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Itzchak E. Kornfeld
Hebrew University of Jerusalem

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GEOLOGY, THE MARCELLUS SHALE, EXPERTS, AND DISPUTE RESOLUTION

*Itzchak E. Kornfeld**

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* Ph.D. in Law (Hebrew University). Girardi Fellow, Faculty of Law, The Hebrew University of Jerusalem, Jerusalem, Israel. The author worked as a geologist for a major oil company and as a geologist and landman for independent exploration and production companies. As a geologist, he supervised the fracking of wells in Alabama's Black Warrior Basin, the Haynesville Formation of East Texas and North Louisiana, and the Utica Shale of Ohio. He has advised the legal staff of the Israel Ministry of the Environment regarding natural gas development and regulation, and is currently associated with Lumina Geophysical, Houston, Texas, and London, U.K.

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I. INTRODUCTION

Fracking,[1] AKA hydro-fracking or slickwater fracking, particularly in the Appalachian Basin, has yielded a good deal of legal scholarship. These articles have addressed a host of issues.[2] However, that scholarship has yet to consider an indispensable topic: the science that underlies and controls the fracking process, and how it fits within the framework of dispute resolution. The present Article seeks to fill that void by laying out a number of geological principles that undergird oil and gas development and wedding them to legal doctrinal concepts, specifically those that involve dispute resolution and the use of experts.

Indeed, as in any discussion of the environment or oil and gas exploration and production, knowledge of the geology of the subsurface terrain

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[1] ASS'N OF AM. ST. GEOLOGISTS, HYDRAULIC FRACTURING (2012), *available at* http://www.stategeologists.org/temp/AASG%20Hydraulic%20Fracturing%20statement.pdf ("Hydraulic fracturing as applied in the oil and gas industry (commonly referred to as 'fracking,' 'fracing,' or 'hydrofracking' [or slickwater fracking]) is the process of pumping a mixture of water, sand or similar material, and chemical additives, under high pressure, to create small interconnecting fractures to increase permeability in targeted subsurface rock formations. Oil and gas companies perform hydraulic fracturing after a well is drilled, cased, and cemented to increase the well's productivity. Sand is used to prop open the fractures, and chemical additives reduce friction, control bacteria, decrease corrosion, and serve other purposes."); *see also* T. W. Phillips Gas & Oil Co. v. Jedlicka, 42 A.3d 261, 261 n.1 (Pa. 2012); *Water: Hydraulic Fracturing, Hydraulic Fracturing Background Information*, U.S. ENVTL. PROT. AGENCY, http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_hydrowhat.cfm (last updated May 9, 2012).

[2] *See, e.g.*, Keith B. Hall, *Hydraulic Fracturing Contamination Claims: Problems of Proof*, 74 OHIO ST. L.J. FURTHERMORE 71 (2013) (addressing the problems of proof of contamination claims, causes of alleged contamination and *Lone Pine* orders); Jeffrey C. King et al., *Factual Causation: The Missing Link in Hydraulic Fracture—Groundwater Contamination Litigation*, 22 DUKE ENVTL. L. & POL'Y F. 341 (2012) (hydraulic fracturing and groundwater contamination litigation); Thomas W. Merrill & David M. Schizer, *The Shale Oil and Gas Revolution, Hydraulic Fracturing, and Water Contamination: A Regulatory Strategy*, 98 MINN. L. REV. 145 (2013) (addressing how to regulate this risk of water contamination); Hannah Wiseman, *Regulatory Adaptation in Fractured Appalachia*, 21 VILL. ENVTL. L.J. 229 (2010) (examining the adaptation of state regulation in addressing fracking, and arguing that regulations must be modified to meet the new challenges); Travis Zeick, Note, *Hydraulic Fracturing Goes to Court: How Texas Jurisprudence on Subsurface Trespass Will Influence West Virginia Oil and Gas Law*, 112 W. VA. L. REV. 599 (2010).

is essential. For example, if a well's casing is not cemented[3] correctly, or if a cement bond survey[4] is faulty, a series of experts, including a cementing engineer or cement scientist,[5] and a geologist,[6] will need to demonstrate to the trier of fact what the proper cementing methodology or standard is,[7] and whether it was followed. Similarly, if a plaintiff seeks medical monitoring as a consequence of a well operator's actions, which may cause or have caused a plaintiff to become ill, experts in geochemistry, epidemiology, among others, will be required;[8] or if a plaintiff asserts a claim for negligence or negligence

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[3] *Cementing*, HALLIBURTON, http://www.halliburton.com/en-US/ps/cementing/cementing-services.page?node-id=hdhdvbxs (last visited Feb. 28, 2014) ("Successful primary cementing operations result in a cement sheath to bond and support casing and provide zonal isolation. Good zonal isolation helps prevent the loss of production, control inter-zonal flow and/or flow to the surface, reduce water production and improve confinement of stimulation treatments."). Casing is "steel pipe placed in an oil or gas well to prevent the wall of the hole from caving in, to prevent movement of fluids from one formation to another and to aid in well control." *Oil and Gas Well Drilling and Servicing eTool*, OCCUPATIONAL SAFETY & HEALTH ADMIN. (2001), https://www.osha.gov/SLTC/etools/oilandgas/glossary_of_terms/glossary_of_terms_c.html.

[4] OCCUPATIONAL SAFETY & HEALTH ADMIN., *supra* note 3 ("Cement Bond Survey: an acoustic survey or sonic-logging method that records the quality or hardness of the cement used in the annulus [the space around a pipe in a well bore] to bond the casing and the formation. Casing that is well bonded to the formation [of the rock surrounding the borehole that the casing is run through] transmits an acoustic signal quickly [because it is solid]; poorly bonded casing transmits a signal slowly.").

[5] *See generally* Rorem v. Halliburton Oil Well Cementing Co., 246 F.2d 427 (5th Cir. 1957) ("The 'squeeze' comes from the fact that by the use of a device (packer) that part of the oil well hole where a leak exists can be sealed off to permit introduction of cement slurry under high pressures (1,000 psi [pounds per square inch] or more) to force it into the fracture for hardening as a permanent closure."); Tona Kunz, *The Formula for Turning Cement into Metal*, ARGONNE NAT'L LAB. (May 27, 2013), http://www.anl.gov/articles/formula-turning-cement-metal.

[6] Ensco Offshore Co. v. Salazar, No. 10-1941, 2011 WL 121936, at *11 n.4 (E.D. La. Jan. 13, 2011), *vacated in part*, 781 F. Supp. 2d 332 (E.D. La. 2011) ("The engineering review consists of, but is not limited to, a review of the proposed drilling procedure, well location, and directional program; *geological and geophysical hazards*; pore pressure and fracture gradient of the subsurface environment; wellbore design and schematic; design calculations for pressure containment during drilling and completion; cement volumes; and testing pressures for the well control equipment, casing, and casing shoe." (emphasis added)).

[7] *See, e.g.*, Sinclair Oil & Gas Co. v. Bishop, 441 P.2d 436, 445 (Okla. 1967) ("Lessees' expert evidence in this regard, was that the bottom two feet perforated was in a section which was low in permeability and in porosity and that it was sufficiently tested; *one further reason for perforating and testing this two foot section was to determine whether the cement of the casing was sufficient* . . . ." (emphasis added)).

[8] *See, e.g.*, Fiorentino v. Cabot Oil & Gas Corp., 750 F. Supp. 2d 506, 513 (M.D. Pa. 2010) ("Plaintiffs have alleged that Defendants negligently drilled wells and engaged in hydraulic fracturing that uses 'fracking fluid',[sic] the composition of which 'includes hazardous chemicals that are carcinogenic and toxic.' Further, Plaintiffs allege that Defendants utilized other materials, such as diesel fuel, lubricating agents, and defoaming agents that likewise consist of hazardous chemicals. [However, in order to prove these allegations, expert testimony will be

per se a series of experts—including geologists or geological engineers—will need to testify regarding the defendant's deviation from its duty and any subsequent breach.[9] Finally, experts in geology, hydrogeology and hydrological modeling[10] are needed in actions claiming fracking-related water contamination.[11]

Consequently, I posit that understanding the geology, reservoir characteristics, and science behind the fracking process is critical for a number of simple but fundamental reasons. These include the following: (1) analyzing pooling and unitization issues;[12] (2) the assessment of claims asserting subsurface trespass as a consequence of the fracking process; (3) liability issues; (4) claims of water contamination; and (5) gauging whether the opinions of experts in geology and petroleum engineering are sound.[13]

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required]."); Redland Soccer Club, Inc. v. Dep't of the Army, 696 A. 2d 137, 145–46 (Pa. 1997) (identifying seven elements that a plaintiff must establish in order to prevail on a claim for medical monitoring, noting that "[p]roof of these elements *will naturally* require expert testimony" (emphasis added)).

[9] *See, e.g.*, *Fiorentino*, 750 F. Supp. 2d at 515.

[10] *See, e.g.*, Aransas Project v. Shaw, 930 F. Supp. 2d 716, 748 (S.D. Tex. 2013) (opinion "was offered without objection as an expert on circulation, salinity, distribution, hydrology and modelling."); Oppliger v. Vineyard, 803 N.W.2d 786, 798 (Neb. Ct. App. 2011) ("[H]e has worked for several companies doing "hydrology, hydraulics, sediment transport, modeling river analysis . . . ."); Robert Jerome Glennon & Thomas Maddock, III, *The Concept of Capture: The Hydrology and Law of Stream/Aquifer Interactions*, 43 ROCKY MTN. MIN. L. INST. 22, n.155 (1997) ("The *science of hydrology has become extraordinarily sophisticated, incorporating computer modeling* and other available techniques to provide extremely accurate answers to what, even fairly recently, would have been unanswerable questions." (emphasis added)).

[11] *See, e.g.*, Beaverkettle Farms, Ltd. v. Chesapeake Appalachia, LLC, No. 4:11CV02631, 2013 WL 4679950, at *7 (N.D. Ohio Aug. 30, 2013) ("Beaverkettle expressed 'considerable anxiety about potential fracking accidents given the sensitive location of the' Tharp Unit and requested that Chesapeake provide 'written assurances of safety measures that would provide better assurances against fracking failure and contamination of the Little Beaver Creek Watershed.'"); Ctr. for Biological Diversity v. Bureau of Land Mgmt., 937 F. Supp. 2d 1140, 1148 (N.D. Cal. 2013) ("Although so far there was no direct evidence of contamination of drinking water due to fracking there is potential risk for contamination because fracking brings certain fluid chemicals and naturally occurring materials in the geologic formation to the surface where it could mix with water sources . . . ."); *In re* Lipsky, No. 02-12-00348-CV, 2013 WL 1715459, at * 1 (Tex. App. Apr. 22, 2013) ("Property owner and his wife brought action against natural gas drilling company to recover for alleged contamination of their water well.").

[12] *See generally* Kevin L. Colosimo & Daniel P. Craig, *Compulsory Pooling and Unitization in the Marcellus Shale: Pennsylvania's Challenges and Opportunities*, 83 PA. B. ASS'N. Q. 47 (2012); Bruce M. Kramer, *Compulsory Pooling & Unitization: State Options in Dealing with Uncooperative Owners*, 7 J. ENERGY L. & POL'Y 255 (1986).

[13] One assumes that the threshold for expert testimony required by the *Daubert* standard, or its state equivalents, on the admissibility of expert witness testimony will be required. *See* Daubert v. Merrell Dow Pharm., 509 U.S. 579 (1993); *see also* Gen. Elec. Co. v. Joiner, 522 U.S. 136 (1997); *In re* Paoli R.R. Yard PCB Litig., 35 F.3d 717 (3d Cir. 1994) (amplifying *Daubert*).

Before moving on, I wish to make clear two points. First, the fracking process is controlled by the geology of the fracked shales—which are not uniform or homogeneous either laterally or vertically. Second, the process of fracking, particularly in the Northeast's Marcellus[14] and Utica shale formations, but also in north Texas's Barnett Shale, has been the subject of intense controversy and debate over the past decade.[15] Indeed, fracking has spawned a stream of litigation. For purposes of this Article the focus of that litigation will be the Marcellus Shale.[16]

Furthermore, as litigation over the previously discussed issues increases, courts and lawyers will need to understand what occurs in the subsurface and why. They will also have to familiarize themselves with the

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> [T]he recent revival in Marcellus exploration began in 2004–2005 when Range Resources-Appalachia introduced two key drilling and treatment technologies that had previously been developed for the Barnett play of Texas: horizontal wells and slickwater fracturing. The initial reports announced a spectacular success in Pennsylvania, kicking off a new shale-gas play.

KATHY R. BRUNER & RICHARD SMOSNA, NAT'L ENERGY TECHNOLOGY LABORATORY, DOE/NETL-2011/1478, A COMPARATIVE STUDY OF THE MISSISSIPPIAN BARNETT SHALE, FORT WORTH BASIN, AND DEVONIAN MARCELLUS SHALE, APPALACHIAN BASIN 37 (2011), *available at* http://teamfrack.pbworks.com/w/file/fetch/46422820/DOE-NETL-2011-1478%20Marcellus-Barnett.pdf.

[15] *See, e.g.*, SEAMUS MCGRAW, THE END OF COUNTRY: DISPATCHES FROM THE FRACK ZONE (2012); Bill Toland, *Deep in the Heart of the Gas Drilling Controversy: What Have Texans Learned?*, PITTSBURGH POST-GAZETTE (Mar. 6, 2011) http://www.post-gazette.com/stories/local/marcellusshale/deep-in-the-heart-of-the-gas-drilling-controversy-what-have-texans-learned-211199/#ixzz2gJmEYiVP ("Of the many environmental concerns [in the 5,000 square mile Barnett Shale play] that the energy industry tries to tamp down and foes seek to illuminate, the biggest is that drilling can damage water quality in rural areas. Property owners worry that gas can seep into the water table, ruining water wells, or that some of the fracking water used at a gas well site—up to 8 million gallons, or more than 12 Olympic-sized swimming pools—can likewise end up in rivers and streams. The industry says claims of well water contamination are exaggerated and, in most cases, unfounded because the fracking and gas-capture happen thousands of feet below the water table, and because drilling channels themselves are encased in concrete."); Eric Nicholson, *The Industry Unveils a New Tactic in the Dallas Fracking Debate: Calling Its Opponents Liars*, DALL. OBSERVER BLOGS (Aug. 26, 2013, 11:54 AM), http://blogs.dallasobserver.com/unfairpark/2013/08/the_industry_unveils_a_new_tac.php; *Traditional Oil & Gas Industry*, PA. INDEP. OIL & GAS ASS'N, http://www.pioga.org/pa-oil-gas/traditional (last visited Mar. 2, 2014) ("There has been significant attention focused recently on developing natural gas from the Marcellus and Utica shale formation [sic] in Pennsylvania and Ohio, along with questions about the drilling process, especially in areas of the region unfamiliar with oil and natural gas exploration and production.").

[16] *See, e.g.*, Roth v. Cabot Oil & Gas Corp., 919 F. Supp. 2d 476 (M.D. Pa. 2013) (water contamination); Eisenberger v. Chesapeake Appalachia, LLC, No. 3:09-CV-1415, 2010 WL 457139 (M.D. Pa. 2010) (lease dispute); Fiorentino v. Cabot Oil & Gas Corp., 750 F. Supp. 2d 506 (M.D. Pa 2010) (water contamination); Caldwell v. Kriebel Resources Co., LLC, 72 A.3d 611 (Pa. Super. Ct. 2012) (no implied duty to drill).

vocabulary of geologists, engineers, drilling crews, landmen, and the cast of other players in the hydrocarbon exploration and development field. Awareness and comprehension of scientific principles and their lexis will also aid lawyers, judges, arbitrators, and mediators in resolving disputes between plaintiffs and defendants, competing operators (oil and gas companies), lessors in dispute resolution, surface landowners and lessees, and owners of mineral/subsurface rights, as well as between drillers and operators.[17]

The aim of the present Article then is to place the science of geology and its interpretations—whether by observation, experimentation, or by expert testimony—within the framework of dispute resolution. The Article however does not address either the geology or the science of the fracking process. Accordingly, Part II of this Article, which is titled "The Science: Petroleum Geology 101" is definitional, describing such geological phenomena and concepts as oil and gas traps, facies, porosity and permeability, among others. However, the reader is forewarned that the geological descriptions, terms, and diagrams employed here are not, and indeed cannot, be a complete narrative or account of the geological sciences as they relate to oil and gas exploration and production, due to the complex nature of the geology of each basin or play. This ensuing discussion therefore provides the foundation for the remainder of the Article. In this Part of the Article, just as in the whole, I follow the example of geological literature, and by employing graphics and pictures I ascribe to the adage that a picture is worth a thousand words.

Part II focuses on the science of petroleum. This discussion concentrates on two traps within the universe of hydrocarbon-bearing formations and the porosity and permeability of reservoir rocks. Part III seeks to understand the juxtaposition of geological evidence within the framework of the resolution of disputes, with its applications to the Marcellus Shale. In turn, Part IV reviews the geology of the Appalachian Basin, which is the crucible of the Marcellus and Utica shales. Part V builds on the previous section by exploring oil and gas production within the Appalachian Basin. Part VI examines the role of geological experts in disputes involving the Marcellus Shale, while drawing some conclusions in Part VII.

