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.

The *primary study areas* are **Dickman field**, Kansas; **Teapot Dome field**, Powder River Basin, Wyoming; and **Patoka and Sciota fields**, Illinois Basin. These areas represent a range of geologic settings associated with major coal producing and emission generating regions of the United States.

Dickman Field: We have completed a reorganization of the Dickman field well and seismic databases onto GeoFrame from separate GeoFrame and Petra projects. This consolidation will increase functionality to perform integrated seismic attribute and well data studies, especially in the areas of log quality control and petrophysics. We have extended horizon correlations from the initial small study area to the entire survey area and have begun to evaluate volumetric attributes extracted from our initial acoustic impedance inversion of the pre-stack time migrated seismic volume.

Pre-project work using the seismic data in the NE part of the survey area revealed a possible relationship between the proximity of wells to NW-SE trending fractures, which we have interpreted to correlate with lineaments on volumetric curvature attribute maps, and increased water production. On recently processed volumetric curvature attribute maps of the entire survey area, we have identified similar lineaments, but curved anomalies are also prominent. The curved anomalies may correspond to the edges of large karst related depressions or incised fluvial channel meanders on the top Mississippian unconformity. Basal Pennsylvanian sandstones locally fill these paleotopographically low areas and are locally oil-productive.

Successfully mapping the distribution of these basal sandstones using seismic attributes would significantly improve our ability to model the Dickman field reservoir and to evaluate the potential for ***CO2 Enhanced Oil Recovery*** *in Dickman field and similar fields with lithologically complex reservoirs.*

Teapot Dome Field: We completed pre-stack and post-stack Kirchhoff time migrations and depth migrations of the 3-D seismic data at Teapot Dome, during the third calendar quarter of 2007. The aim of that work was to generate a pre-stack depth migrated seismic volume to better resolve the structural features of Teapot Dome field and the seismically-derived reservoir properties of the CO2 sequestration target Tensleep Formation and to determine the structural integrity of the seal rock.

Due to the graduation of the students working with the Teapot Dome data and the delay in the DOE disposition of incremental funding last year, we have not yet been able to staff the project and follow-up the completion of the depth migration work with further analyses. We are currently seeking a suitable candidate to carry out this work and complete the project.

The work required to complete the Teapot Dome study is the following:

1. *Carry out impedance inversion of the new seismic volumes.*

2. *Extract attributes from the inverted volumes and complete the structural analysis of faults and fractures in the Tensleep to basement section.*

3. *Calibrate seismic attributes with well data to map the porosity, permeability, oil saturation and seal integrity of the Tensleep reservoir.*

Patoka Field: The development of an effective method to remove ground roll (Rayleigh waves) continues to be a major challenge in the reprocessing of the pre-stack 3-D seismic data at Patoka field. The CO2 sequestration target Mt. Simon Formation overlies granite basement, which occurs in the depth range of about 1.1 to 1.2 seconds at Patoka. Reflections from the Mt. Simon are only distinguishable at far offsets on shot gathers. High amplitude-low frequency ground roll events severely degrade and blur the seismic data from depths of about 0.6 seconds and deeper. The ground roll noise in the Patoka seismic data, which is a typical problem with land 3D seismic surveys in areas of near-surface glacial till deposits, limits our capability to carry out structural and stratigraphic analyses of the Mt. Simon Sandstone and the shallower CO2 sequestration targets.

We have tried several conventional methods to attenuate the ground roll in the Patoka seismic but have thus far encountered insoluble problems with all of them. Band pass filtering and time-variant filtering result in the loss of usable low frequency signals and do not eliminate aliased noise with higher frequencies than 15 Hz. Radon transform and F-K filtering are not effective methods for use with irregular binning grids, which is the situation at Patoka.

We are now investigating K-L filtering, which looks very promising. If this reprocessing effort is not successful in the near future, we will continue our reservoir analyses with inversion volumes of the post-stack time migrated seismic data originally provided by Continental Resources, Inc. The process itself of inversion of post-stack data has some potential to reduce the noise in the inverted volumes. *Our expectation is that we will successfully solve the ground roll problem and generate a pre-stack time migrated data volume with adequate resolution to evaluate the potential of CO2 sequestration target reservoirs in the Illinois Basin.*

APPROACH

The *aim of this project* is to develop innovative seismic attribute technology and workflows and to apply this methodology to improve the assessment of the structural integrity of seals and reservoir heterogeneity of geological reservoirs for CO_2 sequestration. The specific objectives are to: 1) apply advanced seismic attributes to quantify the thickness, porosity, permeability and lateral continuity of CO_2 sequestration target reservoirs and develop a reservoir model and 2) validate the reservoir model with reservoir simulation studies of CO_2 injection into a saline aquifer associated with a depleted hydrocarbon reservoir.

We have selected four study areas that represent a range of most-likely candidates for gigaton-scale CO_2 sequestration associated with the coal industry (Figure 1). **Dickman field** in Kansas will serve as a pilot area to test the viability of using attribute-based reservoir parameters in computer simulation models of the reservoir. Geophysical logs and production data from wells in the study objective Mississippian-aged carbonate oil reservoir and 3-D seismic data are available to use in the computer model studies. Pre-project work suggests that seismic attributes can successfully delineate reservoir characteristics that affect fluid flow. This study will test the capability to use attribute-derived parameters to predict fluid flow in a depleted oil reservoir under water drive and to evaluate the storage potential of the underlying saline aquifer. If successful, the results of the study will provide a basis to estimate the capacity of similar Mid-Continent reservoirs to store CO_2. The **Teapot Dome field** in Wyoming has 3-D seismic data and over 1600 wells with a large amount of supporting rock, log and engineering data from multiple producing zones. We will use core data, geophysical logs from 35 wells, including five wells with borehole image logs, and production data from the complexly fractured and faulted study objective Pennsylvanian-aged Tensleep depleted oil reservoir to calibrate seismic attributes with the rock data. The **Patoka field** and **Sciota field** in

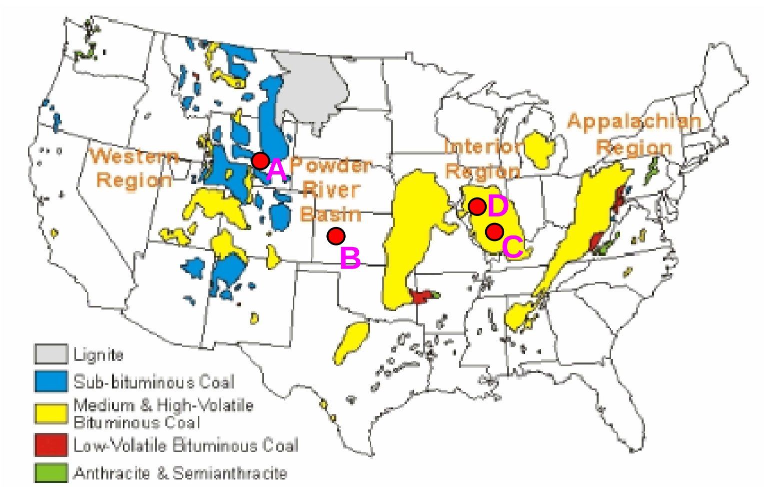

Figure 1. 3-D seismic data sets available for this study are located at: A) **Teapot Dome**, Powder River Basin, Wyoming, a major CO_2 study site for the DOE; B) **Dickman Field,** Kansas, within the Mid-Continent area underlain by the Mississippian Western Interior Plains saline aquifer; and C) **Patoka** and D) **Sciota Fields**, Illinois Basin, underlain by shallow EOR target reservoirs and the Cambrian Mt. Simon Formation, a regional saline aquifer. We selected these data sets for either their proximity to major coal producing or emission generating regions of the United States or for their location near major saline aquifers.

Illinois have well and 3-D seismic data for evaluating the seal integrity and the CO2 storage potential of the Cambrian-aged Mt. Simon Formation, a regional saline aquifer, and the CO_2 enhanced oil recovery potential of shallower reservoirs.

We will integrate the results of the field studies to assess CO_2 sequestration possibilities for the coal industry. *The work has the potential to significantly reduce uncertainties and to expand our technical awareness of how to effectively and safely store CO_2 in depleted oil reservoirs and saline aquifers.*

RESULTS AND DISCUSSION

Task 1.0 - Assemble and Perform Quality Control of Data

We had expected to complete this task in 2006, and we have made substantial progress toward meeting this milestone. However, we now recognize that this work will continue intermittently throughout the project because of the large sizes of the field data sets and the continual acquisition of additional data. We have modified the Gantt chart accordingly.

Task 2.0 - Generate Seismic Attributes

Subtask 2.1 Generate Single-trace and Multi-trace Seismic Attributes

We have generated a range of seismic attributes from available commercial seismic datasets for each field to evaluate the quality of the data and to train graduate students involved in the project.

Subtask 2.2 Perform Target Oriented Migration of Pre-stack Seismic Data

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We have tried several conventional methods to attenuate the ground roll in the Patoka seismic data but have thus far encountered insoluble problems with all of them. Band pass filtering and time-variant filtering result in the loss of usable low frequency signals and do not eliminate aliased noise with higher frequencies than 15 Hz. Radon transform and F-K (Kalman) filtering are not effective methods for use with irregular binning grids, which is the situation at Patoka.

