CARBONATE RESERVOIRS

BOTTOM LINE

Our ability to predict the presence and trends of porosity and permeability in carbonate reservoirs is enhanced by conducting fully integrated, multidisciplinary studies leading to accurate interpretations of the original depositional environment. The depositional history provides the framework; chemistry completes the picture. Everything that is studied – mud versus grain content, grain and cement morphology, types of fossils, trace elements, etc – is an attempt to identify the environment of deposition of the rock and the environment of later diagenesis. Once the correct depositional environment is known, the geometry and trend of the carbonate deposit can be interpreted, and the reservoir can be traced in the subsurface. Our ability to recognize fossil fragments in thin section, samples and cores is very important. If one can identify the organism, one can then interpret more accurately the type and trend of depositional environment. Carbonate particles (ooids, pellets, intraclasts, biogenic) can be tied to specific depositional environments with differing water depths and energy levels, and once again, the trends of these environments can be predicted. Also, if the original grain types in the reservoir are known, then one can understand how they will react over time, and individual pore structure can be predicted as well. Diagenesis, however, controls the final porosity and permeability preserved in carbonate rocks. Diagenesis includes all processes, from deposition to incipient metamorphism at higher temperature and pressure, including cementation, microbial micritization, neomorphism, dissolution, compaction and dolomitization. The bottom line is: use all the evidence, including subsurface, outcrop and modern analogs, to put a complete picture together by projecting a modern 3-D model into an outcrop 2-D model and then to the subsurface, keeping in mind accuracy of relative scales, geometric positions and trends of adjacent environments and facies packages.

PROBLEMS ADDRESSED

Worldwide, 40-50 percent of all oil reservoirs are in carbonate rocks. In spite of this, there still is much to be learned about carbonate rocks in general and carbonate reservoirs in particular. To date, the typical research sequence has begun with petrology, then proceeded to studies of diagenesis, reservoir character, and, more recently, 3-D seismic. However, in the near future, most, if not all, carbonate reservoirs will be studied within the context of a sequence stratigraphic setting.

Most reservoirs are developed in carbonates, sandstones or shales, and different models need to be developed for each of these lithologies. Carbonates differ from sandstone in the way that pores are created; in carbonates, pores are developed after burial, not during burial. The original chemistry and grain components control whether pores will be created and preserved, or created and eventually destroyed.

Carbonates are highly susceptible to volume changes. Fluids move through them, creating and also destroying porosity, and forming cement that binds carbonate grains and holds the rock together.

Although carbonates are typically formed in shallow, warm, subtidal settings, they commonly are moved into deeper water, or landward, due to storm action. In these environments, calcite is stable, but high magnesium calcite and aragonite are relatively unstable and may be dissolved and eventually replaced by calcite or dolomite. Dolomites also can form in the burial environment, following calcite deposition.

The instructors referred to dolomite as "the Holy Grail" of carbonate reservoirs due to their well-connected, intercrystalline porosity and high permeability. Dolomite is the favored carbonate mineral at high temperatures, making it stable in deep burial conditions. As one looks at carbonates going backward in time, dolomite increases whereas calcite decreases. In the Appalachian basin, carbonates formed during the Cambrian are mostly dolomite (Conococheague Formation) or dolomite and calcite (Beekmantown Formation).

TECHNOLOGY OVERVIEW

The workshop was separated into eleven segments, beginning with an introduction and overview: purpose and scope of the workshop, carbonate petroleum reservoirs, history of carbonate reservoir studies, and future directions.

The second section covered the mineralogy of carbonate sediments, essentially the chemical composition and various crystal forms of calcite, aragonite, high-magnesium calcite, and dolomite.

Section three was the longest part of the workshop, covering in depth the various components of limestone, including the types of grains (skeletal and non-skeletal), matrix carbonate mud, limestone textures, and the classification of limestone, which allows researchers to communicate among themselves more accurately.

Section four summarized the various sedimentary structures found in carbonates, and what they can tell us about the original depositional environment. Discussions and examples of bedding planes, hardgrounds, paleokarst structures, current structures and cavity structures were included.

The last section prior to lunch was a summary of carbonate diagenesis, and the chemical conditions and various environments in which diagensesis occurs. Following lunch, dolomites and dolomitization models were introduced, followed by a brief summary of the various tools available to help us better understand diagenesis.

