Sakhalin Energy Investment Company

Review of Phase I Offshore Environmental Monitoring Data June 1998-October 2001

FINAL

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Table of Contents

List of Tables and Figures

1 Introduction

1.1 Project Description

Sakhalin Energy Investment Company (SEIC) installed the stationary oil production platform *Molikpaq* on the Piltun-Astokh (P-A) field in June 1998 and has been producing oil via the Vityaz complex from the P-A field since July 1999. This area lies east of Sakhalin Island, located off the northeast coast of Russia in the Sea of Okhotsk.

The Vityaz production complex comprises the Molikpaq platform and the *Okha* Floating Storage and Offloading (FSO) vessel, the latter being moored to a Single Anchor Leg Mooring (SALM) buoy. The oil from Molikpaq flows via a sub-sea pipeline to the SALM buoy, on to the FSO and then to tankers for batch transhipment to market.

Environmental Surveys around the installation have been carried out in June 1998 (prior to installation), and October 1998, 1999, 2000, and 2001; sediment and water sampling was conducted along four transects around the platform in all 5 surveys (see *Figure 1.1*), two surveys also included sediment sampling around the SALM buoy. The samples were analysed for a typical suite of parameters for monitoring oil and gas industry activities. All surveys included observations of birds and marine mammals.

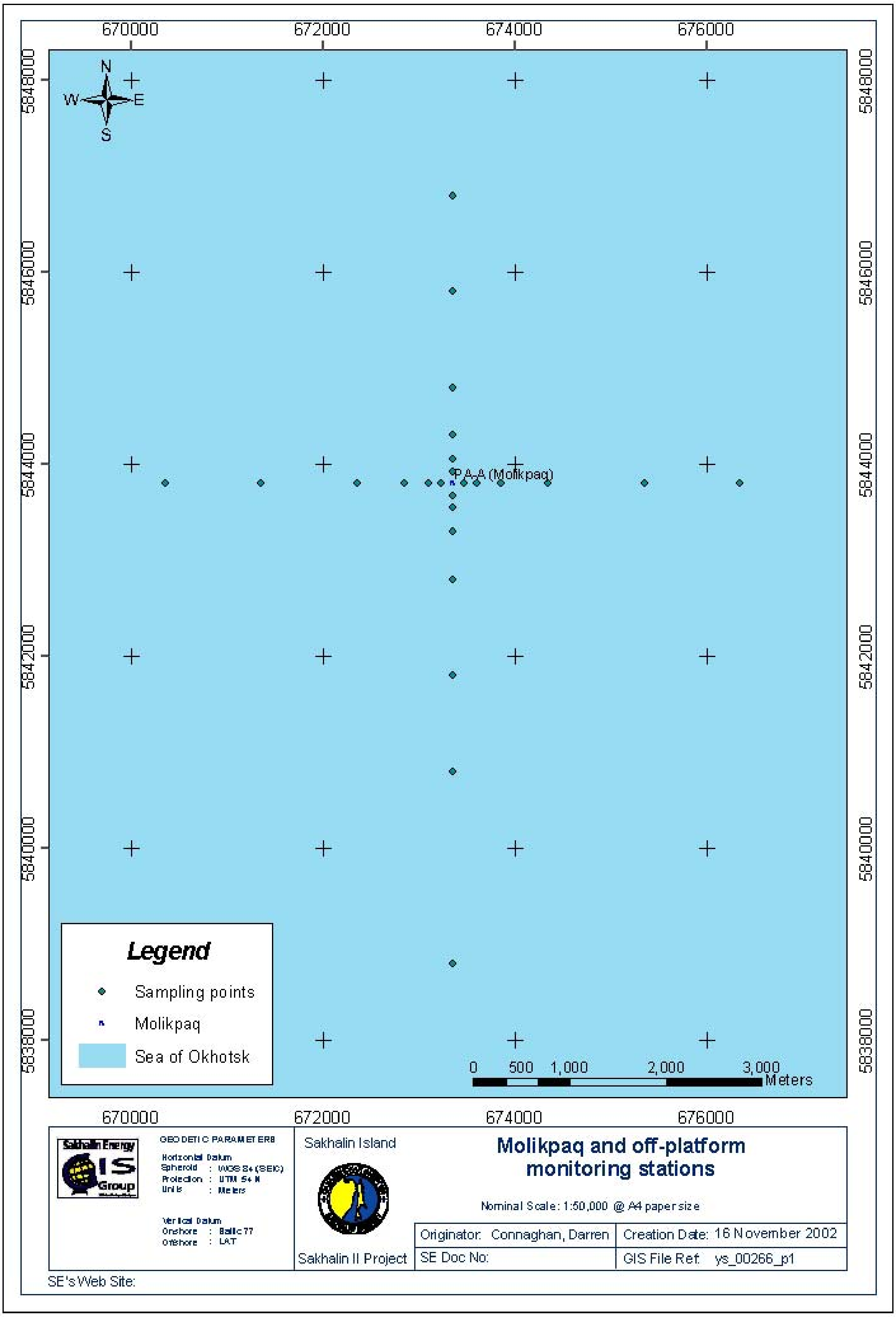
The data collection, analysis and interpretation for the monitoring to date have been undertaken by the Far East Regional Research and Development Hydrometeorological Institute (DVNIGMI), except in 1999 when Sakhydromet were the main contractor.

SEIC requested Rudall Blanchard Associates Limited (RBA) to carry out the following reviews, in order to assist in assessing the effects of SEIC operations to date on the environment and the effectiveness of the effects monitoring programme:

1. Review and interpretation of the available data and summary of the scientific results of the four year vessel-based off-platform environmental survey programme undertaken in the vicinity of the Molikpaq platform.
2. Review of the summary of results for this data produced by DVNIGMI in 2002 (DVNIGMI, 2002b) including comment on the report's accuracy and relevance.
3. Review of the environmental monitoring programme to date (including the survey undertaken in October 2002), incorporating comment on its scientific integrity, and suggested improvements for future surveys.

This report addresses the first and third of the tasks above, summarising the findings of monitoring surveys to date around the Molikpaq installation and giving recommendations on future environmental effect monitoring. A separate report will be produced shortly to address the second task. It should be noted that the compliance monitoring programme, which is complementary to the monitoring of environmental effects, is not within the scope of this review. The compliance monitoring programme measures inputs to the environment from Molikpaq. It is thoroughly documented in SEIC's annual monitoring report to the regulatory authorities.