We are now investigating K-L (Karhunen-Loeve) filtering, which looks very promising. In this method, we will decompose the original data into low frequency and high frequency parts (Figure 2). To analysis for ground roll in the low frequency part, we will scan all dips and azimuths and calculate semblance using small windows (Figure 3). We will then apply K-L filtering on the temporal and spatial locations where the local semblance is greater than a threshold value and recombine the high and low frequencies to produce a seismic volume with attenuated ground roll and preserved signal. We will apply predictive deconvolution and spectral balancing to enhance seismic bandwidth and sharpen reflectivities. 3-D pre-stack common offset migration will be the final processing step.

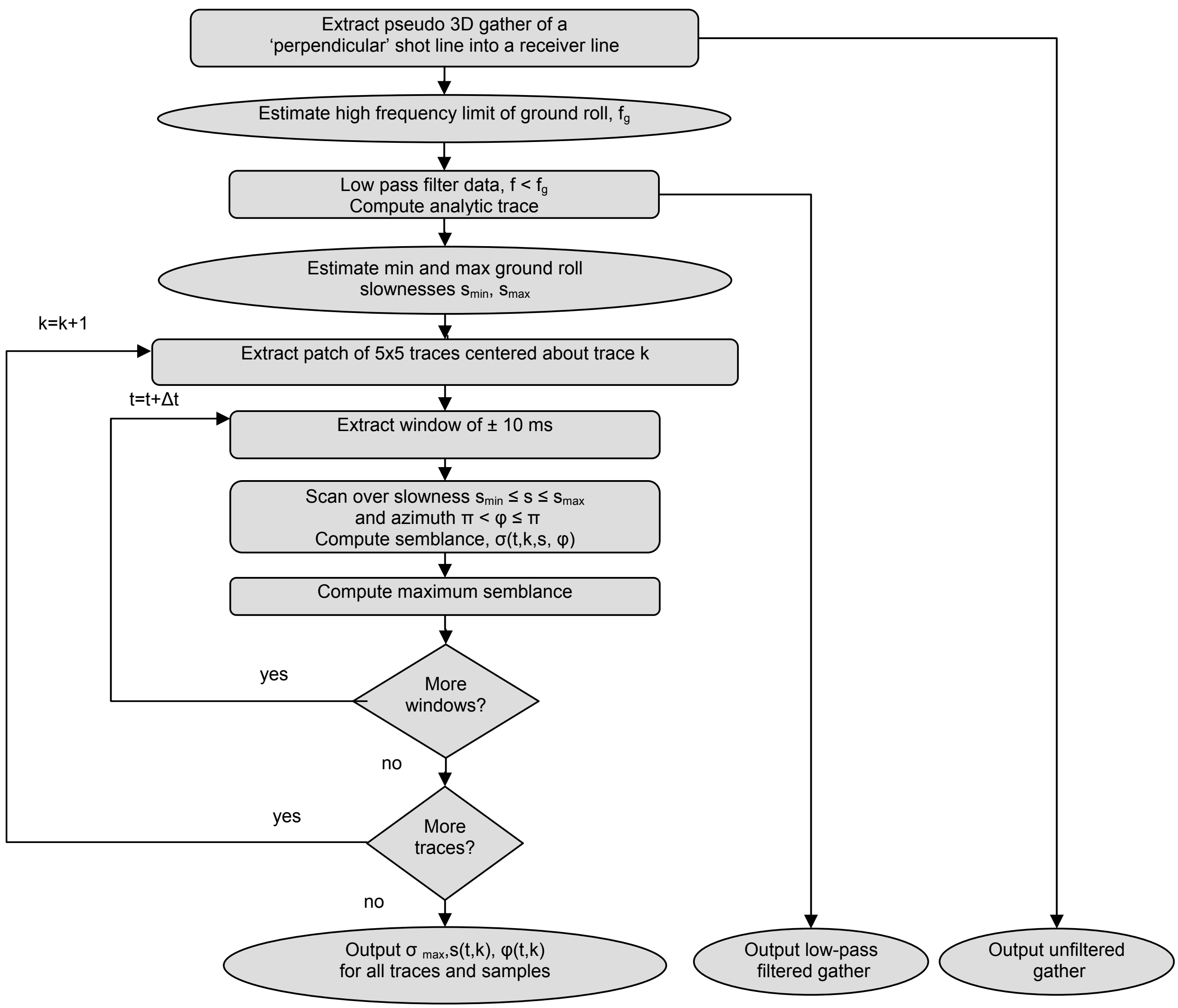

Figure 2. K-L (Karhunen-Loeve) filtering work flow (Part 1). In this process, by using semblance to recognize coherent noise, ground roll in this case, and the slowness differences between ground roll and reflections, we expect to be able to recognize ground roll and remove it from the data.

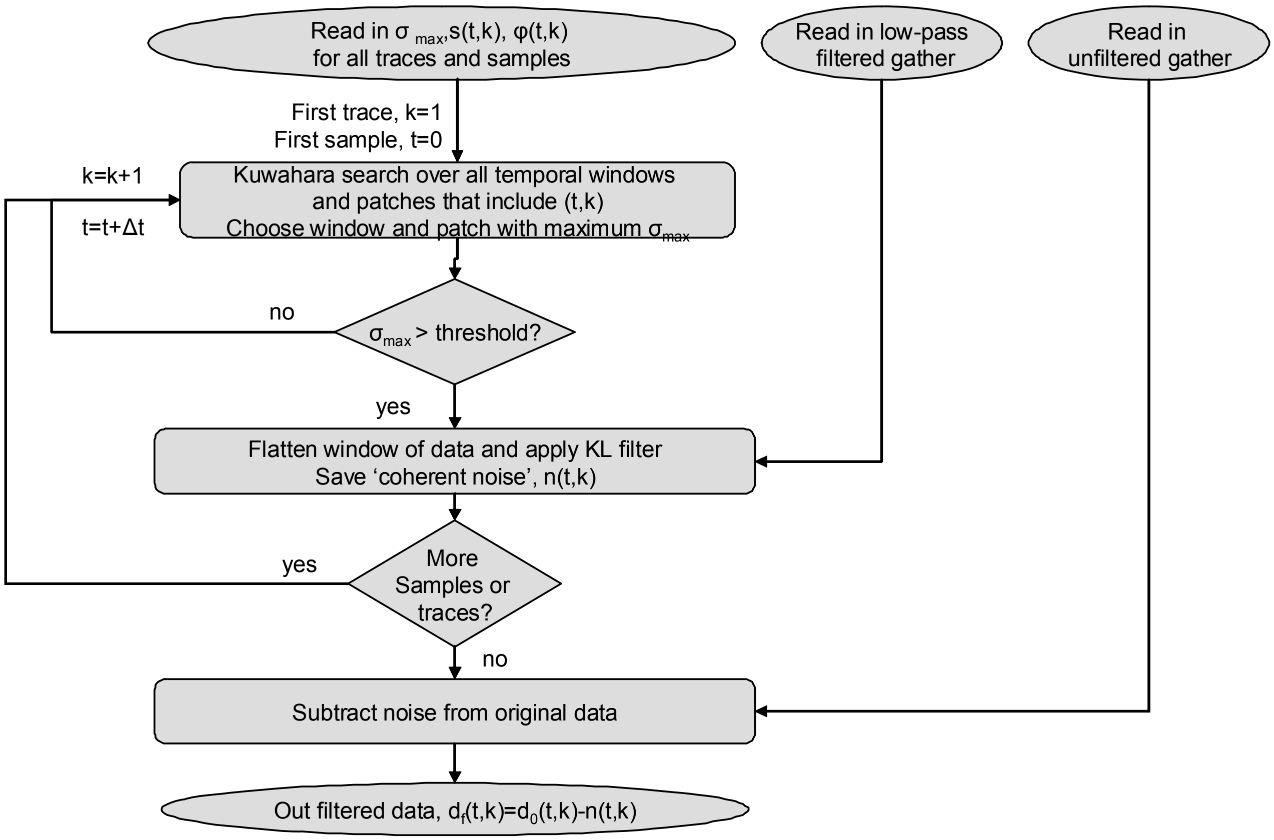

Figure 3. K-L (Karhunen-Loeve) filtering work flow (Part 2). In this part, we will apply the K-L filter to each small window. We will use semblance, which we calculated in Part 1 of the process, to determine which data in the window correspond to ground roll and should be removed. We expect the application of the K-L filter in this processing sequence to significantly attenuate noise due to ground roll.

If reprocessing efforts are not successful in the near future, we will continue our reservoir analyses with inversion volumes of the post-stack time migrated seismic data originally provided by Continental Resources. The process itself of inversion of post-stack data has some potential to reduce the noise in the inverted volumes. *Our expectation is that we will successfully solve the ground roll problem and generate a pre-stack time migrated data volume with adequate resolution to evaluate the potential of the Mt. Simon sandstone and the shallower CO2 enhanced oil recovery target reservoirs in the Illinois Basin.*

Teapot Dome field: We completed pre-stack and post-stack Kirchhoff time migrations and depth migrations of the 3-D seismic data at Teapot Dome, during the third calendar quarter of 2007. The aim of that work was to generate a pre-stack depth migrated seismic volume to better resolve the structural features of Teapot Dome field and the seismically-derived reservoir properties of the CO2 sequestration target Tensleep Formation and to determine the structural integrity of the seal rock.

