

AAPG Abstracts

N. D. Alexandrowicz, P. D. Gerome, and S. P. Huffman, Equitable Production Company

Depositional Trends And Porosity Zone Development In The Big Lime (Greenbrier), Mingo And Logan Counties, West Virginia

Finding productive zones in the Big Lime (Greenbrier) hasn't always been a primary concern for developing acreage. There are numerous potential shallow natural gas reservoirs in southern West Virginia both above and below the Big Lime that have more consistent geometries and can be counted on to produce economic volumes. The Big Lime has produced multiple Bcf from wells in the study area and continues to be an appealing, although somewhat elusive target. In order to more effectively develop acreage where the Big Lime has potential, it is important to understand the geometry of the reservoir targets. In the case of the Big Lime, the target zone includes several oolitic porosity zones in the lower part of the section. Available studies of the Big Lime make primary use of outcrops or well cuttings in describing stratigraphy and petrology. A few studies used wireline logs, but they have either been on a statewide scale with very few wells or at field size where the well data was limited to the vicinity of a small productive field. The detailed stratigraphic analysis and correlation in this study makes use of several hundred wireline logs in Mingo and Logan Counties. The interval mapping is far more detailed than other currently available studies. This study sheds new light on the nature of the McCrady erosional surface at the base of the Big Lime section and its relationship to the development of the Big Lime, its potentially productive porosity zones, and its depositional trends.

Charles E. Banks, James McDonald, Douglas L. Crowell, Lawrence H. Wickstrom, Ohio Division Of Geological Survey

Abandoned Underground Mines GIS for Ohio

Abandoned underground mines present a hazard to the public and to the mining industry. Subsidence of abandoned underground mines can affect highways and buildings, potentially endangering lives and property. Identifying the accurate location of abandoned underground mines aids in preventing mishaps to miners and mine owners, as evidenced by the accident at the Quecreek No.1 mine in Pennsylvania, July 2002. The Ohio Division of Geological Survey, with funding from the Ohio Department of Transportation (ODOT), is creating a GIS of abandoned underground mines that will help mitigate the hazard these mines present to lives and property. The Survey has been mapping the locations of the abandoned underground mines since the late 1970's. The mine outlines and openings had been converted to GIS data layers in the mid 1990's. Since then, new information has become available in the form of over 25,000 annual-mine maps, which show new mines and extensions to older mines. Several upgrades to the abandoned-underground-mine GIS data layer are being performed to make the data layer more accurate, and more useful to ODOT and the public. Mine attribute information is being added to the GIS, along with newly discovered mines and extensions to existing mines. The images of the final mine maps are being hyperlinked to the GIS, allowing the user to see the detailed information about a mine. Finally, GIS applications are being created, which will automate many of the advanced questions a user might ask of the data.

Nathanael C. Barta, Stig M. Bergström, and Matthew R. Saltzman, Department Of Geological Sciences, The Ohio State University

The Late Middle Ordovician (Chatfieldian) Guttenberg Carbon Isotope Excursion (GICE): A Unique Tool Used For Correlation From Kentucky To New York State

A relatively short-lasting positive carbon isotope excursion occurs in late Middle Ordovician (Chatfieldian) carbonates. This excursion, now known as the GICE, was first reported in the Guttenberg Member of the Decorah Formation of Iowa and has been recorded subsequently from sections in Kentucky, Pennsylvania, Illinois, Missouri, Oklahoma, Tennessee, Virginia, Sweden, and Estonia. The excursion provides a powerful tool for detailed long distance correlation of strata in the lower Trenton Group with equivalent strata in other regions, especially in cases where absence of diagnostic fossils and/or lack of K-bentonites has hindered correlation. The GICE's stratigraphic position provides a mechanism to resolve confusing stratigraphic relationships and nomenclature in classical "Trenton" localities (New York, Ontario). In addition, the identification and correlation of the GICE provides a medium to examine the excursion's relationship with K-bentonite marker beds, lithofacies changes, biostratigraphic zonation, and sequence boundaries. Clearly, it has great potential for use in the exploration for hydrocarbons in "Trenton" rocks in eastern North America.

D. A. Billman, Billman Geologic Consultants, Inc. and M. Comini, Superior Well Services, Inc.

Geologic Re-Interpretation and Production Prediction of an Upper Devonian (Lower Bradford Group) Field in Central Pennsylvania

In the course of exploiting the 5th Elk in Council Run Field area, Centre and Clinton Counties, Pennsylvania, Eastern States Exploration Company and others often encountered shallower Elk and Bradford Group Sandstones. One such area is on the Texas Gulf "A" and "B" tracts, where a Basal Bradford (driller's term) was encountered. The productive portion of the Basal Bradford is interpreted as a flood tidal delta, associated with a largely non-productive shoreface bar. This portion of Council Run Field is within the Snow Shoe Syncline, approximately 8 to 10 miles from the Allegheny Structural Front. Log derived porosities tend to be apparently low, ranging from 6% - 8%, with high resistivities (150 ohms or greater) through the interval. Water saturations calculate below 20% wet, which the wells have no signs of water production. Reserve calculations, using 20 acre spacing, from the logs indicate gas in place range from 60 to 120 MCFG. The core data that was available help to support the log-derived values. Although the typical log-derived calculations tended to be low (due to low log calculated porosities), natural open flows were common, often in the 100 MCF/D to 1+ MMCF/D range. Therefore, despite poor log calculated reserves, the reservoir was often completed and produced. Known Estimated Ultimate Recoverable reserves from the Basal Bradford range from 250 to 500 MMCF. The authors will review the actual production from numerous wells in the field and attempt to model the log-derived data to more approximate the actual production. These models will include input from the available geologic and core data.

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Taking a Closer Look

D. A. Billman, Billman Geologic Consultants, Inc.

A Review of Upper Devonian, Elk Sandstone Exploration and Development in Pennsylvania: Random Thoughts on Potential Elk Pitfalls

Since the discovery of Mahaffey Field in Clearfield County and Council Run Field, Centre and Clinton Counties, Pennsylvania the Elk Sandstones (Upper Devonian, Lock Haven Formation) have been well sought after exploration targets. As an example, approximately eight wells in Council Run Field are 1+BCF estimated ultimate recoverable from less than 5,000' total depth. Typically, the Fifth Elk is considered the "major pay" within the Elk Group. It will be shown that numerous zones within the Elk have potential to be primary production contributors. Also discussed will be regional and local mineralogical differences that can have a drastic effect on how an electric log is interpreted and how completion of a well is planned. Aerial extent of Elk deposition, the role of structure in Elk deposition and production and other factors may affect exploration and development strategies will also be discussed. Lastly, an overview of Elk exploration potential for Pennsylvania will be discussed.

Kate Blasingame and Gerry Cales, Enventure Global Technology, Houston, Tx

Solid Expandable Tubular Technology in Mature Basins

For years, the reduction of tubular inside diameter (ID), or "telescoping effect," limited the exploration and production of oil and gas. Using conventional technology, operators faced significant loss of ID in the course of the normal drilling process, during re-entry and deepening of existing wells, or when installing additional casing strings to remediate well problems. The industry has confronted this dilemma with innovative problem solving by using the revolutionary solid expandable tubular technology. Successful applications of this technology have proven its reliability in a variety of conditions and environments. Solid expandable tubulars continue to prove their success as a solution to problems involving gas shut-off, subsidence repair, water shut-off, lost circulation, and remediation of wells slated for abandonment. This paper will discuss the development of solid expandable tubular technology from theory to reality. Case histories will be cited to illustrate how solid expandable tubular systems are applied in a myriad of remedial challenges. In addition, this paper will explore how solid expandable tubulars can be deployed to overcome problems prevalent in more mature basins.

Robert M. Bomar and Edward Dereniewski, Michigan Consolidated Gas Company – a DTE Energy Company

Case Study: Horizontal Well Drilling Project in the Six Lakes Gas Storage Field

In an effort to reverse a historical decline of 5.6% in field deliverability, the first horizontal gas storage well was drilled in 1993. Since that time, 18 additional horizontal wells have been completed in this field. A number of technological improvements to the drilling process were applied along the way to progressively reduce the drilling cost and enhance the well deliverability. In the present study, we compare data from central Pennsylvania (Union Furnace, Reedsville) with preliminary data from Dexter, New York and previously reported data from the Upper Mississippi Valley and the eastern Midcontinent. It is shown that the Napanee Formation in New York correlates with the Logana Member of the Lexington Limestone in Kentucky and the Salona Formation of central Pennsylvania. This report is a portion of the results of a regional investigation that also includes sections in southeastern Ontario and Manitoulin Island.

Charles W. Byrer and Scott M. Klara, U.S. Department of Energy, National Energy Technology Laboratory

U.S. Department of Energy Field Efforts to Sequester CO₂ in Geologic Formations

Nearly one third of the carbon emissions in the U.S. come from power plants. Since electric generation is expected to increase and fossil fuels will continue to be the dominant fuel sources, there is growing recognition that the energy industry can be part of the solution to reduce greenhouse gas emissions by capturing and permanently sequestering CO₂. Long-term storage of carbon dioxide (CO₂) in underground geologic formations has the potential to be a viable concept in the near future. Many power plants and other large point sources of CO₂ emissions are located near geologic formations that are amenable to CO₂ storage. In many cases, injection of CO₂ into a geologic formation can enhance the recovery of oil and gas which can offset the cost of CO₂ capture and storage. The U.S. Department of Energy's (DOE) R&D program for CO₂ sequestration in geologic media is a comprehensive effort to bring about this concept in a timely and acceptable method. The primary goal of the research in this area is to understand and validate the behavior of CO₂ when stored in geologic formations so that CO₂ can be sequestered for the long term in a manner that is secure and environmentally acceptable. Researchers under contract to DOE are trying to determine what effective, safe, and cost-competitive options are available for geologic storage of CO₂ emissions generated from coal, oil, and gas power plants. Currently, the planned and on-going research and technology development includes initiatives to develop baseline information necessary to make decisions about potential demonstration and verification sites for CO₂ geologic storage. This paper presents an updated of DOE-sponsored field tests for injection of CO₂ into existing oil reservoirs, deep saline reservoirs, and unmineable coalbeds. All of these field tests and planned larger-scale efforts will help to predict, validate, and monitor migration and ultimate fate of injected CO₂.

T. R. Carter and A. C. Castillo, Petroleum Resources Centre, Ministry Of Natural Resources

The Petroleum GIS – Three-Dimensional Geological Mapping in the Subsurface of Southern Ontario, Canada

The Petroleum Resources Centre of the Ontario Ministry of Natural Resources collects and manages a large quantity of subsurface resource and geological data at its Oil, Gas and Salt Resources Library in London. The Library maintains an extensive collection of drill cuttings samples representing 13,000 wells and drill core from over 1,000 wells. Hard-copy reports are available for over 20,000 wells and includes data on well location, well status, operator identification, drilling dates and depths, well construction, geological formation top depths and elevations, oil/gas/water intervals, geophysical well logs, core analyses, analyses of oil, gas and water samples, subsurface pressures and production volumes. The data is principally acquired from the drilling and operation of petroleum wells by industry clients. Digital data derived from the well records and samples are maintained in an Oracle relational database known as the Ontario Petroleum Data System (OPDS). The Centre has recently developed a "Petroleum GIS" application using Arcview 3.2 for viewing and querying of well data from OPDS. The petroleum well theme is generated by a dynamic link to the Oracle data tables in OPDS. Elevation data for the tops of subsurface bedrock formations can be extracted from the Oracle data tables using the application, gridded and contoured using specialized software and displayed as a new data theme in the GIS. Three-dimensional maps created from the gridded data are particularly useful for visualization and mapping of subsurface structures such as faults, reefs, salt dissolution and collapse features, regional dip, structural closures, bedrock topography and more. Selected examples from southern Ontario are presented. Basic well data including corrected geographic co-ordinates are available at www.ogsrlibrary.com and clients are able to purchase data on subsurface geological formation top picks, oil, gas and water intervals and enhanced well data. MNR digital base maps are available to corporate members of the Library under the terms of a data sharing agreement with the Ministry of Natural Resources.

