1.0 INTRODUCTION

The drilling of an exploratory well or series of wells has the potential to adversely affect the physical, chemical, biological, and socioeconomic resources of an area. One of the primary impact producing factors associated with exploratory drilling operations is the on-site discharge of 1) used drilling muds employed to facilitate the drilling process; and 2) formation cuttings, which are bits of rock and sediment generated from the formation being drilled. The following impact analysis identifies the potential impacts associated with muds and cuttings discharges.

Proper evaluation of environmental impacts requires an appropriate characterization of the drilling muds that may be used, the potential discharge of used muds and cuttings, and the site-specific resources at risk. These elements are addressed in the following analysis.

1.1 COMPOSITION, APPLICATION, AND DISCHARGES OF DRILLING FLUIDS AND CUTTINGS

1.1.1 Composition of Drilling Fluids

Drilling fluids (i.e., drilling muds) are a complex mixture of clays, chemical additives, and a base fluid (e.g., freshwater and/or seawater, or a synthetic base) that are used to lubricate and cool the drill bit, flush out cuttings, control formation pressures, seal permeable formations, and maintain well bore stability. Drilling fluids also help to minimize damage to reservoirs, prevent the formation of gas hydrates, assist in the transition of hydraulic energy to drill tools, assist in formation evaluation via logging equipment, control corrosion, and facilitate casing cementing (Canadian Association of Petroleum Producers [CAPP], 2001). Drilling fluids or muds can be either water-based (WBF or WBM) or synthetic-based (SBF or SBM), as discussed in detail in **Section 1.2**.

WBM ingredients can be divided into several functional categories (National Research Council [NRC], 1983; World Oil, 1999; Neff, 2005), including:

- Weighting materials – increase density (weight) of mud, balancing formation pressure, preventing a blowout; typical chemicals: barite, hematite, calcite, and ilmenite.
- Filtrate reducers – decrease fluid loss to the formation through the filter cake on the wellbore wall; typical chemicals: bentonite clay, lignite, Na-carboxymethyl cellulose, polyacrylate, and pregelatinized starch.
- Viscosifiers – increase viscosity of mud to suspend cuttings and weighting agent in mud; typical chemicals: bentonite or attapulgite clay, carboxymethyl cellulose, and other polymers.
- Flocculants – increase viscosity and gel strength of clays or clarify or dewater low-solids muds; typical chemicals: inorganic salts, hydrated lime, gypsum, sodium carbonate and bicarbonate, sodium tetraphosphate, and acrylamide-based polymers.
- Thinners, dispersants, and temperature stability agents – deflocculate clays to optimize viscosity and gel strength of mud; typical chemicals: tannins, polyphosphates, lignite, and lignosulfonates.
- Defoaming agents – reduce mud foaming; typical chemicals: alcohols, silicones, aluminum stearate ($C_{54}H_{105}AlO_6$), and alkyl phosphates.
- Alkalinity and pH-control additives – optimize pH and alkalinity of mud, controlling mud properties; typical chemicals: lime (CaO), caustic soda (sodium hydroxide, $NaOH$), soda

ash (sodium carbonate Na_2CO_3), sodium bicarbonate ($NaHCO_3$), and other acids and bases.

- Lost circulation materials – plug leaks in the wellbore wall, preventing loss of whole drilling mud to the formation; typical additives: nut shells, natural fibrous materials, inorganic solids, and other inert insoluble solids.
- Bactericides – prevent biodegradation of organic additives; typical chemicals: glutaraldehyde and other aldehydes.
- Pipe-freeing agents – prevent pipe from sticking to wellbore wall or free stuck pipe; typical chemicals: detergents, soaps, oils, and surfactants.
- Calcium reducers – counteract effects of calcium from seawater, cement, formation anhydrites, and gypsum on mud properties; typical chemicals: sodium hydroxide (NaOH), sodium carbonate and sodium bicarbonate (Na_2CO_3 and $NaHCO_3$, respectively), and polyphosphates.
- Shale control inhibitors – control hydration of shales that causes swelling and dispersion of shale, collapsing the wellbore wall; typical chemicals: soluble calcium and potassium salts, other inorganic salts, and organics such as glycols.
- Corrosion inhibitors – prevent corrosion of drill string by formation acids and acid gases; typical additives: amines, phosphates, and specialty mixtures.
- Emulsifiers and surfactants – facilitate formation of stable dispersion of insoluble liquids in water phase of mud; typical chemicals: anionic, cationic, or nonionic detergents, soaps, organic acids, and water-based detergents.
- Lubricants – reduce torque and drag on the drill string; typical additives: oils, synthetic liquids, graphite, surfactants, glycols, and glycerin.