Due to the graduation of the students working with the Teapot Dome data and the temporary lack of funding for a replacement, we have not yet followed up completion of the depth migration work with further analyses. We are currently seeking a suitable graduate student to carry out this work and complete the project.

The work required to complete the Teapot Dome study is the following:

1. Carry out impedance inversion of the new seismic volumes
2. Extract attributes from the inverted volumes and complete the structural analysis of faults and fractures in the Tensleep to basement section.
3. Calibrate seismic data with well data to map porosity, permeability and the oil saturation of the Tensleep in 3D.

Very few studies of pre-stack depth migrated land 3-D seismic surveys have been published in the United States, and we are not aware any studies of advanced seismic attribute volumes extracted from pre-stack depth migration of 3-D land data that have been published. *Successful inversion of the reprocessed seismic volumes and integration with well data will provide a unique dataset to develop a structurally and stratigraphically integrated geomodel of the Teapot Dome Tensleep reservoir for successor reservoir simulation studies.*

Dickman Field: We successfully carried out 0-10 degree, 10-20 degree and 20-30 degree offset angle pre-stack time migrations and a whole-stack (0-45 degree) pre-stack time migration of the Dickman 3-D seismic data over the entire survey area, during the last reporting period. Refer to **Task 3** below for the status of work on the inversion of the pre-stack migration volumes.

Subtask 2.3 Generate Frequency Dependent and Offset-Dependent Attributes

We have begun to evaluate the application of spectral decomposition to map the distribution of reservoir lithologies and oil saturation in the Dickman Field sandstone and carbonate reservoir. We have found that the areal energy distribution of the low frequency spectra in the interval containing basal Pennsylvanian sandstones is different from that of the high frequency spectra. This work also strongly suggests that volumetric attribute maps of the distribution of low frequency energy might correlate with reservoir properties that relate to production. If we are encouraged by further analysis, we would plan to integrate this work with the attribute studies of impedance inversions of the pre-stack time migrated seismic volumes (See **Task 3.0** below, Dickman Field).

Task 3.0- Conduct Structural/Stratigraphic Interpretations of Seismic Volumes.

Dickman field: We have completed a reorganization of the Dickman field well and seismic databases onto GeoFrame from separate GeoFrame and Petra projects (Phases 1 and 2 in Figure 4). This consolidation will increase functionality to perform integrated seismic attribute and well data studies, especially in the areas of log quality control and petrophysics. We have extended horizon correlations from the initial small study area to the entire survey area and have begun to evaluate volumetric attributes extracted from our initial acoustic impedance inversion of the pre-stack time migrated seismic volume (Phase 3 in Figure 4).

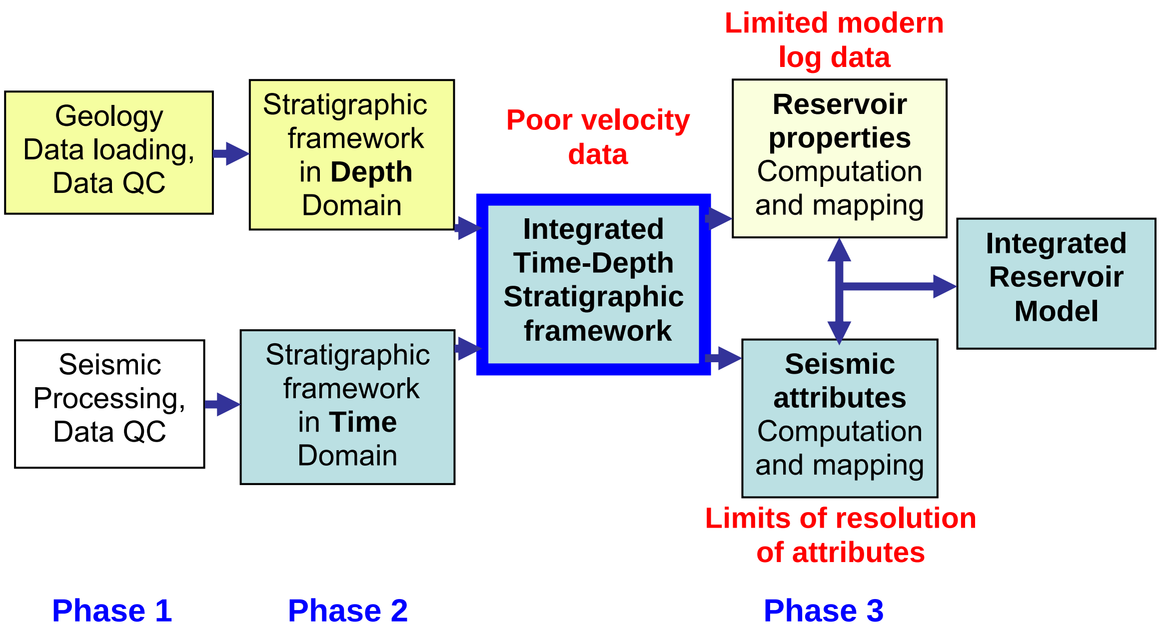

Figure 4. GeoFrame work flow for Dickman project. The comments in red highlight the main challenges in developing a high-resolution reservoir model for Dickman field.

The area of the Dickman field seismic survey contains over 130 wells (Figure 5). To develop an integrated time-depth stratigraphic and structural framework, we plan initially to use the data from about one-third of these wells, which would include all wells with porosity data and wells needed for correlation of stratigraphic units. The sources of porosity data range from uncalibrated neutron logs to compensated density and sonic logs and a few cores. Only one well near Dickman field, Sidebottom 6 (Figure 5), has a complete suite of modern well logs. A cross plot analysis of the logs and lithologic data from Sidebottom 6 show that the Dickman field oil reservoir and the underlying Mississippian saline aquifer consist of three main lithologic units: the basal Pennsylvanian Cherokee chert sandstone and breccia and the Mississippian Warsaw dolomite and Osage cherty dolomite (Figure 6). Quantitative log analysis of the lithologically complex Dickman oil reservoir and underlying aquifer presents a significant challenge for this study. The availability of high quality seismic attributes for mapping reservoir characteristics between wells is essential to overcome the limited log data problem. Phase 2 work is still in progress.

