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Alterations in bottom sediment physical and chemical characteristics at the Terra Nova offshore oil development over ten years of drilling on the grand banks of Newfoundland, Canada

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ABSTRACT

This paper describes sediment composition at the Terra Nova offshore oil development. The Terra Nova Field is located on the Grand Banks approximately 350 km southeast of Newfoundland, Canada, at an approximate water depth of 100 m. Surface sediment samples (upper 3 cm) were collected for chemical and particle size analyses at the site pre-development (1997) and in 2000–2002, 2004, 2006, 2008 and 2010. Approximately 50 stations have been sampled in each program year, with stations extending from less than 1 km to a maximum of 20 km from source (drill centres) along five gradients, extending to the southeast, southwest, northeast, northwest and east of Terra Nova. Results show that Terra Nova sediments were contaminated with $>C_{10}$–C_{21} hydrocarbons and barium—the two main constituents of synthetic-based drilling muds used at the site. Highest levels of contamination occurred within 1 to 2 km from source, consistent with predictions from drill cuttings dispersion modelling. The strength of distance gradients for $>C_{10}$–C_{21} hydrocarbons and barium, and overall levels, generally increased as drilling progressed but decreased from 2006 to 2010, coincident with a reduction in drilling. As seen at other offshore oil development sites, metals other than barium, sulphur and sulphide levels were elevated and sediment fines content was higher in the immediate vicinity (less than 0.5 km) of drill centres in some sampling years; but there was no strong evidence of project-related alterations of these variables. Overall, sediment contamination at Terra Nova was spatially limited and only the two major constituents of synthetic-based drilling muds used at the site, $>C_{10}$–C_{21} hydrocarbons and barium, showed clear evidence of project-related alternations.

1. Introduction

This paper presents findings on alterations of sediment physical and chemical characteristics resulting from development drilling at the Terra Nova offshore oil development. Drilling discharges generally include drill cuttings (crushed formation rock from well holes), and drilling muds used to facilitate the drilling process. Both water-based drilling muds (WBMs) and synthetic-based drilling muds[2] (SBMs) have been used at Terra Nova (see DeBlois et al., 2014-a, for details). To our knowledge, results provided in this volume are the first published account of a 10-year monitoring program (2000 to 2010) on the influence of offshore drilling where SBMs were used and SBM-on-drill cuttings were discharged to the ocean. The OGP (International Association of Oil and Gas Producers) (2003) identified 12 studies assessing chemical

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[2] The synthetic drilling fluid in the drilling mud used at Terra Nova is a low-toxicity hydroisomerized and hydrogenated iso-alkane (iso-paraffin).

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contamination and biological effects from SBM-on-drill cuttings discharge in the offshore. In three of these studies, sampling was conducted for up to two years. Since then, Neff et al. (2005) have reported on a post-drilling study of effects of SBM discharge in the Gulf of Mexico, with time since last drilling at the eight well sites examined ranging one to seven years. Pozebon et al. (2009) and Peralba et al. (2010) reported on two-year post-drilling studies in the Brazilian offshore.

The Terra Nova Field is located on the Grand Banks of Newfoundland (Canada), 350 km offshore, at a water depth of approximately 100 m (Fig. 1). Drilling started prior to the 2000 EEM program, with decreased drilling activity in 2007, prior to the 2008 and 2010 EEM programs (see DeBlois et al., 2014-a, for details on drilling statistics at Terra Nova). Five drill centres are active at Terra Nova: the Northeast (NE); Northwest (NW); Southeast (SE); Southwest (SW); and Far East (FE) drill centres. The NE, NW, SE and SW drill centres are located near the centre of the development within a Fisheries Exclusion Zone (i.e., FEZ drill centres). The FE drill centre is located approximately 5 km to the east of the centre of development. Drilling started at the NE and SW drill centres in 2000, drilling started at the remaining FEZ drill centres and the FE drill centre in 2001 (see DeBlois et al., 2014-a).

Based on the physical properties of drill cuttings and local oceanographic conditions, drilling discharges from the five drill centres at Terra Nova were not expected beyond approximately 15 to 20 km from source, with the greatest accumulation occurring in the immediate vicinity of drill centres (Seaconsult, 1998). Therefore, monitoring examined alterations in sediment physical or chemical characteristics relative to distance from drill centres (i.e., a gradient monitoring design Ellis and Schneider, 1997; Kilgour et al., 2007; Paine et al., 2014-a).