By weight, the prominent drilling mud additives include barite and bentonite clay. Other chemicals and additives are added on an as-needed basis and are considered minor contributors to drilling muds.

SBMs often contain barite, clays, emulsifiers, water, calcium chloride, lignite, and lime. Water or a saline brine (usually containing calcium chloride [$CaCl_2$]) at a concentration of 10% to 50% volume, is dispersed into the hydrocarbon phase to form a water in-organic phase emulsion with water droplets less than 1 µm in diameter (Hudgins, 1991; Norwegian Oil Industry Association Working Group, 1996, as cited by Neff, 2005).

1.1.2 Application of Drilling Fluids

During exploratory drilling, drilling fluid is circulated from a mud pit on the drilling unit (e.g., mobile offshore drilling unit [MODU]) through the Kelly and down the center of a hollow drill pipe (**Figure 1**). Once it reaches the end of the drill pipe, at the drill bit, the drilling fluid exits the bit and picks up drill cuttings while lubricating the bit. Drilling fluid subsequently moves up the annulus (i.e., the space between the drill string and the borehole wall) to the mud return line.

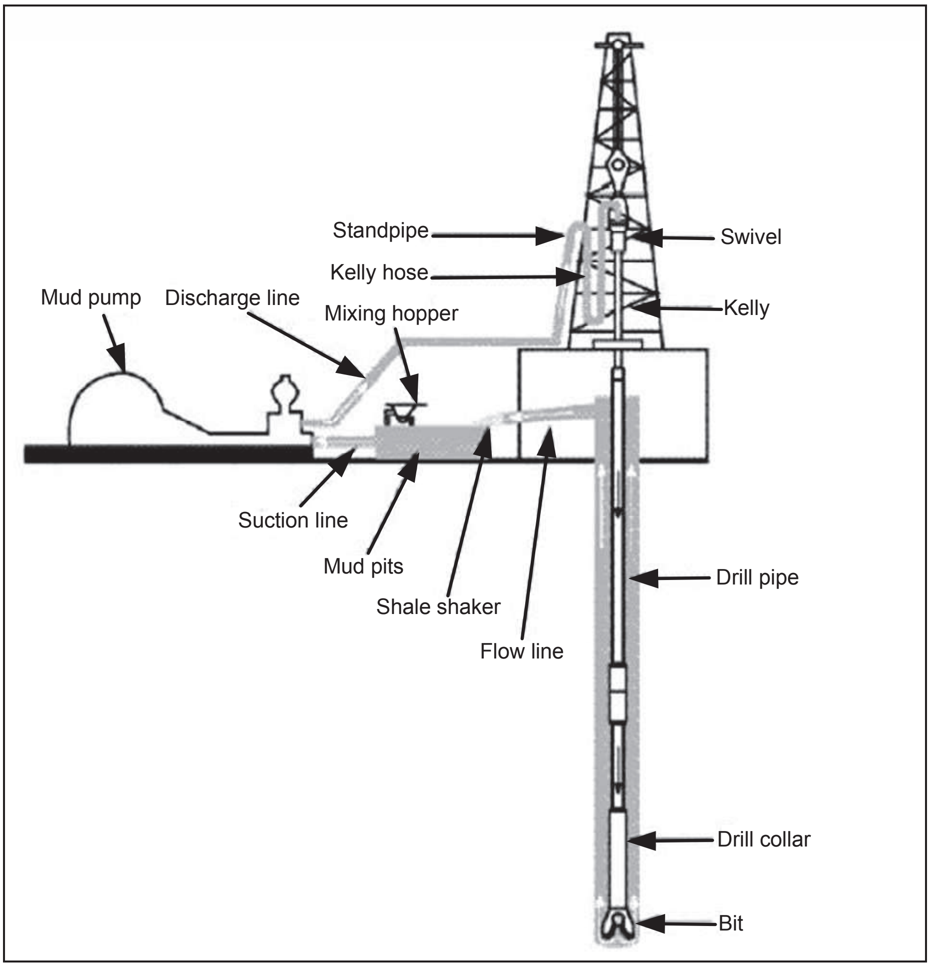

Figure 1. Drilling fluid routing on a typical offshore drilling rig (From: Canadian Association of Petroleum Producers, 2001 and Neff, 2005).

