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An Integrated Approach of Seismic DHI Analysis and Petroleum System Modeling for Shallow-depth Biogenic Play in F3 Block, Western Netherland Basin – A Case Study

Abstract:

Biogenic gas is becoming increasingly important as an exploration challenge in the petroleum industry because it occurs in geologically predictable circumstances and in large quantities at shallow depths as free gas or gas hydrates. In terms of commercial viability as the Biogenic methane is not that profitable like thermogenic gas, the prediction of probable biogenic prospect is critical to make exploration decisions especially in offshore area. As accumulations of biogenic gas result in a subtle synchronization between early generation and early trapping and sealing, we integrated a macroscopic model of microbial gas generation within a 3D petroleum system model. The complete study involved an integrated approach of Seismic Hydrocarbon indicator analysis and Petroleum System Modeling to identify the prospect and validate the same in terms of generation source of the expected hydrocarbon in the target reservoir. The study area for this project was the F3 block situated in the western Netherlands offshore basin. There is a hypothesis regarding the biogenic prospect of the shallow gas accumulations found at 400-500m depth in this area. Hence, in the conclusion stage, the attempt has been made to substantiate the aforementioned hypothesis with an integrated Geophysical (Direct Hydrocarbon Indicator study) and Petroleum System Modeling approach.

Introduction:

The project has been carried out in F3 block of western Netherlands offshore basin. F3 block is situated in the Central Graben of the Dutch offshore Sector which is in the Southern part of the North Sea Basin and North-West to the Netherlands. The study area has experienced quite a complicated tectonic history, dominated by rifting phase of the Mesozoic, with an acceleration in rifting activity at the transition from the Jurassic to the Cretaceous and followed by a post-rift sag phase during the Cenozoic. During this period major deposition of the Tertiary and the Quaternary sediments filled the basin, forming the North Sea Supergroup. This is a siliciclastic sedimentary succession and overlies the Cretaceous chalk group and older Mesozoic strata unconformably. It has been further subdivided into 3 groups, Lower North Sea Group, Middle North Sea Group and Upper North Sea Group.

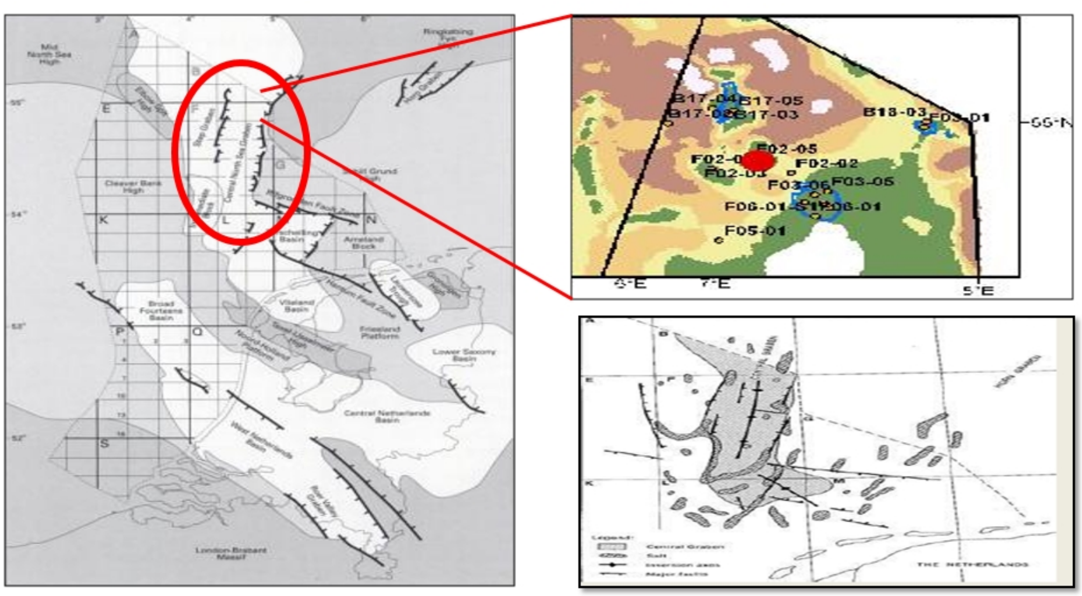

Fig1: Location Map of F3 Block

While the Netherlands part of the Southern North Sea basin is typically a gas basin, with mainly Carboniferous coal and shales as source rocks, there are a number of oil and condensate fields holding hydrocarbons from Jurassic, Posidonia Shale, containing both marine algal sapropel and land derived organic material (type II & III kerogen).In addition there are a number of shallow gas reservoirs of Pliocene-Pleistocene age whose origin has been subject to debate.

