Title: Oil and Gas Potential in Maine – Onshore and Offshore
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Date: Originally published December 2009


Contents: 17 p. report

Recommended Citation: Marvinney, Robert G., 2009, Oil and Gas Potential in Maine – Onshore and Offshore: Maine Geological Survey, MGS Circular 18-1, 17 p.
Oil and Gas Potential in Maine
Onshore and Offshore

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Executive Summary

- Many decades of geologic mapping reveal that there is very little potential for oil and gas accumulations onshore in Maine. With the possible exception of a small area in northernmost Maine, through multiple mountain-building episodes, the rocks of Maine have been subjected to temperatures higher than that which generates and preserves hydrocarbons.
- The onshore oil and gas province in southeastern New Brunswick is in geological units that are younger and less deformed than those found in Maine.
- State coastal waters (to three nautical miles from the mainland and coastal islands) are underlain with geology similar to that of the mainland. There is no potential for oil and gas accumulations in state waters.
- Geologists have investigated the deeper portions of the Gulf of Maine through various geophysical techniques and surveys. Most of the geology is interpreted to be similar to the onshore geology of coastal New England has little potential for oil and gas generation and accumulation. Triassic basins in part of the Gulf may have some potential, but similar basins in eastern North America, both onshore and offshore, have no known economic reserves.
- There is potential for oil and gas accumulations on the Georges Bank. The most recent estimates of undiscovered reserves by the Minerals Management Service are 2 billion barrels of oil and 18 Tcf natural gas for the entire North Atlantic Planning area, which extends from offshore New Jersey through the Gulf of Maine.
Introduction

Geological Investigations: Over many decades of investigations, geologists have developed a robust framework for the geology of Maine and the waters of the Gulf of Maine. During the period 1836-1839 at the direction of the Maine Legislature, Charles Thomas Jackson conducted the first comprehensive geological survey of the State (Jackson, 1837; 1838; 1839), although he produced no map from this work. The first geologic map of the state, authored by Charles H. Hitchcock (1885) outlined the nature of Maine’s bedrock that has been subsequently refined by many later studies. This early work identified the high-grade metamorphic rocks of western and southwestern Maine, enormous granitic and related intrusive rock bodies, particularly along the eastern coast, and the fossiliferous slates of northern Maine. Among the first modern geologic maps was that produced by U.S. Geological Survey geologists Smith, Bastin and Brown (1907) on the geology of Penobscot Bay. Since then, an army of academic, government, and consulting geologists have developed a clear and enduring understanding of the geology of Maine, as summarized in two statewide maps (Hussey, 1967; Osberg and others, 1985). Investigations ranging from basic geologic mapping to sophisticated deep-seismic reflection studies continue to improve our understanding of Maine's geology.

General geology

The geologic history recorded in Maine's bedrock covers more than half a billion years. Over this period of time the geologic processes of erosion and sedimentation, mountain-building, deformation (folding and faulting), metamorphism, and igneous activity, have acted to produce the complex bedrock of the state, dominated by metamorphic and igneous rocks. Geologists have identified hundreds of bedrock formations and igneous intrusions distinguished on the basis of age and rock type. For the purpose of this summary, these rocks have been grouped into eight major units (Figure 1). Seven groups of stratified rocks (layered rocks, including both sedimentary and volcanic rocks) are differentiated here. These are grouped on the basis of their age and possible place of origin. The eighth unit comprises all the major igneous plutons in the state. Maine plutons range in age from Ordovician through Cretaceous (500 to 65 million years old), with the preponderance being Late Silurian to Devonian (430 to 360 million years) in age, and all crystallized from molten magma of various compositions. Each of the major rock groups will be discussed briefly in the following summary.