Drilling fluid returning from the borehole carries drill cuttings – crushed rock produced by the drill bit. Drilling fluid is processed to remove cuttings, then recycled down the well. As part of the mud processing, the muds and cuttings mixture is passed through separation equipment (e.g., shale shaker and other mud and cuttings separation devices) that separates the cuttings from the drilling mud, the latter of which is returned to the mud tanks for recirculation down-hole. Separated cuttings are, in most cases, discharged to the ocean, particularly when a WBM is used. Further restrictions typically exist for cuttings disposal from nonwater based drilling mud systems.

Shale shakers comprise a series of vibrating screens, with each successive shale shaker using a finer mesh screen to collect smaller sized particles. The liquid mud passes through each of the screens and is sent back to mud pits to be reused. If the recycled mud that has passed through the shale shakers contains fine particles that would interfere with drilling performance, the muds are treated using mud cleaners or centrifuges to remove very fine particles. At the end of drilling, or at the end of a particular interval that uses a specialized mud, the bulk mud will either be returned to shore for recycling or discharged to the sea (Argonne National Laboratories, 2008).

The solid cuttings coated with a film of mud remain on top of the shale shakers and are collected at the opposite end of the shakers. If the cuttings are able to meet the discharge standards at this point, they are generally discharged. If they are unable to meet the discharge standards (particularly relevant when SBMs are being used), the cuttings must be treated further by vertical or horizontal cuttings dryers, squeeze presses, or centrifuges. The cuttings dryers recover additional mud and produce dry, powdery cuttings.

1.1.3 Drilling Fluids and Cuttings Discharges

WBMs in volumes of about 20 to 30 m^3 per discharge are discharged to the ocean intermittently, usually from the mud settling pits, at rates of 80 to 300 m^3/h during drilling. Small discharges usually occur every 1 to 2 days and last less than 5 to 20 minutes (Neff et al., 1987; Steinhauer et al., 1992; Neff, 2005). Once drilling is completed, there may be a bulk discharge of up to 200 m^3 of used drilling mud. Bulk discharges last less than 1 hour. A total of 900 metric tons of WBMs and 1,100 metric tons of cuttings may be discharged during drilling of an exploration well (Neff et al., 1987). The total mass of WBMs and cuttings discharged per exploratory well is about 2,000 metric tons/well, and somewhat less for most development wells.

Recovered cuttings are flushed with seawater into a central discharge pipe (shunt line) that releases the cuttings just above or below the sea surface (CAPP, 2001). Occasionally, cuttings may be shunted (i.e., discharged at a designated depth) to localize the cuttings field and avoid serious impact to an environmentally sensitive area. Cuttings are discharged continuously during actual drilling, which usually occurs about half the time during drilling of a well. Drill cuttings containing 5% to 10% adsorbed WBM solids usually are discharged to the ocean at a rate of 0.2 to 2.0 m^3/h (Neff et al., 1987; Neff, 2005). With SBMs, discharged drill cuttings contain 5% to 15% adhering drilling fluids (Neff et al., 2000).

