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Creating a Geologic Play Book for Trenton-Black River Appalachian Basin Exploration

Semi-Annual Report

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ABSTRACT

Private- and public-sector stakeholders formed the new “Trenton-Black River Appalachian Basin Exploration Consortium” and began a two-year research effort that will lead to a play book for Trenton-Black River exploration throughout the Appalachian basin. The final membership of the Consortium includes 17 gas exploration companies and 6 research team members, including the state geological surveys in Kentucky, Ohio, Pennsylvania and West Virginia, the New York State Museum Institute and West Virginia University. Seven integrated research tasks are being conducted by basin-wide research teams organized from this large pool of experienced professionals.

More than 3400 miles of Appalachian basin digital seismic data have been quality checked. In addition, inquiries have been made regarding the availability of additional seismic data from government and industry partners in the consortium. Interpretations of the seismic data have begun. Error checking is being performed by mapping the time to various prominent reflecting horizons, and analyzing for any anomalies. A regional geological velocity model is being created to make time-to-depth conversions.

Members of the stratigraphy task team compiled a generalized, basin-wide correlation chart, began the process of scanning geophysical logs and laid out lines for 16 regional cross sections. Two preliminary cross sections were constructed, a database of all available Trenton-Black River cores was created, and a basin-wide map showing these core locations was produced. Two cores were examined, described and photographed in detail, and were correlated to the network of geophysical logs.

Members of the petrology team began the process of determining the original distribution of porous and permeable facies within a sequence stratigraphic framework. A detailed sedimentologic and petrographic study of the Union Furnace road cut in central Pennsylvania was completed. This effort will facilitate the calibration of subsurface core and log data. A core-sampling plan was developed cooperatively with members of the isotope geochemistry and fluid inclusion task team.

One hundred thirty (130) samples were prepared for trace element and stable isotope analysis, and six samples were submitted for strontium isotope analysis. It was learned that there is a good possibility that carbon isotope stratigraphy may be a useful tool to locate the top of the Black River Formation in state-to-state correlations.

Gas samples were collected from wells in Kentucky, New York and West Virginia. These were sent to a laboratory for compositional, stable isotope and hydrogen and radiogenic helium isotope analysis.

Decisions concerning necessary project hardware, software and configuration of the website and database were made by the data, GIS and website task team. A file transfer protocol server was established for project use. The project website is being upgraded in terms of security.

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EXECUTIVE SUMMARY

The West Virginia University Research Corporation (Research Corporation) was awarded a contract by the U.S. Department of Energy through the National Energy Technology Laboratory to create a geologic play book for Trenton-Black River exploration in the Appalachian basin.

The Research Corporation assigned the contract to the Appalachian Oil and Natural Gas Research Consortium (AONGRC), a program at the National Research Center for Coal and Energy at West Virginia University. The AONGRC organized a Trenton-Black River Research Team, consisting of recognized experts currently employed by the State geological surveys in Kentucky, Ohio, Pennsylvania and West Virginia, and the New York State Museum Institute, an agency in the New York State Education Department.

The Research Corporation, working with the AONGRC, created an industry-government-academic partnership, the "Trenton-Black River Appalachian Basin Exploration Consortium" (the Consortium), to co-fund and conduct the research effort. Seventeen gas exploration companies joined the Consortium. Each contributed cost share through a two-year membership fee, and several expressed an interest in supplying data and expertise while taking an active research role.

This project has three main objectives:

1) to develop an integrated, multi-faceted, resource assessment model of Trenton-Black River reservoirs in New York, Ohio, Pennsylvania, Kentucky and West Virginia;
2) to define possible fairways within which to conduct more detailed studies leading to further development of the gas resource in these reservoirs; and
3) to develop an integrated structural-stratigraphic-diagenetic model for the origin of Trenton-Black River hydrothermal dolomite reservoirs.

The Consortium will achieve these goals by conducting research in eight integrated task areas:

Task 1. Structural and seismic analysis and mapping
Task 2. Analysis of stratigraphic relationships and thickness mapping
Task 3. Analysis of petrographic data and synthesis of depositional environments
Task 4. Analysis of isotope geochemistry and fluid inclusion data
Task 5. Analysis and summary of petroleum geochemistry data
Task 6. Analysis of production, data/histories and horizontal well technology
Task 7. Data, GIS and website management
Task 8. Play book compilation and project management

Most of the effort to this point (October 1, 2003 through March 31, 2004) has been expended to: collect and verify data for research tasks 1 through 6; organize the

database for task 7; and finalize the Trenton-Black River Appalachian Basin Exploration Consortium (Task 8). Geologists with each of the research partners began mining existing data bases to determine areas of data strengths and weaknesses, and began comparing stratigraphic nomenclature and log picks between states. The process of scanning well logs to create digital files was begun. Logs were digitized using DigiRule hardware and software, producing LAS and TIFF files.

Geologists in Pennsylvania and Kentucky conducted field work to describe and sample Trenton-Black River outcrops. Thin sections made from outcrop and core samples were examined, described and compared. Hardware which will be used to collect gas samples from Trenton-Black River wells was collected and assembled, and wells were selected for sampling purposes. Contact was made with the owners of these wells seeking permission. Some samples were collected.

Many decisions about the hardware, software, and configuration of the project website and database were made during the period. The website, database and project GIS need to operate within the West Virginia Geological and Economic Survey's (WVGES) existing network and internet connections. Thus, many people within the WVGES who are not directly working on the project had to be consulted before project personnel could make the decisions necessary to purchase necessary new hardware dedicated to the project.

Production data vary from state to state in terms of monthly or annual data being available. Therefore, for consistency, it will be necessary to analyze basin-wide annual production data. However, for individual field studies, it may be possible to analyze monthly data.

All team agreements have been signed, most of the company cost share has been collected, and subcontracts are in place with four of the five members of the research team. In spite of the long time that it took to put membership agreements and subcontracts in place, the project is on schedule because the individual task teams forged ahead once the contract between DOE and the West Virginia Research Corporation was signed.

EXPERIMENTAL

Gas Isotope Studies

Isotopes are atoms whose nuclei contain the same number of protons but a different number of neutrons. There are two fundamental kinds of isotopes, stable and unstable (radioactive) species. Stable isotopes are not subject to radioactive decay. Their abundance in nature is controlled by biological and physical processes, such as photosynthesis and equilibrium reactions in the case of the stable isotopes of carbon (^{12}C and ^{13}C). Differences in isotopic mass lead to subtle but significant differences in the behavior of the stable isotopes of an element during natural processes. Unstable isotopes experience radioactive decay. Each radioactive isotope has a characteristic decay time known as the half-life, and these isotopes may be used in age dating, e.g. ^{14}C.