Figure 1.1. Arrangement of sampling stations around the Molikpaq platform



2 Operations in the Vityaz Complex

2.1 Operations Prior to 1998

Exploratory drilling in the Piltun-Astokhskoye (P-A) field area was conducted prior to 1998. It is known that 15 wells were drilled by Sakhalinmorneftegas between 1987 and 1992; the locations of the wells are shown in CSA (1995). The nature and quantity of discharges from these operations are not known; no evidence of environmental contamination was discovered in a baseline survey carried out in 1995, when the wellsites were sampled (CSA, 1995).

2.2 Installation of Molikpaq Platform

The Molikpaq platform was installed in the autumn of 1998. Prior to installation, sediment was dredged from the seabed in an area 5 to 10 kilometres to the west of the platform location. Some of this aggregate was used to fill the base of the platform; the remainder was disposed of in an area approximately 12 kilometres to the east-northeast of the platform.

Rock armour was placed around the base of the platform as a protection against scouring of seabed sediment by the strong seabed currents encountered in the area.

2.3 Drilling Programme and Operational Discharges

2.3.1 Drilling Programme and Drilling Wastes

Drilling at Molikpaq

Fourteen development wells were drilled from the Molikpaq platform between October 1998 and December 2000 (the final well was not formally completed until January 2001, but all drilling activity and discharges were finished in December 2000). The wastes from the drilling programme, drill cuttings and drilling mud, were discharged to sea via the sluice approximately 5 metres below mean sea level on the northern face of the Molikpaq platform. A limited amount of drilling mud was also discharged via the 15m J-tube on the same side of the platform.

Drill Cuttings

The rocks overlying the hydrocarbon-bearing strata are primarily clay-saturated sandstone (approximately 20%) and siltstones (approximately 80%). Calcite layers make up less than 0.02% of the formation. This results in very loose, unconsolidated, hydrophilic cuttings. Once discharged to the sea, these cuttings are likely to disaggregate into sand, silt, and clay under the influence of water movements as the clay becomes water saturated. This may occur while the particles settle to the seabed after discharge, or once they have settled, or both.

Some drilling fluid will be discharged adhering to cuttings, although most is separated from the cuttings and recycled into the drill string in order to reduce the requirement for fresh drill fluid. As the drill fluids are all water-based, they are unlikely to have a significant effect on the physical fate of the cuttings, because water-based drill fluids will not increase the cohesion of the discharged cuttings, as oil-based fluids do.

Drilling Muds

All drilling muds used in the Molikpaq-based drilling programme were water-based. Once the drilling of a well was finished, all the drilling fluids used during the drilling process were discharged. This material consists of an aqueous solution of salts, including large quantities of barites, with a suspension of fine particles (eg bentonite). It may settle to the seabed, or be dispersed by the water currents. Measurements of suspended solids and of several chemicals are conducted on seawater samples collected at the edge of the 'control' zone, 250 metres from the platform, as part of the compliance monitoring programme for operations in the P-A field.

Wells outside the Molikpaq area

SEIC has drilled two other wells in the P-A field area, outside the area covered by the Molikpaq environmental effect monitoring program. Monitoring surveys were conducted around these wells, but are beyond the scope of this review as this review deals solely with effects of the Vityaz complex.

2.3.2 Non-Drilling Wastes

Domestic

Domestic (ie grey water and biodegradable food) wastes on Molikpaq are subjected to secondary treatment, and then discharged to sea. The discharge may contain organic matter (soluble and particulate), plant nutrients, detergents, and other domestic chemicals. These discharges are monitored under the compliance monitoring programme and are subject to consent limits under Russian Federation (RF) legislation and the terms of the Water Use Licence.

Produced Water

The hydrocarbon production at Molikpaq to date has not resulted in any produced water discharges to the marine environment.

Oily Water Run-Off

Waste water on Molikpaq which may be contaminated with oil is treated in an oil/water separator prior to discharge. This reduces the oil content to 15 ppm on average in the outflow from the separator. It is then mixed with seawater to further dilute prior to discharge – the concentration of oil in water permitted to be discharged is dependent on the volume of water discharged ie the larger the volume discharged, the lower the concentration of oil permitted.

Atmospheric emissions

Power generation and flaring of waste gas are the main sources of atmospheric emissions from the Molikpaq platform. These emissions are not part of the scope of the environmental effect monitoring programme, nor of this review.

3 Environmental Effect Monitoring in the Vityaz Complex

3.1 The Monitoring Programme

The environmental effect monitoring programme consists of surveys of the seawater and seabed sediments in the area around the Molikpaq platform location which might be affected by operations. The surveys prior to installation of Molikpaq are referred to as baseline surveys, those after installation as operational surveys.

3.1.1 Design of the Monitoring Programme

The theoretical framework for any environmental effect monitoring programme involves prediction of environmental effects prior to commencement of a process; this is the environmental impact assessment. The prediction of effects is based on knowledge of the process to be used and, from baseline environmental surveys, of the environment which may be affected. Having predicted environmental effects, operational monitoring surveys are conducted to measure environmental changes with respect to the baseline situation. Any such changes are compared with the predictions stated in the environmental impact assessment. If any effects are not as predicted, and are deemed to be unacceptable for whatever reason, alterations to the industrial processes must be considered in order to mitigate them.

Industrial operations may result in physical, chemical, and biological changes to the environment, and it is therefore normal for an environmental effect monitoring programme to involve assessment of each of these aspects of the environment. Another good reason for adopting a comprehensive sampling approach, as implemented by SEIC, is that these aspects of the environment are closely linked, so that, for example, natural changes to the physical environment are very likely to affect the chemical and biological environment. Without knowledge of these physical changes, the chemical and biological changes might be perceived as effects of the industrial operations. The better the understanding of the environment and the natural processes occurring in it, the more likely it is that the true cause of any changes detected will be discernible.

The arrangement of sampling points (stations) is an important part of any survey, particularly when the aim is to assess environmental effects. In a case such as operations at Molikpaq, where effects are caused by operations at a discrete point in space, rather than a diffuse source of impact such as acid rain, the accepted arrangement of stations is one or more transects, which are straight lines originating at the source of impacts, and with samples taken at several distances from that source. If the operations result in an effect on the surrounding environment, that effect will be greatest in magnitude at stations closest to the source. At successively more distant stations, it is expected that a reduced effect will be seen, until at some distance, no effect is detected. Thus a transect arrangement of stations is ideally designed for detection of effect and for delimitation of the area of that effect, since data from each station is supported by the data from neighbouring stations.

