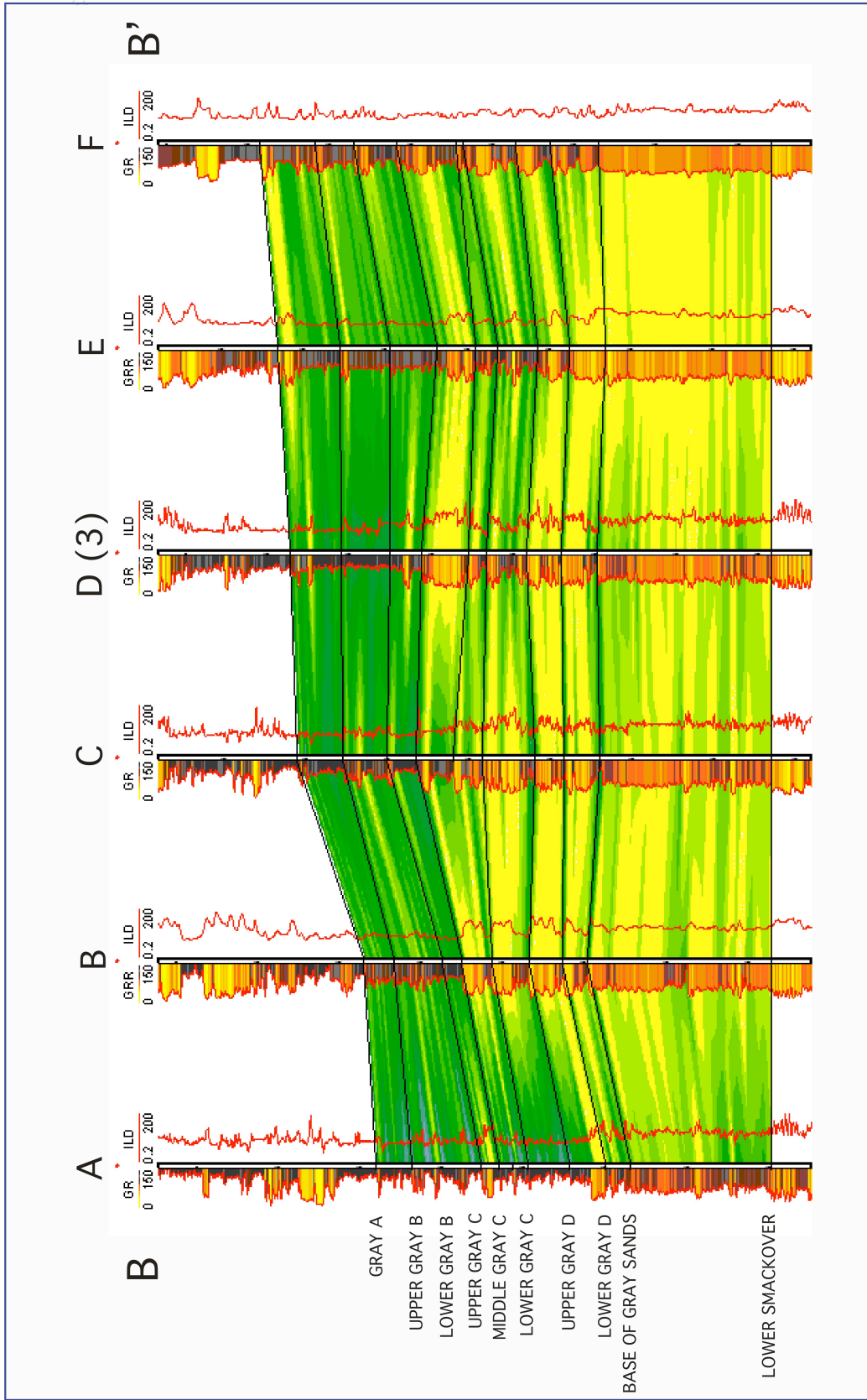


Figure 19. Stratigraphic cross-section B-B'. Datum is top of lower Smackover. Geocolumn shading has been applied to the GR log. Interpretative color fill is based on the magnitude of the GR response (yellow = sand, green = shale). See figures 6 and 17 for location of cross section. Notice that well D here corresponds to well #3 in Figure 18.

lower “C” sand is more sandy in wells B and C. The lower C sand then passes into siltstone and shale both to the west (A) and to the east (D). The middle and upper “C” sands show a similar pattern. These sands are thickest in well D (3), where the lower “C” is absent, and passes into siltstone and shale in the two neighboring wells. In some cases, the discontinuous sands in the “C” interval may stack vertically to form thicker, composite sand bodies. In other cases, the thicker parts of sands higher in the section are displaced relative to the thicker parts of sands lower in the section.

Net Sand Isochore Maps

After correlating the sandstone units throughout Cotton Valley field, net sand estimates were made using the SP log. A minimum deflection of -15mv from the shale baseline was used to pick sandy intervals. Sand picks based on the SP log show a good correlation with estimates based on GR and porosity logs. Net sand isochore maps were then made for each of the sandstone units in Cotton Valley field (Figs. 20-25). Each sandstone unit consists of eastern and western lobes separated by an area with little or no sand.

The lower “D” sand is the basal unit in the Gray Sandstone series in the field. It reaches a maximum thickness of 40 feet in the NE corner of S15 and the NW corner of S14 of T21N R10W (Fig. 20).

The remaining net sand maps reveal the development of a bifurcating feeder channel system directly north of the Gray Sandstone lobes. The upper “D” sand reaches a maximum thickness of 40 feet in the southwest corner of section 15 of T21N R10W (Fig. 21). The western lobe of the lower “C” sand resembles a crevasse splay with a maximum thickness of 45 feet in section 21 and 22 of T21N R10W (Fig. 22). This sand extends

