Source Rock as a Reservoir: A Personal Odyssey*

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Introduction

In 1965, G.T. Philippi, a Shell geochemist, published a remarkable paper "On the depth, time and mechanism of petroleum generation." Philippi made the novel proposal that petroleum was generated from organic matter in sediments that had been buried deeply enough to be exposed to warmer earth temperatures, converting the organic matter, with heat and time, to warmer earth temperatures, converting the organic matter, with heat and time, to petroleum.

At that time, nearly every geologist believed that oil was contained in shales and squeezed out into adjacent reservoirs. Indeed, in 1952, P.V. Smith of Esso announced that large amounts of hydrocarbons were extractable from recent sediments of the Orinoco Delta. Unremarked at the time was the fact that hydrocarbons observed in recent sediments were not petroleum molecules. Those hydrocarbon molecules found in shallow sediments are merely detritus of recently living matter. Most geologists – indeed, most Shell geologists – continued to argue for a local origin of petroleum, as Philippi, a brilliant but irascible organic chemist, found it difficult to answer criticisms of his work.

Origin and Migration of Hydrocarbons

Chemists at Shell and Mobil Field Research in Dallas established that petroleum was a natural mixture of hydrocarbons that could only be produced by thermal cracking of organic matter, clearly supporting Philippi's theory.

In 1964, a team of Shell geologists and chemists, J.T. Smith, Peter Moore and Bernie Ferris, conducted a thorough review of Phillipi's work over the past 30 years and recommended to Shell's head office in New York that a major research project be established at Shell's Bellaire Research Lab to evaluate the usefulness of Philippi's ideas, proposing that knowledge of the origin and migration of oil could provide competitive advantages in exploration and production.

Shell's research project, "Origin and Migration of Hydrocarbons" was funded at 35 man-years per year and benefitted from such geologic talents as Gordon Rittenhouse, Bob Heacock, Fred Meissner, Tim Schowalter, John Castano, Les Magoon, Ies Havenaar and Kees de Groot.

(Dietrich Welte spent a post-doctoral year with the Shell group). I became involved with source rocks in 1963, when a Shell vice president remembered my early degree in chemistry.

Archie Hood, a marvelous scientist and a wonderful man, was leader of the research group. After my second year in the group, Archie asked me to come into his office on a Friday afternoon. He closed the door behind us, and formally suggested that I sit down. I took a deep breath. I knew what was coming – times were tough and I was the junior person on the project. At least, I thought I knew what was coming. He said, “Marlan, I’ve talked to the VP. We think you can manage the project better than I can. Monday, you will be in charge of the project. I will be working for you, and will go back to doing science. Have a nice weekend.” (See Figure 1.) What a mentor! Is there anyone like that around nowadays?

My direct supervisors and friends, giving me unqualified support, were Ray Thomasson and, later, Bert Bally (Figure 2). We wondered, what characteristics define a great source rock? With regard to source rock candidates, was 1000 feet of 1 percent organic matter as good as 100 feet of 10 percent organic matter?

Since we found that a significant amount of generated oil is retained in rock pores, all good oil source rocks need to contain a high percentage of organic matter to provide any surplus oil to expel. Good source rocks needed to have very significant richness, of a particular kind of organic matter, heated in the earth for a known time and temperature. The generation process was governed by the Arrhenius equation: time, temperature and type of organic matter are variables. Shell’s work established that hydrogen-rich organic matter was needed to create oil, and humic, hydrogen-deficient organic material could only produce gas. As maximum temperature was so important in the maturation of organic matter, considerable effort was expended to provide operating units with tools to measure maximum temperatures of rocks.

Work by Chris Gutjahr in the early 1960s created a spore carbonization color chart, calibrated to coal rank. Color comparison charts were widely distributed to operations units using progressively charred sugar particles, shaded from pale yellow to black. Jack Mase made a chart for conodont color alterations, useful in settings where other types of organic matter were rare. We visited M. Teichmüller, learning about her vitrinite reflectance (VR) work on coals, and modified the coal procedure to use organic matter extracted from rocks. The vitrinite reflectance measurements adapted from coal petrographers seemed to be the most quantitative and useful method of determining temperature history of source rocks, and in 1966, John Castano supervised the installation and standardization of VR labs throughout Shell’s operating offices.

