OIL SPILL SCIENCE

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OIL ON THE BEACH: WHAT HAPPENED AFTER DEEPWATER HORIZON?

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Beaches not only serve as a great place for recreation and vacation but also provide habitat for a wide variety of plants and animals. Once oil makes its way to the shoreline, it can take on many different forms, such as buried oil, submerged oil mats in nearshore waters, surface residual patties, or surface residual balls. Where oil lands on the beach can impact how long it stays in the environment. Oil that is buried in sand can persist longer than oil that remains on the surface and is exposed to the elements. The following publication discusses what happened to oil that reached Gulf of Mexico beaches in the aftermath of the Deepwater Horizon oil spill.

Oil from the Deepwater Horizon oil spill washes onshore. (Reprinted from Hayworth, 2011)

OIL ON THE BEACH

After the Deepwater Horizon (DWH) oil spill, currents and waves moved oil toward the northern Gulf of Mexico shoreline. Crews of emergency responders evaluated impacts using Shoreline Cleanup Assessment Technique (SCAT) ground survey data, which they collect as part of response activities. During DWH, SCAT team members regularly surveyed to determine the location and amount of oil on the shore, recording the overall amount, width, and thickness of oil deposits.[1] Newer studies built

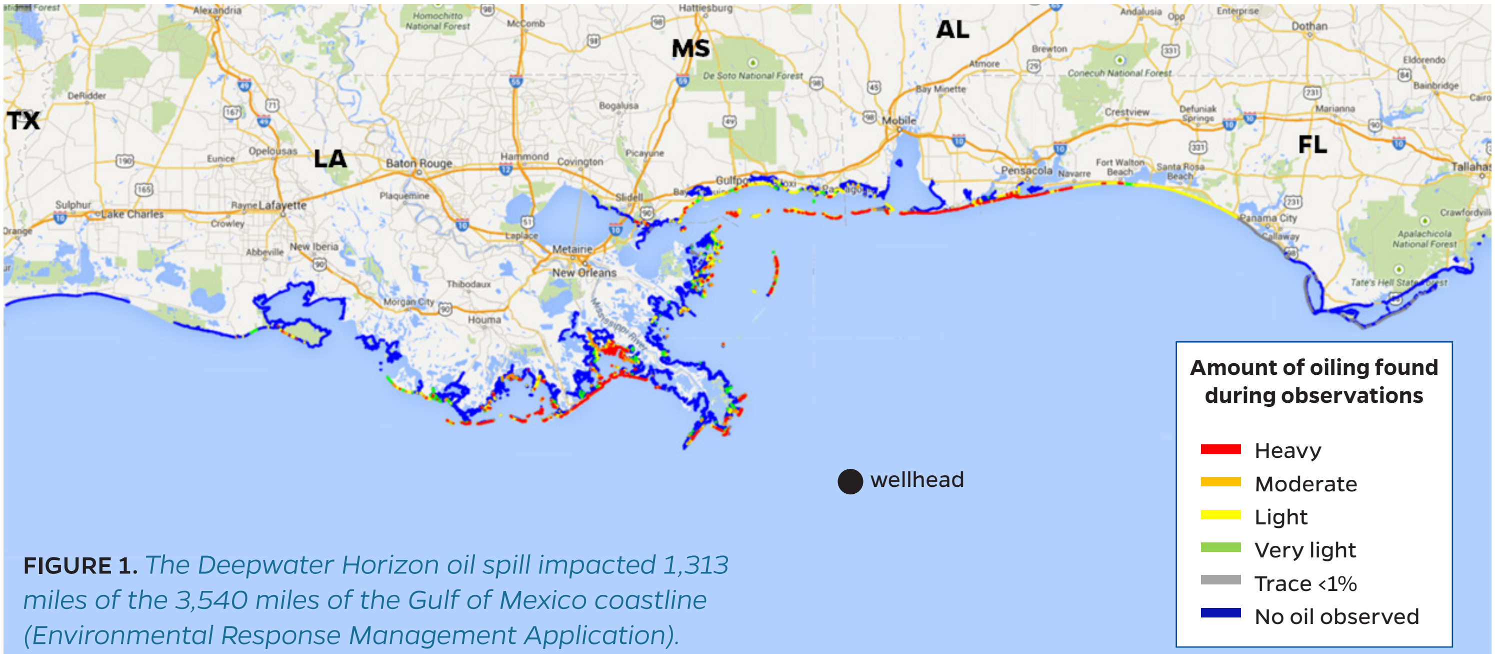


FIGURE 1. *The Deepwater Horizon oil spill impacted 1,313 miles of the 3,540 miles of the Gulf of Mexico coastline (Environmental Response Management Application).*

upon initial surveys to provide an updated summary of shoreline oiling. Data showed surface oiling along 1,313 miles of Gulf shoreline. Of those 1,313 miles, 687 miles (52%) of those were wetlands and 600 miles (46%) were sandy beaches.[2] Louisiana saw the largest percentage of total oiled beaches, though significant oiling also occurred in Florida, Mississippi, Alabama, and Texas (**Figure 1**, **Table 1**).[2] Most of the oil stranded on beaches during a three-month period.[3,4]

