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Reservoir Characterization and Production Modeling/Evaluation of a Rose Run Sandstone Reservoir

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Five wells produce oil and gas from the Colfax Field in Fairfield County, Ohio. The primary production is from the Rose Run Sandstone preserved in an erosional remnant created at the Knox Unconformity.

The main Rose Run sand body within the Colfax remnant appears to be fairly consistent in terms of thickness and porosity based on log and sample evaluations, however production varies dramatically from one part of the remnant to another. Detailed core analysis is available from sidewall cores taken in one well, the poorest producing well. Quartz is by far the dominant framework grain. The only other significant framework grain is potassium feldspar. Cementation is moderate, with quartz overgrowths as the predominate cement. Primary intergranular porosity accounts for the bulk of total porosity. Secondary dissolution porosity only amounts to 1% to 3% of total porosity in this poorly producing well.

A reservoir engineering study evaluated various methods for depletion of the Rose Run Formation. The study reviewed the productive geologic intervals, estimated the original oil in place, and then estimated the drainage area affected by the five existing wells. The estimates of the ultimate recovery of the oil and gas reserves associated with each well were completed through performance/decline trend analysis, volumetric analysis, material balance, and computer modeling. Finally, the study evaluated the possible impact of additional conventional drilling, horizontal drilling, re-stimulation, and water flooding. Preliminary indications are that closer well spacing may best increase primary recovery and that water flooding may be a viable secondary recovery option.

Recent Drilling Activity in the Upper Ordovician Trenton-Black River Limestone, West Virginia and New York

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Recent gas discoveries in the Upper Ordovician Trenton and Black River limestones in New York and West Virginia have generated new interest in the resource potential of the Appalachian Basin. Trenton - Black River strata have been known to be productive since the 1800's in eastern Kentucky, New York, and Ohio. Both comprise widespread, shallow marine carbonates deposited throughout the Appalachian Basin during a Late Ordovician transgression. Late Ordovician, organic-rich, black shale source rocks immediately overlie the carbonates and are interbedded with limestones near the top of the Trenton.

The discovery of gas in the Trenton - Black River in western New York in the mid-1980's was not pursued seriously until the late 1990's when Columbia Natural Resources (CNR) initiated an exploratory drilling program. Encouraged by the NY results, CNR drilled a discovery well in Roane County, WV in spring, 1999 and has followed this with more than a dozen successful wells in the 10,000 foot depth range. In NY, the reservoir is highly fractured, dolomitized limestone; in WV, the reservoir is highly fractured limestone. Narrow grabens related to basement structures form the traps in both states. Modern seismic data are valuable in defining these traps. Production of more than 12 Bcfg from the Trenton - Black River in both states from 1999 to 2000 makes this play a significant new discovery in an old basin.

Porosity/Permeability Trends in a basal Pennsylvanian channel sandstone, Caseyville Formation, Crawford County, Illinois

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During the drilling of the Valdez #7A in the fall of 2001, a 30-foot core was cut through a basal Pennsylvanian channel in section 1, T5N, R13W, Crawford Co., Illinois. The core, cut at a depth of 1219-1249 feet, recovered 24 feet of basal Pennsylvanian sandstone, underlain by six feet of Mississippian sandstone, limestone and shale. The following aspects of the core are notable:

- The core includes the entire channel reservoir, plus the Mississippian-Pennsylvanian unconformity. A basal pebble conglomerate marks the unconformity.
- The sandstone is coarse grained and relatively clean, with little or no shale laminations, and was oil-saturated throughout the entire interval.
- Porosity averages only 15.4%, but permeabilities are high, especially in the upper 11 feet of the reservoir. Horizontal permeabilities range from 1360 to 2536 millidarcies. Vertical permeabilities are 60 to 100% of horizontal permeability, and actually exceeded horizontal permeability in one foot, reflecting the clean nature of the reservoir.

The Valdez #7A was a twin to Valdez #7, and therefore was not logged with geophysical tools. However, a remarkable correlation exists between the resistivity curves recorded in Valdez #7 and the porosity and permeabilities observed in the core recovered from Valdez #7A.

Reservoir Characterization of the South Buckeye Oil Field, Dundee Limestone, Michigan Basin

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Commercial accumulations of oil were first discovered in the South Buckeye Oil field, Gladwin County, Michigan, in 1935. To date, the field has produced nearly 5.5 million barrels of oil from carbonate rocks of the Middle Devonian Dundee Limestone Formation. Secondary oil recovery is currently in progress through a water flood program involving water injector and oil producer wells throughout the field.

Drilling technology during the initial "boom" years in the '30's and '40's (cable tool drilling) involved simple percussion of the subsurface rock formations using a drill bit at the end of a wire line without blow-out prevention apparatus nor effective sampling procedures in use. This technology resulted in the termination of well drilling within the top few feet of an oil-bearing rock stratum with little geological information recovered from the oil reservoir. In general little was known about the geological properties of the reservoir rock formation, even in oil fields like South Buckeye that were highly productive and economically significant. The urgency of oil resource needs during the war years of the 1940's further de-prioritized the collection of scientific data necessary to understand and efficiently produce the South Buckeye reservoir and other Michigan oil fields. The efficiency of oil recovery was probably well below 30% of the original oil in place in South Buckeye up to the 1970's when only stripper wells were in operation.

Wiser Oil Company initiated an enhanced oil recovery (water flood) program in the early 1970's in South Buckeye. In the course of this undertaking, Wiser drilled a number of new wells using modern mud-rotary drilling technology and acquired modern wire-line logs (about 40) and core samples (about 25) from the field. Careful study of this material in the formulation of an enhanced recovery program was never fully completed and the field ownership subsequently changed in the 1980's. A reservoir study was contracted by the new operators, Cronus Energy, at this time in order to more carefully evaluate the spatial distribution and reservoir properties. Results of this study suggested an isotropic and radial distribution of reservoir properties. Enhanced (water flood) recovery was generally not successful and termination of production from the field was considered.

This study evaluated the sedimentary facies present in the Dundee Limestone in South Buckeye field on the basis of core sample material and wire line log analysis. Five sedimentary rock facies were identified from core. The boundstone, grainstone, and dolomitic, silty wackestone facies (in decreasing significance) were found to possess sufficient porosity and permeability to be considered reservoir facies. These reservoir facies were found to be laterally and vertically discontinuous over the field area consistent with an initial distribution controlled by sedimentary depositional environments in a shallow marine, carbonate shelf or ramp environment in the Michigan basin in Middle Devonian time.

The spatial distribution of the boundstone reservoir facies (stromatoporoid "reefal" strata) was considered to be the most significant factor in the reconfiguration of the location of water injector and oil producer wells. Both elevation of the oil bearing strata (geometry and elevation of the Dundee Limestone top surface and position of the oil water contact) and the thickness of this sedimentary facies are important in evaluation of water flood production procedures in the field. Higher elevation and greater thickness of the boundstone facies are the key factors indicating the potential for addition oil production through water flood. Lateral continuity of the main reservoir rock type (boundstone facies) is also fundamental in the configuration of the water flood program.

The main conclusion of the study is that the boundstone bodies have a laterally discontinuous geometry between the northern lobe to the southern higher elevation area of the field. Initial distribution of reefs during deposition of the Dundee Limestone was laterally discontinuous with formation of a probable windward, arcuate reefal body to the west. Cross sections indicate that the northern lobe (despite generally lower initial production and lower structural elevation) may have the greatest potential for enhanced recovery and that the location of injector wells near the periphery of the boundstone facies "thick" in the northern lobe and producer wells in the middle of the lobe would be most effective.

Seismic evidence of faulting and fault reactivation of the Rome Trough with implications for Trenton exploration in West Virginia.

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High-resolution seismic data acquired over the central portion of the Rome Trough reveal at least four periods of tectonic stress release resulting in large scale faulting and fault reactivation. Vertical displacement along the fault planes can exceed 5000 feet at the basement contact and displacement of 250 feet can be found at the Trenton.

Reactivated fault systems, in particular, appear to be an essential exploration criterion for locating highly fractured Trenton Black River carbonates.

Applications of the new "PAYZONE" GIS oil production data set in exploration and development programs in Illinois

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A current database upgrade project, "PAYZONE," has in the past year added thousands of oil producing zones to the ISGS oil and gas Oracle digital database. This database upgrade has direct and immediate applications for use by operators, geological scientists, the public, and the ISGS's scientists in its research and service programs and its contractual obligations. Analysis of the petroleum resources of Illinois is greatly enhanced though use of this expanding database. PAYZONE is the foundation we are building to vastly expand the power to merge Illinois oil production data with other database attributes, such as well status/history, location, formation tops, production volumes, proximity to injection wells and waterflood units, porosity, permeability, and other database attributes. These data can be displayed, analyzed, and interpreted in many manners, such as by mapping using a Geographic Information Systems approach and spatial and statistical analysis techniques. Customers may purchase these data as custom database queries that are readily downloaded into standard spreadsheets or data management software, or as hard copy paper plots. Future ISGS products such as the annual oil and gas fields production reports, waterflood reports, and other oil and gas resource analyses will rely on the improved and enhanced database. Examples of standard and custom PAYZONE applications will be provided, and the steps to acquire and utilize the data in custom applications will be documented.

Coal Resources in the Michigan Basin: Some Suggestions for Development

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Coals in the Michigan Basin are in thin, relatively discontinuous, laterally variable seams (mostly a meter or less in thickness) with numerous partings. The coals are of non-coking, high volatile B and C bituminous rank, with a range of 10,300-12,300 Btu, 3-9 percent ash, and 1-3 percent sulfur. The coal-bearing strata, up to 200 m thick, are of Lower to Middle Pennsylvanian age. Bedrock overlying Pennsylvanian strata unconformably in the central and western part of the basin (Jurassic age "Michigan Red Beds") is comprised of red, gypsiferous shales, gypsum pods, and coarse to fine-grained, pink to tan sandstone with yellow/orange tinge. This sequence is both a caprock seal and in some parts a large aquifer. Elsewhere, Pennsylvanian strata are overlain by unconsolidated Pleistocene and Recent sediments (gravels, silts, clays, and peat) up to 200 m thick.

