EMD Oil Shale Committee

EMD Oil Shale Committee Annual Report - 2011

Jeremy Boak, Ph.D., Chair
April 1, 2011

Vice-Chairs:

Lauren Birgenheier, Ph. D., (Vice-Chair – University), University of Utah
Ronald C. Johnson, Ph.D., (Vice-Chair – Government), U. S. Geological Survey

Advisory Committee: TBA

Observing Committee:

http://emd.aapg.org/members_only/oil_shale/index.cfm#observers

Committee Activities

In the 2010-2011 business year, the Oil Shale Committee appointed two Vice-Chairs, 1) Ronald C. Johnson (Ron Johnson), Oil Shale Task Leader for the U. S. Geological Survey as Government Vice-Chair, and 2) Lauren Birgenheier (LBirgenheier@egi.utah.edu), of the Energy & Geoscience Institute at the University of Utah as the University Vice-Chair. The Industry Vice Chair will be appointed later this year.

The Oil Shale Committee has engaged in a broader international discussion about technical terminology regarding “oil shale” and “shale oil.” For a summary of thoughts regarding the thorny question of what is shale, and how the Petroleum Geology community can help provide clarity among the various shale-associated resources, see the attachment to this report (beginning on page 11).

Oil shale related presentations and posters at the ACE in Houston include:


1C. Source Rock Characteristics in the Green River Oil Shale, Piceance Creek Basin, Colorado – An Integrated Geochemical and Stratigraphic Analysis J. Feng; K. Tanavsuu-Milkeviciene; J. Sarg

23A. New Insights Regarding Aquifers in the Uinta Basin, Utah: Implications for Saline Water Disposal. M. D. Vanden Berg; P. Anderson; C. Morgan; S. M. Carney

16B. Main Geological Characteristics and Resource of Oil Shale and Its Development in Northwest China. B. Yunlai
9C. Redefining Jordan’s Oil Shale Resource; Overcoming the Challenges of Subsurface Characterisation and 3-D Modelling on a Country-Wide Level.  S. F. Kolonic; S. Neal


Lacustrine Carbonates and Evaporites - Facies Evolution and Diagenesis: Eocene Green River Formation, Piceance Creek Basin, Colorado.  N. Suriamin; J. Sarg; K. Tanavsuu-Milkeviciene

The premier international meeting on oil shale is the Oil Shale Symposium hosted by the Colorado School of Mines in October.  The 30th Oil Shale Symposium occurred October 18-22, 2010, which also included an optional field trip to western Colorado and Eastern Utah.  The 31st Oil Shale Symposium will occur October 17-21, 2011 in Golden, with a field trip probably to both Colorado and Utah.  All presentation materials from the 26th through 29th Oil Shale Symposia are posted at http://www.costar-mines.org/.

Planning is under way for a possible Oil Shale Symposium in Jordan in April 2012.

Oil Shale Commodity Report

World Oil Shale Production

Total global production of shale oil is currently about 20,000 barrels per day (BOPD).  All of this production comes from mining and retorting operations in Brazil, China, and Estonia.  Indications are that Chinese production, which was just over 10,000 BOPD in 2010, will increase to approximately 11,000 BOPD in 2011.  Current projections show that oil shale will not be a significant part of global production (>500,000 BOPD) for another decade.  However, projects are in line over the next four to five years that could increase production by at least two fold, and potentially by four or five fold.

Highlights

The last six months have seen a number of developments in oil shale both in the United States and globally, including:

• Announcement of settlement of two lawsuits regarding oil shale development by the U. S. Department of Interior, which are considered negative to oil shale development by the oil shale industry, as they increase uncertainty about decision making in the Department of Interior

• Announcement of planned purchase of Oil Shale Exploration Company by Estonian energy company Enefit.  The price has not been disclosed, nor has there been any announcement about the participation of Petrobras and Mitsui, partners to OSEC in development of their RD&D lease.  Enefit intends to develop a mining and retorting operation that will contribute 57,000 barrels per day of production by 2019.

• Initiation of drilling as part of a test of oil shale production technology in the Tarfaya oil shale deposit in Morocco by San Leon Energy.

• Announcement of participation by Rupert Murdoch and Lord Rothschild in Israel Energy Initiatives plan to develop Israeli oil shale.  Development of this resource in a less developed part of Israel has energized protest by environmental groups.