High wind and wave conditions during storms move sand around. After the DWH oil spill, storms also caused oil to move around. Some patches of oil moved further up the beach, and other patches that had been buried were re-exposed.[1,5] Patches of oil stranded further up the beach were absorbed by surface sands and then covered by wind-blown sand or sand deposited by tides. In some places, sand moved by waves and human activities covered the oil and buried it up to three feet deep (**Figure 2**).[1,4,6]

OIL DEGRADATION IN BEACHES

Buried oil **degrades** at different rates depending on oil type, temperature, oxygen levels, and the availability of nutrients. Bacteria naturally living in sand are essential to this process. Certain types of bacteria are better able to use oil for food than others. These oil-degrading bacteria increased in numbers following the spill. In heavily oiled areas, oil degrading bacteria were a hundred times more abundant than in non-oiled areas. This increase initially caused a decline in other groups of bacteria in the area. By October 2010, as levels of oil decreased, the makeup of these bacterial communities had returned to pre-spill conditions.[4,5] To learn more about bacteria and degradation, read the Sea Grant publication ***New Discoveries in Microbiology, Genomics, and Oil Spill Impacts.***

Increases in the number of oil degrading bacteria that use oxygen to aid in the breakdown of oil can cause a

TABLE 1. *Each state experienced a different amount of oil on their beaches and wetlands.*[2]

State	Miles of oiled beaches	Percentage of total Gulf of Mexico beaches oiled	Miles of oiled wetlands	Percentage of total Gulf of Mexico wetlands oiled
Louisiana	182	30%	656	95%
Florida	176	29%	0	0%
Mississippi	121	20%	27	4%
Alabama	85	14%	4	1%
Texas	35	6%	0	0%

FIGURE 2. *Sand that came ashore from tropical storms and hurricanes covered oil that had previously washed up on beaches after Deepwater Horizon. Scientist took samples from the beach to study the bacterial communities located in the layers of buried oil.[5] (Adapted from Huettel et al., 2018).*

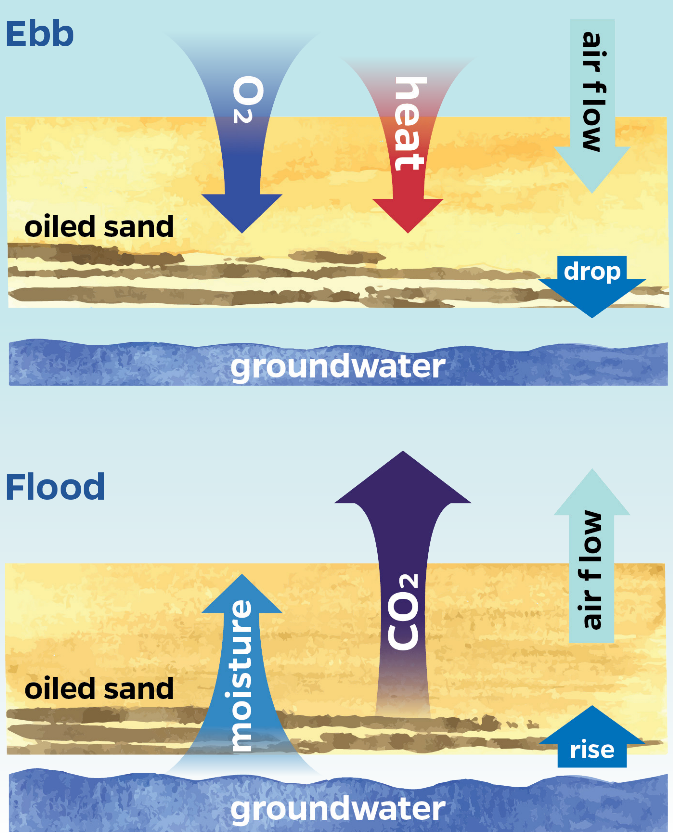
decrease in oxygen levels. Some bacteria can break down oil without oxygen, but this process takes much longer. Scientists observed low oxygen levels at various depths in the sand heavily contaminated with oil. However, once they measured deeper than 10 inches, oxygen levels increased again, suggesting that this oxygen was moved into the sediment by a process other than passively filtering in from the surface. That process is called tidal pumping, which occurs as the tides rise and fall, moving the groundwater level within the beach sand up and down, allowing the beach to "breathe." Researchers recreated the process of tidal pumping in the lab and found that if they artificially stopped the pumping, oxygen levels decreased, and buried oil degradation slowed down. When they started tidal pumping again, oxygen levels increased, which enhanced degradation.[5]