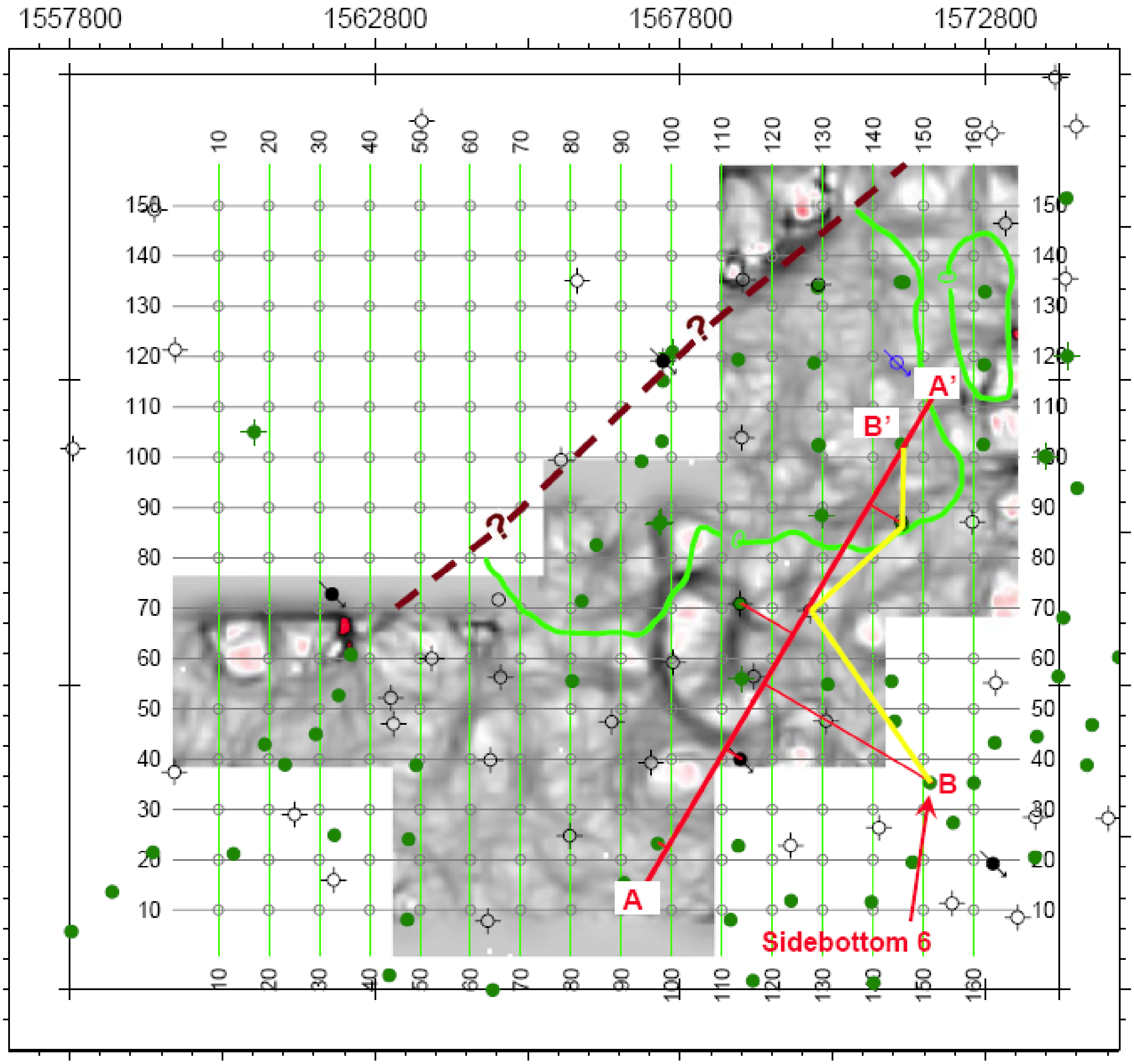

Figure 5. Map showing Dickman field Mississippian oil producing area, seismic line locations, well locations and limits of 3D seismic data shown (Mississippian positive curvature attribute map. See discussion of curvature attributes below.). The green line is the approximate oil-water-contact location. The brown dashed line is the location of possible fault projected from the NW corner of the survey. Line B-B' is the location of the well log stratigraphic section in Figure 8. Line A-A' is the location of the seismic profile in Figure 9.

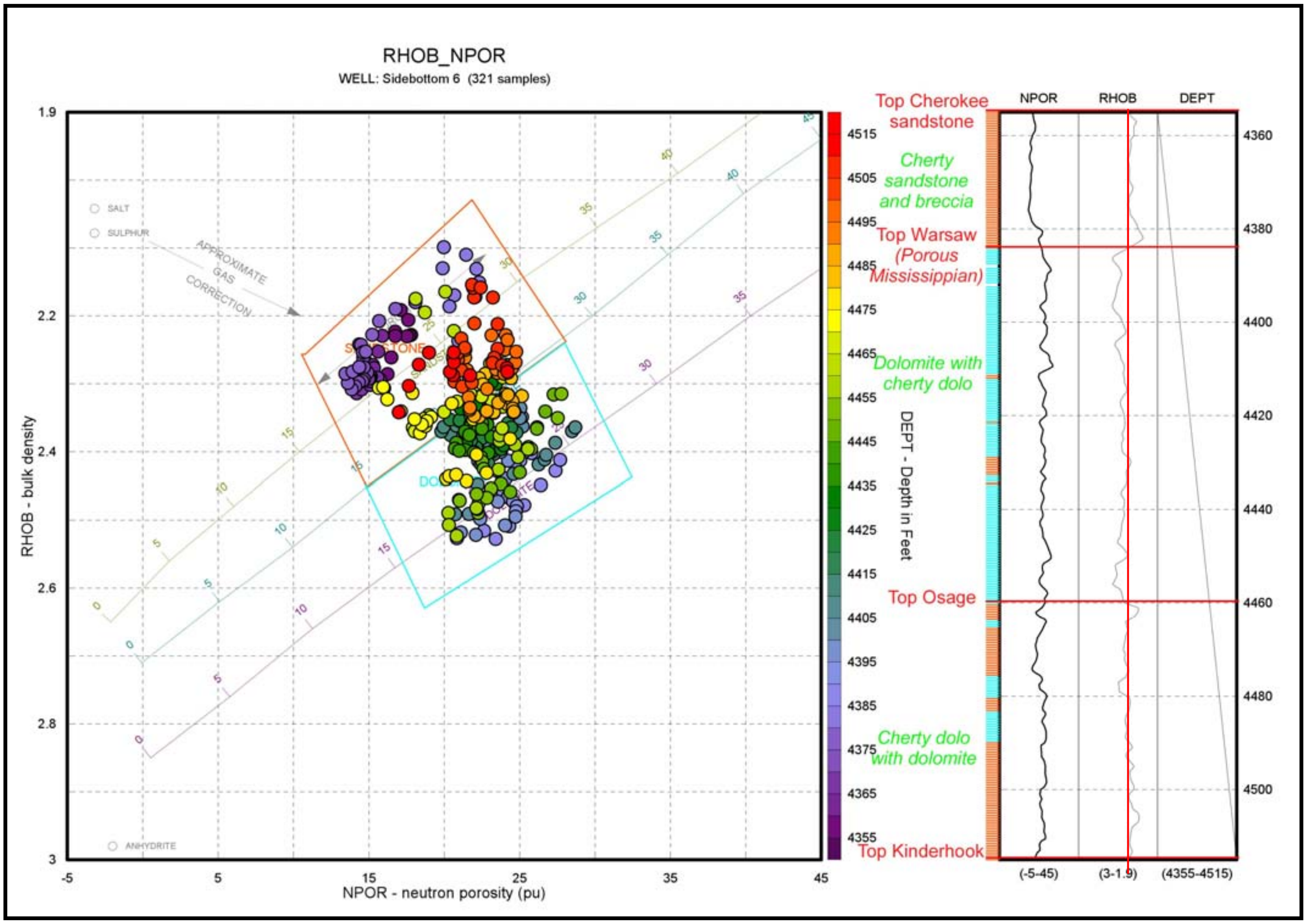

Figure 6. Sidebottom 6 neutron-density log cross plot. The lithologic zonation shown from 4355' to 4515' reflects the integration of cutting descriptions, cross plot data and log correlations. The colored solid circles on the cross plot correspond to well depths shown on the vertical color bar on the right side of the chart. The orange horizontal lines along the left side of the log curves correspond to points within the orange rectangle on the chart; the blue lines correspond to points within the blue rectangle.

Pre-project work using seismic attribute maps in the NE part of the survey area (pre-project study area) revealed a possible relationship between the proximity of wells to NW-SE trending fractures, which we have interpreted to correlate with lineaments on volumetric curvature attribute maps, and increased water production. On recently processed volumetric curvature attribute maps of the entire survey area, we have identified similar lineaments, but curved anomalies are also prominent (Figure 7). The curved anomalies may correspond to the edges of large karst related depressions or the edges of incised fluvial channel meanders on the Mississippian unconformity, either of which would delineate the boundaries or limits of the basal Pennsylvanian sandstones.

The successful application of volumetric attribute data to characterize reservoir properties requires good correlations between well tops and seismic horizons and careful selection of the window length (Z dimension) used to extract volumetric attributes. We used the default window of 10 ms to extract the volumetric attribute maps in Figure 7. The

Mississippian dolomite oil reservoir at the Dickman field is generally less than 50 feet thick, and the basal Pennsylvanian sandstones range from zero to over 100 feet in thickness. To ensure that volumetric attribute maps do not include data from adjacent beds, attribute window lengths should be less than about five milliseconds. We plan to use 2-4 millisecond window lengths in future volumetric attribute extractions of horizon and time slices.

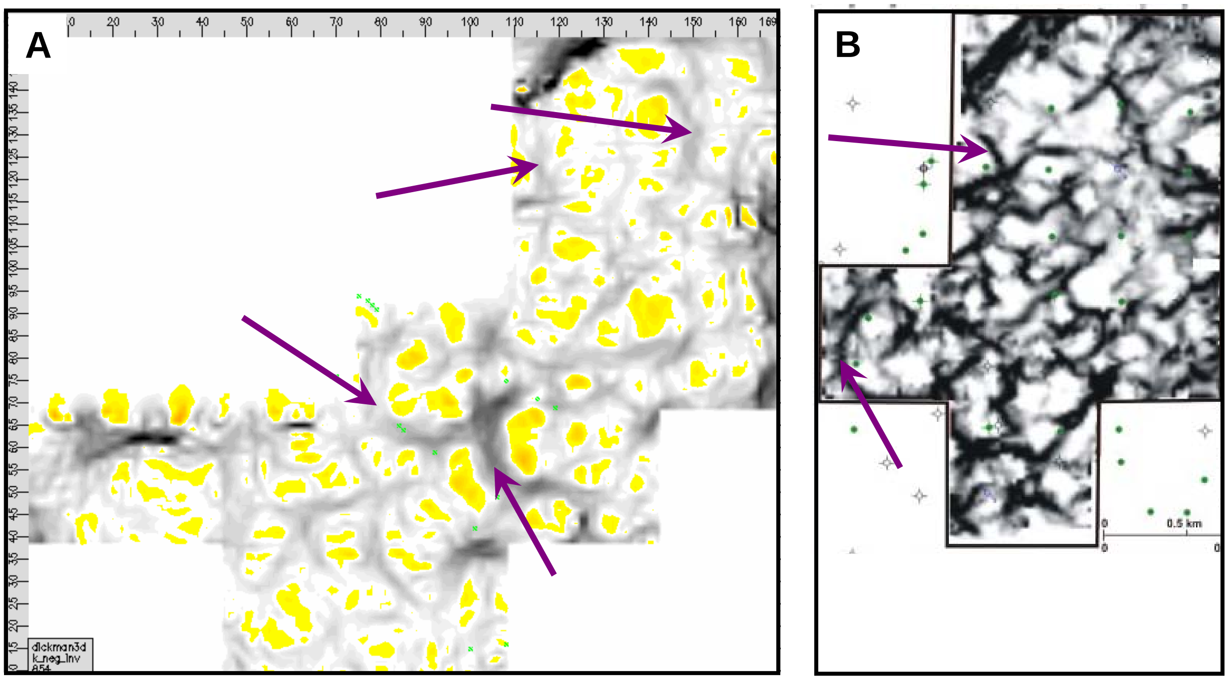

Figure 7. Dickman field volumetric curvature attribute maps of porous Mississippian dolomite. **A.** Negative curvature time slice at 0.854 sec from impedance inversion of entire survey. **B.** Negative curvature horizon slice near the base of the porous zone (Gilmore City) in the smaller pre-project area (Nissen, S. E., et al., *in press*). The maps are extractions of slightly different volumes of seismic data in the area common to both maps. The purple arrows point to curved features that may be important indicators of the distribution of the Cherokee sandstone.