• Advancement of oil shale development in Jordan with agreements in place with Eesti Energia (Estonia) and with Jordan Energy Minerals Limited (with startup planned for 2014 at 15,000 BOPD, estimated breakeven price of $38/barrel).
Research Funding Sources

Funding for oil shale research in the United States comes primarily from corporations actively pursuing oil shale development. These include Federal RD&D leaseholders (Chevron, Shell, American Oil Shale/Total) and others holding land underlain by the Green River Formation (ExxonMobil). U.S. Federal sources include the U.S. Department of Energy through its National Energy Technology Laboratory, as part of the Fossil Fuel program. However, such funding has been very limited this year. Other companies may have provided smaller grants that are not widely publicized. Other private funding appears to support development at least of the Red Leaf Resources program. International funding comes from diverse sources, not all of them publicly acknowledged. It is clear that governments in Jordan and Morocco are actively supporting granting of concessions and dissemination of available data. Companies in Estonia (Eesti Energia, Viru Keemia Grupp), Brazil (Petrobras), and China (CNPC, Fushun Mining Company and others) are supporting internal development and, in some cases, external development efforts.

Current Research

Current research on oil shale is best identified through presentation at the Oil Shale Symposium held each October in Golden, CO at the Colorado School of Mines. All proceedings abstracts, presentations, and papers for the 26th through 29th Oil Shale Symposia are available at:


Proceedings of the 30th Oil Shale Symposium should be available for sale by the end of the AAPG Annual Convention and Exhibition in Houston at:

http://outreach.mines.edu/cont_ed/oilshale/?CMSPAGE=Outreach/cont_ed/oilshale/.

In addition, international research in oil shale processes and impacts is published in the journal Oil Shale, published in Estonia. The journal can be accessed at: http://www.kirj.ee/oilshale.

Current industry research focuses on development and testing of a variety of techniques for extracting oil from oil shale and on minimizing the environmental impacts of these techniques. These fall into three main categories: 1) mining and retorting, 2) in situ heating and extraction, and 3) in-capsule extraction.

The first is the traditional method of oil shale extraction, which has been pursued with some intermittency for more than one hundred years. Developments in this area generally relate to increasing the efficiency and decreasing the impact of retort operation. The development of advanced fluidized bed reactors is a current area of research and development. In addition, research continues on the impacts of past mining and retorting, and on utilization of spent oil shale and oil shale ash from burning of oil shale in power plants. The most obvious applications involve use of spent shale and ash in cement and brick manufacture, but more advanced techniques involving extraction of various constituents from the material have been investigated. The Fushun Mining Company in China has set as an objective no net waste products from oil shale production.

The second method, in situ heating and extraction, is the focus of intensive research to develop a method to heat and pyrolyze kerogen-rich rocks underground and efficiently extract the resulting oil and gas from the formation. Shell has been a leader in this area, but ExxonMobil, Total/AMSO, Chevron, and others are investigating different processes. In situ heating takes much longer (on the scale of years), but as a consequence pyrolysis occurs at lower temperatures, and additional reaction at depth leads to a lighter oil with a larger gas fraction. The amount of
secondary processing to meet refinery requirements is generally considered to be less than for retort products. Research on in situ processes and on processing the resulting material is ongoing at companies developing these methods, but results are generally proprietary. Symposium presentations have described general results in containment, heating, extraction, refining, and reclamation.

The third method, in-capsule extraction is the method being pursued by Red Leaf Resources of Cottonwood Heights UT. It involves mining of oil shale, encapsulation in a surface cell akin to a landfill, heating and extraction of the products, and final sealing of the exhausted retort. A recent trial has been completed and the results are favorable. The process is described in more detail at Red Leaf's website: http://www.redleafinc.com/. Currently, Red Leaf is not directly involved in supporting research on its method. However, results reported at the 30th Oil Shale Symposium indicate that the company anticipates moving forward with production of 9,500 BOPD within 24 months, and plans to expand that to a 30,000 BOPD facility that will start construction in 2013. This would be a globally significant development for oil shale. Red leaf currently estimates an energy return on investment of 11.5 to 1.

List of Specialists in the United States

The list may not yet be complete:

- Gary Aho, Oil Shale Exploration Company (OSEC), Rifle CO, oil shale production technology
- Mike Batzle, Center for Rock Abuse, Colorado School of Mines, physical properties of oil shale
- Jeremy Boak, Center for Oil Shale Technology and Research (COSTAR), Colorado School of Mines, Golden CO, assessment of CO₂ emissions and water consumption by oil shale production; geologic characterization of oil shale.
- John Berger, COSTAR, Colorado School of Mines, Golden CO, modeling of fracturing in oil shale
- Justin Birdwell, U. S. Geological Survey, Lakewood CO, organic geochemistry of oil shale and other source rocks
- Lauren Birgenheier, Energy Geosciences Institute, University of Utah, Salt Lake City UT, stratigraphy of oil shale
- Neil Bostrom, Schlumberger-Doll Research, Cambridge, MA, pyrolysis of oil shale, kinetics, and characterization
- Adam Brandt, Stanford University, Stanford CA, assessment of CO₂ emissions from oil shale production
- Michael Brownfield, U. S. Geological Survey, Lakewood CO, geology, stratigraphy, sedimentology and resource evaluation of Green River Formation oil shale
- James W. Bunger, Bunger and Associates, Salt Lake City, UT; production planning and impact assessment for U.S. oil shale
- Alan Burnham, AMSO LLC, Livermore, CA, properties of oil shale, in situ retorting of oil shale
- Alan Carroll, COSTAR, University of Wisconsin, Madison, WI, stratigraphy, sedimentology and geochronology of Green River Formation, Wyoming; lacustrine stratigraphy and sedimentology
- Gerald Daub, Daub and Associates, Grand Junction CO, geology of Green River Formation
- Milind Deo, Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT, chemistry and simulation of oil shale retorting processes
- John Dyni, U. S. Geological Survey (ret.), Lakewood CO, geology and resource evaluation of oil shale
- Benjamin Harding, AMEC Environmental, Boulder CO, water use for oil shale production
- Michael Herron, Schlumberger-Doll Research, Cambridge MA, mineralogic and chemical characterization of oil shale
• Hai Huang, Idaho National Laboratory, Idaho Falls, ID, geomechanical behavior of oil shale
• Ronald Johnson, U. S. Geological Survey, Lakewood CO, geology, stratigraphy sedimentology and resource evaluation of Green River Formation oil shale
• Mark Kuchta, Colorado School of Mines, Golden CO, underground methods for in situ production of oil shale
• Daniel Levitt, Los Alamos National Laboratory, Los Alamos NM, hydrology of oil shale deposits
• Michael Lewan, U. S. Geological Survey, Lakewood CO, organic geochemistry of oil shale and other source rocks
• Timothy Lowenstein, Binghamton University, Binghamton NY, chemistry and formation of evaporite minerals and spring deposits of the Green River Formation, Colorado and Wyoming
• Jonathan Mace, Los Alamos National Laboratory, Los Alamos NM, explosives application to fracturing of oil shale
• Malka Machlus, Schlumberger-Doll Research, Cambridge MA, stratigraphy of Green River Formation oil shale
• Glenn Mason, Indiana University Southeast, New Albany, IN, geology of Green River Formation oil shale
• Earl Mattson, Idaho National Laboratory, Idaho Falls, ID, hydrology of oil shale deposits and water consumption patterns for oil shale production
• Bill McKinzie, Shell, Houston TX, in situ conversion processes for oil shale
• Carl Palmer, Idaho National Laboratory, Idaho Falls, ID, mineralogic and chemical effects of pyrolysis on oil shale
• Donatella Pasqualini, Los Alamos National Laboratory, Los Alamos, NM, energy systems analysis for Western Energy Corridor
• Ron Pugmire, University of Utah, Salt Lake City, UT, chemistry and kinetics of oil shale pyrolysis
• J. Frederick Sarg, Colorado School of Mines, Golden CO, stratigraphy and sedimentology of Green River Formation, Colorado
• Philip Smith, Institute for Clean and Secure Energy, University of Utah, Salt Lake City, UT, chemistry and simulation of oil shale retorting processes
• Kati Tanavsuu-Milkeviciene, Colorado School of Mines, Golden CO, stratigraphy and sedimentology of Green River Formation, Colorado
• Judith Thomas, U. S. Geological Survey, Colorado Water Science Center, Grand Junction, CO, hydrology of Piceance Creek Basin
• Michael Vanden Berg, Utah Geological Survey, Salt Lake City, UT, geology and stratigraphy of oil shale, Utah
• Jessie Yeakel, ExxonMobil Upstream Research, Houston, TX, geology of Green River Formation oil shale
• Wei (Wendy) Zhou, Colorado School of Mines, Golden CO, Geographic Information Systems for oil shale water resource evaluation

List of International Specialists
The current list is preliminary and incomplete:
• Omar Al-Ayed, Al-Balqa Applied University, Faculty of Engineering, Amman Jordan, properties of Jordanian oil shale and shale oil
• Yuval Bartov, Israel Energy Initiatives, Ltd., Jerusalem, Israel, lacustrine stratigraphy, Green River Formation and Israel
• Mohammed Bencherifa, Organization National des Hydrocarbures et des Mines (ONHYM), Rabat, Morocco, engineering and geology of Moroccan oil shale
• Alan Goelzer, Jacobs Consultancy, Durham, New Hampshire, modeling of retorting and hydrogenation processes
• Jaan Habicht, Tartu University, Tartu, Estonia, Environmental effects of oil shale ash and spent shale
• Uuve Kirso, Tallinn Technical University, Tallinn, Estonia, Environmental effects of spent shale and oil shale ash
• Shuyuan Li, China University of Petroleum, Beijing, China, Properties of oil shale in China
• Zhaojun Liu, Jilin University, Changchun, China, Geology, stratigraphy, and resource evaluation of Chinese oil shale
• Tsevi Minster, Geological Survey of Israel, Jerusalem, Israel, Resource characterization for Israeli oil shale
• Vaino Puura, Tallinn Technical University, Resource assessment of oil shale
• Jialin Qian, China University of Petroleum, Beijing, China, Properties of oil shale in China
• Aya Schneider-Mor, Ben-Gurion University of the Negev, Beer Sheva, Israel, Geology and stratigraphy of Israeli oil shale
• Jyri Soone, Tallinn Technical University, Tallinn, Estonia, Environmental effects of oil shale ash and spent shale
• Mahmoud Zizi, ZIZ Geoconsulting, Rabat Morocco, Geology and engineering for Moroccan oil shale