Over the hundreds of millions of years of time recorded in the geology of Maine, the rocks we now recognize as bedrock have been involved in several significant tectonic events. Plate tectonics is the theory that the crust of the earth is composed of large, mobile plates. As they move across the globe, plates interact in fundamental ways. In places one plate may plunge or subduct beneath another. Current examples are where the Pacific plate is plunging beneath the Bering Sea, producing the Aleutian Islands. Where the Pacific Plate plunges beneath the continent of South America, it results in the volcanoes of the Andes Mountains. Where two plate of continental crust collide, mountain ranges, such as the Himalayas, are thrust up. In other places, plates are being pulled apart, or rifted, producing large volumes of volcanic rocks. The mid-Atlantic rift system, including Iceland, is an example in oceanic crust. An example in continental crust is the east African rift system. The geology of Maine records multiple episodes of subduction with attendant volcanic rocks, minor rifting, and collisions of subduction-related
volcanic islands and micro-continental plates with the eastern margin of ancestral North America.

Figure 1. Generalized geologic map of Maine. Modified from Osberg and others, 1985.

Precambrian geology (older than 545 million years), Unit 1: The primary area of Precambrian rocks is in northwestern Maine (Figure 1). The geology there contains a complex sequence of metamorphosed sedimentary and volcanic rocks long thought to include the oldest rocks in Maine. Some of these rocks may be as old as 1.5 billion years, significantly older than the Precambrian rocks of the closest North American crust to the west (Boone and Boudette, 1989). Some sedimentary and volcanic rocks on islands in Penobscot Bay were metamorphosed and cut by a pegmatite dated at 647 ± 4 million years old (Stewart and others, 1998), and are therefore also Precambrian.

Early Paleozoic rocks (545 to 443 million years ago,) Unit 2 and Unit 4: During the earliest Paleozoic time, several island chains composed of volcanic and sedimentary rocks formed through subduction within the ancestral Atlantic Ocean. These island chains or arcs collided
with the older rocks of Unit 1 in the first generally recognized orogenic (mountain building) event in Maine, the Penobscottian orogeny (Neuman, 1967). Deformation (folding and faulting) and low-grade metamorphism associated with this event are recorded in Precambrian through Upper Cambrian and lowest Ordovician rocks throughout the central portion of the state (Boone and Boudette, 1989).

Following rapidly on the heels of this event was the Taconian orogeny of Middle Ordovician time (~ 450 million years ago). As originally described by Zen (1972) and Rodgers (1971), during this event the various sedimentary rocks (sandstone, shale, limestone) of the continental shelf and slope were sliced and essentially stacked up on the continental margin. In Maine, the Cambrian through Ordovician rocks of northernmost Maine, primarily, (Unit 2, Figure 1) show the effects of this event. Most geologists recognize this event as the collision of one or more island arc terranes with the eastern margin of North America (see Drake and others, 1989; Boone and Boudette, 1989). Limited igneous activity accompanied the Taconian orogeny and several significant Ordovician plutons are included in unit 8 (Figure 1).

Unit 4 consists of Cambrian through Ordovician volcanic and sedimentary rocks that were part of a terrane which collided with North America during the Taconian orogeny. They have been metamorphosed to such high degree that most of the rocks are now gneisses.

Early Paleozoic Events Preserved in Coastal Maine (545 to 443 million years ago), Unit 3: Geologists’ understanding of the older rocks of coastal Maine has been complicated by more recent high grade metamorphism, which has obscured much of the evidence for their early history of the rocks. A general lack of age constraints in the form of fossils or datable rocks compounds the problem. In spite of this, a distinct geologic terrane has been identified through careful mapping. It is composed of highly metamorphosed volcanic and sedimentary rocks. The tectonic origin of these units is even more speculative than that of the northern Maine rocks partly because any rocks related to subduction processes which brought these terranes together either have not been recognized or were later destroyed.

Uncertainty as to place of origin and mode of emplacement also extends to the Silurian and Lower Devonian volcanic rocks (440-390 million years) of coastal Maine (Unit 6, Figure 1). The character of the volcanic rocks of the eastern part of this group indicates a rifting or divergence event that occurred elsewhere along a margin of the ancestral Atlantic Ocean (Gates and Moench, 1981). Likewise, the volcanic rocks of the central coastal portion of this group have some characteristics indicative of an island arc (subduction) setting.