Remaining reserves are in 100-1500 (mostly less than 250) acre parcels. The principal factors constraining further subsurface development would be the small area available for each mine, the thinness and irregularities of the coal and partings, splitting at the margins of fields, the weak character of roof shales, and the disturbance of significant overlying aquifers.

A three-stage exploration program is proposed: reevaluation of existing logs and cuttings of oil wells penetrating the coal within each parcel selected; the drilling of one test core with geophysical logs within each of thirty townships with demonstrated coal; and determination of gas content of each coal and the sandstone and shale above and below, documenting potential methane recovery.

Environmental Assessment and Remediation of Oil and Gas Exploration and Production Sites

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Environmental remediation and responsibility are important goals for today's Illinois oil and gas producers and royalty owners. The Illinois Petroleum Resources Board (IPRB) environmental remediation programs improve the industry's image and credibility by demonstrating industry resolve for environmental responsibility. The IPRB is committed to providing a practical and economical remedy for environmental problems caused by abandoned oil and gas exploration and production sites in Illinois. The IPRB risk-based environmental assessment and remediation processes follow recognized environmental standards specially adapted to meet the unique needs of the Illinois oil and gas industry. These processes allow IPRB environmental remediation projects to achieve environmental and economic efficiency.

The IPRB uses specially adapted risk-based environmental management processes to achieve environmental and economic efficiency. The IPRB goal to improve the image and credibility of the Illinois oil and gas industry is achieved through risk mitigation planning of environmental remediation projects. Environmental and economic efficiency is achieved when the incremental benefits of a remediation project, including private benefits and external social benefits, are equal to the incremental costs of the remediation project, including private costs of capital and external social costs. In

addition to risk management, IPRB remediation projects are designed not only to cover the explicit costs of their completion, but also justify the cost of capital used in their pursuit. The IPRB fiduciary responsibility to Illinois oil and gas producers and royalty owners is met by employing the economics of environmental efficiency. Porosity/Permeability Trends in a basal Pennsylvanian channel sandstone, Caseyville Formation, Crawford County, Illinois

The Tectonic Development of the Rome Trough: A New Model and Its Exploration Implications

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Preliminary seismic data interpretations for the Rome Trough of eastern Kentucky indicate that the tectonic history previously attributed to the feature has been only partially complete. Classically, the trough has been understood to be simply a syndepositional Cambrian extensional basin that was affected by later unspecified reactivation. Much of our understanding of this feature is based on well data. Only recently has seismic data been broadly available outside the oil industry. The Kentucky River Fault Zone on the north and the Rockcastle River Fault Zone on the south define the Cambrian syndepositional area. New interpretations of seismic profiles show that these fault zones are often characterized by major low-angle, north-vergent thrusting and associated folding that affect the section at least as high as the Knox Group. Above the Knox, data available to us do not sufficiently image the section. However, shallow structure-contour maps in the Carboniferous show folded areas south of and parallel to the thrust faults, indicating post-Pennsylvanian movement. Surface faulting in these areas, however, shows down-to-south normal faults.

Based on these observations, it appears that the tectonic development of the area consists of three major events: (1) Middle Cambrian synsedimentary extensional faulting, (2) Alleghanian contraction that developed thrust faults and anticlinal structures along original Cambrian extensional fault zones, and (3) relaxation or extensional post-Alleghanian normal faulting within these same fault zones, possibly related to the early Mesozoic break-up of Pangea. This new tectonic model has major implications for future petroleum exploration strategies in the area.

Coalbed methane potential of the Seelyville Coal Member in Indiana

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The Seelyville Coal Member, Linton Formation (Pennsylvanian) is one of the most extensive and thick coals in Indiana. Because of its high ash and sulfur content, however, it has become less attractive for mining. Currently, it is being considered as a major target of coalbed gas exploration in Indiana because it is relatively thick (from 1 to more than 9 feet) and occurs at depth up to 1400 feet**.**

Coal thickness, seam depth, rank, and gas content have been used to evaluate the coalbed gas potential of the Seelyville Coal. Coal rank has been determined based on the heating value (Btu/lb, daf basis) and vitrinite reflectance. Gas content was mapped using values calculated from Kim's formula (1977). The calculated values have been compared to available direct determinations of gas content.

In Indiana, coal rank increases southwestwardly tower the center of the Illinois Basin. Exceptions to this trend occur in some parts of Vigo and Greene Counties where coal rank is higher. Calculated gas contents generally follow the trend in rank increase, with the values ranging from 25 scf/ton in Vigo County to 333 scf/ton in some parts of Posey County. Measured values of the gas content tend to be lower that the calculated values, which could be related to gas depletion either at shallow depth or in zones associated with porous clastic rocks.

Petroleum Well Location Maps: A Geographic Information System (GIS) Approach to Petroleum Mapping in Indiana

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For more than 100 years, the Indiana Geological Survey (IGS) has acted as a repository for petroleum well records for the state of Indiana. Historically, well records for Indiana's approximately 70,000 wells were managed using a paper filing system, and well maps were produced using traditional drafting techniques. The IGS recently unveiled a new computer-based system (Petroleum Database Management System or PDMS) for managing well records. Maps of petroleum-related information are generated using information extracted from the PDMS.

This new GIS-based map series, known as the Petroleum Well Location Map (PWLM) series, will replace the existing Petroleum Exploration Map series. This series incorporates all functional aspects of the hand-drawn maps, and provides several significant enhancements over the traditional product. The basic map shows well locations, well symbols, and petroleum field outlines, and may include additional well information such as total depths or producing formations and pipeline locations. Especially significant is the ability to make customized

maps showing information such as producing formations or initial production (IP) values.
The PWLM series is offered as a print-on-demand GIS-based map product. Each map in the series is developed using the Environmental Systems Research Institute's (ESRI) ArcGIS suite of GIS software. The methodology for generating maps relies on dynamically created layer files to display well and label locations stored in the IGS petroleum well database. This provides continuity between the PDMS and the PWML maps.

Coalbed Methane Potential in Illinois-Regional Mapping Data

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Data for major Illinois coals have been compiled to identify areas that have the best potential for coalbed methane development. The thicknesses and depths to the following major coals have been mapped: Danville, Herrin, Springfield, Jamestown, Colchester, Dekoven-Davis and Seeleyville. In addition an aggregate average Illinois coal thickness map illustrates the variation in total coal distribution across Illinois. The greatest total coal thickness occurs in the eastern and southern parts of the state. Individual coals range in thickness from their pinchouts to as much as 10 feet, whereas, the total thickness of all major coal beds may exceed 35 feet locally.
Gas content varies geographically from coal to coal and with coal rank. The first major coal deposited in the basal Carbondale formation, the Seeleyville coal, occurs mainly in eastern Illinois and splits into the Dekoven and Davis coals in southern Illinois. The Seeleyville/Dekoven-Davis coal interval is about 1400 feet below the ground surface at the deepest part of the Illinois coal basin. In our recent test hole drilling program, we encountered the Seeleyville at 817 feet in eastern Illinois and the Dekoven-Davis at 1054-1077 feet in southern Illinois. The most mature Illinois coals have the high-volatile bituminous A rank and occur in the extreme southeastern part of the Illinois coal field. Coal rank decreases to high-volatile bituminous B and then to high-volatile bituminous C from southeast to northwest and north across the coal field.

Online well information for Illinois: finding oil at 11:00 p.m.

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The oil and gas business is a technology-driven one. The amount and types of information that are required to evaluate a prospect are continually expanding, due to the development of new technology. Reserves are regularly being upgraded, as new technology continues to aid in finding new reserves, and to make economic that which was once non-economic. While all this additional information has increased what a geologist has to work with, it has also amplified the difficulty of making a "go / no go" decision on a given prospect. Fortunately, on-line technology is available to retrieve, process, and filter the vast quantity of information that goes into the drilling decision.
Technology is in place to deliver well logs, structure and isopach maps, scout tickets, and geophysical data to your computer at your convenience. It is possible to deliver these data to any geologist—anywhere in the world and at any time of day (or night). The next prospect that you create or review could be done from your own home after traditional business hours.
There is another advantage to creating a central well database that is universally accessible. Illinois is still lagging during a period of generally increased domestic exploration. Many local operators simply lack the financial and technical resources to drill the deeper parts of the stratigraphic section. It is certain that the greatest future successes in the Illinois Basin will not come from the deliberate search for the Cypress and Aux Vases. If exploration in the basin is to accelerate, the driving force will have to come from companies outside the basin. By providing easier access to the information that the State holds, even companies without a *physical* presence in Illinois will be encouraged to work the basin.
In summary, the present is the most propitious time to create an on-line center for accessing geologic data that will expedite exploration in the state.

The Trenton Formation: Why Aren't We Doing Something About It in Illinois?

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The Trenton Formation is a prolific producer of oil and gas throughout the eastern United States and Canada. In 2001, 34 Trenton wells in New York accounted for an estimated 12 BCF of gas. Over its lifetime, the Lima-Indiana trend has produced an estimated 500 million barrels of oil. At Albion-Scipio Field in Michigan, the Trenton-Black River has produced over 150 million barrels of oil from a depth of about 4,000 feet. In southwestern Ontario, the Trenton is responsible for more than 75% of the province's oil and gas production.
These examples are compared to the Illinois Basin. First, analogous basin-forming histories can be drawn between the Illinois and Michigan Basins. Second, similar stratigraphic assemblages exist in all of the above-mentioned productive Trenton areas. Third, Trenton

production has been established in Illinois, although thus far only along a few structural crests. Despite these facts, there has been very little exploration for Trenton reservoirs in Illinois, despite the obviously favorable comparisons to the geology of other basins in the East that do produce from Trenton/Black River rocks.
Integrating geologic and geophysical data, especially geologic mapping of the Precambrian surface, is an important component in the search for Trenton reservoirs. Geologic and/or geophysical data from some of the above Trenton-producing areas will be shown to document successes elsewhere, and encourage future exploration in Illinois.

