Calcareous Deposits Study

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Abstract

Calcareous deposits are a scale that develop on cathodically protected subsea equipment and infrastructure in seawater. Deposition in the gaps of retrievable components pose reliability, functionality and retrievability issues. Cleaning of deposits occurs by a Remote Operated Vehicle during intervention campaigns, and severe deposition leads to extended intervention time and thus increases operating expenditure. The objectives of this project are to provide insight and understanding of the factors associated with deposition, and use available data to predict whether deposition on critical components will occur and to what extent using the statistical programming language R. To achieve these objectives, a longitudinal dataset tracking intervention history on Chevron's critical interfaces was built from available operational data. Using this dataset, principal component analysis and survival analysis was performed, and several statistical models and machine learning models were built. The principal component analysis performed showed that the most influential variable associated with increased calcareous deposition was installation duration, and not location specific environmental factors. The survival analysis provided the median survival time of components and survival curves of components against cleaning.

1. Introduction

Chevron uses Cathodic Protection (CP) via sacrificial anodes to provide corrosion control on the subsea equipment and infrastructure installed as part of their Gorgon and Wheatstone projects in the North West Shelf. This results in a scale composed of calcium carbonate and magnesium hydroxide precipitating on protected metal surfaces. Chevron regularly cleans this scale, referred to as a calcareous deposit, during planned intervention campaigns using a Remote Operated Vehicle (ROV) run from a vessel.

As calcareous deposits have electrically resistant properties, deposition on static and/or permanent installations extend the life of CP systems (Barchiche et al., 2003). However, deposition in the gaps of retrievable components is problematic, such as the electrical flying lead in Figure 1. Severe deposition can seize the movement of mating surfaces leading to extended component cleaning time. Offshore vessel and equipment hire costs around AUD$250K a day, thus extensions in campaign length incur significant campaign cost.

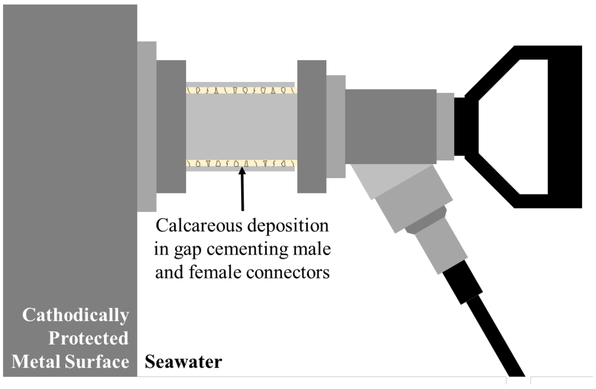

Figure 1 Interface of a seized electrical flying lead due to calcareous deposition.

1.1 Literature Review

Calcareous deposits form on cathodically protected surfaces in seawater due to an increase in seawater pH at the seawater/metal interface (Wolfson & Hartt, 1981). This interfacial pH increase causes a decrease in the solubility of calcium carbonate and magnesium hydroxide, causing precipitation (Wolfson & Hartt, 1981). Deposition of a thin magnesium hydroxide layer occurs first, followed over time by a thicker calcium carbonate layer on top (Mantel et al., 1992). The main electrochemical reactions taking place are summarised in Figure 2.

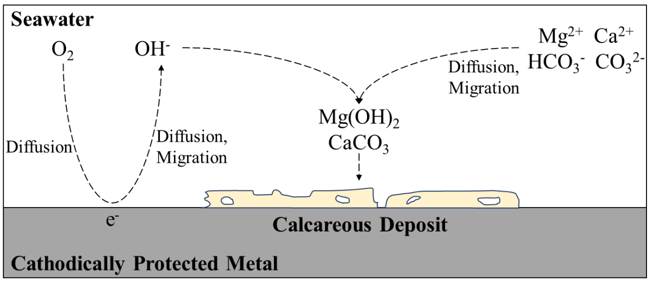

Figure 2 Calcareous deposition mechanism (Sun et al., 2012; "Science of Stuck Part 1," n.d.).

Calcareous deposits are generally characterised by a white calcification, and contains magnesium hydroxide which precipitates in the form of brucite, and calcium carbonate which precipitates as aragonite and/or calcite (Carré et al., 2020). Regardless of the allotropic variety, the deposits promote a physical barrier against oxygen diffusion (Barchiche et al., 2004) by blocking the active surface area available for electrochemical reactions (Yan et al., 1993). This decreases the required current density and sacrificial anode consumption (Yan et al., 1993). Deposits can form on all metal substrates and various surface finishes (Mantel et al., 1992).

The variables influeincing interfacial pH, and thus deposit growth, composition and properties are shown in Figure 3.