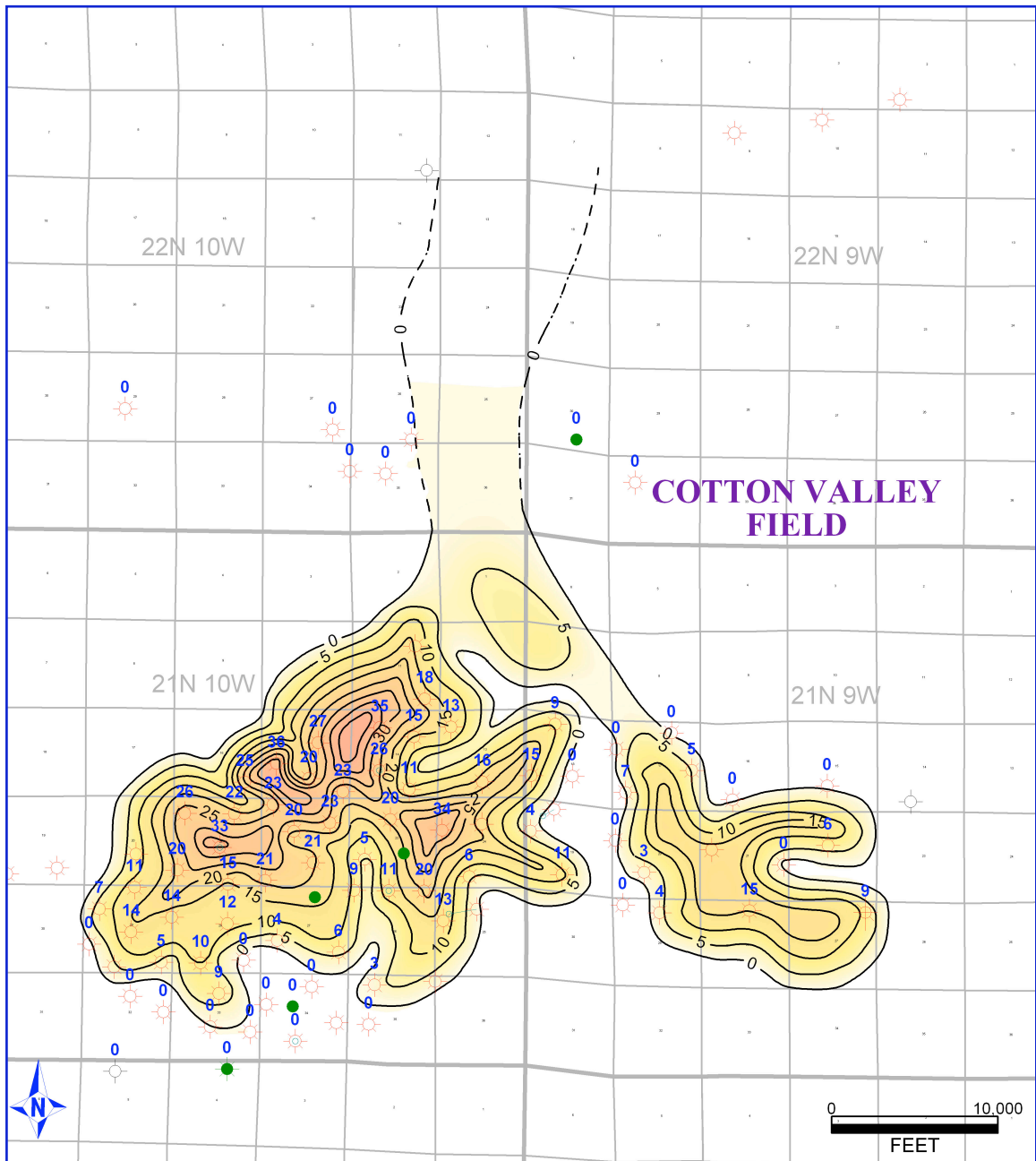


Figure 20. Isochore map, lower Gray "D" sand. Contour interval, 5 feet.

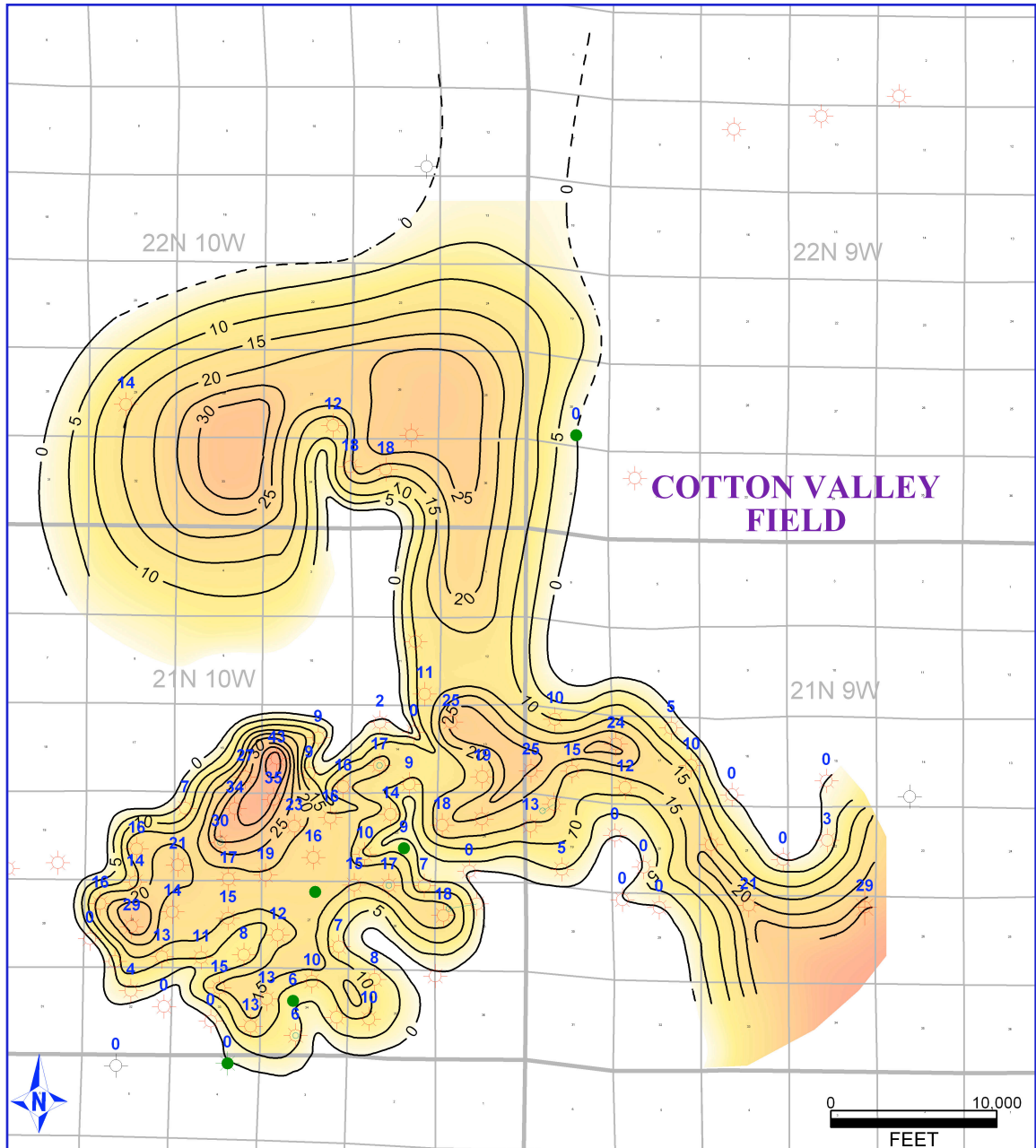


Figure 21. Isochore map, upper Gray "D" sand. Contour interval, 5 feet.