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Taking a Closer Look

Donald Clark, Brooklyn College

A Fracture Analysis of the Beekmantown Group Carbonates of Eastern New York State

Fractures, within potential natural gas or petroleum reservoirs, are essential both for the migration and concentration of economically recoverable amounts of these resources and for their successful extraction. Faulting and fracturing of the Beekmantown Group Dolomites in the Quebec Lowlands, for example, has resulted in the formation of productive natural gas reservoirs in that area. The largest, the St. Flavien field, has produced some 7.75 bcf of natural gas. The importance of fractures to the successful development of natural gas or petroleum reservoirs makes it essential to have accurate quantitative information about the fractures. The examination of cores is an excellent way of collecting fracture information, since the data can be taken directly from the depth and formation of interest. The collection of fracture data from core also enables geologists to track changes and trends in fracture density and orientation, fracture width and degree of healing. Fracture data, from the cores from a series of eleven bore holes from Montgomery, Fulton, Herkimer, Schoharie and Saratoga Counties, was recorded and analyzed for fracture spacing, fracture width and degree of fracture healing. It was found that the normal faults that bisect the Mohawk River Valley were the major controlling factor influencing the degree of fracture development within the carbonate rocks of the Beekmantown Group in this area. Beekmantown Group core samples from Jefferson, Essex, Warren and Washington counties were then examined to determine if faulting was the controlling factor influencing the degree of fracturing in those areas, as well.

Steven Cordivola and Brandon Nuttall, Kentucky Geological Survey, University Of Kentucky

Oil and Gas Records on the Web: An Independent's Dream

In July 2002 the Kentucky Geological Survey (KGS) inaugurated a free service to provide images of oil and gas records from Kentucky over the Web (<http://www.uky.edu/KGS/pubs/lop.htm>). Coupled with an online searchable database, this service allows anyone to inspect, copy, and print plats, drillers' logs, completion reports, and even geophysical logs from anywhere in the world, 24 hours a day, 7 days a week. The data set of images contains over 1 million pages of documents for over 130,000 drilled wells throughout the state. KGS uses modern compression technology (DjVu® from Lizardtech™) so that users can quickly download thumbnails of the documents from a selected folder (each folder contains all the documents for a single well). The document image is loaded into the DjVu Viewer, which is available free for most Web browsers, only after a user selects a specific thumbnail. Since the images are relatively small, this system provides very fast access, even when relatively slow modems are being used. This service has been well received, and many diverse users from industry, government, and the general public have found it invaluable. The feedback has helped KGS to develop additional features and make better use of technology, but has also instigated some special challenges for KGS, such as dealing with documentation issues, training, and special requests, which were not anticipated in the design of the online system. These challenges and solutions may provide valuable experience to others who wish to develop a similar service.

Michael K. Decker, Gasco Energy

Potential Gas Committee 2002 Natural Gas Resource Assessment

The Potential Gas Committee (PGC), now in its 39th year, is comprised of 140 volunteer members from the natural gas industry, government and academic institutions, who biennially assess the size and location of the nation's natural gas resource base. These estimates, when combined with the U.S. Department of Energy's estimates of proved reserves of natural gas, make possible an

objective and credible appraisal of the nation's long-range natural gas supply. The year-end 2002 PGC natural gas resource estimate of 1,127 Tcf (excluding proved reserves) includes 958 Tcf attributable to traditional reservoirs and 169 Tcf in coalbed reservoirs. Compared to year-end 2000, the traditional resources increased 2.4%, and the coalbed gas resource increased 8.8%. These increases have been assessed even though approximately 38 Tcf of domestic natural gas has been produced in the two-year period between reports. Therefore, the PGC estimate represents a significant increase over the last biennial estimate of the nation's natural gas resource. The Potential Gas Committee (PGC) reports gas resource estimates biennially in categories of decreasing certainty: *Probable*, *Possible* and *Speculative*. For each category, a *minimum*, *most likely*, and *maximum* resource volume is estimated for each of 89 geological provinces. A comparison is made of the Atlantic area with the remainder of the United States.

Justin Deming, Richard Nyahay, and Langhorne Smith, Reservoir Characterization Group, New York State Museum

The Empire State Oil and Gas Information System (ESOGIS): An Essential Tool for Exploration and Development in the 21st Century

We have developed an interactive Internet application that will provide quick and easy access to all publicly available oil and gas data from New York. Freely available to all users will be: well location data, production data (from the DEC), scanned photographs of the museum's core collection, digital maps, reports and more. All this data will be integrated and linked in a single GIS-based program with a user-friendly interface. Users will be able to search for individual wells, fields, towns, counties, wells with specific log suites, producing formations and more. The site will include a new digital oil and gas map for the State that can be updated daily or weekly to include newly named fields and new wells in old fields. We also hope to link publicly available seismic data and digital versions of any pertinent outcrop and core studies to the site. In addition to the publicly available data, ESOGIS subscribers will be able to view and download scanned paper files, scanned logs, digitized logs and formation tops. Newcomers to the State will be exploring for hydrocarbons in a matter of days rather than months because there will be little time and money spent on building and managing datasets. Companies already working in New York will be able to access and work with data in a digital format, which will be more time and space efficient than working with paper files. ESOGIS truly is an essential tool for 21st exploration and development in the State of New York.

James A. Drahovzal, Kentucky Geological Survey, University Of Kentucky

Mississippian Goniatices of Alabama, U.S.A.

Two new faunas of Mississippian goniatices have been found in the Pride Mountain Formation of Alabama. One is present in the Eastern Interior Plains Province and the other in the Valley and Ridge Province of Alabama. The one in the Eastern Interior Plains Province occurs at two horizons within the Pride Mountain Formation, south of Tuscumbia, Colbert County, Alabama. The lower fauna, 50 to 55 ft above the base, consists of *Lusitanoceras granosum*, *Lusitanites subcircularis*, *Sulcogirtyoceras limatum*, *Neoglyphioceras utahense*, and *Lyrogoniatites sp.* The upper fauna, 100 to 110 ft above the base, consists of *Dombartites choctawensis*, *Sulcogirtyoceras limatum*, and *Neoglyphioceras utahense*. The faunas of these two horizons are very similar to those known from the Ruddell Shale Member of the Moorefield Formation of northern Arkansas and from the Slade Formation of northeastern and south-central Kentucky. The fauna found in the Valley and Ridge Province occurs at the base of the Pride Mountain Formation, north of Birmingham, Jefferson County, Alabama. The goniatices fauna here is of similar age, but is much less diverse than that in northwestern Alabama, consisting of only two elements—*Lyrogoniatites georgiensis* and *Girtyoceras meslerianum*. The former element dominates the fauna. This fauna is almost exactly like that found near Rome, Georgia, in the Floyd Formation. The relationship between these two faunas is currently unknown, but they are thought to be closely similar in age. Their occurrence in

two distinct provinces suggests that there may have been paleoenvironmental, paleogeographic, or both types of controls acting on their distribution.

Craig A. Eckert and Michael J. Kovarik, Equitable Production Company

Geology and Production Characteristics of Nora CBM Field, Dickenson, Russell, Wise and Buchanan Counties, Virginia

Production of coal bed methane in Nora Field began in 1988, decades after the establishment of conventional Mississippian and Devonian production. Prior to that time geologists working the field noticed that gas shows from shallow coals were commonly higher than those from the deeper targeted sands and shales, suggesting the potential for a significant development opportunity. Early attempts to launch this play were met with skepticism due to perceptions of low initial rates of gas production, high initial rates of water production, low ultimate gas recoveries and high operating costs. The earliest wells were drilled on anticlines for added permeability and gas trap in fractures and cleats. Many of these wells exhibited two major phases of production, initially producing at high rates with steep hyperbolic decline (fracture production), then reaching the desorption phase where production decline became exponential. Single stage limited entry completions using low sand volumes and energized water evolved recently into multiple stage jobs where thick coals can be staged alone. Presently, mapping of net total seam thickness of the numerous coal seams combined with production vs. lineament trend analysis, and detailed structure mapping allow for advantageous location selection. Aggressive drilling schedules allow for the rapid development of this resource. Horizontal drilling is also being tested in some of the thicker more continuous seams in Nora field.

Jonathan C. Evenick and Robert D. Hatcher, Jr., University Of Tennessee, Department Of Geological Sciences

Potential Ordovician Hydrocarbon Plays in the Cumberland Plateau of Tennessee and Southern Kentucky: Finding a Needle in a Haystack?

The hydrocarbon potential of the Cumberland Plateau has been explored for over a century with most discoveries to date being small oil or gas fields in Mississippian limestone reservoirs sourced by the Devonian-Mississippian Chattanooga Shale. The underlying Knox and Middle-Upper Ordovician (Stones River or Black River Group, and Nashville or Trenton Group) carbonate rocks, however, have only been cursorily explored, with only minimal success in Tennessee. The historic success of the Rose Hill field in southwest Virginia, other fields in Middle Ordovician rocks farther northeast, and the recent development of the Swan Creek field in the Knox and Middle Ordovician rocks in northeastern Tennessee indicate there is greater potential in the Middle and Upper Ordovician rocks beneath the Cumberland Plateau. The source of these hydrocarbons is the Ordovician rocks (gas chromatography by R. Burruss, USGS). Deformed zones related to previously unmapped blind faults and décollements may locally enhance an otherwise primarily porosity-dominated province. Research currently underway intends to identify markers (other than the known K-bentonites) in geophysical logs that will permit detailed resolution of units in the Stones River and Nashville Groups. These units have been mapped in surface exposures on the Nashville dome and in the western Valley and Ridge, as well as in the Sequatchie anticline that dissects the central and southern Plateau in Tennessee. Such resolution will provide new opportunities to better understand the structure and reservoir characteristics in the subsurface beneath the Plateau and Eastern Highland Rim of East Tennessee and southern Kentucky.

George Eynon, GEOS Energy Consulting

Canada's Oil & Gas Resources—Surplus to Requirements, But Not Enough to Satisfy US Demand

Canadian production (approximately 17 Bcfd and 2.4 MMbopd) more than meets a domestic demand (7.5 Bcfd and 1.6 MMbopd) that is growing only modestly. The balance is exported. Canada's gas production has increased almost every year—until now—despite increased decline rates. Light oil production is declining significantly, but technology advances—and environmentally responsible operations—have permitted a dramatic increase in heavy crude oil production. Ongoing development of vast shallow gas resources in innumerable small pools, and discoveries in deeper parts of the Plains, Foothills, Front Ranges more than replaced production through the 90s; technology improvements will also enable continued development of deep tight gas and coalbed methane in western Canada and other basins over the next decade. But, for the present at least, gas additions are slowing down and may not replace production again this year. Alberta's heavy oil and bitumen resource base rivals that of light oil in the Middle East, and production is increasing in both mining and *in situ* recovery, but it is much more costly to produce, of course. Canada's east coast and northern frontiers are being developed; oil production from the Mackenzie corridor and offshore Newfoundland, gas from the Scotian Shelf and Liard Basin. Gas from the Mackenzie Valley and Mackenzie Delta-Beaufort Sea is possible within the decade. Offshore west coast gas resources are still under a moratorium, though even that situation is being reconsidered. US demand is growing much faster than Canada's, particularly gas for power generation and crude oil for transportation, but the US produces less than 45% and less than 85% respectively of its own oil and gas requirements. Canadian Imports of oil and gas are 8.5% and 15% of requirements respectively. Can Canada keep it up?