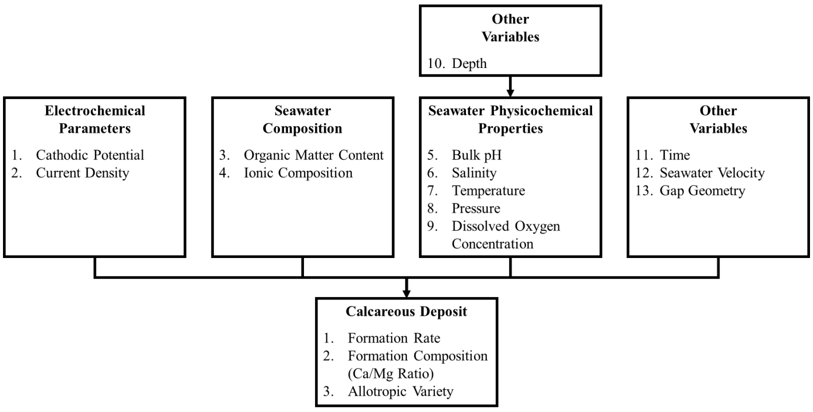

Figure 3 Influential variables for calcareous deposition due to CP in seawater.

1.2 Project Objectives

The project objectives were:

1. Cataloguing of intervention history for critical components subsea.
2. Analysis of intervention history and environmental conditions.
3. Development of a model for predicting whether cleaning will be required at a critical component at a well location.
4. Development of a model for predicting the extent of calcareous deposition on critical components at a well location.
5. Analysis on the time interval between the cleaning of critical components.

These deliverables will better inform Chevron to target cleaning activities and optimise the time spent by ROVs in cleaning. This will assist in ensuring intervention costs are not inflated, as extension in cleaning/retrieval time by the ROV directly translates to campaign length and thus operating expenditure.

2. Methodology

The methodology for this project had three stages: data collection, data processing, and analysis and modelling. A longitudinal dataset was built consisting of 346 entries that were classified as either events where continued ROV cleaning effort was required, or non-events where cleaning wasn't required.

2.1 Data Collection

There were three main data sources used to build the dataset. Firstly, daily progress reports which log all significant activities undertaken on an offshore vessel, including any cleaning performed by an ROV. Secondly, well reports and data packages which provide information on the location and original installation dates of each well. Thirdly, automated underwater vehicles which are used on an intermittent basis and record several environmental variables.

2.2 Data Processing

The installation duration of the components was a variable created during data processing. When a component is cleaned for the first time, the installation duration is taken as the time since the original installation. However, if a component is revisited some time later, the installation duration becomes the time passed since the last cleaning. Whether a component was being cleaned for the first time was stored as another variable.

There were 18 AUV dives over 2017 and 2019 providing 503,512 measurements, from the four fields. Measurements were averaged for a well location if they were located within a given depth, latitude, and longitude tolerance. These tolerances were found through iteration to obtain reasonable sample sizes (>30). These were 10 m for depth, and 0.002 decimal degrees for latitude/longitude.

2.3 Analysis and Modelling

For this paper, only the principal component analysis and survival analysis will be discussed.

2.3.1 Principal Component Analysis

Principal component analysis (PCA) is a method to reduce the dimensionality of a dataset while still capturing most of the variation (or statistical information) in the original dataset (Jolliffe & Cadima, 2016).

The objective of PCA is to find linear combinations of the explanatory variables in the original dataset to produce new principal components that are uncorrelated and successively maximise variance (Khan, 2011a). The principal components are ordered such that the first principal component captures the largest proportion of the variability in the original dataset (Khan, 2011a). Usually, analysis is focussed on the first few principal components, as they highlight the most important patterns and behaviours in the dataset (Jolliffe & Cadima, 2016).

2.3.2 Survival Analysis

Survival analysis refers to a set of methods used to analyse time-to-event data. Such data has a start point and well defined endpoint at which an event of interest occurs, such as component cleaning (Khan, 2011b). This time duration is referred to as the survival time.

The Kaplan-Meier (KM) estimator is a non-parametric method of survival analysis that doesn't make any assumptions about the distribution of survival times in a dataset. Unlike the KM estimator, the Cox proportional-hazards model is a parametric method that is a linear regression model that can use explanatory variables to describe survival.

3. Results and Discussion

3.1 Principal Component Analysis

The dependence of all explanatory variables on the principal components can be represented graphically on a biplot, with a vector representing each variable. The direction and magnitude of each vector indicates the strength and direction of the component on the corresponding variable. An acute angle between vectors indicates positive correlation, an obtuse angle indicates negative correlation, and an orthogonal angle indicates no correlation.