OIL-SEDIMENT RESIDUES

Many types of oil-sediment residues have similar compositions but form under different conditions and have different fates in the nearshore environment. Most

A BREATHING BEACH

In sandy beaches, a process known as tidal pumping helps the beach breathe by exchanging gas, heat, and moisture. Groundwater below the surface of the beach rises (floods) and falls (ebbs) with the tides. The groundwater is a mix of seawater and terrestrial fresh groundwater, such as rainfall, making it **brackish**. This process allows water and air to move into and out of the sand, improving air flow circulation.[5] When groundwater levels drop during the ebbing tide, oxygen is pulled down through the sand to the buried oil and the bacteria working to break it down. During the flood tide, groundwater rises upward through the sand, pushing carbon dioxide out of the beach. Similar to breathing, tidal pumping increases the exchange of oxygen and carbon dioxide gases, enhances oxygen and moisture in the oiled sand layers, and thereby supports the growth of **microbes** and oil breakdown.[5,7,8]



(Anna Hinkeldey, Adapted from Huettel et al., 2018)

FIGURE 3. *Hot, summer temperatures caused oil that made it to shore after Deepwater Horizon to melt into layers on top of the sand.[5] (Ray Palmer, Adapted from Huettel et al., 2018)*

of these residues develop in nearshore environments where waves and currents help the resuspended sediments (sand, clay, or other fine particles) interact with the suspended oil.[9] While microscopic (only visible with a microscope) and macroscopic (visible to the naked eye) oil-sediment residues both exist, this publication focuses on the macroscopic residues.

Submerged oil mats

Large patches of floating oil can interact with sediments to produce sediment-oil mats. Sunny weather and hot temperatures cause oil on beaches to melt, spreading on the sand and producing large oil layers (**Figure 3**). As beaches go through cycles of erosion and sand is deposited by waves, the oil moves around as it becomes buried and exposed repeatedly. Oil mixes with sand and shell to produce thick deposits called **sediment-oil mats/submerged oil mats (SOM)** or tarmats.[3,4] Following the DWH oil spill, SOMs most commonly appeared on shallow submerged sandy beds of the Florida Panhandle and coastal Alabama. SOMs tended to gather in areas of lower wave energy, such as troughs between the shore and sandbars, lagoons, and estuaries.[10] Over time, SOMs can be broken apart due to natural coastal movements forming **surface residual balls (SRBs)** (**Table 2, Figure 4**).[3,4,6]

Surface residual patties

Surface residual patties (SRPs) are smaller than oil mats but larger than surface residual balls, typically about four inches to three feet in size.[6] Scientists used PAHs to help identify oil sand patties that washed up on Sunset Beach in southern Pinellas County, Florida in January of 2013. Scientists wanted to investigate if the oil patties that washed on shore were from a past spill that occurred in the Tampa Bay area in 1993 or from the 2010 DWH oil spill. They compared PAHs found in sand samples taken in 1994 after the Tampa Bay spill and sand samples taken in 2011 after DWH to the SRPs found in 2013. Results indicated that the PAHs found at Sunset Beach were similar to those found in samples from the Florida Panhandle and coastal Alabama.

TABLE 2. *Listed below are the different types of sand and oil combinations as well as the characteristics of each.[4,6,9,10,13,15]*

Type	Approximate size	Key characteristics
Submerged oil mats (SOM)	1 to 10 meters in length and width, 1 to 10 inches thick	Large mats of buried oil, patchy in size and distribution, found in the water between the shore and sandbars, difficult to locate and remove
Surface residual patties (SRP)	4 inches to 3 feet in size	Flat, have relatively fresh oil at their core
Sediment-oil-agglomerates (SOA)	A fraction of an inch to several inches in diameter	Highly fragile, not rubbery, contains sticky, partially weathered oil, oval-shaped, composed mostly of sand (70-95%)
Surface residual balls (SRB)	Smaller than 4 inches	Fragile, sticky brownish material, can have strong petroleum odor when fresh, contain 10-20% oil