G. Michael Grammer, Western Michigan University, Department Of Geosciences, Paul M. (Mitch) Harris, ChevronTexaco Exploration And Production Technology Company, and Gregor P. Eberli, University Of Miami, Comparative Sedimentology Laboratory

Modern Analogs for Carbonate Reservoirs – Great Bahama Bank Revisited

Study of modern depositional environments in the Bahamas formed a cornerstone of carbonate facies analysis in previous decades. Numerous workers provided details on facies types, depositional processes, and early diagenesis that were incorporated into the development of classical carbonate facies models. The Bahamas continue to be an invaluable modern laboratory for a new generation of studies that focus more on the details of reservoir distribution and evolution through time. Modern environments are valuable as analogs for conceptualizing the spatial distribution of reservoir facies within a single time-slice and for obtaining a first-order quantitative approximation of geometrical attributes for potential reservoir facies. Combining remote sensing data such as satellite images and aerial photographs with surface sediment maps provide facies trends and dimensionality data that can be used to show patterns and assist the modeling of a reservoir relative to simulated well spacing. These two-dimensional data are of even more value when combined with either results of coring studies from modern environments, or from detailed outcrop work that provide the third (i.e. vertical) dimension to the reservoir system. Combining this geometrical data with recent advances in our understanding of early diagenesis enhances the predictability of probable reservoir and flow unit distribution in the subsurface. New insights, such as the potential for syndepositional marine cementation at depths up to 100m, the presence of "meteoric" diagenetic fabrics in marine burial environments, and effects of pore architecture on petrophysical characteristics of carbonate rocks have all led to a better understanding of the distribution of potential reservoirs in the subsurface.

William B Harrison, III, Michigan Basin Core Research Laboratory, Department of Geosciences, Western Michigan University

Horizontal Drilling for Oil and Gas in the Michigan Basin

The first horizontal well was drilled in Michigan in 1985. As of April 1, 2003 there have been 452 horizontal wells drilled and completed. Another 36 wells are pending, having been permitted and are in various stages of planning, drilling, or waiting on completion. All horizontal wells have been drilled in known fields in previously productive reservoir zones. Most of these fields were considered to be depleted or approaching an economic productivity limit with respect to their existing vertical wells. About 90 % of the completed horizontals are considered to be successful. Only about 10 % have been declared as dry holes. Horizontal wells in Michigan are mainly being used as a secondary recovery technology to improve productivity in Michigan's aging fields. About 21 percent of the horizontal wells have been drilled in gas storage reservoirs to greatly enhance injection or withdrawal rates. Fifteen different reservoirs have thus far been targets of horizontal wells. They range in age from Ordovician to Mississippian and include sandstone, carbonate, and shale lithologies. The majority (59%) of the horizontals have targeted the Middle Silurian Niagaran Reefs. Another large group of horizontals have exploited the Late Devonian gas-producing black shale of the Antrim Formation. Success for these horizontals has been mixed. A few wells have recovered significant additional reserves, while many have had only marginal economic success. There have also been many wells that have not encountered economic volumes of reserves or were declared as dry holes. One of the most successful applications of horizontal drilling in Michigan has been in gas storage. Horizontal wells have revolutionized the development and continued utilization of underground gas storage in several different formations.

Robert G. Hickman, Structural Solutions, W. Norman Kent, Kent Geoscience, Jeff Martin, and Mark E. Odegard, Getech

Exploring the Appalachian Basin for Hydrocarbons Trapped in Hydrothermally Altered Reservoirs

Trenton-Black River exploration has focused attention on hydrothermal dolomite reservoirs. Understanding these reservoirs and the fluids that produced them suggests additional exploration opportunities and strategies. The fluids that formed these reservoirs were brines with temperatures of 50° to 200° C, which are higher than formation temperatures produced by the geothermal gradient. The sources of the large flux of water required for dolomitization are deep, basin-wide regional aquifers such as the Mt Simon/Potsdam and Knox. Hot brines moved laterally in these aquifers and then upward through faults or across unconformities into shallower aquifers. Their high salt content increased calcite solubility and facilitated dolomite replacement. Upward cooling of the brines further increased calcite dissolution. In contrast, cooling reduced silica solubility. Consequently, deep sandstone aquifers and sandstones in the areas of upflow may have enhanced secondary porosity while peripheral sandstones are silica cemented. Integrated regional mapping of aquifers, seals and faults using logs, potential fields data and seismic can identify potential fluid pathways and prospective trends. Sandstone and carbonate aquifers have enhanced porosities of regional extent, but require four-way closures or updip truncations for trapping. Sandstones adjacent to carrier faults may have abnormally good reservoir properties. Hydrothermal dolomite reservoirs occur along faults that tap a deep aquifer at a favorable position such as the erosional truncation of the aquifer. Typically, the faults were reactivated over Precambrian terrane boundaries, faults, and contacts and may have a small component of strike-slip displacement. Fluid flow and dolomitization is focused at releasing fault bends and interaction zones.

W. Norman Kent, Kent Geoscience, Robert G. Hickman, Structural Solutions, Jeff Martin, and Mark E. Odegard, Getech

Hydrothermal Hydrocarbon Systems

Recently hydrothermal dolomite and its relation to hydrocarbon accumulations have captured the attention of the petroleum industry. An inclusive definition of the hydrothermal hydrocarbon system, in which dolomite is only one component, yields new, geneses-based models for finding oil and gas. Distinguishing features of the hydrothermal hydrocarbon system include diagenetic products and late stage porosity enhancement. Most recognized hydrothermal hydrocarbon accumulations occur in carbonate reservoirs, but clastic units are also affected by hydrothermal systems. Typically, hydrothermally altered reservoirs are found in relatively undeformed rocks adjacent to foreland basins or within the leading structures of fold belts. At the basin scale, hydrothermal system may produce several accumulation types having different reservoir characteristics. However, accumulations within different areas of the basin form districts containing many similar fields. Hydrothermal accumulations are localized by facies tracts, edges of sandstone or shale units, breccias, and reactivated faults. Within districts, accumulations share one or more of these features. Development of districts suggests that horizontal fluid migration is more effective than vertical migration and implies that vertical conduits are connected to regional aquifers. Diagenesis in carbonates results in dolomitization, brecciation, calcite or sulfate dissolution and authigenic growth of feldspar or clay. In clastic units, dissolution of carbonate cements, feldspar grains and development of authigenic clays are common. Fluid inclusion data suggests that the hydrothermal fluids are basinal brines with low Ph and Eh containing 10 – 30 weight percent salt. Modifications of the fluid composition during migration and changes in the host rock explain variability between districts.

C. S. Kulander, U. S. Geological Survey (presently University Of Oklahoma) and R. T. Ryder, U. S. Geological Survey

Seismic Images of the Northern West Virginia-Southwestern Pennsylvania Depocenter of the Central Appalachian Basin

Three CDP seismic profiles (1980s vintage) were reprocessed and interpreted to characterize the deep structure of the northern West Virginia-southwestern Pennsylvania depocenter and to identify potential areas for deep gas entrapment. Also known as the Dunkard basin, the depocenter contains as much as 30,000 ft of Paleozoic strata that have been moderately deformed by extensional and contractional tectonics. Line A trends east-west for about 120 mi across northern West Virginia from near the western margin of the Rome trough in Ritchie County, across the eastern margin of the Rome trough in Taylor County, to the Allegheny structural front in Mineral County. Lines B and C are shorter and located north of line A in northernmost West Virginia, western Maryland, and southwestern Pennsylvania. Seismic reflections are correlated with stratigraphic units in the depocenter by a synthetic seismogram for the No. 1 Burley well, Marshall County, West Virginia, that was drilled into Upper Cambrian strata at a total depth of 16,500 ft. The dominant structures on the profiles are foreland-vergent, imbricate fans and ramp anticlines that originated from Alleghanian thin-skinned contractional deformation. The oldest structure imaged on the seismic data is the Rome trough with its eastward-thickening wedge of Cambrian strata and accompanying basement-involved extensional faults. Overall, the Rome trough is an asymmetric graben with large, down-to-the-west normal faults along its eastern margin and minor down-to-the-east faults on its east-dipping west flank. Several intratrough fault blocks are recognized. The deeper parts of the Rome trough are located in discontinuous subbasins across its eastern flank. Partial structural inversion of the Rome trough is indicated by 1) the propagation of several basement faults into Ordovician and younger strata and 2) the presence of deeply rooted anticlines on the original downthrown side of several basement faults. These anticlines may be traps for deep gas.

Christopher D. Laughrey, Pennsylvania Geological Survey

Petrology and Petroleum Geochemistry of Trenton - Black River Carbonates and Shales, Central and Northwestern Pennsylvania

Limestones and dolostones in the Trenton and Black River formations of central and northwestern Pennsylvania were deposited on a gently sloping carbonate ramp under normal marine conditions. Black River carbonates comprise skeletal grainstones, packstones, and wackestones, mudstones, and dolostones deposited in intertidal, lagoonal, and shallow subtidal environments. Trenton rocks include skeletal grainstones, packstones, and wackestones, laminated and nodular mudstones, and black calcareous shales deposited in relatively deep-water environments. Centimeter-scale cyclic patterns, induced by storms, suggest various sedimentary processes that were active during deposition of the Trenton and Black River formations. Diagenetic features in the Trenton and Black River formations reflect mostly marine and burial environments of cementation and alteration. Evidence for marine diagenesis includes micritization, isopachous cements, sparry calcite cement, and hardgrounds. Compaction features, fractures, silicification fabrics, idiotopic and xenotopic dolomite textures, and MVT mineral assemblages all denote burial diagenesis. Trenton and Black River rocks in northwestern Pennsylvania contain as much as 2.95 % Total Organic Carbon (TOC). These rocks are at peak thermal maturity and are gas-prone. TOC in the Trenton and Black River formations of central Pennsylvania also reflect good petroleum potential (up to 1.72%), but the rocks here are over mature and their kerogens are exhausted. Nevertheless, these rocks appear to be generating low-molecular weight hydrocarbons at a rate that might result in commercial gas accumulations. Low and high temperature pyrolysis data reveal the presence of bitumen sorbed on the mineral matrix of Trenton and Black River carbonates. This bitumen is cracking to gas today.

H. E. Leetaru, R. Finley, J. S. Cokinos, and A. Luther, Illinois State Geological Survey

The Application of GIS in CO₂ Sequestration

Reducing carbon dioxide emissions is an important goal in slowing the rate of global warming. This project looked at the feasibility of using GIS (Geographic Information System) software for locating potential CO₂ sequestration sites in saline aquifers and oil field reservoirs. Subsurface strata are one of the best potential targets for storage of CO₂ from individual sources such as utility power plants. We applied the criteria for site selection using GIS software, making subsurface maps of key reservoir intervals, computer mapping of subsurface data, and collecting subsurface reservoir attributes such as permeability and porosity. We concentrated our efforts on studying the potential of subsurface saline and hydrocarbon reservoirs as CO₂ sequestration targets. In this project we selected five significant criteria for evaluating CO₂ sequestration sites in Illinois. The five selected criteria were: Subsurface depth of the target reservoir; Lateral proximity of the target reservoir to its equivalent freshwater interval; Reservoirs with adequate porosity and permeability for storage of CO₂; The quality of the reservoir seal; and Earthquake hazards. This research showed that (GIS) is useful in assessing CO₂ sequestration project and that it can be used to optimize the best location for sequestration sites. Additional criteria and data need to be integrated into the GIS application for actual site assessment.