**Leading Companies in Development of Oil Shale**

Efforts by major international oil companies in the United States are generally led out of Houston, but Shell, ExxonMobil, Chevron and AMSO also have regional offices in western Colorado. International oil companies with activities in oil shale include:

- Chevron
- ExxonMobil
- Petrobras (Brazil)/ Oil Shale Exploration Company (OSEC)
- Shell
- Total/American Shale Oil (AMSO)

In addition, two other large oil companies have significant land holdings underlain by oil shale, and one major oilfield service company has acquired technology for oil shale production:

- Anadarko Petroleum Corporation
- ConocoPhillips
- Schlumberger

Smaller U. S. companies pursuing development, mostly in the United States include:

- Combustion Resources, Inc.
- EnShale Inc.
- General Synfuels International
- Independent Energy Partners
- Mountain West Energy
- Natural Soda, Inc.
- Red Leaf Resources
- Shale Tech International
- AuraSource Inc.
International leadership is held mainly by companies producing oil shale at the present time (listed first), but other companies are also currently pursuing development of oil shale (second group):

- Eesti Energia/Enefit (Estonia)/Outotec (Finland)
- Fushun Mining Company (China)
- Viru Keemia Grupp (Estonia)
- Altius Resources (Canada)
- Queensland Energy Resources (Australia)
- San Leon Energy (Ireland) [concession in Morocco]
- Jordan Energy Minerals Limited (England) [Agreement in Jordan]
- Israel Energy Initiatives Limited (Israel)
- International Corporation for Oil Shale Investment (Incosin) [MOA in Jordan]

National agencies/oil companies involved in developing oil shale include:

- China National Petroleum Corporation (China)
- National Resource Administration (Jordan)
- Organization National des Hydrocarbures et des Mines (ONHYM), Morocco

**Focus of Recent Activity**

Recent oil shale activity in the United States has centered on the development and testing of oil shale technology. The U. S. Bureau of Land Management continues to process three applications for a second round of Research Development and Demonstration (RD&D) leases. The technical review was completed in the Spring of 2010, and in September, the BLM announced that it would advance all three leases to the next stage of environmental analysis. This step is expected to take four to eighteen months to complete. The leases offer the same 160 acre RD&D area as the previous round. However, the lease preference area, which becomes available at fair market price after a company has shown commercial feasibility for its technology, has been reduced to 480 acres, for a total of 640 acres.

Shell applied for a permit to begin testing on one of its RD&D leases in western Colorado. Shell continues to experiment with its In situ Conversion Process (ICP), which involves electric heating of a block of rock contained by a freeze wall to protect ground water and minimize heat loss to flowing water. Shell has demonstrated all of the elements of this system on a small scale, and has completed a test freeze wall on a larger scale on private land in Colorado. They have also reported on experiments that complete the process by circulating water through the block to remove hydrocarbons not extracted through the production wells.

ExxonMobil continues work at its Colony site to investigate its ElectroFrac™ technology, which also involves electric heating, but through large plate electrodes created by hydrofracturing from horizontal wells and injecting an electrically conductive proppant to create what ExxonMobil itself characterizes as a “Giant Toaster”. They have now demonstrated that the process can create an effective connected heating element.

American Shale Oil (AMSO) plan to conduct a pilot test of their in situ process (Conduction, Convection & Reflux – CCR™) in 2011. The pilot test facilities are under construction. They have drilled six wells in the area and will drill six more in 2011 as part of the test. The test will be conducted in the illitic oil shale of the Garden Gulch Member of the Green River Formation. Modeling of microseismic and other methods will be used to image the growth of the retort zone. Experimental results suggest the process yields a 35-40 PI gravity oil with lower nitrogen than typical, metal contents below detection levels, and a net energy return of ~4:1.
Chevron has completed geologic and hydrologic characterization (and monitoring) wells at its RD&D lease in Colorado. It has been relatively quiet about development of its own technology for in situ extraction.

A number of companies, many located in Utah, are moving ahead with plans to build surface retorting systems. A substantial amount of work by these companies has centered around efforts to reduce the carbon and water footprints of the systems while still maintaining a positive energy balance. In addition, Red Leaf Resources Ecoshale Division has tested their in-capsule technology (described in a previous section of this discussion). They anticipate startup of a 9,500 barrel per day operation within 24 months.