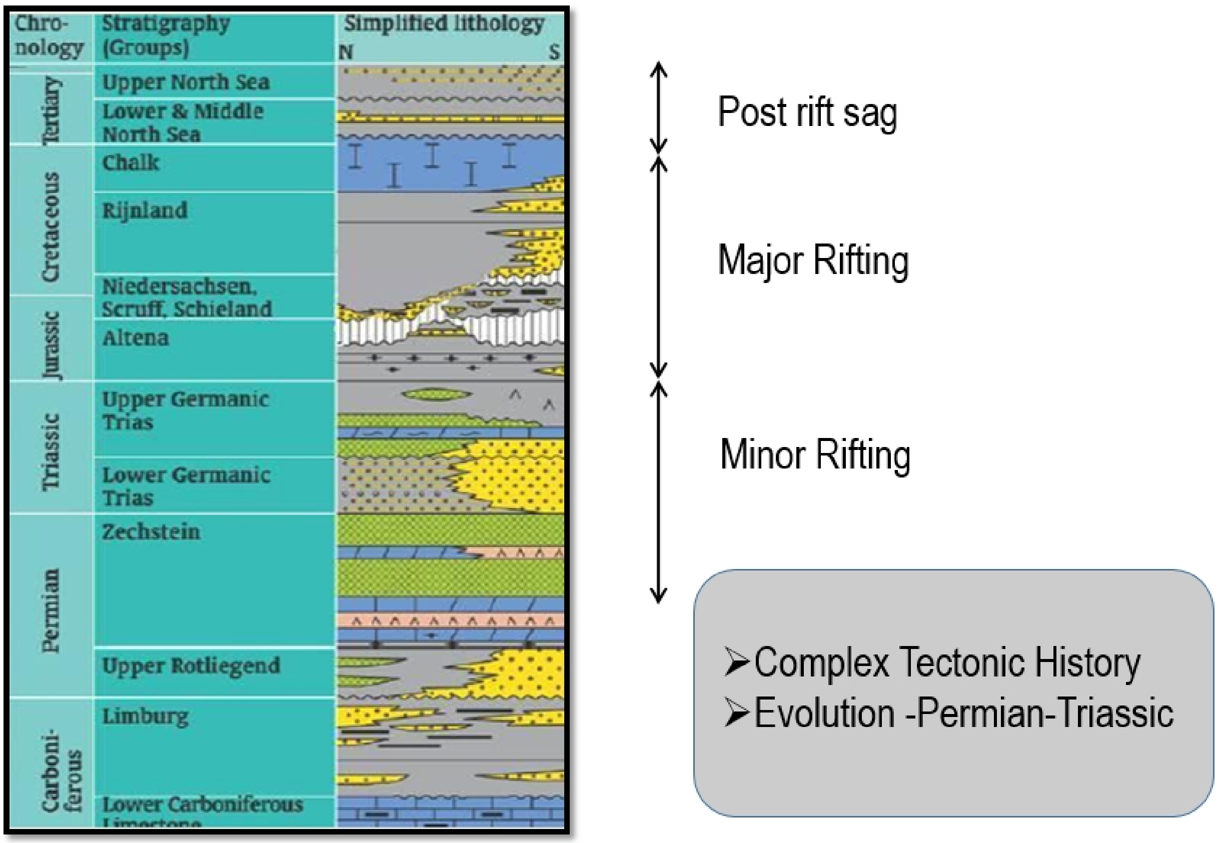

Fig2: General Stratigraphy and Tectonics of the Study Area

Stratigraphically, the sediment sequence of this basin can be sub-divided into 3 major groups –
Lower North Sea Group - It encompasses the Paleocene to Eocene age and is subdivided into the Landen and Dongen formations of Thanetian to Bartonian age which lie unconformably over each other.
Middle North Sea Group - It mainly consists largely of Oligocene Sediments and encompasses the Priabonian to Aquitanian. This group rests unconformably on the lower North Sea group.
Upper North Sea Group - It is of Neogene and Quaternary age and rests unconformably on the Middle North Sea Group.