H. E. Leetaru and D. G. Morse, Illinois State Geological Survey

Characterization of the Mt. Simon Sandstone Gas Storage Reservoirs at Herscher and Herscher Northwest Fields, Kankakee County, Illinois

Herscher Field in Kankakee County was originally an Ordovician-age Trenton oil field that was abandoned in the early 1900's. In 1952, the storage of natural gas for peak delivery to the Chicago market was begun in the Cambrian-age Galesville Sandstone. In 1956, storage of natural gas was begun in the

underlying Cambrian-age Mt. Simon Sandstone and Elmhurst sandstone member of the Eau Claire Shale, which provided a better-sealed reservoir. Geologic characterization of the Mt. Simon/Elmhurst reservoir at Herscher has been fraught with difficulty because of the lack of modern wireline logs. Core data from seven wells, and neutron and gamma ray curve data, the only wireline logs available, were used for petrophysical analysis. Most of the wells were drilled and logged after the initial storage of gas had begun; therefore, many of the neutron logs were influenced by the 'gas effect' and resulting calculated porosity values were too pessimistic. An alternative empirical methodology using Vshale to estimate porosity was used to improve models in gas effected intervals. Even this method does not fully capture the porosity variation seen in core for the cleanest sandstone. Nevertheless, three-dimensional modeling of the Mt. Simon/Elmhurst reservoir, using Vshale, shows shale interval baffles and porosity variation within the fields, but there are no laterally extensive shales that would vertically compartmentalize the reservoir. Methodologies used in this project can be applied to other gas storage reservoir characterization projects where data quality is an issue.

Courtney M. Lugert, Langhorne B. Smith, Richard Nyahay, Reservoir Characterization Group, New York State Museum, and Stephen J. Bauer, Sandia National Laboratories

Brine Disposal: Overcoming the Dominant Barrier to Salt-Cavern Gas Storage in the Northeast

Salt caverns are ideal for natural gas storage because of high deliverability rates and short cycle times. New York has enough salt in the Silurian Salina Group to make good-sized caverns in the south central portion of the State. Currently within the state there is one operational salt-cavern storage facility and several others in various stages of completion. The greatest obstacle to successful completion of many of these salt caverns is disposal of the brine created during solution mining. The purpose of this study is to systematically analyze each potential formation for its ability to accept brine. We have made a first pass analysis and are limiting our studies to sandstones and carbonates (excluding shales) that occur below the salt. We are now doing more detailed reservoir characterization on many potential targets. Our studies include studies of porosity and permeability, sequence stratigraphy, mechanical stratigraphy (fracture distribution) and more. Final deliverables will include detailed analysis of potential targets with maps, cross sections, core analysis and more. At this point in the study, the most promising prospects include the Queenston Sandstone, and the Trenton/Black River and Beekmantown carbonates. Using New York as a representative model, we will establish a system model that can be used in other regions where brine disposal is also a barrier. This poster presents the current results of our efforts towards this research.

Ernest A. Mancini, Eastern Gulf Region of the Petroleum Technology Transfer Council, University of Alabama

Mesozoic Thrombolitic Reef Play, Northeastern Gulf of Mexico

Thrombolitic reefs are known from Upper Jurassic and Lower Cretaceous carbonate strata of the northeastern Gulf of Mexico. These microbial buildups are Upper Jurassic petroleum reservoirs in the eastern Gulf Coastal Plain area. These thrombolites developed on Paleozoic rocks on the inner part of a carbonate ramp as part of early highstand systems tract deposits. They attain thicknesses of 150 ft and areal extents of 1 to 2 square miles. These microbial reefs include microbes, cyanobacteria and other bacteria that are chemosynthetic, and encrusting organisms, *Tubiphytes*, foraminifera and metazoans. Upper Jurassic microbial buildups have been interpreted from seismic data from the continental shelf of the northeastern Gulf of Mexico. Lower Cretaceous microbial reefs have been observed from core slabs from a well in Louisiana. These thrombolites developed seaward of the Lower Cretaceous shelf margin on a continental slope. Buildups of 22 ft have been observed. The presence of thrombolites in deeper water is consistent with the occurrence of Upper Jurassic microbial buildups observed in outer carbonate

ramp settings from Upper Jurassic outcrops in Portugal. The development of microbial reefs in Upper Jurassic strata in the northeastern Gulf of Mexico and in Lower Cretaceous continental slope paleoenvironments extends the thrombolitic reef play from inner ramp, shallow water paleoenvironments of the eastern Gulf Coastal Plain to Upper Jurassic and Lower Cretaceous deeper water paleoenvironments in the northeastern Gulf of Mexico. The key factors for microbial buildups are hard substrates for colonization, low background sedimentation rate and sea-level rise for continued growth and abnormal marine conditions (shallow water with low salinities or water depths below the euphotic zone) to reduce organism competition for niche space and to reduce predation. Detection of these microbial buildups involves seismic reflection interpretation and geologic modeling of reef development and lateral and vertical variabilities

Jeff R. Martin, Mark E. Odegard, GETECH, W. Norman Kent, Kent GeoScience, and Robert G. Hickman, Structural Solutions

An Integrated Analysis of Deeper Hydrocarbon Plays for Eastern Ohio and Western Pennsylvania Using Gravity, Magnetic, Satellite and Geological Data

High gas prices and recent discoveries have focused attention on hydrothermal dolomites of the Trenton-Black River (TBR) of the Appalachian basin. An integrated GIS analysis using gravity, magnetic, topographic and well data, satellite imagery, and surface geology has proven to be a cost-effective method to help find these small and subtle fields. Additionally, our ongoing work has shown that both deeper and shallower horizons in the productive trends have been affected by hydrothermal processes and may be prospective. To make a region prospective, a favorable connection needs to exist between regional aquifers, unconformities and fault zones. This allows adequate flow of hydrothermal fluids necessary to develop reservoir porosity and permeability, and in some cases mature organic material within the TBR. This complete hydrothermal process may affect multiple horizons in its path. Migration of hydrocarbons commonly occurs simultaneously with diagenesis and may follow the same pathways as the hydrothermal fluids. An exploration key is to first identify faults that extended down into the hydrothermal system when it was active. Reactivated basement faults crossing flow paths through the basin, are favorable since they cut all deep aquifers and are likely to have been permeable at multiple times. Fluid flow and diagenesis (hydrothermal dolomites) are focused at the intersections of faults and fracture zones. The amount of diagenesis and the lateral extent of the dolomitization are also dependent on the original porosity and permeability of the target horizon. Since the hydrothermal dolomite reservoirs are developed along fault and fracture zones, part of our approach has been to use topographic, gravity and magnetic data for mapping both fault zones and basement terrain boundaries that localize younger faulting. Satellite imagery can then be used to further refine the probable locations of intersecting fault systems. Use of GIS software allows quick integration of many types of data. This allows the explorationist to more easily high grade areas for more intensive exploration efforts. This integrated method is a cost-effective way of identifying prospective areas and thus focusing exploration dollars for land acquisition, additional seismic or geochemical surveys in the best places. This approach is illustrated by examples taken from the eastern Ohio and western Pennsylvania area.

John P. Martin, New York State Energy Research And Development Authority

New York's Utica Group Shales: The Next Fractured Shale Play?

In 1821, a shallow well drilled in the Dunkirk shale ushered in a new era for the United States when natural gas was produced, transported and sold to local establishments in the town of Fredonia, New York. In spite of this early success, the shales have not been a major producer in New York. With new technology, however, all shales are getting another look. In eastern and central New York, the Ordovician Utica Group shales were deposited in the foreland basin as the Taconic Orogeny continued to the east. They drape over the shallow platform carbonates of the Trenton formation and reach a thickness of over 1,000 ft. The

group goes from outcrop in the Mohawk Valley to nearly 10,000 feet at the Pennsylvania border. These black shales have significant fracturing and abundant pyrite. They are sub-bituminous and fresh samples may ignite. If a fresh sample is submerged in water, "an oily sheen rises to the water's surface." Though data is sparse, TOC's have been measured at over 3% by weight in eastern New York and Quebec. Gas shows have been encountered in wells in eastern and central New York. Current shale plays such as the Barnett and Antrim show that every shale play is somewhat unique, each with its own characteristics and problems. It is clear that the fractured Utica Group shales of New York offer the potential to be an economic play. More research is needed that addresses the geologic and reservoir properties of the shale.

Philip L. Martin, Consultant

Detailed Surface Structural Mapping Reveals Multiple CSD's and Other Significant Structural Stratigraphic Relationships West-Central Pennsylvania

Within the sixty or seventy odd airline miles from Johnstown, Cambria County, Pennsylvania northeastward to Snowshoe, Centre County, Pennsylvania, at least ten prominent northwest-trending Cross Strike Discontinuities (CSD's) are traced on detailed surface structure maps (twenty six 7 1/2 Quads as of September, 2003) created through the stereoscopic interpretation of aerial photos. Marking these CSD's are such structural features as abrupt strike offsets, trend offsets of major folds, abrupt changes in axial direction of major folds, abrupt plunging of major folds, small narrow folds paralleling CSD's, and actual normal faults which probably have more strike-slip than vertical motion. These CSD's will be of great interest to the industry as Trenton exploration moves southward from New York. Detailed mapping of all the major folds in the area is enhanced by the delineation of subtle flank steep zones and structural terraces hinting at deep development in the area will recognize some striking subtle, and not so subtle, relationships between depicted surface structure and Upper Devonian productive facies distribution. In addition, because of the large extent of the mapped area, some interesting regional tectonic implications can be inferred. The construction of the detailed surface structure maps utilized in this study was made possible through the unique three-dimension perspective afforded by stereoscopic viewing, which permits the accurate tracing on the aerial photos of the outcrops of many exposed Appalachian Plateau bedrock units. When carefully plotted from photos to 7 1/2' topographic maps, the intersections of these outcrop traces with topographic contours yield a dense network of elevation control points. Contouring these data produces detailed surface structure maps, which neither overemphasize micro-geology nor smooth over subtle structural detail. Utilizing these maps to extrapolate surface structural detail from known productive areas to undrilled "look-alikes" could lead to the identification of new leads and/or the enhancement of existing prospects.

Ronald L. Martino, Kenneth R. Marcum II, and Timothy D. Cook, Department Of Geology, Marshall University

Stratigraphy, Petrography, and Sedimentary Facies of Lower Pottsville Sandstone (Lower Pennsylvanian) in the Greasy Ridge Oilfield, Southeastern Ohio

The Greasy Ridge Oilfield is an area of anomalous, shallow (550-800 ft) oil production. The field was discovered in 1985 and was estimated to have 3,040,000 STB of original in place oil, with about 10% recoverable by primary methods. A detailed stratigraphic, structural and petrographic analysis of the field has been undertaken to develop a better understanding of the reservoir and trap. This preliminary analysis is based on 34 geophysical logs, 4 cores, and 7 thin sections and comparison of this subsurface data with outcrops 25 to 50 miles from the oilfield. The pay sand ranges from 2 to 30 feet, has an average thickness of 15.9 ft, and consists of fine to very fine sandstone. The base occurs about 75 feet above the top of the Sharon Sandstone. The pay sand overlies black sideritic shale containing *Lingula* and burrowed siltstone with *Teichichnus* and is overlain by a series of coals. Mean framework grain composition is

Q₉₄F₁L₅. Porosity averages 14.4% but varies substantially due to the patchy nature of the cement. Most of the porosity appears to be secondary and formed by selective dissolution of feldspar grains and carbonate cement, as evidenced by grain corrosion, oversized pores, and honeycombed grain fabric. Structural contours drawn on top of pay sand indicate 2 or 3 structural highs elongated ENE-WSW with relief of 20-30 ft. Depositional cycles exhibited by Lower Pottville strata in the region involve fluvial incision followed by aggradation of fluvial-to-estuarine sands, which are capped by coals and restricted marine shales.