Geometry And Porosity Trends in Subsurface Ooid Shoals of the Mississippian Ste. Genevieve Formation, Illinois Basin, USA

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Genevieve Formation, an economically important Illinois Basin reservoir, requires better constraints on depositional geometry and trends of subsurface oolitic limestone. Three-dimensional modeling of subsurface core data has identified NE-SW trending ooid shoal bars that indicate strong NW-SE tidal currents were active at the time of deposition. Terrigenous siliciclastics extend for 80 km across the shoal complex from Lawrence County to the Clay City Consolidated field. The distribution of porosity is directly controlled by the orientation and position of these ooid bars. High porosity ($\geq$ 7%) occur as either residual primary interparticle porosity in the oolites or microintercrystalline porosity in microcrystalline dolomites. Periodic subaerial exposure trapped freshwater lenses within the ooid bars contributed to early dolomitization at the base of the ooid bars and in the lime-mud-rich sediments directly underlying the ooid bars. Large interbar lenticular layers of microcrystalline dolomite also occur along the flanks of these ooid bars, possibly indicating a deeper-burial diagenesis of the surrounding facies. Entrapment of hydrocarbons in these lithologies is a result of structural closure, coincident with lateral and vertical changes low-permeability mudstones into wackestones. Future exploration and development strategies in the Ste. Genevieve Formation should incorporate the regional northeast trend of the ooid shoals. Future plays will target high porosity dolomitic reservoirs in the overlying oolite sand bodies as well as along the interbar flanks of the ooid shoals.

Reservoir Characterization for an Alkaline-Surfactant-Polymer Flood of Mississippian Cypress and Pennsylvanian Bridgeport Sandstone Reservoirs in Lawrence Field Illinois

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Research results from a Department of Energy-sponsored alkaline-surfactant-polymer (ASP) pilot flood in Future successful hydrocarbon exploration in the Ste. Lawrence Field, Illinois will be described. Of the estimated 0.7 to 1.0 billion barrels of original oil in place in Lawrence Field, over 330 million barrels of oil have been produced from shallow Middle Mississippian Cypress and Lower Pennsylvanian Bridgeport sandstone reservoirs. Presently, oil cut is less that 3% for this 96 year old field. A successful full field, seven sq. mile, ASP flood has the potential to recover 42 million barrels of oil. A thorough understanding of the reservoir is necessary to realize this potential.
Cypress Sandstone reservoir architecture at Lawrence Field, as well as at many other Illinois oil fields, is characterized by multiple 10 to 40-foot thick, vertically stacked or shingled sandstones. These sediments were originally deposited in shallow marine environments including tidal shoals and linear sand ridges. Oriented northeast-southwest, the ridges are commonly isolated and compartmentalized.
Detailed reservoir characterization of the Pennsylvanian Bridgeport A, B, and D sandstones in a 60 acre pilot area shows that rapid facies changes are responsible for compartmentalization of Pennsylvanian reservoirs. Facies interpretations based on core from six new wells in the pilot area show that these reservoirs are thin, fluvial-deltaic and shallow marine deposits. Evidence from detailed core descriptions, and mapping and modeling of facies architecture show that the porosity, permeability and reservoir quality are closely associated with the distribution of discrete sedimentary facies. Effective implementation of secondary and tertiary recovery strategies need to address compartmentalization and the aerially limited, facies-related differences in reservoir quality.
Petrographic analysis of reservoir rocks and chemical analysis of reservoir oils show there are major mineralogic, diagenetic and chemical differences between the reservoir rocks and oils in the Bridgeport and Cypress reservoirs. Special attention to reservoir compartment geometry and proper chemical formulation of floods are required for optimal recovery from these reservoirs.
Note
Bridgeport and Cypress core from the Lawrence Field pilot area and Cypress core from other fields will be on

process in which over 75 wells were diagnosed and treated using damage identification and reservoir quality diagnostic results in five gas storage reservoirs are presented. Comprehensive diagnostic analyses, which resulted in damage-specific stimulation treatments based on the operator's objectives to enhance existing deliverability, were employed.

In these studies, damage mechanisms were identified using improvements to methods described in a previous Gas Research Institute (GRI) project. Damage in each well was quantified using well test analysis and historical injection/withdraw cycle performance matching. Log analysis, petrophysical data, geological data, wellbore imaging, and work-over historical data were also used for treatment-design criteria. The deliverability improvement was quantified for each well using post treatment diagnostics. Each study incorporated several unique treatment options addressing a variety of damage mechanisms. Treatments were selected to produce the highest deliverability enhancement and maximize the operator's return on investment (ROI).

In the case studies, high-pressure jetting, tailored acidizing, hydraulic fracturing techniques, damage-specific fluid treatments, and high-pressure jetting with foamed chemical treatments were used. The discussion will include the decision-making techniques used in each case and the application of the chosen treatment.

The post-treatment evaluations were updated with one-year and two-year follow-up evaluations to show how the "Solution Team" process significantly optimized deliverability by using the new and improved diagnostic practices**.**

GIS Based Mapping and Distribution of New Oil/Gas Pay Horizon Maps in Illinois

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Oil and gas have been commercially produced in Illinois for over 100 years. Annual oil production peaked at 147.6 million barrels in 1940 and has steadily declined to around 12 million barrels. Current production is dominated by low volume stripper wells. Recent calculations indicate that remaining mobile resources in the Illinois Basin may be as much as 4.1 billion barrels. In an effort to increase the annual production of oil, the ISGS has begun a GIS based approach geared toward analyzing a large database of historical well information.

A new series of pay horizon maps will graphically display the extent of each producing zone. This series will be distributed over the Internet using ArcIMS software that permits users to access and interact with GIS data at their desktops. Additional GIS layers will be added to include historical waterflood and reservoir data.

Reserves Versus Depth

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Review of the Permian Basin was used to test the question if reservoir depth influenced the amount of recoverable reserves. One hundred and ninety-two reservoirs were present from 1,250 feet to 13,800 feet. With depths divided into intervals of 500 feet the largest number of reservoirs, 15, were found at depths of 2,500-3,000 feet, 4,000-4,500 feet and 4,500 to 5,000 feet. Recoverable reserves per reservoir varied from 10.4 million barrels to 2 billion barrels, totaled 23 billion barrels with three billion barrels, 16% of the total, at depths of 4,500-5,000 feet. Oil-column thickness varied from 47 to 1,400 feet, averaged 352 feet with average oil-column thickness of 278 feet at a depth of 4500-5,000 feet. Reservoir porosity varied from 1 to 25 %, averaged 10 %, with average porosity of 13% at a depth of 4,500-5,000 feet. Permability varied from 0 to 903 millidarcys, averaged 35 millidarcys with average permability of 17 millidarcys at a depth of 4,500-5,000 feet. Second largest reserves were at 6,500-7,000 feet with 2.6 billion barrels,

average oil-column thickness of 336 feet, average porosity of 9% and average permability of 15 millidarcys. Average porosity decreased with depth and had little effect on reserves. Average oil-column thickness neither increased or decreased with depth and had little effect on reserves. Increasing with depth the most effective reservoir propertyappears to have been average permability. Results may not apply everywhere but concept in basin study is helpful.

Ordovician dolostones in central Kentucky: possible analogs for Trenton–Black River gas Reservoirs in the Appalachian Basin

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The occurrence of discrete dolostone bodies in Upper and Middle Ordovician limestone strata of central Kentucky has been well documented by geologic mapping done in the 1970's. These dolostone outcrops are spatially related to mapped faults, and have been interpreted as products of hydrothermal fluids that moved along fault conduits, replacing adjacent limestone. There is new economic interest in fault-controlled dolomitization as the result of significant natural gas discoveries in the Ordovician Trenton–Black River Formations in central New York. Gas production from these formations is attributed to dolostone reservoirs localized along faults.

With funding from the New York Energy Research and Development Authority, U.S. Department. of Energy, and Triana Energy, the Kentucky Geological Survey and New York State Museum are studying the central Kentucky outcrops in a 2-year project to provide an analog for similar reservoirs in the Appalachian Basin. Goals of this work include interpreting the timing, structural control, and origin of dolostones, and their relationship to hydrocarbons. Field work has documented stratigraphic controls on replacement of limestone by dolomite. Petrographic work will provide data on the diagenetic sequence and relative timing of dolomitization. Boreholes will be drilled to core two of the larger dolostone bodies, to better characterize their three-dimensional geometry and vertical variability. Geochemical work in progress on the dolostones includes trace element, stable isotope, and fluid inclusion analyses to help constrain a dolomitization model.

Results from the well-exposed outcrops in Kentucky will be linked to cores, logs, cuttings, and production data from active Trenton-Black River fields in New York. The knowledge gained from the outcrops in Kentucky should lead to a better understanding of these complex reservoirs in New York and throughout eastern North America.

Using the Economics of Environmental Efficiency to Conduct Cost-Effective

Directional Drilling for Oil and Gas in Michigan

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Directional drilling is a technology employed by drilling companies to reach subsurface locations from surface locations which are not directly (vertically) above the target area. Several types of directionally drilled wells can exist. Simple deviated holes begin at a surface location and are drilled at some fixed angle to terminate at a bottom hole location geographically offset from the surface location. Complex deviated holes may change angle and/or direction several times before reaching the final bottom hole location. Horizontal wells are a special kind of directional hole that achieves a nearly 90 degree angle of drilling in the bottom portion of the well.

Directional drilling began in Michigan in 1972. Since then more than 3,800 wells have been directionally drilled as simple or complex deviated holes. Additionally, more than 400 horizontal wells have been drilled since the early 1980's. This represents about 8 percent of the nearly 49,000 total oil and gas wells drilled in Michigan since 1925.

Most people did not know that directional drilling even occurred in Michigan until Governor John Engler requested a Michigan Environmental Science Review Board Panel convene to evaluate the risk of directional drilling under the Great Lakes. The Panel's recommendations issued in late 1997 stated that there was little to no risk of contamination to Great lakes bottom or waters through releases directly above the bottom hole portion of directionally drilled wells. There is, however a small risk of contamination at the well head (on land). The panel also suggested that the Michigan DNR rules that regulated Great Lakes bottomland leasing be revised to afford additional environmental protection.

After the MESB's recommendations were made Governor Engler decided to lift existing drilling bans on directional drilling under the Great Lakes from onshore locations. The Michigan DNR was instructed to prepare new leasing regulations in accordance with the MESB recommendations. A final draft of the DNR Real Estate Division's leasing regulations were published in spring of 2001 after extensive consultation with environmental and industry representatives. After the announcement of the intention to renew leasing of Great Lakes bottomlands belonging to the State of Michigan, environmental activist groups began a major media and legislative campaign to reverse the decision.

