Application of Cutting-Edge 3-D Seismic Attribute Technology to the Assessment of Geological Reservoirs for CO2 Sequestration

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EXECUTIVE SUMMARY

The *goals* of this three-year project are to develop innovative 3D seismic attribute technologies and workflows to assess the structural integrity and heterogeneity of subsurface reservoirs with potential for CO_2 sequestration. Our *specific objectives* are: (1) to apply advanced seismic attributes to quantify the thickness, porosity, permeability and lateral continuity of CO2 sequestration target reservoirs and the integrity of the seals, (2) to construct a reservoir model and (3) to validate the reservoir model with reservoir simulation studies.

Introduction

Dickman field, Kansas, one of the primary study areas in this project, is a pilot area to test the viability of using attribute-based reservoir parameters in simulation models of the reservoir, and the capability to use attribute derived parameters to predict fluid flow in a depleted oil reservoir under water drive. A three-phase workflow was proposed in the Q1 2008 report in which all data were to be migrated to GeoFrame and quality control carried out for logs and formation tops during the Q1 period (Phase 1). This report presents the Phases Two and Three activities of the workflow and preliminary results obtained in Q2 2008, roughly corresponding to the tasks 3.0, 4.0, 5.0 and partially 6.0 in the revised Gantt table of the Q3 2007 report.

The progress presented here includes (1) improved understanding of the geometry and physical properties of the two shallower reservoirs immediately above and below the Mississipan Unconformity and the deeper saline aquifer; (2) improved knowledge of the tie between geological and geophysical interpretation from depth and time domains, and (3) improved understanding of the relation between the seismic attributes and properties of shallower targets. The activities and methods presented in this study can possibly be applied to the rest of the areas in this proposal for attribute-based quantitative modeling of CO2 sequestration compartment and fluid properties. Data used in the GeoFrame system for the tasks and the results in Q1 are summarized in Fig. 1.

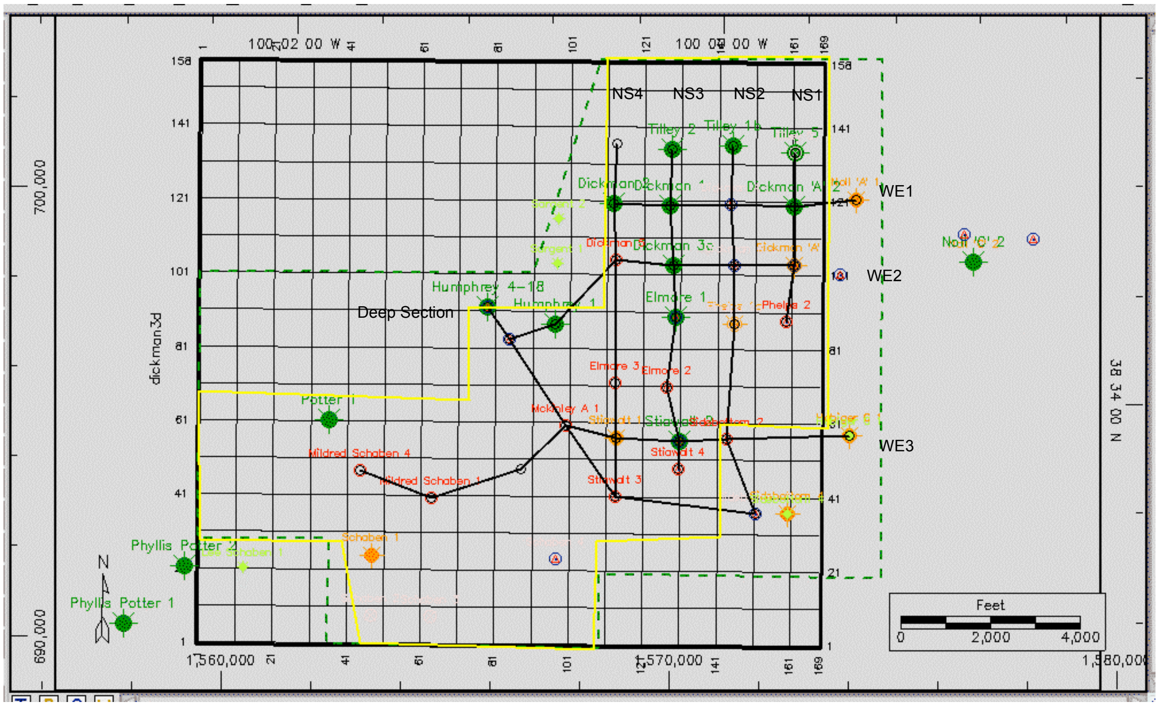
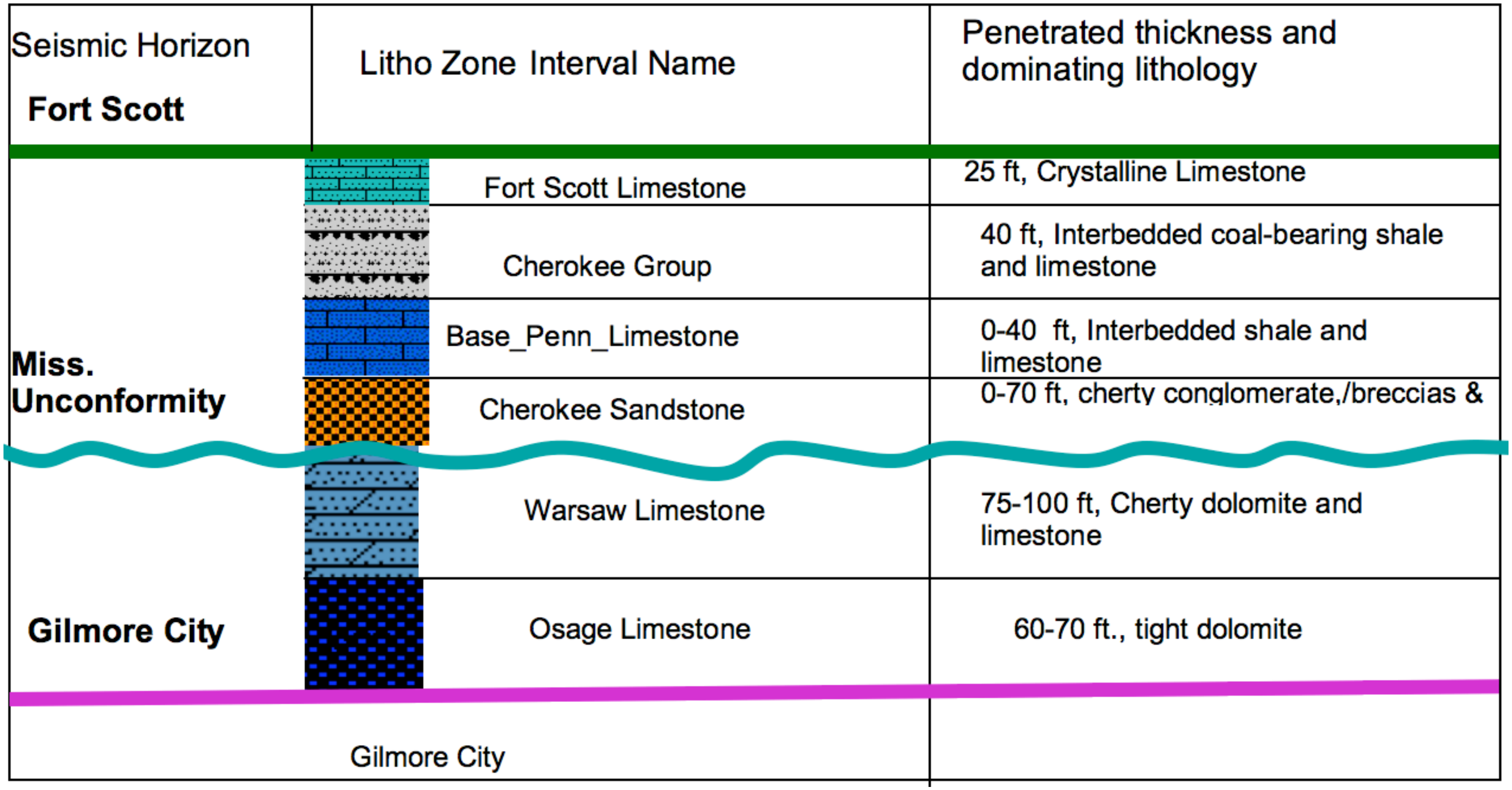


Fig. 1 Data map showing seismic data boundary (yellow line), seismic line grid (black thin lines), geological data boundary (green dash line), and locations of all wells used in log correlation as circles. Solid circles are oil wells (production coded: dark green color for Miss, brown for Cherokee, light green for undifferentiated production). Also shown are locations of well log correlation sections including four north-south cross sections (NS1 to NS4 from east to west), three west-east cross-sections (WE1 to WE3 from north to south), and one roughly NW to SE section (Deep Section) across three deep wells penetrating the strata below the deep saline aquifer.



Seismic Horizon	Litho Zone Interval Name	Penetrated thickness and dominating lithology
Fort Scott		
	Fort Scott Limestone	25 ft, Crystalline Limestone
	Cherokee Group	40 ft, Interbedded coal-bearing shale and limestone
	Base_Penn_Limestone	0-40 ft, Interbedded shale and limestone
Miss. Unconformity	Cherokee Sandstone	0-70 ft, cherty conglomerate,/breccias &
	Warsaw Limestone	75-100 ft, Cherty dolomite and limestone
Gilmore City	Osage Limestone	60-70 ft., tight dolomite
	Gilmore City	

Fig. 2, Local stratigraphic column based on the well log and mud log information from Dickman Field using the same nomenclature as seen in field data. Seismic horizons interpreted from the full stack migrated volume include: Fort Scott (green), Miss. Unconformity (blue), and Gilmore City (pink).

1. Enhanced Stratigraphic Framework Interpretation

Stratigraphic correlation was carried out in both depth and time domains, focusing on consistency of interpretation. The depth correlation was extended from using 38 wells having at least one log (as mentioned in Q1 report) to using more than 70 wells with tops) from the Kansas Geological Survey (KGS) well database. More than 120 tops were added or modified to construct the correlation sections. The lithology descriptions in geology reports of nine wells were used as reference to define and map the six litho-zones as shown in the local stratigraphic column in Fig. 2.

In time domain, the three previously picked horizons in 2007 were used: the Fort Scott horizon as a local stratigraphic reference “datum”, the Miss Unconformity as the boundary separating the two shallower reservoirs, and the Gilmore City horizon as the lowest boundary of the deeper saline aquifers (Fig. 2). The wells with logs and tops were then were posted on the seismic sections to get a first version of the depth-time tie for further calibration work.

1.1 Depth Domain Results

The log correlations for strata through the Miss. Unconformity are shown in Figs. 3 and 4 and below the Miss-unconformity in Fig. 5. The former focuses on shallower reservoir targets and the latter the deeper saline aquifer. All sections shown in Figs. 3 and 4 have been hung on the Fort Scott limestone to remove later structural deformation and better show the unconformity surface. The section in Fig. 5 has been hung on the Miss. Unconformity.

The strata between Fort Scott and the Miss. Unconformity (120-160 ft) are subdivided and correlated using four “litho zones” as shown in Fig. 2. One of the benefits from such a sub-division is the realization of a mis-tie between the interpretation in depth and time on the Fort Scott as will be discussed in section 1.2. The log characteristics and lithologic properties of these litho zones are as follows.

***Fort Scott Limestone Litho Zone* (72 wells).** Dominated by light tan or varying color fossiliferous, oolithic, crystalline and cherty limestone. Characterized by low gamma ray (GR, 10-40 API), relatively low acoustic slowness (55-75 μs/ft), variable density (2.1-2.7 g/cm^3) and low neutron porosity (NPHI, 2-12 %). Very little vertical or lateral variations of bed thickness and log response is observed, therefore the seismic reflection should be continuous and highly traceable laterally. Probably formed on a marine carbonate shelf or ramp during sea level high stand following a post-Mississippian marine transgression.

***Cherokee Group Litho Zone* (43 wells).** Interbedded coal-bearing black shale and limestone sequence. Characterized by high and variable GR (130-250), large acoustic slowness (90-115), relatively low but highly variable density (1.8-2.6), and low NPHI (2-12). Vertical and lateral log variations are the highest of all litho zones in most wells, with 2-3 very high density and acoustically fast thin limestone layers (2-8 ft) in the sequence. These characteristics may result in seismic reflectors of a poorer lateral continuity, although thickness is relatively consistent. This Litho Zone is of both marine and non-marine origin (Moor, 1979), deposited in an alternative shallow-ramp and coal-swamp and/or costal plain environment. Continued transgression eventually buried and compacted the peat to become a coal-bearing sequence (McCabe, 1991).

Base Penn Limestone Litho Zone **(68 wells).** Mud log description as an interbedded shale, sandstone and limestone section. Sandstone beds in some wells are actually the fine part of the underlying Cherokee cherty conglomerates and breccias. This litho zone does not show log characteristics of typical carbonates, rather, it is characterized by highly variable GR (40-170), relative large acoustic slowness (60-120), variable density (2.1-2.6) and very high NPHI (25-40). In terms of the lateral and vertical variation in log readings and thickness, it is a transition between the coal-bearing Cherokee Group above it and the Cherokee Sandstones below. Because of this variability, it may be less trackable on seismic sections despite a local thickness up to 40 ft.

Cherokee Sandstone Litho Zone **(40 wells).** The lower part of this zone (recognized in more than 20 wells) contain the shallower clastic reservoir. As seen from the mud log, it is a fining-upward sequence containing a lower part of cherty conglomerates/breccias and an upper part of sandstone and shaly sandstone beds of variable color. Characterized by highly variable GR (20-80), intermediate acoustic slowness (60-90), and near constant density around 2.2. The GR shows lateral variation (GR=10 north at Telley2, 80-120 at Dickman1 and NollC3, 50-70 at Elmore 3 to south, 20-30 at Sidebottom 6 to southeast, and 70-80 in Humphrey area to the west). This zone represents a low stand system track of channel fills in major topographic lows on the Miss. Unconformity.

The thicknesses of the Fort Scott limestone and Cherokee Group coal-bearing are laterally more consistent than that for the Base Penn Limestone and Cherokee Sandstone (Figs. 3 and 4). The thickness center of Base Penn Limestone is at the Elmore 3 well, where the Cherokee Sandstone (Fig. 3d) is relatively thin. The Base Penn Limestone is much thinner to the south (Fig. 4a-c), while the Cherokee Sandstone is thicker and more laterally continuous to the south (Fig. 4c). The Cherokee Sandstone thickens southward on line 2 (Fig. 3b), with a maximum at wells Elmore 2 (Fig. 3c) and Mckinley A1 (Fig. 4c). A part of Cherokee Sandstone with good porosity and permeability contributes to the shallower reservoir (Fig. 2, brown solid dots), but are tight in the area with maximum thickness. The Cherokee Sandstone and underlying Warsaw Limestone reservoirs share the same oil water contact.

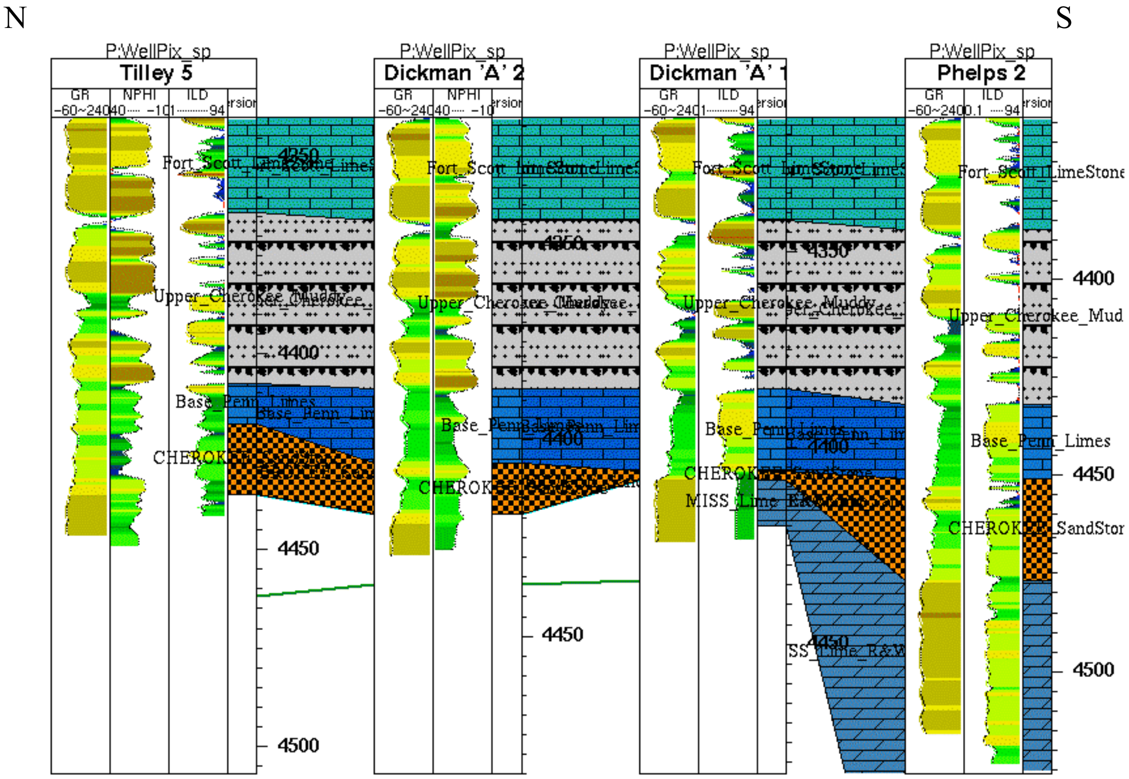


Fig. 3a Stratigraphic section NS1 shown in Fig 1.