Objective:

The entire project work is aimed at identifying the prospect and establishing the generation process of the expected hydrocarbon – Thermogenic or Biogenic. The project starts with Direct Hydrocarbon Indicator analysis (DHI) from seismic to pinpoint the prospect which is followed by the interpretation, mapping and complete Geological Model building for Petroleum System Modeling. In the Petroleum System Modeling stage, the static Geological model was converted to a dynamic model to perform a time dependent Pressure, Thermal, Geochemical model to create the generation and migration model for combined Thermogenic and Biogenic system. The calibrated model with existing porosity, temperature and Vitrinite data had undergone several scenarios of thermogenic and Biogenic cases with different combinations to obtain the most reasonable scenario for the hydrocarbon origin prediction.

Project Stages:

The project work can be sub-divided in to several stages representing the integration of different technical domains – Seismic Interpretation, DHI Analysis, G&G Modeling, Petroleum System Modeling.

A. Seismic Interpretation: In order to aid the interpretation of various structural elements and to identify potential prospects, different volume attributes were attempted to alter the basic components of a seismic wavelet like amplitude, frequency, phase and wavelength thereby enhancing relevant information in the seismic data. Various attributes that were used during this project to facilitate the Fault and Horizon interpretation process included: Cosine of instantaneous phase, Sweetness, second derivative, RMS amplitude etc. The attributes like Cosine of instantaneous phase, second derivative were applied on the seismic amplitude for betterment of the continuity of the horizons which further helped in picking the horizons at different stratigraphic level. Alongside, we also generated different structural attributes like Variance, Chaos on the seismic after being filtered by structural smoothing attribute which helped in identifying the faults from seismic. Several structural attributes that we tried in this project, are Structural smoothing to minimize the noise keeping in my mind that original amplitude and along with that we had run Variance attribute to enhance the discontinuity or fault from original seismic cube. Finally, this attribute cube was directly used as the input for ant tracking process to extract the fault from the seismic. This is an edge enhancement method and is executed in three steps-Seismic conditioning using structural smoothening, edge detection applying variance attribute followed by edge enhanced detection using the Ant Track attribute. In the Ant-tracking process we have tries different ranges of parameters like the deviation from local maxima, no. of steps of the agent, the radius for the agent to look for local maxima etc. to extract the best pattern of discontinuities from the seismic. There are two modes in which ant tracking can be applied-Passive mode which captures strong regional features and Aggressive mode which captures higher level of details in discontinuities. The result of ant tracking was used to improve the fault picking process with a better insight of the fault pattern.