After many hearings before State congressional committees and the Michigan Natural Resources Commission. The Michigan House initiated a bill to ban directional drilling beneath the Great Lakes. On April 5, 2002 that bill became law and is now known as Public Act 148. Existing producing wells and valid oil and gas

leases on Great Lakes bottomland are exempted from this ban. This legislation has no effect on vertical wells near the lakeshore or directional wells that do not bottom beneath Great Lakes waters.

Resource Assessment of the Springfield, Herrin, Danville and Baker Coals in the Illinois Basin

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This assessment provides overviews of the geologic setting, distribution, quantity, and quality of the major producing coals in the Illinois Basin. These coals are the Springfield, Herrin, Danville, and Baker Coals of Pennsylvanian age. The main products of this assessment are: 1) updated coal resource estimates for the major coals categorized by state, mining district, county, geologic reliability of the estimate, and coal thickness and depth, 2) regional and statewide maps that depict coal extent, thickness, elevation (structure), mined-out areas, areas where the coal may potentially be mined at the surface or underground, and geographic distributions of ash, sulfur, and major, minor, and trace-element contents, and 3) digital databases that contain all publicly available point-source data on thickness, depth, and coal quality. This assessment was a cooperative effort between the State Geological Surveys of Illinois, Indiana, and Kentucky and the U.S. Geological Survey.
Assessment results include:
Danville and Baker Coals – Remaining, identified resources in deposits >42 inches thick and at depths <150 feet are estimated at 1.4 billion short tons; for depths >150 feet, 9.2 billion short tons. Mean ash yield is 11.9 percent (n=334), sulfur content, 2.9 percent (n=335), mercury content, 0.11 parts per million (n=39), and arsenic content, 19 parts per million (n=39). Mean, as-received, calorific value is 10,920 Btu/lb (n=295).
Herrin Coal – Remaining, identified resources in deposits >42 inches thick and at depths <150 feet are estimated at 6.3 billion short tons; for depths >150 feet, 62.4 billion short tons. Mean ash yield is 10.8 percent (n=2,542), sulfur content, 3.0 percent (n=2,517), mercury content, 0.12 parts per million (n=206), and arsenic content, 6 parts per million (n=216). Mean, as-received, calorific value is 11,170 Btu/lb (n=2,390)., and
Springfield Coal – Remaining, identified resources in deposits >42 inches thick and at depths <150 feet are estimated at 5.7 billion short tons; for depths >150 feet, 60.0 billion short tons. Mean ash yield is 11.2 percent (n=1,832), sulfur content, 3.5 percent (n=1,830), mercury content, 0.12 parts per million (n=123), and arsenic content, 12 parts per million (n=145). Mean, as-received, calorific value is 11,280 Btu/lb (n=1,770).

Where Are the Trenton-Black River Hydrothermal Dolomite-Hosted Fields of the Illinois Basin?

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Platform carbonates of the Trenton-Black River (TBR) extend across the northeastern U.S. and adjacent Canada. Recently, gas and oil discoveries have been made in hydrothermal dolomite reservoirs in the TBR of the Appalachian basin, and S. Ontario respectively. Closer to the Illinois basin, similar reservoirs host the Albion-Scipio oil field of the Michigan basin, and parts of the Lima-Indiana field. Are such fields present in the Illinois basin?
These reservoirs formed along reactivated basement-involved faults and fracture zones that served as conduits for saline hydrothermal fluids derived from regional circulation or deep circulation along faults to traverse the low permeability Trenton-Black River. Porosity and permeability were created by solution of carbonate and volume reduction due to the conversion of calcite to dolomite. Oils were derived from distinctive Ordovician source rocks, probably within the TBR and migrated updip via regional aquifers, unconformities and fault zones. Unaltered carbonates and overlying Ordovician shales form the seals.
The elements for development of such fields are present in the Illinois basin. Lack of discoveries may be due to the few TBR tests and targeting of wells toward anticlinal closures rather than flanking, underlying faults. Public domain data are sufficient to model migration of dolomitizing fluids and hydrocarbons. Trenton dolomite reservoirs may occur along minor faults underlying folds of the LaSalle fold belt and along reactivated faults of the Rough Creek-Shawneetown fault zone. Potential fields data can delineate basement-involved faults in favorable migration settings. This allows the seismic data needed to recognize these reservoirs to be acquired in the most prospective areas.

Coal Availability Studies in Illinois - A summary of results for a 10 year program

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Current estimates of original coal resources for Illinois total over 225 billion tons. Over nearly a decade the ISGS has been part of a program sponsored by the U.S. Geological Survey to examine the availability for future mining of major coal seams in the US. The criteria used to define available and restricted resources include rules

based on interviews with mining companies and observations of mining practice. "Available coal" as defined, means that the surface land-use and geologic conditions related to mining the deposit (e.g. thickness, depth, in-place tonnage, stability of bedrock overburden) are comparable with coals currently being mined in the state.
8 major seams have been examined, the Danville, Jamestown, Herrin, Springfield, Colchester, Dekoven, Davis, and Seelyville Coals, which contain 221 billion tons of original resources. Of these combined resources, 96 billion tons are identified as available for mining and 7 billion tons as available with potential restrictions that make these resources less desirable for mining. Technological factors (geologic conditions and economic parameters such as size of reserve block) are the major restriction to mining, and restrict almost 43% of these combined resources. Land-use factors (e.g. towns, highways) restrict 5% of the resources. Whether or not the resources of these coals are ultimately mined is still dependent upon a variety of other factors that were beyond the scope of these studies to assess.

ISGS Digital Coal Database: Herrin Coal Availability and Other Applications

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The Illinois State Geological Survey has been building coal-related databases for more than 60 years. Stratigraphic data from drill holes, quality data from coal samples, as well as field descriptions of rock outcrops and mine exposures initially compiled on punch-cards have been used to construct and update both paper and digital map files used in, and resulting from, coal-related studies.
In the past few years, the traditional idea of a database as a collection of discrete observations or analytical results has widened to include geographic information system map layers, digital image files, and associated metadata. Recently completed statewide assessments of total coal resources and the availability for mining for several coal seams have been used to update separate database elements and bring them together into a standard coal-related data set which both serves, and is served by, a variety of studies on energy and environmental issues. Map layers from our recent capstone study, *Availability of the Herrin Coal for Mining in Illinois*, are now available to the public, industry, and government agencies as published products and as a documented digital dataset.
The ISGS digital coal database includes key map elements such as thickness, depth, structure, mining extent, quality, and availability for mining of each major coal seam. These digital map layers are now being used in studies such as: coal bed methane potential, mine-mouth power plant siting, carbon dioxide sequestration potential, and other projects that require fundamental coal seam information on a regional basis.

Digital Databases To Support GIS Mapping Applications: A Review of Available Databases

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During the last few years, GIS databases have become increasingly available to address needs at the local, statewide, and national levels. In order to access and use this information however, the user must navigate the uncharted waters of arcane technology terms and acronyms. DRGs, DLGs, DEMs, and DOQs are discussed in the same breath as terms such as 1-meter resolution, Thematic Mapper, vector, raster, street centerlines, Landsat, NSDI, Mr. SID, and others. This presentation is designed to take the mystery out of digital databases by presenting information on a number of specific digital databases for GIS and remote sensing applications. The focus of the presentation will concern data sets that are being used and/or are available for users from the USGS, state clearinghouses, and other sources. Specific data types that will be discussed include
Digital Orthophoto Quarter-quads (DOQs), Digital Line Graph (DLG) files, Digital Raster Graphic (DRG) files, Digital Elevation Models (DEMs) and satellite imagery for remote sensing applications. The presentation will also present information on sources such as clearinghouse web sites that can be used to access and download digital databases.

Facies, Sequence Stratigraphy and Diagenesis of Selected Tertiary Cores, North Carolina

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The sequence stratigraphic framework of Paleogene continental shelf sediments of North Carolina has been based on quarry exposures and well cuttings from exploratory wells. This study documents the facies, sequence stratigraphy and bounding surfaces of several Tertiary cores. These include the Kure Beach core, N.C. drilled by the USGS-NC Earth Sciences Coalition, and other previously selected shallow cores. The Kure Beach core is strategically important because it is located in an area that underwent much Tertiary incision by the Gulf Stream and is located near one of the basin-bordering arches.
Facies in the core include near-shore marine quartz sands and mollusk sands, grading offshore into foram quartz silts, and black shale (in Paleocene and Oligocene), open shelf bryozoan-echinoderm grainstone/packstone, and

deep shelf, fine skeletal wackestone/mudstone, foram silts and planktic foram marls. These facies formed on the swell-wave and current swept continental shelf, which had a distinctive inner shelf, shelf break, deep shelf, and continental slope morphology. Paleosols are not developed on sequence boundaries, which are marine condensed surfaces (hardgrounds). The hardgrounds are actually multiple cemented surfaces, with multiple phases of cavity formation and sediment infiltration, and they commonly are overlain by phosphatic clasts reworked from underlying units, some of which are cemented lowstand sands veneering sequence boundaries. These hardgrounds formed during boundary current sweeping. The bryozoan facies contrast with similar facies elsewhere in that they formed in warm water (but non-tropical), rather than a cooler water setting. Local dolomitization of sequences may have occurred in deeper marine, reducing conditions, and porosity is being gradually plugged by calcite cementation, initially under marine conditions, but now as part of the regional aquifer system.

Controls on Silurian Reef Distribution Allow for Cost-Effective Exploration, Clinton and Washington Counties, Illinois

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Production of significant volumes of oil has been associated with Silurian reefs in Clinton and Washington counties, Illinois. More than (??) million barrels of oil have been produced from reef facies and more than (??) million barrels have been produced from shallower, units draped over the reefs in these two counties. Early exploration methods for Silurian reefs included geomorphology, gravity, and coal structure maps identifying shallow structures associated with the underlying reefs. As the large or easily identified features have been drilled, new reefs have been more difficult to find.