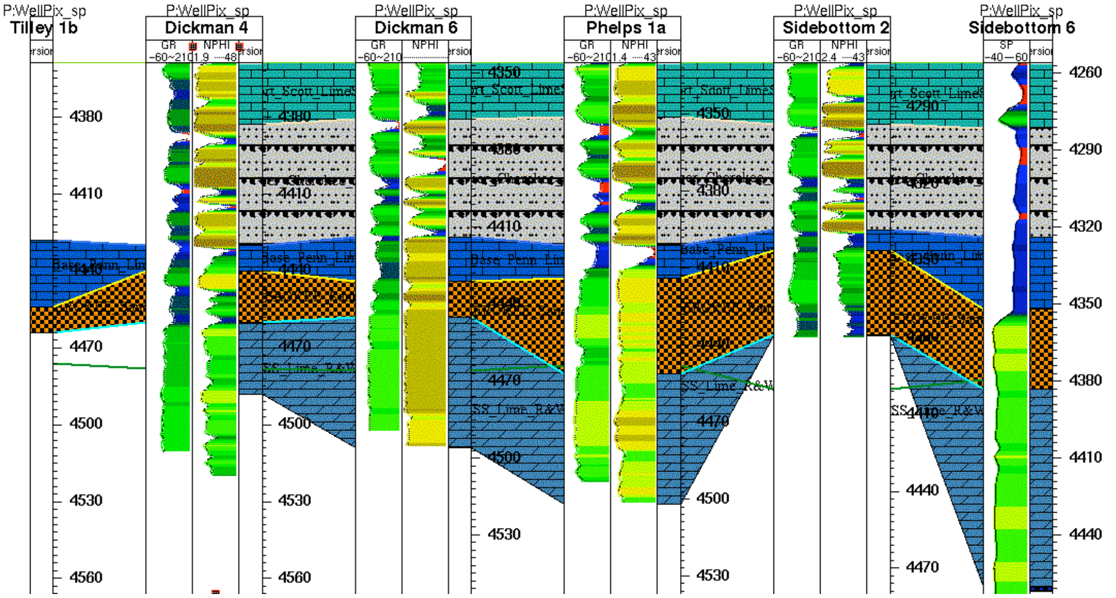


Fig. 3b Stratigraphic section NS2 shown in Fig 1. Note the Cherokee Sandstone becomes thicker to the south

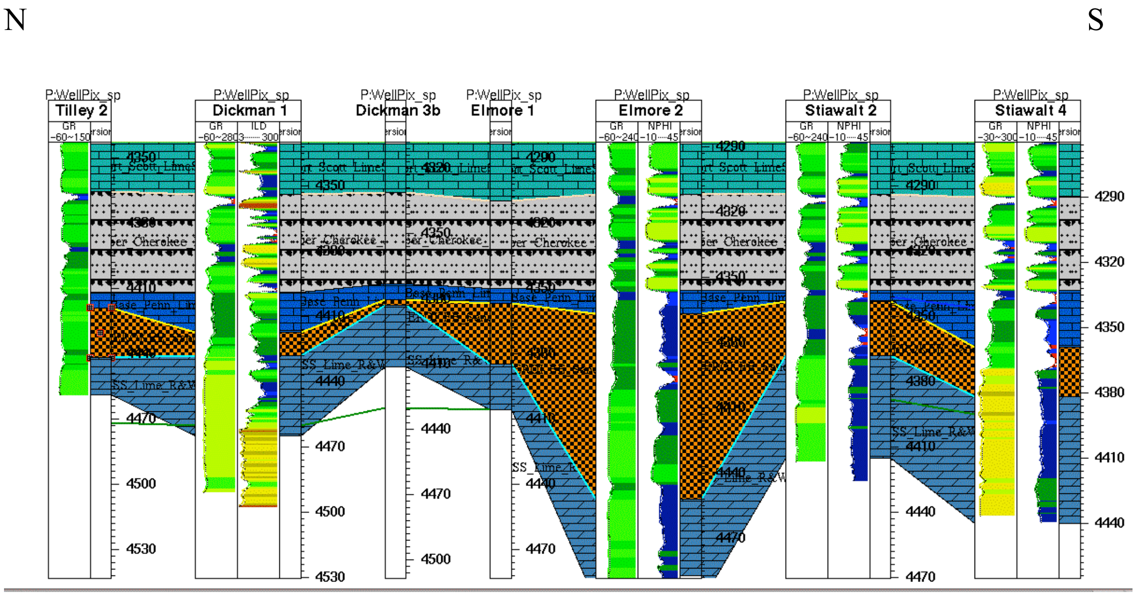


Fig. 3c Stratigraphic section NS3 shown in Fig 1. Note the maximum thickness of Cherokee Sandstone at well Elmore 2. The sandstone above the oil water contact (green line) is tight.

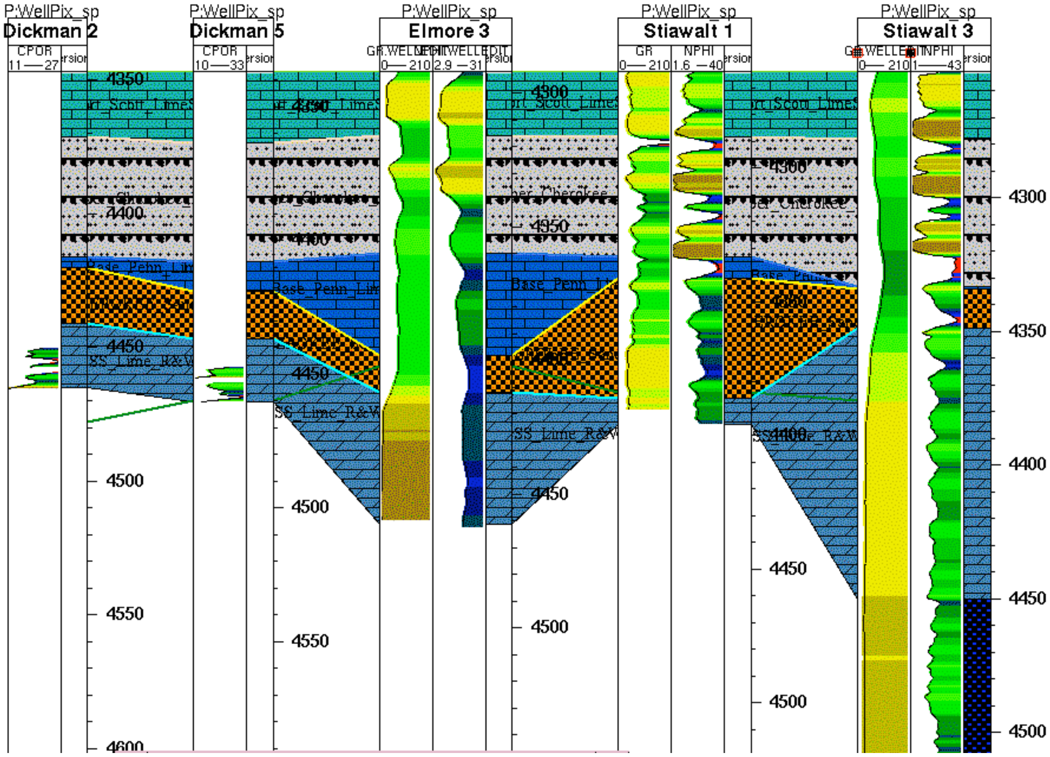


Fig. 3d Stratigraphic section NS4 shown in Fig 1. Note the maximum thickness of the Cherokee sandstone at the Staiwalt 1 production well. The Warsaw limestone is below the oil water contact. Wells Dickman2 and 5 have only core porosity data, with Dickman 2 producing from Warsaw limestone.

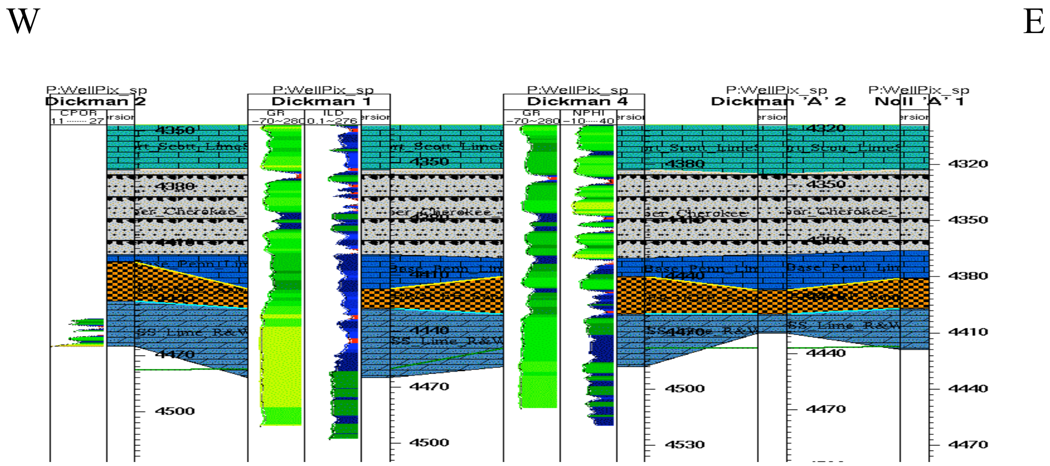


Fig. 4a Stratigraphic section WE2 shown in Fig 1, showing thin Cherokee sandstone.

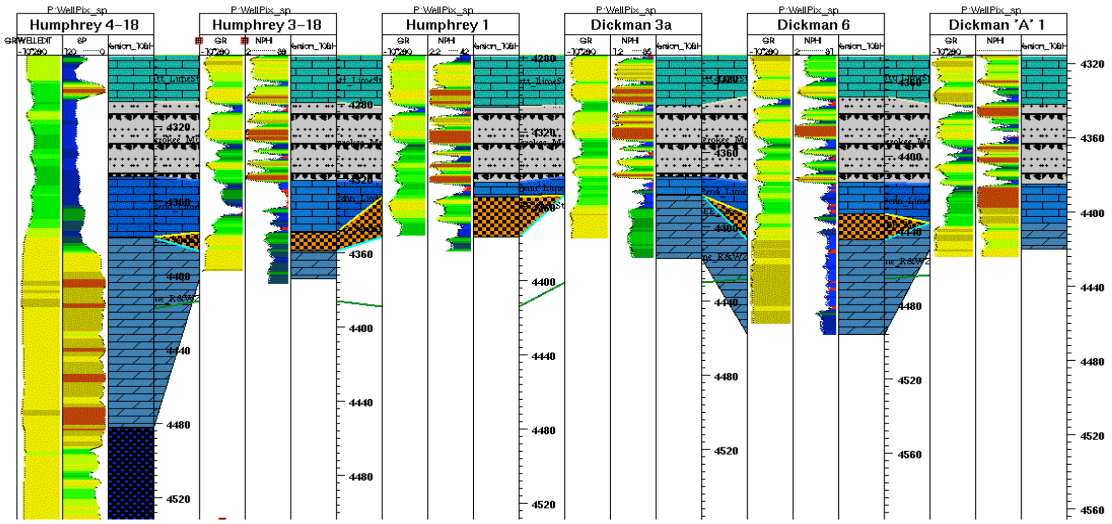


Fig. 4b Stratigraphic section WE1 shown in Fig 1. Note that Cherokee sandstone is missing in wells where the Base_Penn Limestone is thick

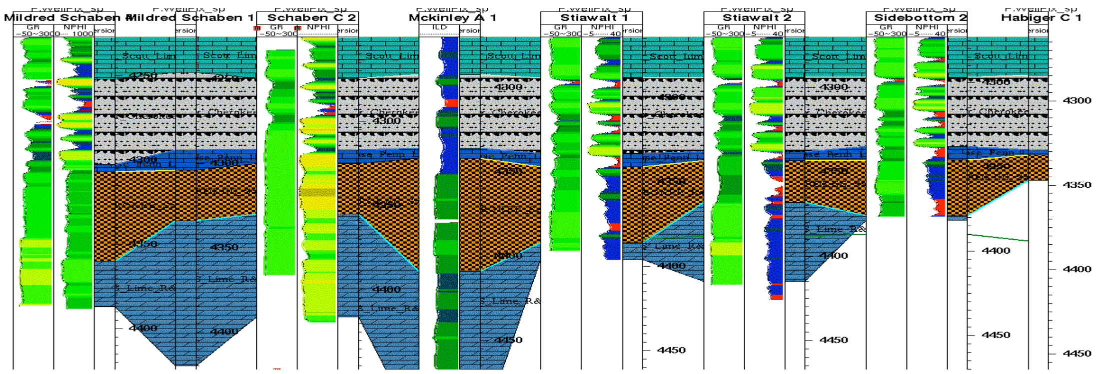


Fig. 4c Stratigraphic section WE3 shown in Fig 1, showing the Cherokee Sandstone is thick where the Base Penn Limestone is thin.

Fig. 5 shows correlation of the Mississippi Unconformity, including the shallower Warsaw Limestone reservoir and partially eroded strata above it within the Meramecian (75-100 ft), and the deeper saline aquifer of Warsaw-Osage dolomite and limestone, (65-70 ft). The Warsaw and Osage litho zones were fully penetrated by 3 wells only, and a partial penetration by one more well. Their log characteristics and lithologic properties are as follows.

Miss Unconformity **(70 wells).** Characterized downward by sharp change in GR from high to low, acoustic slowness from large to small, and density from low to high.

Warsaw Limestone Litho Zone **(4 wells).** Top defined as the Miss. Unconformity and zone may include remains of strata above it within the Meramecian. Mudlog described as semi-granular limestone interlaminated with saccharoidal dolomite, with relatively large amounts of distinctive, gray microfossiliferous chert. Glauconite occurs in the lower part. Insoluble residues of some dolomites contain sponge spicules (Goebel, 1968). Zone is characterized by low and little variable GR (20-40), lower acoustic slowness (55-70), and variable density (2.3-2.55). The Warsaw Limestone was deposited as a shallow marine carbonate ramp, and is a major reservoir in the Dickman Filed (Fig. 2) north of the study area

Osage Limestone and Dolomite Litho Zone**(4 wells).** Consists of dolomite, limestone, chert, and cherty dolomite and limestone beds, characterized by low GR (20-40), slightly higher in acoustic slowness (65-70), and slightly lower density (2.2-2.5) than the overlying Warsaw Limestone. Distinguished from the underlying Gilmore City carbonate by slightly higher GR, much lower density, and much greater acoustic slowness as shown in Fig. 5. The total thickness of the deep saline aquifer between the oil-water contact and the Gilmore City top is more than 100 ft, including lower part of the Warsaw Limestone (30-40 ft) and the Osage dolomite (60-70 ft).

The Osage saline aquifer is a major Mississippian oil producing zone in the Shaben Field, 25 miles southeast of the Dickman field. It occupies a structurally similar position on the southwest flank of the central Kansas uplift. Study of three cores taken from Osage dolomite (Franseen et. al, 1998) recognized three depositional facies: "Sponge Spicule-rich Wacke-Packstone (SWP), the Mudstone-Wackestone (MW), and the Echinoderm Wacke-Pack-Grainstone (EWPG). The SWP facies are important reservoir facies. MW facies and local shale layers that tend to be tight impart a complex vertical heterogeneity. The EWPG facies are extensively dolomitized and are also locally favorable reservoir facies. Post depositional silica cementation and replacement of original lithologies is abundant in all facies types. Both SWP and MV_facies are more indicative of a low energy and restricted setting, transport and reworking of sediment by currents likely generated from tides or storms. The EWPG facies is_mostly characteristic of a shallow subtidal ramp setting with at least intermittent high energy, some likely represents deposition from storm and turbidity currents or from migration of subtidal shoals or banks."

One important implication of the core study for this Osage interval is that original depositional facies and relatively early diagenetic events have a significant influence on present reservoir characteristics. The later fracturing and dissolution from karst and/or structural influences are locally important but may not be the primary control on favorable reservoir conditions, in contrast to the karst-modified reservoir model related the to post-Mississippian Unconformity (Franseen et. al, 1998). Further study of the depositional facies is needed to better define reservoir properties of the deep saline aquifer.