Carbon occurs in a wide variety of compounds, from highly oxidized inorganic materials such as CO_2 and sedimentary carbonate rocks to highly reduced organic substances in the biosphere. Sedimentary carbonates and organic matter possess distinct stable carbon isotope compositions because of the operation of two different reaction mechanisms (Hoefs, 1997):

1. Isotope equilibrium exchange reactions within the inorganic carbon system (atmospheric CO_2 – dissolved bicarbonate – solid carbonate) lead to an enrichment of ^{13}C in carbonate rocks.
2. Kinetic isotope effects during photosynthesis concentrate ^{12}C in organic matter.

The stable isotopic composition of carbon in a sample of any material is expressed using the delta (δ) notation,

$$\delta^{13}C_{sample} = \{[(^{13}C/^{12}C)_{sample} - (^{13}C/^{12}C)_{standard}] \div (^{13}C/^{12}C)_{standard}\} * 1000$$

$\delta^{13}C_{sample}$ is in parts per thousand or per mil ($^{o}/_{oo}$). The standard is the internationally recognized PDB reference standard for carbon (see Hoefs, 1997). The PDB standard has been assigned a value of zero per mil. Negative δ-values mean that the sample is enriched in the lighter isotope (^{12}C) relative to the standard, whereas positive δ-values mean that the sample is enriched in the heavier isotope (^{13}C) when compared with the standard. Stable isotope geochemistry provides a powerful method for distinguishing natural gases from different sources (Schoell, 1983). Although methane is the primary constituent of most natural gases, other important components include higher hydrocarbons, nitrogen, hydrogen sulfide, and CO_2. The δ-values of carbon in hydrocarbon gases and CO_2 are useful for determining microbial, thermogenic, and inorganic sources of the gases (Schoell, 1983; Hoefs, 1997).

Helium is found in natural gases. It has two isotopes, ^{3}He and ^{4}He. The relative abundance of these two isotopes in a natural gas indicates the source of the helium. ^{4}He is mostly generated by the disintegration of radioactive elements in sedimentary rocks. ^{3}He originates in the earth's mantle. Low $^{3}He/^{4}He$ ratios ($\sim 10^{-8}$) indicate a sedimentary origin, whereas ratios of $\sim 10^{-7}$ to 10^{-5} indicate a mantle source. The ratio of $^{4}He/^{40}Ar$ is approximately 10 – 20 for a sedimentary origin and 1 – 2 for a mantle origin. We plan to measure these quantities in the Glodes Corners field samples to address the suggestion of abiogenic gases there.

All samples collected so far were shipped to Isotech Laboratories in Champaign, Illinois for molecular and isotopic analyses. Samples are prepared offline and then analyzed by dual inlet isotope ratio mass spectrometer (IRMS).

Geochemical Studies

A range of geochemical and fluid inclusion analyses are being conducted on Trenton and Black River limestone and dolomite samples to help build models for dolomitized reservoir formation and to aid in correlation between widely spaced stratigraphic sections.

In order to better understand the origin of the dolomite in these two predominantly limestone formations, stable isotope, strontium isotope, trace element and fluid inclusion analyses will be conducted. The combination of these analyses will help build confidence in any interpretations. Each of them by themselves can be equivocal, but together they can build a strong case. It is our hypothesis that these dolomitized reservoirs are of a fault-controlled, hydrothermal origin. In general, hydrothermal dolomites have:

• Light ^{18}O isotopes (-2 to -18). Oxygen stable isotope values in dolomites are directly dependent on the temperature and composition of the water. If the water has a composition of +5 or +10, even hot fluids can make heavy (positive ^{18}O value) dolomites. Incorporation of CO3 from the precursor limestone could also produce heavier (more positive) ^{18}O values. Because the value of the water and the rock water ratio are not known, these are the least reliable of all of the tests by themselves. When conducted in combination with other analyses, however, they can be very valuable and they also are the least expensive.

• Radigenic $^{87}Sr/^{86}Sr$ ratio. The radiogenic signature shows that fluids have flowed through continental basement rocks or feldspar-rich sediments overlying the basement. Exceptions: Mafic basement rocks, resetting, incorporation of original strontium from limestone can be problems

• Relatively high Fe and Mn contents. Exceptions: Most hydrothermal fluids pick up Fe and Mn in the basement or overlying feldspar-rich sandstones, but some may not. It all depends on the composition of the basement rocks.

• Fluid inclusions with homogenization temperatures >75ºC and salinities that average ~20 wt % (6 times normal seawater) Fluid inclusions almost always are hot in dolomites. Commonly this is attributed to resetting. It is our belief that resetting can and does happen, but that a lot of dolomite probably does form in hot water.

All of these will be studied together to learn the origin of the dolomite. Knowing the origin of the dolomite and the composition of the fluid that made it will help to build an overall model of reservoir formation. This model can then be used as a predictive tool for finding new hydrothermal dolomite reservoirs in the Trenton-Black River interval of eastern North America and in similar carbonates around the world.

Early work on this project has confirmed that there are significant changes in ^{13}C within the limestones and dolomites. Carbon-13 is a stable isotope of carbon that is routinely analyzed when doing stable isotope analysis. These changes in ^{13}C are abrupt and can be used as a correlation tool when the study interval is sampled and analyzed at different sections. It is believed that these changes reflect secular variations in seawater chemistry, so the changes in 13C should occur in all carbonates that are of the same age. This could be a very powerful tool when correlating between long distances.

RESULTS AND DISCUSSION

Task 1: Structural and Seismic Investigations

The Kentucky Geological Survey (KGS) was assigned the lead role for Task 1. KGS assembled a Task 1 Team that included research team members from geological surveys in other states as well as in Kentucky. This team began to compile available seismic and basement map data from cooperating state agencies and industry partners. To date, the Task 1 Team has successfully quality checked and loaded 3,425 miles of Appalachian Basin digital seismic data within Kentucky, West Virginia, Pennsylvania and New York. In addition, team members made inquiries into the availability of additional data from government and industry partners within the Trenton-Black River Appalachian Basin Exploration Consortium (Consortium), some of which has been received. Currently, seismic data gaps are in much of Ohio, the western part of Pennsylvania, parts of New York and northern and central Kentucky. Efforts to fill these gaps are underway.