Archie labored to create a Level of Organic Metamorphism (LOM) scale, to inter-compare descriptions of spore coloration, coal rank, VR, etc. for use in identifying the onset of oil generation, and to determine the likely expulsion product at each level of organic metamorphism. Standard techniques of measuring carbon did not differentiate between “live” carbon or “dead” carbon, nor whether the “live” carbon was hydrogen-rich or hydrogen-poor. We recognized that a significant portion of organic matter in rocks is “dead” carbon, endlessly recycled, and we emphasized the measurement of reactive organic material in source rocks; first supplying operating units with pyrolysis-fluorescence equipment in 1963, later using more quantitative pyrolysis-FID analytical devices (“Rock-Eval” is a name for such now-commercially available services).

In 1966, I was encouraged to test our growing quantitative skills and provided a material balance charge oil calculation for the Woodford Shale in the Anadarko Basin of Oklahoma. I collected and analyzed hundreds of samples of the Woodford shale, measuring temperature history, thickness, type and amount of organic material by calculating volume of expected-to-be expelled oil versus known oil. Results suggested that several times more oil should have been generated than I could account for in all known fields.

In 1967, my source rock work moved from Shell's Bellaire Lab to Denver operations as chief geologist. Dave Baker drilled a seismic anomaly in the Uinta Basin that resulted in the Shell wildcat well penetrating 8,000 feet of Green River oil shale; immature in the shallow hole, gradually becoming mature, oil-bearing and finally gas-generating at the bottom of the hole. It was an in-situ oil generation model. Very little reservoir rock was recognized by our reservoir engineers, but the source rocks were oozing oil and gas! Few realized that source rocks with, say, 8 percent organic carbon (by weight) represented about triple that amount of kerogen (by volume) in the source rock. The kerogen was concentrated in layers, and as the rock matured and the kerogen liquefied, the rock fabric altered and the fluid pressure greatly increased.

At that time, we knew we had oil retained in the source rock, at high pressure. We thought we needed to have the source rock interbedded with some conventional permeability rock to extract significant oil volumes at useful rates. I would like to have been the genius who said in 1968, "We know the oil is within the source rock; we merely have to get it out!" None of us was that wise, and industry continued to move very slowly to the concept of a mature source rock as a desired reservoir.

Source Rock as Reservoir

A first step was extracting methane gas from coal beds. Few thought of coals as useful sources of methane; coal miners considered the contained methane as a dangerous nuisance. Safety-inspired work by the Bureau of Mines showed the usefulness of lateral bore holes for draining potentially explosive methane from coal in advance of mining. With temporary assistance from government price subsidies, thousands of wells proved the efficiency of the horizontal drilling technology to produce coal-bed methane.

The remarkable persistence of George Mitchell's team in drilling long laterals in the Barnett gas source rock, and combining those long laterals with effective fracturing, jump-started the shale gas reservoir revolution. Mitchell taught the industry what focused engineering and management persistence could do to solve source-rock reservoir problems.

After Mitchell's success, industry attention re-focused on the concept of gas source rock… as a reservoir. To my surprise, I found that Shell had mislaid much of its former knowledge; many companies were struggling to learn about the characteristics of source rocks. Since 2000, my company, Roxanna Oil, has helped companies expand their expertise in locating and evaluating shale gas and shale oil reservoirs.

Gas shales require an abundance of organic matter, as well as a high temperature history. Not only does the organic matter generate the gas, it modifies to provide internal micro-porosity during the metamorphism of the organic matter (J.T. Smith, in 2001, in one of his last scientific acts, provided Roxanna Oil his insightful analysis of the benefit provided by micro-porosity created as a side effect of the thermal metamorphism of organic matter).

As difficult as creating a producing shale gas reservoir has been for the industry; creating flow paths allowing oil production from an oil-shale source-rock reservoir is at least 10 times more difficult. The problems of moving a methane molecule to a borehole are dwarfed by the task of extracting a much larger oil molecule from an oil source rock.

In selecting the Bakken oil shale formation, wise explorers recognized an extremely rich oil source rock, with local interbeds of more transmissive material. The successful Bakken Shale effort owes much to its rapidity of improvement; well production rates increased linearly with time, with technology and industry persistence consistently driving increased flow rates and profitability.