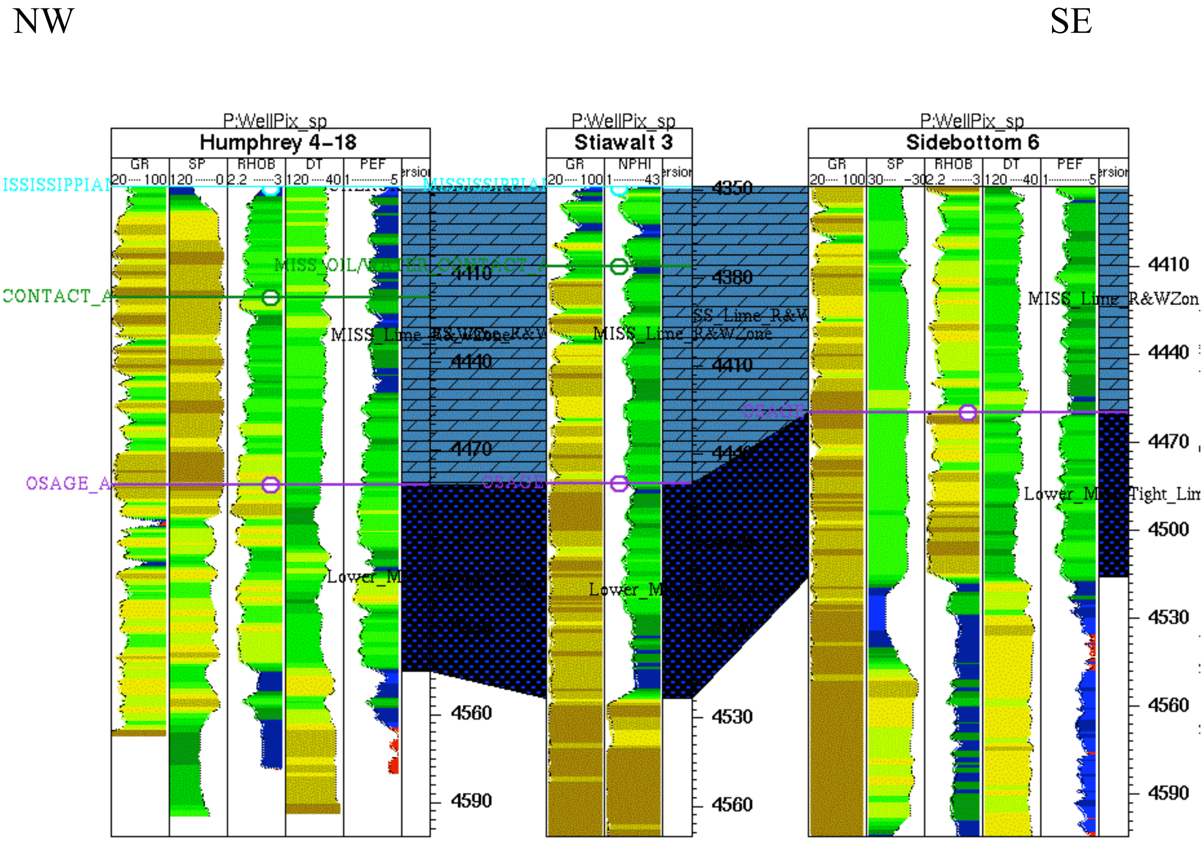


Fig. 5 The stratigraphic “deep Section” as shown in Fig. 1 hung on the Miss. Unconformity.

1.2 Stratigraphic correlation in time domain

Previously interpreted horizons were used as a base for detailed interpretation. The three major horizons (Fort Scott, Miss. Unconformity, and Gilmore) were re-interpreted on every 10th seismic line. Regional NE and NW faults and local small vertical displacements were revised below the Miss. Unconformity for comparison with seismic attributes.

As stated in the 2008 Q1 report, the main challenge for time-depth calibration is the lack of a vertical seismic profile (VSP) and/or sonic checkshots. Synthetics were created using wells with sonic logs (3) and the synthetic trace, logs, and tops, were posted on seismic profiles for visual correlation. An example is shown in Fig. 6a. The seismic track contains 10 field seismic traces on each side of the borehole, along with the computed synthetic. The green curve is the GR log, and the brown one is the sonic (DT). In seismic cross section (Fig. 6b, 6c), the green horizon is picked peak for the Fort Scott Limestone, a trough (blue) for the Miss. Unconformity, and a peak for the Gilmore City carbonate. There is a reasonable time-depth tie at the Dickman1 well (Fig. 6b). Synthetics were also created from two wells slightly outside the 3D seismic area and visually correlated into the seismic volume to judge accuracy of the time-depth correlations.

A different time-depth approach is generation of pseudo-check-shots at well locations that have picked horizons in time and depth. This relates seismic time picks to log tops.

The horizon corresponding to the top of the Fort Scott should probably be shifted up at least 10 ms to the nearest laterally continuous positive peak. Another possible mistie may be the Gilmore City horizon, the correct pick being at least 10 ms shallower than the current position. These observations, together with the possible amount of corrections, will be further discussed in Section 2.1 below. These improved time-depth correlations will improve accuracy of our interpretation and, ultimately, the geologic gridded model to be used in flow simulation.

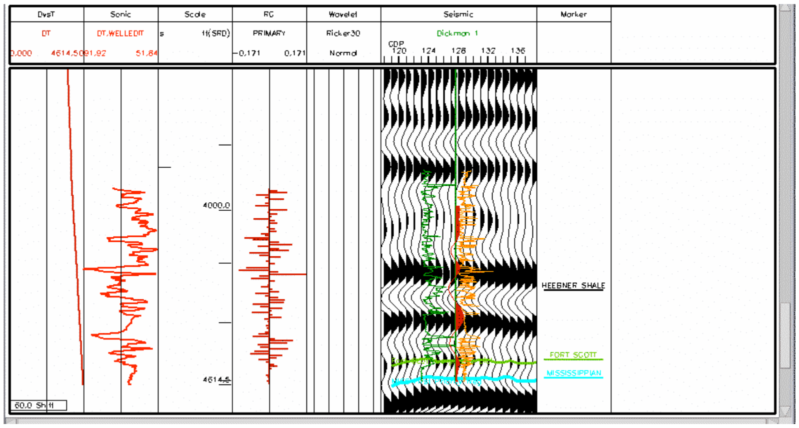


Fig. 6a: Synthetic created from sonic log of the Dickman1 well. In the seismic track, the synthetic is shown as an overlay of field seismic data, along with GR (left) and sonic (right). Note that in the depth track (third from left) there is a shift due to the difference between the seismic processing datum (2600 ft) and the well KB.

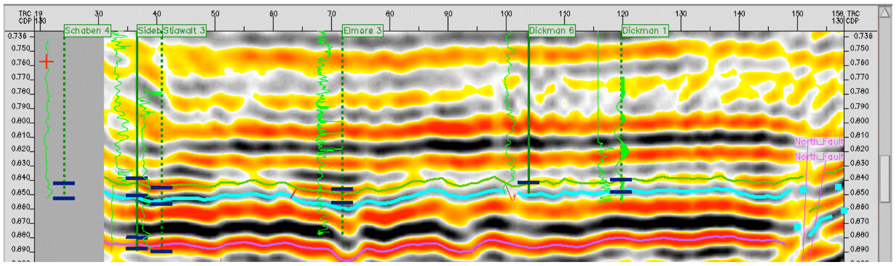


Fig. 6b seismic line across NS3 (Fig. 3c) overlying logs and stratigraphic markers from 5 boreholes to make pseudo-checkshots. The near-vertical pink lines to the right represent the NE fault system. The short near-vertical red lines represent local vertical.

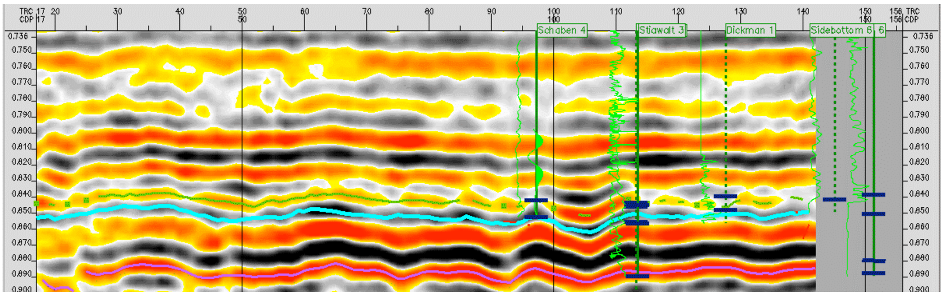


Fig. 6c. Seismic line across WE3 (Fig. 4c) showing Shaben 4 synthetic. Note the well to the right is the Sidebottom 6 with both sonic and density logs, indicating a mistie of seismic and geology markers in the deeper section (Fig.11b).A primary result of such efforts is also shown in Fig. 6b and 6c, showing multiple well data with seismic cross sections for the identification of misties. A comparison of the position of horizon markers shown in Fig. 6 with the geological correlations shown in Figs. 3-5 reveal a discrepancy between the seismic picks and log tops near the Miss. Unconformity. The two-way time through 120-140 ft of mixed clastic and carbonate rock above the unconformity has a two-way time of 10-14 ms, while 150-180 ft of high-velocity carbonate rock below is 24-38 ms . This discrepancy suggests mistie at the Fort Scott and Gilmore City horizons.

1. 3 Mapping of Strata and Reservoirs

Data for mapping are based on depths of stratigraphic markers and the two-way time of three seismic horizons. The results from depth and time domains are compared for further information on subsurface geology and also the validation of corrections for mistie discussed in Section 1.2. Table 1 lists well control that contributed to structure maps shown in Figs. 7-10.

1.3.1 Structure maps

The structure tops for the Fort Scott horizon, Miss. Unconformity and Gilmore City horizon are shown in Fig. 7a-c. The depth maps reflect the true subsurface. While time-structure ideally should reflect the subsurface geometry, it may also be influenced seismic multiples and lateral variations in velocity (sediment in-fills of paleotopography that is different from surrounding older rocks).

A comparison of time and depth structure helped to differentiate true structure from error due to velocity and multiples.. The comparison suggests that the first-order morphology of time-structure reflects the overall subsurface geometry represented by well tops. For instance, time-structure lows in Figs. 7a-c closely follow the real topography lows on the depth maps. Therefore tops in time and in depth represent least two roughly parallel surfaces. The depression-like features seen on the time-structure maps represent, the true geometry with some minor distortions. The difference is shown as a residual map in Fig. 8a by subtracting the seismic top from the geologic top. For Dickman seismic survey, multiples are weak enough relative to the primary reflections to be ignored, as indicated by the autocorrelation of selected traces (Fig. 8b). Therefore the residual map may be used to visualize the contribution from subtle lateral velocity errors.

A comparison of the structure maps from older to younger strata (from Fig. 7c to Fig. 7a) revealed that isolated lows seen on or below the older Gilmore City horizon were inherited, enlarged, or connected laterally in younger strata near the Miss. and finally became a bend feature near youngest Fort. These lows between Gilmore City and Miss. are associated with small vertical displacements as shown in Figs. 6b, but those on Fort Scott are not. Section 2.2 will give some insights into some of these lows.

Name of tops	No. of penetration	Maps using tops
Fort Scott	72	Figs. 7a, 9a
Mississippi Unconformity	69	Figs. 7b, 9a, 9b, 10a
Gilmore City	5	Fig. 9b
Lower Cherokee Sandstone	20	Fig. 10c
Miss Oil Water Contact	51	Fig. 10 a, b

Table 1. Summary of well count used in depth maps. Maps of Fort Scott and Miss. Unconformity have a higher quality than maps using Gilmore City (5 wells only) and Lower Cherokee Sandstone (20).

1.3. 2 Thickness isopach

Based on time and depth picks shown in Fig. 7, thickness isopachs were prepared for the younger strata between Fort Scott and Miss. Unconformity (Fig. 9a) and the older section between Mississippian and Gilmore City (Fig. 9b). Again, the thicknesses in depth represent the true geometry, and the thickness in time may be influenced by geometry, velocity errors, and multiples. Comparison of the thickness maps in time and in depth may help to differentiate these components and their role in forming the time structure map.

For younger strata (Fig. 9a), the lateral variation in time thickness is minor compared to thickness variation in the depth domain. The major thickness centers shown in the time map (red, upper) partially imitate thickness centers in depth map (red, lower) with slight distortions. The thickness centers of the younger strata filled into Miss. lows as shown by the geological sections (Figs. 3 and 4). This is also evident in the Miss. Unconformity map (Fig. 7b), where the older strata s thinner (green, Fig. 9b). This observation further suggests that the general trend of the time thickness reflects the geometry of the strata, while the distortions between thickness in time and in depth are probably more or less related to the lateral variation of rock properties, assuming that the re-adjustment of Fort Scott horizon (as suggested in Section1.2) will not change the general trend significantly.

The thickness trends for older strata below the Miss. Unconformity is different than the younger strata. There are many smaller isolated thickness centers shown by the time-map (red area, Fig. 9b, upper). One of such time center (red area between lines 31-41, CDP 91-111, Fig. 9b, upper) overlays the depth thickness center (red, Fig. 9b, lower). This suggests that some isolated time thickness centers reflect true strata thicknesses. Furthermore, most of these thickness centers coincide with Gilmore City structural lows (red, Fig. 7c, upper), implying the lows are inherited by strata above the Gilmore City.

The above observations and explanations will be further validated in the discussion of seismic curvature and special feature studies (sections 2.1, and 2.2).

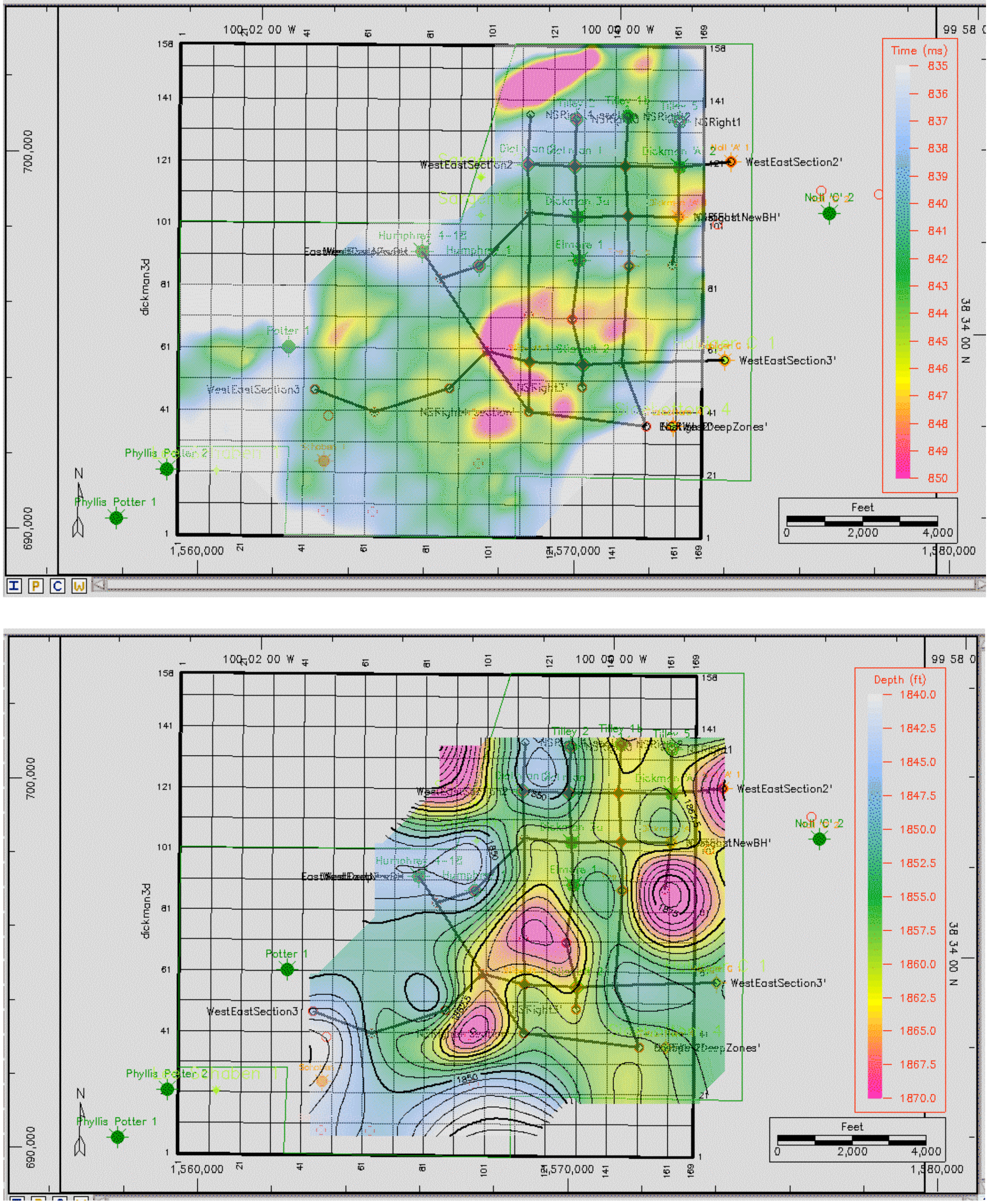


Fig. 7a. Fort Scott maps in two-way time (upper) and in depth (lower). Time window is 835-850 ms (15 ms variation) and depth window is 1840-1870 ft TVDSS (30 ft variation) based on stratigraphic markers. Note in the time map the red area to the far north represents the down-thrown hanging wall of the NE fault. The red bending feature on the lower right of the time map roughly reflects true structural lows shown in the depth map with some distortions.