David L. Matchen, Ronald R. McDowell, Katharine Lee Avary, and Michael E. Hohn, West Virginia Geological and Economic Survey

Reservoir Characterization of the Devonian Gordon Sandstone in Two West Virginia Oilfields: Using Modern Techniques to Understand an Old Reservoir

The Jacksonburg-Stringtown oilfield in northern West Virginia has produced 20 MMBO since 1895; the smaller Wileyville field, 9 miles to the north, has produced 1.6 MMBO since 1899. Waterflood projects in both have been beset by problems including very high injection pressures, low oil-to-water recovery ratios, and unpredictable water flowpaths. WVGES has undertaken geologic and petrophysical studies in each to assist the operator in optimizing waterflood performance. Six cores from Jacksonburg-Stringtown and two from Wileyville were described in detail, correlated to well logs, and permeability profiles were constructed using minipermeameter data. Five lithofacies were defined based on core and well log observations; statistical analysis of log data allowed the definition of four electrofacies. Lithofacies did not directly correspond to electrofacies, however, the Featureless Sandstone lithofacies (FSS), the pay sandstone in both fields, was identifiable as single, distinctive electrofacies. Correlation of log data allowed construction of a sequence stratigraphic framework for the Gordon. This framework consists of four parasequences, three containing reservoir quality sandstone. Creation of a 3-D electrofacies model for the Gordon in each field allowed the construction of horizontal and vertical slice maps demonstrating reservoir compartmentalization. The Gordon reservoir is composed of compartments isolated vertically and laterally by low permeability sandstones and shales. Poor waterflooding performance may be the result of injection of water into permeable sandstones of one parasequence and completion of production wells in permeable, but noncommunicating sandstones of a different parasequence. The completion of injectors and producers in porous but impermeable sandstones is another potential problem. This work was supported by U.S. Department of Energy Contract Number DE-AC26-98BC15104 and Stripper Well Consortium Contract Number 2285-WVGS-DOE-1025.

James McDonald, Ernie R. Slucher, Donovan M. Powers, E. Mac Swinford, and Lawrence H. Wickstrom, Ohio Division Of Geological Survey

Bedrock Geology and Bedrock Topography GIS for Ohio

The Ohio Division of Geological Survey is now releasing a number of statewide data sets in geographic information systems (GIS) format. These GIS data sets of Ohio include: 1) a digital-elevation model; 2) the original land subdivisions; 3) the bedrock topography; 4) and the bedrock geology. The most geologically significant are the bedrock-geology and bedrock-topography GIS data sets. The bedrock-geology and bedrock-topography maps and GIS data sets are the culmination of a project to remap the bedrock geology of Ohio, and represent the first major update since 1920. This new mapping has resulted in the production of bedrock-geology and bedrock-topography maps and GIS data sets at 1:24,000 scale, and a new state-bedrock map and GIS data set at 1:500,000 scale. As part of an effort to make the data user-friendly, GIS applications have been created that will allow the 1:24,000-scale bedrock-topography and bedrock-geology maps and GIS data layers to be extracted for stand-alone use and printing. The multidimensional utility of the bedrock-geology and bedrock-topography data sets will facilitate future oil-and-gas exploration in Ohio. The

bedrock-topography data set is especially useful for identifying potential lineaments, fracture zones, faults, pre-glacial drainage patterns, and other geomorphic anomalies. A number of relationships can be shown between the bedrock geology and oil-and-gas fields. These GIS data sets, as well as additional GIS data sets to be developed by the Ohio Division of Geological Survey in the near future, will allow unprecedented analytical capabilities for exploration and research of the state's geology.

Robert C. Milici, Robert T. Ryder, and Christopher S. Swezey, U.S. Geological Survey

Petroleum Resource Assessment of the Central and Northern Parts of the Appalachian Basin, Eastern U.S.A.

The U.S. Geological Survey completed an assessment of the technically recoverable, undiscovered oil and gas resources within the central and northern parts of the Appalachian Basin in 2002. The assessment was based on the identification of the major Total Petroleum Systems (TPS) in the basin. The TPS approach to hydrocarbon assessments requires the identification of the major source rocks and an understanding of the following: (1) thermal maturation and expulsion of hydrocarbons from their source rocks, (2) the migration of hydrocarbons, and (3) the entrapment of hydrocarbons within their principal reservoirs. Five major petroleum systems were identified: the (1) Conasauga-Rome/Conasauga TPS; (2) Sevier-Knox/Trenton TPS; (3) Utica-Lower Paleozoic TPS; (4) Devonian Shale-Middle and Upper Paleozoic TPS; and (5) the Carboniferous Coal-bed Gas TPS. These five systems were divided into 25 assessment units that were classified either as conventional or continuous (unconventional) based generally upon the presence or absence of the gravitational separation of gas, oil, and water within structural and/or stratigraphic traps, respectively. Undiscovered oil resources in the Appalachian Basin are associated primarily with 10 conventional assessment units, whereas most of the undiscovered natural gas and natural gas liquids are associated with 15 continuous reservoirs. Conventional hydrocarbon resources, associated with TPS 1-4, were assessed at the mean as 54.3 million barrels of oil (MMBO), 4.3 trillion cubic feet of gas (TCFG), and 39.3 million barrels of natural gas liquids (MMBNGL). Continuous hydrocarbon resources associated with TPS 3-5 were assessed at the mean as 65.98 TCFG and 833.2 MMBNGL.

John B. Nelson, University of Maine

Site Characterization of Historical Cemeteries Using Electrical Resistivity Measurement

Historical cemeteries (>1600 CE) must be included in site characterization studies prior to resource extraction, environmental remediation or development. In many states, cemeteries are protected by law, and there is a lively public interest in identifying and restoring old cemeteries that have been obscured or lost through neglect. Two case studies are presented in which electrical resistivity measurement was used to infer the three-dimensional boundaries of cemeteries, and to describe the location of their contents. Surveys with 3m-node spacing have a horizontal accuracy at the surface of 0.75m and a depth range to 12m in typical soils. A calibration study on a nineteenth-century cemetery revealed a densely utilized hillside plot delineated by its sandy lithology. Walls or fence-post traces were absent. A buried sarcophagus was identified by a sharply rectilinear profile, the peaked-roof wave profile from the top of the sarcophagus, and internal high resistivity, interpreted as air space. Areas with presumably decaying wooden coffins were readily apparent, with internal high resistivity, but with blurred rectilinear edges. Peaked-roof wave profiles were absent. The second application involved successfully locating the purported burial of a local Revolutionary War hero beneath a Depression-era homestead. Exacerbating the debate was a conflict between developers, heirs, and the local historical society. These two examples are used to illustrate the benefits of electrical resistivity as a non-destructive, non-invasive method of cultural resource evaluation.

Richard E. Nyahay and Langhorne B. Smith, Reservoir Characterization Group, New York State Museum

Vertical and Lateral Distribution of Hydrothermal Dolomite Reservoirs in Trenton-Black River Carbonates of New York

Most of the producing Black River hydrothermal dolomite reservoirs in New York are in a relatively small trend that extends from Steuben County to Chemung County in the south central part of New York State. Most productive wells are dolomitized in the uppermost clean carbonates in the Black River and variably throughout the lower parts of the Black River and rarely in the Trenton Group. The purpose of this poster is to show that hydrothermal dolomite occurs in the same stratigraphic intervals far to the north, east and west of the current producing area. All wells that penetrate the Black River with density logs were used to find occurrences of dolomite. This analysis shows what is interpreted to be tight hydrothermal dolomite occurs as far east as Otsego County (approximately 100 miles east of the current production), and as far west as western Cattaraugus County (approximately 90 miles west of current production). The occurrence of dolomite suggests that the same processes have occurred in these locations that made the reservoirs in the south central part of the State. To the north, dolomite was found in the Blue Tail Rooster and Auburn Geothermal Fields in Cayuga and Onondaga Counties (50 miles northeast of current production). The well at the Auburn Geothermal Field has been producing behind pipe from the dolomitized interval for more than 20 years. This work suggests that armed with the appropriate model, explorationists may soon find Black River hydrothermal dolomite reservoirs across much of central and western New York.

Frank A. Revetta, Warren Belile, Justin Spanneut, Andrew McDermott, Geology Department, SUNY College At Potsdam, and Joseph Wallach, J. L. Wallach Geosciences, Inc.

Gravity Anomalies, Faults and Gas Fields

Abandoned natural gas fields exist along the southern and southwestern periphery of the Tug Hill Plateau, an elevated physiographic sub-province located east of Lake Ontario and bordering the Grenvillian basement in New York State. The Tug Hill Plateau is inferred to be an uplifted-fault-bounded block which if correct might account for the existence of those gas fields. Because of the paucity of exposed bedrock, ground-based gravity surveys were conducted in the vicinity of three gas fields to help ascertain whether or not the physiographic limits of the Tug Hill Plateau are surficial expressions of deeply related faults. Surrounding and including the Sandy Creek-Lacona and Pulaski gas fields, gravity data were recorded at 176 stations which cover four 7.5 minute quadrangles. In the area encompassing the Camden field, 122 measurements were made in six 7.5 minute quadrangles. Station spacing varied from 1 to 2 kilometers. Within the area of the Sandy Creek and Pulaski fields the physiographic boundary of the plateau is oriented north-south, whereas in the Camden area it is oriented north-west. These trends in both areas are reflected in the contoured Bouguer gravity data. In addition, the west-northwest trending Salmon River Valley, inferred to be a fault, cuts across Pulaski field and is also evidenced in the gravity contours. The foregoing, therefore, lends credence to the fault interpretations. Also, gravity and magnetic traverses were conducted across faults in the Trenton-Black River Group in the Tug Hill Plateau. Gravity and magnetic anomalies across the faults are interpreted as indicating faults in the Trenton-Black River are controlled by faulting in the Precambrian basement.

Jeffery G. Richardson, Columbus State Community College and Stig M. Bergström, The Ohio State University

Regional Stratigraphic Relations of the Trenton Limestone (Chattfeldian; Ordovician) in the Eastern North American Midcontinent

The Trenton Limestone and equivalents have been one of most economically important Paleozoic units in North America. With renewed interests in and discoveries of hydrocarbons the Trenton-Black River of the Appalachian Basin, a detailed biostratigraphic and sequence stratigraphic study of this succession would be extremely useful for the ongoing hydrocarbon exploration. The Trenton Limestone in the primary study area (Ohio, Indiana, Illinois) is composed of a 10-400 foot thick succession of carbonates that contains a transition from a cratonic inner-shelf environment to a platform environment. Over 12,000 conodont elements were identified from six cores in the study area to gain a better understanding of the facies relations and sequence stratigraphy of the Trenton Limestone. The conodonts recovered are characteristic of the *Phragmodus undatus*, *Plectodina tenuis*, and *Belodina confluens* Conodont Zones (equivalent to part of the *Amorphognathus tvaerensis*-*Amorphognathus superbus* North Atlantic Conodont Zones). Within the Trenton succession, the conodonts provide not only an excellent biostratigraphic framework, but also are used to identify the M4-M5 and M5-M6 sequence boundaries. Transects were constructed using the six cores and geophysical logs from the study area (Ohio, Indiana, Illinois) along with previously described and sampled sections including the stratotype of the Trenton in New York State, sections in Pennsylvania, a well in the eastern Michigan Basin, and outcrop data from Kentucky. These transects provide a detailed understanding of the regional biostratigraphic and facies relationships of the Trenton Limestone in the eastern Midcontinent.