The distances at which stations are located depend on the expected area of effects, predicted in the environmental impact assessment. In this instance, stations are located at 125, 250, 500, 1000, 2000 (in later surveys), 3000, and 5000 metres. Water and plankton samples are collected only at stations 250 metres from Molikpaq, sediments for chemical and biological analysis at all stations. In addition, three reference stations at approximately 10 kilometres distance from Molikpaq have been sampled in all monitoring surveys. These stations are shown in *Figure 1.1*.

The surveys in 1999 and 2000 included sampling around the SALM buoy location, approximately 2 kilometres south-southwest of the Molikpaq platform. Water samples were not collected in this area. Sediment sampling consisted of 8 stations in 1999 (250 and 500 metres from SALM buoy to the north, east, south, and west). The 500-metre stations were re-sampled in 2000. No sampling is conducted specifically to measure the environmental effects of the *Okha* FSU; this is because the FSU is moored at a single point, and thus moves freely around the mooring, making sampling impractical.

The environmental attributes measured during surveys around the Molikpaq platform location are summarised in the following table.

Table 3.1 Environmental Monitoring in Piltun-Astokhskoye Area: Environmental Attributes

Seawater	Bottom sediments	Biota
Temperature	Grain size distribution (PSA)	Phytoplankton
Salinity	Metals (Al, As, Ba, Cd, Cr, Cu, Fe, Hg, Pb, Zn)	Zooplankton
pH	Total petroleum hydrocarbons (TPH)	Ichthyoplankton
Suspended solids	Aliphatic hydrocarbons	Benthos
Biological Oxygen Demand (BOD)	Polynuclear aromatic hydrocarbons (PAH)	Birds
Plant nutrients (N, P, Si)		Marine mammals
Chlorophyll *a*		
Total petroleum hydrocarbons (TPH)		
Phenol		
Detergent (synthetic surfactants)		
Metals (Fe, Ba, Mn, Zn, As, Cd, Co, Cr, Cu, Mo, Ni, Hg, Pb)		

Not all attributes were measured at all stations in every survey.

The sampling and analytical methods used correspond fairly closely to standard methods used in many parts of the world in marine environmental monitoring surveys, and are described in detail in the survey reports (CSA, 1995; DVNIGMI, 1999; Sakhydromet, 2000; DVNIGMI, 2001; DVNIGMI, 2002a). Most of the procedures are scientifically acceptable, and are suited to the task of assessing the environmental effects of operations at Molikpaq. Three procedures are worthy of note, however.

1. The first relates to the procedure used for collecting and processing sediment samples. To date, all surveys have used a 0.2 m^2 van Veen grab. The overlying water is siphoned off and retained, then the grab is separated into two (approximately) equal parts by inserting a divider. Samples for chemical analysis are taken from one half of the grab, while the other half is removed, then processed along with the overlying water as the biological sample. This means that the sample size is unknown; it is somewhere between 0.1 m^2 and 0.2 m^2. Moreover, the effective sample size is different for each species, depending on the proportion of the total number of individuals of that species which is present in the overlying water when the water is siphoned off. This will in turn depend on several factors, including (but not limited to) the size of the individuals, the cohesiveness of the sediment, the depth of burial in the sediment, and the degree of agitation of the sample during retrieval. These samples cannot be assumed to be quantitative for any species; the effect on abundance estimates of the commonest species, *Diastylis bidentata*, is discussed in section 3.2.1 below.

2. It is also worth noting that the analysis of biological samples involves several calculations involving the volume of material retrieved in the grab, and the type of seabed (mud, sand, or gravel), and data reported are estimates of species' density in the environment. Additionally, in some cases the number of individuals of a species in a sample is not measured directly (by counting), but calculated from the biomass, using a procedure based on the proportions of animals of different sizes (and hence masses). This practice leaves the data open to some questions; it is safer, and the data are more robust, if the number and biomass of each species in the sample is directly measured and reported without any calculations. In order to re-analyse the data from sediment sampling, the number of individuals of each species in each sample was provided by DVNIGMI, entered into a spreadsheet, and used as the raw data for the re-analysis.

3. The third issue is the analytical protocol used to measure barium in sediment samples. This has been altered from one survey to another, so that the results are not comparable to each other. This is in itself an inadvisable practice. Barium, as barites (barium sulphate) is a major component of the drilling mud used at Molikpaq. As such, it can be used as a marker for the discharged drilling mud, as any area where discharged drilling mud has accumulated should be readily detectable by a large elevation in the barium content of the sediment. The use of barium as a marker for drilling mud depends on using an analytical technique that detects barium in the form of barites (which is an inert substance highly resistant to chemical breakdown by many standard techniques). It is at present unclear whether the techniques used to date have detected any barium present in the form of barites, but it seems unlikely that any of the techniques has detected all such material present in the samples. This issue has been addressed as a priority. All samples from the October 2002 survey have been analysed by two techniques – carbonate fusion extraction to determine total barium including barites, and acid extraction to permit direct comparison with the results of previous surveys.

3.1.2 Surveys Before Installation of Molikpaq

Prior to installation of the Molikpaq platform, surveys were conducted in September - October 1995, October 1996, and June 1998. Full data sets from these surveys were not available for re-analysis, as the reports were available as hard copies or as electronic data files which could not be manipulated. The results were examined and reviewed to assist in building a picture of the environment and the changes identified over the period from 1995 to the present.

3.1.3 Surveys After Installation of Molikpaq

Operational monitoring surveys were conducted in October 1998, October 1999, October 2000, September - October 2001, and October 2002. There are minor differences in the sampling pattern and the analytical programme between surveys, though the basic pattern of four transects centred on the Molikpaq platform remained constant. Biological raw data were not available from the 1998 survey, chemical data were not available from the 2002 survey; the 2002 survey is outside the scope of this document, though the methods used and some data were considered by the author. The available data were re-analysed after entry by hand into a spreadsheet.

3.2 Review of Survey Data

3.2.1 The Sakhalin Shelf Environment

The details of physical, chemical, and biological analyses of samples from each monitoring survey are reported in the survey reports, and are not reproduced here. A brief overview of the salient characteristics of the marine environment around the Molikpaq platform is given below.

Physical and Chemical Environment

The environment around Molikpaq is physically highly dynamic, affected by a strong diurnal tidal regime, by heavy wave action in autumn, and by ice in winter. Tidal streams flood southward and ebb northward; the average resultant current is approximately 30 cms^{-1} southward, while the maximum flows measured were 145 cms^{-1} (2.8 knots) southward and 114 cms^{-1} (2.2 knots) northward (ASL, 2000). Significant wave heights reach 6 metres in autumn, while maximum wave heights reached 11.75 metres (ASL, 2000). These data were collected in 1999, after installation of the Molikpaq platform. No major changes are evident compared to similar data collected before installation. A more direct comparison of current measurements, before and after installation, at locations where the presence of the platform was predicted to alter the current regime might have revealed significant changes; the hydrodynamic surveys were not designed with this aim in mind. Logically, the physical presence of the platform must influence the current regime to some extent, at least locally (up to tens of metres from the platform). This would apply to any structure of such dimensions.