Recovery efficiencies for oil shale reservoirs are likely less than 15 percent; a lot of oil remains in the source rock reservoir. A new industry is gathering – one based on re-stimulating older wells to access additional production. Visualize a fracture network outward from a long lateral, and remember that the only oil that has been taken out is from rock within a few feet of a fracture. Any undrained source rock a few feet from a fracture retains most of its original pressure, and its original content of oil. On re-fracturing, the fluid first fills any currently open fractures, and then seeks the weakest portion of the reservoir; the weakest rock is now the undrained portion, reflecting its unrelieved high pore pressure.

Source rocks, as oil and gas producing reservoirs, are largely a North American activity today, but most of the world's source rocks reside in other countries, which are undeveloped. Wise development of the world's source-rock reservoirs will require the attention of the best and brightest of our grandchildren.

Great source rocks make great source rock-reservoirs.

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Author (See Figures 3, 4, and 5)

AAPG Giant Marlan Downey Passes

By Brian Ervin, Managing Editor, AAPG Explorer

The Association has lost one of its legends with the recent passing of Marlan W. Downey. He died peacefully on Memorial Day, May 29, in Dallas at the age of 85, surrounded by his wife, Marea, and their six children. He was laid to rest on June 1 in Dallas, and a celebration of his life was held on June 24. He was elected president of AAPG in 2000 and received AAPG's highest honor, the Sidney Powers Medal, in 2009.

Along with the enduring impact he made in petroleum geology and within the Association, Downey was a man who made a lasting and positive impression on everyone he encountered. In the words of some of those who knew him best: "AAPG has lost one of our finest. I had the great benefit of knowing Marlan since I was a toddler," said past AAPG President Scott Tinker. "He was a man of few words; but when he spoke, we all listened! Marlan was not free with his praise, so if it came, it really meant something. After my term as AAPG president, Marlan wrote a two-sentence email to me. It is a treasured sentiment that I will hold onto for life. I will miss him dearly," Tinker added. "Serving with Marlan on the AAPG Executive Committee was one of the best experiences of my volunteer life," said Robbie Gries, who before she became AAPG's first woman president served as president-elect during Downey's presidency. "His management model and astuteness regarding business were things I tried to retain. Plus, he was just a very kind person." "Marlan, indeed, was an amazing guy; quite appropriate that he received the Powers Medal in 2009," said past AAPG President Paul Weimer.

Andrew Hurst, AAPG Member and chair of production geoscience at the University of Aberdeen, related how he met Downey 20 years ago when he was part of a group from the University of Oklahoma visiting the University of Aberdeen on an academic mission. "That visit and a return visit to Dallas and Norman a few months later became the seed for a lively and always enlightening professional relationship and a close personal friendship," said Hurst. "I have no idea what Marlan saw in me but his care and mentoring surely made me a better professional and a better man." "I will forever miss 'Well pardner, you may like to think about that from another perspective …' and 'Why don't you write something about exploration risk, Andy? I am confident that people will find your thinking interesting,'" he added. "Marlan and I shared thoughts and ideas freely, and I suspect that it will be challenging to find a similar relationship elsewhere. What a great man and what a privilege to have his friendship."

Downey was born in Falls City, Nebraska, on October 2, 1931, where he grew up. Upon graduating Peru State College with a degree in chemistry, he was inducted into the U.S. Army and served in an artillery unit during the Korean War. After two years in the Army and an honorable discharge, Downey earned a master's in geology from the University of Nebraska. He joined Shell Oil in 1957, retiring in 1987 as president of Pecten International, Shell Oil's international subsidiary. He founded Roxanna Oil in 1987, then returned to corporate life in 1990 to serve as president of Arco International, retiring in 1998. He then joined the University of Oklahoma as Bartell Professor and chief scientist of the Sarkeys Energy Center. He remained active, serving on three oil company boards, chairing Roxanna Oil and actively consulting around the world.