Internationally, Estonia is in the process of significantly expanding its capability to produce oil from shale, while de-emphasizing the use of oil shale for combustion in power plants. Jordan is actively pursuing partnerships to develop its significant resources of oil shale, partnering with Petrobras, Shell, Eesti Energia, Jordan Energy Minerals, Limited, and others to define a path toward energy independence. Petrobras and Total have been working with Morocco to develop well-characterized oil shale deposits near Timadhit. San Leon Energy of Dublin Ireland has begun drilling preparatory to testing of its in situ technology later in 2011. Eesti Energia has recently signed an agreement with Morocco to evaluate a group of other oil shale deposits around the country.

China appears to be rapidly increasing its capacity to produce shale oil through surface retorting. Currently, it appears there are over 500 retorts of various sizes (mostly 100 tonne/day shale, Fushun-type retorts) installed with more than 200 under construction. Although total production was only about 10,000 barrels per day, the numbers do not make clear whether the current limitation is the capacity or the efficiency of the retorts. A significant number of the retorts are new in the last year, and may not yet be on line.

Professor Jialin Qian of China University of Petroleum, a leading investigator of oil shale in China for many decades, has authored a book entitled Oil Shale – Petroleum Alternative, and prepared an English translation which is now available. A limited number of copies are available through the Colorado School of Mines (contact Jeremy Boak at jboak@mines.edu). The book can also be ordered by contacting the publisher at vtt@sinopec.com.

**Estimated U.S. and International Resources/Reserves and Strategic Impact**

World resources of oil shale were previously estimated to be >3.0 trillion barrels, of which about two trillion barrels were located in the U.S.A. (Dyni, 2006). The largest oil shale deposit in the world is the Green River Formation of Colorado, Utah and Wyoming. The U. S. Geological Survey is currently reevaluating oil shale resources of the Green River Formation in Colorado, Utah, and Wyoming. The Colorado assessment was released last October, and increased the amount from the 1.0 trillion barrel previous estimate to 1.5 trillion barrels. A new assessment of Utah resources indicates 1.32 trillion barrels of oil in place. A Wyoming assessment is in review, with preliminary values of the total resource that exceed those of Utah, and release is expected soon.

Additional updates to the projected resources of oil shale come from Israel and Jordan. Each now estimates the potential for more than 100 billion barrels of oil (BBO) in place. Yuval Bartov of Israel Energy Initiatives Limited suggested resources as high as 250 BBO, and JEML reports an estimated resource of 102 BBO for Jordan. However, these estimates have not been evaluated in a consistent manner, a critical need as the industry matures.
These estimates are based largely on measurements of oil shale yield by Fischer Assay, a method designed to approximate the recovery of retorting methods. Most estimates of resource size tied to modern retort methods, whether retorting is done at the surface or in situ, are tied to this surrogate measurement. Some processes that focus on hydrogenation of the kerogen can recover amounts greater than the Fischer Assay. In addition, because the Fischer Assay calculates the gas fraction by difference, this measure does not adequately account for non-condensable hydrocarbon gases potentially present in the mass fraction lost during assay. In situ processes tend to have a higher gas/liquids ratio. Thus, it is difficult to provide consistent estimates of the potential resource of oil shale available at this time. The U. S. is the only place where extensive analysis and evaluation has been published for a large oil shale resource.

However, the estimates of Dyni are considered conservative estimates of the resource potential. Estimates of the recovery potential for U. S. oil shale are generally near 50%, but vary widely. The current Chinese estimate postdates Dyni’s estimate, and significantly increases the world estimate. However, China’s assessment indicates that they expect only about 25% recovery of the available resource.

Some resource evaluations are very old, and may be highly uncertain. An up-to-date method for assessment of oil shale resources, and modern resource estimates would provide a better picture of the significance of this resource. The producing countries have provided reasonably reliable estimates of the resource in place, although these can be challenging to track down. The strategic significance of oil shale resources varies from country to country. In the U. S., much has been made of the size of the resource. However, its availability remains uncertain. Technology to produce the vast quantities of oil potentially recoverable is currently being tested, but no developer has projected significant production in less than a decade. The projection shown in

![Figure 1: Projected oil shale production and historic production of U. S. crude oil and Canadian oil sands. The exponential curve fits to data indicate extended periods with growth rates of ~9% and ~10% for the U. S. and Canadian examples, and project >14% for oil shale even to reach one million barrels per day by 2035.](image-url)
Figure 1 indicates that oil shale may take longer still to become a significant player in the global petroleum supply. In the figure, the growth in oil shale production is compared to the growth rates for historic U. S. oil production and for Canadian oil sand production (Boak 2009). The growth rate required to reach one million barrels per year by the 2030s is >14% compared to ~9 and ~10% for U. S. oil and Canadian oil sand. These results are achievable, but will require considerable focus and investment.