1.2 DRILLING FLUID TYPES

There are two major types of drilling fluids – water-based fluids (WBFs) and nonaqueous base fluids (NABFs). WBFs typically consist of fresh or salt water, barite, clay, caustic soda, lignite, lignosulfonates, and/or water-soluble polymers. NABFs are emulsions – a base fluid consisting of a liquid hydrocarbon or other water insoluble organic chemical forms the continuous external phase while calcium chloride brine forms the discontinuous internal phase (Neff et al., 2000). NABFs contain barite, clays, emulsifiers, water, calcium chloride, lignite, and lime. The two types of NABFs are oil-based fluids (OBFs) and synthetic-based fluids (SBFs). OBFs use a base fluid such as diesel fuel or a petroleum-based mineral oil; SBFs have a synthetic organic chemical as a base fluid. SBF base fluids include linear-α-olefins, poly-α-olefins, internal olefins, linear alkyl benzenes, ethers, esters, or acetals. The SBF base fluids used most frequently in U.S. waters are linear- α-olefins and internal olefins (Neff et al., 2000).

As well depth increases, the amount of barite required to successfully drill a well also increases. The average amount of barite in drilling muds used to drill wells offshore during 1998 in the U.S. Gulf of Mexico increased, with increasing well depth, from about 27.8 metric tons for wells up to 524 m deep to more than 362.9 metric tons for wells greater than 3,048 m deep (Boehm et al., 2001). More barite is required when drilling deep-water wells. Based on 1998 data for the U.S. Gulf of Mexico, barite requirements ranged between 1,360.8 to 4,535.9 metric tons for wells in 305 to >1,219 m of water. The total amount of barite used in the Gulf of Mexico in 1998 to drill 43 deep-water wells was 1.23×10^5 metric tons (Boehm et al., 2001; Neff, 2005).

An example of an SBM used in exploratory operations is Paradril-IA3 – an SBM with PureDrill IA-35 as the base oil, together with weighting agents, wetting agents, emulsifiers and other additives. PureDrill IA-35 synthetic drilling fluid is classified as a high purity, synthetic alkane consisting of isoalkanes and cycloalkanes (Williams et al., 2002). PureDrill IA-35 is a clean, colorless, odorless fluid that is safe to handle (Williams et al., 2002). It has an aromatic content of <0.01% and a polycyclic aromatic hydrocarbon (PAH) content of <0.001 ppm. It is nontoxic to human, plant, and marine life. PureDrill IA-35 base oil is a component of a whole mud system called ParaDrill that received a Group E classification by the OCNS classification system employed in the United Kingdom. The Group E classification is the best rating achievable under the OCNS system. It is assigned to chemicals that have relatively low toxicity and/or does not bioaccumulate or readily biodegrade.

The cuttings from analysis of PureDrill IA-35 synthetic drilling fluid demonstrated a low acute toxicity potential. Extrapolations carried out to determine the possible size of toxic zones indicated little or no risk of toxicity as close as 1,000 m or less from the rig (Payne et al., 2001). SBMs were developed as a replacement to OBMs, which were toxic and partially responsible for the longevity of cuttings piles (i.e., cuttings which have been deposited on the ocean floor). SBMs are typically used for long reach (i.e., onshore to offshore) drilling, directional drilling, and in deep waters where hole stability and integrity are critical. The SBFs used in the preparation of SBMs are water insoluble and, as such, the SBM does not disperse in water in the same manner as a WBM (Hurley and Ellis, 2004).

1.3 MUDS AND CUTTINGS DISCHARGE BEHAVIOR

Muds and cuttings discharged on site are dispersed in the water column, with dispersal dictated by mud and cuttings composition and ambient oceanographic conditions (**Figure 2**). Muds and cuttings will settle to the sea floor, with heavier cuttings and larger mud particles being deposited closer to the discharge point.

Finer portions of the muds discharge will be dispersed at greater distances from the discharge. WBM discharges form two plumes – an upper plume and a lower plume. The upper plume represents ~10 % of the mass of discharged solids. It contains fine-grained, unflocculated solids and dissolved components of the mud. The lower plume, ~90% of the mass of the discharge, contains dense larger-grained particles, including cuttings and flocculated clay/barite particles; it settles quickly.

WBM solids undergo dispersion, dilution, dissolution, flocculation, and settling in the water column. WBM containing high concentrations of organic matter may produce an anaerobic sediment layer near the surface. The cuttings pile is altered by reduction-oxidation (redox) cycling, bioturbation, and bed transport (Neff, 2005).