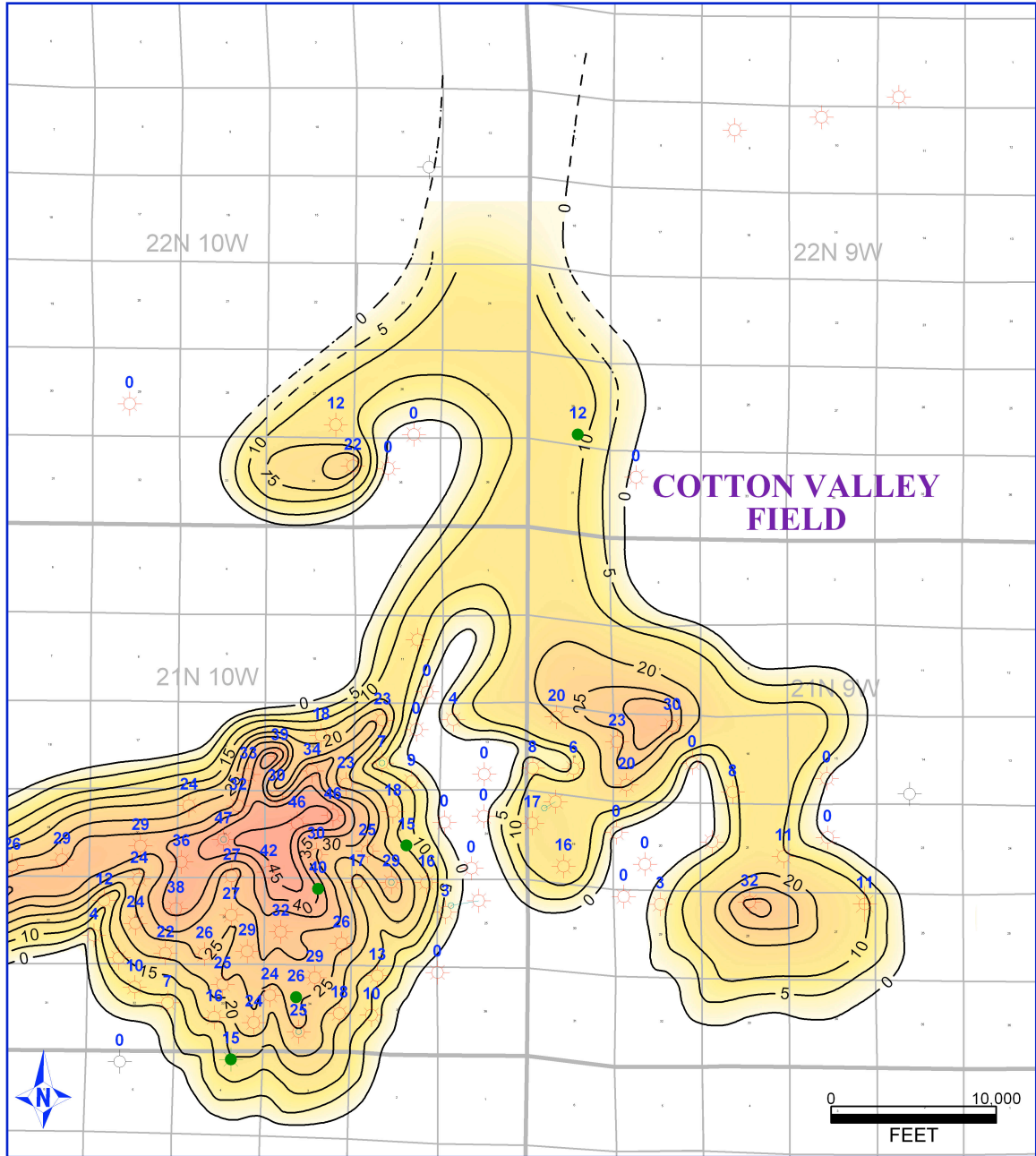


Figure 22. Isochore map, lower Gray "C" sand. Contour interval, 5 feet.