Middle Paleozoic (443 to 360 million years ago) Unit 5: The orogenic events of the Early Paleozoic caused regional uplift which led to an unknown amount of erosion of the older rocks. In Late Ordovician time there was subsidence and renewed deposition along the eastern North American margin. In fact, geologists now can demonstrate evidence in Silurian rocks for rifting or divergence of plates, which is superimposed on the convergence structures of the older rocks (see Osberg and others, 1989). The ancestral Atlantic Ocean then consisted of a narrow basin which received sediment through Silurian and Devonian times from both the east and west.

The Silurian and Devonian rocks throughout central Maine are characterized by sandstone and slate which were originally sediments deposited in a deep-sea setting (see for example Hanson and Bradley, 1989). That much of these rocks have an eastern source means that in the east there must have been an uplifted, mountainous area which was shedding material through erosion. Initiation of an eastern source area is interpreted by many to herald the
beginning of the next and most significant orogenic episode, the Acadian orogeny. This represented a collision in the Early Devonian between North America and a very significant land mass to the east, either the combined European/African continent, or a large intervening plate, or both. The dominant structural "grain" in Maine, the northeast-southwest trending belts that characterize the distribution of rock types, is due to the Acadian orogeny. Osberg and others (1989) review this development in detail. Another important geologic feature caused by this event is the high-grade metamorphism exhibited by the rocks in southwestern and coastal Maine. Original sandstones, shales, and volcanic rocks in these regions have been metamorphosed to high-grade gneisses and in places have even melted because they were up to 9 miles beneath the mountains hurled upward in this event. The vast majority of igneous plutons in the state owe their existence to the Acadian orogeny (Unit 8).

Following the Acadian orogeny in the Early Devonian, limited deposition of post-orogenic sediments occurred in scattered locales, providing evidence of geologic conditions in Middle and Late Devonian time. These scattered deposits form the last major group of stratified rocks shown on the geologic map (Unit 7) and represent erosion of the mountains built during the Acadian orogeny. These rocks consist mostly of sandstones and conglomerates deposited on land.

Maine’s geology contains no stratified rock units younger than the Devonian, about 360 million years in age. There are a few younger igneous intrusions in southern Maine.

Metamorphism and its bearing on the preservation of hydrocarbons: All of the tectonic events described in the previous section included components of metamorphism. Through the application of heat and pressure, the original mineral components of rocks change to forms more stable under the specific conditions, usually with the expulsion of water, CO$_2$, and other gases. This is the process of metamorphism. Therefore, geologists can use characteristic suites of minerals to establish the metamorphic conditions that acted on rock units in the geologic past.

Guidotti (1989) provides an excellent overview of the metamorphic history of Maine rocks, based on characteristic mineral suites. From southwest to northeast across the state, metamorphic grade progressively decreases from highly metamorphosed rocks to those that are weakly metamorphosed rock (Figure 2). The highest-grade metamorphic rocks in southern Maine contain various amphibole minerals plus K-feldspar and were heated to at least 600°C. In some areas of the south, rocks have been heated beyond the melting point. Progressing to the northeast, the amphibolite grade rocks experienced at least 500°C. Much of the central and eastern parts of the state experienced greenschist-grade metamorphism with the development of abundant chlorite at between 350°C and 500°C. From about the latitude of Mt. Katahdin northward, the rocks are only weakly metamorphosed, having experienced temperatures in about the 200°C range. There are three small rock bodies that post-date the significant metamorphic events and they are all terrestrial in origin – the Trout Valley formation of Baxter State Park, the Mapleton Sandstone near Presque Isle, and the Perry Formation on the St. Croix River near Eastport.

It has been well documented by petroleum geologists that the optimum temperature range for the development of hydrocarbons from the naturally occurring organic material in sedimentary rocks is about 100-200°C (Figure 3). Above about 225°C, organic carbon is converted to graphite. In fact, graphite is a common mineral in many of the metamorphosed sedimentary rocks of Maine.
Figure 2. Generalized metamorphic map of Maine. Modified from Guidotti, 1985. Metamorphic grade increases from light yellow to dark red colors. Intrusive igneous rocks (mainly granites) are shown in gray.