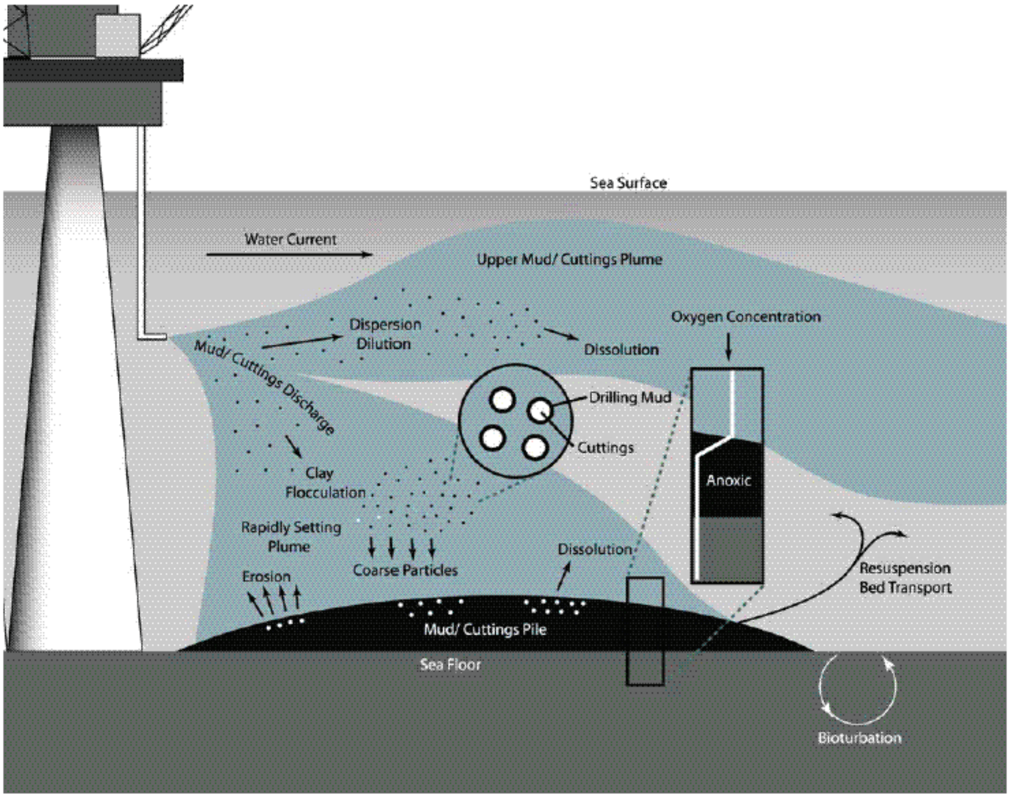

Figure 2. Fate of water-based drilling muds following discharge to the ocean (From: Neff, 2005).

1.4 FATES AND EFFECTS OF DISCHARGED MUDS AND CUTTINGS

Recent analyses of drilling fluids fate and effects, building upon earlier synopses (e.g., NRC, 1983), include Neff et al. (2000), Hurley and Ellis (2004), and Neff (2005). Current analyses have reviewed and updated the assessment of the fate and effects of water-based and synthetic-based drilling muds.

Drilling muds discharged to the ocean are diluted rapidly to very low concentrations, usually within 1,000 to 2,000 m downcurrent from a discharge and in less than 1 hour after the discharge. When water current speeds are high, the dilution of drilling muds and cuttings discharges is very rapid. For example, discharges from an exploratory drilling rig in Cook Inlet were diluted by 10,000-fold within 100 m of the rig (Houghton et al., 1980b). In well-mixed ocean waters, drilling mud is diluted by more than 100-fold within 10 m of the discharge. A 43-m^3 discharge of drilling mud from a platform off the coast of southern California, U.S.A., was diluted by 183-fold at 10 m and by 1,049-fold at 100 m (O’Reilly et al., 1989).

Depending upon subsurface (near bottom) currents, deposited muds and cuttings may persist as discharged or undergo rapid or prolonged dispersion (Neff, 1987, 2005). Drill muds and cuttings and their potential effects have been discussed in several studies (CAPP, 2001; Hurley and Ellis, 2004; Neff, 2005).