A seismic profile oriented SW-NE across Dickman field and a log stratigraphic cross section illustrate structural and stratigraphic variations of the main lower Pennsylvanian and upper Mississippian lithologic units (Figures 8 and 9). The Ft. Scott Formation above the top Mississippian and a seismic reflector at about 0.95 seconds below the upper Mississippian porous zone are structurally flat compared to the irregular top of the Mississippian, which is an unconformity (Figure 9). The Mississippian unconformity exhibits erosional relief of over 100 feet, which probably reflects carbonate dissolution in the phreatic zone and subaerial erosion associated with fractures and the formation of karst sinkholes and related features. The thick sandstone and chert sequence in Elmore 2, which we have interpreted to be basal Pennsylvanian channel or karst deposits, is tight above the Dickman field oil-water-contact and water productive below the contact, based on drill stem tests (Figure 8). The chert in the lower part of this basal unit probably represents a residuum from the dissolution and redeposition of silica derived from sponge spicules in the Mississippian carbonates.

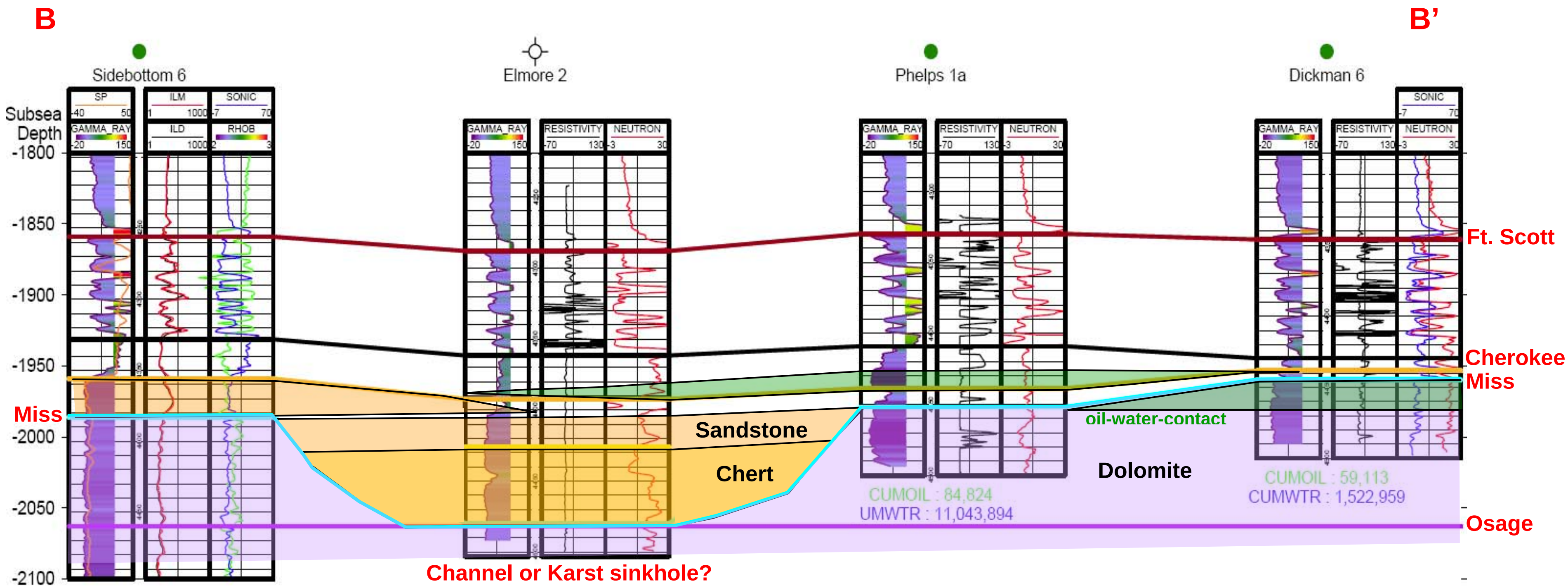

Figure 8. Dickman field stratigraphic cross section B-B' (sea level datum and no horizontal scale). The oil productive zones are the Cherokee sandstones and the upper Mississippian dolomites above a depth of ~1981 subsea (green-shaded units). The Cherokee (orange-shaded unit) in Sidebottom 6 tested wet. A DST that straddled the top Ft. Knox recovered oil. The base of the Mississippian saline aquifer (top Gilmore City) is not shown on the cross section because of limited well control. The base of the upper unit of the porous Mississippian dolomite is the Osage. The interpretation of the paleo-channel or paleo-karst feature penetrated by Elmore 2 is based on lithologic descriptions from the operator. The light blue horizon is the top Mississippian unconformity. See Figure 5 for the location of the cross section and Figure 9 for a nearby seismic profile.

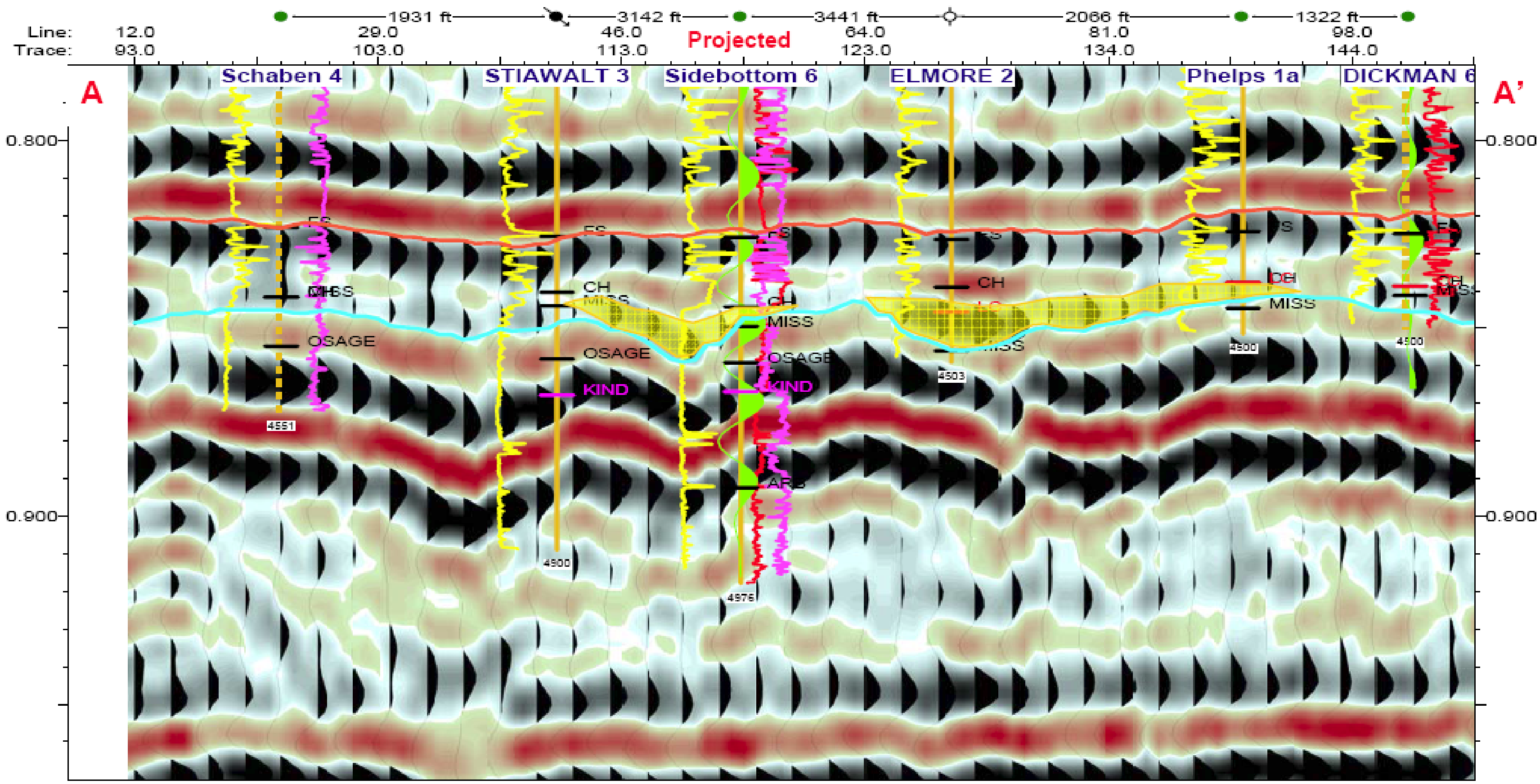

Figure 9. Dickman field seismic profile A-A' from a whole-stack (0-45 degree) pre-stack time migrated volume. Top Mississippian is light blue horizon. Top Ft. Scott is red horizon. Log curves: yellow = gamma ray, pink = density, red = sonic and green = synthetic seismogram. The shaded yellow unit above the top Mississippian may correspond to the location of the basal Cherokee sandstone that is oil productive in Phelps 1a. We plan further work to investigate the origin of the anomalous, high amplitude events below the top Mississippian and to refine the time-depth relationships. See Figure 5 for the location of the profile and Figure 8 for nearby stratigraphic cross section.