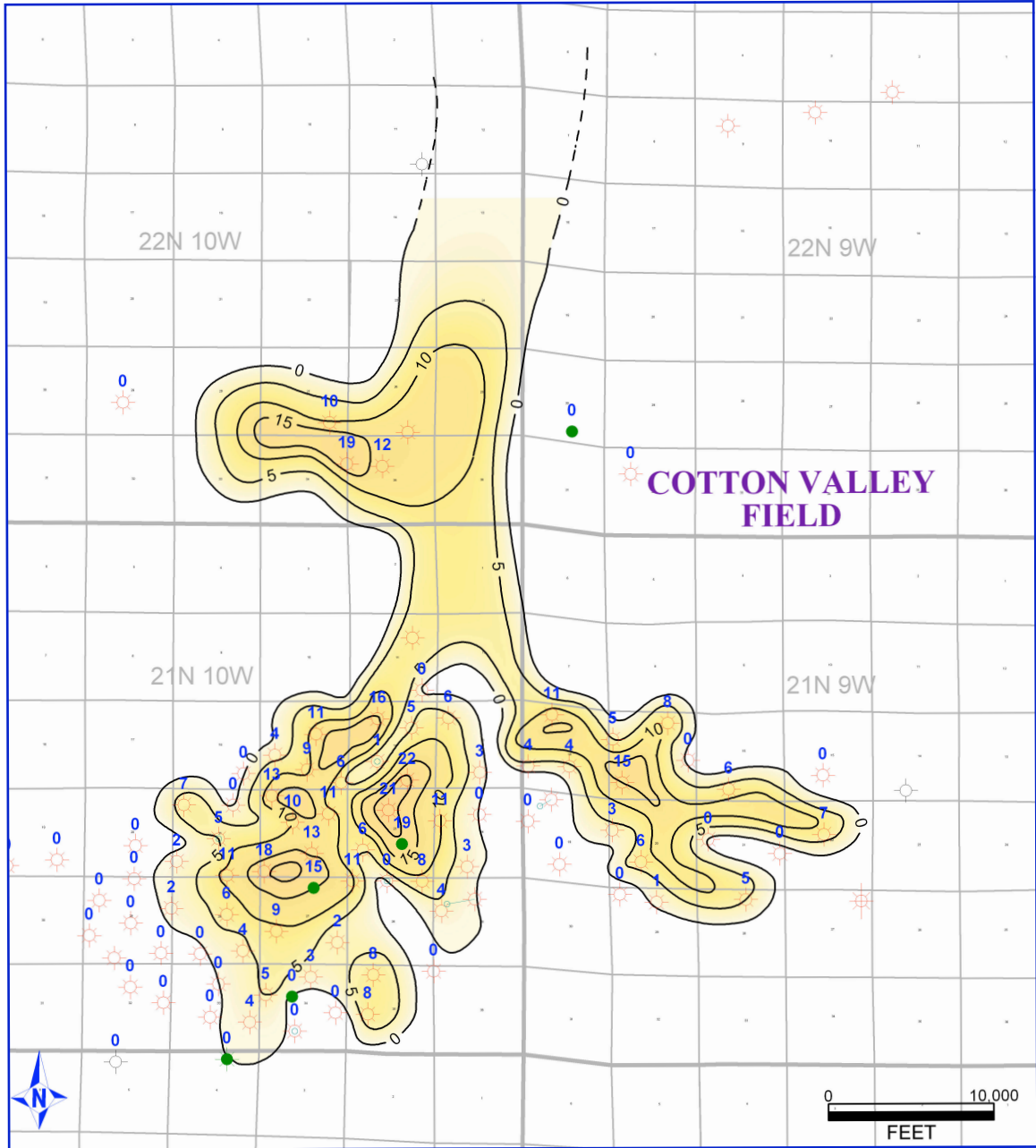


Figure 23. Isochore map, middle Gray "C" sand. Contour interval, 5 feet.

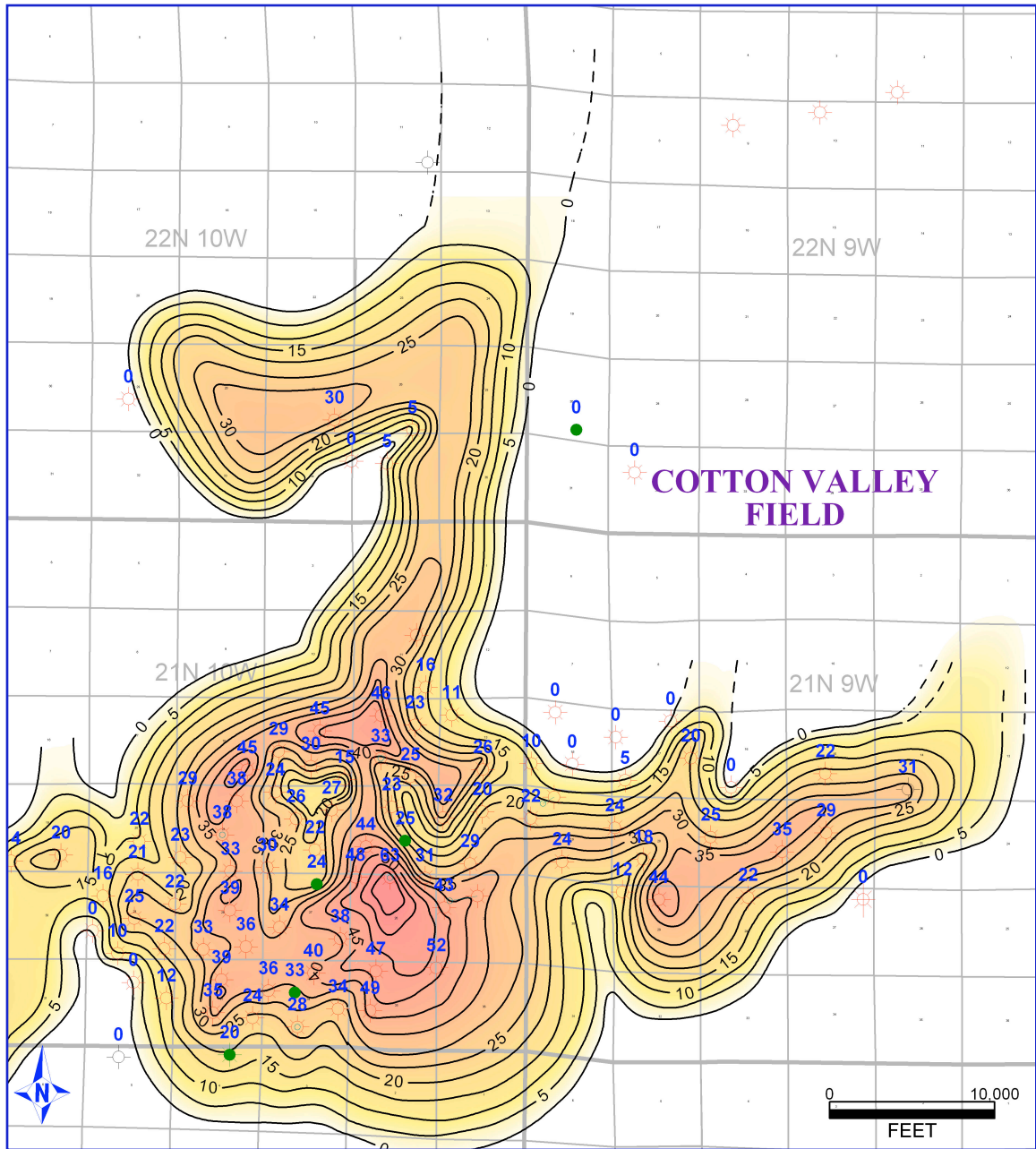


Figure 24. Isochore map, upper Gray "C" sand. Contour interval, 5 feet.