It is likely that in some areas, the near-seabed current is stronger than before the installation of Molikpaq, in other areas weaker. Overall, the effect is a local strengthening of water currents as an unchanged volume of water must now pass through a restricted area, similar to the effect seen around a bridge support in a river. Stronger water currents will tend to scour fine sediments from the seabed, leaving a seabed consisting of coarse sand, gravel, pebbles, or cobbles in progressively stronger current regimes.

As expected in the hydrodynamic regime described in the studies before and after installation of Molikpaq, the results of grain size analysis around the platform location show that in all surveys, seabed sediments tended to be coarse sands and gravels. However, significant quantities of fine sand (up to 40% of sediment) and silt/clay (up to 10% of sediment) were also present. The seabed sediments are very patchy, with large differences between replicate samples at a single station in one year, and also large variations between average values for a station between years. This suggests that the surface sediments are highly mobile; and that fine material in particular is continually deposited on the seabed and re-suspended by current and wave action.

Evidence for sediment mobility in the Molikpaq area was seen on pipeline inspection video recordings taken along the route of the pipeline between Molikpaq and SALM buoy in both spring and autumn in successive years. It was apparent that the degree of burial of the pipeline changed dramatically over a period of months. This may be due in part to local changes to the seabed current regime caused by the pipeline itself, but may also indicate a more general mobility of sediments in the Molikpaq area.

The levels of contaminants measured in water and sediments around Molikpaq are extremely low. It is unusual to include measurements of contaminants in water as part of an environmental effect monitoring programme, particularly in open sea areas, because of the practical difficulty of obtaining a representative sample and the theoretical difficulty of linking any changes found in water column chemistry to the operation being monitored. Both difficulties arise from the fact that the water is not indicative of a particular location in the way that a sediment sample is. In the tidal regime existing around Molikpaq, the tidal excursion of a body of water would be of the order of tens of kilometres.

This means that a small body of water at the platform at, for example, 0000h would move with the tidal stream for a period of approximately twelve hours at between 1 and 1.5 metres per second (3.6 to 4.8 kmh^{-1}), travelling up to *ca* 50 km northward. It would then be subject to a tidal stream moving approximately southward for approximately twelve hours, returning by 2400h to a point within several kilometres of the starting point at 0000h. During this time, any contamination source along the route could result in elevated concentrations of a particular chemical being detected in the water sampled at another, distant point. Oceanic currents and wind-driven currents further complicate the water movement.

Contamination detected in a water sample could therefore have come from a source remote from the study area. In contrast, the analysis of sediment samples arranged on transects, as described above, provides representative samples which are indicative of chemical conditions in a small area, and comparison of samples taken at different distances from the potential source of contamination allows direct assessment of the environmental effect of operations at that source.

It is notable that the sediment at stations close to Molikpaq (up to 1 kilometre) is coarser than elsewhere in the survey area (gravel particles, greater than 2 mm in diameter, constitute up to 60% of the sediment). This fact will strongly affect the chemical adsorptive capacity of these sediments, and of course the biological community inhabiting the seabed. This is not a result of the installation of Molikpaq, as the situation was the same in June 1998, prior to platform installation.

There are no clear indications of contamination of the seabed around Molikpaq by metals or hydrocarbons. The highest sediment and water hydrocarbon concentrations were observed in June 1998, before the start of operations at Molikpaq. Measurements of hydrocarbon concentrations in sediments 500 metres from the SALM buoy (to the south and east, and particularly to the north and west) indicated an increase in concentration in 2000 compared to 1999. The increases were small (from <0.50 μgg^{-1} in 1999 to concentrations ranging from 0.52 to 1.35 μgg^{-1}in 2000), and the increased levels were not distinguishable from background concentrations for the Vityaz area. The maximum measured concentration was 1.35 μgg^{-1}, compared to a maximum concentration of 22.70μgg^{-1}, and a mean concentration of 1.89μgg^{-1}, in the Molikpaq sediments in the baseline survey of June 1998. The sampling pattern was not sufficient to indicate that the source of the hydrocarbon was operations at the SALM buoy. Due to the presence of the FSO tanker *Okha*, no samples were collected at stations 250 metres from the SALM buoy in 2000; no sampling has been carried around the SALM buoy since October 2000.

Some indications of high barium concentration in the sediment close to the platform site were seen in June 1998, before installation of Molikpaq. This may indicate residual contamination from earlier, non-SEIC, exploratory drilling activities, or simply a natural area of sediment with high barium content. A similar pattern noted in October 1999 may be the result of discharged drilling mud, though the variations in methods of barium analysis mean that no firm conclusions on the distribution of this element around the platform can be drawn. The changes in the distribution of other metals appear to be the result of natural environmental fluctuations, rather than of contamination originating at Molikpaq. Metals other than barium are trace components of WBM drilling fluids; only copper and lead are present in drilling mud components (bentonite and barites) at concentrations significantly higher than those present in the seabed. Therefore in the absence of measurable barium contamination, it is highly unlikely that variations in the concentration of other metals would be the result of discharged drilling wastes. No pattern of elevated copper or lead, or any other metal, in sediments was detected in the monitoring surveys.

Biological Communities

Investigations of the plankton communities around Molikpaq are indicative of a highly productive sea area. There was no evidence of any effect resulting from operations at Molikpaq. The use of plankton communities in environmental effect monitoring is rare, for similar reasons to those described above with regard to measurements of contaminants in water samples. While knowledge of planktonic communities is an important part of understanding the ecological processes of an area, the natural patchiness of plankton communities, particularly the lack of a link to a specific location, makes them a poor tool for monitoring environmental effects of point sources such as stationary oil platforms.

An important feature of the zooplankton data is the presence in zooplankton samples of significant quantities of animals normally characterised as benthic in habit. Three crustacean taxa (cumaceans, mysids, and gammarids) made up more than 10% of the zooplankton biomass in October 1998, 1999, and 2001. Many “benthic” crustaceans are epibenthic in habit (ie they live on the surface of the sediment rather than buried within it), and mysids and cumaceans are often described as hyperbenthic, since they are known to swim in the water column, particularly at night. Nonetheless, it is unusual to find them in such quantities and so regularly in plankton samples. This may be indicative of an unusual mobility of the sediment/water interface in the study area.