Figure 3. Conditions for oil and gas generation in organically rich sedimentary rocks. Oil is generated between ~80-150°C. Above 225°C, all the organic components in rocks are converted to graphite. Graphite is a common component of Maine’s metamorphic rocks.
In a study of the reflectance of graptolites (a common fossil type), Malinconico and Roy (1993) established a small zone in northern Maine that may not have exceeded the thermal conditions for hydrocarbon generation. (Assessing “reflectance” of organic materials in rocks is a well-accepted method of establishing their thermal maturity.) In the map (Figure 4), the areas in green experienced the thermal conditions required for gas generation, and the light blue for oil. The lavender area near the northern border did not achieve temperatures high enough for hydrocarbon generation. Therefore, if there are sufficiently organic rich source rocks in this section of northern Maine, there may be limited hydrocarbon potential. In New Brunswick, there has been some hydrocarbon exploration near Campbellton on Chaleur Bay in similar rocks.

**Gas Province of Coastal New Brunswick:** The coastal area of New Brunswick in the area of Moncton is experiencing resurgence in gas exploration. Several fields have been producing gas and small quantities of oil in the past several years, most notably the McCully field (Figure 5). These fields are located within the Maritimes Basin of eastern New Brunswick – a thick sequence of unmetamorphosed sedimentary rocks that rest unconformably above the highly metamorphosed older rocks of western New Brunswick and eastern Maine. The Maritimes Basin contains lacustrine and fluvial sandstones, terrestrial red beds, and marine carbonates. These units are of Carboniferous age (290-354 million years ago). Rocks of this province do not extend westward into Maine.

**Figure 4.** Map of northern Maine showing thermal maturity of rock units based on graptolite reflectance and other thermal indices. Areas shown in yellow and orange have been heated beyond the temperatures necessary for oil and gas generation. From Malinconico and Roy (1993).

**Figure 5.** The extent of Carboniferous basin rocks with oil and gas potential are shown in yellow. Areas shown in dark brown and blue are metamorphosed older rocks. From New Brunswick Dept. Mineral Resources.
Summary of onshore hydrocarbon potential

Due to significant tectonic events with attendant weak to high-grade metamorphism, almost all of Maine’s rocks have been heated well above the temperature required for hydrocarbon generation. The one exception is a small area of northernmost Maine that may have escaped these high temperatures. The productive gas province of eastern coastal New Brunswick is in unmetamorphosed younger sedimentary rocks that do not extend into Maine.

Offshore Oil and Gas potential

*Hydrocarbon potential of Maine’s Coastal Waters:* Maine’s coastal waters extend to three nautical miles offshore from the mainland and coastal islands. Beyond three miles, waters of the Gulf of Maine are in federal jurisdiction. Geologists know a great deal about the geology of the State’s marine waters. Well-exposed rocks on Maine’s coast have attracted geologists for centuries. Some particularly detailed investigations of coastal geology are Hussey and others (2008) in southern Maine, Gates (2001) in central coastal Maine, Gilman and others (1988) at Mount Desert Island, and Gates (1977) in eastern coastal Maine. All of these efforts and many more confirm that the immediate coastal areas and coastal islands have experienced a similar geologic history to the remainder of Maine. Multiple tectonic and metamorphic events have affected these rocks. They have been heated to between 300-500°C and have been intruded by numerous igneous rocks, including the Vinalhaven granite (Devonian), the Cadillac granite (Silurian), and the gabbro that makes up most of Monhegan Island (Devonian).

Geologists have also investigated the submarine geology of Maine’s state waters. Kelley and others (1998) summarize a multiyear effort to characterize the ocean bottom using side-scan sonar and seismic reflection profiling. Side-scan sonar images reveal a rocky bottom that shows the same northeast-southwest orientation of rocky ridges as are found onshore. High-frequency seismic surveys reveal a thin (10s of meters thick) veneer of marine mud and glacial deposits overlying deformed rocks. In places, the thin marine mud generates gas from decaying organic material, such as in Belfast Bay (Kelley and others, 1994) where pockmarks develop in the seafloor through gas-escape processes. Similar to swamp gas or landfill gas, there is no economical way to exploit the disseminated gas in the thin marine mud.