Interpretation of several prominent reflecting horizons within the seismic data has begun in large portions of eastern Kentucky, West Virginia, north-central Pennsylvania and south-central New York. Periodic error checking is performed during the interpretation stages by mapping the time to these horizons and analyzing for any anomalies. A regional, 3-D geological velocity model is currently being created in order to make time-to-depth conversions.

Initial draft structural maps for parts of the area have been generated using the interpretations from the wells and seismic data that are currently available. These preliminary maps will be updated as more seismic data become available and as additional velocity information from wells clarify time-to-depth relationships.

Task 2: Stratigraphic Analysis and Thickness Mapping of Key Units

The Ohio Division of Geological Survey (ODGS) was assigned the lead role for Task 2, and has assembled a Task 2 Team that includes members from each of the other state agency partners. During the reporting period, interstate stratigraphic correlation differences among team members in Ohio, Kentucky and West Virginia were resolved. Team members from the various geological surveys compiled data sets of available well cores for applicable stratigraphic formations and forwarded them to the ODGS for compilation. Digital (LAS) files for 99 deep wells in eastern Kentucky (Lower Ordovician and older formations at total depth) were transferred to ODGS for use in preparing preliminary cross sections and maps. Additional digital (LAS) files are being prepared by team members in other states, and will be transferred to ODGS shortly.

Most of the work performed during this first semi-annual period focused on collecting all available data for use in the stratigraphy task, and data that could be used by other members of the Consortium for their respective tasks. This included updating the Trenton-Black River core database, examining core files and descriptions, and noting any cores with dolomitized Trenton-Black River zones. Team members also searched core records for any data on source rock evaluation, fluid inclusion data, thin section data, or other pertinent information that could be useful for the other tasks. This information was incorporated into the core database to assist in prioritizing the cores for sampling in Tasks 3 (Petrographic analysis), 4 (Isotope geochemistry and Fluid Inclusion analysis) and 5 (Petroleum geochemistry). Xerox copies were made of these data and disseminated to the leaders of Tasks 3, 4, and 5. Wells with continuous core through the entire Trenton-Black River interval, and wells with dolomitized zones, have been prioritized for sampling. Several key cores with continuous Trenton-Black River intervals were identified in Ohio and West Virginia. These cored wells include the following: several Chevron tests from the Utica to Knox in Wyandot and Marion Counties, Ohio (core numbers 3372, 3373, 3374): the ODGS continuous core from the Silurian Greenfield to the PreCambrian in Seneca County, Ohio (core number 2580); the OGS continuous core from the Cincinnatian to Precambrian Middle Run Formation in Warren County, Ohio (core number 2627); a continuous core from the Pennsylvanian to Rome in Scioto County, Ohio (core number 3409); and a continuous core from the (Cincinnatian to the Precambrian in Wood County, West Virginia(core number 768). Cores that are reported to have dolomite in the Trenton-Black River interval based on core descriptions are noted in the core database.

Task 2 Team geologists examined, photographed and correlated 2 cores to geophysical logs (cores 2580, 3372). Core examination focused on dolomitized zones, porous zones, oil shows and marker beds (i.e., bentonite beds) to assist in understanding regional correlations.

Regional lines for cross sections were determined using Precambrian wells, and a map showing these wells was circulated among team members in all states for review. Other wells considered for use in regional cross sections are prioritized based on wells with dolomitized Trenton-Black River, significant producing wells, wells with core, or wells indicating significant facies changes.

In summary, the Task 2 Team accomplished the following during the first semi-annual period of the project:

- Performed literature search on the Trenton-Black River interval
- Collected stratigraphic columns from all Consortium states and Ontario for creation of a basin-wide generalized correlation chart
- Collected core databases from all Consortium states and Ontario; created database for all Trenton-Black River cores in the study area
- Constructed a basin-wide Trenton-Black River core map
- Compiled a database of all Precambrian wells in the northern Appalachian basin for use in regional cross sections
- Scanned significant geophysical logs into TIFF files for use in preliminary cross sections and for use with significant cores
- Laid out 16 regional cross section lines across the basin using Precambrian wells only
- Created 2 preliminary stratigraphic cross sections illustrating the stratigraphy of the Ordovician Utica Shale to Precambrian interval
- Examined all Ohio Trenton-Black River core records
- Two cores examined, photographed and correlated to geophysical logs
- Created preliminary database for Ohio wells that have a total depth (TD) in Utica or deeper, and wells that are productive in the Utica-Trenton-Black River interval, and created a map showing these wells
- Have made isopach maps for three intervals (Black River, Trenton and Utica-Lorraine) in New York
- High-graded Ordovician tops for New York wells
- Presented an update of this work at the quarterly meeting in Pittsburgh

Task 3: Petrology and Petrography of Trenton and Black River Carbonates

The Pennsylvania Geological Survey (PGS) has been assigned the lead role for Task 3. PGS staff geologists Christopher Laughrey, Jaime Kostelnik, and John Harper studied the petrology and petrography of the Trenton-Black River carbonates and provided information to team members with other state geological surveys during the first six months of the project. Here is a list of accomplishments during that period:

- Completed a sedimentological and petrographic study of the Union Furnace roadcut in central Pennsylvania
- Initiated sedimentologic and petrographic descriptions of whole-diameter and sidewall cores from Pennsylvania wells
- Made arrangements with personnel from the New York, Ohio, West Virginia and Kentucky Geological Surveys to obtain and study selected Trenton-Black River cores in each of these states

- Collected and crushed samples to a fine powder for trace element, stable isotope and Strontium isotope analysis

The work performed during this first semi-annual period focused on collecting all pre-existing data for use in the geochemistry task, and data that could be used by other members of the Consortium for their respective tasks. The pre-existing data were entered into Excel spreadsheets.

The original porous and permeable carbonate facies distributions were determined within a sequence stratigraphic framework. These facies distributions would have influenced travel by dolomitizing fluids through subsurface fairways in the geologic past. These facies distributions also would have influenced reservoir storage capacities. The spatial distribution of reservoir seals, reservoir compartmentalization and diagenetically-controlled pore geometry are partially or wholly due to original sedimentological features.

