From: Donna Kniss <donna.kniss@epa.state.oh.us>
Sent: Thursday, August 05, 2010 3:32 PM
To: Chuck McCracken
Subject: Fwd: Proper Testing of wastewater from oil and gas facilities
Attachments: Proper Testing of wastewater from oil and gas facilities

FYI

Donna J. Kniss
Ohio Environmental Protection Agency
Division of Surface Water
Northeast District Office
2110 East Aurora Road
Twinsburg, Ohio 44087
330-963-1285
fax 330-487-0769

donna.kniss@epa.state.oh.us

>>> Ryan Laake 8/4/2010 10:24 AM >>>

McCracken, Chuck

From: Kari Matsko <karimatsko@hotmail.com>
Sent: Monday, August 02, 2010 3:18 PM
To: ryan.laake@epa.state.oh.us
Cc: eyesondrilling@epa.gov
Subject: Proper Testing of wastewater from oil and gas facilities

Hello Ryan

Please advise whether the EPA is addressing all possible known reported contaminants via GC/MS and other testing - including but not limited to radium 226, 228, and those listed below with regard to processing oil and gas wastewater in Ohio from your website:
"Some of the requests have been for the discharge of lower salinity "flow back" water from the hydraulic fracturing of the shale (described by the industry as less than 50,000 mg/l total dissolved solids (TDS)), while other requests have been for the discharge of higher salinity brines and wastewater."

FROM PA DEP 12/08

Frac Water Chemicals Chemical Components (From MSDS)

2,2-Dibromo-3-Nitrilopropionamide	Guar gum	Frac Stage #1
2-butoxyethanol	Hemicellulase Enzyme	Hydrochloric Acid
2-methyl-4-isothiazolin-3-one	Hydrochloric Acid	Propargyl Alcohol
5-chloro-2-methyl-4-isothiazotin-3-one	Hydrotreated light distillate	Methanol
Acetic Acid	Hydrotreated Light Distilled	Acetic Acid
Acetic Anhydride	Isopropanol	Acetic Anhydride
Alphatic Acid	Isopropyl Alcohol	Frac Stage #2
Alphatic Alcohol Polyglycol Ether	Magnesium Nitrate	Methanol
Ammonia Persulfate	Mesh Sand (Crystalline Silica)	Boric Oxide
Aromatic Hydrocarbon	Methanol	Petroleum Distallate Blend
Aromatic Ketones	Mineral Spirits	Polysaccharide
Boric Acid	Monoethanolamine	Potassium Carbonate
Boric Oxide	Petroleum Distallate Blend	Sodium Chloride
Butan-1-01	Petroleum Distillates	Potassium Hydroxide
Citric Acid	Polyethoxylated Alkanol (1)	Ethylene Glycol
Crystalline Silica: Cristobalite	Polyethoxylated Alkanol (2)	Boric Acid
Crystalline Silica: Quartz	Polyethylene Glycol Mixture	Sodium Bicarbonate
Dazomet	Polysaccharide	Monoethanolamine
Diatomaceus Earth	Potassium Carbonate	Frac Stage #3
Diesel (use discontinued)	Potassium Hydroxide	Hydrotreated light distillate
Ethane-1,2-diol	Prop-2-yn-1-01	Ethoxylated Alcohol
Ethoxlated Alcohol	Propan-2-01	Glutaraldehyde
Ethoxylated Alcohol	Propargyl Alcohol	Dazomet
Ethoxylated Octylphenol	Propylene	Sodium Hydroxide
Ethylene Glycol	Sodium Bicarbonate	Methanol
Ethylhexanol	Sodium Chloride	Diesel (use discontinued)
Ferrous Sulfate Heptahydrate	Sodium Hydroxide	2,2-Dibromo-3-Nitrilopropionamide
Formaldehyde	Sucrose	Polyethylene Glycol Mixture
Glutaraldehyde	Tetramethylammonium Chloride	Mesh Sand (Crystalline Silica)
Glycol Ethers		

Thanks

Kari Matsko
Director, NEOGAP - Ohio
440-579-5314
www.neogap.org

McCracken, Chuck

From: Donna Kniss <donna.kniss@epa.state.oh.us>
Sent: Wednesday, August 04, 2010 7:37 AM
To: Chuck McCracken
Subject: Fwd: Marcellus Brine Disposal

Chuck:

I'm going through my e-mail to set up a cd for the Patriot/warren test file, and I came across this e-mailed link. You may have already seen it, but I thought I'd pass it on in case you hadn't.

Donna

>>> Brian Nickel 6/28/2010 9:05 AM >>>
Donna,
I've worked with Federal Facilities down here in Southwest District Office and been involved in radiological issues. I recently became aware of the proposed disposal of the Marcellus brine in Ohio WWTPs and the Warren Water Treatment Plant pilot project. I spoke with Keith Riley and he suggested I contact you. Through my work with ASTSWMO Radiation Focus Group, I've heard a little bit about the radiological issues associated with the brine. Radium 226 and 228 have been found at very high levels. The links below discuss/contain the data New York developed. I apologize if this is all old news but I was surprised with the elevated levels of radium in the brine and wanted to learn more.

Has ODH completed their review the pilot project? I have calls into my contacts at ODH. I am interested in any conclusions or concerns they may have regarding the disposal or reuse of the WWTP sludge after treatment of the brine. Also, can you email me copy of the report?

http://marcelluseffect.blogspot.com/2009/12/radioactivity-present-in-marcellus.html

http://www.tiogagaslease.org/images/BVW_11_26_09_2.pdf

Appendix 13
NYS Marcellus Radiological Data
From Production Brine

http://www.dec.ny.gov/docs/materials_minerals_pdf/ogsgeisapp1.pdf

Call me at 937-285-6468 if you have any questions.

Thanks
Brian Nickel

McCracken, Chuck

From: Hopkins, Mike <Mike.Hopkins@epa.state.oh.us>
Sent: Friday, July 29, 2011 12:57 PM
To: 'mlupardus@artexoil.com'; 'cfritz@artexoil.com'; 'bill@bassenergyco.com'; 'beckenergy@hotmail.com'; 'will.ward@brammer.com'; 'grover.campbell@chk.com'; 'david@davidrhillinc.com'; 'info@mqexp.com'; 'will_porche@xtoenergy.com'; Martin Thalken; 'rwhitmire@enervest.net'; 'bdavis@magnumhunterresources.com'; Parsons, Misty; Hodanbosi, Bob; Cirker, Benjamin; Suttman, Cheryl; Hall, Andrew; Stevenson, Laurie; Powell, Laura; Nally, Scott; Settles, Mike; mick_pompelia@urscorp.com; terry.black@erm.com; 'Stewart@ooga.org'; James, Robert (rjames@bricker.com); Hayes, William D.; 'Chris.Perry@dnr.state.oh.us'; 'Heidi Hetzel-Evans'; Husted, John F.; 'mike.hallfrisch@dnr.state.oh.us'; 'mike.mccormac@dnr.state.oh.us'; 'rick.simmers@dnr.state.oh.us'; 'ted.lozier@dnr.state.oh.us'; 'thomas.tugend@dnr.state.oh.us'; 'tom.tomastik@dnr.state.oh.us'; Shear, Aaron; Hall, Brian; Lowe, Chuck; Nygaard, Eric; Goicochea, Joe; Weiss, Kristopher; Burkleca, Lee; Taliaferro, Lindsay; Baker, Mike; Eggert, Michael; Laake, Ryan; Freeman, Tracy; Harcarik, Tom; Nickel, Brian; Kniss, Donna; Underwood, Dan; Adams, Eric; Gomes, Erm; Snell, Fred; Riley, Keith; Rice, Nancy; Blasick, Rich; DiFranco, Stivo; Saines, Steve; Williams, Steve; Wilson, Virginia; Chuck McCracken; Michael Snee; Rebecca Fugitt; 'robert.owen@odh.ohio.gov'; Stephen Helmer; David Lipp; Abbruzzese, Chris; jpounds@ohiochemistry.org; Thorp, Jed; Bouder, Richard; Ahern, Mike; Russell, Gregory D. (GDRussell@vorys.com); Ward, Adam; Charles, Cindy; Fasko, Ed; Budge, Mark; Weinberg, Bruce; Schneider, Tom; 'Brad.Miller@hamilton-co.org'; 'bhasenyager@schd.org'; 'tdzienis@cantonhealth.org'; 'Laura Miracle'; Osborne, Craig; David Hearne; 'marseejs@rapca.org'; Granata, Karen (KAREN.GRANATA@toledo.oh.gov); clinefcd@rapca.org; Duane LaClair
Subject: Oil & Gas Well Site Draft for Comment General Permit - Comments Due by Friday, August 12.
Attachments: Michael E Hopkins P E .vcf

To: Any interested party.

On July 29, 2011, Ohio EPA issued for comment draft Qualifying Criteria and draft Model General Permit terms and conditions for natural gas well site operations. See the bottom of the web page: http://www.epa.ohio.gov/dapc/genpermit/genpermits.aspx for links to these materials. Comments are being solicited now in order to help the Ohio EPA develop an appropriate General Permit. The official General Permit 30-day comment period will occur **at a later date**.