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[17] *See, e.g.*, David Hammer, *Hearings: BP Representative Overruled Drillers, Insisted on Displacing Mud with Seawater*, THE TIMES-PICAYUNE (May 26, 2010), http://www.nola.com/news/gulf-oil-spill/index.ssf/2010/05/hearings_bp_representative_ove.html ("The chief mechanic on the Deepwater Horizon testified Wednesday that he was at a planning meeting 11 hours before the rig exploded at which the BP company man overruled drillers from rig owner Transocean and insisted on displacing protective drilling mud from the riser that connected the rig to the oil well.").

II. THE SCIENCE: PETROLEUM GEOLOGY 101

For decades geologists and operators of oil and gas wells have used numerous tools in their quest to discover new oil and gas reserves.[18] Some of these devices include well logs[19] and seismic surveys,[20] which are used to identify prospects. They are also utilized in identifying structural and stratigraphic traps,[21] or reservoirs,[22] in sandstone[23] and limestone[24] formations.[25]

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[18] *See, e.g.*, *Oil and Gas Commonly Asked Questions*, OKLA. GEOLOGICAL SURV. (2009), http://www.ogs.ou.edu/oilgasfaq.php (last visited Apr. 3, 2014).

> 2) . . . Detailed mineral/oil/gas evaluation requires a great deal of work and ultimately the services of an expert geologist. . . . Independent consulting geologists perform mineral/petroleum evaluations. . . . 7) . . . Well-log interpretation, also known as formation evaluation, is extremely important in the petroleum industry. Incorrect interpretation can result in the abandonment of potentially successful wells or the expensive completion of a well with little potential for commercial production. . . . All major petroleum companies have formation-evaluation specialists on their staffs. Smaller companies and individuals may hire consulting geologists . . . as needed.

Id.

[19] A "well log" is a tool that is connected to a metal cable and suspended into an oil or gas well to measure different rock properties. The logging tool is generally utilized once a well has reached its total depth ("TD"), in order to generate a record of the kind of rocks or formations that were drilled through. The tools used in "logging" wells are extremely sophisticated, and evaluate as well as quantify various rock characteristics including the electrical resistance or conductivity of the rocks, their radioactive attributes, the true diameter of the wellbore, borehole temperature, among other measurements. *See, e.g.*, Mark A. Anderson, *Discovering the Secrets of the Earth,* 23 OILFIELD REV. 60 (2011), *available at* http://www.slb.com/~/media/Files/resources/oilfield_review/ors11/spr11/defining_logging.pdf. "Specialists lower these tools into the wellbore . . . . Often several tools are run simultaneously as a *logging string*, and the combination of results is more informative than each individual measurement." *Id.*

[20] *See generally* Mark R. Milligan, *"Glad You Asked": What are Seismic Surveys and How Much "Shaking" Do They Create?*, UTAH GEOLOGICAL SURV. NOTES, July 2004, at 10, 10, *available at* http://geology.utah.gov/surveynotes/archives/snt36-3.pdf ("Like Superman, geologists have X-ray vision – well, sort of. Seismic surveys use reflected sound waves to produce a "CAT scan" of the Earth's subsurface. . . . Seismic images are produced by generating, recording, and analyzing sound waves that travel through the Earth (such waves are also called seismic waves). Explosives or vibrating plates generate the waves and a line or grid of geophones records them. Density changes between rock or soil layers reflect the waves back to the surface, and how quickly and strongly the waves are reflected back indicates what lies below.").

[21] Trap identification is the first step in evaluating drilling prospects. It is also a critical part of any exploratory or oil and gas evaluation program. Kevin T. Biddle & Charles C. Wielchowsky, *Hydrocarbon Traps*, *in* THE PETROLEUM SYSTEM—FROM SOURCE TO TRAP 219 (L. B. Magoon & W.G. Dow eds., 1994), *available at* http://geoclasses.tamu.edu/gandg/mancini/619/Class%20Reading%20Assignments/Biddle.pdf.

[22] A reservoir is "[a] porous and permeable underground formation containing a natural accumulation of producible oil and/or gas that is confined by impermeable rock or water barriers

A. *Traps in Hydrocarbon Bearing Formations*

1. Structural Traps

Structural traps are formed by mechanical forces within the earth. For example, in *In re Edmiston Oil Co.*,[26] the court noted, "Traps can be structural in nature in which the oil and gas accumulate in the upper part of rock folds or in faults and fractures."[27] Fault-derived traps[28] are created when blocks of rock move either vertically or horizontally depending on the type of fault.[29] Anticlinal traps are produced by folds in the earth's crust that result in a sine wave.[30] The upper portion resembles an "A" or an upside "U," as shown in Figure 1.[31]

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and is individual and separate from other reservoirs." CONOCOPHILLIPS, GLOSSARY OF OIL AND GAS TERMS 9, *available at* http://www.conocophillips.com/investor-relations/fact-sheet-financial-data/Documents/PDF/SMID_392-COP-Glossary-of-Terms-External-FINAL-5202013.pdf (last visited Mar. 2, 2014).

[23] Sandstones are rocks consisting mostly of quartz grains that are derived from the erosion of existing rocks. Depending on the local terrain, the source rocks may include igneous, metamorphic, or sedimentary rocks in the form of eroding mountains, beaches, or river deposits. Sandstones are also termed terrigenous rocks by geologists. Terrigenous derives from the Latin word *terra*, meaning earth, and *genus*, which means producing or generating, *i.e.*, derived from the land, especially by erosive action. Sandstones are generally classified by their grain or sand size. GERALD M. FRIEDMAN & JOHN E. SANDERS, PRINCIPLES OF SEDIMENTOLOGY 188 (John Wiley & Sons eds. 1978).

[24] Limestones, also referred to as carbonate rocks, are organic sedimentary rocks that precipitate from sea water and are autochthonous, *i.e.*, formed or originating in the place. They form due to the accretion of the shells of dead organisms, coral reefs, and algal fragments in sea water. The rock consists primarily of calcium carbonate ($CaCO_3$) in the form of two minerals, calcite or aragonite, as well as dolomite, ($CaMg(CO_3)_2$). Limestones generally form in clear, warm, shallow marine waters or aerobic or anaerobic environments. *Id.* at 148, 170.

[25] A formation is the "fundamental formal unit of the lithostratigraphic classification; it is of intermediate rank in the hierarchy of lithostratigraphic units and is the only formal unit which is used for completely subdividing the entire stratigraphic column . . . ." *Id.* at 426.

[26] 269 P.3d 833, 837 (Kan. Ct. App. 2013).

[27] *Id.* at 837.

[28] "A fault is a break in [brittle] rocks that make up the Earth's crust, along which rocks on either side have moved past each other." *What is a Fault?*, USGS.GOV, http://geomaps.wr.usgs.gov/sfgeo/quaternary/stories/what_fault.html (last modified Aug. 18, 2006); *see also* MARLAND P. BILLINGS, STRUCTURAL GEOLOGY 174 (3d ed. 1972) ("Faults . . . are ruptures [in a rock] along which the opposite walls have moved past each other.").

[29] *See generally Fault [Types:] Normal Faults[,] Reverse Faults[,] Strike-Slip Fault[,] Fault Scarp*, USGS, http://geomaps.wr.usgs.gov/parks/deform/gfaults.html (last modified Jan. 13, 2004).

[30] *See, e.g.*, JEAN-PIERRE BURG, FOLDS 19 (2013), *available at* http://www.files.ethz.ch/structuralgeology/JPB/files/English/8folds.pdf ("Amplitude and

Fault-based structural traps generally juxtapose a porous and penetrable or permeable rock or zone against one that is non-porous and non-permeable.[32] Consequently, oil and/or gas that has either migrated into or was previously stored in the porous zone is trapped because it cannot cross through or escape via the impermeable barrier.[33] In contrast, petroleum confined in anticlines is trapped at the top of the anticline, due to two physical forces.[34]

The first of these has to do with the fact that a permeable layer, either a sandstone, limestone, or a reservoir composed of fractured crystalline, basement igneous, or metamorphic rocks,[35] is underlain by an impermeable layer—called a "cap rock"—so that the petroleum cannot leak out or escape.[36] The second reason has to do with gravity. Because natural gas (or methane) is less dense or physically lighter than oil and water, it sits above or on top of the

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wavelength define the size of a single fold and refer to the mathematical terminology used to describe a sinusoidal curve.").

[31] Figure reproduced from *Petroleum: Where is the Petroleum?*, FUEL CHEMISTRY DIVISION, http://www.ems.psu.edu/~pisupati/ACSOutreach/Petroleum_2.html (last visited Jan. 17, 2014).

[32] *See generally Structural Traps*, PALEONTOLOGICAL RES. INST., http://www.priweb.org/ed/pgws/systems/traps/structural/structural.html (last visited Jan. 17, 2014).

> Fault traps are formed by movement of rock along a fault line. In some cases, the reservoir rock has moved opposite a layer of impermeable rock. The impermeable rock thus prevents the oil from escaping. In other cases, the fault itself can be a very effective trap. Clays within the fault zone are smeared as the layers of rock slip past one another. This is known as *fault gouge*.

Id.

[33] *Id.*

[34] Kansas Geological Survey, *Petroleum: A Primer for Kansas*, U. KANSAS, at 5 (Apr. 2001), http://www.kgs.ku.edu/Publications/Oil/primer05.html.

> Anticlines are important types of 'structural traps' in petroleum geology, as petroleum migrating up the dip along a flank of the fold is trapped at the crest. It can't rise any farther up the tilted strata and can't go back down the other flank, at least until the fold is full of oil and/or gas.

Id.; *see also* Figure 1, *infra*.

[35] In the United States, basement-originated metamorphic oil-bearing reservoirs produce in a number of states, including the Wilmington and Edison fields in California, the El Dorado and Orth fields in Kansas, and the Apco field in Texas. *See, e.g.*, Nick Petford & Ken McCaffrey, *Hydrocarbons in Crystalline Rocks: An Introduction*, 214 GEOLOGICAL SOC'Y OF LONDON (SPECIAL PUBLICATION) 1, 3 (2003), *available at* http://sp.lyellcollection.org/content/214/1/1.full.pdf.

[36] *See generally Oilfield Glossary: Caprock*, SCHLUMBERGER, http://www.glossary.oilfield.slb.com/en/Terms.aspx?LookIn=term%20name&filter=cap%20rock (last visited Mar. 24, 2014) ("A relatively impermeable rock, commonly shale, anhydrite or salt, that forms a barrier or seal above and around reservoir rock so that fluids cannot migrate beyond the reservoir . . . .").

oil, which sits on top of an underlying layer of water, which is shown in Figure 1.

2. Stratigraphic Traps

Stratigraphic traps are formed at the time of sediment deposition.[37] Following thousands of years of pressure and chemical reactions caused by the burial of succeeding layers of sedimentary strata, the sediments turn to rock. For example, in Pennsylvania, the Marcellus Shale attains a subsurface thickness of up to several hundred feet,[38] and is found at a depth of 9,000 feet.[39] Geologists know that the Marcellus, Utica, Barnett, Haynesville, and similar shales display the deposition of successive generations of muds that were deposited over millions of years.[40] Over time these muds were converted into shale.[41] This is shown in Figure 2. How then do shales form stratigraphic traps? That is the next topic.

Stratigraphic traps are generally caused by a change in facies (pronounced "face ees"),[42] as seen in Figure 3 and Figure 4. A facies change

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[37] Sediment deposition is the process of depositing of rock fragments, sand or limestone grains, silts, and clays by water, *e.g.*, rivers or oceans, blowing wind, or glacial ice. In most, but not all, cases, once the sediments are deposited they begin to be lithified, *i.e.*, the process by which sediments are turned into rock via compaction and cementation. *See, e.g.*, FRIEDMAN & SANDERS, *supra* note 23, at 63.

[38] *Marcellus Shale*, PA. DEPARTMENT OF CONSERVATION & NAT. RESOURCES, http://www.dcnr.state.pa.us/topogeo/econresource/oilandgas/marcellus/marcellus_faq/marcellus_shale/index.htm (last visited Mar. 27, 2014) (The gross thickness of the Marcellus shale ranges from less than 20 feet along the Lake Erie shoreline in northwestern Pennsylvania to several hundred feet in central and northeastern Pennsylvania. The net thickness of organic-rich Marcellus shale varies from less than 10 feet in western Pennsylvania along the Ohio border to over 250 feet in northeastern Pennsylvania.).

[39] Rachel Curtis & Kenneth Klemow, *How Did Marcellus Shale Form?*, INST. FOR ENERGY & ENVTL. RES. FOR NORTHEASTERN PA. (July 25, 2011), http://energy.wilkes.edu/pages/155.asp ("However, finer-grained fragments (silt and clay-sized) continued to flow as a slow underwater landslide, accumulating within the deepest part of the Appalachian Basin. Adding to those fine rock fragments were organic materials originating from the algae and other microorganisms living in the water.").

[40] *Id.* ("Marcellus shale developed from the deposition and later compression of minute rock particles and organic matter at the bottom of a sea during the middle Devonian era, 383–92 million years ago.").

[41] *See infra* Figure 2.

[42] A facies is a body of rock with specific environmental characteristics. For example, a beach facies will have sand from the beach itself, and possibly dunes that may be situated to the rear of the beach, and then the fore-beach, that is the area that is located below the average or mean low-tide line. Although beaches form along lakes, and sometimes along rivers, we generally think of them as forming in a marine environment, adjacent to a sea or ocean. *See, e.g.*, Maine Geological Survey, *Beach Pebbles Tell a Story*, MAINE.GOV,

can be described as different rock types that grade, or pinch out, into each other.[43] Consequently, impervious shale may grade into either a reservoir or porous rock sandstone or limestone, or, vice versa, so that the natural gas or oil is trapped at or near the junction between these two formations (porous and non-porous).[44] The Supreme Court of Alaska recently addressed this phenomenon, by observing that the "[d]elineation of a [known geologic structure] recognizes the existence of a continuous entrapping structure, on some part of which there is production, or of numerous related, but nevertheless independent stratigraphic . . . traps.'"[45] This case is a good example of how a court employs geology in an effort to effect a remedy, *i.e.*, the linking of science and law.

Note that in Figure 3, the sandstone facies grades laterally into the mud/shale facies, and the mud/shale facies, in turn, grades into a limestone. If the sandstone contained oil and/or gas, this diagram would be an excellent example of a stratigraphic trap. Because the impermeable shale acts as a barrier to petroleum migration, it would not allow any of the gas or oil to move or escape, as seen in Figure 4. Moreover, if one was to draw spaced-parallel horizontal lines across the three facies, each line would indicate a time horizon—a fixed point in time when the sand, shale, and limestone were deposited, at the same temporal interval, *i.e.*, the three rock types were deposited contemporaneously. Indeed, identifying different rock layers or strata—like measuring tree rings—is how geologists measure the time of deposition, as seen in Figure 5.

Similarly, note that in Figure 3 each facies has a different "design." The sandstone is dotted, the shale is stippled, and the limestone is labeled with adjoining boxes. These are the conventional symbols that geologists use to describe each of these rock types. Finally, Figure 4 is a graphic illustration of the two types of traps.[46]

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http://www.maine.gov/dacf/mgs/explore/marine/facts/sep00.pdf (last updated Oct. 6, 2005) ("The smooth, sandy beaches of southern Maine are popular with summer sun-seekers. In contrast, most beaches along the middle and eastern Maine coast are made of stones.").

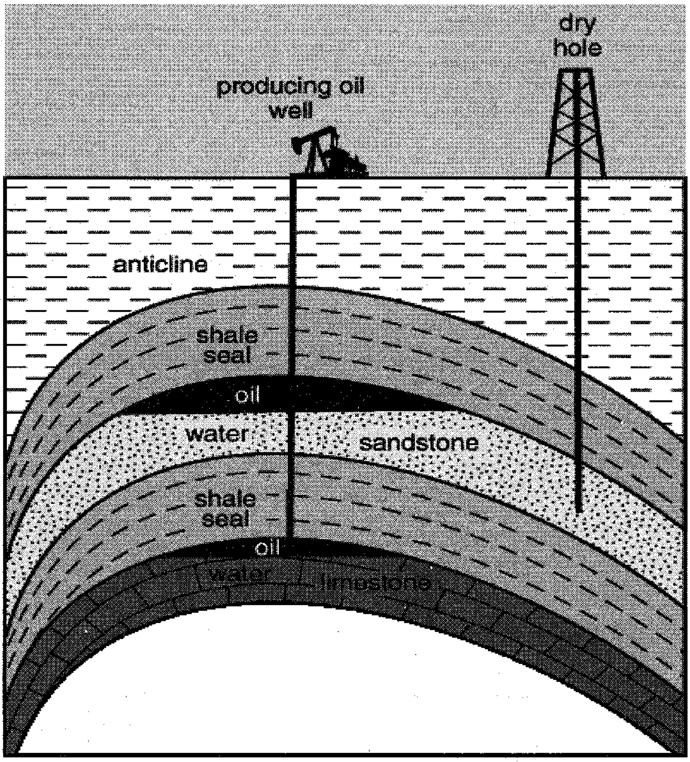
[43] "The term **facies** refers to *lithologic and lithologic and biologic characteristics of a sedimentary deposit, imparted by the depositional environment.*" FRIEDMAN & SANDERS, *supra* note 23, at 196 (emphasis in original); *see also infra* note 52.

[44] *See infra* Figure 3.