Much of the research effort during first semi-annual period was concentrated on the Union Furnace outcrop in central Pennsylvania (Figure 1) where we measured 240 m (787 ft) of Trenton and Black River rocks (Figure 2). Seventy nine (79) thin sections for microfacies determination were prepared and examined . There are numerous reasons for spending resources on this single outcrop. First, the Trenton-Black River play is basin-wide in scope, and accurate stratigraphic correlations and analyses are necessary for rigorous petroleum exploration and development. Lithostratigraphic and sequence stratigraphic interpretations of the outcrop will facilitate calibration of subsurface core and log data. In addition, sedimentological interpretations of the Trenton-Black River lithologies will assist interpretations of the petroleum source rocks in the play. The outcrop descriptions will be used to help calibrate facies interpretations in core samples. Carbonates and shales of the Black River and Trenton at the Union Furnace outcrop comprise at least five third-order depositional sequences within the Turinian and Chatfieldian North American Stages. Black River rocks include skeletal grainstones, packstones, and wackestones, mudstones and dolostones. They also exhibit some autochthonous, organically bound limestone textures. Black River rocks were deposited in intertidal, lagoonal and shallow subtidal environments on a gently sloping barrier-bank ramp (Figure 3). Trenton rocks include skeletal rudestones, floatstones, grainstones, packstones, and wackestones, laminated and nodular mudstones, and black calcareous shales. These rocks were deposited in relatively deep subtidal environments on a distally steepened ramp (Figure 4). Centimeter-scale cyclic patterns, induced by storms, were superimposed on larger scale, eustatically-controlled successions in both the Trenton and Black River carbonates.

The sampling process has begun on some cores in the New York collection. The Task Team hopes to have access to about 75 thin sections from cores in New York. These cores are confidential at this point but will be public by the end of the study period. Plans have been made to visit the Kentucky, Ohio and West Virginia surveys to sample cores in their collections, as well. A database for Trenton-Black River thin sections was received from the Ohio Division of Geologic Survey. All sampling for laboratory analysis should be done by the end of June. After samples are collected, they are crushed to a fine powder for trace element, stable isotope and Strontium isotope analysis. About 130 samples have been crushed so far. Member states have been contacted concerning the availability of cores, particularly any cores with dolomitized Trenton-Black River zones. So far the project is right on schedule

Task 4: Isotope Geochemistry and Fluid Inclusion Analysis

The Task 4 Team is comprised of staff members from the New York State Museum, including Langhorne Smith, Richard Nayhay, Justin Deming and Rose Schultz. All team members worked on the Trenton-Black river study during the first six months of the project.

The work performed during this first semiannual period focused on collecting all pre-existing data for use in the geochemistry task, and data that could be used by other members of the Consortium for their respective tasks. The Task 4 Team entered the pre-existing data into Excel spreadsheets, and began the sampling process on cores in the New York collection. Plans were made to visit the Ohio and West Virginia geological surveys to sample some of their cores. Team members also will visit Kentucky on the same trip. The goal is to complete the sampling phase by the end of June.

After samples are collected, they will be crushed to a fine powder for trace element, stable isotope and strontium isotope analysis. Thus far, about 130 samples have been crushed. Most of the member states have been contacted about available cores, particularly any cores with dolomitized Trenton-Black River zones. So far the project is right on schedule.

In summary, this is a list of accomplishments during the reporting period:

- Performed literature search on geochemistry studies in the Trenton-Black River interval in the Appalachian and Michigan basins
- Still in the process of collecting pre-exisitng geochemical data from Consortium states and Ontario for creation of a basin-wide database
- Are entering all pre-existing data into Excel spreadsheets and will have a comprehensive basin-wide data set at the end of the project
- Collected core databases from all consortium states and Ontario; making plans to visit each survey for sampling
- Prepared 130 samples for trace element and stable isotope analysis
- Prepared 6 samples for strontium isotope analysis; sent them to a laboratory for analysis
- Sent thin section photos, digitized logs and core descriptions from New York to all surveys
- The NYSM gave ESOGIS database access to all States. This includes tiff images of all New York deep wells and digitized logs for many of them
- Have learned that there is a good possibility that we will be able to use carbon isotope stratigraphy to correlate the top of the Black River from

state to state. This should enhance the reliability of the cross sections considerably

- Presented update of this work at quarterly meeting in Pittsburgh

Task 5: Petroleum Geochemistry of Trenton and Black River Gases

The Pennsylvania Geological Survey (PGS) has been assigned the lead role in Task 5. PGS staff geologist and Task Team Leader Christopher Laughrey initiated a study of the isotope geochemistry of Trenton-Black River mature gases in the Appalachian basin. Other team members assisted him by arranging to collect samples in Kentucky, New York, Ohio, Pennsylvania and West Virginia. In addition, Dave Harris and Bandon Nuttall of the Kentucky Geological Survey assisted Laughrey in the field in Kentucky. Here is a list of accomplishments during the period:

- Collected gas samples from wells in Kentucky, New York and West Virginia
- Sent all samples to Isotech Laboratories in Champaign, IL for compositional, stable carbon and hydrogen, and radiogenic helium isotope analyses

The work performed during this first semi-annual period focused on collecting gas samples from wells in Kentucky, New York and West Virginia and sending them to Illinois for laboratory analyses.

Natural gases vary in chemical and isotope composition as a function of their formation and migration history. The stable isotope composition of methane, ethane, propane and higher homologs provides very specific genetic information about the gas produced from a well. The type of organic material, or kerogen, that was the source of the hydrocarbons, and the thermal maturity of that organic material at the time the gas was generated, can be determined. This is useful for interpreting what source rocks generated the hydrocarbons produced from a reservoir, the timing and direction of reservoir charge, and what were (or are) the petroleum migration fairways. Mixing of gases from different sources in a reservoir also can be recognized. The utility of this kind of information in the Trenton-Black River play is obvious. Examples of this kind of work are explained in Schoell (1983). Some specific applications of this approach in the Appalachian basin include Jenden and others (1993) and Laughrey and Baldassare (1998).

When this work is done, the ratios of stable isotope concentrations of carbon and hydrogen in methane, and the ratios of stable isotope concentrations of carbon in ethane through pentane are measured. Sometimes the isotope ratios in CO_2 and N_2 also are measured. Samples are collected from the wellhead in clean, stainless steel high-pressure cylinders designed for this application.

Carbon and hydrogen isotope ratios are conservative properties that do not change significantly upon depressurization, solution or dissolution and other physical processes that occur during oil and gas production. Thus, the stable isotope concentrations in gases are independent of reservoir and sampling conditions rendering them useful as tracers for many gas field operations. These include reservoir identification, reservoir compartmentalization and fault block mapping, reservoir allocation, gas storage and identification of gas seeps. These applications are clearly outlined in Schoell and others (1993).