Comments should be sent to me at the below address.

Please let me know if you have any questions.

Michael E. Hopkins, P.E.
Assistant Chief, Permitting
Ohio EPA, DAPC
50 W. Town Street, Suite 700
Columbus, Ohio 43215
614-644-3611 (w)
614-644-3681 (Fax)
Mike.hopkins@epa.state.oh.us
Ohio Environmental Protection Agency

Michael E. Hopkins, P.E.
Ohio EPA, DAPC
Assistant Chief, Permitting

(614) 644-3611 Work
Mike.Hopkins@epa.state.oh.us
50 West Town Street, Suite 700
Columbus, Ohio 43215
http://www.epa.ohio.gov/

McCracken, Chuck

From: Michael Snee
Sent: Monday, July 19, 2010 11:41 AM
To: Chuck McCracken
Subject: FW: Marcellus Shale
Attachments: Marcellus Shale Meeting- Final Agenda.doc

Michael Snee
Ohio Department of Health
Bureau of Radiation Protection

-----Original Message-----
From: Robert Owen
Sent: Wednesday, July 14, 2010 11:30 AM
To: Michael Snee
Subject: FW: Marcellus Shale

Mike, are you available for a 2:00 conference call with Craig today? Where are we at in generating our TENORM rule? Thanks.

Robert E. Owen, Chief
Bureau of Radiation Protection
-----Original Message-----
From: Craig Butler [mailto:Craig.Butler@epa.state.oh.us]
Sent: Wednesday, July 14, 2010 8:32 AM
To: Bob Knipmeyer; Jim Sferra; Laurie Stevenson; Robert Owen
Subject: Marcellus Shale

Bob:

Hi Bob. It's been a while and I wanted to check in and also ask for your help and extend an invite to a meeting that Ohio EPA and ODNR have been working to pull together. The meeting agenda is attached for your review.

We're planing this to be an informal state agency discussion on the topic of Marcellus Shale drilling, its possible effects to human health and the environment, and how Ohio agencies can and should prepare to meet the challenges and issues this drilling will present.

In addition to having you or other staff attend the meeting, I think there are a few issues ODH may be working on that would fit nicely into the agenda. Namely, I think the TENORM issues related to drill cuttings management in Ohio solid waste landfills and in Frac water that is/may be diluted through municipal wastewater treatment plants and discharged to Ohio rivers. I believe ODH was involved with the Warren Ohio project and this may be good information to share with the group.

Please take a look at the agenda and give me a call to discuss the issue.

Sincerely,

Craig Butler, Chief
Ohio Environmental Protection Agency
Southeast District Office
(740) 380-5202 - Direct
(740) 385-8501 - Reception
craig.butler@epa.state.oh.us

Marcellus Shale Meeting
OEPA/ODNR/ODH

August 3, 2010
10:00 a.m. – 1:00 p.m.
Ohio EPA, Center for Excellence, 6th Floor

AGENDA

Marcellus Shale Drilling

- How/where is it done
- Potential for drilling in Ohio?
- Water usage and management of wastewater from drilling
- Other alternatives – recycling, class 2 injection, road salt production, etc.

Environmental Impacts

- Wastewater disposal
- Drinking water/potential impacts from drilling/disposal
- Other impacts

Regulatory/Policy Discussion

- Current OEPA/ODNR regulations/policy for Marcellus Shale drilling

- Additional decisions necessary to minimize environmental impact
  Long-term water quality impacts for dischargers (TDS)

Next Steps

McCracken, Chuck

From: Brian Nickel <Brian.Nickel@epa.state.oh.us>
Sent: Tuesday, June 29, 2010 2:19 PM
To: Chuck McCracken
Subject: Fwd: RE: Rad Focus Group Call / TENORM Whitepaper - MS insert
Attachments: PA-NORM_Oil+Gas-Sites-Study_1991.pdf; PA-Geology-Magazine_Vol38-No1_DCNR_Spr2008.pdf; MS-Gas-Ops_ASTSWMO-TENORM-WP-section_6-25-2010.doc

Attached is Dave's summary and other if you may be interested in.

Have fun!

>>> "Allard, David" <djallard@state.pa.us> 6/25/2010 6:28 PM >>>
Hi Charles,

Good to talk to you and others today... TENORM white paper is shaping up.

Attached is a small section of text regarding the Marcellus Shale TENORM issue to insert at the end of the "Oil and Gas Production" section (bottom of pg 32 in my latest version). I'm open to edits...

Also, I may have passed these along in previously, but I've attached the references and/or given URL links in the write-up.

Enjoy,

Dave

****

David J. Allard, CHP, Director
PA Dept. of Environmental Protection
Bureau of Radiation Protection
P.O. Box 8469
Harrisburg, PA 17105-8469

Tel: 717-787-2480
Fax: 717-783-8965
E-mail: djallard@state.pa.us
http://www.dep.state.pa.us/brp/

****

-----Original Message-----
From: Dale Rector [mailto:Dale.Rector@tn.gov]
Sent: Friday, June 25, 2010 11:14 AM

To: charlesr@astswmo.org; David.Jones@deq.idaho.gov; MSandhu@dtsc.ca.gov; Brian.Nickel@epa.state.oh.us; jimitche@gw.dec.state.ny.us; dwhitfill@kdheks.gov; jay.hyland@maine.gov; Jennifer.opila@state.co.us; millie.garcia-serrano@state.ma.us; bobby.lopez@state.nm.us; Allard, David
Cc: daniar@astswmo.org; Clarence.Smith@Illinois.gov
Subject: Rad Focus Group Call

Dear Focus Group
I have looked over the draft TENORM paper and believe once Charles accepts the changes, it will be nearly Allie ready. It looks like Mary and Dania had some comments, so we might want to pick out those and discuss them today. We still need a conclusion if we want one. Units and measures, and conversions are prone to error and a last check of those while Allie is editing might be appropriate.
Bobby and Mohinder, can give us a general summary of their edits so we all understand the final product.
Also the Number 3 below, I think we agreed could be a lessons learned about Liberty Radex. Emphasis on disposition of solid waste from RDD or IND, other big radiological incident. Incorporating the use of the DDDST of EPA and so forth, as appropriate. Uncle Dave would kick start it since he was at RadEx. Objective being to inform Solid Waste Managment Officials of contingencies required for solid rad waste disposal.
I have not done a good job of following the Tritium Ruling, DU Ruling, Blending Ruling, or Mixed Waste, etc. So a short group discussion might catch us all up.
Dale
Hey everyone - call information for Friday:
Dial: 866-502-8312
Code: 811706
Thanks,
Charles
Charles Reyes
Federal Facilities Staff Associate
Association of State and Territorial Solid Waste Management Officials (ASTSWMO)
444 North Capitol Street, N.W., Suite 315 Washington, D.C. 20001
(202) 624-7882 - tel
(202) 624-7875 - fax
charlesr@astswmo.org

NORM Survey Summary [1]

I'd like to update you on the status of surveys we have been conducting to determine levels of Naturally Occurring Radioactive Materials (NORM) at oil and gas sites in Pennsylvania.

Since 1991, the Bureau of Oil and Gas Management and Bureau of Radiation Protection have been conducting surveys and collecting samples at wells sites and related facilities in 26 counties.

Facilities surveyed include over 400 oil and gas well sites, nine pipe yards, and about 500 miles of dirt road that were sprayed with brine for dust suppression.

About sixty percent of the well sites had readings at or below background levels. Thirty four percent had readings within 10 microroentgens per hour (microR/hr) of background, three percent were in the range of 11-20 microR/hr above background, and two percent were 21-54 microR/hr above background. One site was 195 microR/hr above background.

To put this in perspective, several states have adopted regulations which include action levels for contamination. Louisiana has adopted 25 microR/hr and is in the process of changing to 50 microR/hr. Texas, Arkansas and Michigan set levels at 50 microR/hr. Mississippi set its level at 25 microR/hr.

From the more than 400 sites tested, we found two samples, at 54 and 195 microR/hr that would be of concern in states with regulations.

Sludge and soil collected at well sites were generally at or below the level of 5 picocuries per gram (pCi/g). Louisiana, Texas and Mississippi have adopted levels of 30 pCi/g and Arkansas adopted a level of 5 pCi/g.

No significant radiation levels were seen at pipe yards from pipe taken from Pennsylvania wells. One elevated reading was found from pipe from another state.

Several brine treatment facilities surveyed had radiation levels above background, but were not sufficiently elevated to require controls for the protection of the general public.

Road surveys for gamma radiation were generally at or below background levels. All areas with elevated readings are attributed to shale outcroppings.

In summary, our survey results indicate that NORM is not a problem at oil and gas well sites in Pennsylvania. Consequently, development of regulations to address this issue is a low priority.

We will probably continue to elevate brines and sludges to expand our database and for future consideration.

([1] This article was prepared in April 1995 for the *IOGA NEWS*. The attached NORM Survey Summary was prepared September 1, 1992.)

NORM SURVEY SUMMARY

From February to October 1991, The Department conducted a survey to determine the levels of naturally occurring radioactive materials (NORM) associated with oil and gas wells and related facilities. The survey was conducted in three phases. This project was conducted by the Western Area Health Physicist, the Bureau of Radiation Protection, the Oil and Gas Field Operations and the Bureau of Oil and Gas Management. The Bureau of Laboratories conducted the laboratory analysis.