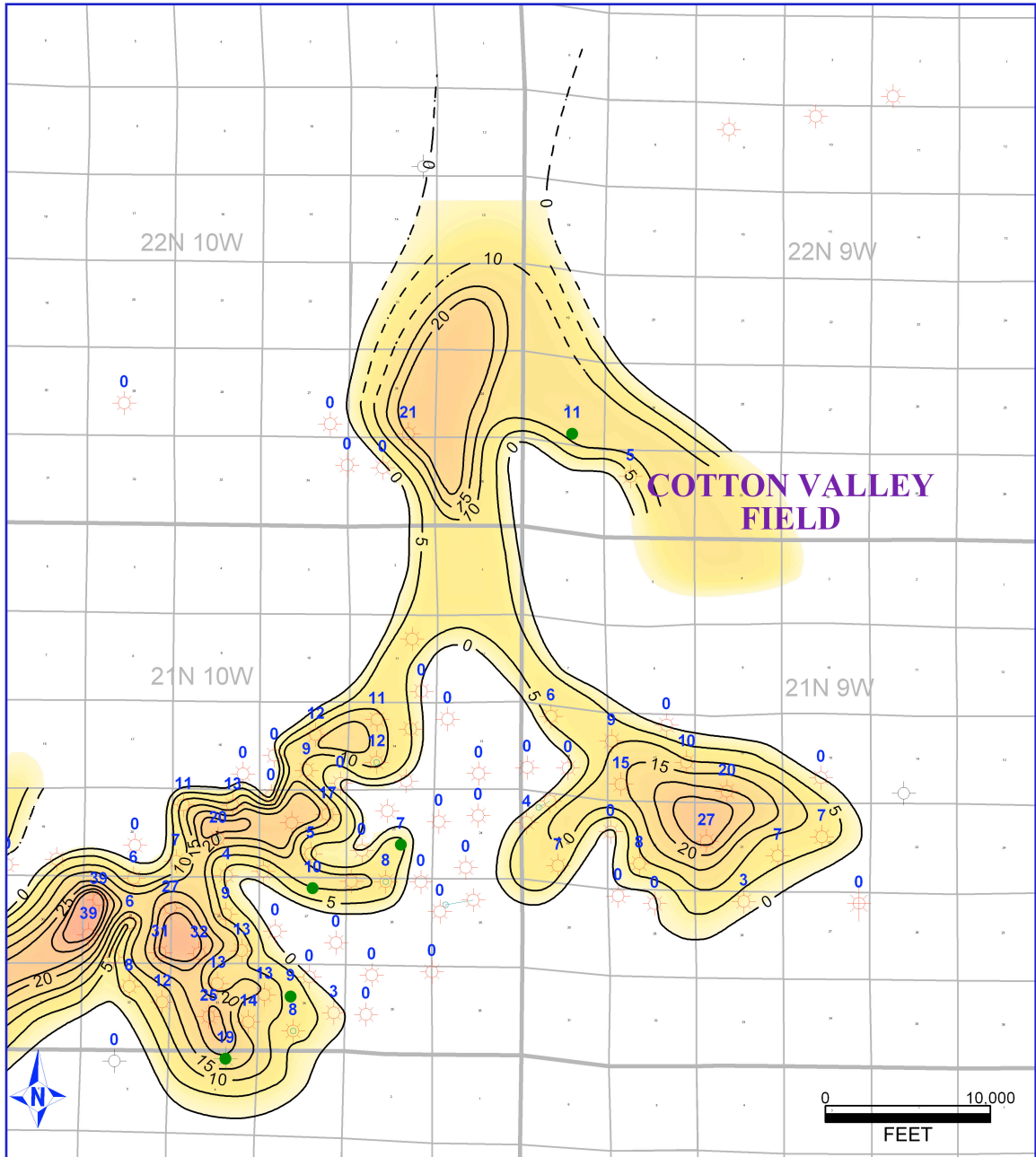


Figure 25. Isochore map, composite Gray "B" sand. Contour interval, 5 feet.

farther south than the others. The middle “C” sand is the thinnest, least extensive unit, reaching a maximum thickness of only 20 feet (Fig. 23). The thickest, most widespread member is the upper “C” sand (Fig. 24). This sand has a maximum thickness of 60 feet in section 26 of T21N R10W. The upper “C” is thin just to the northwest over section 22, which corresponds to the thickest interval of the lower “C” sand. The “B” sand, which consists of lower and upper units, was mapped as a single unit (Fig. 25). Deposition of the “B” sand appears to have been on the western and northeastern areas of the upper “C” sand deposition.

The vertical stacking patterns of the individual sandstone lobes suggest that depositional morphology of the Gray Sandstone was influenced by bathymetric highs on the sea floor. Sandstone lobes higher in the sequence are deposited on the flanks of earlier lobes. The lower “C” sand is thickest in sections 21 and 22 of T21N R10W (Fig. 22). The middle and upper “C” sands are both thin over this area and thickest on the flanks of the lower “C”. The upper Gray “C” and the Gray B show a similar relationship. (Figs. 24 and 25). Sea-floor bathymetry, not deep-seated salt structures, controlled the depositional morphology of the Gray Sandstone in Cotton Valley field.

DISCUSSION AND INTERPRETATION

Depositional Environment

The bifurcating sandstone lobes comprising the Gray Sandstone in Cotton Valley field were deposited at right angles to regional present-day structure and depositional strike (shoreline trend), beyond the shelf-edge break. The size, shape and orientation of

the lobes resemble those given for mud/sand-rich submarine fans by Reading and Richards (1994). According to those workers, such fans are typically deposited in deep water well below storm wave base. Sediment is supplied to such fans by both high-density and low-density turbidity currents. The fans consist mainly of sand (30-70 percent). Classic proximal and distal turbidites with well-developed Bouma sequences comprise the bulk of the fan deposits. Based on the regional paleogeography and the geometry and orientation of the sandstone units, the Gray Sandstone series in Cotton Valley field is best interpreted as a prograding mud/sand-rich submarine fan deposited in deep water (Fig. 26).

However, the trace fossil assemblage and other sedimentary features seen in core argue against such an interpretation. The trace fossils *Planolites*, *Chondrites*, *Rossellia*, *Helminthopsis*, *Tiechichnus* and *Phycosiphon insertum* are typical of the *Cruziana* ichnofacies. This ichnofacies is found in a variety of settings ranging from estuaries, bays and lagoons to open continental shelves (Ekdale *et al.*, 1984). It is most typical of shelf settings where it is often associated with storm deposits (tempestites). In storm layers, as in turbidites, the idealized sequence of features and structures results from waning flow. Storm layers commonly have a basal erosion surface with rip-up clasts overlain by hummocky cross-stratified sands followed by evidence of lower flow regime oscillatory conditions. The return to fair-weather conditions following the storm is marked by deposition of mud from suspension. The surface is then re-colonized by organisms, producing the *Cruziana* ichnofacies.

The vertical sequence of textures and structures seen in core indicate the Gray Sandstone was deposited above storm wave base by analog with studies of modern storm deposits (Fig. 27). Basal erosion surfaces with rip-up clasts in the Gray Sandstone represent the main storm events. An example of such features in recent deposits is shown