For this study we are addressing the genetic origin of the Trenton-Black River gases produced in Kentucky, Ohio, New York, Pennsylvania and West Virginia, and the potential utility of stable gas isotope geochemistry in the development stages of Trenton-Black River field production. The petroleum produced from Trenton-Black River reservoirs has been ascribed to various potential source rocks by different workers: 1) Utica (Antes) Formation (Wallace and Roen, 1989; also Ryder and others; 1998); 2) self-sourced Trenton (Obermajer and others, 1999); 3) Cambrian marine black shale (Ryder and others, 2003); and 4) serpentinization of basement peridotite within the Rome trough (Keith and others, 2003). The latter is quite a radical interpretation and something we plan to look at critically with our data. To that end we will add measurements of $^{3}He/^{4}He$ to our analyses of the Glodes Corners Road field (New York) gases and perhaps gas from some other fields as well.

For the development aspects of the study, the isotope ratios of methane collected from different wells in structurally complex fields, such as Glodes Corners Road, Saybrook and Stagecoach, will be measured first to determine if the gases produced from the Trenton-Black River carbonates are genetically the same within the reservoirs or if they are different in different parts of the reservoir. If different, higher hydrocarbons will be analyzed to see if fracture compartments can be defined.

Task 6: Analysis of Production Data/Histories and Horizontal Well Technologies

Production data vary from state to state in terms of the availability of monthly versus annual data. This was made very clear to all project members at the project meeting on March 17, during which the type of production data that are publicly available for each state was summarized. New York only has annual data, released on July 1 for the previous calendar year. Pennsylvanian has only annual data, with a 5-year confidentiality period. Therefore, no Pennsylvania production data are likely to be available for this study, as the first Trenton well was drilled in 2003. Kentucky has monthly data by well. Ohio has annual data back to 1984, and monthly data for some wells. West Virginia has monthly and annual data back to 1978. Therefore, production data will need to be analyzed on an annual basis in order to have a common time period among all states. Monthly data may be analyzed where available.

Task 7: Database, GIS and Website Management

Many decisions about the hardware, software, and configuration of the project website and database were made during the period. The website, database and project GIS need to operate within the West Virginia Geological and Economic Survey's

(WVGES) existing network and internet connections. Thus, many people within the WVGES who are not directly working on the project had to be consulted before project personnel could make the decisions necessary to purchase new hardware that will be dedicated to the project.

A file transfer protocol (FTP) server was established for project use. The server is currently designed as an anonymous FTP server (anyone could download/upload files), and as a user-account (user name and password account) server. However, a more secure user-account protocol (i.e., SFTP which involves encryption) will be necessary for the project and will be set up in the next quarter.

The overall, general project webserver is being upgraded in terms of its security functionality, especially in terms of the Secure Socket Layer protocol. This effort was delayed somewhat while the original operating system software and documentation were located. The machine had been moved several times, and the supporting components had not been moved with the hardware, at some point in time.

ArcIMS development for the project will proceed using the current version of IMS (4.0.1); if a newer version of IMS is available during the duration of this project, the Trenton IMS may be migrated to version 9.0. After much discussion, the specifications for purchase of a new ArcIMS server machine were agreed upon. Early in the next quarter, the purchasing process will be initiated.

Decisions about the exact placement of the ArcIMS server in relation to the WVGES network and the project webserver will be made early in the next quarter. Security and firewall options for the ArcIMS server also will be made. In conclusion, decisions about the specifications for the ArcIMS server took longer than expected, but were necessary to ensure functionality

Task 8: Play Book Compilation and Management

The compilation of the play book will occur in the final reporting period (April 1, 2005 – September 30, 2005) as each of the individual task teams complete their assignments.

The Project Manager and Senior Management Team had several goals and key challenges during the initial reporting period. Chief among these were obtaining signatures from each research team member and company partner on a “Trenton-Black River Appalachian Basin Exploration Consortium” membership agreement that defines membership and member fees. Once this agreement was signed and most of the membership fees were paid, the next goal was to get subcontracts and budgets in place with each of our research team members. This would allow them to begin their research efforts.

Other management goals were to organize and hold the first meeting of the Research Team, schedule the first meeting of the entire Trenton-Black River Appalachian Basin Exploration Consortium, and make assignments to Task Leaders who would write the first semi-annual technical report.

A total of 13 companies had committed to join the proposed Trenton-Black River Research Consortium (the "Consortium") prior to September 2003 when the original research proposal was submitted. Subsequent to that time, another seven companies expressed an interest in becoming members. Consequently, when the membership agreement was written, copies were sent to 20 potential companies, some of whom had already submitted their membership fee. Unfortunately, one of the companies could not abide by the language in the membership agreement, and requested that we refund their fee, which they had paid in full. Two other companies who had submitted a commitment letter became disenchanted with the play and requested to be released from their prior commitment. By the end of the reporting period, the Project Manager had obtained signed membership agreements from 17 companies and all five research team members, enough to ensure that the West Virginia University Research Corporation would meet their contractual cost share. Consequently, subcontracts were written and sent to each of our research team partners.

By the end of the reporting period, four of the five research partners had returned their signed subcontracts and each had been partially funded. The final subcontract is expected soon, once it clears the legal department in that state.

On March 17^{th}, the initial meeting of the research team was held in the offices of the Pennsylvania Geological Survey in Pittsburgh. All members were in attendance. The primary goal of the Project Manager for this meeting was to get the talent pool of researchers from five different partners organized into task teams, each with a task leader. By doing so, the basin-wide research effort could then be conducted by these task teams, not by individual surveys who are separated by state lines. A second, but very important goal, was to organize individual task research plans into one coordinated plan where the needs of one task team could be met in a timely manner by other teams.

Other goals were to establish a base line of play metrics prior to initiating our research program; to summarize the extent of our knowledge of prior research that is of significance to the project; and to exchange lists of public data that each partner will provide to other task teams. Once the amount of available data had been assessed, it was possible to develop more realistic time-lines for data analysis, interpretation and integration.

All of these goals were achieved during the meeting. Task leaders were introduced to task team members in each of the member states and teams were created. Each of the Task Team Leaders presented a Research Plan for their individual task. However, before the meeting ended an integrated research plan with goals and deadlines had been created.

CONCLUSIONS

Although more than 3400 miles of seismic data have been collected and quality checked, large gaps in seismic coverage remain in parts of Ohio, Pennsylvania, New York and Kentucky. The seismic team has concluded that they will need additional donations to fill these gaps and in order to provide adequate coverage for structural mapping.