Ronald A. Riley, Joseph J Wells, James McDonald, and Lawrence H. Wickstrom, Ohio Division Of Geological Survey

Assessment of CO₂ Sequestration for Enhanced Recovery in Ohio

Updated oil-and-gas-fields maps of Ohio have been created using a geographic information system (GIS) to assess potential fields for CO₂ sequestration and CO₂-assisted enhanced recovery. This work was performed as part of the Midcontinent Interactive Digital Carbon Atlas and Relational Database (MIDCARB) project, a U.S. DOE-funded consortium of the Ohio, Kansas, Illinois, Indiana, and Kentucky state-geological surveys. This oil-and-gas-fields GIS has been linked to Ohio's oil-and-gas-well database, RBDMS, and oil-and-gas-production database, POGO, to permit greater flexibility of mapping and analyses. Individual oil-and-gas fields are grouped into eight major plays defined by producing horizon to enable better reservoir characterization for potential CO₂-sequestration zones. Each oil-and-gas field contains associated attributes, where available, such as reservoir characteristics (i.e. average depth, lithology, porosity, permeability, reservoir temperature, and net thickness), production data (i.e., cumulative production, original-oil-in-place, and remaining-oil-in-place), and fluid properties (i.e., oil gravity, oil viscosity, and average water saturation). Using this data, oil-and-gas fields can be screened for CO₂-sequestration and enhanced-recovery potential, and CO₂-storage capacity can be calculated. Oil samples from representative reservoirs throughout the state were collected to test the minimum miscibility pressure (MMP), one of the most critical screening factors for CO₂-enhanced-recovery projects. Initial test results for the Knox MMP is approximately 1500 psia, indicating many Knox reservoirs in eastern Ohio are potential candidates for CO₂ sequestration.

Luisa Rolon and Jaime Toro, Department of Geology and Geography, West Virginia University

Extensional Structures Related to the Jurassic-Cretaceous Rift of the Middle Magdalena Valley Basin – Colombia

The Middle Magdalena Valley Basin (MMVB), Colombia, evolved to its actual configuration through several stages closely linked with the tectonic events of the northwest corner of South America. During Early Jurassic extensional deformation related to the break-up of Pangea, resulted in the development of rift structures in the MMVB area. The syn-rift infill consists of fluvial and lacustrine sedimentary rocks (Jordan, Giron and Santos formations), overlain by limestones and shales (Rosablanca and Paja formations). Irregular discontinuous

reflectors, rotated by normal fault blocks and increasing thickness towards the south-east, characterize the Jurassic syn-rift section. In Early Aptian, a post-rift phase controlled by thermal subsidence started. During this phase the Tablazo, Simití, La Luna and Umir formations were deposited. The seismic character of this sequence, consists of continuous reflectors and slow changes in thickness. From the end of the Cretaceous through the present, the collision of the oceanic terranes of the Colombian Western Cordillera first, and the Panama Arc later, caused thrusting in the Central and Eastern Cordilleras until the MMVB became an intermontane basin. Sedimentation during this period consisted of fluvial deposits accumulated as continental molasses. The rift structures are well preserved in the northern part of the MMVB. In addition, it has been proposed that the range-bounding faults of the Eastern Cordillera are controlled by the geometry of the Jura-Cretaceous rift, however it is often difficult to demonstrate this unambiguously due to the complexity of the Andean structure. In contrast, many smaller scale compressional structures in the MMVB are cored by high-angle reverse faults that are clearly inverted normal faults. Inversion can be documented by thicker rift strata on the hanging wall and by variation of fault throw with depth.

John A. Rupp, M. Mastalerz, Indiana Geological Survey, Grzegorz Lis, and Arndt Schimmelmann, Department Of Geological Sciences, Indiana University

C, H-Isotope Ratios of Indiana Coalbed Methane and Their Genetic Implications

Sedimentary basins containing low-rank coals have, until recently, not been targeted for coalbed gas exploration, primarily because the low thermal maturity was not expected to have generated sufficient thermogenic gas. However, the accelerated coalbed methane (CBM) development in the Powder River Basin has changed this perspective and initiated growing interest in the coalbed gas potential of less mature basins like the Illinois Basin. Limited information exists on the content and origin of gas in the Illinois Basin; therefore an adequate exploration model for CBM in this basin is lacking. This study addresses the origin of coalbed gas in Indiana based on carbon and hydrogen stable isotope ratios in methane. Gas samples were collected in Indiana from wells in Knox and Sullivan Counties. Several gas samples were collected from wells producing coalbed gas from the Seelyville coal at depths ranging from 350 to 475 ft. For comparison, samples were collected from wells producing gas from mine voids in the Springfield coal (423 ft. deep) and from a Pennsylvanian sandstone reservoir (850 ft. deep). Methane from the Seelyville coal has isotopic ratios ranging from $\delta^{13}\text{C} = -59$ to -65.5 ‰, and from $\delta\text{D} = -180$ to -205 ‰. Methane in mine gas from Springfield coal has a $\delta^{13}\text{C}$ value of -60 ‰ and a δD value of -201 ‰. In contrast, methane from the sandstone reservoir is characterized by $\delta^{13}\text{C} = -52.5$ ‰ and $\delta\text{D} = -208$ ‰. The overall ranges of $\delta^{13}\text{C}$ and δD values for coalbed methane suggest a dominantly biogenic/microbial mechanism of gas formation. On the other hand, methane from the sandstone reservoir is likely thermogenic in origin, with minor biogenic input.

R. T. Ryder, U. S. Geological Survey, D. C. Harris, Kentucky Geological Survey, P. Gerome, Equitable Production Company, T. J. Hainsworth, GCSI, R. C. Burruss, P. G. Lillis, U. S. Geological Survey, and D. M. Jarvie, Humble Geochemical Services

Cambrian Petroleum Source Rocks in the Rome Trough of West Virginia and Kentucky

A 130-ft-thick Cambrian marine black shale from a core between 11,150-11,195 ft in the Exxon No. 1 Smith well in Wayne County, West Virginia, is a good petroleum source rock that, combined with favorable oil-source rock correlations, defines a petroleum system in the Rome trough. This black shale occurs in the Middle Cambrian Rogersville Shale of the Conasauga Group. Total organic carbon (TOC) values of 4 samples that range from 1.2 to 4.4%, average 2.6%, are the highest reported to date in the pre-Knox section of the Rome trough. Although the samples are in the zone of gas generation based on low HI values (55 to 63) and Tmax values of about 465, S1 values of 0.81 to 2.71 indicate that they contain free extractable hydrocarbons. The gas

chromatogram (GC) of a bitumen extract is characterized by *n*-alkanes from C₁₁ through C₃₀, strong odd-carbon predominance in the C₁₅ to C₁₉ range, and small amounts of pristane and phytane. The strong odd-predominance is diagnostic of the alga *G. prisca* whose age is usually restricted to the Ordovician. This study may be among the first to document *G. prisca* characteristics in Cambrian-age source rocks. Thin black shale in the Lower to Middle Cambrian Rome Formation in the Texaco No. 1 Kirby well in Garrard County, Kentucky, having TOC values as high as 3.2%, HI values as high as 417, and similar extract GC characteristics, may be a secondary source rock in the petroleum system. The GC fingerprint of the bitumen extract from the Rogersville Shale correlates closely with oils from Cambrian reservoirs in eastern Kentucky. These oils are from the Homer field in Elliott County; Inland No. 529 White well in Boyd County; and Miller No. 1 Bailey well in Wolfe County. The new petroleum system probably extends along the Rome trough from eastern Kentucky to at least central West Virginia.

Alan H. Silliman and Melissa Noebes, W. L. Gore & Associates, Inc.

Adsorbent Sample Surface Geochemistry: Mechanics, Application, and Value as Applied to Petroleum Exploration

Adsorbent-based surface geochemical samplers are frequently used to detect a wide range of volatile organic hydrocarbon compounds in soil. Many of these compounds are likely to be of thermogenic in origin, from underlying petroleum reservoirs. Microbuoyancy theory has been proposed as the mechanism for vertical migration of organic compounds, through the stratigraphic column to the surface. This method provides direct detection data for reservoir hydrocarbons, which when integrated with other G&G information may significantly reduce exploration risk. Heavy saturated compounds are detectable in minute amounts (10⁻⁹ grams). Geochemical samplers are used to collect surface geochemical signatures from exploration areas, and also from available regional petroleum production and dry well sites ("control samples"). Control samples are used to assist the interpretation of survey sample data through a process of "geochemical modeling" (comparing exploration area samples to control sample signatures). The sampler type consists of engineered hydrophobic sorbents contained in a permeable membrane made from expanded polytetrafluoroethylene (ePTFE). The hydrophobic character of the adsorbents is an important feature, to enable the high sensitivity detection of organic compound vapors in at times high relative humidity environments. Samplers are placed in the soil to depths of ~80 cm for a period of usually 2-3 weeks, and collect vertically migrating volatile and semi-volatile organic compounds. Samplers are analyzed for 87 organic compounds, from ethane (C₂) to octadecane (C₁₈), and including pristane (2,6,10,14-tetramethylpentadecane) and phytane (2,6,10,14-tetramethylhexadecane). The analytical list includes several compound classes: aliphatics (normal, branched, cyclic alkanes, alkenes), aromatic and polyaromatic hydrocarbons, aldehydes, terpenes, and miscellaneous compounds (furans). Samplers are analyzed by thermal desorption GC-MS. An example of the application of this technique, and its value in petroleum exploration, is illustrated with project data from a Trenton – Black River play in New York State. The integration of surface geochemistry with 2D seismic proved a successful combination, and led to a gas discovery. This was possible despite a less than optimal survey design, imposed by survey area access considerations. Cumulative project experience indicates that this technique accurately predicts petroleum presence at a rate of ~88%, and has a false negative rate of ~7%.

Langhorne B. Smith, Richard D. Bray and Richard Nyahay, New York State Museum

Multiple Play Types in the Hydrothermally Altered Beekmantown Group Carbonates of East-Central New York

Two play types may occur in the Cambro-Ordovician Beekmantown Group of the Mohawk Valley, New York: a laterally extensive matrix dolomite play in the

Cambrian Little Falls Formation and a fault-related hydrothermal dolomite play in the overlying Ordovician Tribes Hill Formation. The cyclic Cambrian Little Falls Formation is composed of seven 3rd-order sequences that have mud-dominated carbonates in the TST and grain-rich carbonates in the HST. Some of the laterally extensive grain-dominated carbonates have excellent intercrystalline porosity that can be correlated across the 30-mile wide study area. Because the porosity zones are laterally extensive, four-way closures may be necessary to develop a good trap. The overlying Tribes Hill Formation carbonates are only dolomitized around faults. In one outcrop, the dolomite clearly follows NW-SE trending en echelon strike-slip faults; in others the dolomite may form around NE-SW trending normal faults. These faults were active during the Late Ordovician Taconic Orogeny. Because the dolomite pinches out laterally into tight limestone, there may be a play in the Tribes Hill Formation in diagenetic traps around faults similar to the Trenton Black River play. Although there is probably some early dolomite, most of the reservoir facies are probably in hydrothermal dolomite. This includes the coarse dolomitized grainstones and fracture and void filling saddle dolomite of the Little Falls and almost all of the dolomite in the Tribes Hill Formation. Other indicators of hydrothermal alteration include: quartz and sulfide-filled fractures and vugs, abundant anthraxolite, and a clear link between faults and dolomitization. Strontium isotopes, stable isotopes, trace elements and fluid inclusions all support a hydrothermal origin for the fracture-filling saddle dolomite and most of the matrix dolomite.