Hurley and Ellis (2004) recently conducted an analysis and summarization of water-based and synthetic-based drilling fluid and cuttings impacts. The following summary has been excised from Hurley and Ellis (2004).

Muds and cuttings discharges produce both physical-chemical and biological effects, including:

- Physical-chemical effects: Heavy particles tend to settle near the discharge site and can form a pile on the sea floor. Chemical properties of the cuttings pile depend on particle size, sorption capacity of the crushed rock, type and formulation of drilling fluids, physiochemical parameters in the drilling zone, conditions of the mud and cuttings contact with extracted hydrocarbons, and methods of cuttings separation and treatment.
- Biological effects: Potential exists for biological effects from the presence of cutting piles, including smothering of benthic communities and creation of artificial reef effects (Forteath et al., 1982) where piles attract marine organisms and provide substrate for epifaunal animals (e.g., crabs). NRC (1983) concluded that impacts from drilling operations are most severe on benthic communities. Laboratory and field toxicity studies have focused on the fate of drilling waste discharges and their acute and chronic effects on the benthic infauna and epifauna and bottom-dwelling fish species. Most studies have focused on the physical effects of the clay fractions of the mud and/or the biological effects of the petroleum hydrocarbon contamination from the drilling fluids. Observed impacts of drilling wastes have generally been attributed to chemical toxicity or organic enrichment. However, there is increasing evidence to indicate that fine particles in drilling wastes (e.g., bentonite and barite) contribute to the effects observed around drilling platforms. There are additional concerns about the potential for heavy metal pollution at petroleum exploration and development sites, including cadmium, lead, and mercury, which are found in drilling wastes (Cranford et al., 2001). Mercury, which naturally occurs in barite in a nonbioavailable form, has recently been shown to be nontoxic to biological communities. Recent attention has been focused on the potential for effects on fish and shellfish to address knowledge gaps considered important to the fishing industry.

1.5 WATER-BASED VERSUS SYNTHETIC-BASED MUDS

Recently there have been a number of reviews that summarize differences between environmental effects associated with WBM versus SBM. The Environmental Protection Agency (EPA, 2000) reviewed seabed surveys conducted at sites where cuttings contaminated with SBM and WBM were discharged and summarized either sediment or biological effects associated with WBM or SBM. Specifically, drilling fluid tracer concentrations (either barium [Ba] or SBM base fluid) in the sediment at varying distances from the drill site were documented to determine drilling fluid dispersion.

Biological effects were documented from benthic community changes, and used to assess effects such as increased metals and/or anoxia on biota. The primary literature used in the EPA review included studies performed in the U.S. Gulf of Mexico and in the North Sea, and included studies performed by regulatory bodies, industry groups, or individual companies. The EPA review noted that a large number of field studies of environmental impacts of exploratory well drilling discharges in several offshore locations provide sufficient information to arrive at reasonably reliable findings for WBM seabed impacts. However in contrast, existing data for SBM were considered more limited (EPA, 2000). When WBMs have been used, only limited environmental harm was likely to occur.

Cuttings can affect the local ecosystem in three ways: by smothering organisms, by direct toxic effect of the drilling waste, and by anoxic conditions caused by microbial degradation of the organic components in the waste. The use of SBM instead of WBM carries with it the risk of organic enrichment and the potential that synthetic-based fluid biodegradation products may be persistent. However, these risks must be weighed against the potential impacts that bulk WBM dumps have on turbidity levels and the discharge of heavy metals often associated with barite (Cranford et al ., 2001). On a broad risk basis, EPA now prefers the use of synthetic-based muds over water-based muds for deeper water exploration and development drilling activities (Hurley and Ellis, 2004).

1.5.1 Water-Based Muds

Hurley and Ellis (2004), in summarizing the results from their analysis of 20 case studies involving the use of WBMs, suggest that the degree of impact of drilling fluids and cuttings on benthic and demersal species is highly dependent on a number of local environmental variables – depth, current and wave regimes, and substrate type. Impacts are also influenced by the nature and volume of the discharges, including cuttings size and location of the outfall in the water column. However, consistent “zones of detection” for drilling fluids and biological impacts for WBM were documented.