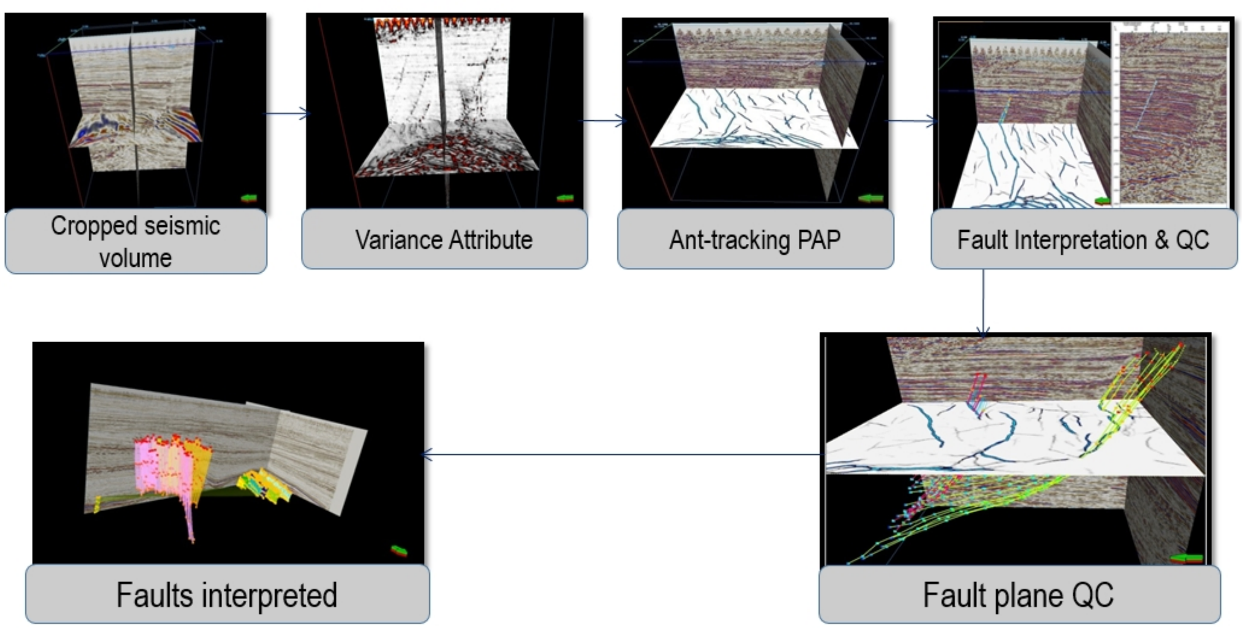

Fig3: Fault Interpretation using Ant Tracking Method

B. DHI Analysis - To identify the potential hydrocarbon prospects in the area, different direct hydrocarbon indicators were identified while laying special emphasis on the accumulations in the shallow depth which form our zone of interest. The major Hydrocarbon indicators which we observed in the seismic are phase polarity reversal, velocity sagging, bright spot (High Amplitude), flat spot etc.

Various volume attributes were applied to enhance the amplitudes of which envelope, RMS amplitude and Sweetness gave the best results Several high amplitude anomalies called bright spots were observed in the shallow zone of interest at about 550 ms.

One of the bright spot in the zone of interest showed lateral variation in polarity which is an indication of a low impedance hydrocarbon replacing an otherwise high impedance brine saturated sandstone.

After applying the envelope and instantaneous frequency attributes, the bright spots were found to be associated with low amplitude and low frequency shadow zones (25-30 Hz) respectively indicating that these high amplitudes contained gas and the seismic signal below had been heavily attenuated.

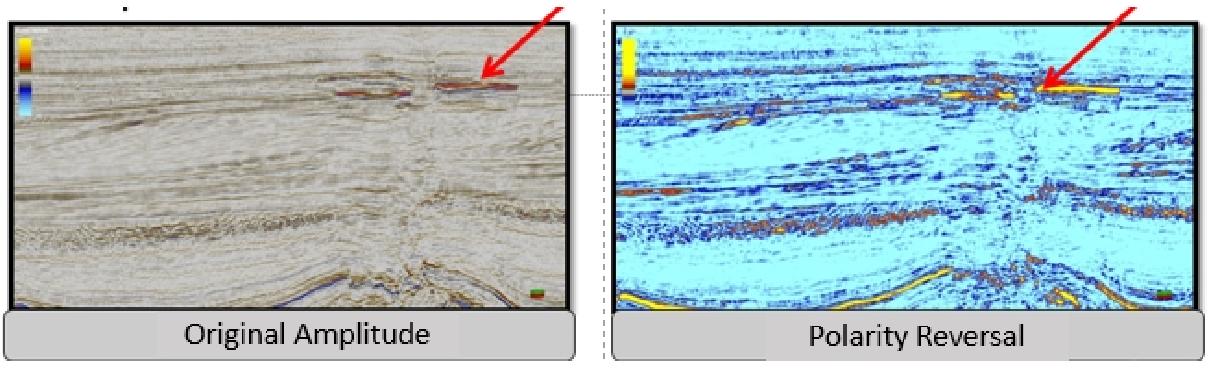

Fig4: DHI Analysis of the Shallow Reservoir

The DHI analysis process was followed by Geobody extraction of the target reservoir and the identified prospect from DHI analysis. In order to determine the areal extent of the reservoir in my zone of interest as well as to define its facies, the reservoir was extracted as a discrete object called geobody from the seismic data.

C. Geological Model Building: All the horizon and fault interpretations have been incorporated to build a structural model. Simultaneously we built a velocity model using both velocity cube and well velocity. We established an anisotropy relation between the well velocity and seismic velocity at well location and applied that on the seismic velocity to get it calibrated with well velocity. Using that calibrated velocity cube a velocity model has been built and used to convert the time structure model in to a depth structure model. In the next step, we populated the facies in that structural model through the establishment of the Geostatistical relationship of the well data which is further guided by the seismic attributes. The detail Facies Modeling has been attempted for the main target reservoir zone. For the rest of the Stratigraphic levels, the regional Gross Depositional Environment maps were used. Apart from the 3D coverage in context of incorporating the major depocenter, some 2D regional sections were taken into consideration to extend the maps.