Phase one of the NORM survey began in February and ended in September 1991. The objective of the survey was to obtain samples of brine and brine pit or tank sludge from well sites across the state for laboratory analysis. The samples were tested for radium-226 and radium-228 and are reported in pCi/l for liquids and pCi/kg for solids. In addition, brines and bottom sediments were taken from brine treatment plants and disposal well sites for analysis of combined radium. In this phase, there were 48 sites surveyed.

In Phase II, nine pipeyards were surveyed in seven counties using a low level radiation detection meter. If a pipe showed above background, a sample of scale inside the pipe was taken and sent to the laboratory for analysis. None of the facilities surveyed conducted pipe cleaning operations as described in Louisiana.

From July to October 1991, the Department conducted Phase III by surveying oil and gas well sites using low level detection meters to determine the exposure to low level radioactivity resulting from NORM. Surveys were also conducted at brine treatment plants, municipal treatment plants which accept brine, disposal wells, gas storage fields, and road spreading operations.

OIL AND GAS WELLS

There were 413 oil and gas well sites surveyed. About 374 of the sites were surveyed using the field meters and 39 were surveyed by taking samples of the liquids or solids for laboratory analysis.

At the well sites surveyed with the field meter, readings were taken of background, the well head, pits and tanks, pipes, and other equipment that was present using a low level radiation detection meter. The results were reported in uR/h. At the other well sites, samples of brine or tank sludge was collected for analysis by the DER laboratory. At one site, samples of drill cuttings were collected from one formation that was suspected to be a problem. The samples were analyzed for radium-226, radium-228, specific conductance, total dissolved solids, chloride, sulfates, calcium, strontium and barium. The results for radium-226 and radium-228 are in pCi/l for liquids and pCi/kg for solids.

Of the 374 sites surveyed with the field meter, 60.5% (226) of the sites had readings at or below background. Another 34.2% (128) of the sites had readings within 10 uR/h of background, and 3.2% (12) of the sites had readings within 20 uR/h. The remaining 2.1% (8) of the sites had readings that ranged from 21 to 54 uR/h above background, with one site at 195 uR/h above background.

Of the 374 wells surveyed, 264 were gas wells and 110 were oil wells. The county distribution is shown below. The sites surveyed were also tracked by target formation. This distribution is also shown below.

COUNTY DISTRIBUTION OF SITES SURVEYED

COUNTY	OIL	GAS	COUNTY	OIL	GAS
Allegheny	1	4	Fayette	0	11
Armstrong	2	15	Forest	12	6
Beaver	5	0	Greene	6	4
Butler	4	4	Indiana	0	24
Cambria	0	5	Jefferson	0	16
Cameron	0	4	McKean	19	14
Centre	0	9	Mercer	3	8
Clarion	4	8	Potter	7	9
Clearfield	0	11	Somerset	0	10
Clinton	0	8	Venango	8	11
Crawford	3	10	Warren	16	15
Elk	7	12	Washington	11	4
Erie	2	27	Westmoreland	0	15

FORMATION DISTRIBUTION OF SITES SURVEYED

FORMATION	OIL	GAS	FORMATION	OIL	GAS
Bald Eagle	0	2	Mississippi	1	4
Bass Island	2	1	Murrysville	0	2
Bois Blanc	0	1	Ohio Shale	0	6
Bradford	53	59	Onondaga	0	4
Bralier	0	3	Oriskany	0	54
Elk	1	10	Oswago	0	1
Helderberg	0	4	Pennsylvania	0	1
Huntersville	0	16	Ridgeley	0	5
Lock Haven	0	12	Salina	0	3
Lockport	0	3	Tuscorora	0	4
Marcellus	0	3	Unknown	21	4
Medina	0	41	Venango	32	21

Samples for laboratory analysis were obtained at 39 sites. Brine samples were obtained at 37 sites (26 gas, 10 oil and 1 combination) and sludge samples were obtained at three oil well sites. In addition, samples of drill cuttings from a formations believed to be a problem were obtained at one gas well site.

The radium-226 in the brine samples ranged from 3.29 pCi/l to 2,575 pCi/l with one at 4,685 pCi/l. The average was 742 pCi/l. Radium-228 in the brine samples ranged from 7.17 pCi/l to 2,196 pCi/l. The average was 676 pCi/l. Following is a listing of the results by well type.

		Radium 226 (pCi/l)			Radium 228 (pCi/l)		
Well Type	#	Avg.	High	Low	Avg.	High	Low
All	38	742	4,685	8.34	676	2,196	12.06
Deep Gas	9	1,243	4,685	203	1,475	2,110	499
Shallow Gas	17	946	2,575	20	665	2,196	13
Shallow Oil	12	86	275	8.34	94	456	12.06

There were three samples of sludge from the pits at oil wells. Two sites were in Warren County and one was in Venango County. The Radium 226 and Radium 228 results are as follows:

County	Radium-226 (pCi/kg)	Radium-228 (pCi/kg)
Venango Co.	102	165
Warren Co.	153	296
Warren Co.	12.9	7,988

At a gas well being drilled in Venango County, drill cuttings from the well were taken at intervals of 10 feet starting at a depth of 3,959 feet to 3,979 feet. The target formation for these samples was the Tioga-Metabentonite. Shown below are the results of the analysis on those drill cuttings.

Depth (ft)	Radium-226 (pCi/kg)	Radium-228 (pCi/kg)
3959	1.85	1,031
3969	1.48	740.35
3979	1.52	649.97

BRINE TREATMENT FACILITIES

All six of the operating brine treatment facilities and one of the industrial facilities that accepts brine were surveyed. These facilities were surveyed using field meters. Samples of the brine and sludges were collected and sent to the laboratory for analysis. Readings from the facilities varied considerably. Field meter readings ranged from less than 5 uR/h at one facility to 125 uR/h at another facility (activated charcoal filter was 300 uR/h). The brine or effluent from the six facilities had radium-226 of 3.29 to 2,069 pCi/l and radium-228 of 7.17 to 1,555 pCi/l. At four of the facilities, the sludges had radium-226 of 1,274 to 186,333 pCi/kg.

The JJ Bucher facility in Potter County treats brine from oil wells. Readings at the facility were less than 5 uR/h. The laboratory analysis of the brine from the storage tanks showed radium-226 of 14.52 pCi/l and radium-228 of 14.26 pCi/l.

The Minard Run Oil Company's Flood 4,5,E,F,Lewis Run is a discharge from an oil waterflood operation in McKean County. The laboratory analysis of brine discharge showed radium-226 at 3.29 pCi/l and radium-228 at 7.17 pCi/l.

The Petro Tech Treatment Facility in Venango County also treats brine from oil wells. Readings at the facility range from 5 to 10 ur/h (background) at the wet well, to 50 to 80 at the first four holding tanks. Other readings at the site were: other twc holding tanks - 10 to 15 uR/h; 12 settling tanks - 10 to 20 uR/h; and the sludge storage tank - 20 to 25 uR/h. The laboratory analysis of the effluent showed a radium-226 of 1,143 pCi/l and radium-228 of 985 pCi/l. The sludge from the facility had radium-226 of 1,274 pCi/kg and radium-228 of 434 pCi/kg.

The Castle Gas Treatment Facility in Indiana County treats brine from shallow gas and oil wells in Indiana and Westmorleand Counties. Sludge is shipped to Ohio for disposal. Readings at the facility were at background or in the 5 to 15 range. The oil separation chamber had the highest reading of 40 uR/h at the bottom and 20 uR/h on the side. Other readings were: brine receiving tanks - up to 15 uR/h; holding tanks - up to 5 uR/h; other tanks - background; dumpster - background except for hot spot in center at 5 uR/h; treatment tanks - background; polymer feed tank - 5 uR/h; and other tanks and piping - background. The laboratory analysis of the brine from the storage tanks showed radium-226 of 2,069 pCi/l and radium-228 of 1,555 pCi/l.

The Hart Chemical Treatment Facility treats brine from shallow gas wells from Armstrong, Indian, and Jefferson Counties. Sludge is shipped to the B.F.I. landfill in Brockway. Readings at the facility ranged from background to 100 uR/h at the two collection tanks. Readings of samples taken from the large tanks were 10, 6, and 2 uR/h. The sludge in the trough which connects the collection tank and the treatment tank had a reading of 120 uR/h (Note - reported to be left-over AMD sludge). The laboratory analysis of the brine from the storage tanks showed radium-226 of 287 pCi/l and radium-228 of 89 pCi/l.

Readings at the EDC Brine Treatment facility in Warren County were in the 5 to 15 uR/h range with background at 5 uR/h. The reading at the sludge trailer was 10 to 15 uR/h while a previous survey of the facility reported a reading of 40 uR/h around the trailer. The sludge is shipped to the BFI's Greentree Landfill in Kersey, Pa. The laboratory analysis of the effluent from the facility showed radium-226 of 411 pCi/l and radium-228 of 604 pCi/l. An analysis of the sludge showed radium-226 of 13,267 pCi/l and radium-228 of 16,323 pCi/l.

