Marine Pollution Bulletin 62 (2011) 2170–2180

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

The influence of drill cuttings on physical characteristics of phytodetritus

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ARTICLE INFO

Keywords:
Drill cuttings
Phytoplankton aggregates
Oil and gas industry
Settling speed
Critical shear velocity
Carbon transport

ABSTRACT

Sinking of aggregated phytoplankton cells is a crucial mechanism for transporting carbon to the seafloor and benthic ecosystem, with such aggregates often scavenging particulate material from the water column as they sink. In the vicinity of drilling rigs used by the oil and gas industry, the concentration of particulate matter in the water column may at times be enriched as a result of the discharge of 'drill cuttings' – drilling waste material. This investigation exposed laboratory produced phytoplankton aggregates to drill cuttings of various composition (those containing no hydrocarbons from reservoir rocks and those with a <1% hydrocarbon content) and assessed the change in aggregate size, settling rate and resuspension behavior of these using resuspension chambers and settling cylinders. Results indicate that both settling velocity and seabed stress required to resuspend the aggregates are greater in aggregates exposed to drill cuttings, with these increases most significant in aggregates exposed to hydrocarbon containing drill cuttings.

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1. Introduction

The majority of the transport of material from the surface waters of the worlds ocean's to the depths is made by the sinking of coagulated organic and inorganic aggregates (Alldredge and Silver, 1988). These aggregates comprise of a mixture of living and dead cells of phytoplankton, zooplankton, bacteria, and protists, detritus, excretory products, such as fecal pellets and marine gels (Burd and Jackson, 2009; Kiorboe et al., 1990). They also entrain 'ballast' minerals on their surfaces, namely, opal (SiO_2), calcium carbonates ($CaCO_3$) and fine lithogenic minerals (sands, clays, dust) (Armstrong et al., 2001; Hamm, 2002; Klaas and Archer, 2002). Aggregates with adsorbed 'ballast' govern the POC export from euphotic zone to the ocean interior and sediments (Armstrong et al., 2001; Francois et al., 2002; Klaas and Archer, 2002). Aggregates are also microhabitats for flagellates and bacteria communities, which control remineralization of the sinking fraction of POC. Recent studies have demonstrated that bacterial production and community respiration are strongly coupled with sinking aggregates, revealing microbial activity in aggregates as an important factor in regulating POC flux in the ocean (Egge et al., 2009; Grossart and Ploug, 2000; Iversen and Ploug, 2010; Kiorboe and Hansen, 1993). Once they enter the bottom boundary layer close to the marine sediments, these aggregates are often consumed by the benthic communities in a process known as benthic pelagic coupling (Graf and Rosenberg, 1997).

Phytodetrital aggregates formed by natural processes in the vicinity of drilling rigs operated by the offshore industry are of particular interest on the local scale as they may scavenge fine suspended lithogenic material released into the marine environment during drilling operations (Neff, 2005; Schaanning et al., 2008). This material is known generally as drill-cuttings, but these cuttings can vary in both size (from clay to coarse gravel) and material composition. Cuttings consist of a combination of (1) fragments of the various lithological types of sedimentary rock through which the drill passes, and (2) the drilling fluid used to ensure both positive drill pressure and cooling of the drill bit during drilling. The drilling fluid component can be water based, synthetic based, or oil based, and consist of a mix of various ingredients. Most of the drilling in the North Sea (focus of this study and source of the drill-cuttings used here) is performed with water based drilling fluids, with barite ($BaSO_4$) or ilmenite ($FeTiO_3$) the main components of the mix. Typically, the lithological components of water based drill cuttings consist of grey shale chips from the lithological layers drilled through; minor constituents such as hematite, limonite, goethite, and carbonate can be present, altering the color of drill-cuttings. Following release into the marine environment, coarse drill-cuttings have been observed to settle close to the discharge point, with dispersal models employed by the offshore industry indicating that the fine fraction may stay in suspension and travel over large distances before settling to the seabed (Neff, 2005; Neff et al., 1989; Rye et al., 2006).

These dispersal models predict that the fine clay-sized unflocculated fraction of the discharged drill cuttings creates a plume

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0025-326X/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2011.07.002

in the upper water column that drifts with prevailing currents away from the platform, diluting rapidly with the distance, and settling slowly over the large area of the sea floor. Ayers (1994) using the Offshore Operations Committee (OOC) Drilling Mud Discharge Model, predicted the dilution of 300,000 mg/l of drill cuttings at the source of discharge to 8 mg/l at ~760 m from point of release, after one hour of transport (given a discharge rate of 42,300 gal/h) (Ayers, 1994). Drill cutting discharges modeled by Voparil et al. (2009) with the same model showed dilution to 150 mg/l 100 m from the source (discharge rate 65,000 gal/l). Applying the Dose-Related Risk and Effect Assessment Model (DREAM model), Rye et al. (2006) estimated high concentrations of the suspended drill cuttings (>200 mg/l) within 50 m from the discharge point, with subsequent dilution to 50 mg/l ~100 m away from the platform (Rye et al., 2006). At the benthic boundary layer (BBL) concentrations of drill cuttings can reach 100–1000 mg/l close to the rig site (250 m), and up to 100 mg/l 5 km away from the platform site (Niu et al., 2009).