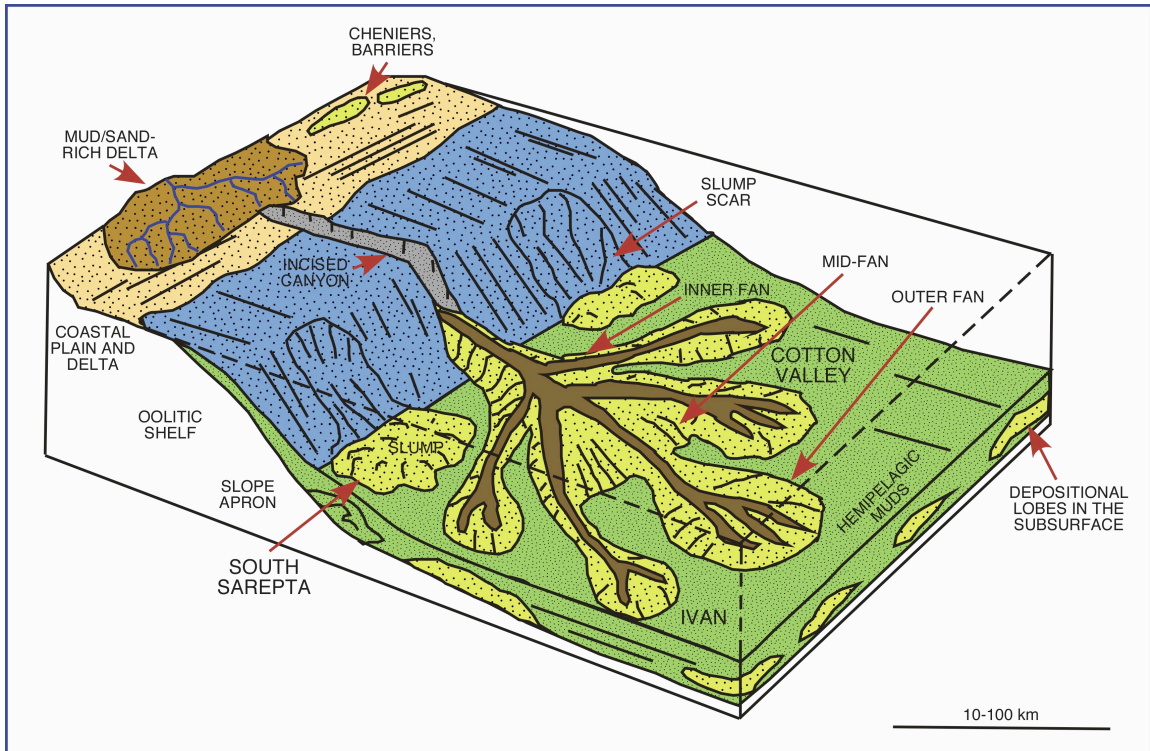


Figure 26. Block diagram of a mud/sand-rich, down-dip bifurcating submarine fan complex illustrating sand body morphology of subsurface lobes and location relative to the shelf-edge. Cotton Valley, South Sarepta, and Ivan fields have been labeled next to proposed location in the depositional system. Modified from Reading and Richards (1994).

in figure 27. This is overlain by hummocky cross-stratification deposited by long- period storm waves. Wave-ripple lamination representing temporary weakening of the storm waves are present in some cases within the bed, and wave ripples, which formed as the storm subsided, are present on the upper surface. As storm conditions weakened, fall-out of fine-grained sediment from suspension blanketed the coarser storm deposits, and endobenthic organisms churned and homogenized the sediment. The heterolithic finer-grained facies (A, B) represent the cessation of storm conditions, return of fairweather energy levels, and re-establishment of biogenic activity.

The stratigraphic and sedimentologic evidence is difficult to reconcile. The *Cruziana* ichnofacies can be found in open shelf settings below storm wave base, but has not been reported from deeper water deposits. If the diffuse horizontal lamination seen in core is correctly identified as hummocky cross-stratification, then the sands were deposited above storm wave base. The wave ripples seen in the core support the interpretation of the lamination as hummocky cross-stratification. The geometry and orientation of the sands, however, suggest deposition on a submarine fan, not on an open shelf as tempestites.

I interpret the Gray Sandstone in Cotton Valley field and the surrounding area as ramp deposits of a storm-generated, progradational mud/sand-rich submarine fan complex deposited at the mouth of a down-dip bifurcating feeder channel. The unchannelized, laterally extensive sheet sands of the lower section of the Gray Sandstone are overlain by laterally discontinuous, channelized sands, which suggests the Gray Sandstone was deposited during a third-order fall in relative sea-level (Fig. 28). I do not

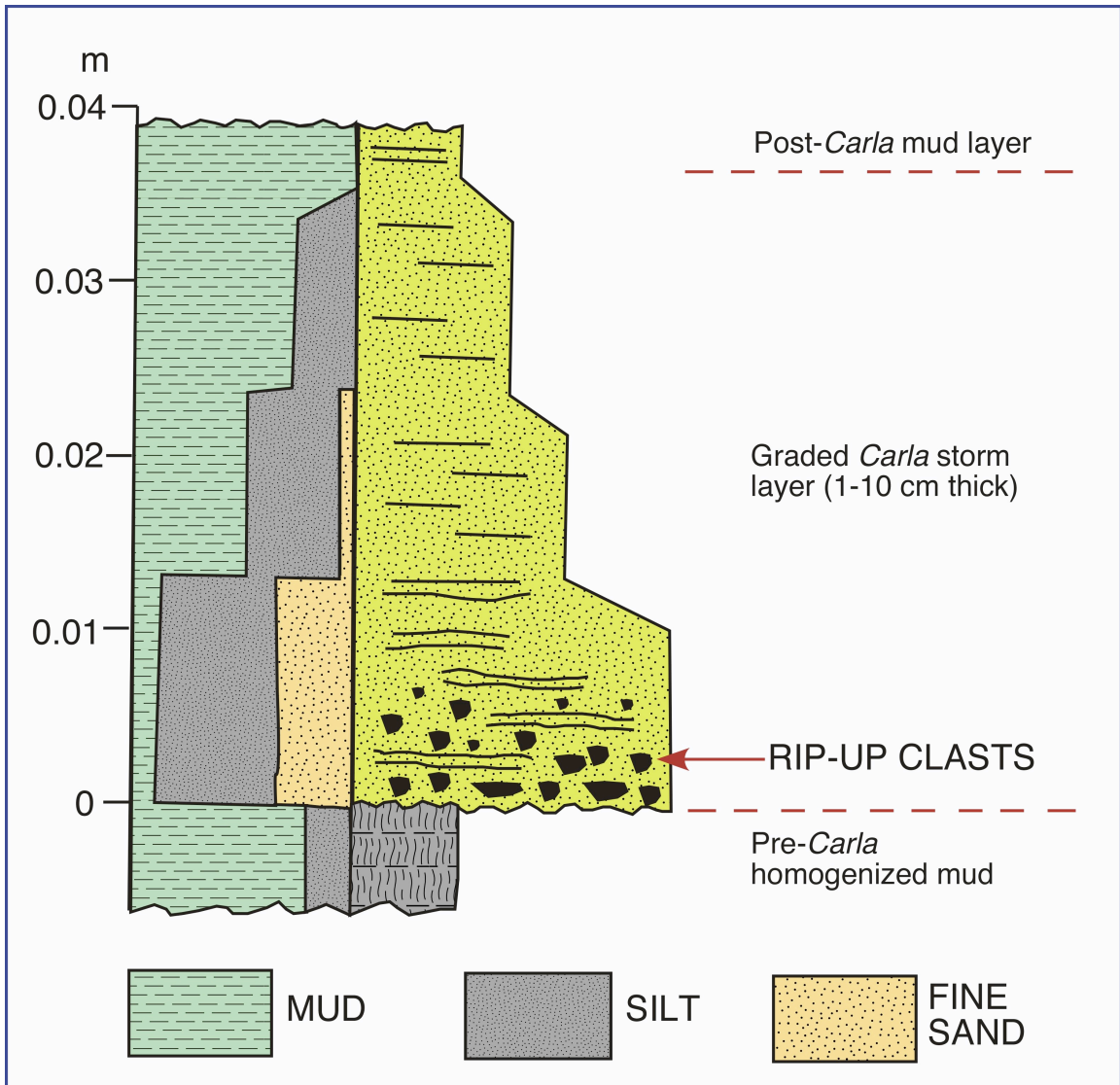


Figure 27. Graded sand layer, offshore Texas, resulting from Hurricane *Carla*, found beneath 18 to 36 m of water. Modified from Hayes (1967).