The ConGas Division 5 Brine Treatment Facility is in Jefferson County. Most of the brine comes from shallow wells, while about 5% comes from deep Oriskany wells. The readings at the three impoundments were in the normal 5 to 7 uR/h range. The sludge in the second impoundment had readings up to 125 uR/h. The sand filter had readings of 35 and 15 uR/h while the charcoal filter had readings of 300 and 80 uR/h. The laboratory analysis of the effluent was reported at radium-226 of 1,177 pCi/l and radium-228 of 157 pCi/l. The laboratory results of the sludges for the three impoundments are as follows:

Impoundment	Radium-226 (pCi/kg)	Radium-228 (pCi/kg)
1 - Bottom Sludge	4,128	1,893
2 - Bottom Sludge	11,384	5,837
2 - Top Sludge	186,633	65,815
3 - Bottom Sludge	3,858	1,822

At the Franklin Brine Treatment plant, readings ranged from a background of 5 to 7 uR/h to 90 pCi/l. The readings for the three sludge storage bins were: 20 to 30 uR/h; 20 to 40 uR/h; and 30 to 60 uR/h. Other readings at the facility are: Brine storage tanks - 15 to 20 uR/h and 30 to 60 uR/h; neutralization tank - 90 uR/h; flocculation tank - 40 uR/h; sludge decanters - 20 uR/h and 15 uR/h; two solids accumulation tanks - 20 uR/h; effluent monitoring tank - 20 to 30 uR/h; and the lime storage tank - 5 to 7 uR/h. The laboratory analysis of the effluent was reported as radium-226 of 352 pCi/l and radium-228 of 153 pCi/l. The sludge was reported at radium-226 of 57,527 pCi/kg and radium-228 of 54,365 pCi/kg.

MUNICIPAL TREATMENT PLANTS

Three municipal sewage treatment plants that accept brine or drilling fluids were surveyed. Radiation levels were near, or at background.

The Moshannon Valley Sewage Treatment Plant in Centre County accepts frac water from gas drilling operations. It does not accept brines. The frac water is mixed with the sewage in the wet well and is pumped to the activated sludge unit. Readings were less than 5 to 10 uR/h.

The Clearfield Municipal Authority Treatment Plant treats about 15,000 gal./da. of brine. Readings at the brine storage tanks were around 5 uR/h while the sludge was at background (less than 5 uR/h).

The Bellefonte Wastewater Treatment Plant accepts frac water and no brines. The brine is mixed with the sewage and run through the plant. Readings at the facility did not exceed 5 uR/h.

DISPOSAL WELLS

Four of the seven brine disposal wells in the state were surveyed, one operator did not participate in the survey. The facilities were surveyed using field survey meters. Samples of brine at two of the facilities were collected for laboratory analysis.

At the Dando disposal well in Armstrong County, the two storage tanks had areas with readings at 30 uR/h above background, while the rest of the facility was at background. The brine had a radium-226 level of 1,895 pCi/l and a radium-228 level of 1,157 pCi/l.

The brine and oil tank at the TH Yuckenberg disposal well in Indiana County had a reading of 20 uR/h at the bottom of the tank. The rest of the facility was showed readings at or below background. The brine had a radium-226 level of 1,874 pCi/l and a radium-228 level of 1,420 pCi/l.

The Spencer Land Company's #2 salt water disposal well is in Clearfield County. The readings at the site range from 5 to 15 uR/h with background at 5 ur/h. No brine samples were collected.

The NEA Cross disposal well in Erie County did not have any readings above background.

The Cottonwood Operating Company which operates the West Shanksville disposal well in Somerset County did not want to participate in the survey.

GAS STORAGE FIELDS

Four gas storage facilities were surveyed: the Blackhawk Storage Field in Beaver County, the Leidy Station in Clinton County, the Ellisburg Station in Potter County, and the Sabinsville Station in Tioga County. Although there were some elevated readings, no significant radiation levels were found.

At the Blackhawk Storage Field, readings at the well head, drip pump, and storage tank ranged from less than 5 uR/h to 15 to 20 uR/h.

The Leidy Station consists of wells for gas storage, three dehydrators for drying the gas, and two brine storage tanks. Readings at the equipment ranged from 5 uR/h to 10 to 15 uR/h. There was one hot spot at one end of one of the storage tanks that showed readings of 20 to 22 uR/h.

The brine evaporation pond at the Ellisburg Station Storage Field in Potter County was surveyed. The facility consisted of a covered and roofed pond with several sludge tanks. Readings inside and around the perimeter were around background (200 to 250 cpm). The readings at the three sludge holding tanks ranged from near background to 10 to 13 uR/h (500, 800, and 800 cpm).

At the brine evaporation pond at the Sabbinsville in Tioga County, only background readings (around 3 uR/h) throughout the facility were noted.

ROADSPREADING OPERATIONS

Routes 03045 and 03169 in Kiskiminetas Township, Armstrong County, where brine has been spread for several years for dust control and road stabilization, were surveyed. The readings at the edge of the road were in the minimum detectable range, while all other areas were indistinguishable from background.

PIPEYARDS

Nine pipeyards were surveyed in seven counties as follows: Indiana (4); Warren (1); Clarion (1); Crawford (1); Forest (1); and McKean (1). The pipe at the pipeyards was surveyed using a low level radiation detection meter. If a pipe showed above background, a sample of scale inside the pipe was taken and sent to the laboratory for analysis.

The pipeyards surveyed included five well pipe suppliers, and four were pipe storage areas for oil or gas production companies. None of the facilities surveyed conducted pipe cleaning operations as described in Louisiana.

At seven of the locations (Pool Well Service, Miller Supply, TW Phillips Gas and Oil Company, McCalls Supply Company, Cabot Oil and Gas Company, Pennzoil, and Meridian Exploration), readings were at background, while in the other two cases, readings were above background.

At the McJunkin pipeyard in Indiana County some six inch casing from a well of unknown type in Kentucky showed readings of 15 uR/h. From the laboratory analysis, the scale from the casing measured 137,091 pCi/kg of radium-226 and 7,656 pCi/kg of radium-228.

At the North Penn Pipe and Supply Yard in Warren County, some two inch production tubing (probably used in a shallow oil well in New York or Pennsylvania) showed levels of 35 uR/h. Radiation levels in the soil were high at the North Penn Pipe and Supply Yard which may have interfered with a good reading. The results of the laboratory analysis for the scale showed radium-226 at 1,361 pCi/kg and radium-228 at 1,055 pCi/kg.