TO STICK OR NOT TO STICK

Whether oil sticks to particles in the water depends on the type of oil spilled and its **viscosity**. Factors such as evaporation and temperature can change the viscosity of oil, causing it to increase from low to high the longer the oil is exposed to the elements or **weathered**. When oil has a high viscosity, it becomes sticky and can form thick surface residual balls and patties. These are usually coated with sand but do not penetrate into the sand on beaches or in the water. Alternatively, less viscous oils will stick much less to sand that is floating in the water and will soak into the beach sands.[10]

FIGURE 4. *Responders found a submerged oil mat in a trough after the Deepwater Horizon oil spill (top). Surface residual balls that formed from submerged oil mats from the Deepwater Horizon oil spill (bottom).[10] (Adapted from Michel, 2020/Snorkel SCAT).*

Scientists also found low levels of **dioctyl sodium sulfosuccinate (DOSS)** in the sand patties. DOSS is a component of the **Corexit 9500 dispersant** used during the DWH oil spill, and it is also found in many common household products.[11]

Sediment-oil agglomerates

Sediment-oil-agglomerates/sand-oil-agglomerates (SOAs) form when weathered oil mixes with sand.[6] SOAs are the most common forms of oil contamination impacting coastal shorelines after a major oil spill. A large number of SOAs were found buried across the northeastern Gulf of Mexico beaches. They have a high sand content, causing them to sink. Scientists conducted a three-year experiment to understand how SOAs buried in the upper 20 inches of a beach in northern Florida degraded over time. They filled mesh tea ball infusers with SOAs and buried them in the beach out of the reach of seawater and groundwater (**Figure 5**). Over the course of three years, SOA consistency changed from soft and cohesive to hard and brittle. The color turned from brown to black. The rates of decay of oil decreased the deeper the SOAs were buried. Over the course of the three-year study, SOAs buried in the beach lost approximately 99% of their PAHs. Scientists calculated that SOAs that were one inch in diameter may completely biodegrade after 30 years.[4,14]

Surface residual balls

Surface residual balls (SRBs) are like SOAs but occur at the surface causing them to disintegrate faster than buried SOAs. SRBs can be found on the beach surface and are exposed to changing environmental conditions unlike oil that was buried. Scientists surveyed Alabama beaches and found that the appearance and disappearance of small SRBs (less than the size of a

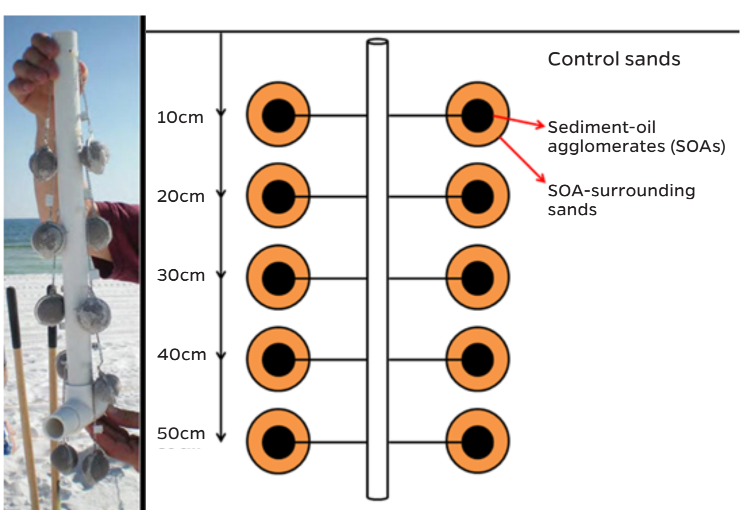


FIGURE 5. *Scientists filled mesh tea balls with sediment-oil-agglomerates (SOAs) and buried them in the beach to study the impacts of biodegradation.[4] (Reprinted from Shin, 2019)*

penny) near the shore mimic the behavior of sand and shell fragments. SRBs disappear under large wave conditions and reappear under normal wave conditions. Scientists also observed that the smaller the SRBs become, the more resistant they are to physical degradation. Pea-sized SRBs are unlikely to be recovered because many are difficult to see. These SRBs will most likely remain in the nearshore until they are either degraded or become stranded in the area of the beach that is above the reach of high tides. Over the four-year study, scientists also noticed a decrease in the number of SRBs found along Alabama's beaches.[15] However, recent studies have shown that the Alabama beaches continue to be contaminated with SRBs from DWH. In March of 2020, scientists surveyed 28 miles of the Alabama coastline. They collected over 250 SRBs ranging in size from 0.5 to 4 inches. They used oil **biomarkers** to identify the source of the oil and found that the SRBs they collected 10 years after the spill contained residue from DWH.[16]