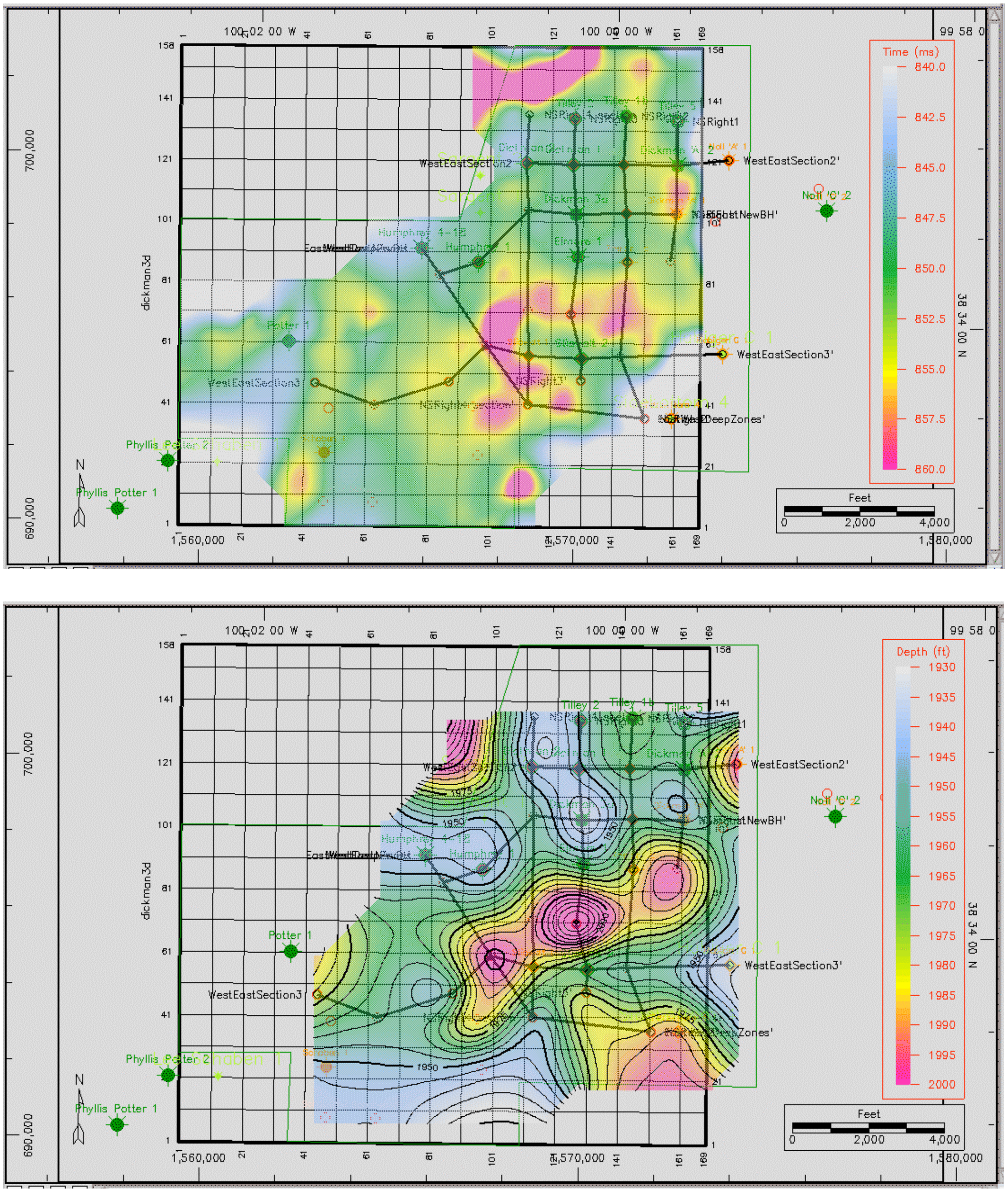


Fig. 7b. Mississippian Unconformity maps in two-way time (upper) and in depth (lower). Time window is 840-860 ms (20 ms variation) and depth window is 1930-2000 ft (70 ft variation). The down-thrown hanging wall of the NE fault is the same as in Fig. 7a. The red bending feature seen on the lower left of the time map (upper) roughly reflects a true structure low shown in the depth map (lower) with more distortions than Fort Scott.

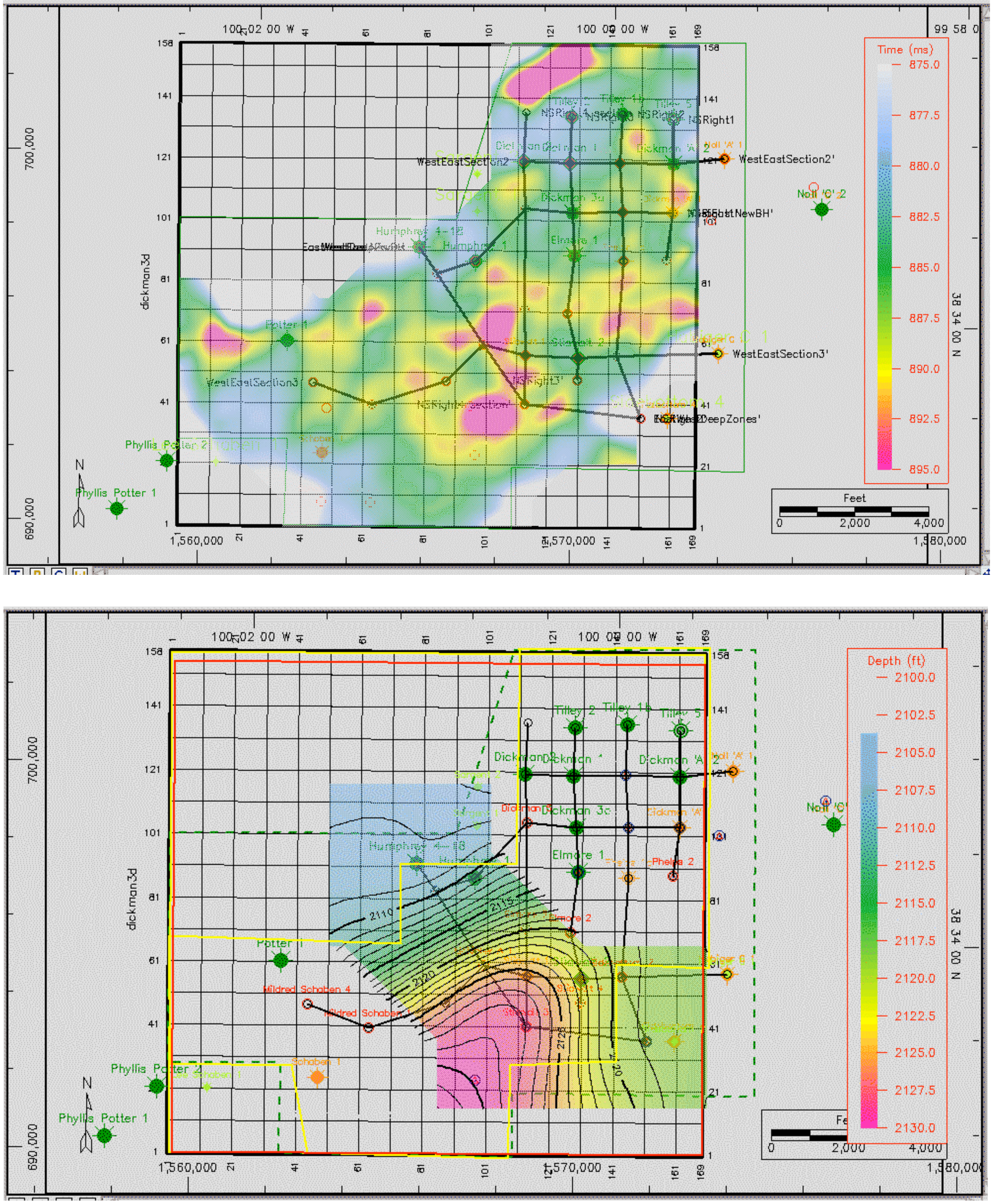


Fig. 7c. Gilmore City in two-way time (upper) and in depth (lower). The time window is from 875 -895 ms (20 ms variation) and the depth window is from 2100-2130 ft (due to the limited well penetration). The red areas to the far north and southwest of the time map are the down-thrown hanging wall of the NE fault system. On the time map there are a lot isolated lows of 1000-1500 ft in diameter (red), and at least one is overlapping the stratigraphic "low" shown in the depth map. These are likely due to sparse well control (5 wells contributing).

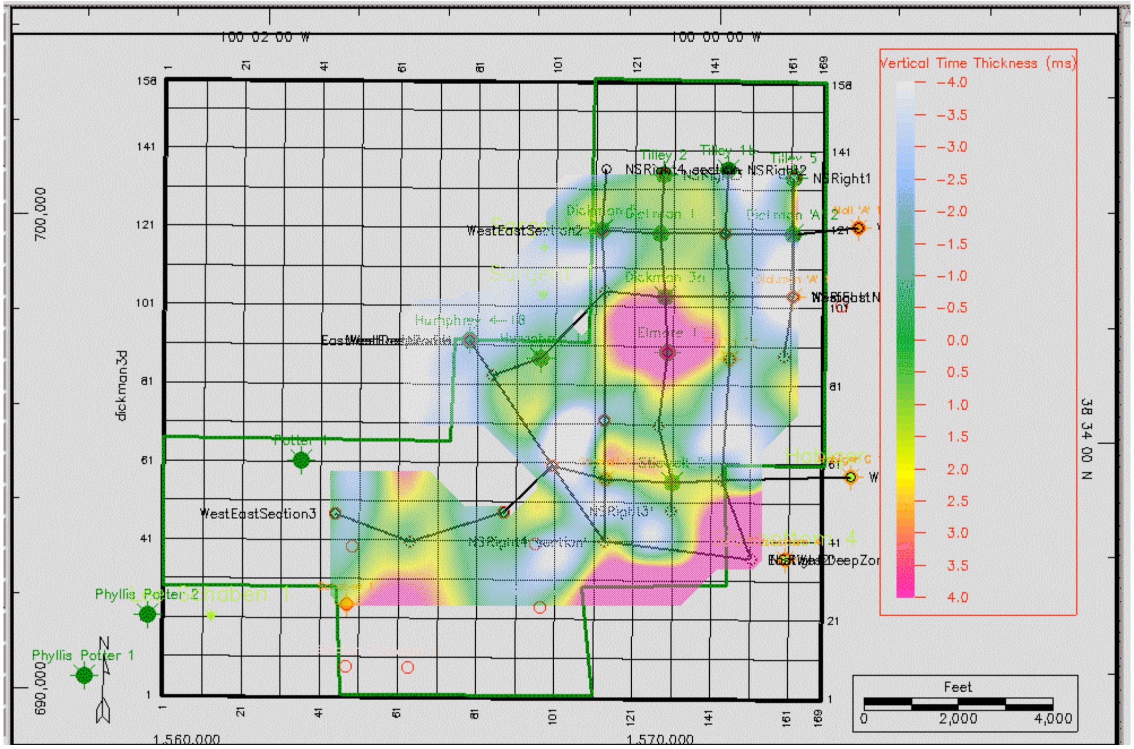


Fig. 8a. Residual time map for Miss. Unconformity, showing the deviation between the seismic top of the Mississippi unconformity (Fig. 7b, upper) and time pick of 19 markers extracted from the depth map (Fig. 7b, lower).

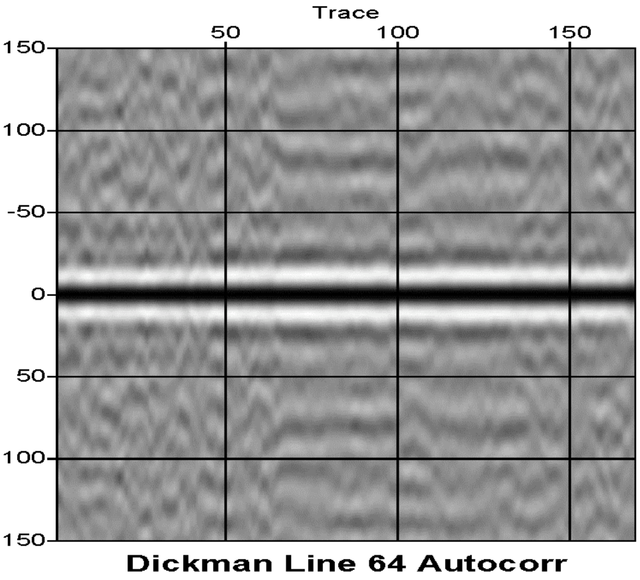


Fig. 8b. Autocorrelation for all traces on line 64. Vertical axis is autocorrelation lag and horizontal axis is trace number. The strong band at zero lag is present for any time series since this is the sum of squared amplitudes. If multiples are present in the data they would show up as strong features on the autocorrelation function away from zero lag. Some weak banding that may indicate weak interbed multiples are insignificant.

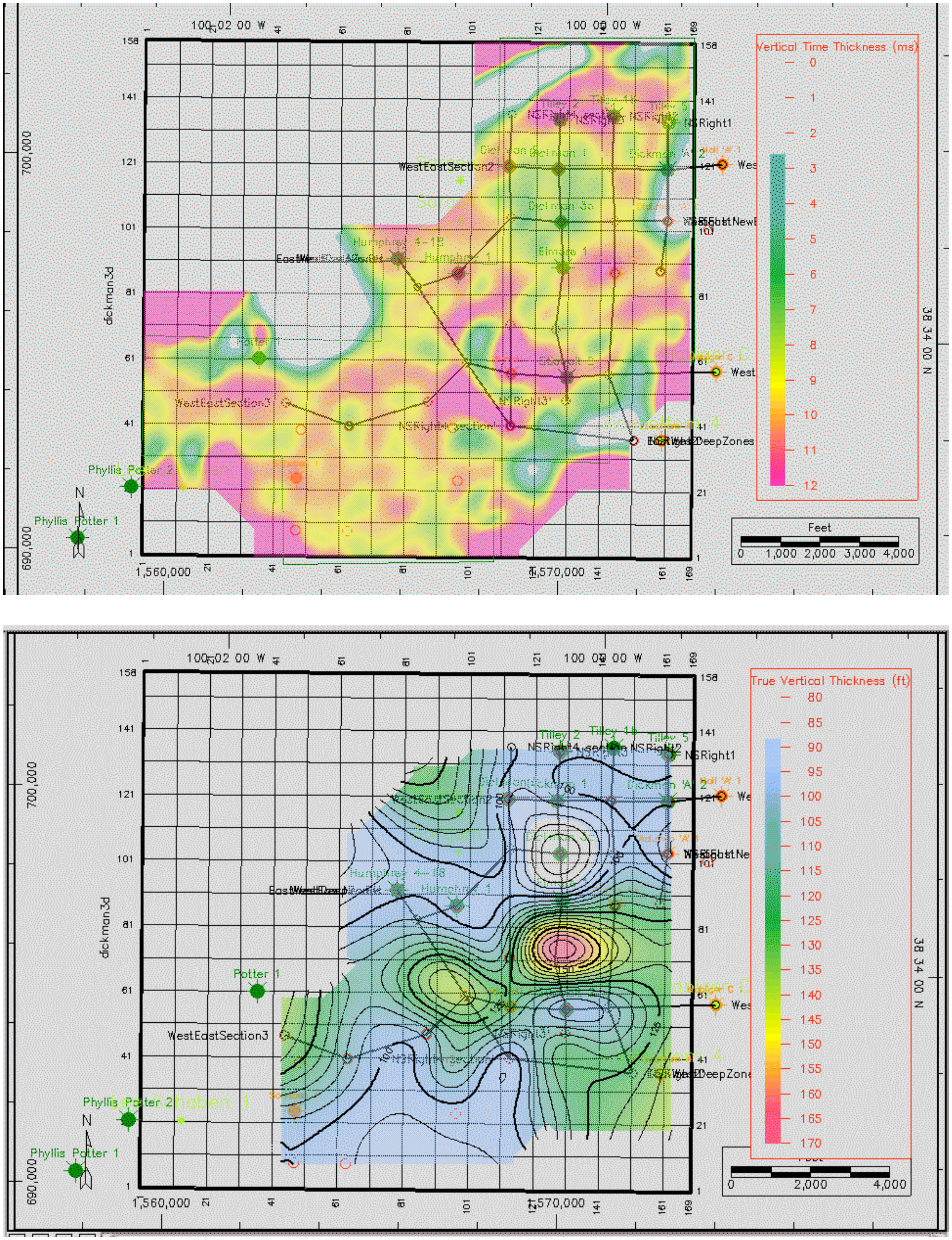


Fig. 9a Fort Scott time and depth isopachs. Red indicates a greater thickness. In the time map, red areas to the far north and northwest of the area are the hanging wall of the NE fault system.