Presence of drill cuttings in the surface waters has two effects on primary production and transport of carbon from surface waters. Firstly, presence of the fine drill-cuttings fraction in suspension can lead to turbidity increase in the water column (Lynch et al., 1994), with associated light limitation that can negatively affect primary production. Secondly, fine drill-cuttings incorporated into aggregates can act as mineral 'ballast' increasing the settling rate of the aggregate, therefore reducing the residence time in the water column (Curran et al., 2002; Schaanning et al., 2008).

On the Norwegian Margin seabed there are numerous developed cold-water coral reefs. These ecosystems develop slowly, with scleractinian corals forming complex three dimensional reef structures with growth. These skeletal structures provide habitat niches for a variety of benthic organisms and reefs are considered to be local hotspots of regional biodiversity. These ecosystems are of public and legislative concern in Norwegian waters, and therefore any potential risks to their viability posed by human activity must be investigated. Previous experimental study investigating the sedimentation of fine drill cuttings onto cold water corals in laboratory experiments showed that: (1) the structure of coral branches of commonly occurring European corals such as *Lophelia pertusa* minimize the chance of surface coverage by deposited material (Larsson and Purser, 2011), a process assisted by surface cleaning by coral mucus production (Allers et al., in review). Coral polyp behavior is affected in the short term following exposure to drill cuttings, indicating a reduction in feeding with possible negative consequences on the energy budget of the organism is a possible result of exposure over a long period (Purser et al., 2010a). Given that net capture rates by *L. pertusa* are highest during low flow conditions (Purser et al., 2010b), repeated resuspension of drill cuttings followed by settling in periods of reduced flow (such a situation may be associated with tidal cycles in the region) may well reduce active feeding in the long term. (2) After 3 months of constant exposure to fine drill cuttings, respiration rates of *L. pertusa* were not affected, indicating the ability of the organism to endure long term exposure, even if active feeding is reduced (Larsson and Purser, 2011).

From the research to date, the risks posed by drill cuttings to the reef organisms are not fully understood. Given this fact, it is perhaps sensible to wherever possible minimize exposure by the reef to drill cutting material. To best achieve this, drill cutting dispersal predictions, following release to the ocean, should be as accurate as possible. This study concentrates on assessing the interactions between fine drill-cuttings and fresh phytodetrital aggregates. The main objectives of the study being to compare the effects of two classes of fine drill-cuttings on the hydrodynamic behavior of phytodetritus; one class representing pure lithogenic drill-cuttings, (hereafter referred to as regular drill-cuttings (DC)) and a further class additionally containing hydrocarbons from the reservoir, referred to hereafter as hydrocarbon containing drill-cuttings (HCDC). According to Norwegian regulations these HCDC drill cuttings have an oil content of formation oil of less than 1% of dry matter. From 2004 to 2008, the discharge of cuttings from water based drilling fluids decreased from 86,000 t to 70,000 t/year of which up to 2500 t/year were transported to land.

Potential implications of this research are locally significant, as the alteration of physical properties of aggregates may affect transport of materials in the vicinity of drilling activities, and therefore expose regions of the seabed to material at concentrations not predicted by dispersal models which do not take into account the process of aggregation. This is an important consideration for benthic ecosystems, as the entrainment of drill-cuttings of various chemical compositions within sinking aggregates might not only impact microbial activity and remineralization processes within the aggregates, but also alter community structures and food webs within the benthic community (Sanders et al., 1987; Schaanning et al., 2008; Trannum et al., 2010). Consequently, it is essential to be able to predict the fate of fine drill-cuttings released into the water column. Given the variable quantity, hydrodynamic behavior and composition of the drill cuttings which can be released to the ocean during a drilling operation, it is important to best assess how release of this waste material can be best managed to reduce ecosystem impact.

The hypothesis investigated by this study was that

1. the discharge of drill cuttings into waters containing phytodetrital aggregates would alter the hydrodynamic characteristics of both the phytodetrital aggregates and drill cutting particles.

2. Materials and methods

To test the proposed hypothesis, three experimental investigations were conducted. The first of these investigated whether or not drill cuttings would aggregate with phytodetritus under typical oceanographic turbulence conditions. The second set of experiments focused on determining whether phytodetritus aggregates exposed to various types or concentrations of drill cuttings settle at different rates in the marine water column. The third set of experiments investigated the degree to which resuspension behavior varied between phytodetritus aggregates exposed to different drill cutting types and concentrations. Prior to carrying out the experimental investigations, phytodetrital aggregates were produced in the laboratory and drill cuttings homogenized, sieved and quantified for use in the experiments.

2.1. Production of phytodetrital aggregates

In the natural marine environment, aggregation and mass cell sedimentation often terminates a phytoplankton bloom (Crocker and Passow, 1995; Kiorboe and Hansen, 1993; Kiorboe et al., 1994). Diatoms are very abundant during blooms and play an important role in the aggregate formation process (Smetacek, 1999; Thornton, 2002). One of the crucial parameters of aggregation is the stickiness of the particles, which usually increases at the decline of diatom bloom. During this period of nutrient limitation, a special class of marine gels, called transparent exopolymer particles (TEP), is abundant in both the water and aggregates (Alldredge et al., 1993; Kiorboe et al., 1994; Passow, 2002). TEP are generated abiotically from polysaccharide precursors released mainly from diatoms as dissolved colloidal matter (DCM) (Kepkay, 1994). DCM undergoes 'annealing' when polymers from one gel diffuse and interpenetrate into neighboring gels forming microgels (Chin et al., 1998). Since the TEP are sticky, they act as biological glue, increasing attachment probability of the particles once

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