However, especially for smaller countries with lower energy demands and no other hydrocarbon resources (Estonia, Jordan and Morocco for example) development of this resource can be very important strategically.

**Critical Technology Needs**

Critical technology needs mainly concern the development of more energy efficient and environmentally-friendly methods of extraction, production and upgrading of oil shale.

Especially in the U. S., issues have been raised about the greenhouse gas emissions and water consumption of an oil shale industry. The primary source of emissions for in situ production is power plant emissions of CO$_2$, and power plant water consumption is the second largest use for a Shell-type in situ operation (Boak 2008, 2010). So minimizing energy use for these processes is essential. ExxonMobil has suggested air-cooled power plants to reduce water use, but these may increase CO$_2$ emissions (Thomas, 2010). AMSO has emphasized the potential for sequestration of CO$_2$ in exhausted in situ retorts (Burnham and Collins, 2009).

Understanding and mitigating the environmental affects of oil shale production across entire productive regions is clearly not the responsibility of individual leaseholders, but rather of the majority steward of the land, the Federal government. In the past, the U. S. Department of Energy managed an Oil Shale Task Force charged with defining and integrating baseline characterization and monitoring needs for environmental impacts within the basins of the Green River Formation. The Task Force included representatives of government and industry, including the environmental firms retained by major potential producers. Congress does not recognize this as a critical need, and therefore the need is not being addressed systematically.

Internationally, there is a lack of consistently structured resource assessments. As the energy security of the world stands to benefit from enabling otherwise resource poor developing countries to develop indigenous energy sources, it may be beneficial to support the development of resource assessment tools for countries that do not have the large database of Fischer Assay and other measurements available in the U. S. Developing criteria and methods for such assessments would be a contribution to the global development of this resource, and would potentially create good will between the U. S., the European Union, and the developing countries with oil shale resources. Critical to such assessments will be careful estimation of the uncertainty regarding resource estimates where data are sparse.

**Critical Environmental or Geohazard Issues and Mitigation Strategies**

The critical environmental issues are how to extract, produce and upgrade shale oil in an environmentally friendly and economically sound way such that:

1) the use of energy to pyrolyze the kerogen is minimized
2) the greenhouse gas emissions are reduced or compensated for by carbon trading or CO$_2$ sequestration
3) the water used in construction, operation, power generation, and reclamation is minimized and does not deplete the water resources of arid regions
4) the extraction, production and upgrading of the shale oil does not unduly affect the quality of the air, the native biological communities, or surface and ground water of the region.

Socioeconomic impacts are also issues of concern. The recent offering of Research, Development, and Demonstration leases required that each of these concerns be addressed explicitly in the lease application. In addition, Shell has determined that developers must interact with 47 separate regulatory bodies before production can begin. These interactions include at least two separate environmental impact assessment stages likely to focus in the same impacts.

References Cited

Notes on Defining Shale and Shale-Associated Hydrocarbon Resources

Abstract
The term shale has been applied to a vast array of rocks that do not necessarily fall under the classical definitions of shale. The time may have come to re-evaluate the terminology of fine-grained sedimentary rocks. This discussion makes some important observations relevant to such a re-evaluation, but stops short of ardent advocacy for a particular solution. The ideas laid out are intended to suggest directions for a comprehensive review of the terminology of very fine-grained rocks.

Introduction
In press releases, in financial news, in popular accounts of current hot-button issues, the word *shale* is being applied to a very wide range of rocks that contain hydrocarbons – gas, oil, and immature kerogen. The host rocks of these hydrocarbons cover an impressive range of lithologic types, and the formations in which they occur are likewise composite piles of rock with substantial internal variation. Terminology of relatively long standing is being rejected by some,
and argued over by many in the legitimate effort to avoid confusion among various resources with important similarities and important differences.

For at least a century, *oil shale* referred only to organic rich rocks that had never reached the oil window, and contained kerogen (and small amounts of liquid and gaseous hydrocarbons). The industry that produced *shale oil* and electric power from these deposits was tied to mining, as this was the preferred method of extraction. Some people pointed out that the primary target for mining in richest and largest deposit of oil shale (the Green River Formation of Colorado, Utah, and Wyoming) was perhaps properly called a marlstone, ignoring that the lower part of the formation, with equally rich organic content, was a legitimate shale. In the absence of an agreed upon definition, and out of convenience, oil shale stuck as the common term.