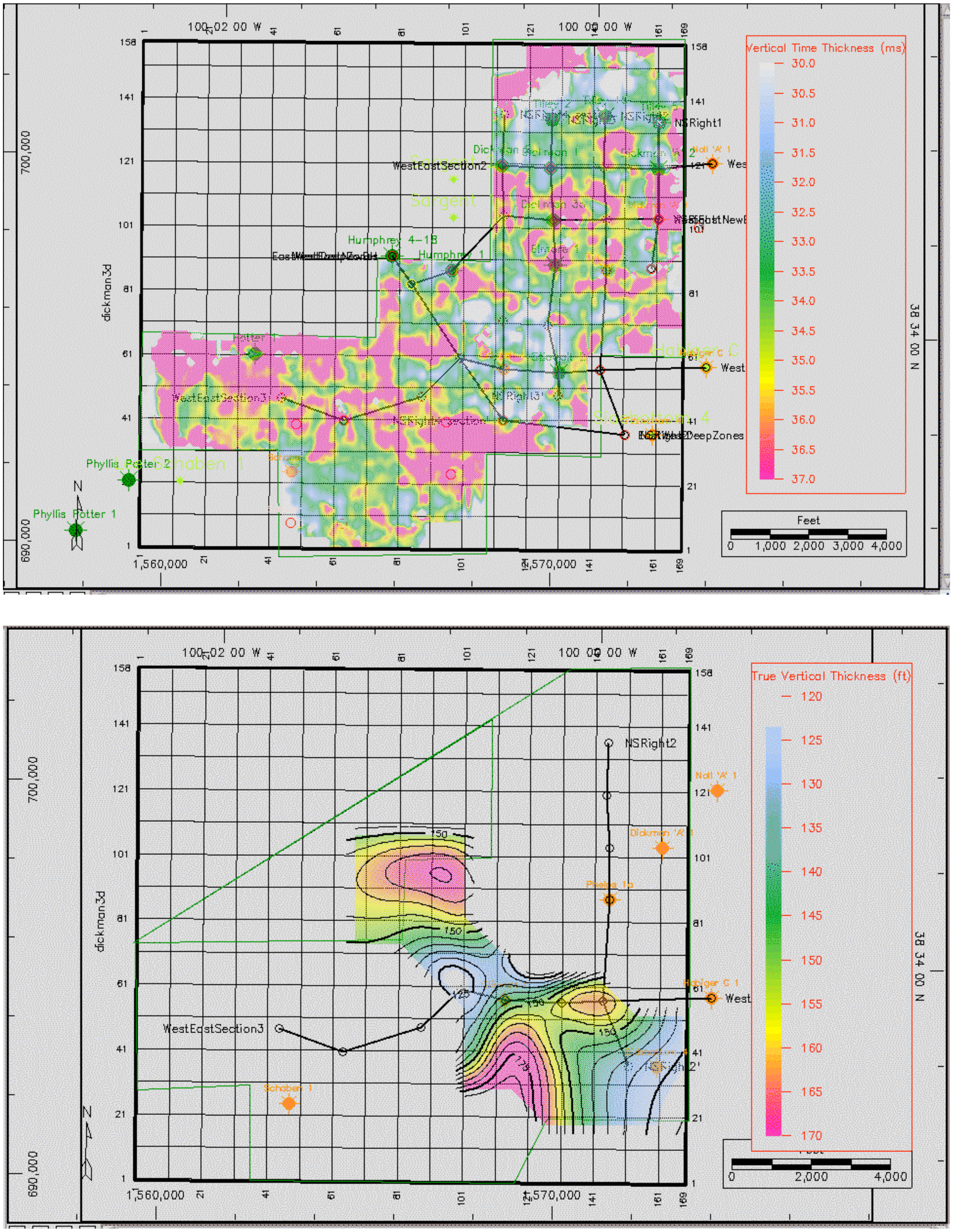


Fig. 9b. Thickness isopach of strata between the Miss. Unconformity to Gilmore City time and depth isopachs. Red indicates a greater thickness.

1. 4. Reservoir geometry mapping

Two depth isopachs for the Mississippian and the Lower Cherokee oil producing zones (Fig. 10) were made to assess the volume of reservoirs that may serve as CO2 compartments. Time isopachs are not available because the reservoir thickness is below seismic resolution. The oil-water contact (OWC) appears as a southwest tilting trend-surface assuming a single, best-fit OWC for the Dickman Field. However, the raw data deviates locally 5-7 ft above or below the trend surface (mainly in the south east part of the survey). This could be interpreted as representing more than one oil-water contact.

The Miss. reservoir isopach is shown in Fig. 10a. The thick producing areas (red, Fig. 10a) partially overlay on one area with positive residual values (Fig. 8a) and the area with zero thickness isopach (blank area in the center, Fig. 10a) seems to partially overlay on one area of negative residual values (blue-white, lower middle, Fig. 8a, faster area). This suggests that features in the residual map may be related to production. This is a tentative conclusion pending re-interpretation based on refined time-depth correlations. This is one of the tasks for the Q3 plan.

Fig. 10b shows a depth isopach for a shallower oil reservoir (Cherokee clastics and Miss carbonate rocks). More stratigraphic markers are needed for a precise reservoir distribution of this producing zone. The thickness of Lower Cherokee conglomerate and breccias is mapped as shown in Fig. 10c. Compared with the Miss. reservoir distribution in Fig. 10b, and referring to the geological sections (Figs. 3-5), it is clear that the Cherokee conglomerate and breccias filled in low areas (see Fig. 10c) between palaeo-highs on the Miss. Unconformity (Fig. 10c, green area, and Fig. 10b green and red area). Because of lateral variation in reservoir properties, a large area is non-producing despite being above the OWC and having thickness greater than10 ft). Furthermore, this non-producing area partially overlays an area with negative Miss. residual values (Fig. 8a, green to white, faster).

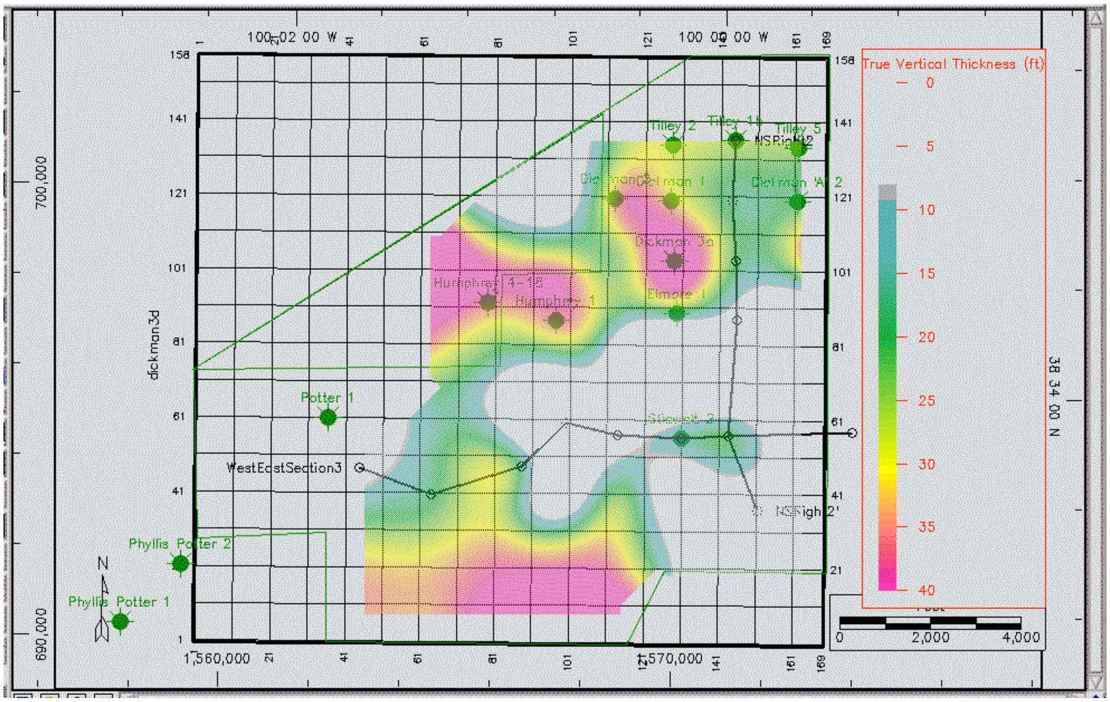


Fig. 10a. Miss. reservoir isopach. Oil producing wells from this zone are posted as large solid green dots.

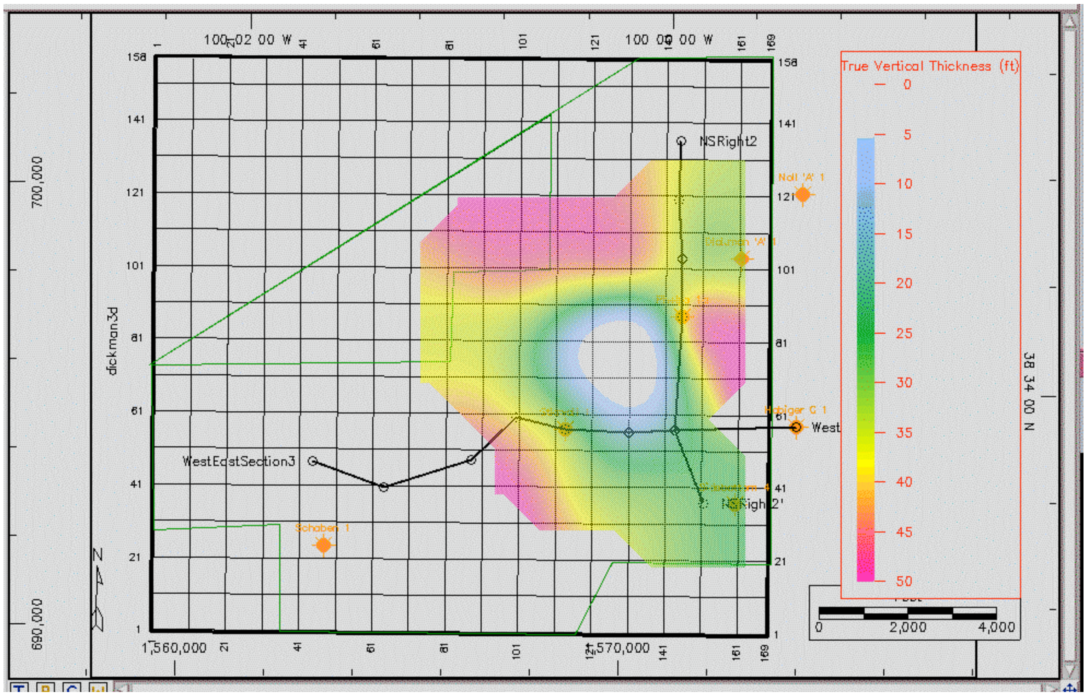


Fig. 10b. Isopach of Lower-Cherokee and Miss. reservoir. Oil producing wells from this interval are posted as larger solid brown dots.

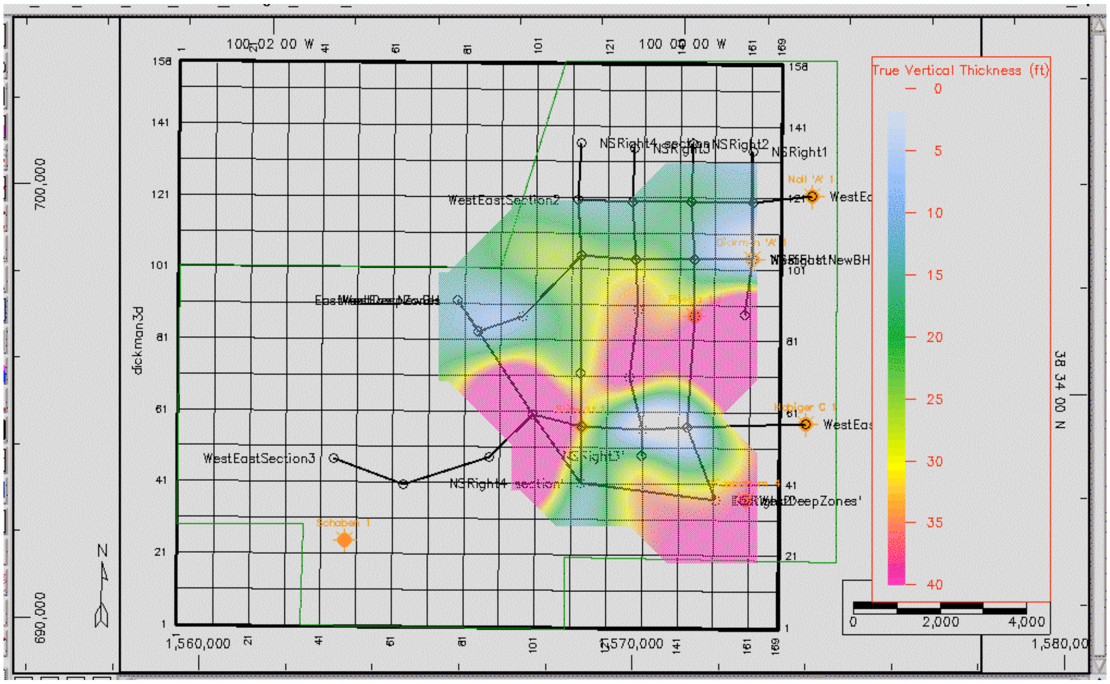


Fig. 10c Isopach of Lower Cherokee conglomerate and breccias.

2. Seismic Attribute Mapping and Reservoir Property Study

The third phase of the Dickman Field study in the workflow presented in the Q1 report involves relating volumetric attributes to reservoir properties. The computation of negative and positive curvature volumes was completed in Q1 and a time slice of the negative curvature computation was included in Q1 report. This section presents further geological interpretation of features revealed by curvature slice maps. A lithology computation diagram for deep saline aquifers using Petra software was done in Q1. This section presents results from reservoir property computation on the shallower Miss. producing zone using both Petra and GeoFrame PetroViewPlus.

2.1 Seismic attribute mapping

The main challenge for the seismic attribute study is seismic resolution relative to thin geologic targets. Efforts were made to compensate for this scaling issue. Time slices are focused on the time window corresponding to the geological targets based on information obtained from the log and lithologic study (Section 1), and cross-referencing with conventional time and horizon slices.

The attribute study included amplitude time slices from the full-stack migrated volume, horizon slices from flattened amplitude volumes (Fort Scott, Miss. Unconformity, and Gilmore City), and time slices from the curvature attribute volume. The attribute computation used a 10 ms window. An advantage of a Miss.-flattened volume is to compensate for problems caused by possible misties of seismic horizons (Section 1.2), and slices within a 25 ms of the Miss. will focus on the two CO2 sequestration targets regardless of future readjustments of horizons above and below. Fig. 11a shows a profile of the flattened amplitude volume. The lower part is similar to the geological cross sections in Fig. 5, which include the shallower reservoirs above and below the zero time line and the deeper saline aquifer. The Gilmore City-centered volume is used as a cross-reference, since the former volume is hung on an unconformity instead of a real horizon.

The horizon-centered volume shown in Fig. 11a further visualizes the possible adjustments for mistie discussed in Section 1.2. The horizon corresponding to the Fort Scott Limestone probably needs a 10-12 ms up-shift and so does the Gilmore City horizon (Fig. 11a). A quantitative estimate of the correction for the mistie from synthetics at well Sidebottom 6 (Fig. 11b) further validated the observation. The Fort Scott and Gilmore City horizons should be picked around 24 and 27 ms above and below the Miss. Unconformity at the well location (825 ms and 866 ms), respectively. This 24-27 ms time window represents roughly 130 ft. Since the well Sidebottom6 is very likely on a structural high area (Fig. 7), the absolute time picks for the horizons in other wells varies according to their structure locations. The time picks relative to the horizon zero time, however, is more predictable at different locations, as shown in Fig. 11a, therefore can be used as a scale to map directly the shallow CO2 sequestration targets in time, which is planned for Q3.