Langhorne B. Smith and Richard Nyahay, New York State Museum

Trenton Black River Hydrothermal Dolomite Reservoirs of New York: An Integrated Structural-Stratigraphic-Diagenetic Play

Fourteen new gas fields have been discovered in New York State over the past several years in fault-controlled dolomites of the Ordovician Trenton and Black River Groups. Production from these fields has driven statewide natural gas production to its second highest level in history. Like the Albion-Scipio trend in Michigan, the reservoirs occur in structural lows in patchy matrix dolomite and brecciated zones. Fluid inclusions, stable isotopes, trace elements, strontium isotopes, field relations and petrography all support a hydrothermal origin for the dolomite. The structural lows are visible on seismic and form over dilational parts of strike-slip faults that developed during the Ordovician Taconic Orogeny, soon after deposition of the Trenton and Black River Groups. These wrench faults were conduits for upward migrating high-pressure, high temperature fluids that leached and dolomitized clean, permeable limestones in the highstand and early transgressive parts of sequences. Argillaceous limestones and shales, which occur in the middle and upper transgressive portions of sequences, impeded further upward fluid migration. The high-pressure fluids induced brecciation and fracturing in the uppermost parts of the clean limestone and lowermost portions of the argillaceous limestones. The breccias and fractures are partially cemented with saddle dolomite and calcite. Porosity and permeability occur in matrix dolomite, breccias, fractures, and vugs. Statewide analysis of logs in the Trenton Black River reveals patchy hydrothermal dolomitization occurs in places across much of the western two-thirds of New York. This suggests that current production may represent just the tip of the iceberg. Analysis of various hydrothermal dolomite play types around the world show that hydrothermal dolomite reservoirs occur in a variety of structural settings. These include wrench faults associated with compressional tectonic events (the TBR play as we know it), fault controlled margins, fault intersections, carbonates deposited on newly rifted or tectonically active basement rocks. There are likely to be opportunities in a variety of structural and stratigraphic settings throughout the eastern United States.

Richard Smosna and Kathy R. Bruner, West Virginia University

Pore Geometry and Permeability in a Dolomite Reservoir

Because pore geometry is an inherent element of permeability, one important objective of reservoir characterization is to describe, classify, and quantify the

pore network of reservoir rocks. The principal components of pore geometry consist of size, shape, number of connecting throats (coordination number), pore-to-throat size ratio, and the spatial arrangement of different pore types. Thin-section analysis of dolomites in the Mississippian Greenbrier Limestone from an old field of West Virginia identifies five different pore types; intergranular, moldic, intercrystalline, intragranular, and feldspar solution pores. Moreover, hundreds of measurements of individual pores show that each type has its own set of petrographic characteristics. Moldic pores, for example, are largest and exhibit a high pore-to-throat ratio and high coordination number. On the other hand intergranular and intercrystalline pores are smaller and have low pore-to-throat ratios and low coordination numbers. Pore types in the Greenbrier reservoir generally occur in combination, and the specific mix of pore geometries proves significant in that it correlates to the dolomite's permeability. In addition to high total porosity and large pore size, the most beneficial properties of a compound pore network include a high number of connecting throats, relatively large pore throats, and a continuous or uniform arrangement of pore types both between and inside the framework grains. Owing to these favorable attributes, dolomite samples with an equal mix of moldic and intergranular pores have the greatest permeability, even though their total porosity is just middling.

Wilfrido Solano-Acosta, John A. Rupp, Agnieszka Drobnik, and Maria Mastalerz, Indiana Geological Survey

Pennsylvanian System in Indiana: A Complex Target for CO₂ Sequestration and Coal Bed Methane Recovery

Indiana's Pennsylvanian System is a complex stratigraphic sequence composed of compartmentalized sandstones, largely continuous coal seams, and organic-rich shales. Such diverse facies architecture makes this sequence unique for CO₂ sequestration, enhanced oil and gas recovery, and potential coal bed methane extraction. As energy demand increases, a closer look at this sequence may be attractive both as a source of energy and as a sink for CO₂ formed during power generation. A consortium of five states (Illinois, Indiana, Kansas, Kentucky, and Ohio) has developed the Mid-continent Interactive Digital Carbon Atlas and Relational dataBase (MIDCARB) in order to identify major sources of CO₂ emissions and to determine the most suitable sites for geologic sequestration in the Midwest. This study presents an evaluation of the distribution of selected geological horizons and their characteristics for CO₂ sequestration within the Pennsylvanian rock sequence. The sequestration potential in mature, nearly depleted oil and gas fields, as well as in the relatively thick and widely distributed Seelyville coal, is substantial. Structural and thickness analysis of the Seelyville coal, together with data on the maximum sorption capacity of CH₄ and CO₂/CH₄ ratios, form the basis for calculation of CO₂ sorption capacity of this coal. Subsurface reservoir data including thickness, porosity, permeability, and depth (pressure), were integrated to make a volumetric estimation of the CO₂ sequestration potential of this diverse stratigraphic Pennsylvanian rock sequence in southwest Indiana.

Allan Spector, Allan Spector and Associates Ltd.

Aeromagnetic/Gravity Data and Hydrocarbon Exploration in the Appalachian Basin

Precambrian basement faults are resolved from a combination of aeromagnetic and gravity data. High-resolution aeromagnetic data (as opposed to reconnaissance data) is notably effective in mapping faults. Analysis of the data in profile form along flight lines is a pre-requisite for this purpose. We find that to a large extent, gravity data relates to Precambrian structure and lithology - Corroborate magnetic faults as well as structures that are weakly magnetic. - Locate potential basement "hot spots". - Locate lithologic changes in the sedimentary section that may be prospective for reservoir development. There are many areas where there are sufficient U.S. government gravity to be useful in this context. Basement faults are shown to have a remarkable association with oil and gas pools in Ontario, New York, West Virginia Ohio Kentucky and Tennessee. The pools may be categorized according to age; Cambrian,

Ordovician, Silurian and Devonian. It can be demonstrated that this use of magnetic and gravity data maximized the utilization of seismic surveying, and much more expensive exploration food.

Jeffrey D. Spruit, Michigan Dept. of Environmental Quality, John Valkenburg, and Hans A. Johannes, Malcolm Pirnie Inc.

A Multi-Agency Clean-Up of an Abandoned Crude Oil Pipeline Along an Urban to Rural Corridor in Kalamazoo County, Michigan

The 17-mile long 6-inch conduit originates from a bulk storage facility in rural southeastern Kalamazoo County and ends at a former crude oil refining facility in the City of Kalamazoo. The pipeline was left abandoned still containing crude oil, posing a threat to several environmentally sensitive areas it crosses. Increasing development pressure along the entire length of the predominantly rural pipeline increased the threat of unfortunate, potentially release-causing encounters with the pipeline. Michigan environmental law considered the pipeline an abandoned container that posed a threat to the environment. The Michigan Department of Environmental Quality (MDEQ) made the commitment to address that threat using both state and federal funding. After draining and cleaning using conventional techniques, over 97% of the pipeline length was grouted in situ to protect environmentally sensitive areas. Less than 1% was left ungrouted while approximately 2% of the pipeline was physically removed. Approximately 80,000 gallons of crude oil were recovered from the pipeline and recycled. The field work was accomplished with a minimal number of releases to the environment. Project success can be attributed to 1.) focused strategic public relations planning; 2.) vigorous project management assistance and oversight performed by MDEQ's consultant; 3.) interagency cooperation between USEPA, MDEQ and local units of government; and 4.) stringent contractor qualification requirements. Property transactions and increased development can now occur in the area without fear of causing a release of crude oil to the environment.

Steven Tedesco, Atoka Geochemical Services Corporation

Use of Iodine Surface Geochemistry for Exploration of Silurian Reefs in the Illinois and Michigan Basins

The concept of surface geochemistry as an exploration tool to find new petroleum reservoirs is based on the concept of vertical migration. Based on this concept, petroleum migrates to the surface from a petroleum reservoir at depth along micro-pores, micro-fractures and micro-unconformities. The petroleum compounds and their by-products in the soil substrate will eventually vent to the atmosphere where they are broken down by plant and bacterial action and react with other elements and compounds. The presence or absence of anomalous surface geochemical conditions directs the explorationist to either proceed forward to define a prospect with potential drilling or to abandon the prospect. Surface geochemistry, if done properly, inherently reduces risk and increases success. Iodine has a unique association with thermally cracked hydrocarbons. Where petroleum is present in the soil or in the subsurface anomalous amounts of iodine are present. Iodine does not seem to bond with biogenic methane. Analyzing for iodine from soil samples allows for a cost effective exploration tool to locate and define the approximate location of Silurian Age reefs in the subsurface. This allows high grading of prospect areas and a more effective use of exploration dollars in shooting seismic and leasing. Examples of successful iodine surveys will be presented from Illinois, Michigan and Ontario where iodine has been effectively used and successful.

Steven A. Tedesco, Atoka Coal Labs LLC

Coal-Bed Methane Activity in the Illinois Basin – An Update

Within the Illinois Basin is a series of Pennsylvanian Age deltaic deposits that contain significant coal reserves and is found in most of Illinois, Southwestern Indiana and Western Kentucky. The basin has undergone intermittent exploration for coal-bed methane since 1985. The coals are relatively thin (1 to 8 feet), have large lateral extent, high volatile C to A bituminous rank, sulfur varies from 2% to 11%, ash from 5% to 15% and moisture contents less than 8%. Gas contents vary from 5 to over 200 scf per ton. Present day coal bed methane production from unmined areas is restricted to Sullivan and Vigo counties, Indiana, wells producing from abandon mines and an ongoing pilot in Central Illinois. Other pilot projects and test wells have been initiated in 2003 with various results. 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 poor to good permeability and marginal to moderate gas contents that vary across the basin. Completion practices have gone from historically single seam to multiple seams. The coal seams that are the main targets are the Seelyville, Colchester (No. 2), Springfield, (No. 5), Herrin (No. 6) and Danville (No. 7) or their equivalents. The basin in late 2002 and into 2003 has seen an increase in leasing and drilling activity and because of its location to strong gas markets is attractive to industry.

Edward R. Tegland, Exploration Development, Inc.

Crooked CDP Lines and Structure; Whose Fault Is It ?

The Trenton-Black River play has created a resurgence of "road" vibrator work in the Appalachian Basin area. This has been coupled with reprocessing of various vintages of legacy seismic data. The primary difference between current and legacy being in group interval, source interval, number of channels and bandwidth of recording. Tegland 1973, and 1974 presented an early scheme for dealing with "crooked line" problems. At that time the the overall offsets were generally smaller and channel count less. "Smearing" of the stacked result due to crossline dip was seen by most people as the most significant problem and limiting the crossline window appeared to be the best answer. This was accompanied by definition of inline traverses that were contorted to take advantage of maximum CDP fold areas. Since the results of stacking changed direction frequently it was necessary to created special "dip projected" lines that could be migrated if migration was desired. While these methods worked they were cumbersome. The more modern acquisition has generally more channels with smaller intervals but greater overall offset ranges. Using the earlier methods still has appeal to some geophysicists, but results in discarding large amounts of basic data. We are proposing much simpler basic CDP definition schemes which can then utilize various display techniques to evaluate the "Cross Line Dip" (CLD) related problems. We will demonstrate how CLD affects processes such as Normal Moveout (NMO) and other time correctional processes. We will demonstrate the behavior of the data relative to the choice of traverse line orientation using model data and actual data. The CLD displays make use of the 3-Dimensional nature of the data and suggest how one might make detailed local evaluation of structure in areas with a high degree of subsurface scatter. The issue of geographic positioning of resulting stack traces will also be discussed. Some ideas will be presented concerning this issue. The best results will require utilization of all a priori geologic information concerning structure. This means close cooperation between the processing and interpretation functions. This may result in more that one orientation of stack line and interpretation of various special displays. Remember one mans "smear" may be another man's 3-D data set.