[45] ConocoPhillips Alaska, Inc. v. State, 109 P.3d 914, 922 (Alaska 2005) (quoting Source Petroleum Co., 112 IBLA 184 (1989)).

[46] *Oil and Gas Traps*, OIL ON MY SHOES: INTRODUCTION TO PETROLEUM GEOLOGY, http://www.geomore.com/oil-and-gas-traps/ (last visited Mar. 6, 2014). Thanks to David Red for permission to use this diagram.

Figure 1: Diagram depicting an Anticline with oil and gas trapped. Note that the oil and gas are floating on water, as they are lighter, and are contained within the sandstone reservoir rock.



B. The Internal Properties of Rocks: Porosity & Permeability

Thus far, we have examined the macro properties of rocks, including facies and traps. We now turn to two internal or micro properties to inform us of whether formations can act as reservoir rocks. The focus here is on two properties: porosity and permeability. Knowledge of a rock's porosity and permeability is a critical factor both in the legal and scientific realm. Indeed, cases have demonstrated that these properties determine the amount of gas or oil in place, and that they govern how much of the petroleum in-place can be produced. Consequently, a lawyer seeking to prove that her client warrants a larger portion of the production for royalty purposes, or for a larger percentage of the production in a unitization scheme,[47] will need to prove that the reservoir is continuous and the extent of its porosity and permeability.

1. Porosity

Porosity is a measure of the ratio of void space versus consolidated space.[48] "It is written as either a decimal fraction between 0 and 1 or as a percentage. For most rocks, porosity varies from less than 1% to 40%."[49] A sponge is a good analogy for explaining porosity. Sponges have a high ratio of void space versus solid space.[50] They would therefore be said to be very porous. However, the ratio of voids to solid is not the sole determinant of porosity. That rock characteristic is also regulated by the kind of rock that is being examined, the rock's grain size, and how the pores are distributed within the rock, as seen in Figures 6[51] and 7 below.

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[47] *See, e.g.*, Grace v. Oil Conservation Comm'n of N.M., 531 P.2d 939, 944 (N.M. 1975) ("[D]ue to the nature of the reservoir the amount of recoverable gas under each producer's tract cannot be practically determined in the subject pool by a formula which considers effective feet of pay, porosity, and water saturation."); El Paso Natural Gas Co. v. Corp. Comm'n of Okla., 640 P.2d 1336, 1339 (Okla. 1981) ("A Leede exploration manager testified that both the Morrow and Springer formations contained discontinuous sands, and there is additional discontinuity as to porosity and permeability, as evidenced by the fact that two wells drilled to the Springer formation proved noncommercial . . . .").

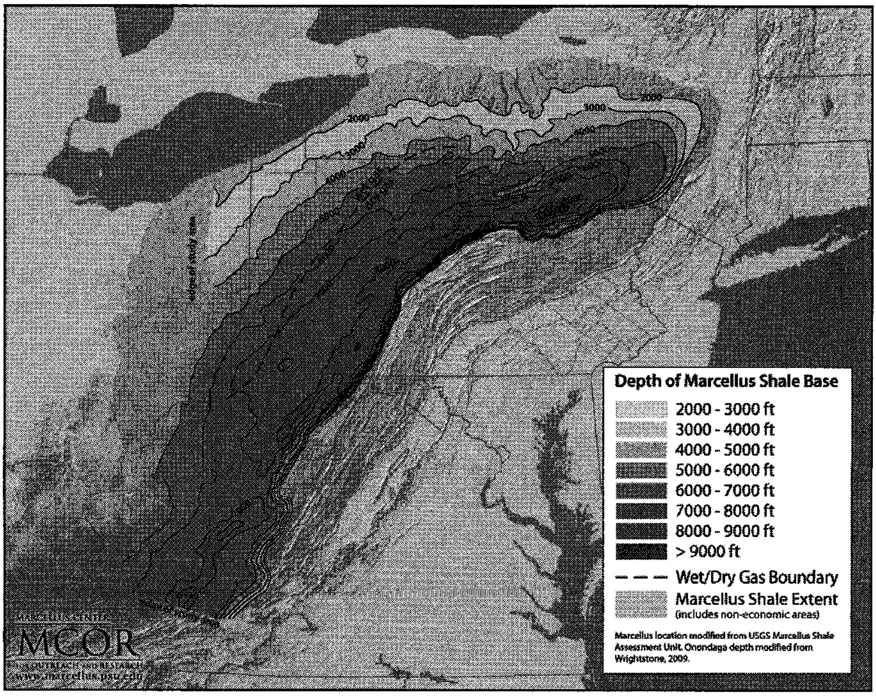
[48] Moncrief v. Wyo. Oil & Gas Conservation Comm'n, 981 P.2d 913, 917 n.1 (Wyo. 1999) ("Porosity is the total volume of open spaces, pores, or voids in a rock or sediment. Permeability refers to the relative ease with which a fluid moves through porous media.").

[49] *Rock Properties: Porosity and Density*, WIS. GEOLOGICAL AND NAT. HIST. SURV., http://wisconsingeologicalsurvey.org/porosity_density/about_porosity_density.htm (last updated Nov. 22, 2010). Mathematically, the degree of porosity is represented by the following equation: $Ø = V_{pore\ space}/V_{total}$. Where V is volume. *Id.* Geologists use the Greek letter Theta, Ø, to represent porosity.

[50] "[A] sponge is very porous because it has a high ratio of voids to solids, whereas clay is less porous because it has a low ratio of voids to solids." Itzchak E. Kornfeld, *Groundwater and Hazardous Waste Landfills Do Not Mix*, 5 TUL. ENVTL. L.J. 557, 568 (1992). There are two types of porosity: primary and secondary.

[51] *Id.*

Figure 2: Contour diagram depicting the subsurface depth to the base or bottom of the Marcellus Shale by location in the Appalachian Basin. Note that the 8,000–9,000 foot contours are bi-modal in Pennsylvania and West Virginia and on the New York and Pennsylvania border. Also, note how bunched-up the contours are on the right or east side of the basin, which shows a steep escarpment.[52]



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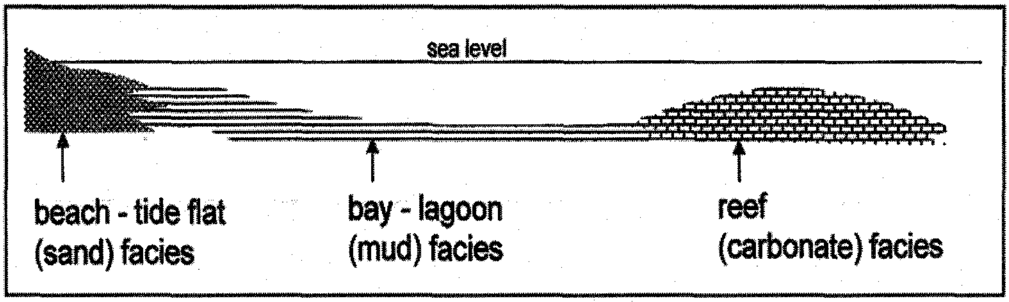
[52] *Depth of Marcellus Shale Base*, MARCELLUS CENTER FOR OUTREACH & RES., http://www.marcellus.psu.edu/images/Wet-Dry_Line_with_Depth.gif (last visited Apr. 12, 2014).

Figure 3. Facies Diagram. Note the gradation from a terrestrial (beach) environment on the left to a marine one on the right.[53]



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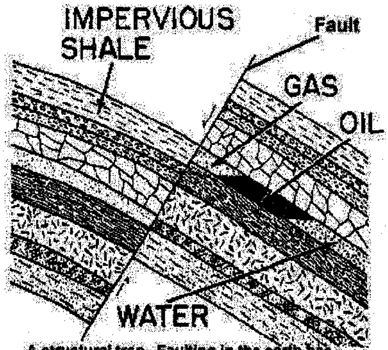
[53] A schematic diagram of three facies: sand, mud (shale), and limestone or carbonate. Note the gradation from one rock type or facies to another at the same time. Ralph L. Dawes, *Geology 101: Introduction To Physical Geology*: *Basics—Depositional Environments*, WENATCHEE VALLEY COLLEGE, http://commons.wvc.edu/rdawes/G101OCL/Basics/depoenvirons.html (last updated July 7, 2011). The study of facies is part of a geological sub-science called stratigraphy. Stratigraphy is the study of strata or layers of sedimentary rocks, their composition, distribution and depositional history.

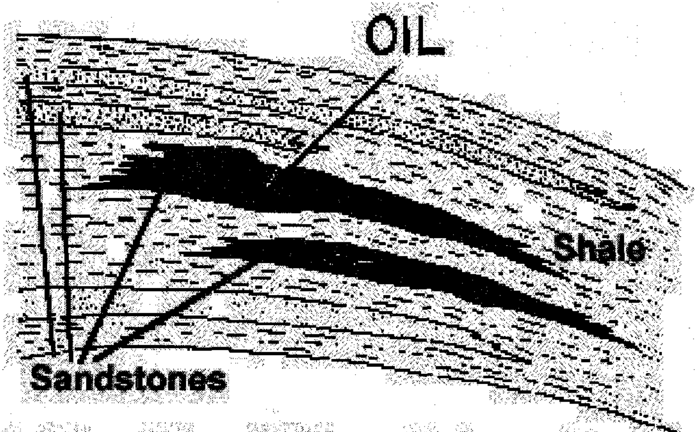
> Understanding the stratigraphy, physical trapping mechanisms, petroleum geochemistry, and stress conditions of unconventional basin gas and oil-bearing formations is critical to determining local and regional variations in gas and oil abundance, composition, and quality that identify rock formation targets and guide operational plans for drilling and hydro fracturing, and for understanding and forecasting the composition of produced waters.

Memorandum from Arun Majumdar, Acting Under Sec. of Energy, Dep't of Energy et al., to Assistant Secretaries (Apr. 13, 2012) (manuscript at 6.6), *available at* http://www.doi.gov/news/pressreleases/loader.cfm?csModule=security/getfile&pageid=289759.

Figure 4. Depicts the two types of traps: structural and stratigraphic.



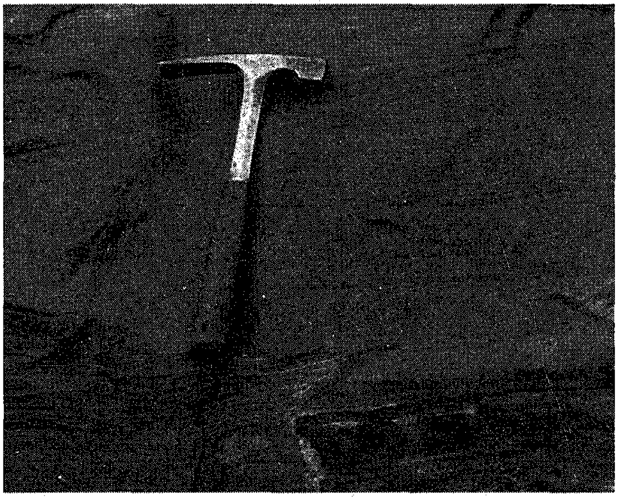
A structural trap. Faulting in the earth has caused vertical movement of the rock layers. Gas and oil cannot pass through the fault boundary, and they are trapped.



A stratigraphic trap. Oil is trapped in two sandstones which are surrounded by shale. The shale prevents the oil from escaping.

Figure 5. Layered beach deposit from the Logan Formation, Jackson County, Ohio, demonstrating stacked layers of sand, each of which was deposited at a different time.

Photograph taken by Mark A. Wilson (Department of Geology, The College of Wooster) on April 28, 2007.[54]



One attribute that controls porosity is how the minerals or clasts are distributed or *sorted* in a rock. For example, in *Moncrief v. Wyoming Oil & Gas Conservation Commission*,[55] the court observed that a geologist "testified that core information indicated that there was significant quartz cementation, as well as pore-plugging clays in the pore spaces of the rocks, which further reduces indicated porosities and permeabilities . . . ."[56] Figure 6 not only shows the percentage of pore space versus mineral grains (solids), but it also displays another characteristic: sorting. Sorting is the degree of grain size uniformity.[57] Thus, "[a] well sorted sediment [or a rock] is one in which the grains are all about the same size. In contrast, a poorly sorted sediment contains a chaotic mixture and large, intermediate and small grains."[58] It should be clear to the

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[54] *Sedimentary Rock*, WIKIPEDIA.ORG, http://en.wikipedia.org/wiki/Sedimentary_rock (last updated Feb. 2, 2014). The rock hammer is for scale and measures approximately two feet in height/length.

[55] 981 P.2d at 913 (Wyo. 1999).

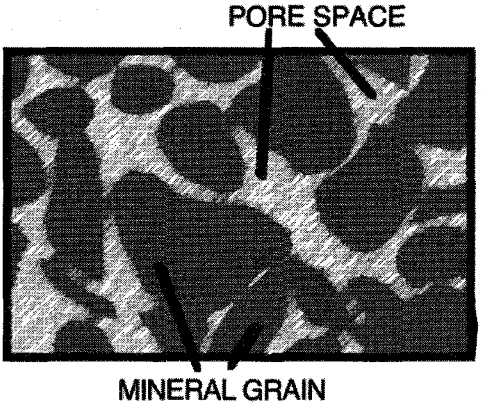
[56] *Id.* at 917.

[57] *See, e.g.*, FRIEDMAN & SANDERS, *supra* note 23, at 66 ("Sorting . . . relates to the relative abundance of various particle sizes . . . .").

[58] STEPHAN ZEEMAN, SAND GRAIN SIZE ANALYSIS, *available at* http://faculty.une.edu/cas/szeeman/oce/lab/sediment_analysis.pdf (last visited Mar. 2, 2014). As

reader that the grain size in Figure 6 and Figure 7 are not uniform. These two samples are therefore not well sorted.

Figure 6. A graphic representation of porosity.



Moreover, the grains depicted in Figures 6 and 7 are neither uniform in size nor shape. Accordingly, these two rock samples would be considered poorly sorted. Figure 7 is a photomicrograph of an actual rock's porosity.[59] It demonstrates two different types of porosity: primary porosity and secondary porosity.

> Primary porosity is formed at the time of deposition or formation of the rock. Where the particles are of uniform size, the porosity will be greater than where the particles are of

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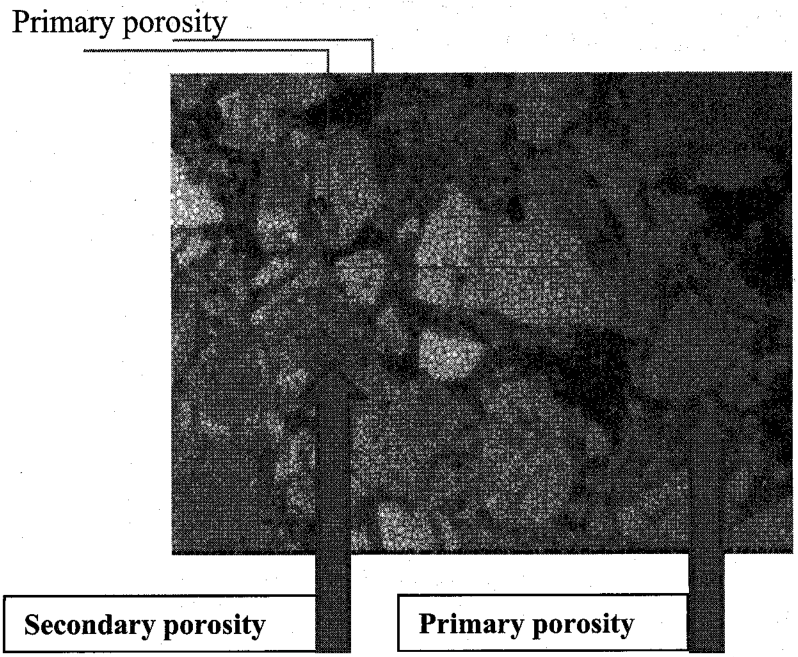
mentioned above, mathematically, the degree of porosity is represented by the following equation: $n = V_{\text{pore space}}/V_{\text{total}}$. Where V is volume. *Id.*

[59] James R. Wood & William B. Harrison, III, *Visual Display of Reservoir Parameters Affecting Enhanced Oil Recovery, Photomicrographs - North Coles Levee Field, Well: CLA 63-32*, MICHIGAN TECH GEOLOGICAL & MINING ENGINEERING SCIENCES (2009), http://www.geo.mtu.edu/svl/pioneer/photomicrographs/nclcla6332.htm (last visited Mar. 1, 2014). The colored material is an epoxy that fills in the pores, and therefore reveals the extent of porosity in this rock. *Id.* A photomicrograph is a photographic or digital image taken through a petrographic microscope. A petrographic microscope is a type of optical microscope that refracts light and is utilized in the study rocks or minerals that are ground down on glass slides. *See, e.g.*, Philip C. Robinson & Michael W. Davidson, *Introduction to Polarized Light Microscopy*, NIKON, http://microscopyu.com/articles/polarized/polarizedintro.html (last visited Mar. 6, 2014); *see also* J.A. Rushing et al., *Rock Typing—Keys to Understanding Productivity in Tight Gas Sands*, SOC'Y OF PETROLEUM ENGINEERS, no. 114164, 2008, *available at* http://www.pe.tamu.edu/blasingame/data/0_TAB_Public/TAB_Publications/SPE_114164_(Rushing)_Rock_Typing_Keys_Productivity_Tight_Gas_Sands.pdf.