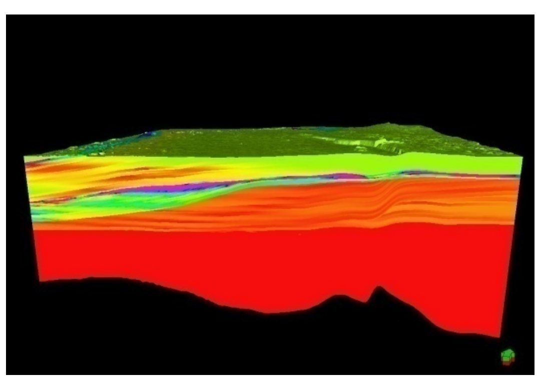

Fig5: Velocity Model Building

D. Petroleum System Modeling: The geological static model was further used to build a petroleum system model to replicate the basin evolution along with several hydrocarbon generation scenarios. In the process of building a dynamic model, the static model was integrated with the additional data like age connotation of the stratigraphy, Paleo Water Depth, Heat Flow trend, Sediment Water Interface Temperature trend.

Geochemical Model - This involved mentioning the Total Organic Carbon (TOC) content and hydrogen index (HI) of the two conventional source rocks in the area Posidonia and Carboniferous Shales. According to prior geologic information Posidonia had 8% TOC content and HI of 600mg HC/g TOC and Carboniferous shales had a 1% TOC content and HI of 200 mg HC/g TOC. Since Posidonia is a very good source rock as compared to Carboniferous which has a very low TOC content, during most of the time in our modelling Posidonia is considered as the only important conventional source rock in the F3 block area.

Thermal Model – The Petroleum System Modeling includes a thermal history model with respect to the Geological time which requires the thermal boundary conditions like Heat Flow trend representing the tectonic history of the basin and Sediment Water Interface Temperature (SWIT) governed the Geological reconstruction and Paleo Water Depth. The North Sea basin is essentially an extensional basin and hence associated with high heat flow values. The mean heat flow value found in the Central Graben was around 63mW/m2 with a higher Heat Flow ranging around 80mw/m2 during the Jurassic representing the rifting phase.

Calibration – The Pressure and Thermal Model were calibrated with respect to the existing pore pressure, porosity, Temperature and Vitrinite reflectance data. The Pore-pressure and porosity helps in establishing the reliability of Pressure model. The temperature and Vitrinite Reflectance data provided support to the calibration of present day Heat Flow and Paleo Heat Flow trend respectively.

Kinetic Modeling – Kinetic reflects the reaction in source rock to generate hydrocarbon from kerogen at a particular Pressure-Temperature regime. Posidonia and Carboniferous shale both the source rocks attained a depth of 5km and 9 km which clearly postulates a thermogenic zone for hydrocarbon generation. Few scenarios with different combination of thermogenic and biogenic kinetics were attempted to charge the identified prospect from DHI analysis. The Burnham TII kinetic has been considered for the thermogenic modeling based on the correlation of the source rock age and depositional environment. On the other hand, Gaussian Biogenic kinetic was used to replicate the thermal range for biogenic gas generation window in the source rock. The peak biogenic window was fixed at 50 degree Celsius with a 10 degree Celsius deviation range.

Scenario -1: Both the source rocks were assigned the Thermogenic + Biogenic reaction. Chalk as well as the Pliocene-Pleistocene Sands were assigned as reservoir rock. All the faults in the area were assigned open fault type such that they behave as conduits for the migration of hydrocarbons. After running the simulation, we obtained no accumulations in either of these reservoir rocks.

The possible explanation to this observation is that although Posidonia had a very high TOC content and was enough matured to generate thermogenic (present day Vitrinite Reflectance in the range of 1.5-4.5) as shown in figure 65, It could not charge the shallow gas accumulations because till chalk was not deposited the gas expelled from Posidonia, escaped as free gas vertically and once chalk was deposited the vertical migration of the gas was inhibited due to chalk which was very compact in our area of study and hence behaved as an effective seal not letting it charge the shallow gas accumulations.