BOGM RADIATION SURVEY SPRING, 1991

COUNTY	MUNICIPALITY	FACILITY	PERMIT	WT	WD	HORIZON	SP COND (UMHOS/CM)	TDS (MG/L)	CL (MG/L)	SO4 (MG/L)	CA (MG/L)	SR (MG/L)	BA (MG/L)	RA226 (pCI/L)	RA228 (pCI/L)
ALLEGHEN	S. FAYETTE	DIKED AREA	003-00826	G	2202		102384	143432	72100	<10	8970		30.4	511.87	202.23
ARMSTRON	COWANSHANNOCK	TANK	005-22232	G	3600									315	185
ARMSTRON	COWANSHANNOCK	TANK	005-20829	G	3530									20	13
CAMBRIA	SUSQUEHANNA	TANK	021-20223	G	3800	CATSKILL/LOCK HAVEN		175296	99800	<10	8790	763	645	1408	904
CAMBRIA	BARR	TANK	021-20605	G	3604	VENANGO		195404	115000	<10	14300	>899	636	1154	1083
CENTRE	CURTIN	TANK	027-20242	G	4975	LOCK HAVEN		222672	116500	110	20400	1270	190	163	128
CENTRE	BURNSIDE	TANK	027-20124	G	4822	CATSKILL/LOCK HAVEN		252980	132000	<10	21700	1160	1060	1469	838
CLEARFIE	JORDAN	TANK	033-22037	G	3850	CATSKILL/LOCK HAVEN		185146	105000	<10	12700		14.1	2015	1749
CLEARFIE	BURNSIDE	TANK	033-21787	G	3701	CATSKILL/LOCK HAVEN		230824	127800	<10	17500			107	77
CLINTON	BEECH CREEK	TANK	035-20378	G	4752	LOCK HAVEN		184902	105000	<10	14233	586	59.8	730.71	490.97
CLINTON	BEECH CREEK	TANK	035-20447	G	4800	LOCK HAVEN		153096	78900	<10	12100	871	12	811.30	530.11
CRAWFORD	BEAVER	TANK	039-21917	G	3665	MEDINA		396012	183000	219	28200	858	1.45	598.98	1882.87
ELK	HIGHLAND	SEP TANK	HIGHLAND	O	N/A	N/A	38798	31502	18500	2256	2830		0.108	15.37	17.68
ELK	HIGHLAND	TANK	047-23007	O	2500	BRADFORD		25159	12800	2264	1790		0.099	22.87	29.15
ERIE	MILLCREEK	TANK	049-24461	G				390928	183000	54	30300	860	1.17	627.78	1478.38
ERIE	CONNEAUT	TANK	049-20162	G	3284	MEDINA		378148	175000	58.4	25100	745	4.1	588.48	1483.47
FAYETTE	SPRINGFIELD	TANK	051-20439	G	8594	HUNTERSVILLE		341916	196900	<10	2000		655	4685	2038
FAYETTE	SPRINGFIELD	TANK	051-20200	G	8150	ORISKANY		354034	145000	<10	19100		498	568	2110
FOREST	HOWE	TANK BATTE	MERIDION	O			105192	130588	69800	121	10200		3.3	42	42
FOREST	KINGSLEY	TANK	BRUNELL	O				86988	44400	29.2	5250		13.3	39.18	55.92
INDIANA	CHERRYHILL	TANK	063-25752	G	3871			168738	113000	<10	13800		922	2019	2196
INDIANA	BURRELL	TANK	063-25556	G	3746			198668	111000	<10	14100	824	704	2575	1866
INDIANA	WHITE	TANK	063-21133	G	3301			121928	58900	<10	7793	216	199	450	313
JEFFERSO	BELL	TANK	065-23083	G	3613									1280	848
MCKEAN	WETMORE	SEP PIT	083-24860	O	2492		38690	36470	18500	1254	2550		0.108	8.34	12.06
MCKEAN	LAFAYETTE	PIT	CURTIS OIL	O										185.28	184.29
SOMERSET	MIDDLECREEK	TANK	111-20049	G	8900	ORISKANY		176876	175000	<10	30000	11900	3470	203	1543
SOMERSET	LINCOLN	TANK	111-20018	G	8560	ORISKANY		182274	175000	<10	22700	7410	1490	1988	499
TIOGA	UNION	DRILL PIT	117-20157	G	DEEP									1137	1457
VENANGO	CORNPLANTER	SEPARATOR	121-23348	O	811		101068	114208	59900	113	7180		5.18	12	30
VENANGO	ALLEGHENY	PIT	BLJ-A-9	O			38018	36282	18050	<10	2420		44.9	54	77
VENANGO	ALLEGHENY	PIT SLUDGE	BLJ-A-9	O										102 pCi/kg	165 pCi/kg
VENANGO	CHERRYTREE	DRILL CUT	121-42962	G	3959	ONONDAGA								1.9 pCi/kg	1031 pCi/kg
VENANGO	CHERRYTREE	DRILL CUT	121-42962	G	3969	ONONDAGA								1.5 pCi/kg	740 pCi/kg
VENANGO	CHERRYTREE	DRILL CUT	121-42962	G	3979	ONONDAGA								1.5 pCi/kg	650 pCi/kg
WARREN	PLEASANT	PIT	DeForest	O			41904	58554	22000	33.2	3840		3.87	34	27
WARREN	PLEASANT	PIT SLUDGE	DeForest	O										153 pCi/kg	296 pCi/kg
WARREN	SOUTHWEST	TANK	123-40354	G	5531	MEDINA		385440	193000	38	47180	1760	3.1	784.64	868.4
WARREN	SOUTHWEST	OILY PIT	CLOSSER	O										13 pCi/kg	7988 pCi/kg
WARREN	WATSON	PIT	PGE DUNN	O			79488	126264	51700	<10	7730		37.4	275	157
WASHINGT	CECIL	SEPARATOR	125-00969	OG	2305		95580	134164	83700	80	8270		3.99	255	456
WESTMORE	WASHINGTON	TANK	129-22382	G	1573			221134	114800	<10	17300		9.87	170	46
WESTMORE	HEMPFIELD	TANK	129-20263	G	1423	VENANGO		402148	158000	<10	23800		177	857	71

BOGM RADIATION SURVEY SPRING, 1991

COUNTY	MUNICIPALITY	FACILITY	PERMIT	WT	WD	HORIZON	SP COND (UMHOS/CM)	TDS (MG/L)	CL (MG/L)	SO4 (MG/L)	CA (MG/L)	SR (MG/L)	BA (MG/L)	RA226 (pCI/L)	RA228 (pCI/L)
DISPOSAL WELLS															
ARMSTRON	KISKIMINETAS	TANKS	DANDO	D	N/A	N/A		232124	113000	<10	16700		597	1895	1157
INDIANA	CHERRYHILL	TANK	YUCKENBURG	D	N/A	N/A		223784	122000	<10	19300		566	1674	1420
BRINE TREATMENT PLANTS															
INDIANA	BURRELL	TANK	PA0095273	T	N/A	N/A		211588	106000	<10	14400	656	883	2069	1555
INDIANA	WASHINGTON	TANK	PA0095443	T	N/A	N/A								287	89
JEFFERSO	HENDERSON	EFFLUENT	PA0101656	T	N/A	N/A								1177	157
JEFFERSO	HENDERSON	BOT SED #1	PA0101656	T	N/A	N/A								4128 pCi/k	1893 pCi/kg
JEFFERSO	HENDERSON	BOT SED #2	PA0101656	T	N/A	N/A								11384 pCi/	5837 pCi/kg
JEFFERSO	HENDERSON	TOP SED #2	PA0101656	T	N/A	N/A								166633 pCi	65815 pCi/k
JEFFERSO	HENDERSON	BOT SED #3	PA0101656	T	N/A	N/A								3858 pCi/k	1822 pCi/kg
POTTER	SHARON	TANK	PA0112623	T	N/A	N/A	27560	30352	12500	180	1550		1.41	14.52	14.26
VENANGO	FRANKLIN	EFFLUENT	PA0101508	T	N/A	N/A		214660	116000	46	26300	1660	24.3	352	153
VENANGO	FRANKLIN	FILTER CAK	PA0101508	T	N/A	N/A								57527 pCi/	54365 pCi/k
VENANGO	SUGARCREEK	EFFLUENT	PA0105279	T	N/A	N/A		149875	92900	30	13500	616	269	1149	865
VENANGO	SUGARCREEK	TANK SLUDG	PA0105279	T	N/A	N/A								1274 pCi/k	434 pCi/kg
WARREN	WARREN	EFFLUENT	EDC BRINE	T	N/A	N/A	51624	163266	77500	135	23600		4.39	411	604
WARREN	WARREN	FILTER CAK	EDC BRINE	T	N/A	N/A								13287 pCi/	16323 pCi/k
MCKEAN	LAFAYETTE	DISCHARGE	MIN RU 4&5	T	N/A	N/A								3.29	7.17
PIPEYARDS															
INDIANA		PIPE SCALE	POOL		N/A	N/A								2691 pCi/k	1334 pCi/kg
INDIANA		PIPE SCALE	MCJUNKIN		N/A	N/A								137081 pCi	7658 pCi/kg
WARREN		PIPE SCALE	NTH PENN	O	N/A	N/A								1361 pCi/k	1055 pCi/kg

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ON THE COVER

An outcrop of the Marcellus shale (see article on page 2), located about 1.8 miles southeast of Milton, Pa. The scale is about 6 inches long. Photograph by Jon D. Inners (Inners, J. D., 1997, Geology and Mineral Resources of the Allenwood and Milton Quadrangles, Union and Northumberland Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Atlas 144cd, p. 37).

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ERRATUM: On page 7 of the previous issue (Pennsylvania Geology, v. 37, no. 3/4), in the first entry of the explanation for Figure 3, the contour interval should be 6 inches.

STATE GEOLOGIST'S EDITORIAL

Shale We Look For Gas?

Recently, you may have noticed articles in the popular press about the abundant riches of gas beneath our feet in Pennsylvania, thanks to the Marcellus shale. Although the Marcellus will probably not be quite as productive as the hype suggests, there is not enough available information to fully evaluate its potential. We often are told that the United States has plenty of oil and gas if only pesky environmental restrictions could be removed and we could drill in Alaska. But peak petroleum production for the United States is past. We can find and produce more, but we are on the downward curve. Even coal, which we have always been taught could keep us warm for hundreds of years, is in shorter supply than we previously thought. The easy stuff (thick beds of Pittsburgh coal) is quickly being mined. In addition, international demand is increasing.

Pennsylvania is, however, faced with another, different kind of opportunity. Rather than producing fossil fuels, we might be able to dispose of waste CO_2 (the process of carbon sequestration), because we have even more capacity for storing waste gases than we do for providing the coal that produces the waste gases. The topic of carbon sequestration was addressed in a previous issue of this magazine (Pennsylvania Geology, v. 34, no. 2, p. 2–9). Here at the Survey we hope to focus much of our energy in the next few years mapping the carbon sequestration potential of the eastern portion of the state, as well as looking at those all-important water resources. All in all, it should be a busy time for us. And with oil at more than $100 per barrel and gold at around $1,000 per ounce, it is an exciting time to be a geologist.

Jay B. Parrish
State Geologist

The Marcellus Shale—An Old "New" Gas Reservoir in Pennsylvania

by John A. Harper
Bureau of Topographic and Geologic Survey

WHAT'S ALL THE FUSS? Black, organic-rich shales are common constituents of sedimentary deposits formed throughout geologic time. In Pennsylvania, black, organic-rich shales can be found in almost all of the Paleozoic systems, as well as in the Triassic rocks of the Newark and Gettysburg basins in the southeast. Some of these shales are the sources of the crude oil and natural gas found in Pennsylvania's sandstone and carbonate reservoirs. One shale unit in particular, the Middle Devonian Marcellus Formation (see front cover), has recently become a hot item with the nation's oil and gas industry, as well as with the news media. One would think, from all the fuss about the Marcellus, that it was a newly discovered gas reservoir containing enough gas to sustain America's needs for decades. In reality, the Marcellus has been a known gas reservoir for more than 75 years. What has made it newsworthy, besides much hyperbole, is that the oil and gas industry has both new technology and price incentives that make this otherwise difficult gas play economical.