> varying sizes. Secondary porosity is formed after the deposition or formation of the rock. This type of porosity is usually an enhancer of primary porosity and manifests itself as fractures, caverns, or caves.[60]

Note that the secondary porosity is pointed out by the arrow. Additionally, numerous other types of porosity exist in nature.[61] However, a discussion of the variant forms of porosity is beyond the scope of this Article.

Figure 7. Stevens sandstone from the North Coles Levee Field, Kern County, California, showing both primary porosity and major secondary porosity.



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[60] Kornfeld, *supra* note 50, at 568.

[61] Some types include (1) inter-granular porosity; (2) fracture porosity; (3) solution porosity; and (4) vuggy porosity, among others. Paul Glover, *Ch. 5: Porosity*, *in* FORMATION EVALUATION MSC COURSE NOTES 43 (2013), *available at* http://www.academia.edu/5840412/Formation_Evaluation_MSc_Course_Notes_Porosity_Chapter_5_Porosity; *see also* FRIEDMAN & SANDERS, *supra* note 23, at 66–68.

2. Permeability

Permeability refers to a porous rock formation's ability to transmit fluids or gases through itself.[62] It is a measure of a rock's inter-connectivity of its pores or fractures.[63] That connectivity can be seen in Figures 6 and 7. In Figure 6, the pores are partially connected, whereas in Figure 7, they are minimally connected. Thus, the rock pictured in Figure 6 would be said to be relatively permeable, while the rock in Figure 7 would be said to be relatively impermeable. Permeability is dependent upon how well the sediment or grains are sorted.[64] The coarser and better sorted the grains, the greater the permeability.[65] But, are porosity and permeability related in some fashion?

In fact, they are. Porosity and permeability are the two critical factors that govern the movement of hydrocarbons across a formation.[66] In evaluating permeability, unlike porosity, one must consider the "following three factors of (1) size, (2) shape, or (3) degree of connection among pore spaces."[67] Indeed, one other factor that controls porosity and permeability is depth. Generally, a rock's or formation's porosity and permeability diminishes with depth due to the weight of the overburden, *e.g.*, the 8,000 feet or 10,000 feet, that rests above the Marcellus Shale.[68] Moreover, fluid or gaseous flow is also influenced by the oil's or gas's viscosity,[69] and viscosity is provoked by temperature and pressure.[70]

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[62] "Permeability refers to the relative ease with which a fluid moves through porous media." Moncrief v. Wyo. Oil & Gas Conservation Comm'n, 981 P.2d 913, 917 n.1 (Wyo. 1999).

[63] SCHLUMBERGER, LOG INTERPRETATION PRINCIPLES/APPLICATIONS 2-2 (1998) (on file with *West Virginia Law Review*).

[64] *See, e.g.*, FRIEDMAN & SANDERS, *supra* note 23, at 69 ("Permeability is related to the distribution of particle sizes in a sediment. In a well-sorted, coarse-grained sand, the permeability may measure thousands of millidarcies [, which is quite high].").

[65] *Id.* at 69.

[66] Indeed, porosity and permeability also control an aquifer's ability to transmit water. *See, e.g.*, Philippe Baveye & Garrison Sposito, *The Operational Significance of the Continuum Hypothesis in the Theory of Water Movement Through Soils and Aquifers*, 20 WATER RESOURCES RES. 521 (1984).

[67] FRIEDMAN & SANDERS, *supra* note 23, at 68.

[68] *See, e.g.*, *Aquifers*, USGS.GOV, http://water.usgs.gov/edu/pdf/earthgwaquifers.pdf (last visited Mar. 6, 2014) ("On average . . . *the porosity and permeability of rocks decrease as their depth below land surface increases*; the pores and cracks in rocks at great depths are closed or greatly reduced in size because of the weight of the overlying rocks." (emphasis added)).

[69]
> *Viscosity is a measure of a fluid's resistance to flow.* It describes the internal friction of a moving fluid. A fluid with large viscosity [like honey] resists motion because its molecular makeup gives it a lot of internal friction. A fluid with low viscosity [like water] flows easily because its molecular

Furthermore, while porosity is a measure of the ratio, or percentage, of void space versus solid space, permeability is a degree of the connectivity of the pores; it is measured using an equation derived from Darcy's Law, represented by *k*. The law was derived from numerous experimental observations through a porous layer of sand.[71] Darcy's Law is also applicable to gases.[72]

A formation's permeability is measured because oil and gas reservoirs are *not* homogenous. Rather, these layers or strata contain both "macroscopic heterogeneities,"[73] as well as microscopic ones.[74] The unit of measurement that geologists and petroleum engineers employ in measuring the permeability of petroleum reservoirs is in a unit termed a "millidarcy."[75] Moreover, "a very low

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> makeup results in very little friction when it is in motion.... Gases also have viscosity, although it is a little harder to notice it in ordinary circumstances.

What is Viscosity?, PRINCETON GAS DYNAMICS LAB, http://www.princeton.edu/~gasdyn/Research/T-C_Research_Folder/Viscosity_def.html (last updated July 27, 1998).

[70] FRIEDMAN & SANDERS, *supra* note 23, at 68.

[71] The law is named for Henry Darcy, a French hydraulic engineer, who, in 1856, derived and published the equation. Darcy's law defines the ability of a fluid to flow through a porous media such as rock. For our purposes an easy way to envisage permeability is to measure the change in height or gradient between two flowing wells. This measure is also known as the hydraulic head gradient. *See generally* CUTLER J. CLEVELAND & CHRISTOPHER MORRIS, DICTIONARY OF ENERGY 252 (2009).

[72] *See, e.g.*, L. J. KLINKENBERG, THE PERMEABILITY OF POROUS MEDIA TO LIQUIDS AND GASES 41–60 (1941); Daniel E. Martire, *Generalized Treatment of Spatial and Temporal Column Parameters, Applicable to Gas, Liquid and Supercritical Fluid Chromatography: I. Theory*, 461 J. CHROMATOGRAPHY A 165 (1989).

[73] James Glimm & David H. Sharp, *A Random Field Model for Anomalous Diffusion in Heterogeneous Porous Media*, 62 J. STAT. PHYSICS 415, 415 (1991).

[74] FRIEDMAN & SANDERS, *supra* note 23, at 88. ("[L]ayers are a characteristic of sediments and result from the spreading out of sedimentary materials.... This layering is a function of the ways in which particles are distributed.... The gross size or composition of particles may change from one layer to the next."); *see also id.* at 89 (A **graded layer** *is a layer of sediment in which the particle sizes change according to a systematic gradient in a verticle and/or lateral direction.*") (emphasis in original).

[75] One millidarcy or *k* is the equivalent of 1/1000 of a darcy. A darcy equals a permeability that allows one cubic centimeter per second of oil or gas with a given viscosity (of one centipoise) to move through a cross-sectional pore area that corresponds to a square centimeter (2.54 inches squared or, 2.54 in.^{2}) that is under a pressure incline or gradient of one atmosphere (the number of atmospheres at the surface of the earth). Personal communication from Professor Robert L. Folk, Jackson School of Geosciences, University of Texas at Austin. Most oil and gas reservoirs produce from rocks that have 10 to several 100 millidarcys. However, tight sands have "[p]orosity [that] averages from 5% to 10% with permeabilities between 0.01 [1×10^{-2}] and 5 mD [millidarcies]." E. R. (Ross) Crain, *Tight Gas Basics*, CRAIN'S PETROPHYSICAL HANDBOOK, http://spec2000.net/17-tightgas.htm#b6 (last visited Mar. 6, 2014).

permeability gas reservoir is defined as a formation having [an extremely low] in-*situ* matrix permeability to gas of 0.5 mD or less."[76]

The previous Part provided a background into rock properties. Part III will address how those geological properties fit into a legal framework and the resolution of disputes.

III. DISPUTE RESOLUTION: APPLICATION OF GEOLOGICAL EVIDENCE WITH APPLICATIONS TO THE MARCELLUS SHALE

> The report of the special master in the federal action, which was largely adopted by the federal district court, makes this plain. The special master found the State *did not conduct a competent assessment of the site's geology, which would have found the underlying rock "fractured and permeable."*[77]

In any dispute over oil and gas production or over petroleum resources generally, studies, or narratives of the analyses of rock or core samples,[78] expert reports and court opinions routinely address a rock's porosity and/or permeability.[79] These characteristics are often at the center of disputes, and dispute settlement. Three non-Marcellus case examples are offered initially in support of the foregoing statement. Marcellus Shale disputes will be considered in due course.

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[76] D. B. Bennion et al., Low Permeability Gas Reservoirs and Formation Damage -Tricks and Traps (2000) (Soc'y of Petroleum Engineers conference paper), *available at* https://www.onepetro.org/conference-paper/SPE-59753-MS. That matrix permeability is generally 0.5 mD or less, which allows only minimal amount of gas to flow through the rock. Fracturing will enhance the rock's permeability.

[77] California v. Allstate Ins. Co., 201 P.3d 1147, 1155 n.2 (Cal. 2009) (emphasis added).

[78] A core is a section of rock, or rock sample, generally of a reservoir formation, that is cut while drilling a well. The reason for coring is to obtain a sample of the rock in order to measure the "true" properties, *e.g.*, the rock's overall description, in order to understand the formation's facies and the environment in which the rock was laid down in, as well as its mineralogy, fabric, porosity and permeability, as opposed to the readings one obtains from well logs. The process of cutting a core, from the well bore itself, is undertaken by utilizing a dedicated subassembly at the base of the drill string. The subassembly employs a specialized diamond bit that cuts the rock. *See generally* DJEBBAR TIAB & ERLE C. DONALDSON, PETROPHYSICS: THEORY AND PRACTICE OF MEASURING RESERVOIR ROCK AND FLUID TRANSPORT PROPERTIES 343–63, 887–96 (3d ed. 2012).

[79] *See, e.g.*, Grynberg Petroleum Co. v. Fed. Energy Regulatory Comm'n., 77 F.3d 517, 519 (D.C. Cir. 1996) ("A tight formation is a geological formation of *low permeability*, *i.e.*, a formation that impedes the flow of gas, thereby requiring a producer to use enhanced production techniques (*e.g.*, fracturing) to improve the flow of gas." (emphasis added)); El Paso Natural Gas Co. v. Corp. Comm'n of Okla., 640 P.2d 1336, 1339 (Okla. 1981) ("The Springer formation is a fractured formation that produces only in sections *with favorable porosity and permeability*; these producing characteristics are not continuous throughout the area, thus increasing the possibility of a dry hole . . . ." (emphasis added)).

First, in *Woody v. State Corp. Commission*,[80] E. M. Woody, and other royalty owners, challenged a unitization order issued by the Oklahoma Corporation Commission,[81] arguing that the Order was not supported by substantial evidence and that it "provides for the allocation of unit production under [a given] formula deprives appellants of their property without due process of law. . . ."[82] The court observed that

> [a] great volume of the testimony is of a highly technical character. In this connection appellants suggest that the evidence is highly speculative, conjectural and of questionable probative value. We do not agree.
>
> We find direct evidence of geologists and petroleum engineers who had been intimately associated with the Elk City field from its first production in 1947, to the time of the hearing before the Commission. They testified that they had examined numerous electric logs and many micrologs that had been run, examined core analysis from the wells, and considered drill stem tests taken in the field, as well as volume production from the wells. From the study so made they were of the opinion that the formations in the field were highly erratic; that there were rapid variations in the thickness of the pay zones, as well as the porosity and permeability of the producing zones; they found greater variations in permeability than in porosity of the sand zones and concluded that the degree of permeability is vitally important to the capacity of a well to produce. There seems to be conformity of opinion among these witnesses that the factor of acreage and saturated hydrocarbon pore space should be considered in any formula adopted.[83]

A second example is the matter of *Southwest Kansas Royalty Owners Ass'n v. State Corp. Commission*.[84] That case involved an appeal by a number of pipeline companies and others, of an order of the Commission, amending a

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[80] Woody v. State Corp. Comm'n, 265 P.2d 1102 (Okla. 1954).

[81] The Oklahoma Corporation Commission regulates oil and gas in that state. *See generally Oklahoma Corporation Commission History*, OKLA. CORP. COMM'N, http://www.occeweb.com/Comm/commissionhist.htm (last visited Mar. 1, 2014) ("The Commission began regulating oil and gas in 1914 . . . .").

[82] *Woody*, 235 P.2d at 1103.

[83] *Id.* at 1106–07.

[84] 769 P.2d 1 (Kan. 1989).

Proration Order,[85] allowing infill drilling in the Hugoton Gas Field. In its review of appellants' challenge, the court assessed the evidence relying on the porosity and permeability of the "pay zones" as follows:

> The issue is whether substantial evidence supports the Commission's finding that an infill well may be required to effectively and efficiently drain a production unit because of *permeability barriers*. Appellants argue no substantial evidence supports *the Commission's finding that isolated zones of gas exist because such zones were not physically located or quantified* by witnesses. Appellants produced evidence before the Commission showing why they rejected the theory of isolated zones.
>
> There was, however, other evidence supporting the theory that isolated and discontinuous zones exist in each proration unit in the entire field. While the evidence was controverted, there was substantial competent evidence supporting the Commission's finding. Therefore, we are not authorized to disturb it on appellate review.[86]

The final example comes from *Corr v. Continental Oil Co.*[87] In *Corr*, plaintiffs/appellees, contending that a new field, which was located above the previously known producing horizon, sought damages for Continental's drainage of the oil from that subsurface layer of appellees'/lessors' lease. The case was tried to a jury, which was unable to reach a verdict. The trial court rejected Continental's demurrer of plaintiffs' evidence.[88]

In affirming the demurrer, the court found that the *Corr* plaintiffs failed to evince sufficient facts to establish a cause of action against Continental.[89] In arriving at its judgment, the Kansas Supreme Court, referring to the critical elements of the case, observed that

> [t]he [plaintiffs'] witness had never measured the porosity nor the permeability of the limestone in this field. He testified that

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[85] Proration Orders are defined in Kansas Administrative Regulations as follows: "'Proration' means the regulation of the amount of allowed production to prevent waste or to prevent any of the following in a manner that would favor any one pool as compared to any other pool in this state . . . ." KAN. ADMIN. REGS. § 82-3-101 (2004).

[86] *Sw. Kan. Royalty Owners Ass'n*, 769 P.2d at 18–19 (emphasis added).

[87] 64 P.2d 30 (Kan. 1937).

[88] *Id.* at 30 ("The jury failed to agree and was discharged. Defendants appeal from an order overruling a demurrer to the evidence of plaintiffs.").

[89] *Id.* at 34 ("The judgment of the trial court is reversed, with directions to sustain the demurrer of defendants to the evidence of plaintiffs.").

> the porosity and permeability are the factors that determine the movement of oil through a formation. He did not know what the porosity or permeability of the formation was . . . . It is conceded in this record that the same thing happened in this field that we know generally happens in oil fields, that is, wells are drilled at a certain place and turn out to be good producers, while a well is drilled a short distance away and turns out to be a dry hole. . . . The porosity and permeability are important for two reasons: First, the porosity determines how much oil there is in a particular portion of a structure; and, second, porosity and permeability determine to a large extent how readily oil will drain away from one part of a structure to another.[90]

In order to understand the geological properties discussed above they need to be placed into a geographic context. The next Part then addresses the geological history of the Appalachian Basin and places the Marcellus Shale within that terrain. Finally, the employment of experts is discussed in Part V.

IV. THE GEOLOGY OF THE APPALACHIAN BASIN

In order to fully understand the depositional history and geology of the Marcellus and Utica Formations, one needs to understand the history of the Appalachian Basin. The Appalachian Basin[91] is part of an ancient foreland basin[92]—"a depression that develops adjacent [to] and parallel to a mountain belt."[93] An unscientific or layman's explanation of a foreland basin is as

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[90] *Id.* at 33.

[91] *See, e.g.*, ROBERT. T. RYDER, USGS, THE APPALACHIAN BASIN PROVINCE (067), *available at* http://certmapper.cr.usgs.gov/data/noga95/prov67/text/prov67.pdf (last visited Mar. 2, 2014) ("The Appalachian Basin is a foreland basin containing Paleozoic sedimentary rocks of Early Cambrian through Early Permian age. From north to south, the Appalachian Basin Province crosses New York, Pennsylvania, eastern Ohio, West Virginia, western Maryland, eastern Kentucky, western Virginia, eastern Tennessee, northwestern Georgia, and northeastern Alabama.").

[92] Geologically, a foreland basin is defined as a structural basin that is created adjacent and parallel to a mountain chain. *See, e.g.*, Frank R. Ettensohn, *The Appalachian Foreland Basin in Eastern United States*, *in* THE SEDIMENTARY BASINS OF THE UNITED STATES AND CANADA 105, 105–08 (Andrew D. Miall ed., 2008) ("Foreland basins sedimentary rocks preserve a record of the evolution of a mountain belt. Indeed, adjacent to ancient, deeply eroded orogens like the Devonian Acadian mountain belt, the foreland basin sedimentary succession is a key source of data on the timing and character of orogenic events and processes long since eroded away."); CHARLES A. VER STRAETEN, THE CLASSIC DEVONIAN OF THE CATSKILL FRONT: A FORELAND BASIN RECORD OF ACADIAN OROGENESIS 7-1 (2009), *available at* http://www.nysm.nysed.gov/staffpubs/docs/20104.pdf.