Scott W. White, Timothy R. Carr, Kansas Geological Survey, James A. Drahovzal, John Hickman, Brandon C. Nuttall, Kentucky Geological Survey, Ron Riley, Ohio Division Of Geological Survey, John A. Rupp, Indiana Geological Survey, Beverly Seyler, Illinois State Geological Survey, Ernie Slucher, Ohio Division Of Geological Survey

An Update on the Midcontinent Interactive Digital Carbon Atlas and Relational Database (MIDCARB) Project

The "Midcontinent Interactive Digital Carbon Atlas and Relational dataBase" (MIDCARB) is a multi-state consortium (Indiana, Illinois, Kansas, Kentucky, Ohio), which has constructed an online distributed Relational Database Management System and Geographic Information System (GIS) for analyzing the relationship of major, stationary sources of anthropogenic carbon dioxide and geologic sequestration options (<http://www.midcarb.org>). The MIDCARB database is a tool that can be used to evaluate the feasibility and associated costs of geologic sequestration. Users have the ability to analyze CO₂ quantities available for sequestration from large point sources (power plants, ethanol plants, and other industrial sources) in relation to nearby geologic sequestration capacity of local and regional geologic reservoirs (e.g. oil or gas fields, deep coal seams, saline aquifers). Consortium states are linked into a coordinated regional database system consisting of datasets useful to industry, regulators and the public. The project provides advanced distributed computing solutions that dynamically link database servers across the five states so that data can be maintained at the local level but accessed through a single web portal. All data is available to the user online and can be queried, assembled, analyzed, displayed and downloaded. The MIDCARB consortium utilizes individual assets in each state to gather, manipulate and display data, including GIS mapping, custom application development, web development, and database design. In the future, the consortium intends to add additional information from other regional sequestration partnerships, thus expanding the breadth of the mapped area and the expertise available to assess the sequestration potential of various reservoirs

Neil E. Whitmer, Robert D. Hatcher, Jr., S. Christopher Whisner, Jennifer B. Whisner, J. Ryan Thigpen, and John G. Bultman, Department of Geological Sciences, University of Tennessee

Middle Ordovician Clastic Wedges in East Tennessee: A New Look at an Old Basin

Two Middle-Upper Ordovician (Taconian) clastic wedges formed in the southern and central Appalachians: the Blountian (Sevier, Middle Ordovician) and the Martinsburg-Tuscarora (Upper Ordovician to Early Silurian). Several depositional models have been proposed for each. We are constructing a 3-D model for the Blountian basin in Tennessee and adjacent states and reevaluating existing models. Development of a 3-D model of the Middle Ordovician clastic wedge in East Tennessee permits reexamination of current models of syn/post-Taconic orogenic basin dynamics. Within this basin major facies changes, both along and across strike, have been previously recognized but not examined in mapping context. Detailed geologic mapping, and stratigraphic and structural analysis are being conducted in selected areas where Blountian basin deposits are preserved in several Alleghanian synclines. 1:24,000- and 1:12,000-scale mapping facilitate more precise delineation of facies distributions and refined correlations of units in the Middle Ordovician Chickamauga Group. Two-dimensional industry seismic reflection data and detailed mapping permit a reevaluation of stratigraphic thickness estimates, previously considered as much as 10,000 ft. More quantitative estimates of Alleghanian structural geometries and stratigraphic thicknesses will yield viable palimpsestic restorations of basin and facies geometries. Paleocurrent indicators in carbonate bank and basin facies are being employed for the first time to determine sediment dispersal and sources. Facies distributions and source areas are particularly important if tectonic and thermal loading of Middle Ordovician black shales are a source of hydrocarbons in carbonate reservoirs farther west.

Douglas R. Wight, CDX Gas LLC

Unconventional Drilling Methods for Unconventional Reservoirs

Traditional surface drilling methods used to extract methane gas from coal and shale reservoirs have historically had low production rates, low recovery factors, do not drain the reservoir uniformly, require considerable surface disturbance to drill, and encounter extended dewatering periods. In recent years, advances in drilling technologies have allowed some operators to re-evaluate the economic viability of developing some unconventional reservoirs that had been previously discounted due to poor production performance. CDX Gas, LLC of Dallas, Texas has developed a patented drilling system that has dramatically enhanced production recoveries from low permeable coals and shales. The Z-Pinnate Horizontal Drilling and Completion System, employs horizontal drilling techniques in a multi-well pattern that create an efficient and environmentally friendly recovery method. A Z-Pinnate well drilled in a coal seam can deplete 1200 acres from a single small wellsite and typically recover 85 to 90 percent of the gas in place within 30 months. A pinnate pattern allows wells to reach maximum production rates in a matter of days by minimizing the dewatering period. Production profiles show that nearly 75 percent of cumulative production is recovered in the first 24 months along with a dramatic increase in recoverable reserves. By reducing the number of wells needed to deplete a project area, the Z-Pinnate Horizontal Drilling and Completion System reduces the surface disturbance caused by locations, gathering systems, and production facilities. This technique also reduces project development costs thus improving project economics and doing so while minimizing the effects on the environment.

Clay A. Wilcox, III, University Of Kentucky, David C. Harris, and James A. Drahovzal, Kentucky Geological Survey, University Of Kentucky

Origin and Geochemistry of Hydrothermal Dolostone Bodies in Central Kentucky

Isolated dolostone bodies in Upper and Middle Ordovician limestone strata of central Kentucky are analogs for subsurface Trenton-Black River dolostone reservoirs in the Appalachian basin. They are composed of coarsely crystalline and saddle-shaped dolomite, are spatially related to mapped faults, and are interpreted as products of hydrothermal fluids. Although 33 separate dolostone bodies are identified in central Kentucky, sample collection and mapping for this study was limited to two localities. Transmitted light and cathodoluminescent petrography reveal at least three types of dolomite. Dolomite I is euhedral to subhedral, rhombohedral-shaped, nonferroan, luminescent, and appears to replace fine grained matrix and grains. In contrast, dolomite II is anhedral, ferroan, nonluminescent, and appears to replace calcite cement and grains. Although not present in every sample, dolomite III is ferroan, saddle-shaped, nonluminescent, and precipitated in fractures and vugs. Cathodoluminescence has also revealed a relative diagenetic sequence for the dolomite. Dolomite I is believed to be the first generation. Since dolomite II and III are nonluminescent, a relative timing is uncertain. In limited samples, late-stage, zoned, calcite is present and thought to be the latest diagenetic event, as evidenced by cross-cutting relationships and luminescent patterns. Electron microprobe analysis of dolomite crystals is ongoing to quantify strontium, calcium, manganese, magnesium, and iron concentrations. Dolomite II and III contain a relative abundance of iron, whereas dolomite I has significantly lesser amounts. None of the dolomites have significant amounts of manganese or strontium. Elemental counts for late-stage calcite are variable with respect to iron and manganese and could explain the multiple zones seen in the late-stage calcite.

PITTSBURGH 2003

Taking a Closer Look

Douglas E. Wyatt, URS/EG&G, National Energy Technology Laboratory (formerly Westinghouse Savannah River Company)

Advanced Geophysical Logging in Shallow Unconsolidated Coastal Plain Sediments

Geophysical logging in the shallow boreholes typically drilled into unconsolidated sediments for geotechnical or environmental studies is usually limited to simple gamma ray and resistivity measurements. These measurements are generally well understood and accepted for simple stratigraphic mapping and fluid modeling. However, utilizing state of the art oil and gas exploration geophysical tools allows for a greater understanding of the complexities that effect groundwater flow and contaminant migration. The Savannah River Site, a large DOE facility in South Carolina, lies on unconsolidated Upper Atlantic Coastal Plain sediments. Sediment thicknesses vary between approximately 200 meters updip to approximately 400 meters downdip. These sediments are generally deltaic to near shore marine in character, and consist of alternating sands and clay. The sands are usually aquifers and the clays are usually aquitards. Because of the varying depositional character of the sediments, vertical and lateral variations occur often. The standard bore hole gamma ray and resistivity geophysical logs provide good sand clay signatures and often indicate relative fluid zones, however permeability and facies variations, necessary for detailed modeling cannot be discerned. During geotechnical characterization for a linear accelerator, detailed geophysical logs were obtained in a correlation borehole. High resolution resistivity, spectral gamma ray, and magnetic resonance logs defined compartmentalized fluid flow zones within aquifers that had been originally modeled as uniform. Comparing these data to a grid of bore holes and cone penetrometer tests allowed for a detailed stratigraphy and fluid modeling not possible using conventional logging tools.

Albert S. Wylie, Jr. and James R. Wood, Department of Geological & Mining Engineering and Sciences, Michigan Technological University

Permeability and Porosity Imaging of a Niagaran Pinnacle Reef Using Log Curve Amplitude Slicing of Core Data - Bell River Mills Field, St. Clair County, Michigan

The Bell River Mills Field was discovered in 1961 and produced over 21 BCF of gas before its conversion to a gas storage field in 1965. Thirty-five of the 54 wells in the field were continuously cored through the Niagaran pinnacle reef and the A-1 carbonate/anhydrite. The cores were analyzed to produce more than 6000 measurements of both horizontal permeability and porosity. Core permeability measurements range from zero to eight darcies with both the low and high values affected by equipment measurement limits; 50% of the permeability measurements are less than 2 millidarcies (md) while 40% range from 2 to 100 md. Core porosity ranges from zero to 33%; 15% of the porosity measurements are less than 2% while 83% range from 2 to 20%. Log curve amplitude slicing, a new technique that generates subhorizontal slices through log curves on a foot-by-foot basis, was used to create a series of amplitude slices from the core permeability and porosity curves in these wells. Animations of the core permeability and porosity slices show the detailed distribution of these important reservoir properties throughout most of the pinnacle reef. Integrating the core permeability and porosity animations and previous animations of the gamma ray curve with rock types and formation tops for the Bell River Mills field produces a series of reservoir models that can be used to visualize the likely permeability and porosity distributions for less densely drilled and cored Niagaran pinnacle reefs as well as pinnacle reefs lacking 3D seismic coverage.

Thomas C. Wynn and J. Fred Read, Dept. of Geological Sciences, Virginia Tech

Three-D Mapping of Sequence Stratigraphic Time Slices Via Well-Cuttings, Carboniferous Big Lime, West Virginia, USA.

Well-cuttings analysis largely pre-dated modern carbonate facies analysis, sequence stratigraphy, reflection seismic and advanced down-hole logging techniques. These higher tech methods have resulted in well-cuttings being neglected as an important data source for subsurface analysis. However, binocular analysis of well indurated Paleozoic well-cuttings from relatively shallow wells (0-4000 ft.), can provide detailed vertical facies successions when tied to wireline logs, and can be used to generate high resolution sequence stratigraphic frameworks for the subsurface, at a higher resolution than is available from other methods. The coarse fraction (1-2 mm) of the cuttings for each sample interval were washed and examined. For each sample interval the lithofacies present were separated into groups, and counted to determine relative abundance. These were recorded on a data sheet, and plotted against depth for each well to form a percent lithology log. Digitized wireline logs were plotted and the cuttings-percent logs were slipped (typically 10 ft or so) for the best match to take into account drilling lag and lithologic columns are produced. Gamma ray logs typically show 5-6 distinctive marker horizons that along with the lithologic columns were used to produce sequence stratigraphic cross sections through the basin and into the outcrop belt reference sections, with a resolution of 10 feet. Sequence stratigraphic time slices showing the thickness variation and distribution of environmentally sensitive facies were then made. This allowed us to track the complex influence of tectonics and eustasy and their effects on the stacking patterns of reservoirs.