Because of the high degree of metamorphism and intrusion of numerous bodies of molten magma, Maine’s state waters to three miles offshore has no potential for economically exploitable hydrocarbons.

*Gulf of Maine hydrocarbon potential – between three miles offshore and the northern margin of the Georges Bank:* While geologists know less about the deeper portions of the Gulf of Maine, there is still considerable information on which to develop a framework of the general geology. One of the very first applications of seismic refraction techniques in the Gulf of Maine was by Katz and others (1953). Their work investigated the nature of the crust along a traverse that extended from about 25 miles seaward of Yarmouth to about 35 miles seaward of Mount Desert Island. The compressional wave velocities they determined with this experiment are consistent with granite similar to that exposed on the coast of Maine.

Ballard and Uchupi (1972) summarized some of the early seismic reflection and refraction work done in the Gulf of Maine. This work helped delineate several Triassic basins
within the Gulf of Maine, part of the Fundy rift system that developed in the early stages of the opening of the Atlantic Ocean. These rift basins are largely filled with terrestrial deposits.

The work of Hutchinson and others (1988) summarizes much of what is known about the geology of the Gulf of Maine. Their map (Figure 6), based on seismic reflection profiles and aeromagnetic surveys, delineates several Triassic rift basins related to the Fundy rift system. Due to a series of sidestepping faults, the rift basins are located progressively farther offshore as one moves from the Bay of Fundy to the southwest. Based on aeromagnetic signatures similar in strength and pattern to those of the subaerial igneous and metamorphic terranes, on seismic refraction velocities, and interpreted seismic reflection profiles, Hutchinson and others (1988) conclude that most of the Gulf of Maine inboard of the Triassic basins is underlain with the extension of the terranes of igneous and metamorphic rocks that geologists have mapped throughout New England.

With regard to oil and gas potential of this region of the Gulf, most is underlain with high-grade metamorphic rocks that have been heated beyond the optimum conditions for oil and gas generation and accumulation. There is potential for oil and gas in the Triassic basins of the Gulf, but analogous basins elsewhere in eastern North America, both onshore and offshore have no known economic reserves of hydrocarbons (Paul Post, Minerals Management Service, personal communication, October, 2008).

Figure 6. Generalized tectonic map of the Gulf of Maine from Hutchinson and others (1988). Dark gray areas are Triassic rift basins. Areas labeled “P.Z.” are dominated by intrusive igneous rocks (plutons).
**Georges Bank Area:** The area with the highest potential for oil and gas reserves is the Georges Bank, a relatively shallow plateau situated more than 100 miles southeastward from the Maine coast. The oval shaped Bank is approximately 150 miles long, 75 miles wide, and with waters as shallow as 30 meters along its northwest edge, forms a barrier to the deeper Gulf of Maine waters to the north (Figure 7). The Georges Bank is underlain with a sequence of Upper Triassic through Cretaceous sedimentary rocks that include interlayered sandstones, limestones, and anhydrite (Edson and others, 2000). The northeastern most portion of the Georges Bank falls within Canada’s territorial waters.

![Figure 7. Outline map of the Gulf of Maine and Georges Bank. Cross-hatched box shows the approximate location of leases and exploration wells of the 1970s and 1980s. Modified from Gulf of Maine Times (2000).](image)

The only oil and gas exploration activity on the Georges Bank was conducted during the 1970s and early 1980s when 10 wells were drilled in the most promising areas identified through the best exploration methods then available. In a summary report, the Minerals Management Service indicated that hydrocarbons were not discovered in these wells, that thermally mature source rocks are lean in the organic material necessary to generate hydrocarbons, and that other units lacked adequate porosity to be considered good reservoir rocks (Edson and others, 2000). The Georges Bank was under annual congressional moratoria on oil and gas leasing from 1982 to 2008. No wells have been drilled on the Canadian portion of the Georges Bank and a leasing moratorium has also been in effect there since 1988.
In neighboring Nova Scotia, however, the industry has demonstrated that geology similar to that of the Georges Bank can be productive. Since exploration began on the Scotian shelf in the 1950s, 24 significant hydrocarbon discoveries have been made in this part of Canada’s outer continental shelf (Canada-Nova Scotia Petroleum Board). These have been mostly natural gas discoveries. The most notable, Sable Island, may eventually produce a total of 2 trillion cubic feet (Tcf) of gas, although estimates vary widely. Since the Sable Island discovery over 30 years ago, a very active exploration program has brought little additional reserve forward. With improved technologies, exploration is advancing toward deeper waters, which may hold the best potential for significant new reserves.