Geophysical log coverage appears to be adequate for the stratigraphic portion of the project. The distribution of log control will allow the construction of 16 regional stratigraphic cross sections and the preparation of isopach maps.

The amount of core material that has been added to the project database is encouraging. Cores are available in each of the states, and will be useful, when correlated to geophysical logs, in the stratigraphic task. In addition, after these cores are sampled, the petrographic and geochemical task teams will have adequate coverage for their research efforts.

There is a good possibility that carbon isotope geochemistry can be a useful tool for correlating the top of the Black River Formation across the basin.

Operators have been very cooperative when asked to provide access to their wells so that samples of gas from the Trenton-Black River can be obtained. The gas geochemistry team should be able to collect gas samples in each of the states with production from this play.

Production data will need to be analyzed on an annual basis in order to have a common time period among all states. Monthly data may be analyzed where available.

The decisions about the specifications for the ArcIMS server took longer than expected, but were necessary to ensure functionality.

Task teams have been organized and are fully functional. Individual task plans have been integrated into one overall project plan. The research is on schedule.

REFERENCES

Hoefs, J. (1997). *Stable isotope geochemistry (4th Edition)*, Berlin, Heidelberg, New York: Springer-Verlag.

Jenden, P. D., Drozan, D. J., and Kaplin, I. R., 1993, Mixing of thermogenic gases in northern Appalachian basin: American Association of Petroleum Geologists Bulletin, v. 77, p. 980–998.

Keith, S., Rasmussen, J. W., and Swan, M., 2003, Integrated hydrothermal dolomite (HTD) gas conceptual exploration model and the identification of an unrecognized major mg-hydrocarbon source (abs.): *http://aapg.confex.com/aapg/sl2003/techprogram/paper_79553.htm*.

Laughrey, C. D. and, Baldassare, F. J.,1998, Geochemistry and origin of some natural gases in the plateau province, central Appalachian basin, Pennsylvania and Ohio: American Association of Petroleum Geologists Bulletin, v. 82, p. 317-335.

Obermajer, M., Fowler, M. G., and Snowdon, L. R., 1999, Depositional environment and oil generation in Ordovician source rocks from southwestern Ontario, Canada: Organic geochemical and petrological approach: American Association of Petroleum Geologists Bulletin, v. 83, p. 1426–1453.

Read, J. F., 1985, Carbonate platform facies models: American Association of Petroleum Geologists Bulletin, v. 66, p. 860 – 878.

Ryder, R. T., Burruss, R. C., and Hatch, J. R., 1998, Black shale source rocks and oil generation in the Cambrian and Ordovician of the Central Appalachian basin, USA: American Association of Petroleum Geologists Bulletin, v. 82, p. 412-441.

Ryder, R. T., Harris, D. C., Gerome, P., Hainsworth, T. J., Burruss, R. C., Lillis, P. G., and Jarvie, D. M., 2003, Cambrian petroleum source rocks in the Rome trough of West Virginia and Kentucky (abs.): 2003 American Association of Petroleum Geologists, Eastern Section meeting, Pittsburgh, *http://karl.nrcce.wvu.edu/esaapg/abstracts/2003abs.PDF*, p. 10.

Schoell, M., 1983, Genetic characterization of natural gases: American Association of Petroleum Geologists Bulletin, v. 67, p. 2225–2235.

Schoell, M., Jenden, P. D., Beeunas, M. A., and Coleman, D. D., 1993, Isotope analysis of gases in gas field and gas storage operations: SPE Paper No. 26171, p. 337-344.

Wallace, L.G. and Roen, J. B., 1989, Petroleum source rock potential of the Upper Ordovician black shale sequence, northern Appalachian basin: U. S. Geological Survey Open-File Report 89-488, 66 p.