A new exploration model was developed to assist in locating unidentified reefs. This model defines the southern boundary of Silurian reef development based on a previously mapped western shelf margin. Localization of reef development on this shelf is controlled, at least in part, by basement faults. Although published seismic data are limited, those reefs with available seismic control are associated with a sub-Silurian fault. Faults may have controlled subtle topography providing more favorable habitat for reef growth or ground water discharge supplying nutrients necessary for reef formation. This model can be used to identify areas of likely reef occurrence on the shelf.

Aeromagnetic data, a cost-effective exploration tool, were used to construct a map of basement fabric/faults. Using the fault map and the geometry of the shelf margin, twelve leads were identified. Reprocessing old seismic lines (another cost-effective technique) provided additional clues to the possible location of reefs in the lead areas. These leads were finally evaluated with acquisition of carefully located, short 2-D seismic lines (<10 miles/lead). Two anomalies were identified and drilling confirmed two Silurian reefs.

Mississippian Biohermal Buildups in the Illinois Basin and Adjacent Regions and Their Hydrocarbon Potential

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Mississippian biohermal buildups occur as (1) small mud mounds in the upper Kinderhookian Chouteau and Compton Formations, (2) biodetrital calcisiltite mounds in the Osagean-lower Meramecian Burlington, Fort Payne and Ullin Formations, (3) biohermal to biostromal bryozoan frame thickets in the lower Meramecian Ullin Limestone, and (4) microbial mud mounds and bryozoan-serpulid-solenoporoid (red algae) bioherms in the lower and upper Chesterian Ste. Genevieve and Kinkaid Limestones. Among these, the only volumetrically important buildups are fenestrate bryozoan frame thickets that are up to 60 m thick. These widely distributed mud-free buildups primarily developed during deposition of the lower Ullin and generally occupied the same niche as Waulsortian mounds. The Kinderhookian-early Meramecian buildups in the Illinois Basin and adjacent regions coexist with crinoidal-bryozoan grainstone facies interpreted to have been deposited in a relatively deep, sub-photic environment. Post-early Meramecian buildups formed in a shallow marine setting and were terminated by rapidly prograding oolitic grainstone facies.

Hydrocarbon production from buildups similar to those we have described here has not yet been proven, but the potential exists. The buildups formed by the bryozoan frame thickets and the other large mounds also create local structures over which porosity zones in the overlying units may be draped, forming hydrocarbon reservoirs. The best such reservoir facies occur in compartmentalized, grainstone sand shoals. The sand shoals consist of crinoidal-bryozoan grainstones in the Osagean-early Meramecian units (e.g., Ullin) and oolitic grainstones in the post-early Meramecian units (e.g., Salem and Ste. Genevieve). Porosity and permeability development in the Osagean-early Meramecian shoal facies is primarily controlled by the relative abundance of echinoderm fragments, which are susceptible to rapid cementation by syntaxial calcite.

Exploration and Development Potential of the Benoist Sandstone in Central Illinois

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The Mississippian Chesterian Age Benoist (Yankeetown) Sandstone produces oil from numerous stratigraphic and structural traps in Illinois. The study area encompassed over 7000 square miles in south-central Illinois with over 1800 correlated wireline logs used in the mapping. Eight different individual Benoist reservoirs were studied for their trapping mechanism and heterogeneity.

Regional mapping of the formation suggests that the Benoist was deposited as part of a deltaic system. A map of the Benoist sandstone isolith shows two distinct linear orientations. The northwest trending sandstone bodies were deposited as distributary mouth bar-channel sandstones. The complex facies mosaic of channels and interdistributary bay deposits can form complex reservoirs with numerous reservoir compartments. The northeast oriented sandstone bodies appear to have been deposited as a series of shoreline strandline systems that formed by coastal processes. The reservoirs within these strandlines can form stratigraphic traps caused by an updip-pinchout of the reservoir sandstone.

Regional mapping of the Benoist depositional systems helps differentiate the play into areas with high and low degrees of reservoir compartmentalization. For development purposes, areas with complex reservoir compartmentalization may have potential infill drilling opportunities because of by-passed oil. The regional mapping also provides a clue on whether an exploration prospect would have a strong structural or stratigraphic component to the trap.

Did Compaction Fluids Influence Paleozoic Reef Development in the Illinois Basin?

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The importance of expelled fluids on the development of "vent" communities in modern oceans is now widely recognized. Many examples of Mesozoic "vent" communities have also been documented. Development of Paleozoic reefs, however, is typically attributed to growth along shelf margins or on subtle paleohighs, despite the fact that many of these Paleozoic reefs developed over thick shale sequences**.**

In the Illinois Basin, two of the best known sets of hydrocarbon-bearing reefs occur in the Silurian, a hundred feet or so above the thick Upper Ordovician Maquoketa Shale, and in the Ullin Limestone, just above the thick New Albany Shale. It seems likely that compaction waters, perhaps combined with biogenic methane, from these shales, migrated out of the shales during burial and compaction. Thus, "vents" on the respective Silurian and Early Mississippian sea floors may have helped localize reef development. Such compaction fluids probably migrated preferentially along faults and fractures that provided permeable pathways for the compaction fluids.

A similar scenario can be used to explain the development of the Lower Mississippian Waulsortian mounds in the Lodgepole Formation of Stark County, North Dakota (Williston Basin). There, surface lineaments intersect in a horseshoe-shaped pattern that apparently allowed vent communities dominated by crinoids, fenestrate bryozoans, and ostracods to form buildups more than 300 ft high. Abundant marine cements helped lithify these buildups, giving them reef walls that dip at up to about 60º.

It remains to be proved if the development of Silurian and Lower Mississippian reefs in the Illinois basin can be related to migration pathways of compaction fluids generated in the underlying shales, but preliminary evidence suggests this idea. Silurian reefs in Washington County, Illinois, for example, formed where linear faults intersect a paleo-shelf margin.

Subsurface Structures and Paleovalley Orientations Delineated from Distribution and Thickness Patterns of Carboniferous Rock Units along the Southern Part of the La Salle Anticlinorium, Illinois Basin, Lawrence County, Illinois

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Subsurface mapping of Carboniferous rock units from the Beech Creek ("Barlow") Limestone of the Pope Group (Mississippian) to the Springfield Coal Member of the Carbondale Formation (Pennsylvanian) at the southern part of the La Salle anticlinorium, Illinois Basin, suggests that small-offset faults (less than 10 feet or 3 m) exist which are parallel or coincident with previously delineated flexures and paleovalleys. Data from 720 geophysical logs derived from a 170 mi^2 (350 km^2) area of Lawrence County, Illinois were used to produce a network of intersecting cross sections and distribution and thickness maps of selected rock units. An informally named sandstone unit ("sandstone A") tentatively correlated at the base of the Caseyville Formation (Pennsylvanian) and three informally named sandstone units ("sandstones B, C, and D") within the overlying interval of the Caseyville Formation and Tradewater Formation were mapped. An east-west trending paleovalley entreched in the Beech Creek ("Barlow") Limestone separates an area of thin "sandstone A" in the north-central part of the study area from an area of thick "sandstone A" to the south. On the western limb of the Bridgeport anticline, a local structural element of the La Salle anticlinorium, "sandstone A" is separated by a

north-south trending "shale gap" facies with the Tar Springs Sandstone (Pope Group). An abrupt westward thickness increase of "sandstone B" west of the hinge line of the La Salle anticlinorium suggests a depositional response to uplift of the anticlinorium or basinal subsidence. A significant thinning of "sandstone C" across the axis of the Bridgeport anticline suggests continued uplift and antiform development. The abrupt thickness changes, discordant dips, and linearity of these sandstone units, as well as the juxtaposition of erosional valleys and the "shale gap" facies suggests the presence of small offset faults that outline an ancestral structural block which is coincident with the Bridgeport anticline. The uncertain correlation of "sandstone A" precludes the exact placement of the Mississippian-Pennsylvanian unconformity and the timing of corresponding structural events.

The Role of Existing Seismic Reflection Data in Evaluating Sites for CO_2 Sequestration and Natural Gas Storage in the Illinois Basin

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For the past several years, the Illinois State Geological Survey (ISGS) has pursued a vigorous program of procuring seismic reflection data from the Illinois Basin previously acquired by the petroleum exploration industry. The availability of these data have been used to leverage acquisition of grant and contract funds from, e.g., the U. S. Geological Survey and the National Science Foundation through the Mid-America Earthquake Center. Such funds are used to support processing, interpretation, and archiving of seismic data at the ISGS. Although most of these data remain proprietary and are used only according to the owner's specification, ISGS researchers may use the data for non-commercial purposes, such as scientific studies of the structural and stratigraphic framework of the basin, seismic hazard evaluation, and detailed analysis of specific geologic features (e.g., anticlines and domes). 2-D and 3-D seismic reflection data are received in varying formats, including paper and film copies and/or digital records of raw or stacked and migrated data. The ISGS has excellent hardware, software, and personnel resources that enable us to scan, reprocess, and create state-of-the-art in-house databases, which allows incoming data to be fully integrated with a great variety of ancillary geological, geophysical, and GIS data. Our reprocessing and data integration capability effectively increases the value of the original seismic data for both the ISGS researcher and for the original data owners. For example, the results of reprocessing and mapping of reflection profiles currently available over the major folds and monoclines of the Illinois Basin reveal deep-seated faults penetrating lower Paleozoic strata and underlying basement that propagate up into the cores of folds. The pervasiveness and pattern of deep fracturing beneath folds are critical factors for evaluating the viability of a structure in Paleozoic strata for CO_2 or other gas storage. The asymmetry of some folds in Mississippian and Pennsylvanian strata suggests the possible presence of a deeper, facilitating reverse or thrust fault. A distinct forward hinge typically appears at the top of Precambrian basement beneath folds mapped in Paleozoic strata. Truncated and offset intra-basement reflectors below this hinge imply a reverse fault within Precambrian rocks. Reprocessed long-record reflection profiles reveal seismic facies with a sedimentary character below the basal Mt. Simon Sandstone (Cambrian), which are bounded by strong, laterally continuous reflectors expressed as broad "basinal" packages that become areally more restricted with depth. At least four highly coherent, layered, unconformity-bounded seismic stratigraphic sub-Mt. Simon sequences that could total several thousand meters in thickness can be mapped in three dimensions over distances in excess of 200 km. The shallowest part of these sequences may host reservoirs capable of storing natural gas or sequestering CO_2. Ultimately the selection of a suitable structure for gas injection will require new 3-D seismic coverage; however, available 2-D profiles can provide a cost-effective means for sifting through the multitude of possible structures in the Illinois Basin.