[93] Andrew D. Miall, *Initiation of the Western Interior Foreland Basin*, 37 GEOLOGY 383, 383 (2009), *available at* http://geology.gsapubs.org/content/37/4/383.short.

follows. Imagine pushing down on a balloon. The area that one pushes down causes an adjacent part of the balloon to rise. The foreland basin is the area that is being pushed down upon, and the area that rises is the adjacent mountain range.

The Appalachian Basin covers an area that is flanked by the Allegheny front[94] to the east, and the Cincinnati Arch[95] to its west, as seen in Figure 9. It measures some 300 miles (483 kilometers) in width at its northern-most extent, and 600 miles (966 kilometers) long from north to south. "Our understanding of the basin, and others like it worldwide, is largely the legacy of a single observation by James Hall in 1857, an observation that also effectively established the framework for the later plate-tectonic paradigm."[96] Indeed, in a recent contract case involving operations in the Marcellus, the court referred to a service company that "supplied coiled tubing, perforation, and logging services in the Allegheny Plateau region of the northern Appalachian Basin."[97]

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[94] The Allegheny Front is the main southeastern oriented escarpment of the Allegheny Mountain Range, AKA as the Alleghenies, and a sub-region of the Appalachian Mountains. The Front is situated in south-central Pennsylvania, western Maryland, and eastern West Virginia. The Allegheny Front forms the boundary between the Valley-and-Ridge, which lies to its east and the Appalachian Plateau, AKA the Allegheny Plateau, which lies to its west. *See, e.g.*, Paul H. Price, *The Appalachian Structural Front*, 39 J. GEOLOGY 24, 24–26 (1931).

> An escarpment is an area of the Earth where elevation changes suddenly. Escarpment usually refers to the bottom of a cliff or a steep slope. (Scarp refers to the cliff itself.)
>
> Escarpments separate two level land surfaces. For example, an escarpment could be the area separating the lower parts of the coast from higher plateaus. An escarpment also usually indicates two different types of land, such as the area on a rocky beach where tall cliffs become rocky sand.

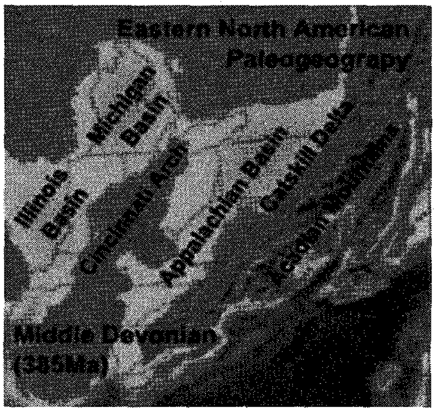
Escarpment, NAT'L GEOGRAPHIC, http://education.nationalgeographic.com/education/encyclopedia/escarpment/?ar_a=1 (last visited Mar. 6, 2014).

[95] The Cincinnati Arch Province is a very broad tectonically uplifted area that is bounded by the Illinois Basin on the west and the Appalachian Basin to its east and southeast. It has been characterized as consisting "of broad, basement-involved arches, domes, and intervening sags and saddles that separate the Appalachian and Illinois Basins." ROBERT T. RYDER, USGS, CINCINNATI ARCH PROVINCE (066), *available at* http://certmapper.cr.usgs.gov/data/noga95/prov66/text/prov66.pdf (last visited Mar. 2, 2014).

[96] Ettensohn, *supra* note 92, at 105. James Hall (1811–1898) was a paleontologist and Director of the New York State Museum from 1870 to 1894. *See, e.g.*, *Important Historical Figures*, HISTORY OF THE N.Y. ST. MUSEUM, http://www.nysm.nysed.gov/history/html/faces-directors.html (last visited Mar. 2, 2014).

[97] TWA Res. v. Complete Prod. Serv., Inc., No. N11C-08-100 MMJ, 2013 WL 4045920, at *1 (Del. Super. Ct. July 30, 2013).

Figure 9. Showing the juxtaposition of the Appalachian Basin to the Cincinnati Arch, among other paleogeographic features, during the Middle Devonian.[98]



A. Orogenous Zones and Mountain Building

The Basin has been tectonically active since Grenville time, *i.e.*, approximately 1.3 billion years ago.[99] However, the majority of the tectonic tumult occurred during the Paleozoic Era, which spanned the period from approximately 541 to 252 million years before present ("mybp").[100] Throughout that time frame, the Appalachian Basin underwent three violent orogonies, *i.e.*, mountain building or deformational periods.

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[98] *Cincinnati Arch*, WIKIPEDIA, http://en.wikipedia.org/wiki/Cincinnati_Arch. (last updated May 8, 2013).

[99] *See generally* Rodger T. Faill, *A Geologic History of the North-Central Appalachians; Part 2, The Appalachian Basin from the Silurian Through the Carboniferous*, 297 AM. J. SCI. 729 (1997); Toby Rivers, *Assembly and Preservation of Lower, Mid, and Upper Orogenic Crust in the Grenville Province-Implications for the Evolution of Large Hot Long-Duration Orogens*, 167 PRECAMBRIAN RES. 237 (2008). Tectonic activity consists of the movement of the earth's crust due to faulting and folding, earthquakes, and volcanic activity. Mike Strickler, *Tectonics: The Study of Earth Processes Which Result in the Creation and Deformation of Magma and Rock*, GEOMANIA, http://jersey.uoregon.edu/~mstrick/GeoTours/TectonicBkgrnd.html (last visited Mar. 6, 2014).

[100] *International Chronostratigraphic Chart*, INT'L COMM'N ON STRATIGRAPHY (Jan. 2013), http://stratigraphy.org/index.php/ics-chart-timescale.

1. Paleozoic Era Deformation

Moreover, "[t]hroughout Paleozoic time, the Appalachian Basin region was the site of accumulation of vast quantities of sediment derived from uplifts created by the Taconic Orogeny (Late Ordovician) [451-444 mybp], the Acadian Orogeny (Late Devonian) [385-368 mybp], and Alleghenian Orogeny (Late Mississippian to Permian) [335-229 mybp]."[101] However, for purposes of this Article, only two of these orogenies are relevant: the Taconic[102] and the Acadian. The Taconic Orogeny began during the Cambrian Period, circa 550 mybp, and abated around 440 million mybp, during the Ordovician Period. [103] It created a mountain range that extended from eastern Canada through the Piedmont.[104] As that mountain chain eroded—beginning about 425 mybp, in the Silurian period, and continuing into the Devonian—sediments were deposited across the entirety of the present-day Appalachian Basin.[105]

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[101] *See, e.g.*, *Valley and Ridge Province*, USGS.GOV, http://web.archive.org/web/20110722154205/http://3dparks.wr.usgs.gov/nyc/valleyandridge/valleyandridge.htm (last updated July 22, 2003). The Paleozoic Era began 540 mybp and extended to approximately 252 mybp, incorporating the Cambrian, Ordovician, Silurian, Devonian, Carboniferous and the Permian Periods. *See generally International Chronostratigraphic Chart*, *supra* note 100.

[102] Rodger T. Faill, *A Geologic History of the North-Central Appalachians; Part 1, Orogenesis from the Mesoproterozoic Through the Taconic Orogeny*, 297 AM. J. SCI. 551 (1997).

[103] *See generally* 52 C. Brannon Andersen, *Provenance of Mudstones from Two Ordovician Foreland Basins in the Appalachians*, *in* SOC'Y FOR SEDIMENTARY GEOLOGY 53 (special ed. 1994); John Rodgers, *The Taconic Orogeny*, 82 GEOL. SOC. AM. BULL. 1141 (1971).

[104] *See, e.g.*, Art Schultz & Scott Southworth, *Geology of the Mount LeConte 7.5-Minute Quadrangle, Great Smoky Mountains National Park, Tennessee and North Carolina (USGS OF 00-261)*, USGS.GOV, http://geology.er.usgs.gov/eespteam/Mtleconte/website (follow "Geology" hyperlink) (last visited Mar. 27, 2014) (noting "Appalachian mountain chain from Newfoundland, Canada to Georgia").

[105] *See generally* Faill, *supra* note 99, at Abstract.

> [T]he newly uplifted Taconic highland spread westward over most of the basin during the Early Silurian.... Before long, however, carbonate deposition once again dominated most of the north-central basin for the remainder of the Silurian and into the Early Devonian. The Early-to-Middle Devonian Acadian orogeny began introducing siliciclastic material into the eastern part of the Appalachian basin . . . .

Id.

2. The Acadian Orogeny

The Acadian Orogeny, like its predecessor, the Taconic Orogeny, "[deposited a] thick accumulation of clastic sediments[106] that are spread throughout the western Valley and Ridge and eastern Allegheny plateau."[107] The Taconic began during the Upper-Devonian, approximately 375 mybp and lasted 50 million years, into the Lower Mississippian.[108] The Acadian Orogeny witnessed an extended mountain building period, which began in the Middle Devonian, and reached its peak in the early portion of Late Devonian.[109]

The Acadian Orogeny's "foreland basin was an elongate trough . . . and extended from Newfoundland to northern Georgia and Alabama."[110] "The 'Appalachian Basin' is only a part of the greater Acadian foreland basin. The former represents a body of rock preserved through the states of New York, New Jersey, Pennsylvania, Maryland, Virginia, West Virginia, Tennessee, Ohio, and parts of southern Ontario."[111] That body of rock attains a thickness of 24,000 feet below the surface[112] and includes the Marcellus Shale.

The foreland basin's Devonian strata are subdivided into pre-orogenic and post-orogenic. The pre-orogenic rocks are of Lower and Middle Devonian age, and include the Oriskany Sandstone.[113] These strata were deposited on a

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[106] The term "clastic sediments" refers to rock fragments or large grains of sand that sit in a finer grained matrix, similar to plums in a pudding, and also similar to the Oriskany Sandstone. *See, e.g.*, FRIEDMAN & SANDERS, *supra* note 23, at 53 (discussing interclasts).

[107] Lynn S. Fichter & Steve J. Baedke, *The Geological Evolution of Virginia and the Mid-Atlantic Region, Cross Section J, The Devonian Acadian Orogeny and Catskill Clastic Wedge: Middle to Late Devonian; 380–350 mya*, JAMES MADISON UNIV. DEPARTMENT OF GEOLOGICAL AND ENVTL. STUDIES, http://csmres.jmu.edu/geollab/vageol/vahist/J-MidlatD.html (last updated Sept. 13, 2000).

[108] *See, e.g.*, Faill, *supra* note 102, at 555; Frank R. Ettensohn, *Rates of Relative Plate Motion during the Acadian Orogeny Based on the Spatial Distribution of Black Shales*, 95 J. GEOLOGY 572 (1987); *International Chronostratigraphic Chart*, *supra* note 100 (for chronology).

[109] DWIGHT C. BRADLEY ET AL., U.S. GEOLOGICAL SURV., MIGRATION OF THE ACADIAN OROGEN AND FORELAND BASIN ACROSS THE NORTHERN APPALACHIANS OF MAINE AND ADJACENT AREAS 1–2 (2000), *available at* http://pubs.usgs.gov/pp/pp1624/pp1624.pdf.

[110] Ver Straeten, *supra* note 92, at 7-3.

[111] *Id.*

[112] *See* Robert T. Ryder et al., *Geologic Cross Section D–D' Through the Appalachian Basin from the Findlay Arch, Sandusky County, Ohio, to the Valley and Ridge Province, Hardy County, West Virginia*, U.S. GEOLOGICAL SURV. SCIENTIFIC INVESTIGATIONS (2009), http://pubs.usgs.gov/sim/3067/pdf/sim3067sheet-2.pdf.

[113] John A. Harper & Jaime Kostelnik, THE MARCELLUS SHALE PLAY IN PENNSYLVANIA, at slide 7, *available at* http://www.marcellus.psu.edu/resources/PDFs/DCNR.pdf (last visited Mar. 24, 2014).

stable continental shelf,[114] equivalent to the shelf underlying today's Atlantic Ocean. The post-orogenic strata are Middle Devonian to Early Mississippian in age, and resulted from Acadian tectonics.[115] They include the Onondaga Limestone, Marcellus Shale, and other Hamilton Group rocks.[116] Figure 10 demonstrates the juxtaposition of the various geological provinces of the Appalachian Basin.[117]

"A look at rocks exposed in today's Appalachian [M]ountains reveals elongate belts of folded and thrust faulted marine sedimentary rocks, volcanic rocks and slivers of ancient ocean floor."[118] These rocks were formed from the erosional debris that was derived from the wearing away of the highlands.[119] This denudation[120] created rock fragments and minerals that ranged from large boulders to micron size clays.[121] These grains or bits of minerals, rock

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[114] United Nations Convention on the Law of the Sea art. 76, Dec. 10, 1982, *available at* http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf (last visited Mar. 1, 2014).

> The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance.

Id. at 53; *see also* Kristian Soegaard & Kenneth A. Eriksson, *Transition from Arc Volcanism to Stable-Shelf and Subsequent Convergent-Margin Sedimentation in Northern New Mexico from 1.76 Ga*, 94 J. GEOLOGY 47, 47 (1986).

[115] *See generally* Christopher Beaumont et al., *Orogeny and Stratigraphy: Numerical Models of the Paleozoic in the Eastern Interior of North America*, 7 TECTONICS 389 (1988); L. L. Sloss, *Section of Geological Sciences: Orogeny and Epeirogeny: The View from the Craton*, 28 TRANSACTIONS N.Y. ACAD. OF SCI. 579 (1966).

[116] *See, e.g.*, ROBERT C. MILICI & CHRISTOPHER S. SWEZEY, UNITED STATES GEOLOGICAL SURV., OPEN-FILE REPORT SERIES 2006-1237, ASSESSMENT OF APPALACHIAN BASIN OIL AND GAS RESOURCES: DEVONIAN SHALE–MIDDLE AND UPPER PALEOZOIC TOTAL PETROLEUM SYSTEM tbl. 2, 10–11 (2006), *available at* http://pubs.usgs.gov/of/2006/1237/of2006-1237.pdf.

[117] *The Appalachians*, USGS.GOV, http://3dparks.wr.usgs.gov/nyc/images/fig51.jpg (last visited Apr. 3, 2014).

[118] *Geologic Provinces of the United States: Appalachian Highlands Province*, USGS.GOV, http://geomaps.wr.usgs.gov/parks/province/appalach.html (last updated Jan. 13, 2004).

[119] *See, e.g.*, *id.* ("Thick layers of . . . rock was deposited on the shallow sea bottom when the region was submerged. When seas receded, terrestrial sedimentary deposits and erosion dominated.").

[120] On denudation, see generally Sheldon Judson, *Erosion of the Land*, 56 AM. SCIENTIST 356 (1968).

[121] *See, e.g.*, Curtis & Klemo, supra note 39 ("During the middle Devonian, sediments eroding from the Arcadian Mountains were washed down into the Catskill Delta. Coarser-grained sediments, including sand and gravel-sized particles quickly settled near the shore. However, finer-grained fragments (silt and clay-sized) continued to flow as a slow underwater landslide,

fragments, and clays were carried in rivers to deltas and estuaries and "dumped" into the sea.[122] The particles then settled by gravity, first forming sandstones; the clays being the lightest and smallest flowed far out to sea and eventually sank. Once they were deposited and buried by later settling clay particles, they formed shales.[123]

The scholarly study of shales is quite recent. It began during the 1970s.[124] In contrast, the characteristics of other sedimentary rock reservoirs, such as sandstones and limestones, have been studied for decades.

B. *Thrust Faults*[125]

One key feature of the Valley and Ridge Province is the predominance of thrust faults, *e.g.*, the Burning Springs anticline in West Virginia,[126] and the

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accumulating within the deepest part of the Appalachian Basin."). A micron is equal to one-thousandth of a millimeter (0.001mm), or approximately 0.000039 ($3.9 ^{x} 10^{-5}$) of an inch. Particles that are one micron in size fall into the clay family. *See, e.g.*, ROBERT L. FOLK, PETROLOGY OF SEDIMENTARY ROCKS 23 (1980). Indeed, clays include "anything finer than 4 microns . . . ." *Id.* at 89. Once sedimentary clay sediments consolidate (turn to rocks) they are known as shales, like the Marcellus shale.

[122] Curtis & Klemo, *supra* note 39.

> The western edge of the Arcadian Mountains met the eastern edge of the Appalachian Basin sea in a region called the Catskill Delta.
>
> During the middle Devonian, sediments eroding from the Arcadian Mountains were washed down into the Catskill Delta. Coarser-grained sediments, including sand and gravel-sized particles quickly settled near the shore. However, finer-grained fragments (silt and clay-sized) continued to flow as a slow underwater landslide, accumulating within the deepest part of the Appalachian Basin. Adding to those fine rock fragments were organic materials originating from the algae and other microorganisms living in the water.

Id.

[123] *Id.*

[124] *See, e.g.*, PAUL E. POTTER ET AL., SEDIMENTOLOGY OF SHALE: STUDY GUIDE AND REFERENCE SOURCE (1980).