Section eight was a lengthy and important discussion of carbonate depositional environments and facies sequences. This discussion led quite naturally to a section on carbonate sequence stratigraphy, and then to a section on carbonate petroleum reservoirs.

A brief section on carbonates as source rocks followed. The workshop ended with a short summary and conclusions, which included a few minutes for questions and answers.

CONNECTIONS

These observations were based on a workshop sponsored by PTTC's Appalachian Region in Washington, PA, March 25, 2008.

Speakers:

Christopher D. Laughrey, Pennsylvania Geological Survey, Pittsburgh, PA 15222; phone 412-442-42??, e-mail claughrey@state.pa.us

William B. Harrison III, Western Michigan University (retired), Kalamazoo, MI 49008; phone 269-387-8633, e-mail William.harrison_iii@wmich.edu

SUMMARY OF EVALUATION FORMS

Forty two people pre-registered for the workshop, and 40 actually attended. Of these, 33 took the time to complete and submit an evaluation form. Twenty nine of the 33 were from industry, and 24 of them had attended previous PTTC workshops.

Of the 33 people who responded to the question, "How did you hear about the workshop?" 16 received one of the e-mail announcements and 11 received a flyer. Two saw the workshop posted on the website and 4 heard of it from other people, i.e., by word of mouth.

Although the vast majority (90%) of attendees was pleased with the workshop content, facility and speaker, a few offered some negative comments. A few would have preferred larger slide reproductions, and in color, not black and white. Some noted that slides used in presentations were not included in the notebook. The addition of extra slides may have been one reason that the workshop got off schedule and ran a little long, as was noted by one person.

Only 9 comments were received under the request for topics for future workshops, and not all of these referred to a topic – several were comments on what could have been included, or omitted, from this workshop. Topics that were suggested included a Petra workshop (one is in the planning stage); aquifer hydrogeology, carbonate sinkhole occurrence and seismic introduction; advances in 3-D seismic; sandstone depositional environments; sequence stratigraphy; and seismic interpretation of carbonates.

EVALUATION: Petroleum Technology Transfer Council Appalachian Region Workshop

1. How did you hear about the workshop?

11 Direct mailing	**0** Periodical	**0** Phone
16 E-mail	**2** Internet/www	**4** Other

2. What additional topics would you like to see in future Focused Technology Workshops? **See other page**

3. Are you a(n):
   - **23** Operator (field supervisor, geologist, engineer)
   - **1** Service Company employee
   - **5** Consultant
   - **0** Educational Institution employee
   - **3** State/Federal Government employee

4. Please circle the response that best indicates your agreement, with 5 being the strongest:

	5	4	3	2	1
A) The program met my expectations	**16**	**11**	**3**	**0**	**0**
B) The speakers/facilities were acceptable	**25**	**5**	**0**	**0**	**0**
C) The program was well organized	**14**	**15**	**1**	**0**	**0**

5. The workshop fee was: **0** too low **29** OK **0** too high

6. Additional comments: (Please use back of page if needed).
   See other page

7. Please indicate which tech transfer method is most helpful to you. Rank from 1 to 5, with 5 being the most helpful:

	5	4	3	2	1
Workshop	**16**	**4**	**1**	**3**	**4**
Individual assistance	**8**	**5**	**5**	**3**	**5**
Reports/Case studies	**3**	**4**	**9**	**6**	**1**
Internet	**4**	**6**	**6**	**3**	**2**
Newsletters	**1**	**6**	**3**	**5**	**6**

8. Have you attended other PTTC events? **24** Yes (how many? **1-many**) **5** No

Have you used any new technologies based on knowledge gained through PTTC events? **_6_** Yes **19** No If yes, please describe (in general) the application/results. (PTTC will only use your response with your permission.)
See other page

9. Would you be willing to share with others any technology innovations or best practices?
_4_ Yes **_14** No If yes, briefly list topics/information you are willing to share. **See other page**

1. What additional topics would you like to see in future Focused Technology Workshops?
Practical experience of real life examples from operators.
Petra workshop.
Aquifer hydrogeo/ carbonate sinkhole occurrence/seismic intro.
More oil and gas production references.
Less background/ theory more practical carbonate info.
3-D seismic advances.
Sandstone/ depo env.
Sequence stratigraphy.
Carbonate Seismic Interpretation.