The development of natural gas reserves in very tight sandstone required application of hydraulic fracturing. Subsequently, the technology began to be applied to still tighter siltstone and mudstone rich in organic material to free up the gas trapped in micropores and nanopores within these rocks. As long as *shale gas* was actually being produced primarily from mudstone, the loosening of terminology was not extreme. Some speakers pointed out that rocks in the Barnett Formation and elsewhere were not true shale in most classic definitions, as they were commonly poorly laminated, very rich in quartz and very poor in clay minerals.

As the shale gas play began to develop, it became apparent that shallower parts of these plays contained condensate and potentially even oil. In addition, in areas like the Williston Basin, a substantial oil play began to revive in the Bakken Formation thanks to the advance of hydraulic fracturing and horizontal drilling technology. By analogy with *shale gas* and *gas shale*, these plays began to be called oil shale plays and the rocks shale oil. It has been pointed out that the reservoir rock in the Bakken at least was actually siltstone, dolomite, and rocks in between these two, and not apparently in the source shale.

In popular reports on these plays, it is common to confuse the two types of oil shale. *Time* Magazine recently published a diagram attributed to the U. S. Department of Energy that purported to describe shale oil production like that in the Bakken, but clearly involved the introduction of heat as required for novel *in situ* production methods for traditional immature oil shale, and not for production of shale hosted in or adjacent to source shale.

It may be time for the technical community to come to some consistent agreement about how it wishes these rocks to be described. In doing so, it must be recognized that the press, financial community, and the broader public will probably continue to lump many things together as shale. Furthermore, the longstanding uses of shale even within industry, will likely continue to be applied.

Much of the confusion has arisen in part because industry has not paid a large amount of attention to detailed description of the composition, properties, and formation history of very fine-grained sediment and sedimentary rocks, as they did not produce hydrocarbons. As long as they provided seal or source, that was all that was of interest. Description of sandstone and carbonate reservoir has driven massive investigation of these properties for the respective rock types. Shale terminology lags because many of the properties of vital interest now did not affect profits before.

**What is shale?**

The current problems of shale terminology are not due to a lack of efforts to classify very fine-grained sediment and rock. The original definition of shale, according to Potter, et al. (2005) comes from Hoosen (1747), where shale is defined as a laminated argillaceous rock.
Thus, in its initial definition, shale included criteria for mineralogy (although not necessarily quantitative), and for macroscopic texture. The term is clearly a field term, and the flaky or even papery nature of shale is partly at least a weathering effect. Some very solid oil shale weathers into a very flaky rock. A wide variety of definitions of shale have been developed since the time of Hoosen, emphasizing various parts of the earlier definition. Even the choice of the common word shale, from older German and Norse words for “scale” emphasizes the importance of fissility and hence fine lamination.

Industry usage has tended to be much looser, as in, for example, the term “shaly sands” and the calculation of Vsh (shale volume?), which are largely based on variations in the spontaneous potential (SP) or gamma ray log signals that could not differentiate between interlayered argillaceous mudstone and transitional argillaceous siltstone-mudstone.

In addition, industry has characteristically been relaxed about the distinction made by the scientific community between terms for unlithified sediment and lithified rock, perhaps because all variations among the two end members were encountered in oil and gas wells. As shown below, formal terminology maintains a relatively simple relation between the two end members.

In this scheme, all the rocks now being called “shale” could legitimately be called mudstone, as they clearly derive from muddy sediment. Some part of the shaly formation is most likely coarse-grained enough to be siltstone, but it is reasonable to call a sedimentary unit – formation or member – mudstone if that is the dominant component, given that most sedimentary units consist of a mixture of rock types.

However, perhaps because of the antiquity of the definition of shale, mudstone has generally been defined as non-laminated and distinct from shale. It might have been more natural to define shale as a subset of mudstones that are laminated and argillaceous, but this does not appear to have been the approach of the scientific community.

<table>
<thead>
<tr>
<th>Example Terminology of Sedimentary Petrology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sediment</strong></td>
</tr>
<tr>
<td>Lime mud (calcite)</td>
</tr>
<tr>
<td>Sand</td>
</tr>
<tr>
<td>Marl</td>
</tr>
<tr>
<td>Silt</td>
</tr>
<tr>
<td>Dolomite mud</td>
</tr>
<tr>
<td>Clay</td>
</tr>
</tbody>
</table>

Mudstone also appears to have been claimed by carbonate petrologists as applying only to very fine-grained carbonate sediment, driving some clastic sedimentologists to coin the awkward term mudrock, which may or may not have a formal definition. Mudrock also appears to be applied as a relaxed term for those rocks where it is difficult to tell whether silt or clay is predominant.