Benthic biological data were available from 1999, 2000, 2001, and 2002 surveys. In addition, the reports on benthic biology from previous surveys were studied as part of this review. Analysis of benthic biological samples is a key element of most marine environmental effect monitoring programmes. There are a number of reasons for this:

- The practical simplicity of obtaining representative, quantitative samples.
- The location-specificity of benthic communities consisting mostly of sedentary animals.
- The fact that the communities reflect the totality of the environmental conditions prevailing at that location, so that even if unknown contaminants are present, or unpredicted effects occur, change in the biological communities will be detectable and may indicate that further investigations into the physical or chemical effects of operations are required.
- As described above, the use of a transect-based sampling pattern allows direct assessment of the linkage between any observed changes and the operation under investigation.

Variations in the number of species present in the benthic community, the community diversity, biomass and other univariate statistics have been reported in original survey reports and reviewed by DVNIGMI (DVNIGMI, 2002b). No effects on benthic communities from operations at Molikpaq were detected. The most notable features of the benthic community are the high standing crop biomass (averaging 210 to 675 gm^{-2} over the survey area), the high variability both between stations and within stations in a single survey, the domination of two taxa: the sand dollar *Echinarachnius parma* and the cumacean *Diastylis bidentata*, and the extremely high density of *D. bidentata* in some samples (up to 1 million per square metre). This last feature may be a spurious statistic, due partly to washing the samples with water containing that species (*D. bidentata* was identified from zooplankton trawls in significant quantities), partly to the estimation of abundance from direct measurements of biomass (the details of how abundance is calculated from biomass are unclear), and partly to a poor sampling protocol, which is likely to artificially elevate the biomass and density of surface-dwelling animals due to the addition of all the supernatant water from a $0.2m^2$ grab sample to a 0.1 m^2 sediment subsample.

An important part of this review was the reanalysis of benthic biological data using multivariate techniques to detect any trends in the data not detected by univariate analyses. The data set consisted of abundance data for each species in each sample analysed from the 1999, 2000, 2001, and 2002 monitoring surveys. Due to the high variability between replicates within stations in a single survey, analyses were conducted on pooled data, representing four replicates at each station. This eliminated most stations from 2001 from the analysis, as only one replicate sample was collected (except at the stations 250 metres from the platform); samples must be of the same size to give a valid result.

The multivariate technique used to analyse the biological data was non-metric multidimensional scaling (NMS), a technique widely used in monitoring and other benthic biological studies. The technique is based on calculating the similarity between every possible pair of stations, then using the resulting matrix to plot a two-dimensional "map" in which the distance between any two stations is proportional to their biological similarity. Figure 3.1 displays the results of NMS analysis on all 4-replicate stations from 1999 to 2002. The figure is difficult to interpret, largely because of the number of stations in the analysis. There is no clear relationship between station placement on the diagram and distance from Molikpaq, or year of survey.

In circumstances where a point source produces a significant effect on the benthic community, the benthic community structure is related to distance from the source. This would be reflected in an NMS diagram by the stations being (more or less) arranged in a straight line, with the stations closest to the source of effect at one end, and the most distant stations at the other. This would be termed an environmental gradient; such gradients also occur naturally – for example, in an area of sloping seabed, shallow water stations will be found at one end of an environmental gradient, deep water stations at the other.

Alternatively, if the benthic community changed dramatically from year to year, in a 'random' way, then it would be expected that an NMS diagram would show several 'clumps' of samples, as all samples from a particular year would be more similar to each other than to samples taken in other years.

Figure 3.1 indicates, however, that there is no temporal trend in the data; the variation within the four-year data set is between different stations, not different years.

The possible relationships between any trends in the biological data and trends in the physical and chemical data were investigated by means of a correlation analysis. The routine "BIOENV" constructs matrices of station similarity using all possible combinations of the physical and chemical variables as the station attributes. It then measures the correlation between each of these matrices and the matrix of similarities based on benthic faunal abundance, in order to determine the set of variables which produce the best match with the biologically based similarity matrix.

The biotic data from the 2002 survey were removed prior to BIOENV analysis, since there were no corresponding abiotic data. The list of variables in the abiotic data matrix was:

10 metals: Al, As, Ba, Cd, Cr, Cu, Fe, Hg, Pb, and Zn

Total petroleum hydrocarbon

Water depth

% gravel

% silt/clay

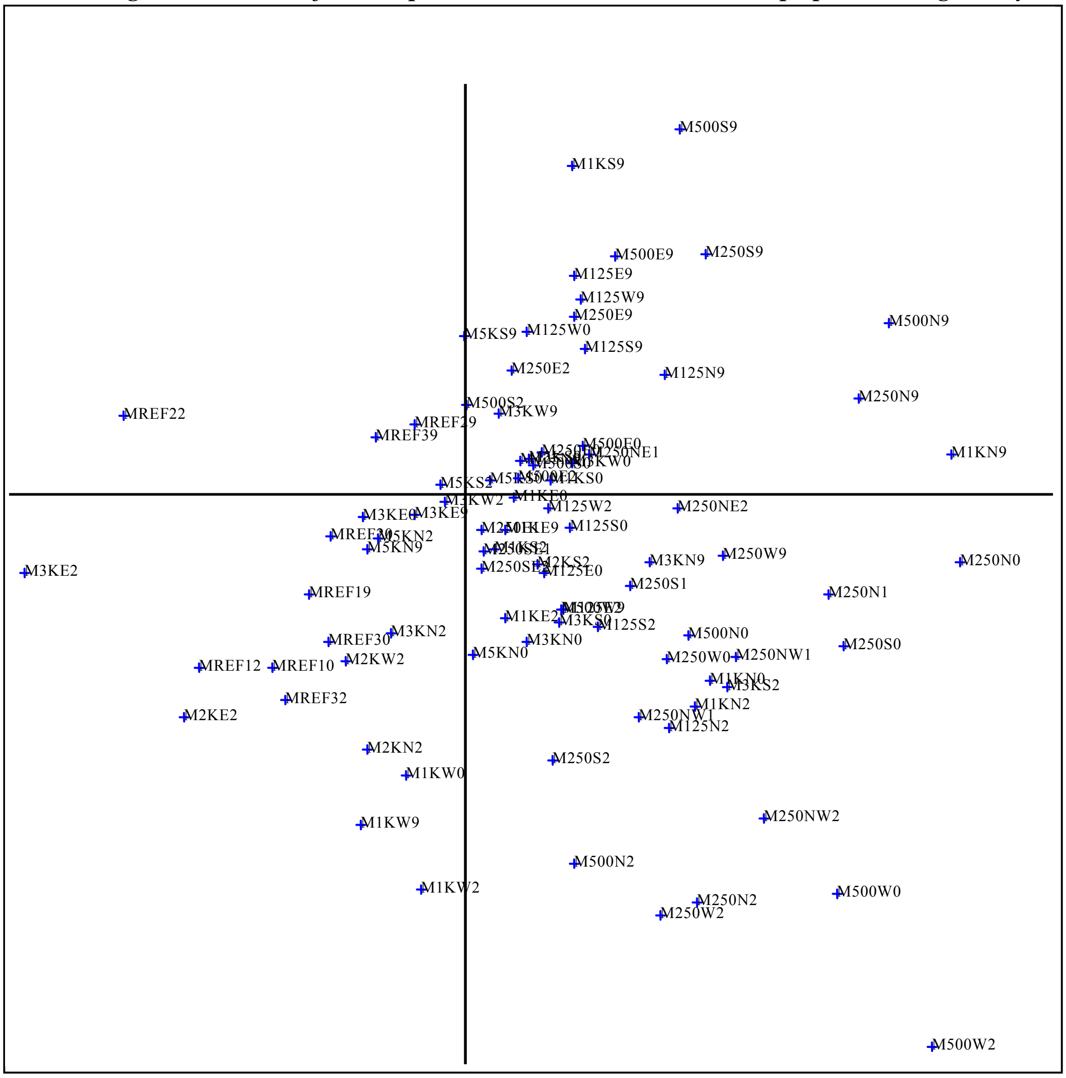
Year

Distance from Molikpaq

Number (NOTE: this is included as a check; the samples were simply numbered sequentially from 1 to 79)

The results of the BIOENV routine indicated that the relationship between the abiotic and biotic data was very weak. The best correlation coefficient for any combination of variables (0.277) was achieved using five variables: copper, percentage gravel, percentage silt/clay, distance, and number. The low correlation coefficient and the fact that the combination includes the check variable (number) indicate that there is only a very weak link between the biological data and the abiotic data, when considering the whole multi-survey data set.

Figure 3.1. NMS of all 4-replicate stations, 1999-2002, Molikpaq monitoring surveys



Another approach was applied to the data; for each of the two surveys for which a full data set was available (1999 and 2000), the data were analysed using NMS, and the abiotic data superimposed on the resulting plot as vectors, giving a visual indication of which variables were most closely linked to variations in the benthic fauna. The length of the line is proportional to the correlation coefficient between the variable and the NMS result; variables with coefficient <0.2 are excluded from the figure to improve legibility. These results are presented as figures 3.2 and 3.3.

The meaning of the abiotic data vectors is best understood by considering the distance variable. In both Figures, it can be seen that the vector representing distance 'points to' the stations furthest from Molikpaq. Similarly, though less obviously, the vector representing arsenic 'points to' the stations at which the highest arsenic concentrations were measured, and the same is true of all the variables. This is an oversimplification, but the more complicated details are less important than the basic patterns seen in the diagrams.

These figures indicate that within a single survey, there is a stronger relationship between biological communities and abiotic variables, the strongest correlation being with distance. The correlation with the check variable is very weak, as is normally expected. It has already been noted that there is a sediment gradient associated with distance from Molikpaq, which existed before installation. This means that although biological communities are linked to distance, that does not prove an effect from operations at Molikpaq. All of the linkages identified by these analyses could be a result of natural gradients in the environment.

The existence of better correlation between biotic and abiotic trends in single surveys than within the data set as a whole implies that the relationship changes from year to year. This is difficult to understand, but may be an indication that chance is a major factor influencing the distribution of the biological communities, rather than their distribution being a deterministic reflection of the abiotic environment. This is not what would be seen in the case of a significant anthropogenic impact: in such a case, the anthropogenic trend in the biological data would reduce the random, chaotic variability seen in the data so far.