Natural Gas Exploration and Development in the Finger Lakes Region of New York: A Tale of Science, Politics and Public Perception

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For the past 30 years, Silurian Medina Group sandstones reigned as New York's major natural gas play. Recent exploration success targeting the Ordovician Trenton / Black River carbonates, however, has transformed New York's industry. With fewer than 100 producing wells, production from the Trenton / Black River is forecast to surpass the Medina by the end of 2002. A quick comparison of reservoir characteristics shows that the Trenton / Black River is more of a technology play compared to the Medina. The structurally-controlled Trenton / Black River reservoirs are formed in narrow zones of hydrothermal dolomitization requiring high resolution seismic and other technical methods of identification.

New York's Trenton / Black River production region is centered around the Finger Lakes and contains a mix of private, state, and federal lands. The region experienced both the Oriskany boom of the 1930s and the Queenston development of the 1960s. In 1998, the federal government received a request to grant a lease in the Finger Lakes National Forest, the only designated national forest in New York. Situated between the southern sections of Cayuga and Seneca lakes, the forest totals approximately 16,000 acres. In 2001, United States Forest Service and the Bureau of Land Management jointly issued the draft environmental impact statement outlining drilling alternatives as required by National Environmental Policy Act. This action generated an acrimonious public debate over natural gas development on federal lands where scientific reasoning was effectively disregarded.

Sequence Stratigraphy of the Lower Mississippian in Ohio and West Virginia: Origin of the Black Hand Sandstone as Incised Valley Fill.

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Lower Mississippian sandstones of the Appalachian Basin have been primary exploration targets since the late 19th Century. These distinct, north-south trending sandstones have been interpreted as everything from delta fronts to fluvial channels. The Black Hand Sandstone of central Ohio may shed some light on the origin of these sandstones. The Black Hand in outcrop is the stratigraphic equivalent of the Big Injun sandstone of the subsurface. A coarse-grained, conglomeratic sandstone surrounded by finer-grained marine clastics, the Black Hand has always been an anomaly. Interpretations range from distributary mouth bar to shoreline sand. The Big Injun and Black Hand share several characteristics-lithology, narrow linear geometries, anomalous thickness, sharp basal contacts - commonly associated with incised valley deposits.

To reach a thickness of 500 feet, as seen in central Ohio, the Black Hand was probably deposited during a series of drops and recovery in relative sea level. Several factors may have contributed. Isostatic rebound of the Appalachian Foreland Basin during the Early Mississippian changed the basin geometry, resulting in rapid southwesterly progradation and contributed to lowering relative sea level and initiating incision. An unconformity at the Kinderhookian-Osagean boundary in the mid-continent also implies a drop in relative sea level. The cause is unclear, but may be related to glaciation of Gondwana suggested by tillites in South America. Available biostratigraphic data points to late Kinderhookian incision followed by a subsequent transgression during the early Osagean. The Black Hand and Big Injun sandstones were deposited as valley fill during this transgression.

The Relationship Between Silurian Reefs and Structural Features in the Michigan Basin

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Early Silurian strata in eastern Wisconsin exhibit previously unrecognized depositional patterns and structural features that played a significant role in the later development of reef trends in the northern portion of the Michigan Basin.

Slow subsidence and shallow, marginal-marine deposition characterized northeastern Wisconsin and adjacent portions of the Upper Peninsula of Michigan beginning in the late Ordovician and extending into the early Silurian (early Llandovery). In the Illinois Basin to the south, normal-marine shelf deposition predominated. During the mid-Llandovery, a prominent uplift occurred in east-central Wisconsin which resulted in a broad topographic high displaying a southwest-northeast trend. This high area became emergent and was karstified. Subsequent onlap during the late Llandovery and early Wenlock produced a shallow water carbonate bank, which overlies and runs parallel to this uplifted area. This bank separated areas of continued shallow water deposition to the north that was commonly marginal marine in nature from basinal environments to the south. Numerous individual reefs developed down slope and basinward of the bank deposits.

This trend appears to extend across Lake Michigan to the northeast where considerable amounts of oil and gas have been recovered from deeply-buried Silurian reefs in the Lower Peninsula of Michigan. Only limited data are available for early Silurian and nonreef rocks in this region, but those that are available fit the depositional trends seen in eastern Wisconsin. Currently there is no information suggesting similar tectonic controls on the location of reef trends in the Silurian rocks of southern Michigan or the Illinois Basin.

Previous studies of the Silurian paleogeography of the Michigan Basin suggested that general basin subsidence was the primary control in the development and distribution of the Silurian reefs. It is now clear that a more localized short-term tectonic event was probably the cause for both the development and location of the northern reef trend.

Illinois Coalbed Methane Assessment

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Illinois, with its huge 200 billion ton coal resource, has lagged behind other regions of the country in coalbed methane (CBM) development. Recent core drilling by the Illinois State Geological Survey (ISGS) provides encouraging new data on the gas content and origin of CBM in the State. Prior to this study limited published gas content values ranged from 8 to 118 ft^3 gas per ton of coal. ISGS drilled a continuously-cored, wireline-retrieved, test hole in each of Richland, Franklin, Clark, Macoupin and Bureau Counties. All major coals and several black shales were cored and analyzed. New gas content values are considerably greater than previously reported- some exceeding 150ft^3/ton. Thicker coals tend to have greater content values per ton of coal, and gas contents tend to increase modestly with depth of coal. The highest gas contents were from coals in Franklin and Clark counties. Desorbed methane isotope values range from delta $^{13}C_{PDB}$ of -55 to -70 parts per mil and delta D_{SMOW} of -230 to -200 parts per mil, indicating primarily a biogenic (CO2 reduction) mechanism for generating the methane with a small thermogenic overprint.

CBM drilling activity is at an early stage in the Illinois Basin. A coal mine project with co-generation of heat and electricity from mine gas combustion powers a hydroponic farm in Saline County; excess electricity is sold. Another company has drilled into several abandoned Franklin County mines and is completing gathering lines and pipelines for transmission pipeline sales. Several companies have drilled coalbed wells, but the only production is from North Dugger field in west-central Indiana where more wells are planned.

Drinking Water / Energy Exchange Groundwater Source Exploration
Using Large Scale Land Forms

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In Indiana, groundwater sources are being developed using large-scale glacial geomorphology for exploration and drill site selection. The requirements of wellhead protection have renewed interest in funding and exploring for the remote and/or buried outwash sand and gravel aquifers.

In Putnam County, west of Reelsville, the ancient (possibly Pre-Wisconsinan) channel was traced under US 40. An apparent stream capture in the regional drainage pattern exposed the buried channel.

In Boone County, at Whitestown, a blanket sand contains a braided outwash channel. The alignment of the local glacial sluiceways indicated the position of the buried, braided sand and gravel aquifer.

In Hancock County, at Fortville, the extension of a series of till plain depressions, backed by local residential water well drilling, shows an apparent buried aquifer.

In Madison County, at Ingalls, a deeply buried tributary valley is being developed as a 1-2 MGD capacity wellfield to replace a surface water source. A series of poorly drained surface depressions on the till plain indicated the location of the buried valley. Individual wells have been successfully test pumped at over 500 gallons per minute.

In Rush County, at Carthage, an erosional saddle that cut across a bedrock high, below an ice age sluiceway, was confirmed to contain a buried layer of sand and gravel more than 50 feet thick in an outwash channel deposit capable of supporting a new replacement wellfield.

Regional Seismic Interpretation of the Rome Trough, West Virginia – Implications for Deep Gas Exploration

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Interpretation of regional seismic data across the Rome Trough of West Virginia reveals a series of significant trough-margin and interior faults that were active at various times during the Paleozoic. Extension, associated with the opening of the Iapetus sea during Cambrian time, created the Rome Trough, a NE-trending failed rift. Increased accommodation space within the rift allowed for the deposition of a thick sequence of Cambro-Ordovician clastic and carbonate rocks, including the Trenton-Black River carbonate section, which is currently a primary exploratory target within the Rome Trough and throughout the Appalachian basin. Significant growth during Cambrian time took place on the interior side of major trough margin and interior faults.

Reactivation of trough-margin and interior faults took place in Late Paleozoic time in response to Alleghenian deformation. Reversal of Early Paleozoic normal faults and resultant structural inversion created shallow- and intermediate-depth structures and enhanced fracturing of deeper strata along pre-existing fault zones.

A number of intermediate-deep gas plays can be related to faults within the Rome Trough. These include: (1) structural traps at the level of the Devonian Huntersville Chert and Oriskany Sandstone and the Silurian Newburg and Tuscarora sandstones; (2) fractured carbonates of the Ordovician Trenton-Black River Groups; and (3) structural and stratigraphic traps within the Cambrian rift sequence.

Plummer Shoal – A Model for Middle Mississippian Salem Limestone Exploration

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The Plummer Oil Field, located in Greene County, IN, was discovered in 1969 and has produced over six million barrels of oil, mostly from the Salem Limestone at an approximate depth of 700 feet. It is the most productive Salem oil field in Indiana.

The total reservoir consists of four skeletal grainstone beds and one skeletal oolitic grainstone bed separated by impermeable carbonate mudstones. These porous compartments thin from over thirty feet in the bottom "E" zone to a maximum of eight feet in thickness in the top "A" zone. The highest recorded log porosity in each of the zones is more than 20%. The geometry of the lower four skeletal grainstones conforms to an arcuate shape of an underlying Silurian reef. The uppermost skeletal-oolitic grainstone is elongated into northeast-southwest possible tidal bars. Four cores in the upper portion of the Plummer Field indicate depositional settings ranging from subtidal shoal, intershoal, restricted lagoon, and tidal flat.

Although the subtidal shoaling conditions existed in a wide range across the inner ramp of the eastern portion of the Illinois Basin, the Plummer Shoal was a dominant seafloor feature. The present structural closure on top of the Salem is about 80 feet. The numerous individual shifting shoals were deposited in a structurally simple intracratonic basin where relative sea level changes and storms produced variable sediment packages and stacked geometries.