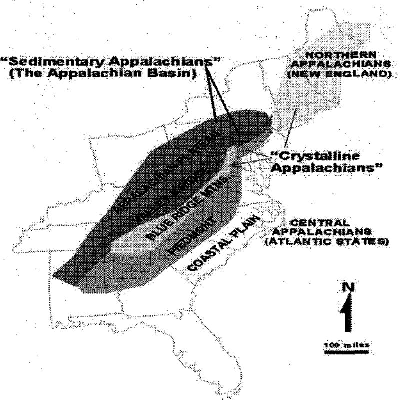
[125] "Faults . . . are ruptures along which the opposite walls [or sides] have moved past each other." BILLINGS, *supra* note 28, at 174.

[126] *See, e.g.*, Joseph F. Schwietering, *Mountains*, W. VA. GEOLOGICAL & ECON. SURV. 1996, at 37, 38 fig. 11, *available at* http://www.wvgs.wvnet.edu/www/geology/mountains.pdf ("It should be noted that all of West Virginia east of the Burning Springs Anticline [trending NE-SW across Ritchie and Wirt Counties] the Mann Mountain Anticline [trending NE-SW across Fayette County] . . . moved west . . . . The amount of westward movement progressively increased from several thousand feet along the Burning Springs Anticline and the Mann Mountain Anticline to several miles in the eastern part of the State."). On thrust faults see generally BILLINGS, *supra* note 28, at 196–98; Parker Gay, Jr., *How Far Did the Appalachian Thrusts Move? A Study of the Burning Springs and Pine Mountain Structure,* U. OF KENTUCKY, http://www.uky.edu/KGS/esaapg07/esaapg07abst/Gay.pdf (last visited Sept. 22, 2013); Richard

Pine Mountain thrust,[127] located in the eastern Kentucky Coalfields. Thrust faults are movements of the earth's crust, whereby older rocks are pushed, slide-over, or are "thrust" over younger rocks "causing rocks of different ages to be juxtaposed . . . ."[128] That is, younger on one side of the fault and older on the other, or vice versa. Sometimes, "[s]everal such thrust slices (sheets) may stack one on top of the other in a staggered pattern,"[129] which is exactly the pattern we see in the Appalachian's Valley and Ridge Province. An example of this can be seen in Figure 11.

Indeed, in the Valley and Ridge, "Paleozoic sedimentary rocks are thrust and folded . . . . Differential erosion of the thrust and folded structures has led to the distinctive valley-and-ridge topography for which this province is famous. Deformation diminishes westward in a transition into the Appalachian Plateau."[130] Thrust faults, like all other types of rock deformation, *e.g.*, folding, and other types of faulting, lead to the creation of joints.

Figure 10. Juxtaposition of the Appalachian's Geological Provinces.



Nickelsen, *Structures of the Appalachian Foreland Fold-Trust Belt: Sequence of Structural Stages of the Alleghanian Orogeny in the Devonian Through Upper Carboniferous Section of the Anthracite Region, Appalachian Foreland, Pennsylvania, in* STRUCTURES OF THE APPALACHIAN FORELAND FOLD-THRUST BELT: FIELD TRIP GUIDEBOOK T166, 26 (1989) ("[T]he region has been important for early studies of thrusting . . . .").

[127] *See, e.g.*, Ralph L. Miller, *Where and Why of Pine Mountain and Other Major Fault Planes, Virginia, Kentucky, and Tennessee*, 273-A AM. J. SCI. 353, 353 (1973), *available at* http://earth.geology.yale.edu/~ajs/1973/ajs_273A_11.pdf/353.pdf.

[128] Nicholas M. Short, Sr., *Remote Sensing Tutorial: Sec. 2, Recognition of Faults and Joints*, FEDERATION OF AM. SCIENTISTS, https://www.fas.org/irp/imint/docs/rst/Sect2/Sect2_7.html (last visited Apr. 4, 2014).

[129] *Id.*

[130] James S. Aber, *Appalachian Mountains*, EMPORIA ST. U. (2001), http://academic.emporia.edu/aberjame/struc_geo/appalach/appalach.htm.

C. Of Joints and Cracks

In geology "joints" are "[w]ell-defined [tight] cracks [or fractures] in a rock [that] divide it into blocks."[131] Generally, joints have no movement or slippage on either side of the crack of fracture,[132] otherwise they would be faults.[133] Jointing causes planar sheets or blocks,[134] as can be seen in Figure 11.

Figure 11. Landsat View of central Pennsylvania section of the Ridge and Valley Province of the Appalachians.[135]

Moreover, joints may extend tens or hundreds of feet.[136] However, as rocks are weathered, as they are in the Appalachian Basin, the joints can open or widen by fissuring,[137] and water that percolates down these fractures may cause them to grow longer.[138] In shales, such as the Marcellus or Barnett, which

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[131] FREDERIC H. LAHEE, FIELD GEOLOGY 268 (1961).

[132] *Id.* However, "[s]light displacement may sometimes be seen . . . ." *Id.*

[133] BILLINGS, *supra* note 28, at 140 ("There has been no visible movement parallel to the surface of the joint, otherwise it would be classified as a fault.").

[134] LAHEE, *supra* note 131, at 268; *see also* BILLINGS, *supra* note 28, at 140 ("[M]ost joints are planes . . . .").

[135] *Landsat Science*, NASA.GOV, http://landsat.gsfc.nasa.gov/?p=2800 (last visited Apr. 4, 2014).

[136] BILLINGS, *supra* note 28, at 140.

[137] *Id.* at 142 ("Because of weathering the joint may be enlarged into an open fissure . . . .").

[138] *Id.*

contain joints or "natural fracturing,"[139] fissuring may be responsible for seeping hydrocarbons. To date, however, the author has been unable to find any publicly available data or report that definitively supports this type of movement. Once again, having laid down additional geological principles, we now turn to an evaluation of petroleum resources in the Appalachian Basin.

V. OIL & GAS IN THE APPALACHIAN BASIN

The Appalachian Basin has a lengthy history of oil and gas production,[140] particularly in West Virginia, Kentucky, Ohio, Pennsylvania, and New York. The Marcellus Shale[141] is a new play in the Basin. Of course, the historical production is nominal compared to that of the Gulf Coast. Pre-2005, the target oil and gas formations, or plays,[142] included the Lower Devonian

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[139] *See, e.g.*, Trisha A. Smrecak et al., *Jointing and Fracturing in the Marcellus Shale*, 5 MARCELLUS SHALE 1, 2 (2011), *available at* http://www.museumoftheearth.org/files/marcellus/Marcellus_issue5.pdf ("[T]he shales surrounding and including the Marcellus have already experienced natural fracturing, or jointing, as a part of their geologic history."); *see also* Terry Engelder et al., *Joint Sets that Enhance Production from Middle and Upper Devonian Gas Shales of the Appalachian Basin*, 93 AM. ASS'N PROF. GEOLOGY 857, 858 (2009).

> Devonian–Mississippian gas shale in the Appalachian Basin is particularly susceptible to joint growth, an observation dating from the early 19th century geological survey of New York state . . . . By the early 20th century, geologists recognized that fracture by joint growth in black shale differs in orientation and density when compared with joint growth within gray shale and siltstones of the Appalachian Basin . . . . Mapping of joints throughout the northern Appalachian Basin revealed that more than one black shale formation, including those of the Marcellus Formation . . . , hosts the same . . . joint[s].

Id.

[140] Ryder, *supra* note 91, at 1.

[141] *See, e.g.*, TWA Res. v. Complete Prod. Serv., Inc., 2013 WL 1304457, at *1 (Del. Super. Ct. Mar. 28, 2013).

> Within the last decade, developments in technology have led to increased interest by the oil and gas industry in the Appalachian Basin, due to deposits of natural gas located in the Marcellus Shale. The Marcellus Shale is a large geographic formation that stretches from Ohio and West Virginia into Pennsylvania and Southern New York, and contains large quantities of natural gas.

Id. (internal footnote omitted).

[142] *See generally* Jaime Kostelnik & Kristin M. Carter, *The Oriskany Sandstone Updip Permeability Pinchout: A Recipe for Gas Production in Northwestern Pennsylvania?*, 39 PA. GEOLOGY 19, 20 (2009). A "play" is defined as a collection of wells or drilling prospects located in a geologically similar located in a specific geographic area/terrain, and has a similar source rock(s) and reservoir(s). *See generally* DOUGLAS G. PATCHEN ET AL., ADDING VALUE TO THE ATLAS OF MAJOR APPALACHIAN GAS PLAYS 7 (1997).

tight Onondaga-Oriskany Sandstone formation,[143] known as the Ridgeley, in eastern West Virginia, the Mississippian age Big Lime, Mauch Chunk, Greenbrier, and Big Injun,[144] as well as the Vanango,[145] and upper Devonian Gordon sandstone interval,[146] among others. The Oriskany, which attains a subsurface thickness of up to 285 feet, has an average porosity that ranges from 1.4% to 14%.[147]

The most prominent porosity types in the Oriskany include what is termed "primary intergranular porosity," which prevails in stratigraphic pinch-out zones; "secondary dissolution porosity"; and "fracture porosity."[148] Secondary porosity occurs when a rock's primary porosity—which develops when the rock is deposited—is extinguished by fluids that flow in between the grains form cements and compacts under pressure during the burial process, when the rock is at depth.[149] These fluids then act as agents, depending on their pH, that dissolve or "eat away" the existing minerals, thereby creating new voids or porosity. An example of this can be found in Figure 6. However, "[t]he history of the Oriskany Sandstone formation in western New York and northern Pennsylvania was and is that it rapidly exhausts."[150]

The other play in the Basin is the gas-producing Bangor Limestone, also known as the Little Lime;[151] the Bangor's reservoirs characteristically

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[143] The Oriskany of "western West Virginia, and eastern Ohio [has] . . . production . . . from a combination of stratigraphic and structural traps." Jaime Kostelnik & Kristin M. Carter, *Unraveling the stratigraphy of the Oriskany Sandstone: A Necessity in Assessing Its Site-Specific Carbon Sequestration Potential*, 16 ENVTL. GEOSCIENCES 187, 187 (2009), *available at* http://www.mrcsp.org/userdata/Articles/eg09005.pdf.

[144] *See Summary Data and Statistics: Oil and Gas Statistics Description of 1997 Drilling Activity*, W. VA. GEOLOGICAL & ECON. SURV., http://www.wvgs.wvnet.edu/www/datastat/dataog97.htm (last revised Dec. 12, 2005) [hereinafter *1997 Drilling Activity*].

[145] *See, e.g.*, *Well Information System*, PA. DEPT. OF CONSERVATION AND NAT. RESOURCES, http://www.dcnr.state.pa.us/topogeo/econresource/oilandgas/resrefs/wis_home/ (last visited Apr. 4, 2014) ("[T]he James Noble No. 9 was drilled in 1998 to the Upper Devonian Age Venango Group. It reached a total depth of 2,615 feet and produced oil from one of the Venango Group sands at a depth of 2,495 feet.").

[146] *See 1997 Drilling Activity*, *supra* note 144 (discussing the Jackson-Stringtown field).

[147] *See, e.g.*, Kostelnik & Carter, *supra* note 143, at 195–96, 198.

[148] *Id.* at 187, 193.

[149] K. Pye & D. H. Krinsley, *Formation of Secondary Porosity in Sandstones by Quartz Framework Grain Dissolution*, 317 NATURE 54 (1985).

[150] Becker v. New Penn Dev. Corp., 64 N.Y.S.2d 837, 837 (N.Y. App. Div. 1946) (per curiam).

[151] *See, e.g.*, JOSEPH L. ISLAS, ASENERGY CONSULTING, GEOLOGICAL REPORT OF THE APPALACHIAN BASIN IN KENTUCKY 5 (2006), *available at* http://www.asenergyconsulting.com/PDF/Appalachian_Basin_Report.pdf.

"lack sufficient permeability to produce at high rates."[152] The formation produces gas from naturally occurring fractures, which creates a heterogeneous and expansive reservoir. These two formations are not notable producers at present, nor were they in the past.[153] Of course, the recently discovered natural gas reserves of the Marcellus and Utica shales have changed the production picture.

A. A Description of the Marcellus Black Shales

When most people think of or hear the term "fracking," they do not paint a picture in their mind's eye of rocks being shattered. But that is undeniably what occurs to rocks when they are fracked. Indeed, due to the violent blow caused by the pressure created by the mixture of water, sand, and chemicals or nitrogen,[154] the shales abruptly break or burst[155] into pieces, away

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[152] *Id.* at 7.

[153] *See generally* THE ATLAS OF MAJOR APPALACHIAN GAS PLAYS (John B. Roen & Brian J. Walker eds., 1996).

[154] *See generally* SIMONE KOTHARE, AIR PRODUCTS AND CHEMICALS, INC., ECONOMICS AND APPLICABILITY OF NITROGEN FOR FRACKING (2012), *available at* http://www.airproducts.com/industries/energy/oilgas-production/oilfield-services/product-list/~/media/F3F68760EB7D49E1A9C8512623254459.pdf.

> Nitrogen gas fracking is used for water-sensitive, shallow, and brittle shale formations because it prevents clay swelling that would otherwise be caused by water-based treatments. Nitrogen is an inert and compressible gas with low viscosity, which makes it a poor proppant carrier. Therefore, nitrogen gas treatments produce the best results in brittle shale formations that have natural fractures and stay self-propped once pressure pumping is completed. Due to the low density of gaseous nitrogen, the main applications for nitrogen gas treatments are shallow unconventional formations: coal bed methane, tight sands, and shale formations less than 5,000 ft deep. These formations tend to have low permeability (less than 0.1 md), low porosity (less than 4%) . . . .

Id.; *see also* Ky. Geological Survey, *Information on Fracking*, FRACTURED - GAS DRILLING IN APPALACHIA (Feb. 2011), http://www.fracturedappalachia.org/for-landowners/information-on-fracking (last visited Mar. 16, 2014).

> In Kentucky, most gas wells are drilled using pressurized air circulated through the drill pipe (not water) and hydraulic fracture stimulation of natural gas wells is accomplished using nitrogen as the main ingredient. The nitrogen is mixed with relatively small amounts of water (i.e., several thousands of gallons and not millions) to create a foam that is more efficient in delivering sand to prop open the induced fractures than is straight nitrogen.

Ky. Geological Survey, *supra*.

[155] *See, e.g.*, *Valentine Well, Ritchie County, West Virginia*, ALAMO PRODUCTION (2013), http://www.alamoenergycorp.com/our-projects/valentine-well-ritchie-county-west-virginia. (last visited Apr. 4, 2014) ("The well was recompleted with a three stage, 5,500 barrel slick water fracture treatment using 50,000 lbs of 20/40 mesh sand for propping up the formation."); *see also* HORIBA INSTRUMENTS, INC., MEASUREMENT OF SIZE AND SHAPE FOR FRAC SAND AND OTHER

from the borehole, forming fissures that extend thousands of feet into the formation.

These ruptures enhance the permeability of the Marcellus shale, which has a natural or original permeability of 0.000047 (4.7×10^{-5}) to 0.000217 (2.17×10^{-4}) millidarcies (extremely small or fine).[156] The augmented permeability allows the petroleum to flow into the bore hole and then up through the casing to the surface, where it is gathered into a series of pipelines that ultimately transport it to urban markets.

Both in outcrop and in the subsurface, the Marcellus Shale's oil and gas-bearing strata are black in color.[157] An example of this can be seen in Figure 13. The reason for this dark color is the Marcellus's high organic content, which is measured as total organic content or "TOC."[158] The Marcellus attains a net thickness of organic shales ranging from 100 feet to 200 feet.[159] In the Appalachian Basin the Marcellus Shale was "deposited in a very deep, sediment starved, anoxic trough that formed in response to an impinging tectonic plate."[160] The term "anoxic" refers to an oxygen starved environment. The modern archetype of an anoxic basin is the Black Sea.[161] Anoxic

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PROPPANTS USING THE CAMSIZER 1 (2012), *available at* http://www.horiba.com/fileadmin/uploads/ Scientific/Documents/PSA/Application_Notes/AN205_app.pdf.

> Typical proppant sizes are generally between 8 and 140 mesh (106 µm - 2.36 mm), for example 16-30 mesh (600 µm – 1180 µm), 20-40 mesh (420 µm - 840 µm), 30-50 mesh (300 µm – 600 µm), 40-70 mesh (212 µm - 420 µm) or 70-140 mesh (106 µm - 212 µm). When describing frac sand, the product is frequently referred to as simply the sieve cut, i.e. 20/40 sand.

HORIBA INSTRUMENTS, INC., *supra.*

[156] C. H. Sondergeld et al., Micro-Structural Studies of Gas Shales (Soc'y of Petroleum Engineers conference paper) (Feb. 23–25, 2010), *available at* http://www.onepetro.org/conference-paper/SPE-131771-MS.

[157] *See generally* BRUNER & SMOSNA, *supra* note 14 (photographs).

[158] *See, e.g.*, Guochang Wang & Timothy R. Carr, *Organic-rich Marcellus Shale Lithofacies Modeling and Distribution Pattern Analysis in the Appalachian Basin*, 20 AM. ASSOC. PETROL. GEOLOGISTS BULL. 1, 5 (2013), *available at* http://pages.geo.wvu.edu/~tcarr/Wang_Manuscripts/The%20fourth%20paper.pdf ("TOC data from 18 wells were evaluated statistically and used to define Marcellus Shale lithofacies in terms of two key factors for shale-gas reservoirs: mineralogy and organic matter richness.").