believe the Gray Sandstone was deposited in abyssal depths on the basin plain. Most likely it was emplaced above storm wave base and below fairweather wave base on the Late Jurassic (Smackover) carbonate ramp.

RESERVOIR DEVELOPMENT MODEL

Reservoir Architecture

Thickening-upward megasedimentation units occur in the axial regions (main channel) of individual sandstone lobes, which is characteristic of progradational submarine fan complexes with meandering upper-fan distributaries and extensive, unchannelized lower-fan sheet sands (Reading and Richards, 1994)). Amalgamated and thicker sandstone beds are interpreted as proximal channel axis deposits, which grade laterally into thinner, more discrete beds with more common and thicker intercalated mudstone deposits. Judice and Mazzullo (1982) noticed similar characteristics in the Gray Sands of Terryville field. In terms of reservoir architecture for the Gray Sandstone of Cotton Valley field, sand body geometry typically forms lenticular channels dominated by sand fill. Net sand percentages are greatest proximal to the main channel axis and decrease toward lateral margins of the channel-levee system (Fig. 29).

Reading and Richards (1994) considered deposits of mud/sand rich submarine fan systems to have the following reservoir attributes: high-to-moderate reservoir heterogeneity, moderate vertical communication between sandstones, and poor lateral reservoir communication. They considered the common reservoir trap type to be stratigraphic trapping of channel and lobe deposits. The main trapping mechanism in

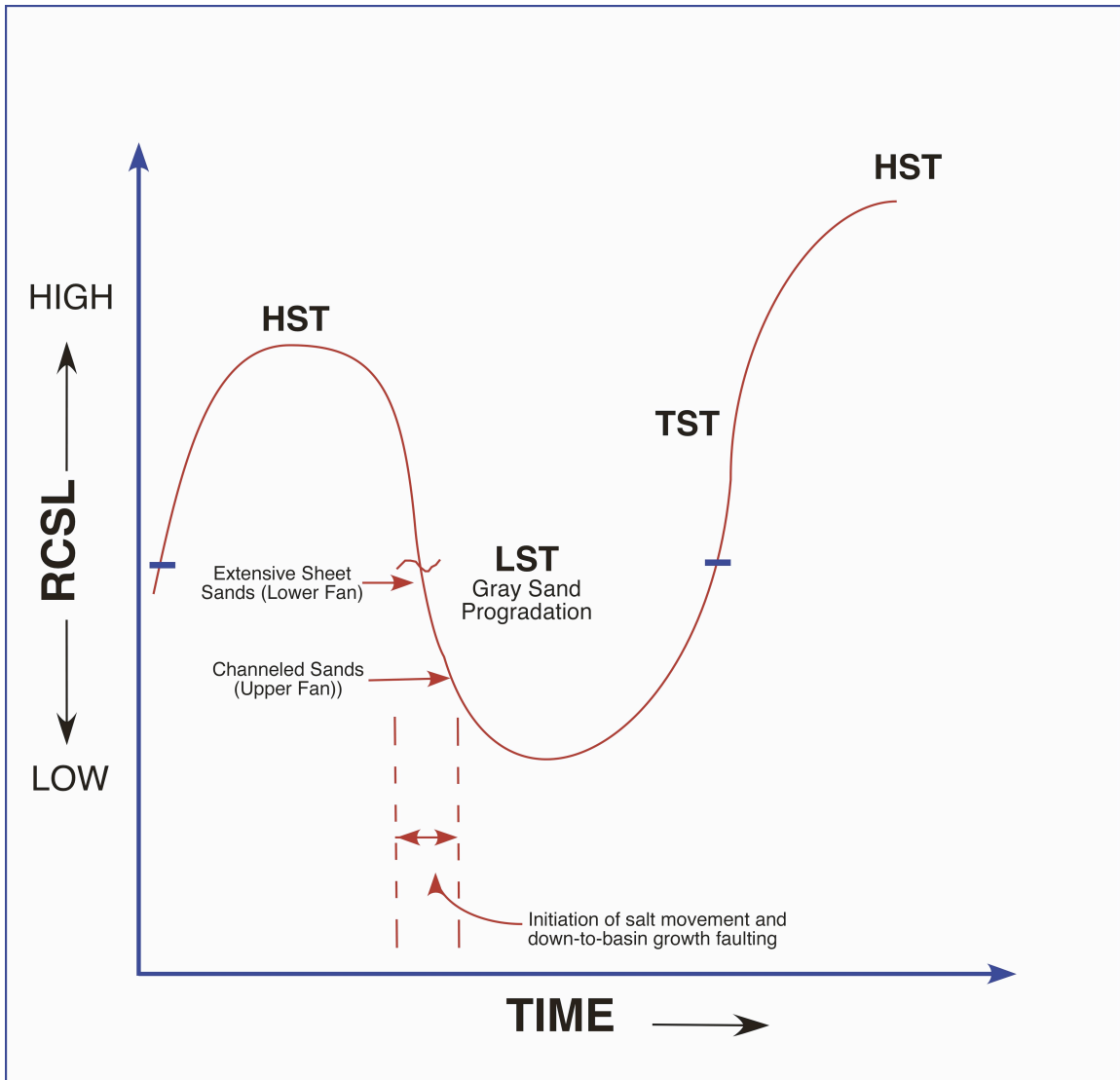


Figure 28. Relative change in sea-level curve (RCSL) showing progradation of Gray Sandstone into Cotton Valley field during sea-level regression. LST, low-stand systems tract; HST, high-stand systems tract; TST, transgressive systems tract.

Cotton Valley field is a combination of stratigraphic and structural, resulting from the draping and bending of sandstone lobes over a younger, deep-seated NE-SW trending salt anticline.