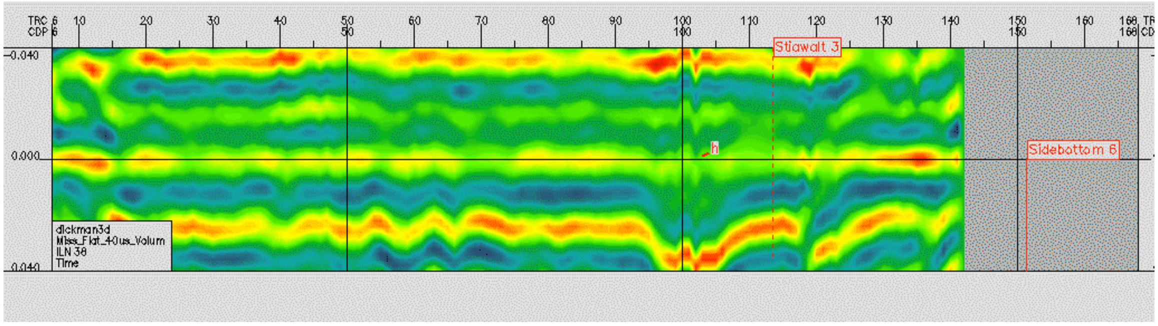


Fig. 11a. West–-to-East section through the amplitude volume flattened on the Miss. Unconformity.

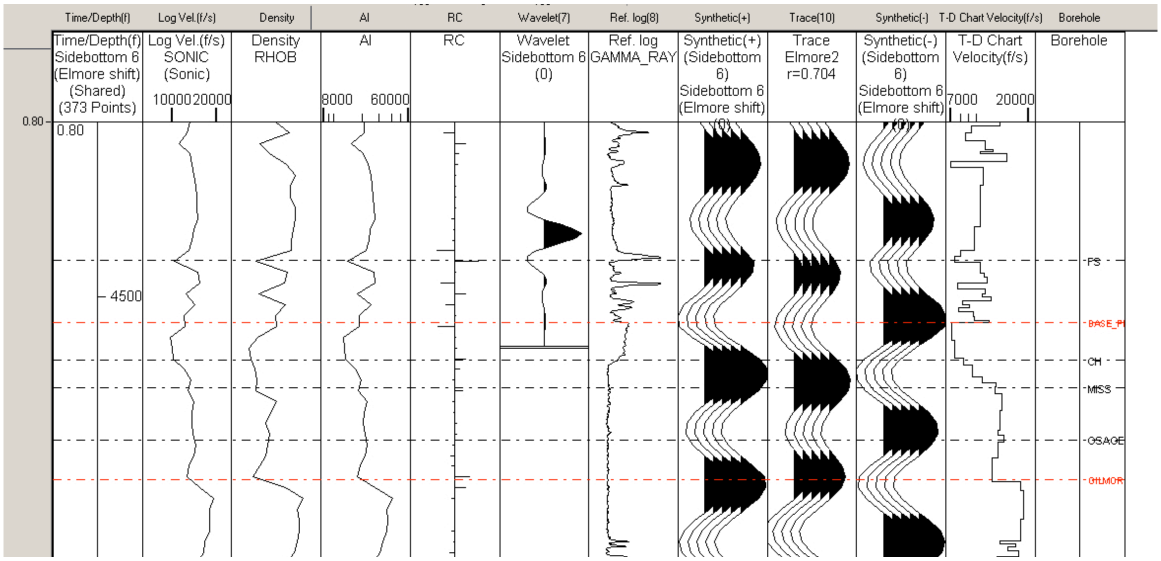


Fig. 11b. A quantitative estimate of the correction for the mistie from synthetics at well Sidebottom 6 near the east boundary of the study area (Figs. 5c and 11a). Fort Scott and Gilmore City horizons should be picked around 25 ms above and below the Miss. Unconformity, respectively.

A comparison of seismic negative curvature with time and horizon slices is shown in Fig. 12. The goal is to quantitatively relate the seismic attribute to reservoir geometry and properties for the the two CO2 sequestration targets. Like the amplitude, the geometry of the reflector can also be affected by both geometry and rock property components, therefore its measurements, such as the negative curvature, may also reflect lateral variations in lithology, structure, velocity, and differential compaction.

Fort Scott amplitude and curvature time slices at 840 ms are shown in Fig. 12a (upper left and upper right), as well as the horizon amplitude slice (lower left). In time slices a bend feature with negative amplitude (yellow) overlays areas with low values of negative curvature (dark brown). In the horizon slice, the channel bend feature is shown by positive amplitude (blue) as originally picked. The bend feature is likely a part of a generally north-south oriented channel with sandy channel fills of a convex geometry (upper left, Fig. 12a). The west and northwest edges of the channel are shown as positive curvature (upper right, Fig. 12a). Note that a large area in the middle of the bend feature corresponds to thin Fort Scott (blue area, Fig.9a, upper), a result needing further investigation. All above observations suggest that the current Fort Scott pick is actually within the Cherokee Group The bend feature starts to fade out 8 ms above the datum (Fig.12a, lower right), possibly denoting passage upward into the unchanneled Fort Scott Limestone.

Fig. 12b shows Mississippian amplitude and curvature time slices (848 ms), and a horizon slice 6 ms above the Miss. Unconformity corresponding to the top of the shallow, cherty conglomerate CO2 sequestration target. The same bend feature is clear on the amplitude and horizon on time, corresponding mainly to areas with low negative curvature (Fig. 12b, upper right) and thin Miss. strata (blue-white area, Fig. 9b, upper). Except this channel feature, other areas with low negative curvature correspond to areas of thick Mississippian (blue-white color, Fig. 9 upper), possibly reflecting un-eroded Miss. highs adjacent to sediment-filled lows.

Fig. 12c shows 848 ms amplitude and curvature time slices, as well as a horizon amplitude slice 4 ms below the Miss. Unconformity corresponding to the shallow carbonate CO2 sequestration target. The channel feature is less evident at this level. The horizon slice shows a landscape with no prevailing drainage systems, but there are isolated low patches. This trend is seen clearly in Fig. 12d containing amplitude and attribute time slices 864 ms, and a horizon amplitude slice within the deep saline aquifer (22 ms above Gilmore City). Low negative curvature values overlap some Miss.-Gilmore thicks (Fig 9b) and Gilmore City lows (Fig. 7c), as well as low-amplitude features on the horizon slice (Fig. 12d, lower left and lower right).

A comparison of the amplitude data from deeper to shallower (Fig. 12d-a) suggests that isolated lows may be karsts features developed at or above the Gilmore City horizon influencing later sedimentation. These were enlarged and/or connected by the Mississippian unconformity, to become a part of a channel in a major N-S drainage system through the Cherokee sandstone and younger strata.

The curvature attribute slices from deeper to shallower (Fig. 12d to a) reveal a relatively constant curvature pattern throughout the entire geological target window (830-880 us). This may reflect inherited karst landscapes upward from Gilmore City time, or perhaps be caused by the 10 ms window length used in computing the attribute. New computations are planned for Q3 using a sample interval at 2 ms.

Previous studies (Nissen et. al., in press) and the 2008 Q1 report also suggested that the negative curvature may be related to the regional fault/fracture system. To validate this interpretation, all currently interpreted regional faults or local faults with visible vertical displacements seen between Miss. and Gilmore City horizons are posted on the same attribute slice at 864 ms (Fig. 13). Clearly the two areas with low negative curvature at the northwest boundary of the study area are related to the NE fault system, reflecting paleo-highs on the up-thrown foot wall. To complete the fault interpretation and overlay the fault map with the curvature attribute will be one of the Q3 tasks.

Given the very small time thickness of the two CO2 sequestration targets (20-30 ms in Fig. 11), the horizon-centered attribute computation planned for Q3 will help to improve the focus, and to fine-tune the volumetric attribute study in quantifying the thickness, porosity, permeability and lateral continuity.

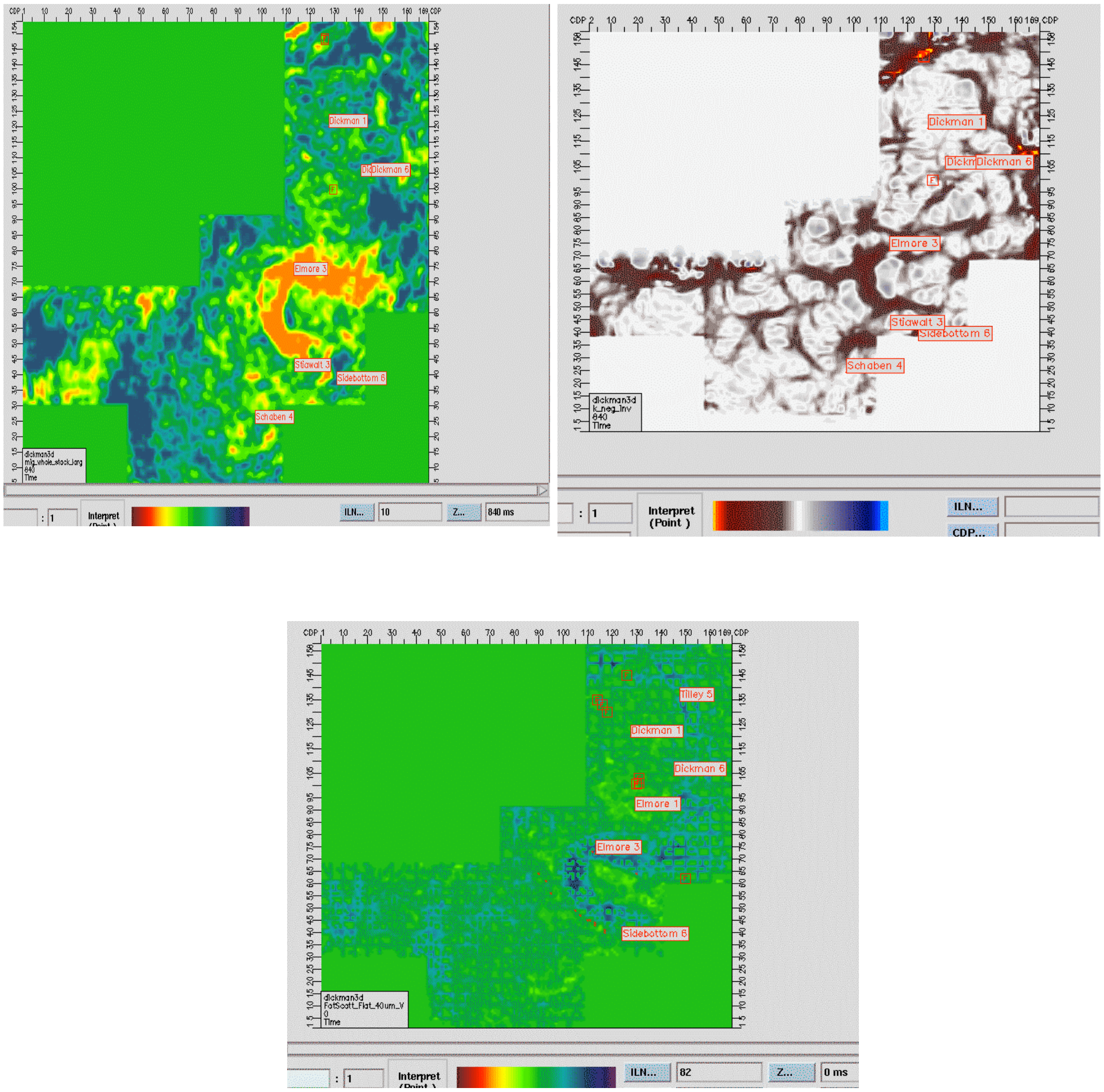


Fig. 12a: Fort Scott amplitude (upper left) and negative curvature (upper right) time slices at 840 ms, and horizon amplitude slice. Color bars indicate negative or low values (red) and positive or high values in blue.

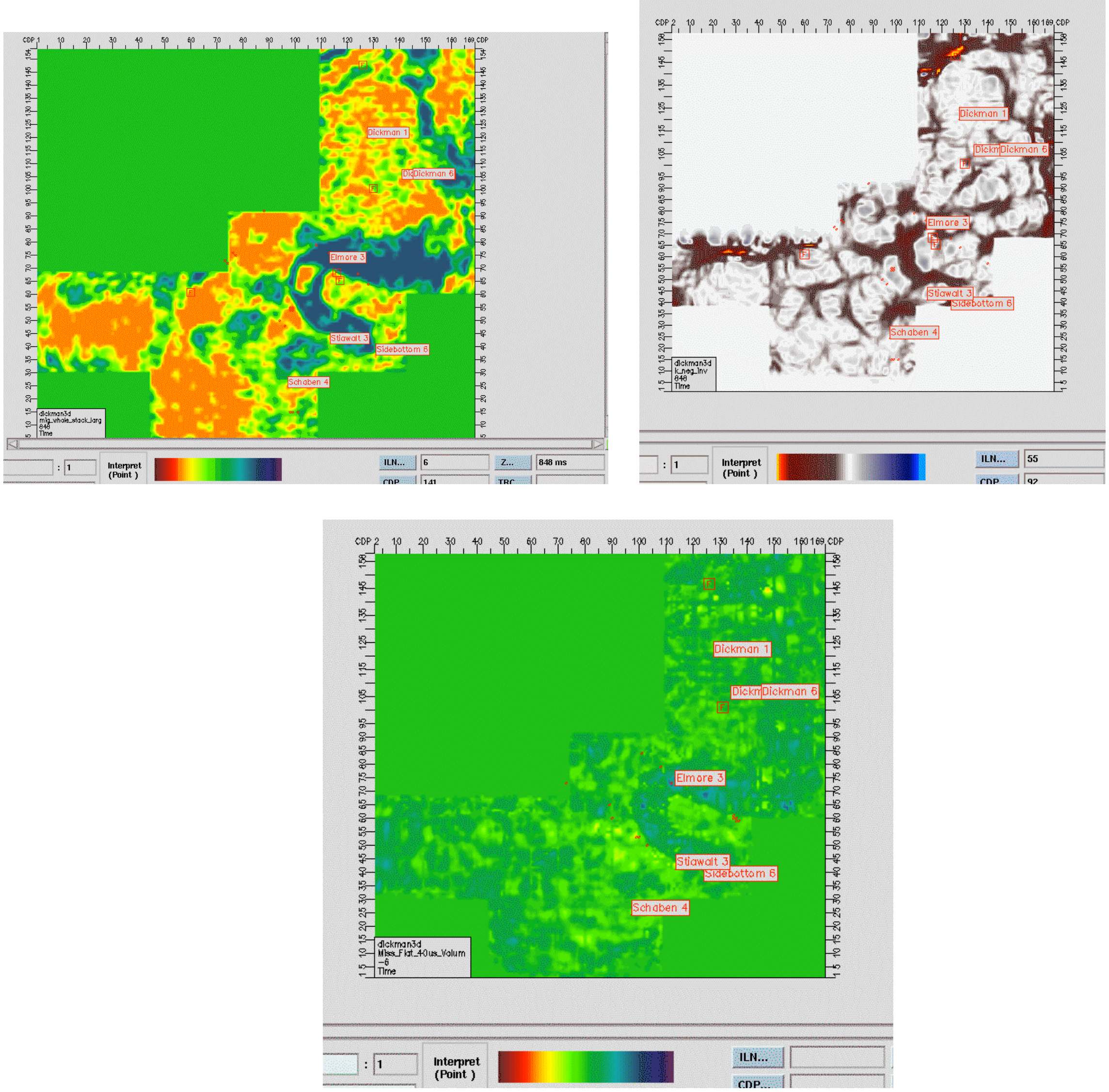


Fig. 12b. Miss. Unconformity amplitude and curvature time slices (upper left and right), and horizon slice is 6 ms above the horizon (lower) roughly corresponding to the top of the shallower cherty conglomerate and breccia CO2 sequestration target.