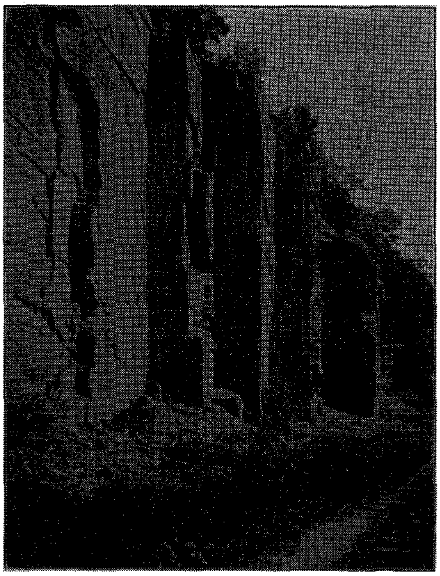
[159] ROBERT G. PIOTROWSKI & JOHN A. HARPER, U.S. DEP'T OF ENERGY BLACK SHALE AND SANDSTONE FACIES OF THE DEVONIAN "CATSKILL" CLASTIC WEDGE IN THE SUBSURFACE OF WESTERN PENNSYLVANIA (1979), *available at* http://dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_007847.pdf.

[160] *A Presentation on the Geology of the Marcellus Shale: The Depositional Setting of the Marcellus Black Shale*, W. VA. SURFACE OWNERS' RIGHTS ORG., *available at* http://www.wvsoro.org/resources/marcellus/RamsayBarrett-Shale.pdf (last modified Apr. 2007).

[161] *See, e.g.*, JAMES W. MURRAY ET AL., Univ. WASH. SCH. OCEANOGRAPHY, OXIC, SUBOXIC AND ANOXIC CONDITIONS IN THE BLACK SEA (2005), *available at*

environments are conducive to the growth of organic materials, which are required for the generation of gas or oil.[162]

Figure 12: Excellent example of vertical jointing. Note the joint planes. Photograph taken by Dr. Edward M. Kimble, United States Geological Survey.[163]



B. The Marcellus Shale's Heterogeneity

The Marcellus Shale is not a monolithic or uniform formation. Evidence of this can be seen in Figure 13. It is divided into members, including the Union Springs Member; the Cherry Valley Limestone and the Oatka Creek Member in New York; the Cherry Valley Limestone, known as the Purcell Limestone Member, in Pennsylvania;[164] as well as the Millboro Shale in

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http://www.ocean.washington.edu/people/faculty/jmurray/BlackSeaOverview.pdf ("The Black Sea is the classic marine anoxic basin.").

[162] *See generally* G. J. Demaison & G.T. Moore, *Anoxic Environments and Oil Source Bed Genesis*, 64 AM. ASS'N PETROLEUM GEOLOGISTS BULL. 1179 (1980).

[163] Dr. Robert Weems, Emeritus Paleontologist, USGS, *Joints in the Portage Formation (Enfield Shale member?)*, Cayuga Lake, Tompkins County, N.Y. (on file with author).

[164] Katharine Lee Avary, *Geology of the Marcellus Shale and Current Activity in West Virginia*, WVWATERCONFERENCE.ORG, http://www.wvwaterconference.org/docs/Combined%20Presentations/New%20Gas%20Well%20

southeastern West Virginia and adjacent Virginia. The Marcellus is part of the Hamilton Group, as shown in Figure 14. The total shale section attains a thickness up to 1,500 feet. However, the producing section, which is radioactive, attains a thickness ranging from less than 50 feet to 250 feet. This can be seen in Figure 15.

Figures 15 and 16 also show the Marcellus Shale's members as they are depicted in well logs and in outcrop. The well logs are run after the well drilling is completed or, in the oil and gas vernacular, "reaches TD (total depth)"—the depth being prearranged by the geologist. Note that the organic-rich section—*i.e.*, the producing section—is highly radioactive, as compared to the other sections of the shale.

Note that in Figure 15, the term "Cal"—the leftmost line in the left panel—refers to the caliper log. It runs down the hole and provides the log interpreter with a continuous reading of both the size and shape of the well bore with depth. It also evaluates whether the well's/hole's walls are holding up and therefore straight,[165] or whether they were "washed out" during the drilling process. The latter would require extra work to keep the well bore straight. "GR" refers to the gamma-ray tool, which measures the radioactivity of a rock.

Moreover, in the log's right panel, the leftmost line is the "SP log," also referred to as spontaneous potential or self-potential log. It measures the electrical conductivity of a rock, in millivolts.[166] Different rock facies have

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Extraction%20Methods%20Does%20Marcellus%20Opportunity%20Mean%20Water.pdf (last visited Mar. 1, 2014).

[165] *See generally Oilfield Glossary: Caliper Log*, SCHLUMBERGER, http://www.glossary.oilfield.slb.com/en/Terms.aspx?LookIn=term%20name&filter=caliper%20log (last visited Mar. 1, 2014).

> Since wellbores are usually irregular (rugose), it is important to have a tool that measures diameter at several different locations simultaneously. Such a tool is called a multifinger caliper. Drilling engineers or rigsite personnel use caliper measurement as a qualitative indication of both the condition of the wellbore and the degree to which the mud system has maintained hole stability. Caliper data are integrated to determine the volume of the openhole, which is then used in planning cementing operations.

Id.

[166] *See generally Oilfield Glossary: Spontaneous Potential*, SCHLUMBERGER, http://www.glossary.oilfield.slb.com/en /Terms/s/spontaneous_potential.aspx (last visited Mar. 1, 2014).

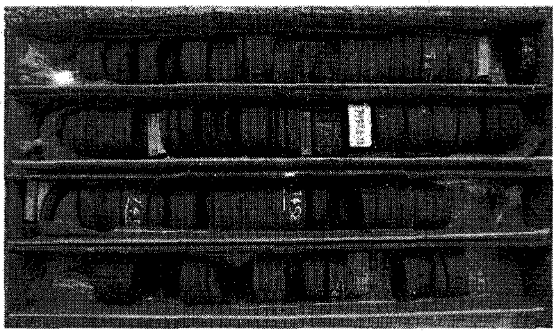
> Naturally occurring (static) electrical potential in the Earth. Spontaneous potentials [SP] are usually caused by charge separation in clay or other minerals, by the presence of a semipermeable interface impeding the diffusion of ions through the pore space of rocks, or by natural flow of a conducting fluid (salty water) through the rocks. Variations in SP can be measured in the field and in wellbores to determine variations of ionic concentration in pore fluids of rocks.

Id.

different electrical properties or signatures,[167] as exemplified by the Onondaga Limestone and the Marcellus Shale. A rock containing petroleum hydrocarbons reduces or dampens the SP log's response.[168]

Additionally, since shales are generally impermeable (and non-porous), they provide a signal that is different from a permeable rock, like a sandstone.[169] Finally, the rightmost log is the Density Log, which measures the rock's density. A petroleum bearing zone will be less dense than one that is not, because the oil or gas that fills the pores is less dense than solid rock.[170]

Figure 13. A core sample of the Marcellus Shale.[171]



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[167] *See generally* Martin K. Dubois et al., Comparison of Rock Facies Classification Using Three Statistically Based Classifiers (Feb. 2005), *available at* http://www.kgs.ku.edu/PRS/publication/2004/OFR04_64 ("Facies and rocks in general have a large number of physical and chemical properties that can be used for classification. In oil and gas wells the most readily available properties related to the rocks encountered are measurements made by petrophysical tools lowered into the . . . wellbore after a well is drilled. Digital information is recorded . . . from a variety of devices that measure a number of physical properties (porosity, natural gamma radiation, resistivity, photoelectric effect).").

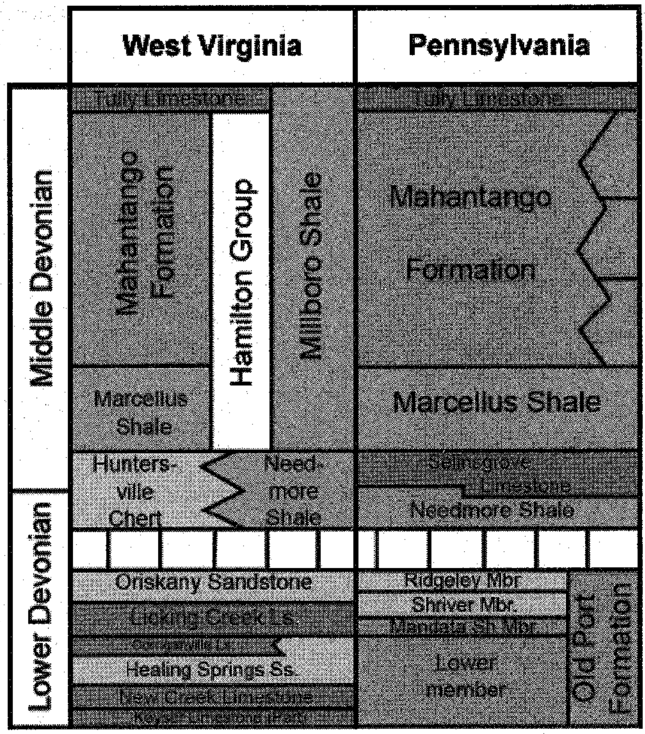
[168] *See generally* Michel Heeremans, Univ. of Oslo, Spontaneous Potential, slide 7, http://www.uio.no/studier/emner/matnat/geofag/GEO4250/v08/undervisningsmateriale/Lectures/BWLA%20-%20Spontaneous%20Potential%20-%20Gamma%20Ray.pdf (last visited Mar. 23, 2014) ("In hydrocarbon-bearing zones, the SP curves deflection is reduced: Hydrocarbon suppression.").

[169] *See, e.g.*, Schlumberger, *supra* note 63, at 3-3 ("[T]he potential observed opposite the permeable sandstone bed is negative with respect to the potential opposite the shale. This negative variation corresponds to an SP curve deflection toward the left on the SP log . . . .").

[170] The DØ and NØ are not relevant for our discussion.

[171] Core of "black, sooty, organic-rich Marcellus Shale; . . . MERC-1 [well], Monongalia County, West Virginia." The depth interval is from 7,451–7,463 feet. Reproduced from Bruner & Smosna, *supra* note 14, at 43.

Figure 14. Stratigraphy of the Lower and Middle Devonian, including the Hamilton Group's Marcellus Shale[172]



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[172] The stratigraphic section is reproduced from MILICI & SWEZEY, *supra* note 116, at tbl. 2. *See also Generalized Stratigraphic Nomenclature Representing Late Mississippian and Devonian Rocks of the Northern Part of the Appalachian Basin Province*, GEOLOGY.COM (last visited Mar. 27, 2014), http://geology.com/articles/marcellus/marcellus-stratigraphy-complete.gif (modifying the work produced by Milici and Swezey from 2006).

Figure 15. Illustration of various log signatures in the Marcellus Shale, and the formations that both underlie and overlie it.

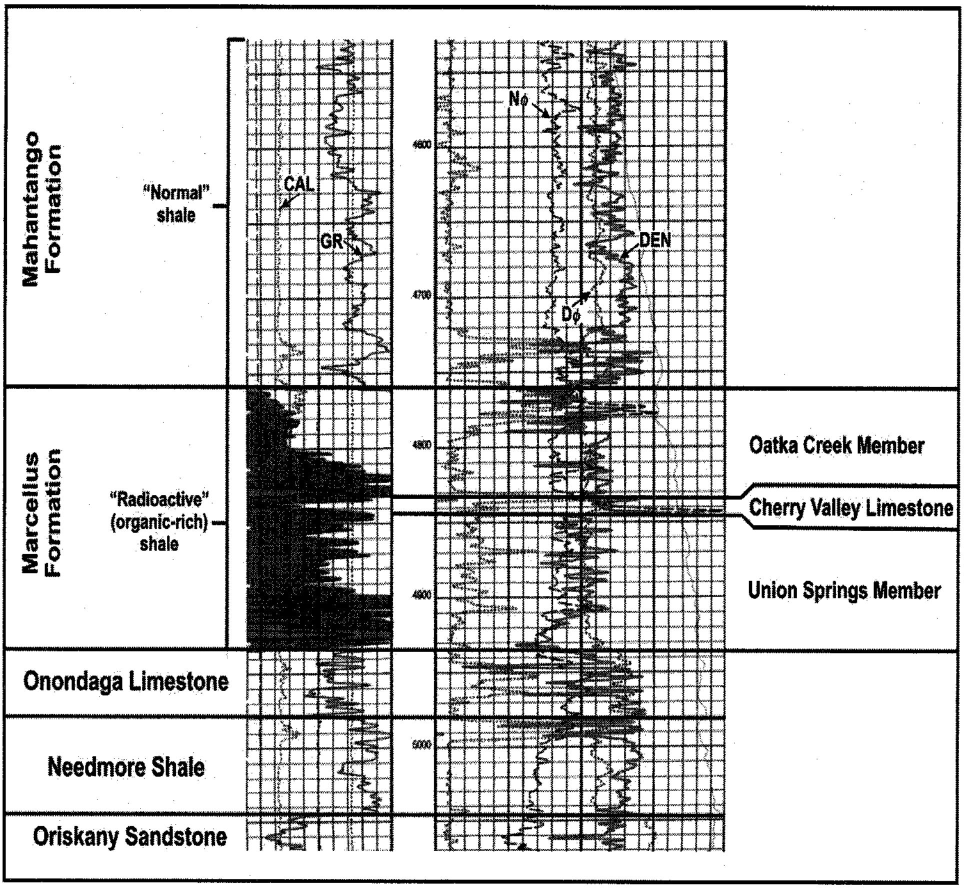
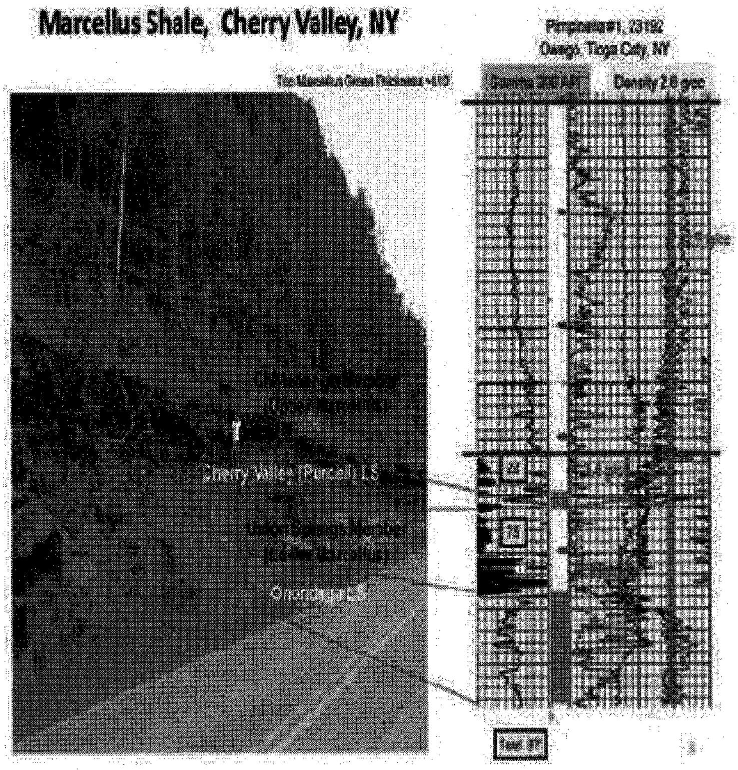


Figure 16. Outcrop of the Marcellus Shale in Cherry Valley, New York, No. 1 Well, located in Oswego, Tioga County, New York. Note that the Marcellus section shown in the photograph is 410 feet (125 meters) thick. (See the person in the white shirt for scale).



Black shales, including the Marcellus and Millboro Shales of the Hamilton Group, cover a wide-ranging area across the Appalachian Basin.[173] They were most likely deposited in comparatively deep water when the foreland basin was first evolving. "The Marcellus Shale . . . is best developed in central Pennsylvania where it is up to 200 feet thick."[174]

The Hamilton Group and its lateral equivalent, the Millboro Shale, in Virginia and West Virginia can achieve a thickness of approximately 1,500 feet.[175] The net thickness of the black radioactive portion of the members of the

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[173] MILICI & SWEZEY, *supra* note 116, at 13.

[174] *Id.*

[175] *Id.*

Marcellus and associated shales measures anywhere from approximately 50 feet "in Ohio and the western parts of New York, Pennsylvania, and northern West Virginia to about 200 feet in northeastern Pennsylvania."[176] Moreover,

> [t]he Hamilton Group and Genesee, Sonyea, and West Falls Formations . . . consist of dark to very dark grayish-brown, calcareous, organic-rich shale . . . . The basal unit of the Hamilton Group is the Middle Devonian Marcellus Shale . . . [, which is a] black shale tongue that was deposited unconformably on the Onondaga Limestone. The Marcellus Shale is characterized by high, natural radioactivity and low density. Core analysis of the Marcellus Shale from a well drilled in Monongalia County, West Virginia, *indicates it possesses high gas permeabilties (5 to 50 md) and gas storage capacity up to 26 hundred cubic feet per cubic foot of shale . . . .*[177]

But, what is the porosity of these rocks? Analyses of a Marcellus Shale core sample from a well in Chenango County, New York (northeast of Binghamton, New York) shows that "[v]isible porosity in tight[] . . . mudstone and shales is sparse or rare and comprises matrix-hosted microporosity, intergranular microporosity . . . and suspect microfracture porosity . . . [with no] preservation of natural fracture porosity."[178]

Finally, with regards to traps, recall that earlier we discussed structural, stratigraphic, or combination traps, these are known as "conventional resources." They are characterized by the discrete layers of water, oil and gas.[179] Alternatively, "continuous accumulations are regional stratigraphic accumulations of hydrocarbons, generally gas, which commonly occur in blanket-like sedimentary deposits such as coal (coalbed methane) [and] shales rich in organic material . . . ."[180] Nevertheless, the Marcellus and Utica Shales

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[176] *Id.* at 38.