Barium and $>C_{10}$–C_{21} hydrocarbons are the main contaminants from discharge of SBM-on-drill cuttings. Barium is the main contaminant from discharge of WBMs. Contamination with metals other than barium and alterations in sediment particle size might also occur to some degree (see DeBlois et al., 2014-a). Biodegradation of hydrocarbons and other organics in SBMs or mortality and decomposition of benthic organisms might also cause reduction in sediment oxidation/reduction (redox) potential, leading to localized increases in sediment sulphide and ammonia concentrations. Therefore, this paper describes pre- and post-drilling alternations in sediment concentrations of $>C_{10}$–C_{21} hydrocarbons and barium, particle size, total organic carbon (TOC), metals other than barium, sulphur, sulphide, ammonia and sediment redox potential. Results presented here also compliment accompanying papers on biological effects (DeBlois et al., 2014-b; Paine et al., 2014-a; Whiteway et al., 2014).

2. Materials and methods

2.1. Field collections

Sediment collection for the Terra Nova EEM program was performed in late summer/early autumn from sampling facilities installed on an offshore supply vessel. Sampling dates for the baseline collection and for EEM programs are provided in Table 1.

Sediment stations for the baseline and EEM programs were established based on a radial design, with a higher density of stations where contamination was expected to be highest. Stations extended from less than 1 km to a maximum of 20 km from drill centres. A total of 49 to 54 stations were sampled in each program year (Table 1). Some stations sampled during baseline collections were relocated for the EEM program because they were located too near subsea infrastructure. Construction activity within the FEZ also prevented sampling in some EEM years. Fig. 2 provides the location of EEM stations and indicates stations sampled in any given year.

Table 1
Sampling dates for sediment collection.

Trip	Date	Number of Stations
Baseline program	September 24 to October 7, 1997	54
EEM program Year 1	September 27 to October 4, 2000	49
EEM program Year 2	August 30 to September 5, 2001	49
EEM program Year 3	September 3 to September 13, 2002	53
EEM program Year 4	October 5 to October 10, 2004	52
EEM program Year 5	August 13 to August 22, 2006	53
EEM program Year 6	September 5 to September 17, 2008	53
EEM program Year 7	October 14 to October 23, 2010	53

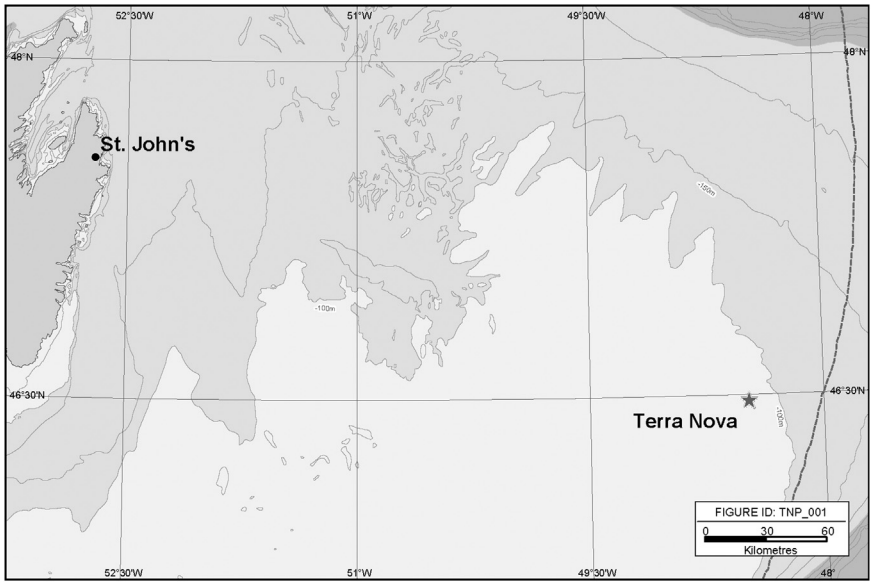

Fig. 1. Location of the Terra Nova Oil Field on the Grand Banks of Newfoundland.