Diagenetic History

The onset and timing of extensional growth faulting and associated salt mobilization did not affect the depositional morphology of the sands. The thickest units of the Gray Sandstone occur directly above the deep-seated salt pillow in Cotton Valley field, which implies salt movement took place after deposition. Judice and Mazzullo (1982) came to the same conclusion for the Gray Sandstone in Terryville field.

However, the timing of salt movement quite possibly had a direct effect on the diagenetic evolution of secondary porosity and associated reservoir development. Early infiltration of hydrocarbons into the primary pore spaces of a reservoir is known to inhibit the nucleation and formation of euhedral quartz overgrowths (Wescott, 1983). If salt movement commenced shortly after the burial of the Gray Sandstones, hydrocarbon migration would have been funneled into the sandstones above the newly formed salt structure, preventing the formation of quartz overgrowths. Areas off the flanks of the present-day salt structure quite possibly are not prospective for Gray Sandstone development because of the high probability of encountering tight, silicified sandstone reservoirs due to the presumed abundance of authigenic quartz overgrowths caused by the lack of early hydrocarbon infiltration.

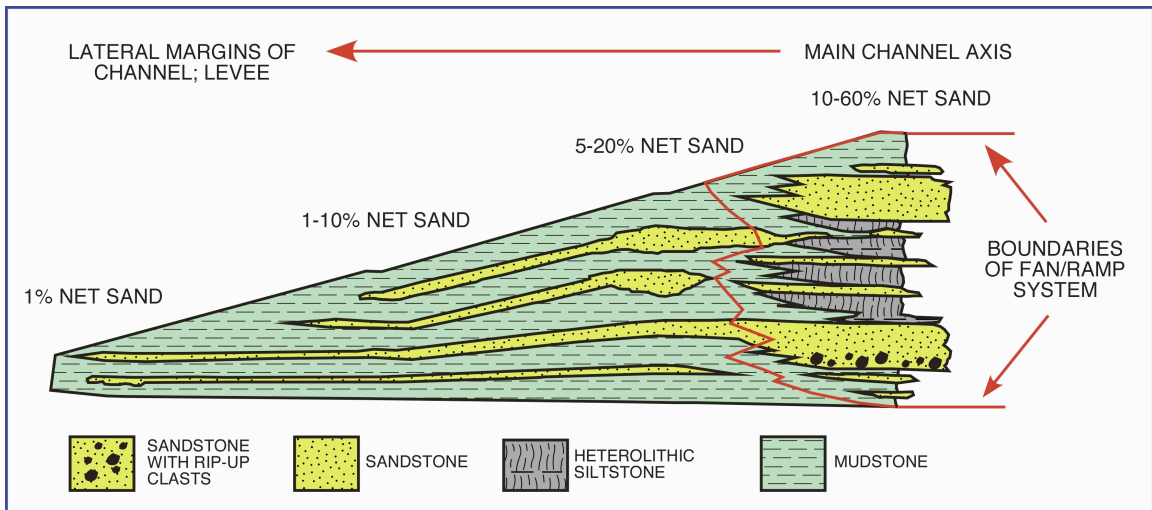


Figure 29. Proximal and distal estimations of net sand percentages in submarine fan deposits. Modified from Reading and Richards (1994).

The major inferred paragenetic sequence of the Gray Sandstones within Cotton Valley field as observed from thin sections made from the MOC Bodcaw #3 core is as follows: eogenetic precipitation of needle-like calcite cement (early marine cement), precipitation of authigenic anhydrite cement, precipitation of syntaxial quartz overgrowths replacing micrite and growing into primary pores (porosity reduction), formation of pseudomatrix caused by compactional deformation of ductile interstitial clays around rigid grains into primary pores, precipitation of authigenic carbonate cement into remaining pores, and finally partial dissolution of carbonate cement and evolution of intergranular secondary porosity. Dissolution of previously formed carbonate cement most likely resulted from thermal maturation of organic matter. Decarboxylation and deesterification at depth increased the partial pressure of carbon dioxide and acidity in subsurface brines, which created an environment favorable for carbonate dissolution (Blatt 1979). This paragenetic sequences is well illustrated in figures 15 16. This interpretation differs from Judice and Mazzullo's (1982) interpretation, in which they suggested that ductile deformation of shale clasts to form pseudomatrix occurred prior to the precipitation of early marine carbonate cements. Early precipitation of carbonate cement may help to preserve a fraction of primary intergranular porosity by preventing the extrusion of labile grains into initial pores. Also Judice and Mazzullo documented the precipitation of pore-filling chlorite, illite and smectite, which was not noticed in the Gray Sandstone of Cotton Valley field. The use of a scanning electron microscope is most likely necessary to observe such quartz coatings of authigenic, pore-filling clays. A scanning electron microscope was not used in this study

SUMMARY AND CONCLUSIONS

The Gray Sandstone of Cotton Valley field is comprised of six individual sandstone lobes clustered at the mouth of a down-dip bifurcating feeder channel complex. The diagenetic sequenced is one dominantly of porosity reduction and present-day secondary porosity is the result of partial dissolution of carbonate cement. The Gray Sandstone in Cotton Valley field presents an interesting enigma. In a stratigraphic sense these sandstones resemble the single point-source mud/sand-rich submarine fan deposits of Reading and Richards (1994). However, these sands do not seem to have been deposited in deep, basinal waters below storm wave base. The sedimentary structures observed in the two cores in the Gray Sandstone in Cotton Valley field argue against their emplacement in deep waters below storm wave base by low-density turbidity currents. Both the sedimentary structures and trace fossil assemblages imply a much shallower depositional environment, quite possibly an medial-to-distal ramp environment. The characteristic vertical succession of sedimentary structures commonly produced by episodic storm events, the presence of trace fossils characteristic of the *Cruziana* ichnofacies, and the absence of shallow marine sedimentary structures that form during fairweather conditions suggest that these sands were deposited between fairweather wave-base and storm wave-base.

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Abstract

DEPOSITIONAL AND EXPLORATION MODEL, GRAY SANDSTONE SERIES (UPPER JURASSIC), COTTON VALLEY FIELD, NORTHERN LOUISIANA

**By Brian William Atwell, M.S., 2008
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The Gray Sandstone series (lower Buckner Formation, Upper Jurassic) in Cotton Valley field, northern Louisiana, consists of discrete sandstone lobes of limited lateral extent. The continuity of the Gray Sandstone across the area is due to the overlapping of discrete sandstone lenses. Net sand isochore maps show the Gray Sandstone to be a series of dip-parallel lobes clustered at the mouth of a feeder channel that bifurcates downdip. Individual lobes may be amalgamated with adjacent lobes and contain sedimentary features and ichnological fabrics most commonly associated with episodic storm deposits. Production from the Gray Sandstone series in Cotton Valley field comes from over a large, doubly plunging, salt-induced anticline. Production occurs both over the crest and on the flanks of the structure.