FIRST, SOME HISTORY. Natural gas has been part of our heritage for more than 200 years. Gas, along with crude oil, was found in numerous wells dug or drilled for salt water in colonial times. The first well drilled specifically to produce natural gas in North America was completed in Devonian shales. Citizens of Fredonia, N. Y., noticed gas bubbling up through the bed of Canadaway Creek, and someone had the foresight to sink a well to collect the gas and use it to light the town in 1821, 38 years before Drake drilled his famous oil well at Titusville, Pa. The Fredonia well was only 27 feet deep, but it produced enough gas to provide the light equivalent of "two good candles." In 1850, the well was deepened to 70 feet and produced enough gas to light 200 burners. In 1858, a second well was drilled to more than 200 feet, and the gas lasted another 30 to 35 years.

As a result of the Fredonia wells, a flurry of drilling activity commenced along the Lake Erie shoreline, eventually reaching at least as far as Sandusky, Ohio. The gas came from black, organic-rich shales and from fractured shales and siltstones above and interbedded with the black shales. Typically, the wells were 1,000 feet deep or less, and many were producing from as shallow as 25 or 30 feet. By the beginning of the twentieth century, just about every backyard and manufacturing plant within a mile of the Lake Erie shore in Pennsylvania had at least one gas well that kept the house or business reasonably well lighted and heated. The wells had unreliable pressures that varied with changes in the weather—when a cold front came through, it was time to break out the wood stove. However, the wells seemed to last forever. Many of the backyard wells drilled in the early part of the twentieth century are still providing gas to residents of Erie County.

In the 1930s, the oil and gas industry began finding large commercial quantities of natural gas in the Lower Devonian Oriskany Sandstone in New York and Pennsylvania. As companies were drilling to this target, their wells penetrated the black shales of the Marcellus Formation, situated a few tens to a few hundreds of feet above the Oriskany. Just about every well had a strong flow of gas that shut down drilling for several days. The Marcellus fascinated the industry until it became clear that the gas occurred in "pockets" and that the flows could not be sustained. These gas flows died down quickly, and the drillers soon began to ignore them when they encountered them. Everyone knew there was gas in the Marcellus, but the consensus was that there was not enough to make a well.

Following the energy crisis of 1973, the onset of energy shortages and the subsequent increase in natural gas prices spurred the U.S. Department of Energy to fund a multistate cooperative program called the Eastern Gas Shales Project (EGSP) that spanned the Appalachian, Illinois, and Michigan basins. The two purposes of the project were to determine the extent, thickness, structural complexity, and stratigraphic equivalence of all Devonian organic-rich shales throughout the basins; and to develop and implement new drilling, stimulation, and recovery technologies to increase production potential. Geological teams correlated and mapped the rocks; geophysical teams worked on new technologies to locate fracture systems and potential reservoirs; geochemical teams investigated ways to modify the shale matrix to increase gas flow; engineering teams derived and tested models of various fracturing techniques and directional drilling procedures; and oil and gas companies drilled and cored numerous test wells in each of the states involved in the project. Five wells were drilled in Pennsylvania (Figure 1), and cores were collected of

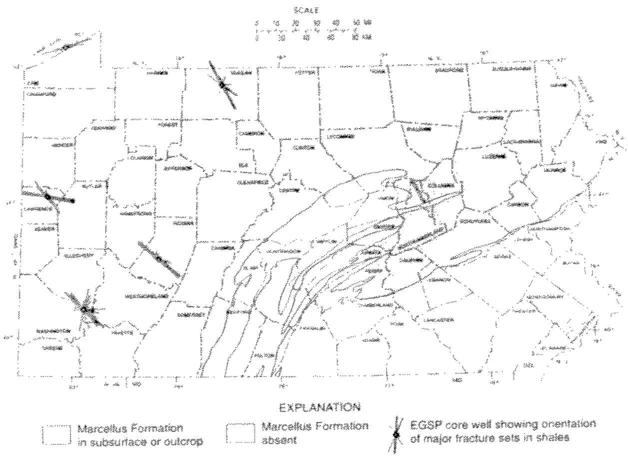

Figure 1. Map showing the general distribution of the Marcellus Formation in Pennsylvania. Also shown are the locations of five wells drilled and cored during the Eastern Gas Shales Project (EGSP) study of the 1970s and 1980s. Orientations of measured fractures are shown (fracture data from Evans, 1994).

the Devonian shales in each that provided a wealth of data about bedding, mineralogy, fracture systems, and so forth.

I was part of the Pennsylvania Geological Survey team that spent several years doing basic mapping and correlation. The end products included numerous cross sections, maps, and technical reports (e.g., Piotrowski and Harper, 1979) showing formation thickness, net feet of organic-rich shales, and net feet of clean sandstone throughout the entire Middle and Upper Devonian sequence in western and north-central Pennsylvania. We determined that the Devonian organic-rich shales could be important gas reservoirs, at least in northwestern Pennsylvania where they were both thick and close to the surface. These shales were thought to have excellent potential to fill the needs of users, especially if the expected development of better technology for inducing and enhancing fracture systems that is so important to sustain production in shale came about. The deeper shales, particularly the Marcellus Formation, were considered to be much less attractive targets and would remain so until gas prices increased and technology advanced enough to make drilling and completion competitive with more conventional targets. Neither occurred until recently.

The furor over the Devonian shales faded during the early 1980s due to low gas prices and lack of sufficiently useful technologies for extracting the gas. The complete EGSP library, which has remained relatively obscure because of the lack of interest, is quite extensive and includes a wealth of physical, chemical, geological, and engineering information. Much of it can be found in the National Energy Technology Laboratory's compendium of natural gas archives (National Energy Technology Laboratory, 2007), which is available at no cost from the U.S. Department of Energy. In addition, summaries have been published over the years, such as that by Roen and Kepferle (1993), which provide very useful information on the shales. Anyone interested in finding out more about Devonian shales as gas reservoirs should consult these publications.

Within the last three to four years, as a result of a combination of higher prices, recent technological advances, and the development of large gas resources from black shales in other parts of the country, the interest in Pennsylvania's organic-rich shales has risen once again to a fever pitch within the state's oil and gas industry. This is particularly true for the Marcellus Formation, which lies beneath much of Pennsylvania (Figure 1). Some companies are paying incredible fees for leases, while others are spending enormous amounts of money to drill Marcellus gas wells across the state, from Greene County in the southwest to Wayne County in the northeast. All of this activity has been exciting the press, landowners, and state and municipal authorities, who look upon the Marcellus as a major economic boon for Pennsylvania.

RADIOACTIVITY = ORGANIC RICHNESS = GAS. The oil and gas industry uses a number of geophysical logging tools to characterize the subsurface rocks. The most commonly run logging tool in the Appalachian basin, the gamma-ray log, is a very sensitive Geiger counter that measures the natural low-level radioactivity inherent in almost all sedimentary rocks. Most of the radiation emitted by these rocks is due to the radioactive potassium isotope (potassium-40) found in feldspars, micas, clay minerals, and other common and abundant silicate minerals. On gamma-ray logs, shales can be differentiated from other rocks such as clean sandstones and limestones because shales have higher concentrations of potassium-40-bearing minerals.

Organic-rich shales have higher radioactivity responses than typical shales because the organic matter tends to concentrate uranium ions that otherwise would be scattered throughout the sediment (Adams and Weaver, 1958; Schmoker, 1981). As a result, many organic-rich shales have uranium and thorium contents that are greater than 10 parts per million and that may approach 100 parts per million, which will show up on a gamma-ray log as higher-than-normal gamma-ray responses (Figure 2). Comparisons of gamma-ray logs with drill cuttings show a fairly strong correlation between higher-than-normal radioactivity and black color in shales, derived from the organic content. To put it simply, black coloration generally correlates with organic richness, which correlates with high gamma-ray response.

The icing on the cake, so to speak, was the number of studies done during and after EGSP that indicated an empirical relationship between high gamma-ray response and both gas production and total gas content in organic-rich shales. In other words, higher-than-normal gamma-ray response also equates to gas-production potential. The correlation might not be 100 percent, but it is very high. This is a very important concept for those looking to produce shale gas. Many companies would look for places where the entire formation is thick, but they should actually be looking for where it is most rich in organic matter. When we mapped the Devonian formations during EGSP, we created maps showing the net feet of shale having higher-than-normal radioactive signatures on gamma-ray logs (equivalent to net feet of organic-rich shale) (e.g., see back cover). It is my belief that these maps are far more accurate for finding good sources of natural gas than just mapping formation thickness.