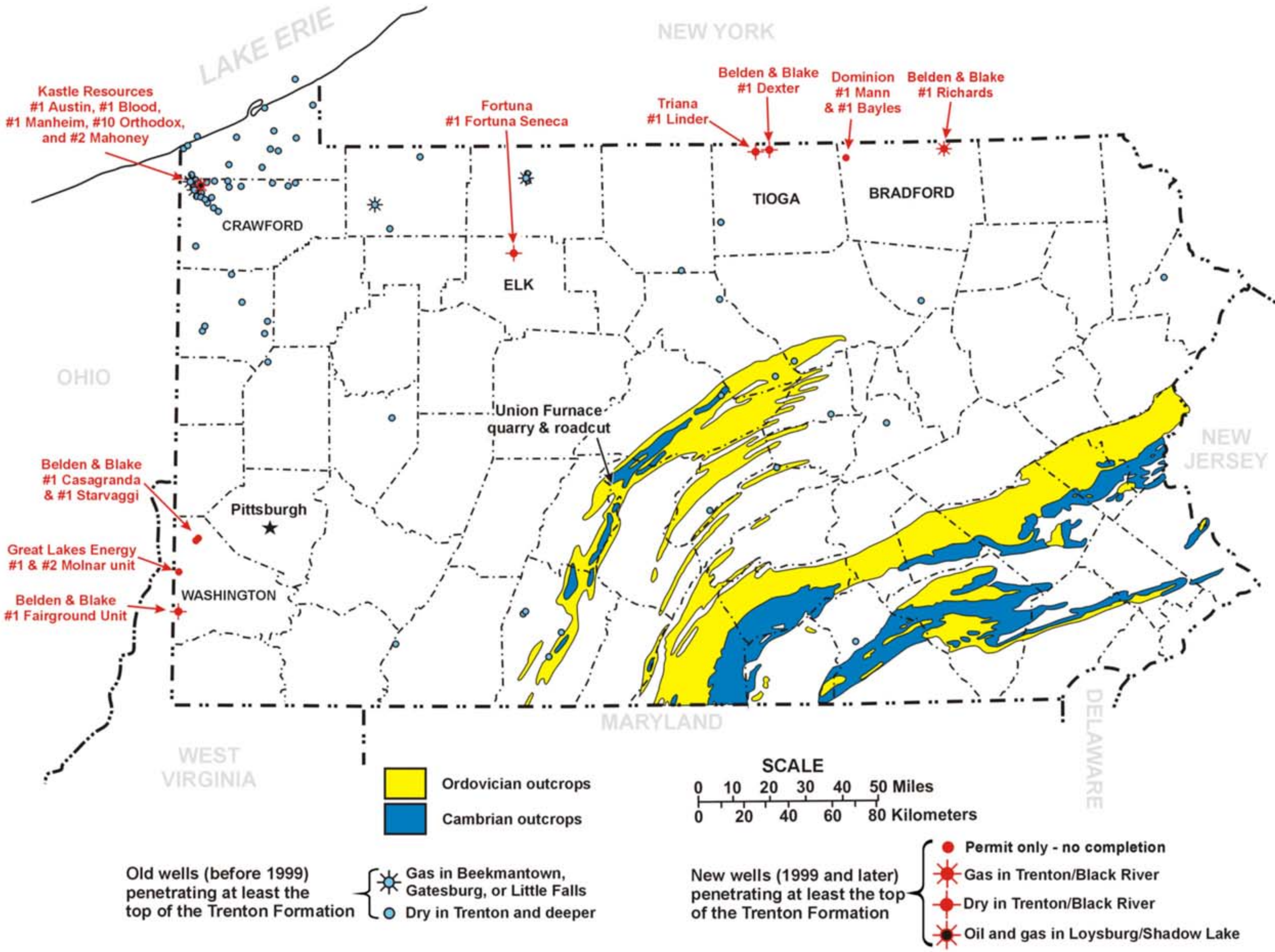

Figure 1. Location of Cambrian and Ordovician outcrops, wells that penetrate the top of the Trenton Group, and new permits for testing Trenton and Black River play (shown in red) in Pennsylvania. The location of the Union Furnace outcrop area is indicated.

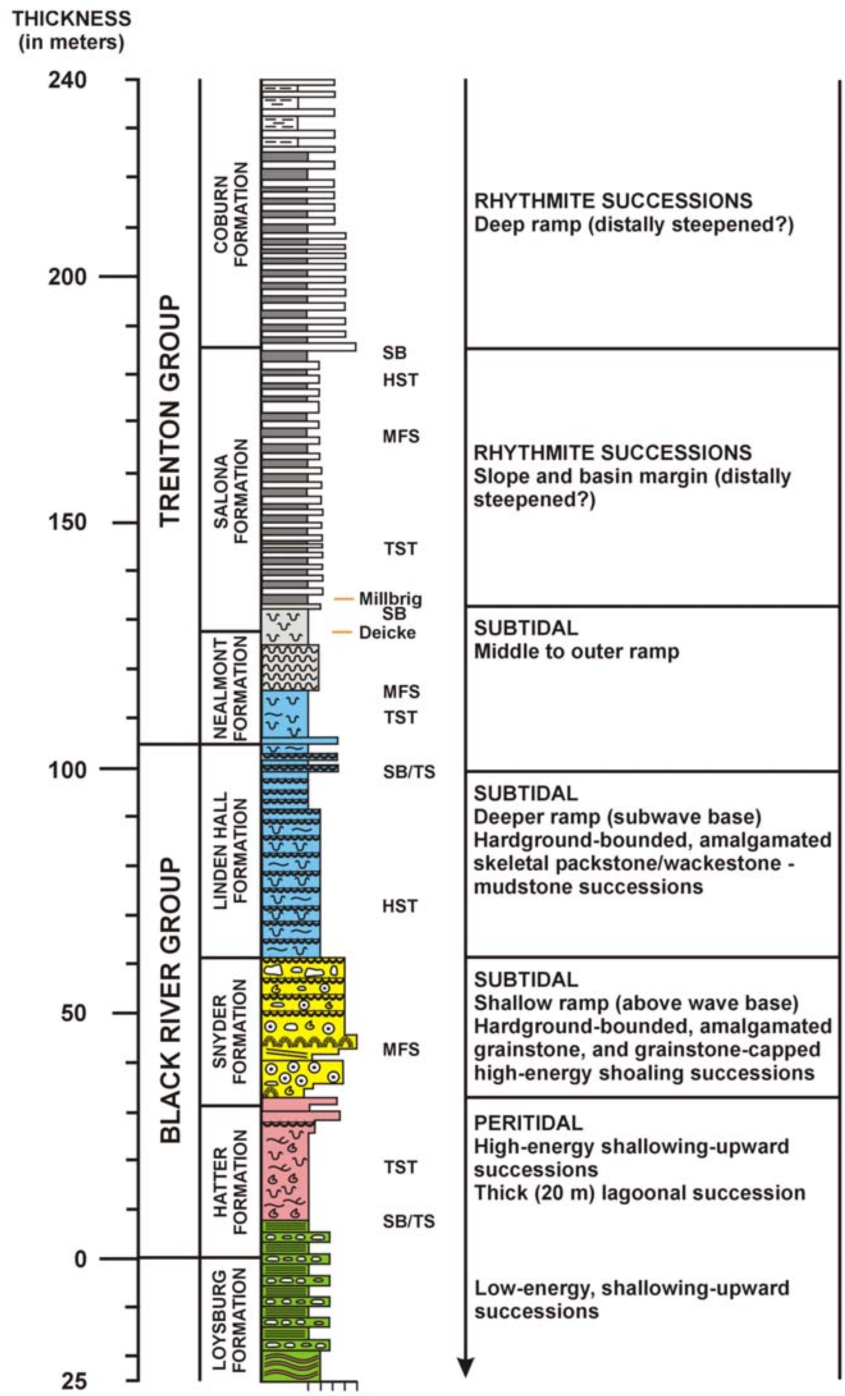

Figure 2. Our measured section (June-July, 2003) for the Black River and Trenton Groups exposed along Pennsylvania Route 453 near Union Furnace, and the vertical stacking pattern of carbonate facies. The designated sequences and associated features are conjectural at this time. SB/TS – combined sequence boundary/transgressive surface. TST – transgressive systems tract. MFS – maximum flooding surface. HST – highstand systems tract.