A map on the top Mississippian unconformity shows that Dickman field is an irregularly-shaped structural closure (Figure 10). The complicated geometry of the closure may be partially related to possible faulting on the north flank but has probably been significantly influenced by post-Mississippian erosion. In the early Pennsylvanian, the area that is now Dickman field may have been a plateau surrounded by topographically low areas. Basal Pennsylvanian cherty sandstones, breccias and clay that accumulated in the surrounding low areas may locally provide lateral closure for the Mississippian oil accumulation. In some areas, the porous Pennsylvanian sandstones are oil productive and might be hydrodynamically continuous with the Mississippian oil reservoir.

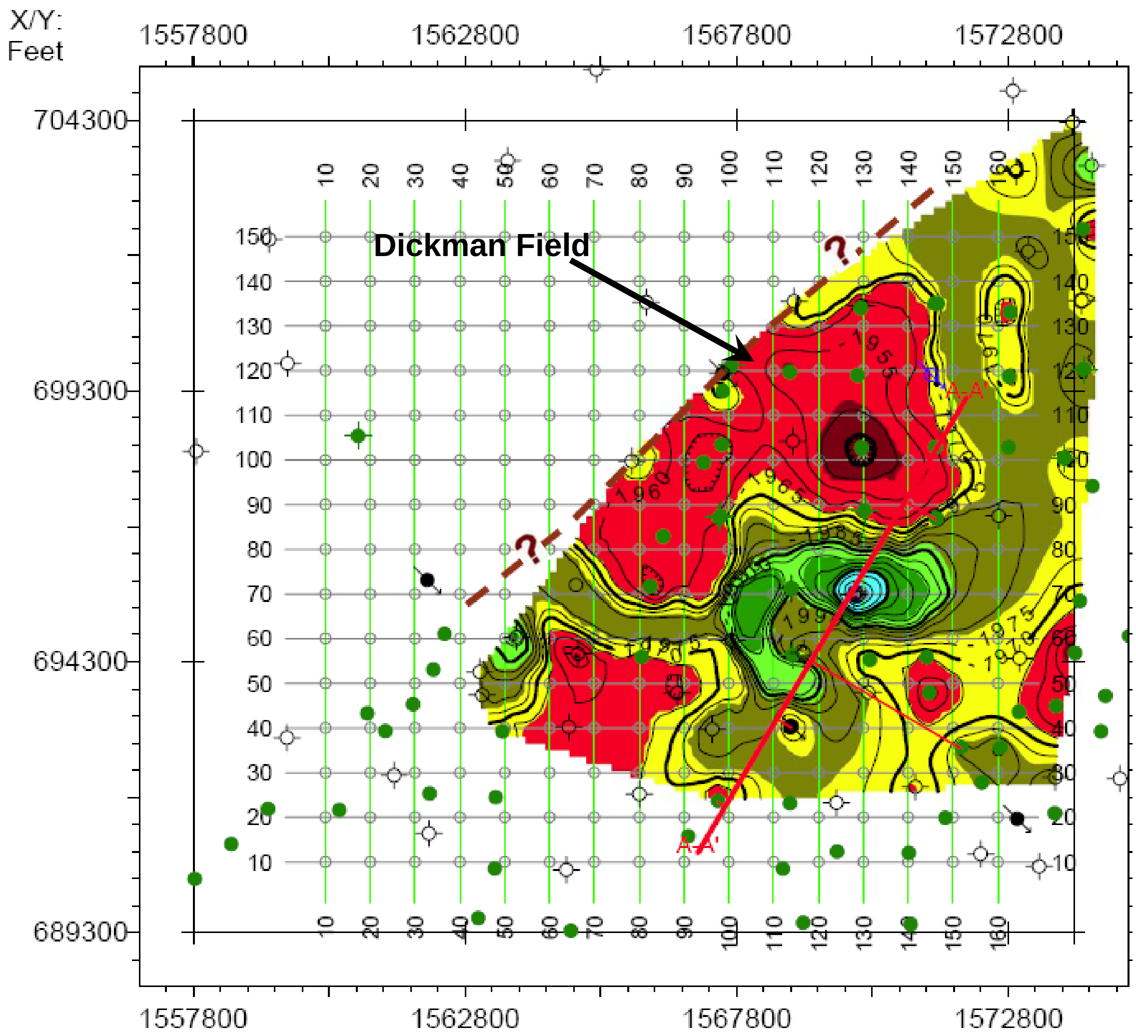

Figure 10. Dickman field and vicinity structure map on top Mississippian. The map patterns created by the structurally low areas may correspond to the edges of large karst related depressions or the edges of incised fluvial channel meanders on the Mississippian unconformity. The brown dashed line is the location of possible fault projected from the NW corner of the survey. Line A-A' is the location of the seismic profile in Figure 9. Contour interval = 5 feet.

To construct a preliminary, gross oil isopach map of the Mississippian oil productive zone, we subtracted the grid of the oil-water-contact surface from the grid of the top Mississippian horizon (Figure 11). We interpreted grid values manually in areas of sparse well control to show a small, separate NE closure and the SW field limit. We plan to refine these interpretations further when we can obtain data from several recently drilled wells. The structural reentrant of the contours may reflect the location of a channel (dashed yellow line) or karst related depression on the Mississippian unconformity. Speculatively, if porous sandstones are present in the depression, the sandstones could be above the field oil-water-contact and oil-bearing. Detailed analyses of seismic attribute data may allow us to determine the reservoir characteristics of the rocks that fill depressions on the Mississippian surface.