THE MEEK SHALE INHERIT THE EARTH. The Devonian shales in Pennsylvania occur at and near the base of a thick sequence of intercalated marine, transitional, and continental rocks known as the Catskill clastic wedge. This sequence is more than 10,000 feet thick in eastern Pennsylvania but thins to about 2,000 feet along the Lake Erie shoreline (Colton, 1970). Pennsylvania's thick sequence of Devonian shales can be divided into organic-rich black shale facies and not-so-organic-rich gray shale and siltstone facies (Figure 2). This sequence is capped by the sandstone-rich portion of the Upper Devonian that has been the "bread and butter" of the oil and gas industry in this state for 150 years.

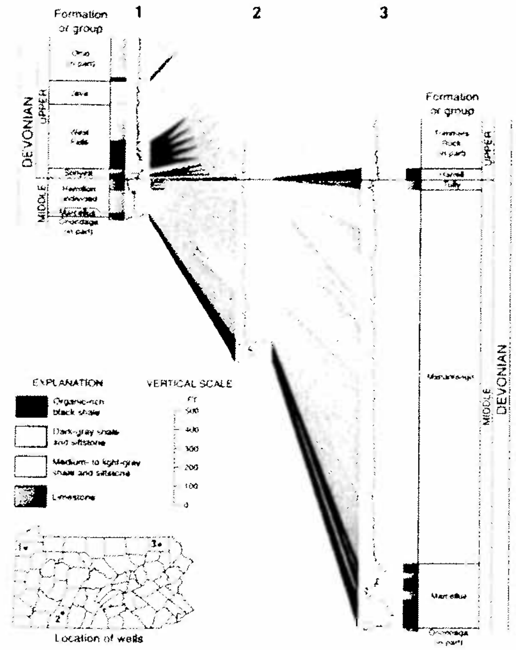

Figure 2. Correlation of Middle and Upper Devonian organic-rich shale facies and interbedded strata in three wells in Pennsylvania, based on gamma-ray log signatures (the jagged purple lines) and descriptions of well cuttings. Note that the black shales correspond in large part to higher than normal gamma-ray readings (radioactivity increases to the right in all log signatures).

The three most important organic-rich shales include the black shale facies of the Middle Devonian Marcellus Formation and of the Upper Devonian West Falls Formation and Ohio Shale (the Rhinestreet and Huron facies, respectively) (Figures 2 and 3). All have been explored at one time or another as natural gas reservoirs. Three less

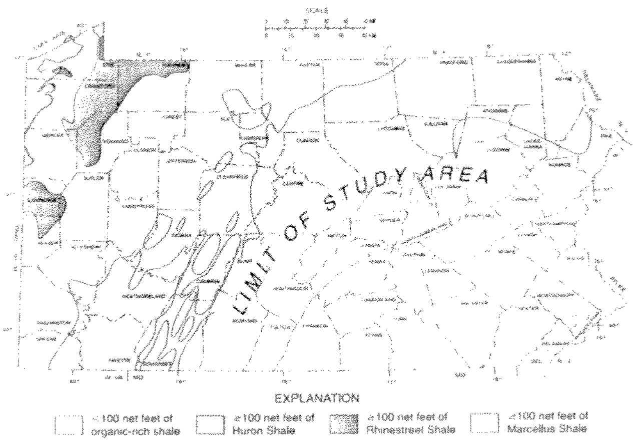

Figure 3. Distribution of the thickest sequences of organic-rich shale in the Ohio Shale, West Falls Formation, and Hamilton Group (Huron, Rhinestreet, and Marcellus facies, respectively) (based on Piotrowski and Harper, 1979, and Harper and Abel, 1980).

important units include the Upper Devonian Harrell (and partially equivalent Genesee), Sonyea, and Java Formations (Figure 2). All of the organic-rich shales, plus the associated gray shales and siltstones that overlie and intercalate with them, participate as the reservoir for the shale-gas production along the margin of Lake Erie. A system of fractures in these shales constitutes the most important part of the reservoir by providing porosity and permeability that allows the gas to leak slowly from the rock.

QUO VADIS, MARCELLUS? The Marcellus Formation underlies most of Pennsylvania (Figure 1), but the organic-rich portion reaches its maximum development in the northeastern part of the state (see back cover). Despite the long history of gas shows in the Marcellus, it took until recently for its potential as a commercial gas target to attract attention.

By standard definition for mapping purposes, the Marcellus Formation in Pennsylvania typically is defined as the black shales at the base of the Middle Devonian Hamilton Group; the upper part of the group is occupied by gray and dark-gray shales, siltstones, and (to the east) sandstones of the Mahantango Formation (Figure 2). The organic richness (i.e., the black coloration) within the Hamilton Group in the subsurface varies from place to place so that the Marcellus/Mahantango boundary fluctuates. Piotrowski and Harper (1979, Plate 3) showed that the Hamilton Group as a whole thickens fairly regularly from northwest to southeast. However, the net feet of higher-than-normal radioactive shale in the Hamilton Group—the Marcellus facies—has an interesting configuration (Piotrowski and Harper, 1979, Plate 4). The Marcellus generally thickens to the east, as expected, but throughout the eastern half of the Appalachian Plateaus physiographic province as far north as Tioga County, it also develops into a series of linear thick areas situated on the crests of anticlines (see back cover). Some of this thickening can be explained by repetition of the section through faulting, but close correlation of logs along and across the anticlines also indicates that, for some reason, more of the Hamilton Group rock section becomes organic rich over these structures.

Pennsylvania's Marcellus shale play began in 2003, when Range Resources–Appalachia, LLC (formerly Great Lakes Energy Partners, LLC) drilled a well to the Lower Silurian Rochester Shale in Washington County. The deep formations (such as the Oriskany Sandstone and the Lockport Dolomite) did not look favorable, but the Marcellus shale had some promise. Range drilled some additional wells, and through experimentation with drilling and hydraulic fracturing techniques borrowed and revised from those used on the Mississippian Barnett Shale gas play in Texas, began producing Marcellus gas in 2005. Since then, the company has permitted more than 150 Marcellus wells in Washington County alone. Other companies have joined the fray with permitting and drilling in many areas of the Appalachian Plateaus in Pennsylvania. As of the end of 2007, more than 375 suspected Marcellus wells had been permitted in Pennsylvania. An additional 78 had been permitted as of this writing (end of February, 2008). Therefore, it appears that the Marcellus gas play will continue until and unless gas prices fall dramatically.

IT'S ALL ABOUT THE FRACTURES. Conventional gas reservoirs, such as the Lower Devonian Oriskany Sandstone, contain gas in pore spaces between the sand grains. The gas migrated into the rock from one or more source rocks during the Alleghanian orogeny about 250 million years ago. Organic-rich shales, however, are their own source rocks, and gas molecules generated from the organic matter adsorb onto the organic matrix of the rock. Over time, with the development of fractures of all sizes and orientations (Figure 1) due to a variety of tectonic and hydraulic stresses, some of the gas desorbed from the matrix and migrated into these fractures. It was these pockets of gas that the early drillers tapped. Because desorption takes place relatively slowly, the fractures could not be refilled quickly enough to maintain a constant flow, so drilling continued past this potential reservoir and commercial quantities were found in deeper conventional reservoirs. The natural fractures are neither numerous nor extensive enough to maintain production except in certain areas of Kentucky, West Virginia, Ohio, and along the Lake Erie shore.

Since the early 1960s, Pennsylvania's oil and gas industry has used hydraulic fracturing (fracing, pronounced "fracking") to enhance the recovery of oil and natural gas. This involves pumping a fluid such as water or kerosene and, usually, sand or some other granular material into the producing formation under high pressure until the rock cracks. The process enhances the porosity and permeability of the rock, and the granular material (the propant) serves to prop open the newly created fractures. As a result, the surface area of the rock increases, allowing gas to travel more readily from the pores to the well bore.

Shales are different than conventional hydrocarbon reservoirs. They have extremely low permeabilities and do not accept frac jobs as readily. During EGSP, petroleum engineers modeled many types of frac jobs trying to find the right combination of fluids, propants, and pressures to maximize production in shales. But it was not until development of the Barnett Shale play in the 1990s that a technique suitable for fracing shales was developed. This technique is called a "slick-water frac" and consists of sand and very large volumes of freshwater that has been treated with a friction reducer such as a gel. Slick-water fracs maximize the length of the fractures horizontally while minimizing the vertical fracture height, resulting in greater gas mobility and more efficient recovery of a larger volume of the gas.