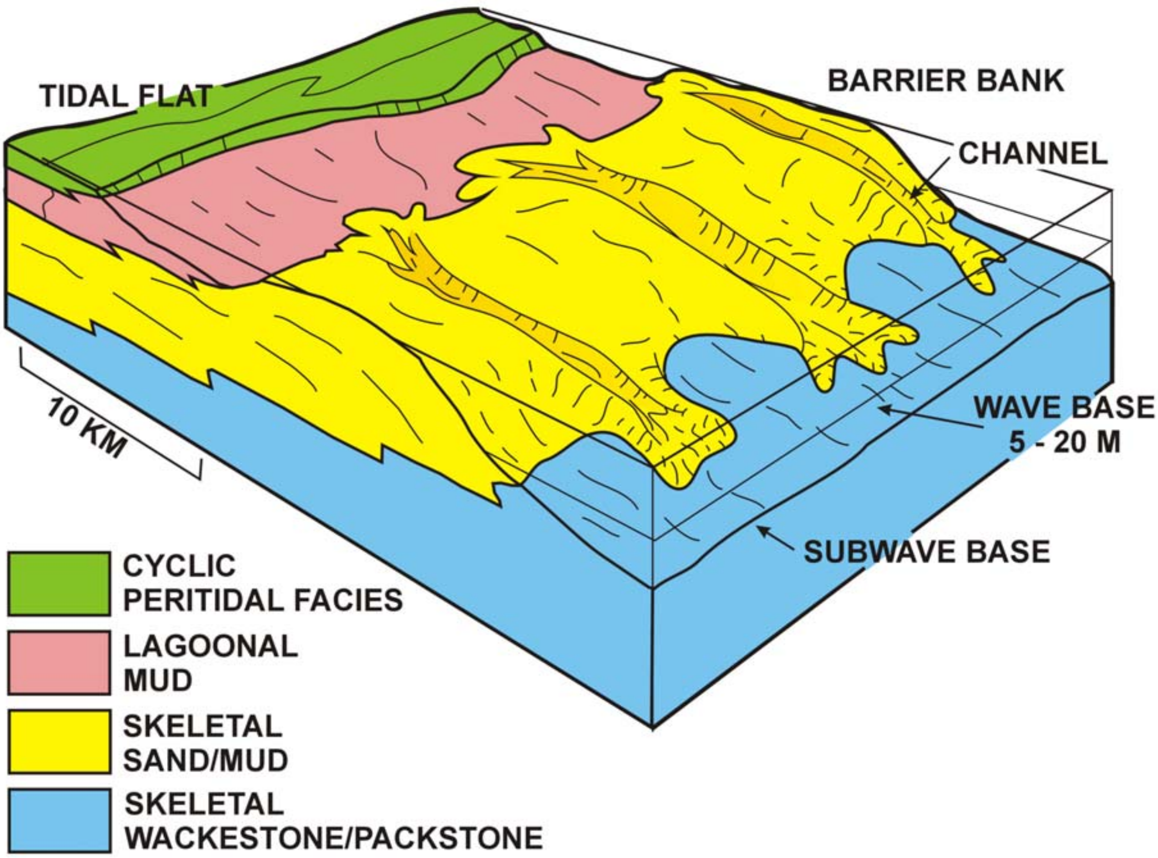

Figure 3. Barrier-bank type carbonate ramp, modified from Read (1985).

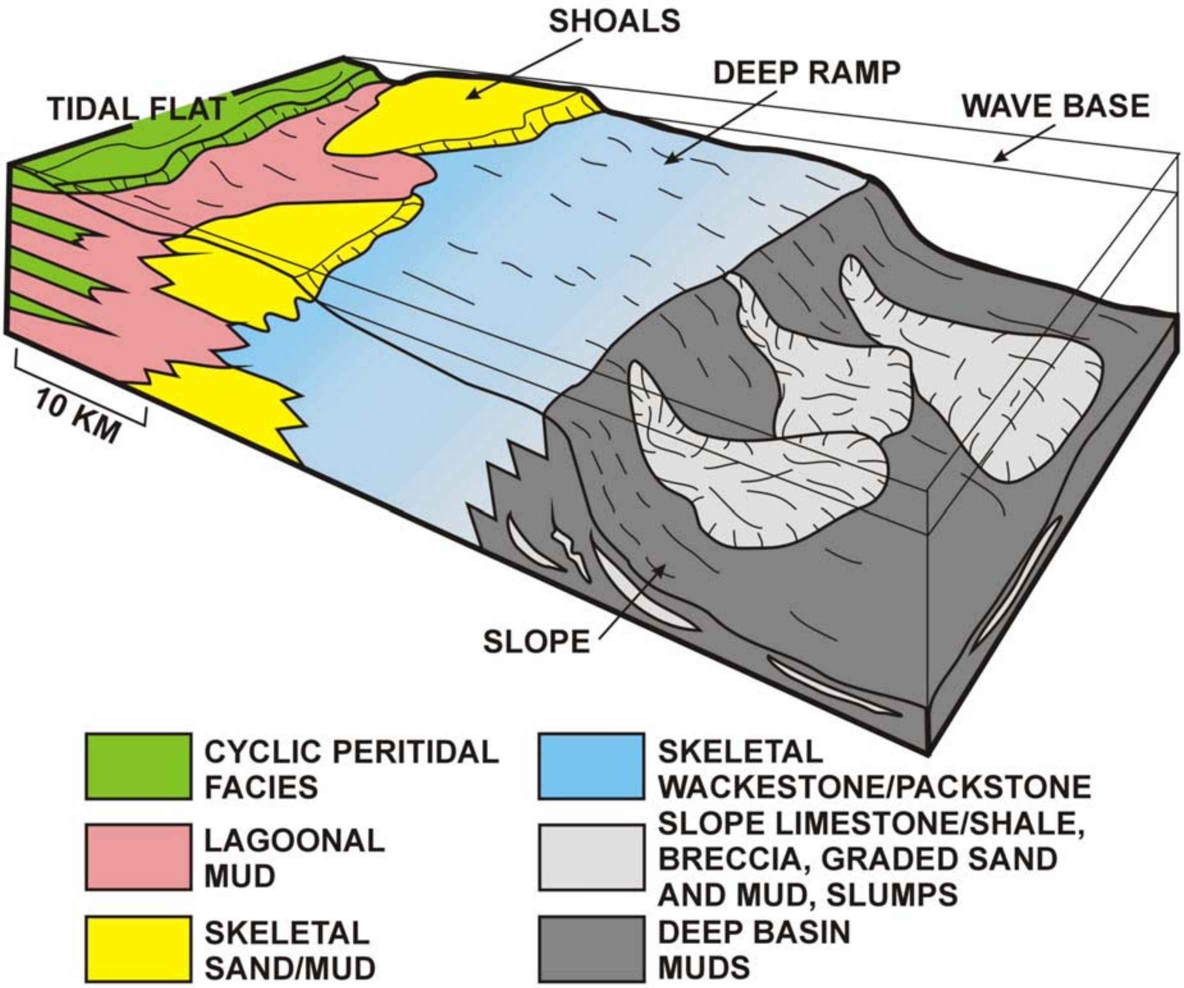

Figure 4. Distally steepened carbonate ramp, modified from Read (1985).