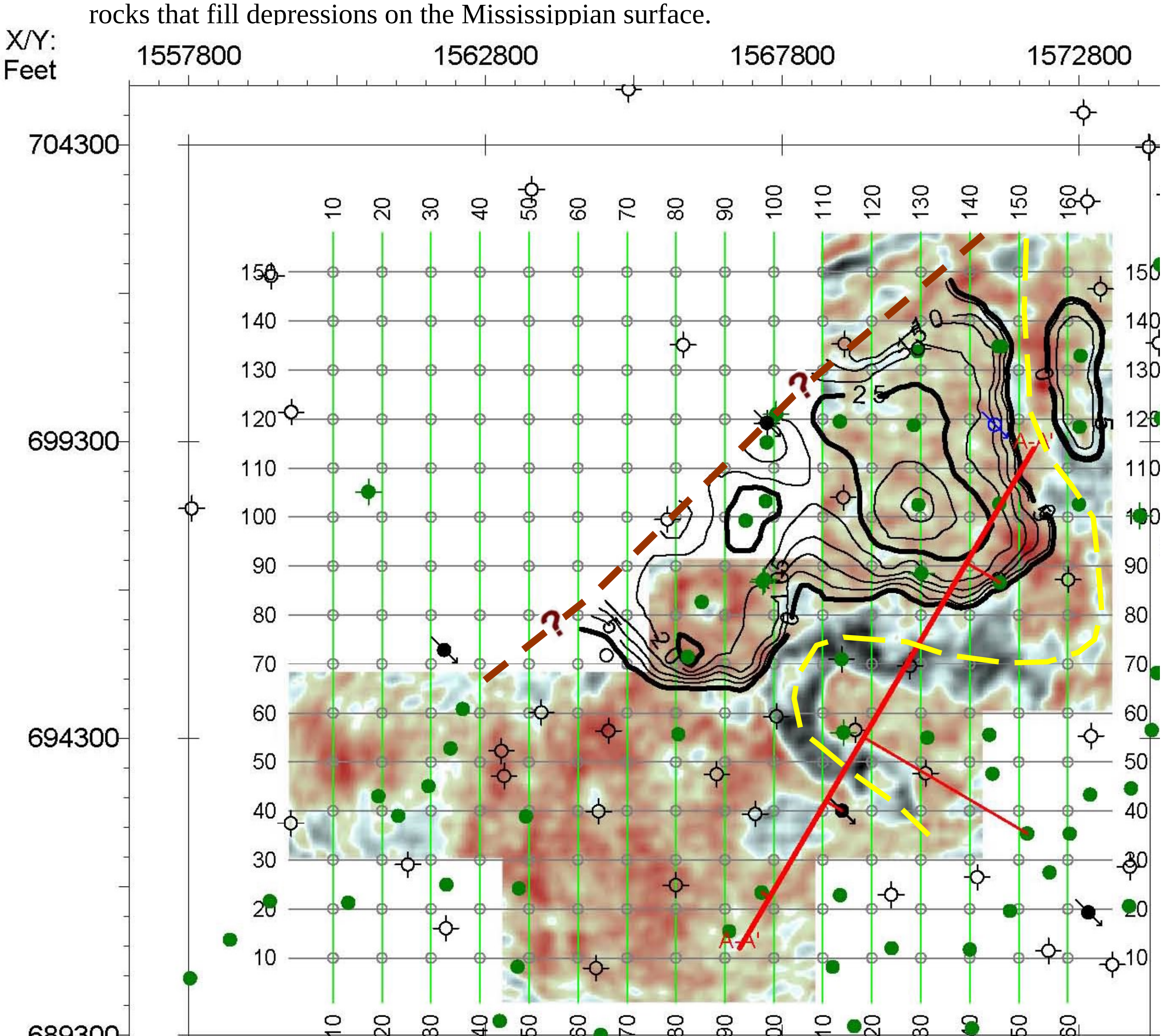

Figure 11. Dickman field. Isopach map of gross feet of Mississippian oil pay overlaid on amplitude slice at 0.85 seconds. High amplitude values (dark gray areas) correlate with possible incised channel on Mississippian unconformity or karst related features. The yellow dashed line is a speculative interpretation of a channel thalweg. The brown dashed line is the location of possible fault projected from the NW corner of the survey. The red line is the location of seismic profile in Figure 9.

A 3-D perspective of the time structure on the top Mississippian and a vertical section extracted from a far offset angle (20-30 degree) pre-stack time migration volume along arbitrary line A-A' show the relationships between structural depressions and discontinuous high amplitude events that coincide with the depressions (Figure 12). This correlation suggests that we can use seismic data to locate the thicker basal Pennsylvanian sandstones, which could significantly improve our ability to model the Dickman field reservoir and to evaluate the potential for CO_2 Enhanced Oil Recovery in Dickman field and similar fields with lithologically complex reservoirs.

After incorporating additional well log impedance data in the inversion of the variable angle, pre-stack time migrated seismic volumes, we plan to use the Hampson-Russell program EMERGE to correlate seismic impedance values with the distribution of lithologic units, porosity and permeability. To further evaluate the fracture model and delineate those fracture trends that influence fluid mobility, we will extract and analyze curvature attribute maps of the porous Mississippian interval from the new impedance volumes. The results of this work will provide the framework for the reservoir model and production simulation studies of the field.

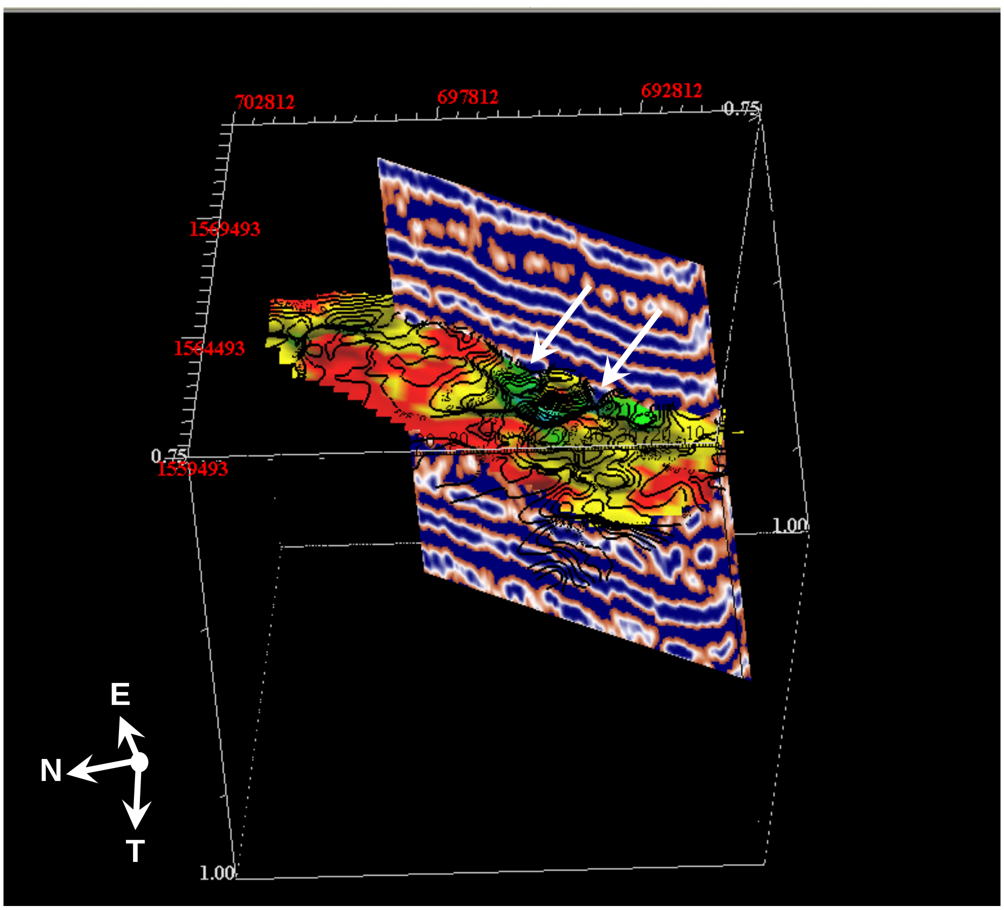

Figure 12. Dickman field. 3-D perspective of time structure (T axis = 0.75-1.00 sec) on top Mississippian and a vertical section from a far offset angle (20-30 degree) pre-stack time migration volume. White arrows point to blue amplitude anomalies in structurally low areas that may indicate basal Pennsylvanian channel sandstones or karst related deposits.

Teapot Dome Field: Because of the graduations of student research assistants and a late disbursement of DOE funding for Fiscal Year 2, we suspended work to analyze further the relationships between attribute lineations, FMI and core-derived fracture interpretations and Tensleep productivity during this report period. We expect to continue this work during the next period.

In the longer term, matching a Tensleep reservoir model with well production data will be the best test of the viability of the reservoir model. Our goal in this phase of the study is to develop a well-constrained, dual-permeability reservoir model that will be suitable for fluid-flow simulation studies of the Tensleep and will demonstrate a seismic-based modeling process with wide applicability in a range of geologic settings. The actual reservoir simulation of production data is beyond the scope of this project.

Illinois Basin-Patoka and Sciota Fields: Work on Sciota and Patoka fields has been deferred pending completion of the processing of the pre-stack data at Patoka field. We plan to carry out impedance inversions of the data from both fields to determine if we can develop 3-D models of the porosity distribution of the Mt. Simon sandstone from the analysis of seismic attributes extracted from the inverted data volumes. Refer to **Task 2.2** above for the status of the reprocessing work on the pre-stack seismic data.

Task 4.0- Calibrate Seismic Attributes with Geological and Engineering Data

Dickman Field: We have deferred work on the integration of seismic and well data pending inversion of the pre-stack migrated data volume, which has just begun (Refer to **Task 3** above for the status of the inversion work).

Task 5.0-Validate Seismic Attribute Analyses Results

We have completed the reprocessing of the pre-stack seismic data for Dickman field (See **Subtask 2.2** above). Our sub-recipient, the Kansas Geological Survey, will carry out the major subtasks, which are to complete the construction of an integrated geomodel at Dickman field and to carry out a reservoir simulation of the field production history.

Subtask 5.1 Construct Integrated Geomodel of Dickman Field, Kansas

Our goal is to validate the results of seismic attribute analyses with a reservoir simulation of the pressure and production history of the field. A necessary requirement to achieve this goal is the construction of an integrated geomodel. The following summarizes our state-of-the-knowledge geomodel for Dickman field.

1. A small structural closure has localized an oil accumulation in the porous Mississippian dolomites and possibly basal Pennsylvanian sandstones, which has an OWC at about -1980 feet subsea and an oil column of about 35 feet.

2. The porous Mississippian saline aquifer underlying the oil accumulation ranges from 200 to 300 feet thick and is a CO2 sequestration target in the Mid-Continent area.

3. The contact between the porous Mississippian and the overlying seal (Pennsylvanian shale and conglomerates of the Cherokee Group) is a karst surface and a slight angular unconformity, which dips to the west.

4. Fractures in the porous Mississippian are aligned N45E and N45W, and the two fracture trends formed at different times. Geologic and production data suggest that the northeast-trending fractures are clay and silt-filled and closed while the northwest-trending fractures are open and form conduits for water to move from the underlying aquifer into the oil zone.