Scientists also tested SRBs from the coast of Louisiana. They sampled different areas of the beach over a 19-month period. Results indicated that the biodegradation rates of the SRBs differed by the location of the beach where discovered. These different rates were due to the unique characteristics (such as salinity, moisture, nutrients, and oil composition) of the environment the SRBs were located.[3]

Waves break on beaches at an angle, moving sand along the shore. (Reprinted from Michel, 2020)

POLYCYCLIC AROMATIC HYDROCARBONS

Polycyclic aromatic hydrocarbons (PAHs) are chemical compounds present in crude oil. PAH types and concentrations vary depending on the type of oil that is spilled and act as a kind of fingerprint of the oil. Some PAHs can easily evaporate into the air. Data has shown that various PAHs found in floating oil weathered by 45% to 100% in the open ocean.[12] Weathering processes such as evaporation, **photooxidation**, **dissolution**, oil degradation by microbes, and biochemical reactions also play an important role in removing PAHs from oil floating in the ocean. However, PAHs can remain in the environment for a long period of time. Once oil is buried, these processes slow down causing PAHs to linger longer. PAHs can be found in all types of oiled sediments and are used to track the presence and origin of oil contaminants in sediment-oil residues.[13,14]

Sea Grant originally released an outreach publication, ***Navigating shifting sands: Oil on our beaches***, on this subject in 2016. This publication uses information from its predecessor as well as more recently published research. The studies mentioned here along with other oil spill studies can be found on the Gulf of Mexico Research Initiative's (GoMRI) website at ***http://gulfresearchinitiative.org***. Access to other oil-spill-related publications referred to in this publication can be found on the Sea Grant Oil Spill Science Outreach Program website, ***www.gulfseagrant.org/oilspilloutreach***.

Researchers found partially buried oil on Pensacola Beach, Florida. The location of the buried oil affects the oil's exposure to oxygen, nutrients, and heat, which can all impact the rates of degradation. (Markus Huettel)

GLOSSARY

Biomarker — A measurable substance in an organism, the presence of which is indicative of some phenomenon such as disease, infection, or environmental exposure.

Brackish — The mixture of fresh water from rivers, rain, or other sources and seawater, which results in slightly salty water.

Corexit 9500A — A dispersant approved for use in U.S. waters to minimize the presence of surface oil slicks during the Deepwater Horizon oil spill.

Degrade(-ing, -s, -ed, -ation) — The breaking down or decomposition of oil.

Dispersants — Chemicals that are used during oil spill response efforts to break up oil slicks and limit floating oil from impacting sensitive ecosystems such as coastal habitats.

Dissolution — When certain compounds found in oil dissolve or disperse into surrounding water.

Dioctyl sodium sulfosuccinate (DOSS) — A primary component of both dispersant formulas used in the Deepwater Horizon oil spill. It increases the attraction between oil and water molecules and hinders the formation of large oil slicks on the surface of the ocean. DOSS can also be found in consumer products such as detergents, cosmetics, and laxatives and, therefore, can be found in coastal waters.

Microbes — Very tiny organisms including bacteria, fungi, archaea, and protists. Some microbes (bacteria and archaea) are the oldest form of life on earth.

Photooxidation — A process in which sunlight causes a chemical transformation of oil into new, oxygen-containing compounds.

Polycyclic aromatic hydrocarbon (PAH) — A chemical group found in many sources, including but not limited to oil, tar, ash, coal, car exhaust, chargrilled animal fats, and smoke from burning oil or wood.

Submerged oil mats (SOMs) — Oil that has mixed with sand after making its way onshore or mixing with sand suspended in the water that causes the oil to sink.

Sediment-oil agglomerates (SOAs) — A term that refers to sand, clay and/or other particulate matter loosely bound by oil.

Surface residual balls (SRBs) — SRBs are mostly made up of oil and sand, pieces of shell, and other materials and are usually smaller than four inches in size.

Surface residual patties (SRPs) — Pieces of oiled sediment that are typically about four inches to three feet in size. SRPs are mostly made up of pieces of sand, shell, and other materials loosely bound by oil.

Viscosity — The measure of a fluid's resistance to flow.

Weather(-ing, -s, -ed) — A collection of physical, chemical, and microbial processes that alter and break down oil. It includes processes such as oil spreading, evaporation, dispersing, biodegradation, and photooxidation. These processes are influenced by many factors (for example, type of oil being weathered, temperature, bacteria present).

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