The government of Nova Scotia is actively supporting exploration activities on the Scotian Shelf due, in part, to the revenue sharing agreement with Canada’s national government that brings to the province $500 million in royalties annually (Canada-Nova Scotia Petroleum Board). In 2010, the governments of Canada and Nova Scotia will decide whether or not to extend the moratorium on Georges Bank leasing which is set to expire at the end of 2012.

While past exploration has not uncovered notable reserves, nor found conditions generally favorable for hydrocarbon accumulation, there is some potential for petroleum discoveries on Georges Bank and elsewhere in the North Atlantic. The Minerals Management Service (MMS) periodically conducts assessments of undiscovered hydrocarbon reserves of the outer continental shelf nationwide, most recently in 2006 (MMS, 2006). These assessments take into account past exploration data and information from new discoveries in areas with analogous geology, which for the Georges Bank include the Scotian Shelf. The assessment of undiscovered, technically recoverable reserves for the entire North Atlantic Planning Area, which extends from the border with Nova Scotia in the Gulf of Maine to the Delaware border, has a mean of 2 billion barrels of oil and 18 Tcf natural gas (Table 1). The greater proportion of this potential is probably in the southern part of this region near New Jersey where earlier exploration wells discovered gas. For comparison purposes, this same assessment indicates that the Gulf of Mexico area contains undiscovered reserves of 45 billion barrels of oil and 230 Tcf of gas – over 20 times more oil and 12 times more gas than the entire North Atlantic Planning Area. Additionally, Gulf of Mexico states already have in place the infrastructure necessary to support exploration and development activities.

Oil and gas exploration and development techniques have improved dramatically in the past 30 years, and if applied to the Georges Bank could possibly generate new discoveries, but these would likely be small compared to other areas of the Outer Continental Shelf.
Table 1. Estimates of undiscovered oil and gas for the Atlantic and Gulf of Mexico planning areas (MMS, 2006).

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<th>Region</th>
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<th>Undiscovered Economically Recoverable Oil and Gas Resources (UERR)</th>
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Summary oil and gas potential, offshore Gulf of Maine

The geology of the marine waters of the State of Maine (3 nautical miles offshore) is an extension of the immediate coastal geology mapped by geologists for decades. The high degree of metamorphism and numerous igneous intrusions preclude any oil and gas accumulations in this area.

Farther offshore, but still north of the Georges Bank, most of the Gulf is underlain with similar geology to that which has been mapped by geologists throughout New England. For the same reasons noted above it is highly unlikely that significant oil and gas reserves occur here. The exceptions are the Triassic basins, but analog basins on land and offshore have no known economic reserves.

The Georges Bank has clear potential for oil and gas generation and accumulation, although early exploration work was not encouraging. The geology of the Georges Bank is similar to gas producing areas of the Scotia Shelf. Minerals Management Service estimates of undiscovered reserves in the Georges Bank are small in comparison to other areas of the outer continental shelf of the United States.

Potential benefits of Georges Bank oil and gas development

Georges Bank oil and gas development could provide benefits to the state of Maine, the Northeast region, and the U.S. Although a substantial period of time is necessary for exploration and development activities, eventually, new hydrocarbon resources could be brought on line that, in small measure, reduce dependence on unstable foreign sources. In addition to the exploration and development jobs themselves, such activities would generate on-shore support jobs. However, it is unlikely that such development will bring substantial direct benefits to Maine. The proximity of the Georges Bank is such that any support base for exploration and development activities there would likely be situated in Massachusetts or Rhode Island. However, Maine has a track record of benefiting from petroleum exploration. One Maine corporation recently constructed two semi-submersible platforms for petroleum development; their work would certainly be enhanced by Georges Bank development. However, this
corporation has also demonstrated that they can compete globally since those two rigs were
deployed in waters off Brazil.