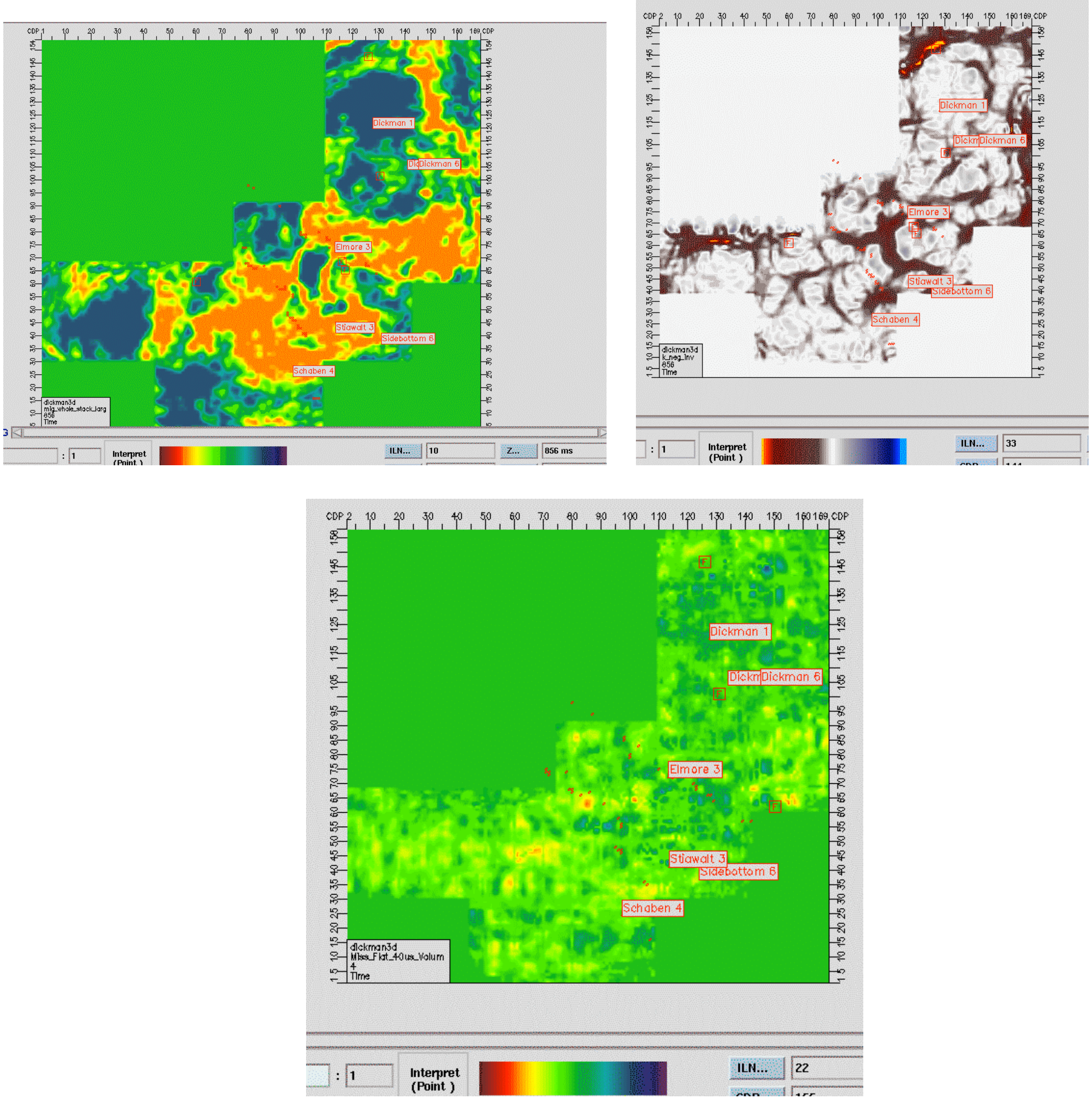


Fig. 12c. Amplitude time slice at 856 us (upper left), negative curvature slice at 856 us (upper right), and horizon slice 4 ms below the Miss. Horizon (lower). The horizon slice roughly corresponds to the carbonate part of the shallower CO2 sequestration target.

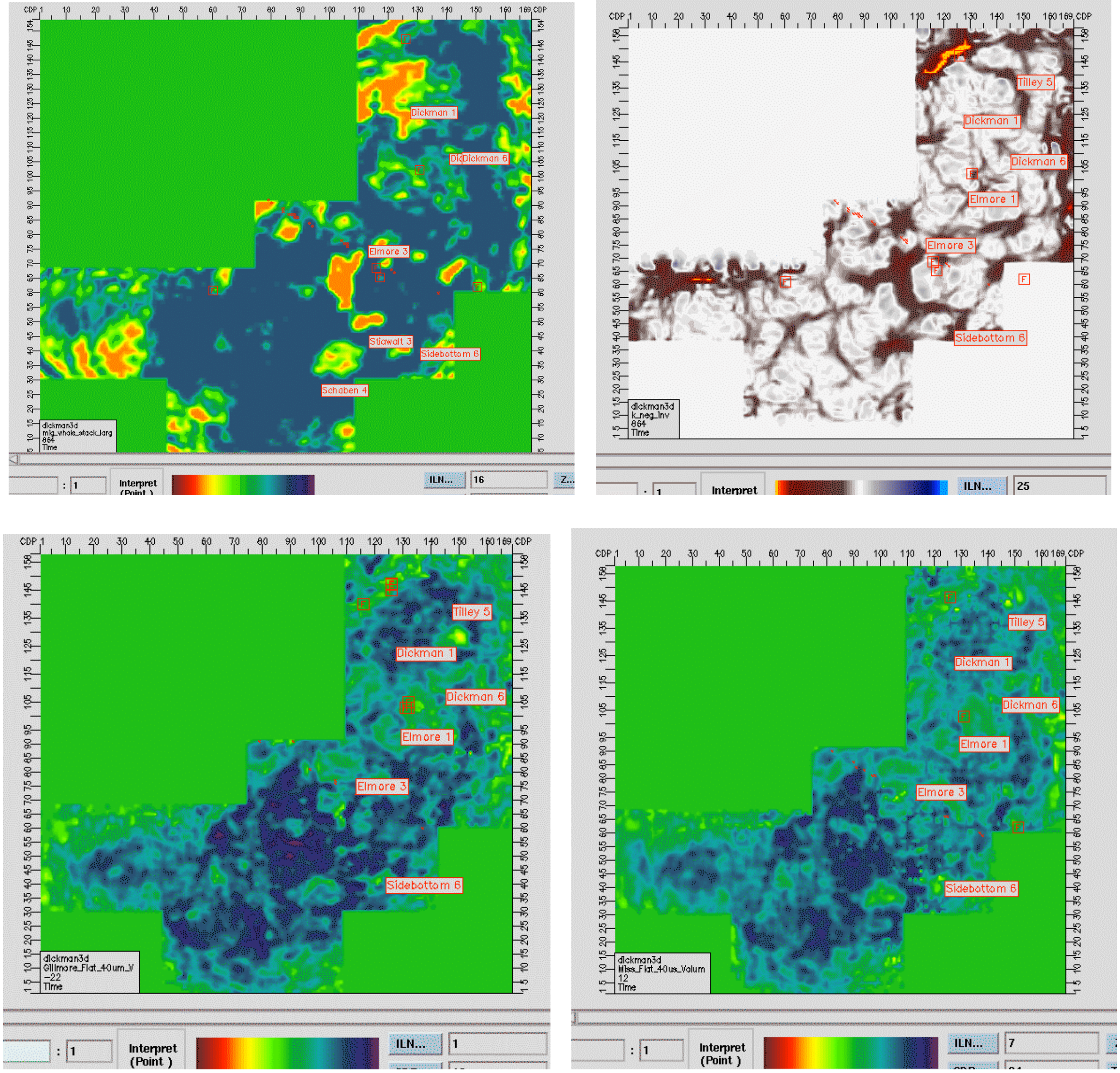


Fig. 12d. Amplitude time slice at 864 ms (upper left), K-negative time slice at 864 ms (upper right). The horizon slice at 12 ms below Miss. Unconformity (lower left) and horizon slice at 22 ms above the Gilmore City (lower right) are at about the same depth within the saline aquifer.

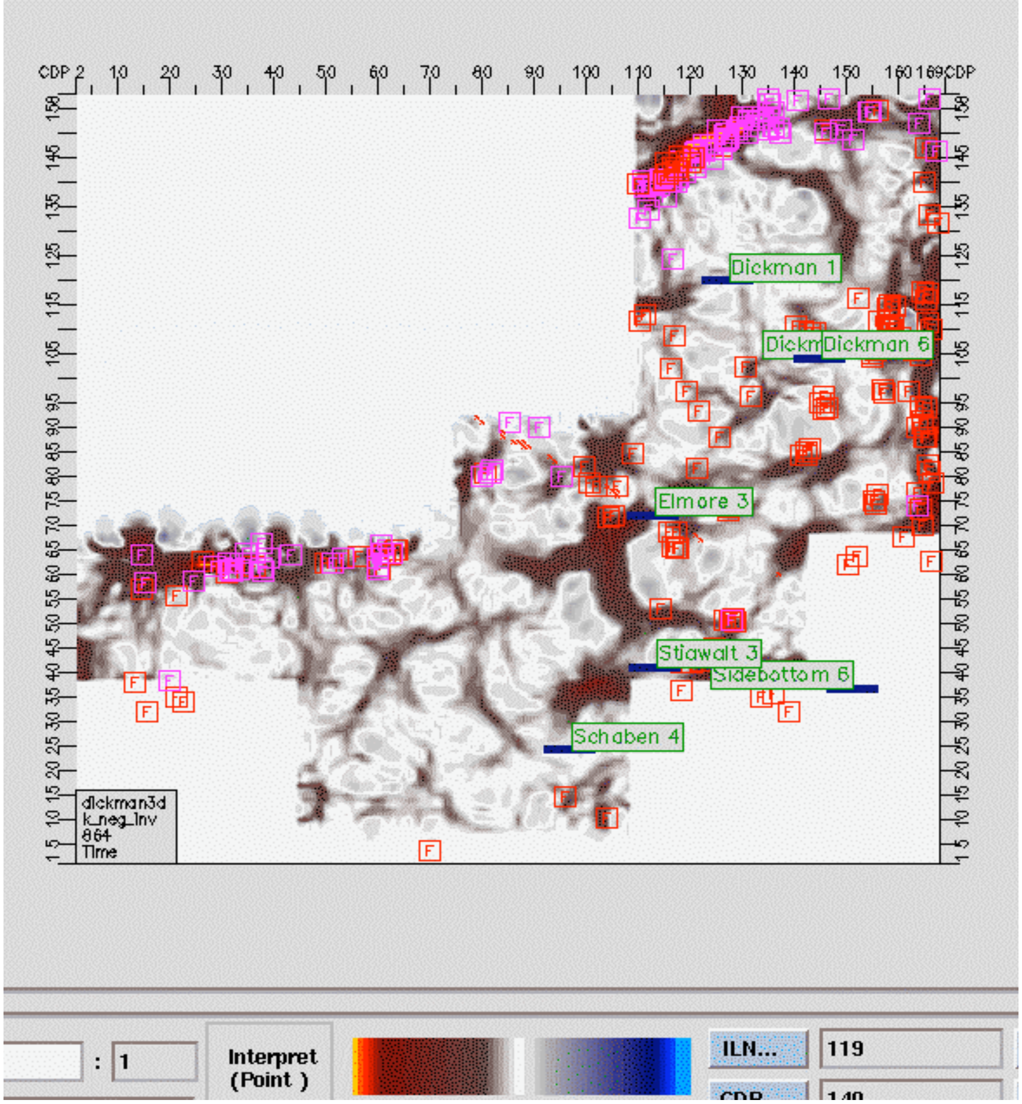


Fig. 13. Time slice (864 ms) from the negative curvature volume showing currently interpreted faults or vertical displacements between Miss and Gilmore City (pink/red squares). The areas to the north and the northwest of the survey with low values are related to the major NE fault seen in Fig. 7. Some small faults oriented NW/NNW and NE (not directly related to the NE faults) also overlays the low negative curvature area. A fault trace map with all fault interpretation is planned for Q3.

2.2 Study of special features

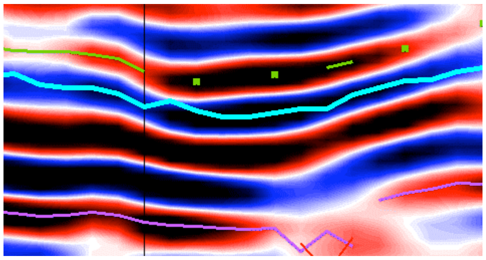
The carbonate sequences between the Miss Unconformity and Gilmore City contain many isolated lows(Fig. 7c) 1000-1500 ft in diameter which are connected and/or enlarged at the Miss. Unconformity (Fig. 7b). They are different from the channel bend (Fig. 12a) seen near the Fort Scott horizon. In cross section view, they appear to be associated with vertical displacements on one or both sides penetrating several reflectors, while the channel feature displays laterally discontinuous lenticular reflectors. Fig. 14a-d gives several samples of these special features, and Fig. 14e is a reference map of seismic section orientations overlaid on the curvature attribute map.

Fig.14a is a section cut through the channel (Fig. 12a) showing laterally discontinuous, lenticular features above the Miss Unconformity. The edges of these features are not associated with vertical displacements. On the positive curvature 836 ms time slice, the edge of the channel bend corresponds to high values. The channel fills may correspond to the distribution of cherty conglomerate and breccias (Fig. 10c) developed in Miss Unconformity depressions during early stages of marine transgression.

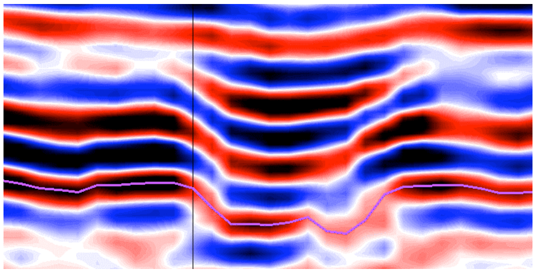
Figs. 14b, c and d are sections across several major Gilmore City lows. They are associated with vertical displacements on one or both sides, mostly affecting section from Gilmore City to below the Miss. Unconformity. By cutting these features in different directions, the sides of the lows with maximum vertical displacements were defined. The edges of the lows are associated with high positive curvature showing vertical displacements (Fig. 14e). These features are possibly Gilmore City isolated sinkholes (see Fig. 7c) and/or sinkholes connected by collapsed karst features with dissolution residuals as seen on the Miss. horizon (Fig. 7b). Both may be accompanied by slump/collapse around their margins and breccia in-fill. Early differential compaction between silicified areas and surrounding matrix during burial can result in further brittle fracturing and soft-sediment deformation of surrounding area. A Shaben Field core study revealed that "brecciation, fracturing and sediment in-fills are ubiquitous throughout the Osagian on macroscopic and microscopic scales, sometimes in several generations. Other field observations also suggested that sinkholes on the Mississippian Unconformity may be controlled by the location of old sinkholes, the areas more susceptible to re-current collapses and slumping" (Pierce and Courtier 1937).

These lows and their vertical displacements may not directly belong to the regional NE or NW fault framework but may be genetically related to it. At a macro scale, karst begins with sinkhole development at major fracture/fault intersections , where fractured carbonates were weakened to have more surface exposed to ground water. The distribution of sinkholes therefore is likely controlled by the regional faulting/fracturing framework. When pre-existing Gilmore City faults/fractures re-activated after Miss. deposition, they could control the distribution of sinkholes in strata. An overlay of a fault map interpreted from seismic on the curvature attribute map planned in Q3 will help to confirm this interpretation.

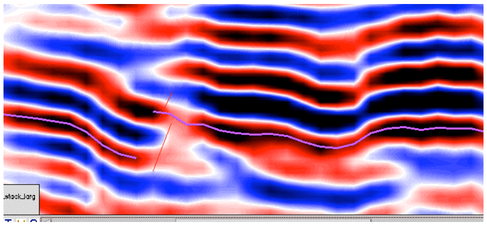
Fig. 14. Special features



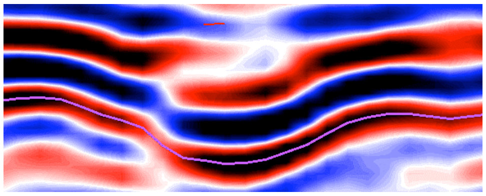
a. EW line across the bend feature seen in Fig. 12a (at L70), showing two super-imposed lenses above the Miss. Unconformity (blue).



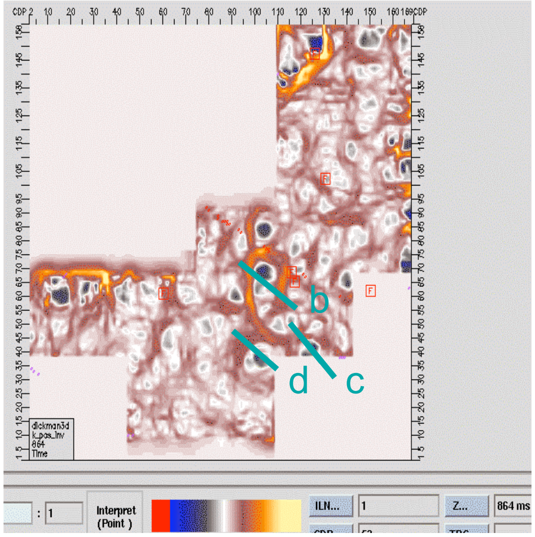
b. NWW trace across the L70C105 low. Possible vertical displacements at both sides of the low related to NE faulting.



c. NW trace across the low at L41C121. Its southeast side shows vertical displacement cutting Gilmore City horizon, and parallel to regional NE fault. Up-thrown foot wall (right) has high value on positive curvature slice (Fig. 14e).



d. NW trace across the largest low at L38C100. The northwest edge (left) of it shows vertical displacements above the Gilmore City horizon within Miss. strata. The displacement may be related to the NE fault. The north edge of the low shows positive curvature (e).



e. Positive curvature slice at 864 ms: high positive curvature areas (yellow-brown) around the relative flat areas (white and black) of the lows shown in Fig. 14, b, c and d, indicating slump scars on one side or sides of sinkholes. The areas to the north and west of the survey with positive curvature are the up-thrown foot walls along the major NE fault.