[177] OHIO DEP'T OF NATURAL RESOURCES, DIVISION OF GEOLOGICAL SURV., A PRELIMINARY ASSESSMENT OF GEOLOGIC CARBON SEQUESTRATION POTENTIAL FOR THE PROPOSED BAARD ENERGY OHIO RIVER CLEAN FUELS PLANT IN WELLSVILLE, OHIO 25 (2010), *available at* ftp://dnr.ohio.gov/Geological_Survey/DOE/Wellsville_Final%20Report.pdf (emphasis added).

[178] DALLAS SPEAR, TERRATEK, INC., PETROGRAPHIC & MINERALOGICAL EVALUATION OF SHALE CORE SAMPLES–BEAVER MEADOW # 1 WELL 6 (2004), *available at* http://www.papgrocks.org/Beaver%20Meadows%201%20PetroMin%20Eval%20of%20Shale%20Core.pdf.

[179] MILICI & SWEZEY, *supra* note 116, at 25.

[180] *Id.*; *see also* Letter from Consol Energy, Inc., to Tia L. Jenkins, Securities Exchange Commission (Feb. 12, 2012), *available at* http://www.sec.gov/Archives/edgar/data/1070412/000107041212000028/filename1.htm.

produce from structural traps. Next, we discuss disputes involving the Marcellus Shale, as well as the use of experts.

VI. MARCELLUS SHALE DISPUTES AND GEOLOGICAL EXPERTS

A snapshot of the Marcellus Shale case law involving geological experts yields a rich tapestry of how geological concepts and geologists fit into the resolution of disputes. Indeed, as is discussed below, expert testimony by geologists assists the trier of fact in comprehending the evidence presented or in deciding a fact at issue in the dispute.[181] Moreover, expert geologists are crucial to an understanding of how a rock's properties are interrelated or fit within the structure of the dispute. This is particularly true in complex cases involving petroleum-bearing shales, such as the Marcellus, where issues of porosity, permeability or the evaluation of other formation properties—whether via core analysis or log interpretation—must be tested by the proofs offered, in order to aid the trier of fact in resolving the factual underpinnings of a dispute.

For example, in *State ex rel. Blue Eagle Land, LLC v. West Virginia Oil & Gas Conservation Commission*,[182] Chesapeake Appalachia, L.L.C., filed a brief asserting that

> [i]n this case, Chesapeake, and the other operators, are interested in evaluating the gas bearing potential of the "Marcellus Shale," a formation that lies directly on top of the Onondaga formation. *As explained by the engineers and geologists* at the administrative hearing before the Commission on May 17, 2007, *the length of the tool that must be used for purposes of logging the Marcellus Shale* formation is 66 feet in length, and another is 34 feet long. In other words, in order to log the Marcellus Shale, the tools must penetrate in excess of 20 feet below the top of the Onondaga in order that the

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[181] *See, e.g.*, FED. R. EVID. 702. Federal Rule of Evidence 702, Testimony by Expert Witnesses, provides in pertinent part that

> [a] witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if:
> (a) the expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue;
> (b) the testimony is based on sufficient facts or data;
> (c) the testimony is the product of reliable principles and methods; and
> (d) the expert has reliably applied the principles and methods to the facts of the case.

[182] 664 S.E.2d 683 (W. Va. 2008).

> operator can properly log and evaluate the complete portion of the Marcellus Shale.[183]

Were the Oil & Gas Commission to challenge Chesapeake's contention that the logging tools "must penetrate in excess of 20 feet below the top of the Onondaga"[184] so that the Marcellus Shale could be accurately logged and evaluated, it would need to present an expert geologist and/or engineer, who was well versed in the field of logging tools, in order to contest the company's position.

Similarly, in *Elbow Fish & Game Club, Inc. v. Guillaume Business Opportunity Group*,[185] the court noted that "Defendant GBOG has provided that *no expert witness will testify to Defendant GBOG's theory as to whether Marcellus shale is similar to coal. . . .*"[186] Likewise, in *In re Application of Chemung County*,[187] one of the issues before the Administrative Law Judge ("ALJ") was whether a sanitary landfill's proposed acceptance of Marcellus Shale well cuttings that were contended to contain high levels of naturally occurring radioactivity was legal.[188] In addressing the admission of expert testimony, the ALJ observed that a

> proposed expert . . . Dr. Anthony Ingraffea, . . . stat[ed] that there is no information in the [permittee's consultant] CoPhysics report that allows one to determine whether the waste that was sampled and tested, as reported, in fact originated from the Marcellus Shale. In response, NEWSNY [, the permittee,] provided a report of Billman Geologic Consultants, Inc. . . . which characterized the drill cutting samples collected during the CoPhysics study as Marcellus Shale, given their classic black color after the samples were washed and viewed under a microscope.[189]

Finally in the Chemung County case, "Dr. Conrad Volz, a third proposed expert . . . stat[ed that] it is not clear from the CoPhysics

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[183] Response of Chesapeake Appalachia, L.L.C., to Petition for Writ of Prohibition, Blue Eagle Land, LLC v. W. Va. Oil & Gas Conservation Com'n, 664 S.E.2d 683 (W. Va. 2008) (No. 33705).

[184] *Id.*

[185] No. 12-00825, 2013 WL 1364007 (Pa. Com. Pl. Mar. 25, 2013).

[186] *Id.* at *6 (emphasis added).

[187] *In re* Application of Chemung Cnty., App. No. 8-0728-00004/00013, 2010 WL 5612197 (N.Y. Dept. Envtl. Conserv. Sept. 3, 2010) (discussing expert testimony regarding acceptance of Marcellus Shale well cuttings).

[188] *See id.* at *2.

[189] *Id.* at *22.

report that samples were taken from and are scientifically representative of waste that originates from the horizontal portion of a Marcellus Shale drilling operation . . . ."[190]

A final example comes from the case of *In re Central New York Oil & Gas Co., L.L.C.*[191] In an appeal from a trial court's grant of petitioner's motion to preclude respondents' expert from testifying at trial, the appellate court noted that that "[r]espondents' report was drafted by Donald Zaengle, a geologist . . . [who] opined that petitioner's easement would preclude respondents from exercising their rights to develop gas in the Marcellus shale formation. Zaengle explained that the Marcellus formation['s] . . . *low porosity and permeability* will serve to prevent stored gas from escaping."[192]

A. The Use of Expert Testimony: The Federal Scheme

As the previous section demonstrated, expert testimony may be indispensable in oil and gas exploration and production cases generally, and in fracking cases specifically, in order to assist the trier of fact. The use of experts in federal courts is governed by the Supreme Court's 1993 decision in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*[193] In *Daubert*, the Court rejected the previous "general acceptance" standard enunciated in *Frye v. United States.*[194] In rejecting the "general acceptance" test, Justice Blackmun held that because "the *Frye* test was displaced by the Rules of Evidence does not mean . . . that the Rules themselves place no limits on the admissibility of purportedly scientific evidence."[195]

Moreover, the Court, noting that the trial judge remains the gate-keeper for all relevant evidence, including expert testimony, declared that "the trial judge [is not] disabled from screening such [scientific] evidence. To the contrary, under the Rules [of Evidence,] the trial judge must ensure that any and all scientific testimony or evidence admitted is not only relevant, but reliable."[196] Thus, under Federal Rule of Evidence 104,[197] the trial judge is

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[190] *Id.* at *16.

[191] 107 A.D.3d 1199 (N.Y. App. Div. 2013).

[192] *Id.* at 1200 (emphasis added).

[193] 509 U.S. 579 (1993). On the use of the *Daubert* standard in complex litigation, see Itzchak E. Kornfeld, *Comment to the Boundaries of Groundwater Modeling Under the Law: Standards for Excluding Speculative Expert Testimony*, 28 TORT & INS. L. J. 59 (1992); see also Susan R. Poulter, *Science and Psuedo-Science: Will Daubert Make a Difference?*, 40 ROCKY MTN. MIN. L. INST. 7 (1994).

[194] 293 F. 1013 (D.C. Cir. 1923).

[195] *Daubert*, 509 U.S. at 589.

[196] *Id.* ("The primary locus of this obligation is Rule 702, which clearly contemplates some degree of regulation of the subjects and theories about which an expert may testify. '*If scientific,*

required to conduct a pretrial inquiry in order to determine whether the scientific findings and expert testimony that is to be proffered is scientifically valid and reliable—both as to methodology and procedure[198]—and will assist the trier of fact. This procedure is called a "*Daubert* hearing."[199]

One factor that courts need to weigh in a *Daubert* hearing is whether the expert's methodologies and procedures have been widely accepted by the scientific community that the expert operates in.[200] Thus, the opinion of a hydrologist about a computer model's output should be evaluated by a

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technical, or other specialized *knowledge will assist the trier of fact* to understand the evidence or to determine a fact in issue' an expert 'may testify *thereto*.'" (emphasis added.) (quoting FED. R. EVID. 702)).

[197] FED. R. EVID. 104, Preliminary Questions, provides the following in pertinent part:

> (a) In General. The court must decide any preliminary question about whether a witness is qualified, a privilege exists, or evidence is admissible. In so deciding, the court is not bound by evidence rules, except those on privilege.
>
> (b) Relevance That Depends on a Fact. When the relevance of evidence depends on whether a fact exists, proof must be introduced sufficient to support a finding that the fact does exist. The court may admit the proposed evidence on the condition that the proof be introduced later.
>
> (c) Conducting a Hearing So That the Jury Cannot Hear It. The court must conduct any hearing on a preliminary question so that the jury cannot hear it if . . .
>
> (3) justice so requires . . .
>
> (e) Evidence Relevant to Weight and Credibility. This rule does not limit a party's right to introduce before the jury evidence that is relevant to the weight or credibility of other evidence.

[198] *Daubert*, 509 U.S. at 590.

> The subject of an expert's testimony must be "scientific . . . knowledge." The adjective "scientific" implies grounding in the methods and procedures of science. Similarly, the word "knowledge" connotes more than subjective belief or unsupported speculation. The term "applies to any body of known facts or to any body of ideas inferred from such facts or accepted as truths on good grounds."

Id. at 589–90 (internal footnotes omitted).

[199] *See, e.g.*, Cook *ex rel.* Estate of Tessier v. Sheriff of Monroe County, Fla., 402 F.3d 1092, 1113 (11th Cir. 2005) ("[W]e stress that the burden of laying the proper foundation for the admission of expert testimony rests with its proponent. . . . We [also] recognize that a *Daubert* hearing before the trial court might have given [Plaintiff/Appellant] Cook an additional opportunity to meet this burden, but we note that the trial court was under no obligation to hold one. As we have explained previously, '*Daubert* hearings are not required, but may be helpful in "complicated cases involving multiple expert witnesses."'" (citations omitted)).

[200] *Daubert*, 509 U.S. at 594 ("Widespread acceptance can be an important factor in ruling particular evidence admissible, and 'a known technique which has been able to attract only minimal support within the community,' may properly be viewed with skepticism." (citation omitted)).

comparable hydrologist, *i.e.*, one with similar work experience and academic credentials.[201]

There is however one caveat to the *Daubert* standard. The majority of scientists, as compared to lay people, are painfully aware that science is neither infallible nor absolute. Indeed, the *Daubert* Court emphasized this point when it acknowledged that

> [o]f course, it would be unreasonable to conclude that the subject of scientific testimony must be "known" to a certainty; arguably, there are no certainties in science. But, in order to qualify as "scientific knowledge," an inference or assertion must be derived by the scientific method. Proposed testimony must be supported by appropriate validation—*i.e.*, "good grounds," based on what is known. In short, the requirement that an expert's testimony pertain to "scientific knowledge" establishes a standard of evidentiary reliability.[202]

The foregoing brings us then to a subject that was greatly in vogue during the 1990s, but still has some salience today—junk science.

B. The Admissibility of Expert Testimony in State Courts

In the Marcellus region's state courts, both West Virginia[203] and Ohio[204] have adopted the *Daubert* admissibility standard. Pennsylvania courts, however, employ the *Frye* "generally-accepted scientific methodology" admissibility standard.[205] Pennsylvania has also established a standard for the admissibility of experts for its trial courts. That standard is fully reproduced below:

> (a) If a party moves the court to exclude expert testimony which relies upon novel scientific evidence, on the basis that it is inadmissible under Pa.R.E. 702 or 703,
> (1) the motion shall contain:

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[201] *See, e.g.*, Itzchak E. Kornfeld, *A Postscript on Groundwater Modeling:* Daubert, *"Good Grounds," and the Central Role of Cross-Examination*, 29 TORT & INS. L. J. 646 (1994).

[202] *Daubert*, 509 U.S. at 590 (internal citations omitted).

[203] *See, e.g.*, Gentry v. Magnum, 466 S.E.2d 171 (W. Va. 1995).

[204] *See* OHIO R. EVID. 702.

[205] *See* Grady v. Frito-Lay, Inc., 839 A.2d 1038, 1044 (Pa. 2003) ("After *Daubert* was decided, a number of state courts adopted the *Daubert* standard. We, however, have continued to follow *Frye*. . . . After careful consideration, we conclude that the *Frye* rule will continue to be applied in Pennsylvania. In our view, *Frye's* 'general acceptance' test is a proven and workable rule, which when faithfully followed, fairly serves its purpose of assisting the courts in determining when scientific evidence is reliable and should be admitted." (footnotes omitted)).

> (i) the name and credentials of the expert witness whose testimony is sought to be excluded,
> (ii) a summary of the expected testimony of the expert witness, specifying with particularity that portion of the testimony of the witness which the moving party seeks to exclude,
> (iii) the basis, set forth with specificity, for excluding the evidence,
> (iv) the evidence upon which the moving party relies, and
> (v) copies of all relevant curriculum vitae and expert reports;
> (2) any other party need not respond to the motion unless ordered by the court;
> (3) the court shall initially review the motion to determine if, in the interest of justice, the matter should be addressed prior to trial. The court, without further proceedings, may determine that any issue of admissibility of expert testimony be deferred until trial; and
> (4) the court shall require that a response be filed If it determines that the matter should be addressed prior to trial.[206]

Those states that have adopted the *Daubert* standard will most likely accept the logic declared in *Kumho Tire Co., Ltd. v. Carmichael.*[207] There, the Supreme Court expanded the reliability and relevancy prerequisites to all expert witness testimony. The Court unambiguously announced that "[t]he trial court must have the same kind of latitude in deciding *how* to test an expert's reliability, and to decide whether or when special briefing or other proceedings are needed to investigate reliability, as it enjoys when it decides *whether or not* that expert's relevant testimony is reliable."[208]

Finally, in order to meet the touchstones set out by the judiciary or legislatures, litigators who employ experts in the unconventional oil and gas arena should consider the following four factors when choosing an expert: (1) whether the expert has credibility and a presence; (2) whether the expert is a good teacher, who can break down complex scientific principles, so that a lay person can understand them without being patronizing or making condescending statements; (3) whether the expert is local, since juries and/or judges, if the latter are the trier of fact, generally prefer someone from their home turf; and (4) whether the expert is really an expert, *i.e.*, know the subject matter in detail, regardless of whether he or she has testified before. If the expert is a master of her subject matter, she will not be shaken or intimidated by the cross-examining lawyer.

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[206] 231 PA. CODE § 207.1 (2014) (Motion to Exclude Expert Testimony Which Relies Upon Novel Scientific Evidence).

[207] 526 U.S. 137 (1999).

[208] *Id.* at 152 (emphasis in original).

VII. CONCLUSION

Drilling in and fracking the shales of the Appalachian Basin, which today include the Marcellus and Utica and possibly other Devonian-age formations, will no doubt result in disputes and litigation. When these cases involve (1) formation evaluation; (2) cement jobs; (3) mud and hole circulation; (4) perforation of zones that have low porosity and permeability, or where the porosity was not sufficiently tested; (5) groundwater contamination; (6) operational mishaps; or (7) fracking induced accidents; experts will be required to provide their opinions, about the what and why of what occurred, before a trier of fact. In the foregoing examples of operational failure within the ambit of the petroleum industry, more often than not, a geological expert will be needed to opine about rock and trap characteristics, among the other subjects enumerated previously.

If previous oil and gas exploration and production litigation is utilized as a historical polestar, then formation analysis, the internal properties of rocks, and the local and regional geology will be key issues in future fracking disputes. One will have to wait and see whether instances of groundwater contamination continue. Lawyers and the wider community, however, need to remember that fracking involving horizontal drilling is a relatively new technology, and that the people who are hurt for the most part—whether lessors, lessees, workers, adjacent landowners—*only* wish to be made whole. We may forget that from time to time. But, as a society, which includes all of the stakeholders involved in the fracking process, we need to maintain our humanity and empathy in these situations for all of the players. That, of course, does not mean that the science involved in this process should be ignored or that all of the parties should not remain vigilant or employ precaution.