Potential risks oil and gas development

Oil and gas development poses risks to the marine environment, as summarized in a report from the National Research Council, *Oil in the Sea III: Inputs, Fates, and Effects* (2003). This report catalogs the sources of petroleum in the seas in these groups: natural seepage, petroleum extraction, petroleum transportation, and petroleum consumption.

*Natural seepage:* In perhaps its most controversial conclusion, the report identifies natural seepage as the source of about 60% of the petroleum entering North American waters. Because it is difficult to directly measure natural seeps, this estimate has high uncertainty compared to others in the report. By their nature, petroleum releases from natural seeps tend to be chronic and at low rates.

*Extraction activities:* While extraction activities are responsible for far smaller quantities of petroleum in marine waters (about 3% of anthropogenic releases), extraction-related spills can be large and catastrophic. Improved equipment and safety training in the past several decades has reduced the incidence of extraction-related releases in the marine environment.

*Transportation activities:* Petroleum transportation also results in significant releases to the marine environment, for North American waters representing 9% of anthropogenic releases. However, by their very nature such releases are catastrophic and often in large volumes along sensitive coastal areas. Currently, the largest threats to Maine coasts come from two sources: transportation of petroleum to and by the Portland-Montreal pipeline, and Irving’s oil refinery in St. John, NB. The Portland-Montreal pipeline has a capacity of over 500,000 barrels of petroleum products each day, all of which comes to Portland via ship (Pipeline website, 2009). While there have been relatively few spills there, the notable *Julie N.* spill of 1996 released about 4,000 barrels of oil into the Fore River, requiring a $43 million clean-up effort (National Transportation Safety Board, 1998). [Note that this spill was unrelated to activities of the Portland-Montreal pipeline.] Irving Oil refines about 110 million barrels of crude oil in St. John annually (Irving Oil, 2009), most of which arrives via ship. In the period 1989-2007, Irving reported no spills greater than 1,000 barrels at its refinery (St. Ross Environmental Research, 2008).

*Consumption activities:* Petroleum releases related to consumption activities form the largest proportion of anthropogenic releases to North American waters, about 85%. These are very small, chronic releases, and mostly on land but introduced to marine waters through run-off, and storm and waste water systems.

*Georges Bank:* Georges Bank is the most westward of the great Atlantic fishing banks - those now-submerged portions of the North American mainland that extend from the Grand Banks of Newfoundland to Georges Bank. They rank among the world’s most productive fisheries. Lying adjacent to New England’s famous seaports, Georges Bank is single-handedly responsible for the development of coastal fisheries in towns such as Gloucester, Massachusetts and Portland, Maine. The varied nature of sedimentary environments on Georges Bank is a key element in the development of the biological community. Seafloor sediment originally was transported to the bank by glaciers. During and after glacial retreat, the rise of sea level and the action of tidal and storm currents marked the start of an erosional episode on the bank that continues today. Gravel formed through this process is an important habitat for the spawning and survival of several fishery species (USGS). For instance, distribution patterns of juvenile cod indicate that the gravel habitat is where they are best able to avoid predators and to find food.
sources. The topography and position of the bank result in upwelling of nutrient-rich waters circulating in the Gulf of Maine. These nutrients, introduced into the sunlit waters over the bank, and interaction with warm Gulf Stream currents on the southern edge of the Banks, support exceptional rates of productivity, including many species of commercial importance. These are important spawning, juvenile and feeding grounds for cod, haddock, herring, and other commercial species. The scallop resource on Georges Bank is also very productive and valuable. In Maine, a substantial portion of the fishing fleet is dependent on the Georges Bank, and the largest dollar value of the commercial catch brought to Maine ports comes from this location.

Certainly, there are issues with over-fishing the Georges Bank, but government efforts focus on managing the fishery to rebuild stocks. Under current conditions, the fishery resources of Georges Bank are important to the economy of Maine and New England. With rebuilding of these resources, their economic value will be increased very significantly.

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