2.3 Reservoir property study

The major challenge for the rock property study is the lack of a complete log set for computation input as stated in Q1 report. A new well (Humphrey 4-18) located on the northwest border of the studied area was completed in March 2008 and included a complete log set. Data from this new well is used as input for an initial rock property computation in GeoFrame. Fig. 15 shows the cross plots for the lithology and porosity study of the new borehole from Petra. Fig. 16 shows the computed porosity log, water saturation, and the resulting pay zone. These computations need more investigation and the task is planned for Q3. When the results are validated with the field data, the same computation will be extended to several wells in the study area to obtain enough data for 3D reservoir property modeling. Properties of the two reservoirs will be computed using sand/shale and carbonate models. The resulting property maps will be used to validate predictions from quantitative seismic interpretation including attribute maps. This will be a task in Q3.

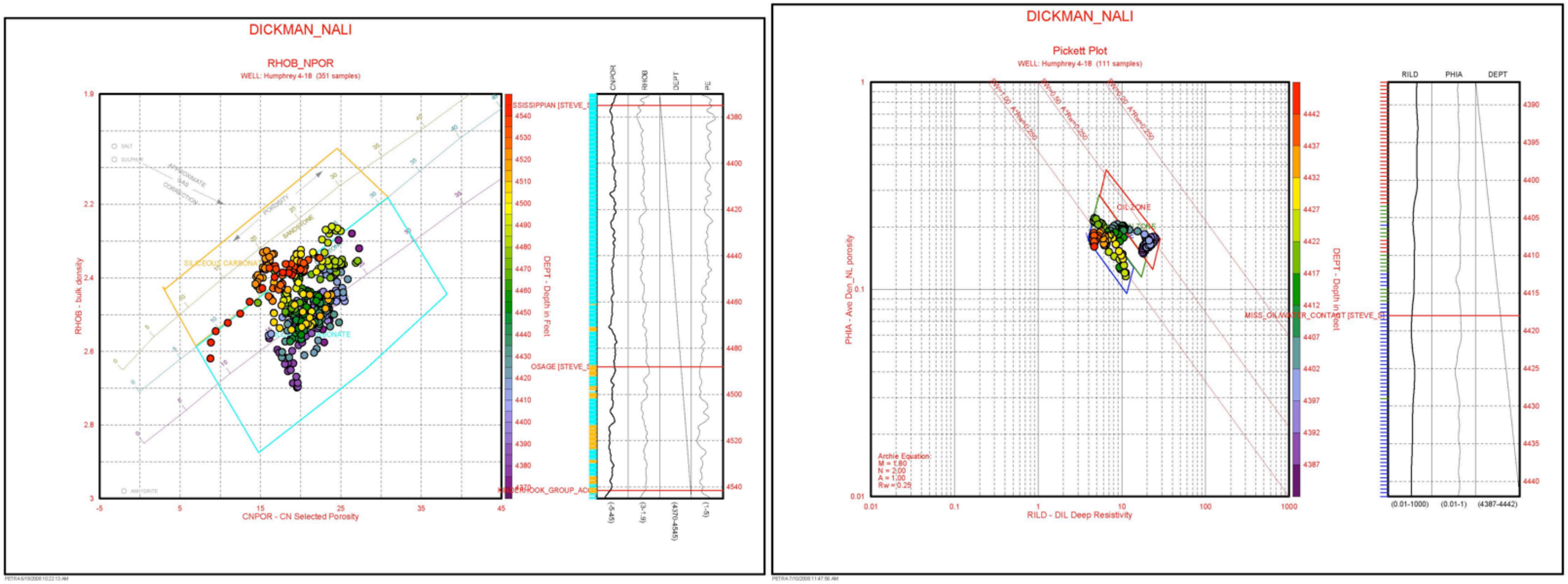


Fig. 15 Humphrey 4-18 petrophysical cross plots. (left) Neutron-density cross plot for lithology discrimination. Colored solid circles correspond to well depths shown on the vertical color bar. The yellow horizontal lines along the left side of the log curves correspond to points within the yellow rectangle on the chart, representing siliceous carbonate lithology. Blue lines correspond to points within the blue rectangle, representing dolomitic carbonate. (right) Pickett plot from 4380-4400 ft, showing the production zone below 4402 ft.

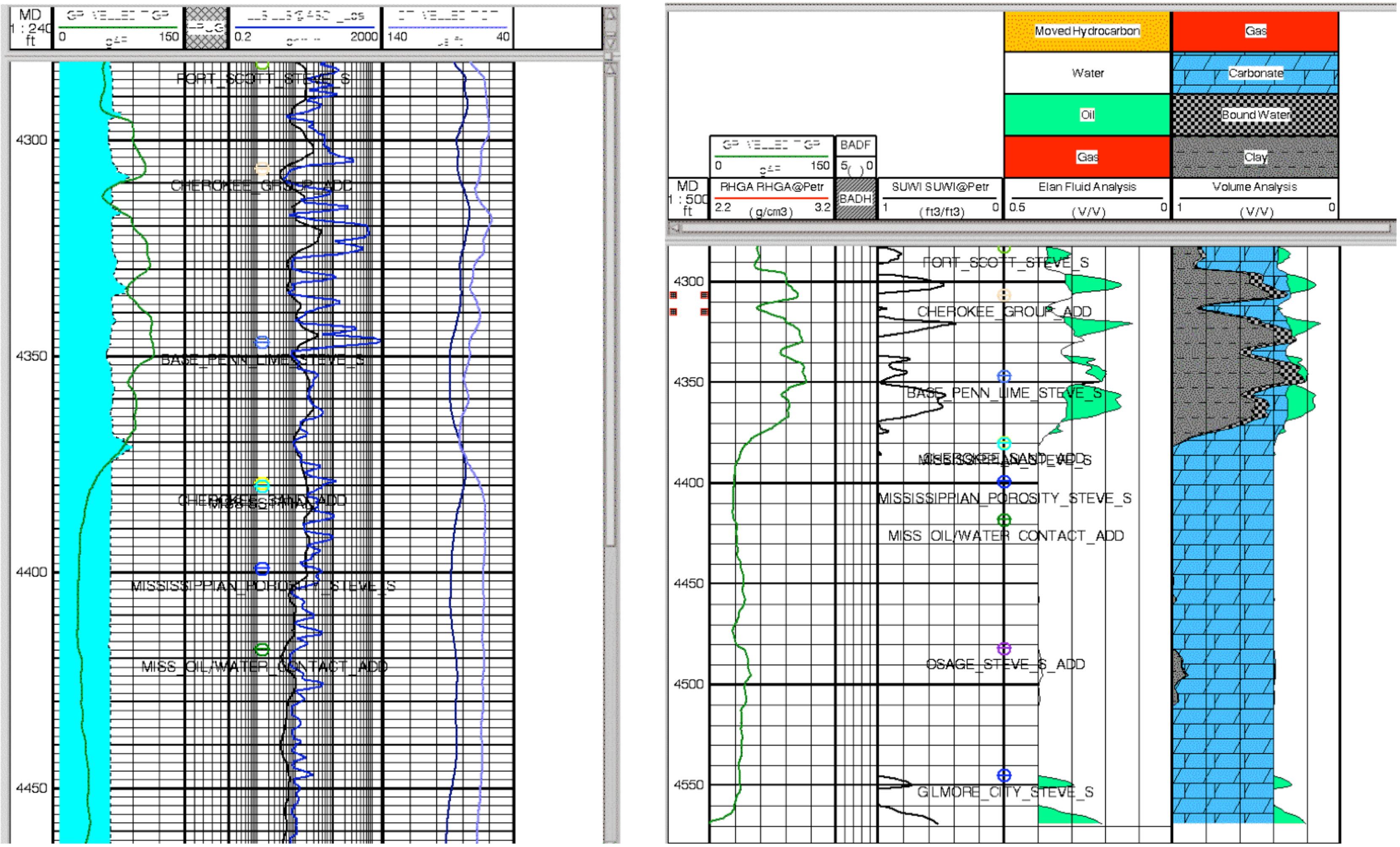


Fig 16. Initial plot of the reservoir computations for the Humphrey 4-18 well. (left) Porosity and water saturation curves computed from logs. (right) Computed pay zones from 4380-4400 ft that are much shallower than reported, needing further investigation on the parameters used for computation.

3. Planned work for Q3 of 2008

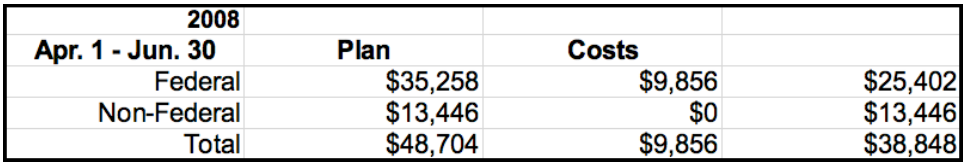
The following tasks are proposed for the next quarter based on the progresses made in Q2 and the need in eliminate as much interpretation uncertainty as possible. A consolidated time/depth stratigraphic framework will be completed in Q3, and the seismic attribute analysis will be worked in the reservoir model.

1. Stratigraphic correlation and depth-time tie (Task 3.0)
    a. After the re-adjustment of the horizon picks (section 2.1, Fig. 11), a second round of time-depth will be based on both synthetics and new well control (Fig. 6). This may also enable mapping of the shallower CO2 sequestration target (Lower Cherokee Sandstone) using amplitude and curvature attribute data..
    b. Improve the thickness isopach for the shallow CO2 target in depth domain based on doubling the number of geology markers (Fig. 10a). Together with the results in a, this will improve geometry and volume estimates for the shallower CO2 sequestration targets.
    c. As suggested by the Osagian core study in the Shaben Field: "original depositional facies and relatively early diagenetic events have a significant influence on present reservoir characteristics". Data will be collected from available facies study of carbonates in similar stratigraphic units in or around the Dickman Filed, for a better understanding on the property and volume of the shallower carbonate reservoir and the deep saline aquifer.
    d. The special seismic features being interpreted as the karst-related lows (Figs. 7 and 14) may not be caused only by geology. Further investigation into possible influences from seismic data processing is needed to validate the topographic and rock property interpretations.
    e. Update maps and interpretation models based on results from tasks a-d.
2. Seismic attribute study (Task 4.0)
    a. Re-compute the curvature computation using a smaller (2ms) vertical window to evaluate the effect of the size of sample window on the resolution of curvature maps relative to the targets (section 2.1, Fig. 12).
    b. Complete the interpretation on fault and vertical displacement within the Miss.-Gilmore City interval, to be used for validating the relation between the curvature features and the regional fault-fracture framework (Fig. 13c).
    c. More horizon-centered attributes may be computed to validate the effectiveness of volumetric attributes in simulating the Karst landscapes.
3. Reservoir property computation and modeling (Tasks 5.0 , 6.0 and 7.0)
    a. Improve the computation of the reservoir porosity and water saturation of the new well Humphrey 4-18 well. After the results are validated by field data, extend this computation to the Sidebottom 6 containing a relatively complete log set (but with no pay zone) and to at least four more wells within the studied area, using extrapolations for missing log inputs. This will help generate enough data points for reservoir property mapping.

b. The reservoir geometry and property maps will be compared with the seismic and volumetric attribute maps to validate the use of attribute-based reservoir parameters in computer simulation models, and the capability of attribute-derived parameters to predict fluid flow in a depleted oil reservoir. (Likely to extend to Q4)
c. Validate the method and workflow on using attribute-based reservoir parameters in computer simulation models of the reservoir, and the capability to use attribute derived parameters to predict fluid. (Likely to extend to Q4)

COST STATUS

Baseline Costs Compared to Actual Incurred Costs



2008			
Apr. 1 - Jun. 30	**Plan**	**Costs**	
Federal	$35,258	$9,856	$25,402
Non-Federal	$13,446	$0	$13,446
Total	$48,704	$9,856	$38,848

Forecasted cash needs vs. actual incurred costs

Analysis of Variance

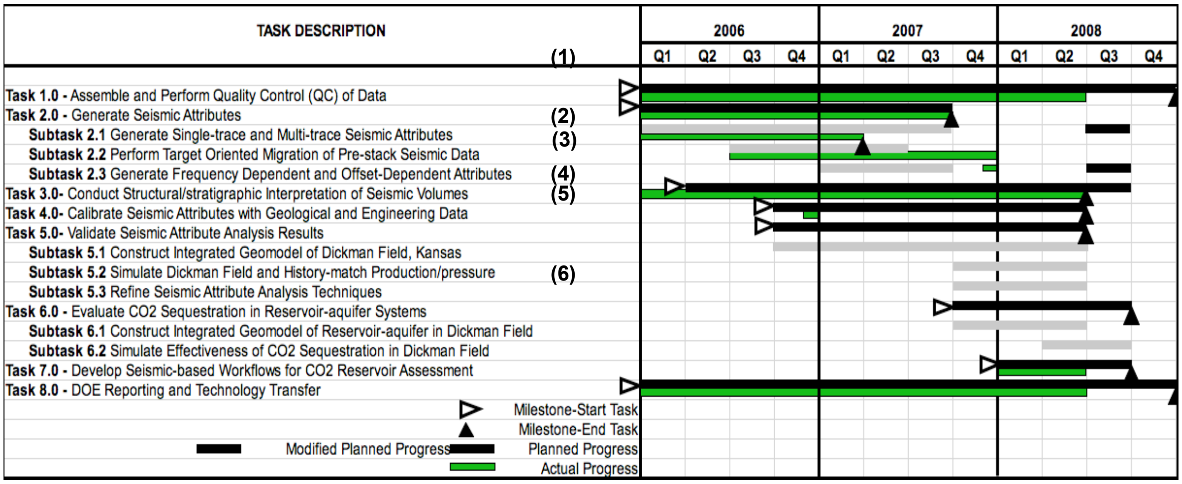
Costs were minimal this quarter as we worked to re-align with cost share partners KU and Continental resources (see comments below). This was also aided by UH department support of June Zeng to work on this project, and change of P.I. to Christopher Liner who had other support this summer.

MILESTONE PLAN AND STATUS

Critical Sub-Milestones for 2008

1. Generate 2 ms curvature attributes on Dickman 3D data **August 15, 2008** (*Subtask 2.1)*.
2. Generate frequency-dependent attributes on Dickman 3D data **September 15, 2008,** (*Subtask 2.3*).
3. Re-calibrate seismic attributes with well data at Dickman field by **August 30, 2008** (*Task 4.0*).

Actual Progress Compared to Milestones



(1) QC of data will continue throughout project.
(2) Complete on Teapot Dome
(3) Dickman field
(4) Further work deferred until next period.
(5) Deferred until next period.
(6) Deferred until next period.

SUMMARY OF SIGNIFICANT ACCOMPLISHMENTS

Good progress has been made in this quarter on improving time-depth correlations leading to better seismic tops for mapping in the Dickman field. With the addition of the new Humphrey 4-18 full log suite, we expect the petrophysics to lead to a much better gridded geological model. The improved level of detail will also improve our ability to quantitatively interpret seismic attributes.

In the Teapot Dome field, volumetric attribute calculation has been completed.

ACTUAL OR ANTICIPATED PROBLEMS AND SIGNIFICANT EVENTS

1. We have identified a graduate student who will be available in the fall semester to participate in the Dickman field study as part of her degree program at UH. We expect to fill several additional faculty positions in geophysics and engineering and graduate student Research Assistant positions during 2008.

2. We continue to pursue options for cost share partners to meet their obligations to the project.

    - Kansas University and the Kansas Geological Survey ($50K cost share) have indicated they would prefer to withdraw from the project due to staff departures and full commitment of remaining staff. Subject to discussions with DOE contract specialists, we are interested in shifting the reservoir engineering functions planned for KU to Texas A&M University. Dr. Behnam Jarfarpour and department chair Prof. Steven Holditch have agreed in principle to this collaboration.

- Several discussions have been held with Continental Resources II ($100K cost share) with no progress to date. Due to staff departures and a changing business climate, they currently have no interest in supporting reservoir characterization studies in the Patoka field, as originally envisioned. In addition, the seismic data quality at Patoka appears to be unsuitable for this kind of study. One option that has been proposed is that CRII support a graduate student at UH for 2 academic years, who will work on the project, to meet a large part of this obligation.

- To account for these partner transitions and redevelopment of staff expertise, we are pursuing a 12 month no-cost extension from the DOE.

- A significant task in the next quarter will be migration of the Dickman field data from Geoframe to Petrel for generation of a gridded geological model suitable for flow simulation using the Eclipse simulator.

TECHNOLOGY TRANSFER ACTIVITIES

Oral presentation

2/20/2008	Fairfield	CO2 Sequestration Research at U. Houston	Bob Shurtleff
3/20/2008	Texas A&M PE	CO2 Sequestration Research at U. Houston	Steve Holditch
3/31/2008	Shell	CO2 Sequestration Research at U. Houston	David Mejia
4/16/2008	WesternGeco	CO2 Sequestration Research at U. Houston	Einar Otnes
5/5/2008	BP	CO2 Sequestration Research at U. Houston	Kevin Dodds
6/18/2008	Shell	CO2 Sequestration Research at U. Houston	Ron Masters
7/14/2008	Exxon	CO2 Sequestration Research at U. Houston	Ganglin Chen

CONTRIBUTORS

University of Houston

Chris Liner (Professor)
Jianjun (June) Zeng

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