A working knowledge of structure, depositional environments, facies, porosity-permeability distribution, and an understanding of lateral-vertical relationships are a must to Middle Mississippian Salem exploration.

Potential for CO_2 Sequestration through Enhanced Recovery in Ohio

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Large, economic sources of CO_2 are currently unavailable for use in enhanced recovery operations in much of the eastern U.S. On-going research into CO_2 separation and sequestration may hold promise for providing local sources of CO_2. Many power plants and other large point sources of CO_2 emissions are located near hydrocarbon reservoirs that are amenable to CO_2 storage. Further, in many cases, CO_2 injection can enhance oil and gas recovery, which can offset the cost of CO_2 capture.

In Ohio, enhanced recovery accounts for less than 1 percent of oil production, compared to as much as 50 percent in the neighboring Appalachian basin states. Many of the older Ohio fields are currently near the end of their economic life in terms of primary recovery and are approaching abandonment. Methods and strategies need to be developed to sustain these older fields through better reservoir characterization that can lead to improved reservoir management and enhanced recovery methods before they are prematurely abandoned. This presentation is focused on selected Knox and "Clinton" fields that have potential for enhanced oil recovery.

With the completion of the Midcontinent Interactive Digital Carbon Atlas and Relational Database (MIDCARB), hydrocarbon reservoir, fluid, and production data will be easily accessible. Determination and estimates of average oil and gas field parameters such as original reservoir conditions (OOIP, area, thickness, porosity, permeability, initial saturations, pressures, temperatures, etc.), fluid data (oil gravity and viscosity, water salinity), and production data (cumulative production, well spacing) should assist the oil and gas industry in seeking potential areas for enhanced recovery.

Subsurface Facies Analysis of the Cambrian Mt. Simon Sandstone in Western Ohio

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In Ohio, the Precambrian basement and overlaying Cambrian section is subsurface. On the western flank of the Cincinnati Arch, the Cambrian Mt. Simon Sandstone is the first sedimentary unit deposited above the basal unconformity, and is of interest as a potential hydrocarbon reservoir and as a target for hazardous waste deep-well injection. Detailed subsurface facies analysis of the Mt. Simon Sandstone was conducted from continuous cores and geophysical logs from two wells: the Ohio Department of Natural Resources (ODNR) Warren County well (DGS 2627) and the British Petroleum Company (BP) Allen County well (BP 4).

In the ODNR well, the Mt. Simon Sandstone shows a generally coarsening- and thickening-upward sequence of sandstone, siltstone and minor mudstone. Tidal rhythmites, flaser and lenticular bedding, mud drapes, interclasts, and significant bioturbation structures attest to a shallow marine, tidally influenced depositional setting. The coarsening-and thickening-upward sequence is interpreted as a transgressive barrier sequence, documenting migration of the barrier itself (the bulk of the Mt. Simon Sandstone) above basal lagoonal/estuarine succession. Independent tests of the geophysical logs shows a characteristic signature of the facies described and interpreted from core samples.

On the basis of the geophysical logs, depositional facies were predicted in the BP well then confirmed by facies analysis of the core samples from that well. Facies were predictably recognized, however it became apparent that previous workers had misidentified the upper contact between the Mt. Simon Sandstone and Eau Clair Formation in this well. A regional interpretation based upon both wells suggests the Cambrian coastline was

oriented NE-SW, and transgression proceeded to the NW during this interval.

The Origin of Prolific Reservoirs in the Geneva Dolomite (Middle Devonian), West-Central Illinois Basin

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The Geneva Dolomite, commonly the basal member of the Middle Devonian Grand Tower Formation in much of the Illinois Basin, is an exploration target that has recently generated much interest. A new discovery in the Geneva was completed for up to 3,000 barrels of oil per day at a depth of 4,000 feet in the west-central part of the Illinois Basin. A study of reservoirs in the Geneva Dolomite at Raccoon Lake, Sandoval, Patoka, Miletus and St. James oil fields shows that pronounced structural closure, fracturing, and formation of secondary porosity through dolomitization and dissolution are associated with reservoir development and entrapment of petroleum.
Draping of younger Middle Devonian strata over Silurian reefs has resulted in approximately 100 feet of closure at Sandoval and Raccoon Lake fields. Patoka field, which overlies a larger, deeper seated structure, also produces from the Ordovician Trenton Limestone. St. James field is an anticline that initially produced from shallower Mississippian strata prior to the discovery of Devonian reservoirs. Examination of core from Geneva Dolomite reservoirs shows the rock to be a brown, vuggy, and sucrosic dolomite. We suggest that post-depositional dolomitization of Geneva carbonates combined with dissolution of fossil material is a viable mechanism to explain the enhanced porosity, permeability, and brecciation found in Geneva Dolomite reservoirs. Mapping suggests that Devonian-age structures, commonly associated with underlying Silurian reefs, are an element that enhances reservoir porosity and more recent structural movement has created the pronounced closure needed for petroleum entrapment.

Fracture Characterization with Borehole Imagery: An Example from the Mount Vernon Unit, Lamott Consolidated Field, Posey County, Indiana

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Horizontal wells with borehole imagery are rare in the Illinois Basin. As part of a detailed reservoir monitoring study, Team Energy, L.L.C. and Schlumberger drilled a horizontal borehole into the Mississippian Cypress Sandstone in the Mount Vernon Unit, less than a mile southeast of the Carbon Fault. Both wireline and logging-while-drilling (LWD) logs were collected in an inclined pilot hole. A full set of LWD logs and electrical image logs were collected using the GeoVISION* tool in the horizontal drain hole. In addition to allowing highly accurate placement of the well into a thin oil column, the borehole imagery revealed the presence of a dense network of steeply dipping, open fractures. Over the 640-ft logged horizontal section, 157 fractures were interpreted from the image logs. Two fracture sets are present; the principal one strikes ENE, and the second strikes NNE. Detailed examination of the fractures on the borehole imagery shows that most of them terminate vertically against thin shale beds, which are acting as mechanical boundary layers. Because these thin shale layers are ubiquitous in the reservoir, the fractures will not contribute substantially to the vertical permeability of the formation but may enhance the horizontal permeability and could affect the drainage characteristics.
*Mark of Schlumberger

Integrated Reservoir Characterization of Dolomitized Cambro-Ordovican Beekmantown Carbonates, Mohawk Valley, New York

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Dolomitized Cambro-Ordovician Carbonates of the Beekmantown Group in New York may be an overlooked natural gas resource. Cores and outcrops from the Mohawk Valley have well-preserved porosity in dolomitized grainstones and dolomite cemented breccias and vugs. Nearby wells have had gas shows from the interval, but there has been little production to date.
The cyclic Beekmantown carbonates are composed of mottled subtidal wackestones, shallow marine high-energy grainstones and packstones and low-energy, and peritidal algally bound mud-dominated carbonates. All of the carbonates in the Lower Beekmantown Theresa and Little Falls Formations are dolomitized; the overlying Tribes Hill Formation is pervasively dolomitized near normal faults, but is mostly limestone away from the faults. Some of the fine crystalline dolomite of mud-dominated carbonates may be of an early “top-down” origin, but coarse dolomite of the grain-rich carbonates and very coarse saddle dolomite cement in breccias and vugs are clearly of a later “bottom-up” origin.
Common subaerial karst breccias a have fine micritic matrix and later hydrothermal breccias have a saddle dolomite and calcite matrix. Later hydrothermal “karsting” preferentially affects previously subaerially karsted intervals.

Reservoir quality is best developed in the dolomitized grain-supported rocks and the hydrothermally fractured intervals. Coarse dolomite replacing grainstones and packstones have excellent intercrystalline porosity, which is commonly reduced by bitumen. Hydrothermal fracturing created large voids, which are only partially filled by coarse saddle dolomite. The combination of matrix and fracture porosity preserved in Beekmantown carbonates could produce economic rates of natural gas given a good source and trap scenario.

Estimating Carbon Dioxide Sequestration Potential in Mature, Multi-pay Petroleum Fields in Indiana

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The record of historical oil and gas production, together with associated reservoir characteristics, offers the best available means to estimate the effective reservoir capacity of a petroleum field and its suitability for CO_2 sequestration. Many of Indiana's potential CO_2 storage fields are large, mature, multi-pay petroleum fields that contain numerous small reservoirs scattered throughout. Unfortunately, produced volumes are not available for individual reservoirs because production often is commingled from different zones and is reported on a lease-by-lease basis rather than by individual well. We analyzed single-pay fields and other fields from which production could be isolated by producing zone to establish representative production volumes and reservoir characteristics for individual formations. In these cases, parameters such as initial production rate, porosity, and permeability can be related to reservoir performance. Using these reservoir characteristics as a guide, it was possible to generally apportion cumulative production in several large multi-pay fields into component formations and isolated reservoirs, and to more thoroughly describe the extent and sequestration potential of the reservoirs.

THE ENGLISH BASIN AND THE LOUISVILLE UPLIFT: EXPLORATION POTENTIAL FOR THE EASTERN SHELF OF THE ILLINOIS BASIN

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The English Basin is interpreted as a Meso- and Neoproterozoic-aged depocenter, developed beneath Paleozoic strata in Kentucky and Indiana. The Louisville Uplift defines the eastern basin margin, interpreted as a western vergent foreland-style basement thrust exhibiting 8 km of vertical uplift.

Seismic data reveals a complex depocenter with a depth to crystalline basement exceeding 6100 m. Seismic reflectors traced over a large lateral area depict a layered Proterozoic sequence. Potential field data tied to regional seismic data allows interpretation of basinal geometry.

A thrust-fault system developed in the lowermost Centralia Group is named the Hoosier Thrust Belt. Above an angular unconformity truncating Centralia strata, the interpreted volcanic and volcaniclastic sediments of the Wyandot Formation (proposed) are deformed by the 600mya foreland thrust. The Neoproterozoic-aged Marengo Formation is interpreted as foreland basin fill.

Subsequent tectonism during the Middle Cambrian resulted in rift style sedimentation within the English Basin. Remobilization tectonism is evident during the Taconic, Acadian and Alleghenian Events, and possibly the Jurassic/Triassic break-up of the Pangean supercontinent.