Observations of the zone of detection of WBM for both single-well and multi-well facilities using barium as a tracer for drilling fluids suggest that average measured background levels are reached statistically at 1,000 to 3,000 m (Houghton et al., 1980a; Menzie et al., 1980; Mariani et al., 1980; Ray and Meek, 1980; Meek and Ray, 1980; Continental Shelf Associates, Inc., 1986; Boothe and Presley, 1989; Jenkins et al., 1989). Single transect values have been elevated at up to 8,000 m from a discharge location. Drilling fluid solids can be transported over longer distances to regional areas of deposition, albeit at low concentrations, based on a study of eight exploration wells (Bothner et al., 1985; Neff et al., 1989a). Barium was detected in the fine fraction of sediment 65 km west (downstream) and 35 km east of an exploratory drilling site after drilling was completed. In this case study, resuspension of drilling mud barite was identified as an important sediment transport mechanism.

Increases in select drilling fluid metals (e.g., arsenic [As], cadmium [Cd], chromium [Cr], copper [Cu], mercury [Hg], lead [Pb], and zinc [Zn]) have also been observed with distance from single well sites. These increases were more spatially limited, generally within 250 to 500 m of the drillsite, when Ba was the tracer. However, increases in other trace metals (i.e., Cr) were detected at 1,000 to 2,000 m for sites on the U.S. Gulf of Mexico shelf (Continental Shelf Associates, Inc., 1986). At deeper locations (in water depths >80 m in the Gulf of Mexico), the concentration of some metals (i.e. Cd and Hg) exceeded levels known to cause effects several years after drilling had ceased.

Biological effects have routinely been detected at distances of 200 to 500 m from a discharge (U.S. Department of the Interior, 1977; Menzie et al., 1980; Lees and Houghton, 1980; Montagna and Harper, 1996; Green, 2003). Effects include alterations to benthic community structure, including changes in abundance, species richness (number of species), and diversity. Taxa affected include annelids, molluscs, echinoderms, and crustaceans. Changes have been attributed to physical alterations in sediment texture and to platform-associated effects more frequently than to toxic effects. However, systematic studies of the relative contribution to observed impacts of varying stressors have not been conducted.

Less routine effects have been observed at greater distances of 1,000 to 2,000 m around single exploration wells. Reductions in the epibenthic coverage of suspension-feeding bryozoan communities were documented for unique hard bottom habitats in the U.S. Gulf of Mexico downcurrent from a single exploratory well (Continental Shelf Associates, Inc., 1989). Elevated concentrations of barium in tissues of polychaetes, brittlestars (primarily *Amphioplus macilentus*), and bivalves (primarily *Lucinoma filosa*) were detected as far as 1,600 m from a single well discharging WBM (Mariani et al., 1980). Studies of benthic community change around single exploration wells suggest that communities returned to baseline conditions generally 1 year after the cessation of drilling. However, in some cases, sensitive species (brittlestar *Amphioplus macilentus*), remained depressed within 90 m of the well site 1 year after drilling (Mariani et al., 1980).

Neff (2005) summarized the fate and effects of water-based drilling muds. When WBMs and cuttings are discharged to the ocean, the larger particles and flocculated solids, representing about 90% of the mass of the mud solids, form a plume that settles quickly to the bottom. The remaining 10% of the mud solids mass, which consist of fine-grained unflocculated clay-sized particles and a portion of the soluble components of the mud, forms another plume in the upper water column that drifts with prevailing currents away from the platform and is diluted rapidly in the receiving waters. In well-mixed ocean waters, drilling muds and cuttings are diluted by 100-fold within 10 m of the discharge and by 1,000-fold after a transport time of about 10 minutes at a distance of about 100 m from the platform. Because of the rapid dilution of the drilling mud and cuttings plume in the water column, harm to communities of water column plants and animals is unlikely and has never been demonstrated.

WBM and cuttings solids settle to and accumulate on the sea floor. If discharged at or near the sea surface, the mud and cuttings disperse in the water column over a wide area and settle as a thin layer of a large area of the sea floor. If mud and cuttings are shunted to and discharged just above the sea floor in order to protect nearby sensitive marine habitats, the drilling solids may accumulate in a large, deep pile near the discharge pipe.