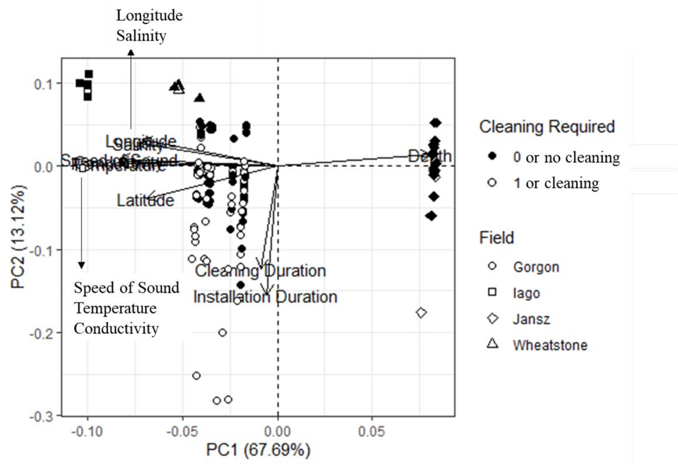

Figure 4 Biplot for principal component 1 (PC1, 68% variance explained) vs principal component 2 (PC2, 13% variance explained).

Installation duration was the only explanatory variable with a strong positive correlation with cleaning duration. The environmental variables show little correlation with cleaning duration. In this biplot, Jansz had an unsurprisingly strong positive correlation with depth as it the deepest, and latitude/longitude point accordingly to the field locations. Latitude also has some positive correlation with installation and cleaning duration, likely due to the Gorgon assets which have the largest latitude having historically been installed longer and therefore taken longer to clean.

3.2 Survival Analysis

The KM Estimator was used to perform analysis on the survival rate considering the occurrence of component cleaning against installation duration. Figure 5 (left) below shows the KM survival curve estimating the probability that a component will not require cleaning against installation duration (survival probability). The shading shows the confidence interval for the survival curve, and the dotted line the median survival time. Unlike the KM Estimator, the Cox PH model enables the survival probability to be estimated while testing for the influence of explanatory variables on survival. The survival curve shown in Figure 5 (right) is relatively similar, however has a slightly shorter median survival time, after which survival probability decreases more rapidly.

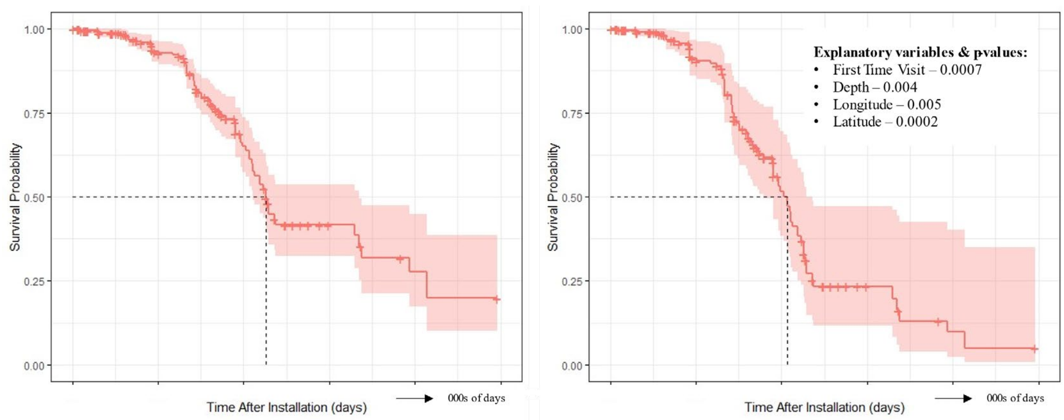

Figure 5 KM survival curve (left) and Cox proportional-hazards model (right).

4. Conclusions and Future Work

The principal component analysis showed that the most influential variable associated with increased deposition was installation duration, and not location specific environmental factors. While literature provides evidence for the influence of environmental conditions such as temperature on deposition, statistical analysis of historical data has shown this is outweighed by installation duration.

The Cox proportional-hazards model built provides the median survival time after adjusting for location. The model indicates the installation duration after which survival probability starts rapidly declining, that is, the probability that cleaning is required rapidly increases. Ideally, components should not go without cleaning for installation durations longer than this interval.

Due to the small and imbalanced nature of the dataset available during this project, it is recommended Chevron revisit the *Calcareous Deposits Study* project in a few years time when more intervention on their newer wells has occurred. This will provide a more comprehensive dataset from which more fruitful analysis and modelling results could be obtained.

5. Acknowledgements

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