Another technique that has become useful in producing Marcellus gas is horizontal drilling. The first horizontal well was drilled in Texas in 1929, but it took until the 1980s for the technology to be improved enough to become a standard industry practice. The technology involves drilling a vertical hole to several hundred feet above the target reservoir, then directing the drill bit through an arc until it is literally drilling sideways instead of downward (Figure 4). This has several advantages: (1) it increases the amount of reservoir penetrated

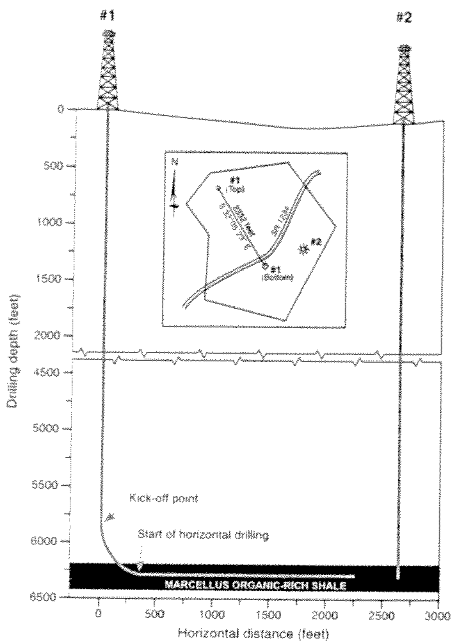

Figure 4. A comparison between a horizontal well and a typical vertical well drilled to the Marcellus organic-rich shales. The horizontal well has the advantages of turning a relatively thin reservoir into a very thick one, and of being certain to intersect a larger number of fractures. The inset map shows a hypothetical lease and the two wells. Note that this map shows the locations of both the top and bottom of the horizontal well and the course and distance between them.

from perhaps a few tens of feet to as much as 3,000 or 4,000 feet; (2) it increases the number of fractures penetrated; and (3) it can be used to develop hydrocarbon resources beneath sensitive areas such as wetlands and cities where a drilling rig cannot be set up. A slick-water frac in a vertical Marcellus well uses from 500,000 to more than 1,000,000 gallons of water (a typical sandstone frac job uses only about

5,000 to 50,000 gallons). A slick-water frac in a horizontal Marcellus well will probably use several million gallons of water. Based on information from the Barnett Shale play, a horizontal well completion might use more than 3 million gallons (so far, I have not seen a well record involving a horizontal shale completion in Pennsylvania).

BUT IS IT REALLY WORTH IT? During EGSP, the U.S. Geological Survey estimated that the Marcellus contains about 295 trillion cubic feet (Tcf) of gas-in-place in the Appalachian basin (Charpentier and others, 1993). Figuring a recovery of 3 to 5 percent, that means 9 to 15 Tcf is recoverable throughout the basin. Briggs and Tatlock (1999) assessed Pennsylvania's natural gas resources and estimated that the Devonian shales could potentially produce 8.4 Tcf within the state, which is in line with the lower estimate of Charpentier and others (1993). A more recent assessment of the Devonian shales in the Appalachian basin (Milici and Swezey, 2006) determined that these shales contain 31.4 Tcf of recoverable gas. Of course, none of these estimates took into consideration today's prices and technologies. One very recent estimate indicates that the Marcellus has more than 500 Tcf of gas in place with about 50 Tcf recoverable (Smeltz, 2008). Whether any of these estimates is reasonable remains to be seen.

The true value of the Marcellus organic-rich shale as a gas reservoir has yet to be determined. Cabot Oil and Gas Corporation, which is leasing and drilling in northeastern Pennsylvania, has been quoted as saying its wells are testing between 800,000 and 1,000,000 cubic feet per day (IHS, 2008, p. 1). Based on the limited production information that has been received by the state so far, the average daily production from a Marcellus well in Pennsylvania is about 45 thousand cubic feet of gas per day, which is considered marginal at best. It should be noted that this average is based on only two years' data from relatively few vertical wells. We still do not have any details from horizontal shale wells. Only time (and more data) will determine just how productive and lucrative the Marcellus play is. It is possible that the Marcellus will ultimately turn out to be the great gas reservoir everyone is fussing about.

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Meet the Staff—Part 6

In Part 6 of "Meet the Staff," we learn about the GIS Services area of the Survey. One of the staff members, John Barnes, also works in Laboratory and Geochemical Services and was previously introduced in Part 4 of this series (see Pennsylvania Geology, v. 37, no. 2, p. 16–18). The other staff are introduced below.

GIS SERVICES. The GIS Services section was created in 2001 to integrate the expanding capabilities of geographic information systems (GIS) and companion digital technologies, such as global positioning systems (GPS), into the daily operations of the agency. In addition to providing cartographic support to other geologic staff, the GIS Services staff also use the analytical capabilities of GIS technology to present complex geologic relationships more clearly. Studies within the state have included such topics as the occurrence of acid-producing minerals, density of karst features, and delineation of physiographic units.

Looking to the future, the statewide imagery and lidar-derived elevation data being generated by the PAMAP program will be used in GIS projects to better define the topography and geology of Pennsylvania. Initially, the level of detail in these data will require that GIS Services staff redefine many fundamental datasets, such as watershed boundaries and stream reaches across the state.

Michael E. Moore. After receiving his B.S. degree in geological sciences in 1975, Mike spent most of the next 11 years working as a consultant for the bituminous coal industry and as a staff geologist for coal-mining companies.

Mike Moore

In June of 1986, he began his tenure at the Survey as a hydrogeologist, working on water-resource investigations. In 1989, Mike was promoted to Chief of the Groundwater Geology Section (now Groundwater Services) and thereby assumed responsibility for supervising water research and policy programs. Eventually, he also administered the Survey's water-well drillers licensing and records programs. Under Mike's watch, the web applications for the collection of data for new wells and access to data for existing wells were created.

As a consequence of a bureau reorganization in 2001, Mike accepted the challenge of supervising the newly created GIS Services section, where he was provided with the opportunity to implement his career-long interest in the application of digital technology in the earth sciences. Since then, Mike and his staff have provided cartographic, spatial analysis, and database services to individuals both inside and outside the Department of Conservation and Natural Resources (DCNR).

Victoria V. Neboga. Victoria Neboga is a native of Kiev, Ukraine, where she earned a master's degree in hydrogeology and engineering geology in 1985. Her first job was as a geologist in the Institute for Projecting Enterprises, Bureau of Geologic Investigations, assisting the Ukrainian sugar industry. Victoria's career with the commonwealth

Victoria Neboga

started in December 2002 in the Department of Labor and Industry, Center for Workforce Information and Analysis, where she produced statistical reports.

Victoria joined the Survey in May 2005, and her first task was to learn GIS software and principles. Now, as a Geologic Scientist, she creates both digital and hard-copy cartographic products that characterize the natural resources of Pennsylvania. Her assignments include working in cooperation with other staff geologists to produce geologic maps and related GIS datasets that are released as Survey open-file reports. Most of these projects are part of the STATEMAP component of the U.S. Geological Survey's National Cooperative Geologic Mapping Program.

As time permits, Victoria also works on a GIS database that will define more than 500 landforms within Pennsylvania. This project benefits from high-resolution imagery as well as lidar-derived elevation data from the PAMAP program. Most recently, Victoria used her GIS skills to create a sophisticated interactive index map that helps DCNR employees identify which of more than 13,000 PAMAP tiles are relevant to their project areas.

Stuart O. Reese. Stuart, a Senior Geologic Scientist, arrived at the Survey in March 2002. Prior to that and after receiving his M.S. degree in geology in 1986, he spent several years working as a hydrogeologist, first at Wright-Patterson Air Force Base in Dayton, Ohio, and then at a Camp Hill, Pa., consulting firm. He went on to serve 10 years with the Pennsylvania Department of Environmental Protection (DEP) in their groundwater protection program. While at DEP, Stuart acquired a strong interest in a newly emerging tool—GIS. When a position opened at the Survey, he applied and was hired to work in the GIS Services area.

Stuart Reese

As part of his bureau duties, Stuart utilizes GIS software not only to make digital maps (such as the STATEMAP products), but also to analyze data associated with concerns ranging from environmental hazards to the DCNR TreeVitalize programs. Some of his work on environmental hazards resulted in the online reports Map 68 and Map 70, which he coauthored with fellow staff geologist Bill Kochanov. These maps use gradational colors to show the concentration of karst features (mostly sinkholes and closed depressions).

Part of Stuart's time is spent on work outside of GIS Services. He was responsible for the Survey's web site for a few years and still maintains several web pages. And although he is not formally assigned to Groundwater Services, Stuart often assists in that area.

Thomas G. Whitfield. Tom has a B.S. in geology and did graduate work in mining technology and borehole geophysics. He started his career as a well-log analyst and completion consultant for two geophysical well-logging companies in the oil and gas fields of western Pennsylvania. He then worked for U.S. Steel Corporation as comanager of their midwestern field office, doing coal-exploration projects for nearly 6 years. In 1986, Tom joined the DEP Bureau of Oil and Gas Management, where he helped implement the program to plug orphaned and abandoned wells.

Tom started with the Geologic Mapping Division of the Survey in March 1991. After about a year, he volunteered to try a new technology called "GIS." In the fall of 1992, Tom became the first full-time GIS person in the Survey and soon after set to work as a key member of the team digitizing the 1:250,000-scale Geologic Map of Pennsylvania and compiling the Bedrock Geology of Pennsylvania dataset. As a Senior Geologic Scientist in GIS Services, Tom works on various GIS projects, including the previously mentioned STATEMAP products. He also works with the technical aspects of PAMAP imagery and lidar-derived digital elevation models. He recently developed a raster-seam conflation tool that repairs seam lines in raster mosaics.

Tom Whitfield

Tom also has an unusual hobby. He is a certified emergency medical technician (EMT) with 28 years of experience, and he volunteers with a local ambulance service. The Survey benefits from Tom's expertise in this area, as he chairs our "Fire and Panic Committee" and educates the staff on how best to handle life-threatening emergencies.