Figure 3.2. NMS of all 4-replicate stations, 1999 Molikpaq monitoring survey

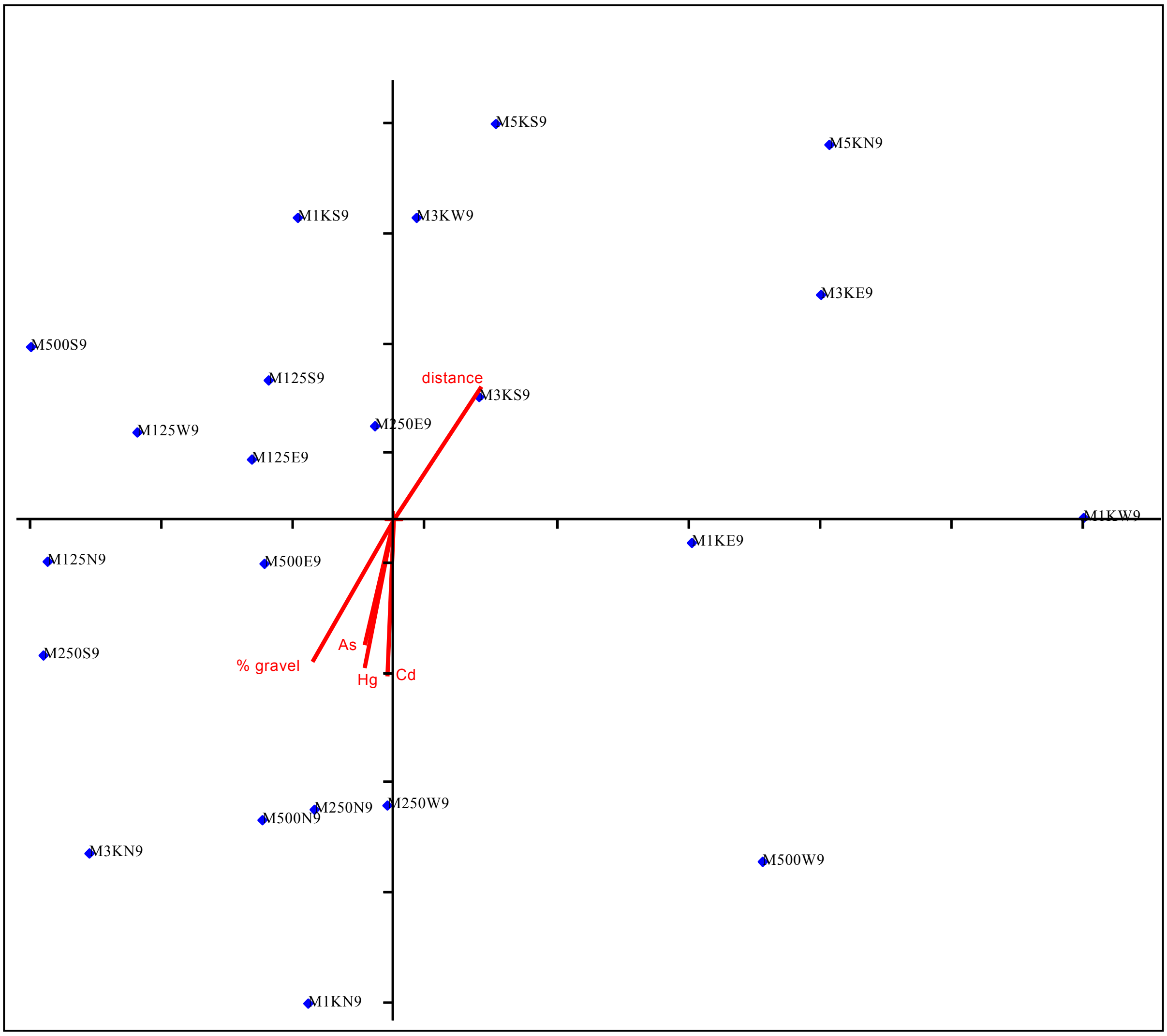
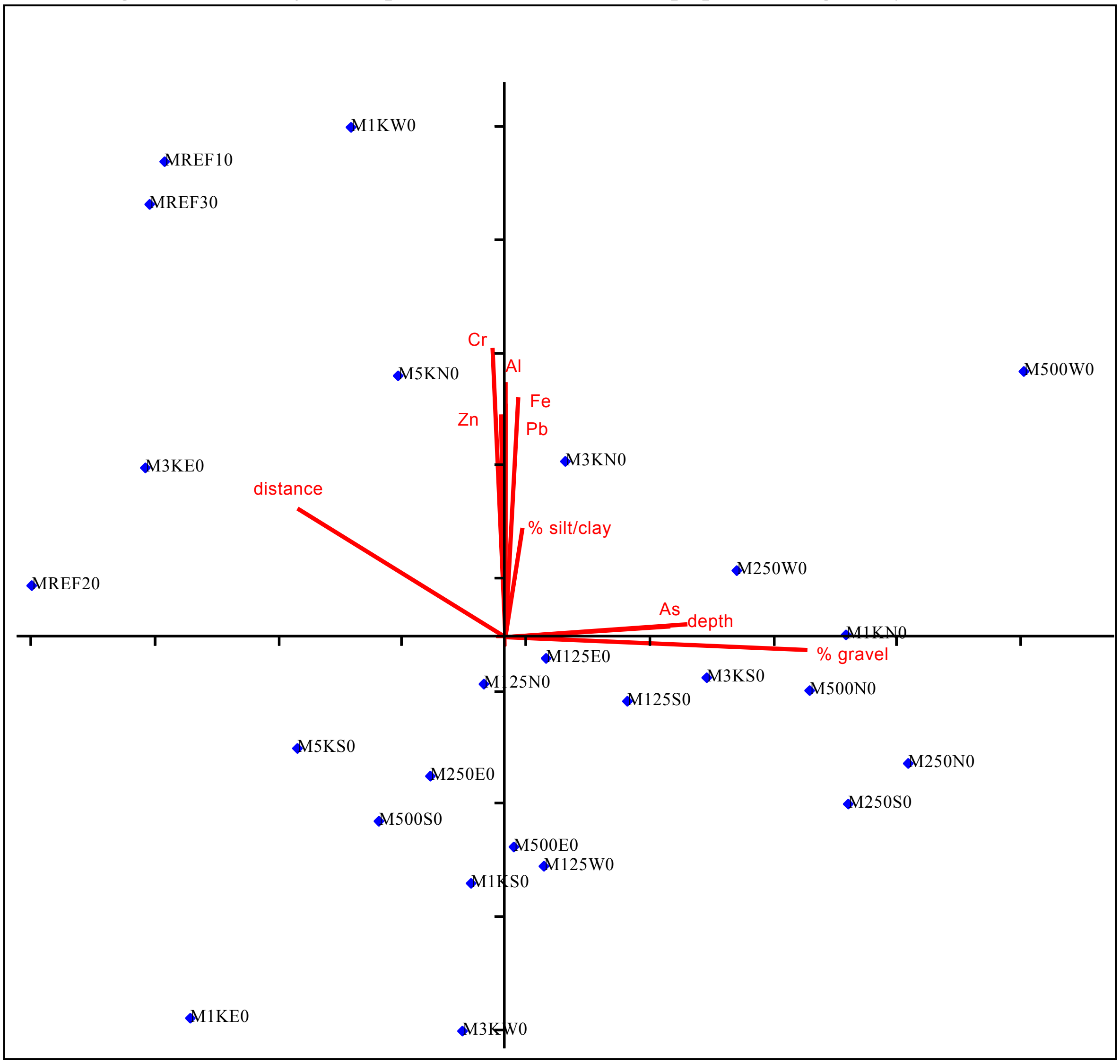


Figure 3.3. NMS of all 4-replicate stations, 2000 Molikpaq monitoring survey



4 Conclusions and Recommendations

4.1 Environmental Effects of Operations in the Vityaz Complex

- The environment remains uncontaminated by any of the materials which are routinely discharged from Molikpaq under the terms of SEIC's Water Use Licence.
- The biological communities show no changes which are characteristic of anthropogenically induced change, nor any definite pattern relating to distance from Molikpaq, other than a sediment-related variation. The sediment gradient existed before the platform was installed.
- There was a high level of natural variability in the physical characteristics of the seabed sediments, and in many related environmental attributes.
- No changes in the environment as a result of operations in the Vityaz complex were detected, based on the validated results of the environmental effect monitoring programme.

4.2 Recommendations for Environmental Effect Monitoring in the Vityaz Complex

Given the highly dynamic and changeable environment around Molikpaq, it will always be difficult to detect minor changes. The monitoring studies carried out to date around the platform have, however, been well designed in terms of sample placement and attributes measured (for the most part) and would detect chemical contaminants if they were present, except for barites. Sampling benthic biological communities should be carefully considered, as the results obtained to date were not as easily interpreted as they might have been. Some recommendations for future monitoring surveys are listed below.