Significant large-scale structures may provide excellent potential for hydrocarbon exploration. The margins of the Louisville Uplift are expressed in Paleozoic strata by shallow fault systems. The remobilization of the faults controlled the development of hydrocarbon fields along the margins of the basin. Other trap types include far-field thrusting, forced folds, wrench faults, extensional fault blocks, and stratigraphic traps.

Estimating Coalbed Methane Desorption from Wireline Bulk Density Logs

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A simple function is used to estimate coal-bed methane desorption from wire-line bulk density logs. The density log is calibrated to lab measured coal-bed methane desorption on cored High Volatile "B" coal samples in the Illinois Basin, Illinois, and Forest City Basin, Kansas, to obtain the function. The function has different constants and exponents for each basin. The calibrated function is applied to non-cored coals of the same type in the same basin to obtain a continuous desorption estimate over the well. Total desorbed gas in place is determined for a given drainage area. Operators can use this technique to identify high quality coals and rank coal-bed methane wells. Gamma ray and density logs are used to quantify coal, clay and rock lithology. In some cases density log values identify rock lithology without cross plotting with another lithology log such as sonic or neutron. These two methods are of particular interest because gamma ray and density are often the only logs available in coal-bed methane wells.

Coal-Bed Methane Potential and Activity in the Illinois Basin

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The Illinois Basin is a Pennsylvanian Age series of deltaic deposits that lie in Illinois, Southwestern Indiana and Western Kentucky. The basin has undergone exploration for coal-bed methane since 1985 has seen intermittent activity. The greatest potential for coal-bed methane lies in the Carbondale and Spoon formations of Desmoinesian age. The coals are thin, have large lateral extent, are high volatile C to A bituminous rank, sulfur content varies from 2% to 11%, ash 5% to 15% and moisture contents tend to be less than 8%. The basin has no historical coal gas production except near the town of Hidalgo from 1907 to 1928. Present day coal bed methane production from unmined areas is restricted to Sullivan and Vigo counties, Indiana and wells that are draining gas from abandon mines. As with all basins, the Illinois Basin coals have their own unique characteristics, basin thermal and structural history. Existing permeability, desorption and adsorption data sets indicate good permeability but marginal to moderate gas contents that vary across the basin. Completion practices have gone from historically single seam to multiple seams. The basin is relatively inactive in terns of leasing and but is situated close to or in strong gas markets.

Mapping Master Faults and Fractures in the Michigan Basin

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A set of 13 Northwest-Southeast trending lineations has been precisely mapped using formation tops data over the entire Michigan Basin. The lineations were mapped using 25,000+ top picks for the Dundee Formation (U. Devonian) compiled in digital form and plotted as a surface relief map on a closely spaced grid using standard PC software. Subsequent mapping using other formation tops data confirmed the Dundee results.

The lineations have been interpreted as basement-controlled fractures and faults that formed in the Late Paleozoic, since they occur in all formations up to the Saginaw Formation (L. Penn) where they cannot be recognized. If the lineaments are reactivated basement faults, the orientation will depend on the orientation of the original basement structures as well as the geologic provenance at depth. Several of the lineations are coincident with previously mapped7faults, such as the Howell and Lucus-Monrow Anticlines in Livingston County. However the majority of the lineations here appear to be new although they are parallel to previously reported structural and geologic trends in the Michigan Basin.

These lineations are important because they appear to be major controls on productive structures and because they may have provided conduits for passage of fluids, including dolomitizing brines and hydrocarbons. A large number of productive oil fields are located in low-amplitude anticlines that parallel the trend of the lineations. In some cases the lineations are clearly faults, with vertical displacements approaching 500-800 feet. In other cases, the evidence for displacement is lacking, although it seems likely that the lineations are at least the locus for fracturing and minor displacements.

Log Curve Amplitude Slicing - Visualization of Gamma Ray Curves for Paleogeographic Reconstruction of the Middle Devonian Traverse Group, Michigan Basin, U. S.

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Well log curve shapes and amplitude trends are routinely used to correlate and map formations and reservoirs across petroleum basins or fields. The methods typically employed for correlation and mapping fail, however, to make full use of the vertical resolution of well log curves. A new technique, log curve amplitude slicing (LCAS) facilitates correlation by generating a series of subhorizontal slices through the log curves using sample-by-sample analysis of log curve amplitudes in all wells between two correlative time-surfaces. The slices represent approximate time lines and are relative chronostratigraphic surfaces that can be gridded and contoured to show trends and patterns in log curve amplitudes in map view. When appropriate logs are used, the slices show the inferred distribution of lithofacies at the time of deposition. Animation allows visualization of changes in the distribution of lithofacies between successive slices. Application of the LCAS technique facilitates correlation because it highlights trends in log curve amplitudes that are not apparent using traditional methods to compare log curves.

Gamma ray log data from 180 wells were used in this study to identify the location, relative timing, and extent of significant fine-grained clastic influx into the carbonate/evaporite-dominated Michigan Basin during deposition of the Middle Devonian Traverse Group. Traverse Group carbonates have produced more than 105 million barrels of oil and currently produce approximately 100,000 barrels per year. Lithofacies patterns observed in

LCAS maps at the basin-scale coincide with productive Traverse Group carbonate trends and reveal new potential areas for exploration and exploitation.

3D Imaging of Niagaran Pinnacle Reefs Using Log Slicing - Chester 18 Field, Otsego County and Bell River Mills Field, St. Clair County, Michigan

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The Chester 18 Field covering an area of 600 acres was discovered in 1971 and has produced over 13.5 million barrels of oil (MMBO) and 11 billion cubic feet (BCF) of gas from 20 wells from a depth of 5900 ft. Water flooding was initiated in 1978 by converting eight of the producing wells to water injectors. 5.5 MMBO have been produced through secondary recovery. The Bell River Mills Field covering an area of 750 acres was discovered in 1961 and produced over 21 BCF of gas from 30 wells before its conversion to a gas storage field in 1965. Gross distribution of reservoir facies and porosity zones in these reefs has been described based upon logs and cores, however, detailed modeling of the three-dimensional distribution of these properties has not been demonstrated. The gamma ray, sidewall neutron porosity, sonic, dual laterolog, and microlaterolog curves for each well in the Chester 18 and Bell River Mills Fields were scanned and digitized where available. Dipmeter logs, mudlogs, sample logs, and well histories were also used in the interpretation. Log curve amplitude slicing (LCAS), a new technique that generates subhorizontal slices through log curves on a sample-by-sample basis, was used to create a series of amplitude slices from the gamma ray and porosity curves in each of these fields. On a basin-scale, computer animations based on gamma ray amplitude slices show the distribution of lithofacies. On a field-scale, similar animations reveal the detailed anatomy of the pinnacle reefs in both fields. LCAS in conjunction with conventional well data aids in the detailed mapping of facies and porosity trends in the reefs. The identification of compartmentalization in the reefs may lead to optimization of enhanced oil recovery and gas storage projects in these as well as other Niagaran fields in the future.

High-resolution Sequence Stratigraphic Model For Subsurface Mississippian Greenbrier Group, West Virginia

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The 50 to 500m thick mixed carbonate-siliciclastic Mississippian Greenbrier Group of West Virginia which formed on the Appalachian foreland provides an outcrop and subsurface analog to better understand Mississippian reservoir stacking patterns and the stratigraphic signatures of global greenhouse to icehouse conditions. We are generating a high-resolution sequence stratigraphic framework for the Greenbrier Group throughout the subsurface in West Virginia, using well data. A series of detailed regional cross-sections and isopachs of time slices are being prepared to better understand the transition from greenhouse to global ice-house conditions and what effect this had on reservoir development. Five major sequences occur composed of three to four regionally mappable high frequency sequences. Major- and high frequency sequences are composed of lowstand red beds up-dip and shallow marine sands along the ramp margin, semi-transgressive shale's, high-stand quartz peloidal grainstone (dominantly eolian), peritidal lime mudstone, peloid grainstone, ooid grainstone, skeletal grainstone, open marine skeletal wackestone/mudstone, and shaly slope mudstone. Sequence boundaries are placed below lowstand sands, red beds, caliches and/or eolianites. Thickness trends strongly reflect tectonically induced basinal subsidence. The ramp margin in the vicinity of the basinal hinge line separates the relatively stable up-dip sections from the faster subsiding basin and localized high-energy grainstone trends, as did subtle tectonic highs. Subsidence rates in the up-dip and downdip areas differ by an order of magnitude, yet the eustatic signal, was the dominant cause of the 3rd order sequences and component 4th order sequences and can be traced into the Illinois Basin.

The extremely complex sequence stratigraphy on the platform, suggests a complex history of relative sea level change. This complex sea-level history has caused the rapid lateral facies heterogeneity on the platform. Three-D mapping of the sequence stratigraphic time slices showing the thickness variation and distribution of environmentally sensitive facies is the only way to track the complex influence of tectonics and eustasy and their effects on the stacking patterns of reservoirs on the platforms.

Cyclical Variation in the Length of the Earth's Radius as the Primary Mechanism for Deep Ocean Basin Development of Global Cycles of Kilometer-Scale Ocean Level Fluctuation and Ocean Low-Stand Surfaces of Erosion, Transportation and Deposition

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Meander-pattern channel morphologies observed on the ocean floor using GLORIA side scan sonar images near De Soto Canyon (Florida) and Monterey Bay (California) are inactive channels, since they are draped by pelagic ooze. More than three kilometers (9,842+ feet) of ocean water presently covers both locations.

If the presence of meander-pattern channel morphology is a unique indicator of known subaerial fluvial processes, then at least three kilometers of ocean level fluctuation is required to develop and then submerge these low-stand surfaces of erosion, transportation and deposition at the above locations.

If the above required ocean volume is assumed to have been stored in enlarged fractures in the ocean bottom, then calculations can be made to determine the necessary radius length increase to generate the equivalent fracture volume.

The simplifying assumptions used in the global cycle calculations are as follows: 1.)Perfect global shell spheroidicity, 2.)Constant volumes for Ocean, Crust and Mantle Shells, 3.)Symmetrical radius variation during regression and transgression, 4.)Global response to pressure, temperature and volume can be approximated by the radius formula $R=1-e^{(-t/T)}$ where t=elapsed time and T=time period.

Observations that are in harmony or conflict with the concept of a variable Earth's radius are presented from many geoscience fields of study.