Yet one more complication enters in the problem of defining clay. For sedimentologists, clay has generally referred to the fraction of clastic sediment in particles <1/256 mm (<0.0039 mm or <0.00015 in.). For mineralogists, clay means aggregations of clay minerals. Clay minerals tend to form very small grains, so the clay fraction of many sedimentary rocks would probably be composed mainly of clay mineral grains. However, grain size analysis is not that common, and for rocks it can be much harder than for unlithified sediment. In addition, many sedimentary rocks have clearly undergone diagenetic recrystallization, changing the original grain size and even potentially bulk mineralogy of the rock. Indeed, one school of thought on the marlstones of
the Green River Formation is that much original clay reacted to other silicates and carbonates in the highly saline Lake Uinta.

As the figure below (Kleinberg et al. [2010]) shows, the realm of fine-grained precursors to sedimentary rocks spans the range from lime muds like the Eagle Ford to marly muds with variable amounts of the generally silty constituents quartz and feldspar like the upper Green River Formation and at least some Niobrara rocks, to the wide range of clay-rich and quartz-rich muds in the lower part of the diagram. Radiolarian oozes are as sticky and gooey as other muds, and their lithified equivalents, unless pure enough to be called porcellanites, have reason to claim the title mudstone. Every indication is that, when individual analyses are plotted rather than averages, the diagram is largely filled with points from rocks that are now being called shale.

The subdivisions on this diagram attempt to provide a simple formal terminology. I have not found a specific definition of marlstone, but it appears to cover the ground of mixed clastic and carbonate mudstone, so I have chosen 1/3 and 2/3 as the boundaries. The additional boundary dividing argillaceous from siliceous mudstone lies at 50% each of the clastic components. Greater degrees of subdivision call for still more complicated terminology, and run the risk of being ignored. The term siliceous used here reflects the fact that the data assembled shows no rocks in which the quartz to feldspar ratio is less than 2.

Many of the current gas shale units are very siliceous, and this is commonly not clastic quartz but biogenic silica of some form. For simplicity, this biochemical silica is lumped together with the clastic silica, with the presumption that it would be sufficient to add adjectives to clarify the origin of the silica for specific shale or mudstone formations.

**Some Possible Solutions**

Shale as a term could be expanded to include all these diverse rocks, in alignment with what is already a fait accompli for the nontechnical community, and even for some parts of the technical community. It is a better sounding word than mudstone, or worse yet, mudrock. This would alter not just the several centuries of geological usage since Hoosen but also ignore the origin of the word in Germanic and Old Norse words referring to the scaly (fissile) character. If this departure from the origins is a problem, it may be appropriate to expand the term mudstone to incorporate all types of rocks consisting of >50% ultrafine grains, recognizing that the determination will still be largely approximate in the field and at the well. As noted above, shale would be a subclass of these rocks that showed clear lamination and fissility.

To differentiate the two types of oil shale, I have suggested informally the use of the term oil-bearing shale and shale-hosted oil for the rock and the product of shale-rich formations that contain oil. If it is inappropriate to use the term “shale-hosted oil” to refer to the Bakken play because the oil may be largely produced from the middle silty and dolomitic member (a question that is as yet unresolved) how is it appropriate to apply any other term for lithified mud to the Bakken? Shale-hosted (or mudstone-hosted) may be taken to imply that the productive unit at the formation level, the Bakken Formation, is a shale, or at least a mudstone.

This question is an important part of any discussion, as the coarser grained rocks that appear to provide much of the storage have distinctly different properties (especially permeability) than the rocks that are called gas shale.

Kleinberg et al. (2010), in a poster at the recent Hedberg conference on shale, pointed out that organic content forms no part of the definition of shale, and the same is also true of mudstone. Those authors also noted that oil shale of both kinds and gas shale, whatever their composition,
were source rocks, because a critical feature of these plays is that they are kerogen-rich, and the hydrocarbons have either not migrated, or have migrated relatively short distances, and are contained largely within the stratigraphic unit where they formed. For this reason, they suggested the term *oil-bearing source rock* for the rock in Bakken-style plays, and *natural source rock oil* for the product. It is hard to imagine non-technical users changing to this terminology, but it could be adopted as the formal technical term.

As a retread metamorphic petrologist and mineralogist who is thrilled to see the recognition that mineral assemblages now mean something for actual production for monetary gain, I am uncertain how to proceed in this arena. But I know that the term “mud” applies both to clastic sediment and to chemical sediment, and it seems to me to be rather parochial to demand a proprietary hold on the term mudstone for carbonate rocks, nor does it seem to fit with my experience as a geologist.

My preference is to refer to this class of fine-grained sedimentary rocks technically as mudstone and possibly as organic-rich mudstone. The source rock terminology of Kleinberg et al (2010) may also have features to recommend it. In discussions with the financial community and probably the general public, we will be unlikely to separate ourselves from the blanket term *shale*. This may be our own fault for not having recognized sooner what a complicated suite of novel reservoir rocks we were diving into.

Perhaps the time has come to really spend a bit of time talking about the technical terminology for these fine-grained rocks, and to determine when to use what term for what type of rocks.