4.2.1 Sampling

- The monitoring programme at the SALM buoy was not sufficient to detect the environmental effects of operations there. To assess the effects (or absence of effects) of operations, a transect-based survey programme should be implemented, with stations at distances such that areas of possible effect and unaffected areas are sampled. It is known that sampling at distances less than 500 metres from the SALM buoy is impractical. A suggested sampling programme would include stations at 500, 1000, and 3000 metres, north and south only (based on a knowledge of the current regime). At each station, four replicate seabed samples for biological analysis and four for chemical analysis should be recovered. The chemical analysis of these sediments should be targeted towards hydrocarbons
- Little additional information was gained by adding stations at 250 metres distance from Molikpaq to the northeast, northwest and southeast. It is recommended that these stations be excluded from future monitoring surveys.
- In all monitoring studies in the Vityaz complex, it is recommended that efforts be concentrated on the benthic environment, as sampling in the water column as part of an effect monitoring programme has many practical and theoretical drawbacks. Water column sampling should, however, remain a key part of the compliance monitoring programme.
- Variations to the sampling programme between years should be carefully considered prior to survey, and justified in monitoring reports. In order to achieve maximum usefulness and intercomparability of results, biological and chemical data should be reported for all stations.
- Four replicate samples is a suggested minimum requirement given the patchiness of the environment; data from single-replicate stations would be too 'noisy'. For biological analysis it is advisable to maintain the same sample size between surveys, as this permits direct comparison and numerical analysis.
- Biological samples should be taken using a 0.1 m^2 grab, and processing the whole sample (sediment and supernatant) to remove doubt over the actual size of the sample. If a 0.2 m^2

grab is used, then it should not be split; the whole sample (sediment and supernatant water) should be processed. If the number of individuals present in such samples causes practical difficulties during analysis, a subsampling procedure can be used in the laboratory; this procedure should be fully and clearly described when reporting results.

- To ensure that epibenthic and hyperbenthic animals do not influence the estimation of abundance of benthic animals, biological samples should be washed using filtered seawater (maximum filter mesh size 0.5 mm) to avoid contamination of samples by animals in the water column. It is not known whether this is the case at present. If this is impossible, then samples might be preserved without washing offshore, and washed in clean fresh water after return to the laboratory onshore,

4.2.2 Analysis and Interpretation

- Analysis of biological samples should include direct measurement of biomass and of abundance for each species identified in a sample; calculation of one from the other may not be valid.
- Analysis of seabed sediment for barium should be conducted using two methods; acid extraction, to retain comparability with previous studies and because it is ecologically relevant, and carbonate fusion, to allow detection of barites.
- Interpretation of survey results should always be based on the consideration of change related to distance from Molikpaq. This is the basis of the transect study. It is complicated in this case by the existence of a natural sediment gradient related to distance from the platform, but if this is taken into consideration when interpreting results, the transect-based survey should still enable the effects of operations at Molikpaq to be assessed.
- A model of the current regime, particularly at the seabed, and the local effects on it of the Molikpaq platform, could be constructed. This would be used to predict those areas where increased seabed scour is expected, and any areas where reduced water movement may favour deposition of sediment.
- Improvements to the monitoring programme implemented after the October 2002 survey, particularly in the analysis of barium in sediments and in the processing and statistical presentation and analysis of benthic macrofaunal data, will permit further definition of the conclusions in future.

5 Company Experience and Quality Control

5.1 Rudall Blanchard Associates

RBA has an established international track record in the energy industry. It is a health, safety and environmental management consultancy that specialises in the upstream sector of the oil and gas industry. The Company has offices in London, Aberdeen, and Houston.

RBA has undertaken a number of studies of environmental monitoring programmes, the most relevant being a review of ecological studies carried out by SakhNIRO on behalf of Exxon Neftegas Limited. That study involved analysis of results from the studies and a review of the quality of the data and the reports produced.

5.2 Quality Control

In order to ensure the high quality of this review, RBA employed the services of Dr Paul Kingston, a Senior Lecturer in the School of Life Sciences at Heriot-Watt University in Edinburgh, to discuss the data and to review the draft report.

Dr. Kingston's research interests centre on the structure and dynamics of seabed communities in relation to industrial and domestic marine developments and he is now an acknowledged expert in evaluating the impact of coastal and offshore developments on the benthic environment. An area of special expertise is bridging the gap between science and technology in the interpretation of marine survey data related to biological community structure, chemical contamination, and other environmental disturbance. He has also made important contributions to the development of sampling and monitoring technology and methodologies associated with surveys in the marine environment.

Dr Kingston has been involved in many major developments of public interest. He has had extensive experience in assessing the impact of the oil industry on the marine environment and has worked on most major North Sea petroleum developments including; Brent, Murchison, Hutton, Statfjord, Forties, Magnus, Piper, Alwyn, Cormorant, Dunlin, West Sole, Brae and many others. He led the original marine environmental assessment for the Channel Tunnel Group and was later retained as marine environmental consultant by Trans-Manche Link and Eurotunnel during the construction and early operational phases of the project.

Dr Kingston has had considerable experience working on the environmental impact of oil spills. His first involvement was with the *Amoco Cadiz* oil spill off Brittany, France in 1978 where he was part of a team sampling the impacted shores. He was also involved in the assessment of the damage and recovery of Prince William Sound, Alaska after the *Exxon Valdez* oil spill (1990-1993) and led a team assessing the impact of the *Braer* oil spill in the Shetland Isles (1993-1994). He was also engaged as an independent advisor following the *Neptune Aries* Oil spill on the Saigon River, Vietnam (1994) and the *Maersk Navigator* incident off the Vietnamese coast (1996). More recently he has worked as environmental consultant on several projects in the Azerbaijan and Kazakhstan Caspian Sea (1995-2001

Dr Kingston was formerly chairman of the ICES (International Council for the Exploration of the Sea) Benthos Ecology Working Group, was a member of the UK Technology Foresight Panel Energy Sub-Group, and chairman of the UKOOA (United Kingdom Offshore Oil Association) Steering Group on Oil Spill Risk Assessment. He has also served on the ICES Advisory Committee on Marine Pollution and ESGOSS (the Scottish Office Ecological Steering Group on the Shetland Oil Spill). He is currently a member of the Environmental Committee of INTERTANKO (International Association of Independent Tanker Owners), the Atlantic Frontier Environmental Forum and sits on a Scientific Review Group set up to oversee the decommissioning of the Ekofisk Tank.

Dr. Kingston has published extensively and currently serves as News Editor of the international journal *Marine Pollution Bulletin*.

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