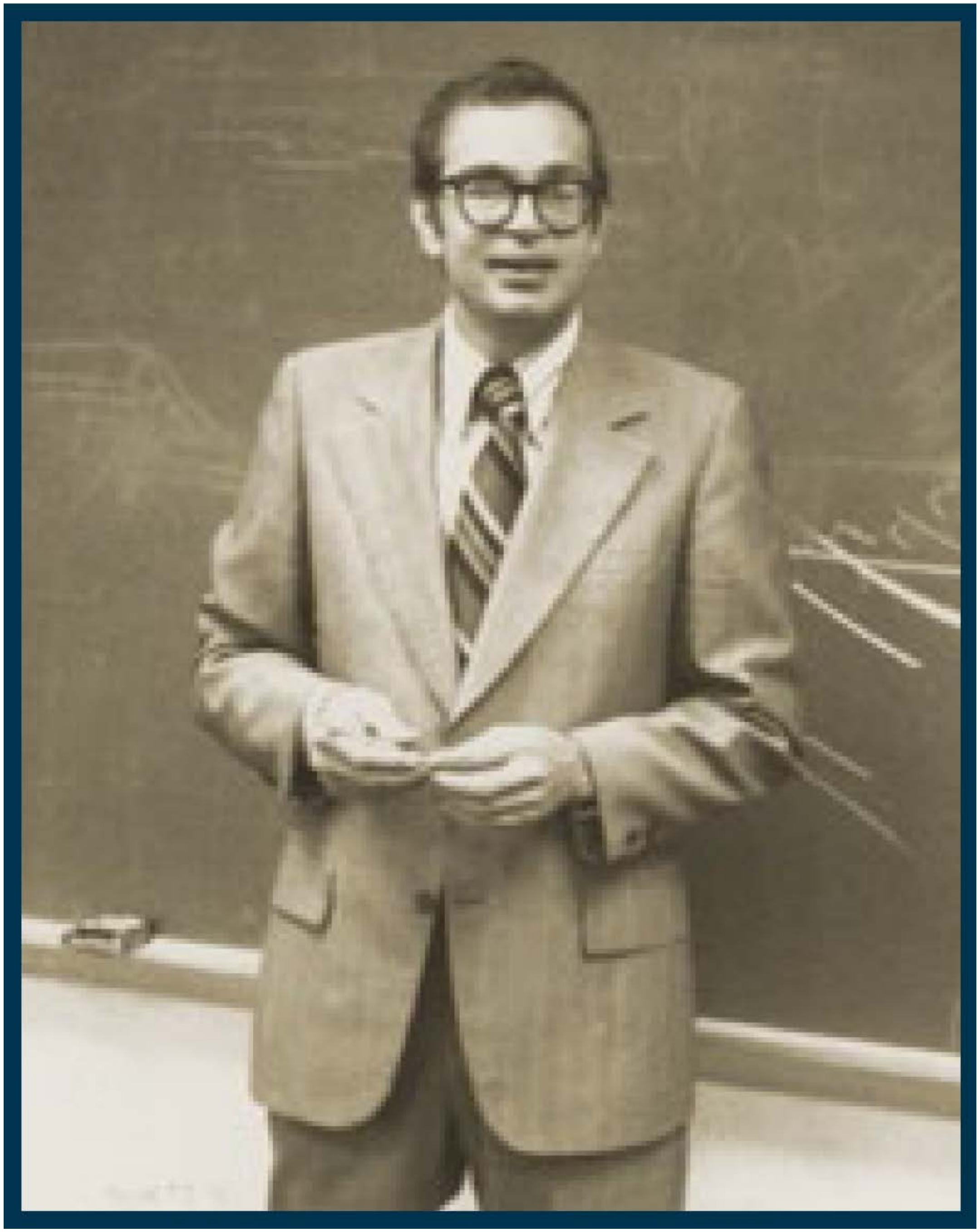

Figure 1. Marlan Downey at the Shell Bellaire Research Laboratory in the early 1960s.

Figure 2. From left: Bert Bally, Marlan Downey, and Ray Thomasson at Shell's Bellaire Research Lab in 1965.