Scenario - 2: After the results for geological scenario 1 were not able to charge the prospect, we considered another scenario where along with the conventional source rocks Posidonia and Carboniferous, we also considered a thin condensed shale section of maximum flooding surface(MFS) deposited during highstand system tract at the base of Pliocene (end of Miocene) as a possible source rock. This was a valid assumption as MFS contains bioturbated organisms which are the primary source of TOC as well can serve as an impetus of biogenic reaction. This source rock was given a TOC content of 2% and was assigned only the biogenic reaction as its depth was only about 650 m which was well within the biogenic window. Also, all the faults in the area were assigned the open type so that they can serve as conduits for the migration of hydrocarbons. After running the simulation, we observed the formation of accumulations in our target zone at shallow depths of around 400-550m in the Pliocene-Pleistocene sand facies imported from Petrel.

The composition of the hydrocarbons in the accumulations revealed that it was gas entirely of biogenic origin. The model shows that the expulsion from MFS started at around 28.5Ma. However whatever gas was formed escaped as free gas due to the absence of a vertical seal. However, at around 1.5 Ma when alternate layers of sand and shale were being deposited, the gas expelled from MFS got trapped forming accumulations in drainage areas defined by the migration model in the sand facies.

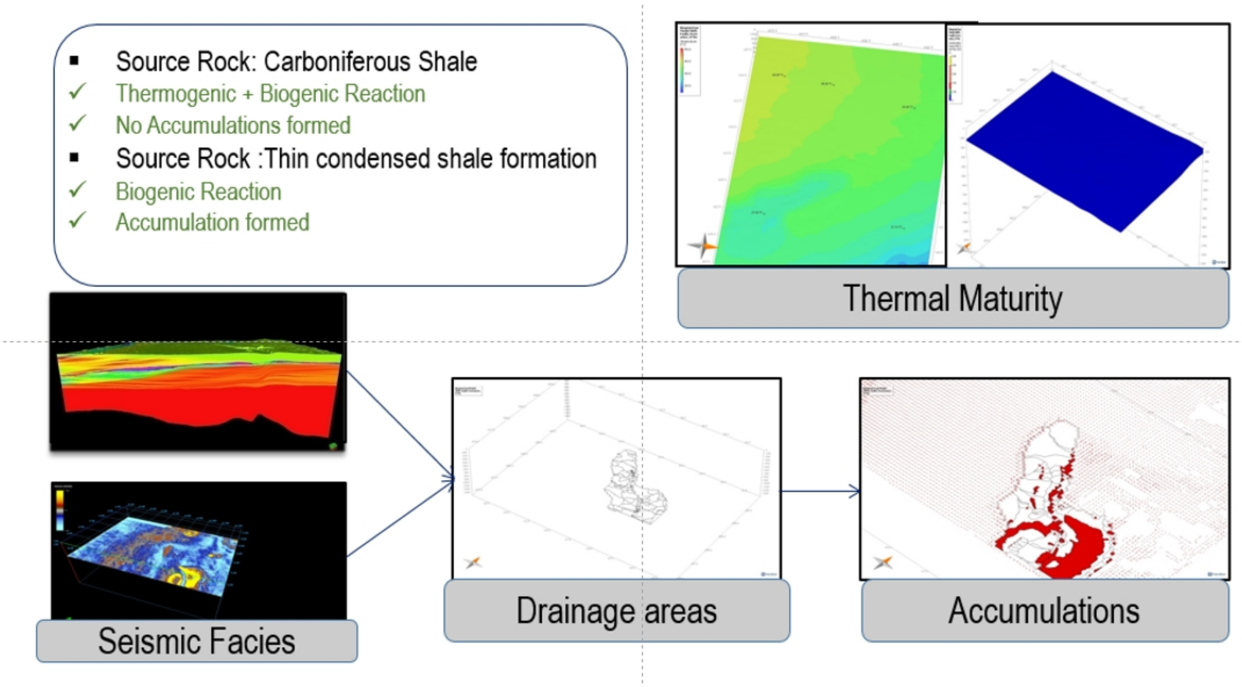

Fig 6: Thermal and Migration Modeling to identify Biogenic Prospect

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