6. Additional Comments:
Excellent workshop/ overall very good.
Need color prints.
Slides could have been smaller so notes could be written in the margins.
Slides with black background impossible to read.
Enjoyed the instructors enthusiasm.
Good mix of review and intro/overview.
Incorporate oil and gas reserves into presentation.
More local reservoir info.
Got off schedule/ a little long.
Addition of slides by speakers were not included in presentation.
More organized if slides in notebook matched the speaker's slides.
Too much info in too little time.
Equipment malfunctions (pretty good recovery—impromptu presentation.)
Very interesting info. Learned some new things along with a good refresher.

8. Have you used any new technologies based on knowledge gained through PTTC events?
Some sessions that described new artificial lift technologies.
Production monitoring several years ago.

9. Topics/info willing to share.

ATTENDANCE LIST

3/25/2008	Carbonate Reservoirs	Washington	PA	WVU	
LastName	**FirstName**	**Address**	**City**	**State**	**Pos**
Avary	Katharine Lee	1 Mont Chateau Road	Morgantown	WV	2650
Billman	Pam	P.O. Box 567	Mars	PA	1604
Blasingame	Jim	445 W. Main St.	Clarksburg	WV	2630
Botterman	Bob	1301 Grandview Ave., Ste. 200	Pittsburgh	PA	1521
Boyer	Dave	560 Epsilon Dr.	Pittsburgh	PA	1523
Brady	Jonathan	560 Epsilon Dr.	Pittsburgh	PA	1523
Chase	Christopher	225 North Shore Drive	Pittsburgh	PA	1521
Cisler	Rick	4727 Kenilwood Av	Dayton	OH	4542
Clark	Ruble	1616 South Voss Rd., Ste 400	Houston	TX	7705
Crawford	Chad	Westpointe Corporate Center One 1550 Coraopolis Heisght Road- 2nd Floor	Moon Twp	PA	1510
Dennen	Chris	13727 Noel Rd., Ste. 500	Dallas	TX	7524
Flaherty	Kathy J.	1000 Gamma Drive, Ste. 400	Pittsburgh	PA	1523
Garland	Bob				
Goodman	Michael	Westpointe Corporate Center One 1550 Coraopolis Heights Road- 2nd Floor	Moon Twp	PA	1510
Grayson	Eric	2163A State Route 821	Marietta	OH	4575
Haney	Michael A.	615 West Higland Ave.	Ebensburg	PA	1593
Harrison, III	William	"Dept. of Geosciences Western Michigan University"	Kalamazoo	MI	4900
Hawk	Joan	615 West Higland Ave.	Ebensburg	OA	1593
Heinrich	Carl	Box 305	Reno	OH	4577
Hoffman	Joel	61 McMurray Rd, Ste. 300	Pittsburgh	PA	1524
Huck	Don	2163 A State Route 821	Marietta	OH	4575
Huck	Gene	2163 A State Route 821	Marietta	OH	4575
Jenkins	Junior	100 Gamma Dr., Ste. 400	Pittsburgh	PA	1523
Kennedy	Elizabeth	1301 Grandview Ave., Ste. 200	Pittsburgh	PA	1521
Laughrey	Christopher	400 Waterfront Drive	Pittsburgh	PA	1522
Lewis	Eric	1 Mont Chateau Rd.	Morgantown	WV	2650
Lupardus	Matt	2163A State Route 821	Marietta	OH	4575
Mackrell	Benjamin	501 56th St.	Charleston	WV	2530
Manion	Lauren	6050 Washington Rd., 5th Floor	Pittsburgh	PA	1522
McClure	Jeff	109 Grove Ave.	Clarksburg	WV	2630
Menotti	Tess	225 North Shore Dr.	Pittsburgh	PA	1521
Miller	Chris	182 East Union	Allegany	NY	1470
Miller	Glenn	6236 W. Grand River	Brighton	MI	4811
Ober	Eric	560 Epsilon Dr.	Pittsburgh	PA	1523
Peterson	Aaron	415 Moon Clinton Rd	Coraopolis	PA	1510

Roberts	Doug	Westpointe Corporate Center One 1550 Coraopolis Heights Road- 2nd Floor	Moon Township	PA	1510
Schmid	Katherine	225 North Shore Drive	Pittsburgh	PA	1521
Vish	Al	120 Genesis Blvd	Bridgeport	WV	2633
Weigand	Kristin	Westpointe Corporate Center One 1550 Coraopolis Heights Road- 2nd Floor	Coraopolis	PA	1510
Wigal	Jim	1000 Gamma Dr., Ste. 400	Pittsburgh	PA	1523