The cuttings pile may contain higher concentrations of several metals, particularly barium (from drilling mud barite), and sometimes petroleum hydrocarbons, than nearby uncontaminated sediments. Chromium, lead, and zinc are the metals, in addition to barium, that are most often enriched in cuttings pile sediments. Until EPA placed limits on the concentrations of cadmium and mercury in drilling mud barite in 1993, some barite used in drilling muds contained elevated concentrations (compared to concentrations in natural marine sediments) of several metals. Cuttings piles containing these muds often contained elevated concentrations of several metals.

Barite has a very low solubility in seawater. The metals associated with drilling mud barite are present as insoluble sulfide minerals. Several laboratory and field studies have shown that the metals associated with drilling mud barite or cuttings piles have a low bioavailability to marine animals – they do not accumulate in the tissues of bottom-living animals.

Small amounts of petroleum products may be added to WBM for lubrication or they may be associated with the cuttings drilled during penetration of some geologic formations. These hydrocarbons may accumulate in the cuttings pile. Although WBMs, which contain petroleum hydrocarbon additives, are more toxic than those without hydrocarbons, WBM cuttings piles usually do not contain sufficient petroleum hydrocarbons to harm bottom-living communities (Neff, 2005). Petroleum hydrocarbon concentrations greater than about 50 to 60 mg/kg in cuttings piles often are associated with altered benthic community diversity. These concentrations usually are not observed unless synthetic-based mud cuttings or oil-based mud cuttings were discharged.

WBMs are nontoxic or practically nontoxic to marine animals, unless they contain elevated concentrations of petroleum hydrocarbons, particularly diesel fuel. Most drilling mud ingredients are nontoxic or used in such small amounts in WBMs that they do not contribute to its toxicity. Chrome and ferrochrome lignosulfonates are the most toxic of the major WBM ingredients. Although used frequently in the past in the Gulf of Mexico, these deflocculants are being replaced in most WBM by nontoxic alternatives to reduce the ecological risk of drilling discharges.

1.5.2 Synthetic-Based Muds

A total of 19 studies were reviewed by Hurley and Ellis (2004) to summarize the environmental effects associated with SBM. The area of detection and scale of biological effects resulting from SBM cuttings discharged were smaller than that resulting from the release of WBM. Maximum sediment concentrations of SBM were more localized than for WBM, and were detected at distances ranging from 100 to 2,000 m from the discharge location. Biological impacts associated with the release of SBM cuttings were generally detected at distances of 50 to 500 m from wellsites (Smith and May, 1991; Candler et al., 1995; Bakke et al., 1996; Daan et al., 1996; Terrens et al., 1998; Green, 2003). In one case study, reductions in the abundance of a few species (e.g., echinoderms) were detected over greater scales out to 1,000 m (Daan et al., 1996). While recovery of benthic communities were generally documented to occur within one year of completion, one case study documented that benthic species richness and abundance were reduced at a distance of 50 m 2 years after exploratory drilling stopped (Candler et al., 1995).

Synthetic-based fluids are water insoluble. SBMs do not readily disperse in water like WBMs. As a result, SBMs tend to sink to the bottom with little dispersion. Consequently, the majority of SBM-related research has focused on determining toxicity in the sedimentary phase. While the biological effects of SBM have been found to be localized, there are some scientific uncertainties regarding degradation processes for SBM. Biodegradation results in predominantly anoxic conditions in the sediment, with limited aerobic degradation processes occurring at the sediment water interface. SBFs typically have a high oxygen demand; they are likely to produce a substantial sediment oxygen demand when discharged in the amounts typical of offshore drilling operations. At present, there is disagreement as to whether slow or rapid degradation of SBFs is preferable with respect to limiting environmental damage and facilitating benthic community recovery. Organic material that biodegrades quickly will deplete oxygen more rapidly than more slowly degrading organic material. However, rapid biodegradation also reduces the exposure period of aquatic organisms to materials that may bioaccumulate or have toxic effects. EPA believes rapid degradation is preferable because sea floor recovery has been correlated with disappearance of SBM base fluids. Existing field data suggest these materials will be substantially degraded on a time scale of one to a few years; however, the distribution and fate of these materials has not been extensively documented.