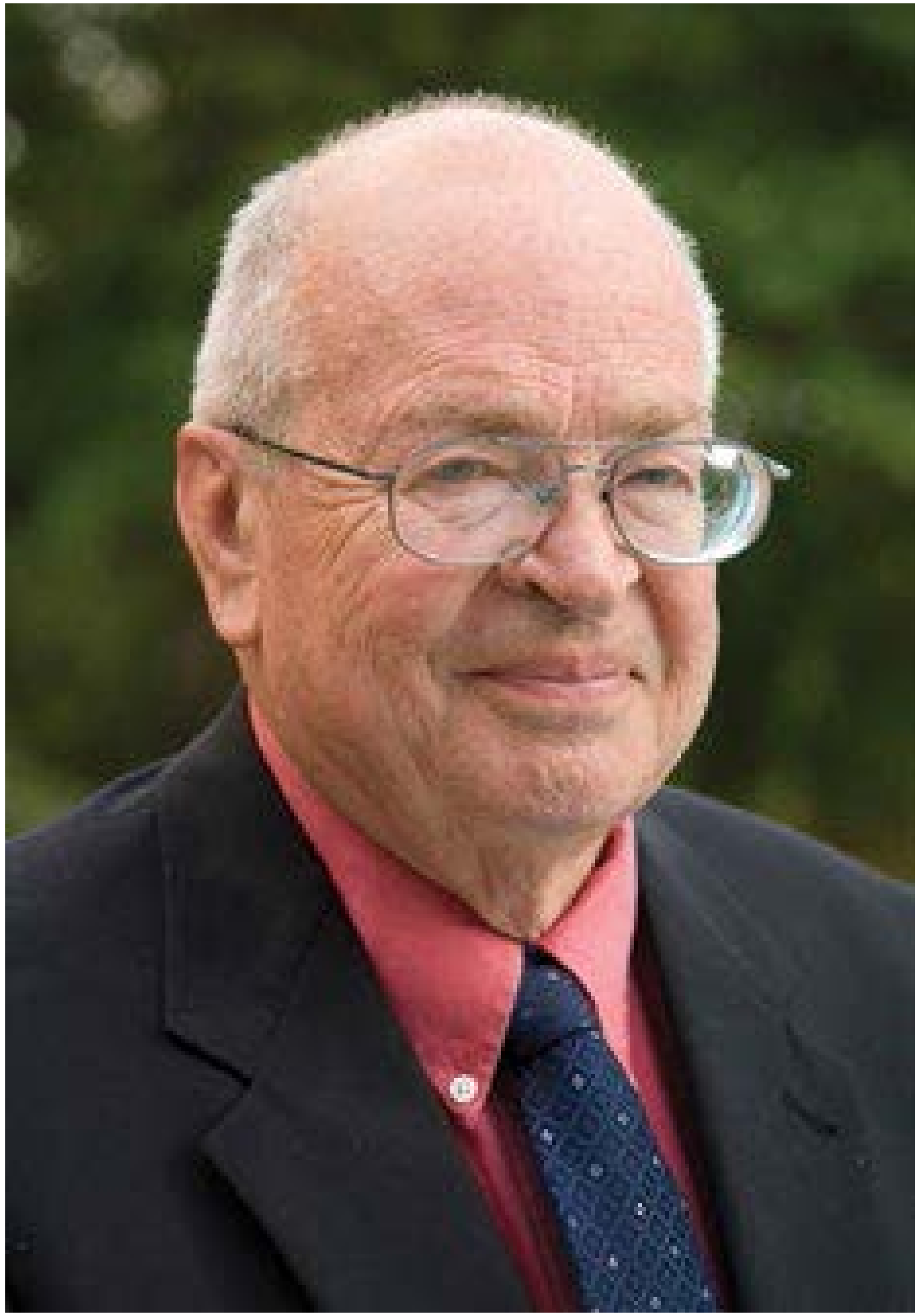

Figure 3. Marlan Downey.

Figure 4. Marlan Downey with Ronald Reagan, the 40th President of the United States.

Figure 5. Marlan with his mother, Elizabeth, during his college years.

About Historical Highlights

A history-based series, Historical Highlights is an ongoing EXPLORER series that celebrates the "eureka" moments of petroleum geology, the rise of key concepts, the discoveries that made a difference, the perseverance and ingenuity of our colleagues – and/or their luck! – through stories that emphasize the anecdotes, the good yarns and the human interest side of our E&P profession. If you have such a story – and who doesn't? – and you'd like to share it with your fellow AAPG Members, contact the editor, Hans Krause (Figure 6), at historical.highlights@yahoo.com.

Figure 6. Hans Krause, 2018 recipient of the AAPG Michel T. Halbouty Outstanding Leadership Award, AAPG Honorary Member, Distinguished Service Award winner, and former chair of the AAPG History of Petroleum Geology Committee.