5. Basal Pennsylvanian conglomerates were deposited in the topographically low areas on the Mississippian unconformity. The distribution of the thickest conglomerates may correlate with the distribution of closed fractures, karst sinkholes or incised fluvial channels or a combination of all of the features.

Important missing pieces of the geomodel are the 3-D distributions of porosity and fractures in the porous Mississippian carbonates and overlying Cherokee sandstones. To obtain the porosity distribution, we plan to correlate porosities derived from well logs with the seismic impedance data generated from the reprocessed seismic data. We plan to further assess our field fracture model with attribute maps extracted from the impedance volume of the entire survey area.

CONCLUSIONS

Dickman Field:

1. Curve-shaped anomalies on volumetric curvature attribute maps may correspond to the edges of large karst related depressions or incised fluvial channel meanders on the Mississippian unconformity. These geologic features may be very important in delineating reservoir limits for production simulation studies.

COST STATUS

Baseline Costs Compared to Actual Incurred Costs

Jan. 1-Mar.31	Plan	Costs	
Federal	$35,257	$20,176	$15,081
Non-Federal	$13,444	$0	$13,444
Total	$47,382	$20,176	$27,206

Table 1. Forecasted Cash Needs vs. Actual Incurred Costs

Analysis of Variance

The University of Houston received the delayed second increment of funding from the DOE late in the last reporting period. Because of the late receipt of the funding, UH was not able to add new staff to replace those lost to graduation, resulting in a net positive balance for federal costs. The KU Research Center, a cost share partner, has not submitted a cost share amount for the period, because of the resignation of their P.I. and a shortage of staff to work on the project. Continental Resources, our industry cost share partner, has replaced the staff lost during the past two years and should now be able to participant in the project in the future. We met with executives from Continental Resources, Inc. (CRII), our industry partner, in Oklahoma City on January 31, 2008 to discuss their participation in the CO2 sequestration project. See below for summary of the results of that meeting and a follow-up meeting at UH on February 7, 2008.

MILESTONE PLAN AND STATUS

Critical Sub-Milestones for 2008

1. Complete pre-stack time migration of Patoka field seismic data by **April 30, 2008** (*Subtask 2.2)*.

2. Use Dickman field well log and core data to develop the reservoir property dataset (Sw and porosities) for calibration and validation of seismic attributes by **April 30, 2008,** (*Task 4.0*).

3. Calibrate seismic attributes with well data at Dickman field by **June 30, 2008** (*Task 4.0*).

Actual Progress Compared to Milestones

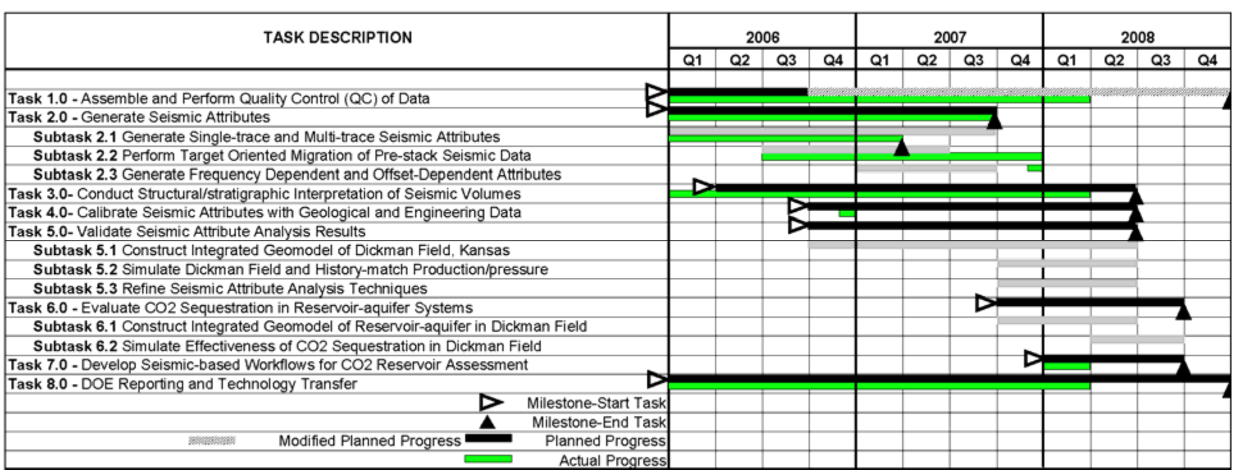

Table 2. Gantt chart

(1) QC of data will continue throughout project.
(2) Patoka migration delayed by noise problem
(3) Deferred pending evaluation of alternatives.
(4) Further work deferred until next period.
(5) Deferred until next period.
(6) Deferred until next period.

SUMMARY OF SIGNIFICANT ACCOMPLISHMENTS

1. On recently processed volumetric curvature attribute maps of the entire survey area, we have recognized curved anomalies that may correspond to the edges of large karst related depressions or incised fluvial channel meanders on the Mississippian unconformity. Basal Pennsylvanian sandstones locally fill these paleotopographically low areas and, if porous, are oil-production on structurally high closures. The ability to use volumetric attribute maps to predict the distributions of basal Pennsylvanian sandstones in geologic settings similar to Dickman field could lead to significantly improved interpretations of the drilling potential of exploration and exploitation targets.

ACTUAL OR ANTICIPATED PROBLEMS AND SIGNIFICANT EVENTS

1. The delay in receiving the second year DOE funding increment has adversely affected our ability to replace students who have graduated in a timely manner. Before the end date of the project on December 31, 2008, we will review the need to adjust project milestones to reflect the temporary cutback in research efforts due to lack of funding and staff.

2. Dr. Robert Stewart, an internationally prominent geophysicist in the Department of Geology and Geophysics at the University of Calgary, will join the University of Houston and CAGE later this year as the Cullen Chair in Applied Geophysics and the Director of the Allied Geophysical Labs (AGL). 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. She is currently a summer intern with a major oil company. We expect to fill several additional faculty positions in geophysics and engineering and graduate student Research Assistant positions during 2008.

3. We met with executives from Continental Resources, Inc. (CRII), our industry partner, in Oklahoma City on January 31, 2008 to discuss their participation in the CO2 sequestration project. At the meeting, we reviewed the progress and challenges of our studies of their Patoka seismic data set. They discussed possible CRII operations to fulfill their $100K in-kind commitment to our CO2 sequestration project. A subsequent meeting with a CRII executive on February 7, 2008 at the University of Houston resulted in the following list of specific CRII project related tasks.

    - Reprocess the Patoka 3-D seismic survey with emphasis on imaging shallow Mississippian CO2 target reservoirs (above 500 ms). UH would be available to provide input on processing parameters.

    - Develop a geological database to support the characterization of reservoir properties with advanced seismic attributes. The work would include quality control of well logs, construction of cross-sections and maps, and calculation of reservoir properties (saturation, porosity, perm., etc.) from logs and core data. Hardcopy and digital data from this work would be available to UH. UH would be available to provide help on geological issues.

- Construct structure and isopach maps on key horizons in collaboration with UH. The primary objectives are Mississippian reservoirs with CO2 Enhanced Oil Recovery potential.

CRII in-kind contributions from this work would include actual external costs incurred for reprocessing of seismic data, new data acquisition for the benefit of the project, consulting time, meetings and travel. In the event that CRII conducts operations because of the work, the costs that directly benefit the CO2 sequestration study would also be in-kind contributions.

TECHNOLOGY TRANSFER ACTIVITIES

The Center for Applied Geosciences and Energy (CAGE) at the University of Houston in January hosted a one-day seminar for consortium members that included 42 oral and poster presentations by graduate students and scientists on the application of state-of-the-art geophysics technology to image subsurface structures and reservoirs and reservoir fluids. Presentations of the results of research related to this project included the following.

Oral presentation

Tom Bjorklund-*The use of 3-D seismic attributes to assess the CO2 sequestration potential of depleted oil reservoirs and deep saline aquifers.*

Poster presentations

Gabriel Perez-*Prestack processing at Dickman Field, KS.*
Zhengyun (Jenny) Zhou-*Case study of impedance inversion in the Dickman Field, KS.*

Outside participants at the seminar represented the following companies and organizations

Amerada Hess	Lawrence Berkeley National Laboratory
BHP	Marathon Oil
Chevron	Paradigm
Conoco Phillips	RepsolYPF
Devon Energy Corporation	Saudi Aramco
ExxonMobil	Shell
Fairfield Industries	Terralince, Colorado
Fusion Petroleum Technologies	TGS

As our project progresses, we will make the results of our research available on the KU CO2 sequestration studies website and the CAGE website at UH. Several researchers plan to present the results of their work at the SEG annual meeting later this year.

REFERENCE

Nissen, S. E., Carr, T. R., Marfurt, K. J., and Sullivan, E. C., *in press*, **Using 3-D seismic volumetric curvature attributes to identify fracture trends in a depleted Mississippian carbonate reservoir: Implications for assessing candidates for CO2 sequestration**, *in* M. Grobe, J. Pashin, and R. Dodge, eds., Carbon Dioxide Sequestration in Geological Media--State of the Art: Special Publication, American Assoc. of Petroleum Geologists.

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