PGE 383 - Stochastic Methods for Reservoir Modeling - Spring 2019

Project Update #3 by Team 8, Univariate, Spatial Data Analysis
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Executive Summary

The purpose of this update is to develop a preliminary understanding of the spatial continuity of facies, porosity, and permeability across the area of interest based on variogram modeling.
The work included:

- Generating variogram maps for porosity (all facies) using declustered data
- Calculating isotropic and directional variograms for facies, porosity, and permeability
- Assessing heterogeneity and analyzing spatial continuity by modeling semivariograms

Variogram porosity map does not give a prominent directionality. However, after analysis of the directional experimental variograms, some preliminary conclusions can be drawn. The results of directionality are the following: Facies variograms show major axis at 157.5° with 500m range and minor axis at 67.5° with 200m range, Porosity variograms show major axis at 120° with 525m range and minor axis at 30° with 200m range, permeability variogram show major axis at 70° with 500m range and minor axis at 160° with 250m range.

Further facies-based analysis is also done. However, due to sparsity of facies 0 (shale), this work is possible only for facies 1 (sand). The result is the following: porosity variograms show major axis at 110° with zonal anisotropy and minor axis at at 20° with 240m range. Permeability variograms show major axis at 60° with 400m range and minor axis at 150° with 125m range.

All of the variograms were modeled using three independent variogram structures (2 spherical and 1 nugget structure). The nugget is to account for discontinuities. In general there seems to be a low degree of geometric anisotropy.

Description of Workflows and Methods

1. Transformed porosity and permeability data to standard normal
2. Generated variogram maps for porosity using different ‘x’ and ‘y’ lag values
3. Performed ocular inspection to determine primary directions
4. Applied an indicator transform for the different facies
5. Generated isotropic and directional (arbitrarily selected) variograms
6. Fitted a valid spatial model using 1 nugget and 2 spherical type nested variogram models

Results and Discussion

Variogram map for porosity and its interpretation

To identify the spatial continuity, variogram maps for the porosity data were plotted. To be able to better understand the directionality, multiple maps were generated by varying the configurations of the cell size/lag distance and the number of cells in each direction. By ocular inspection there does not seem to be an apparent directionality. However, there seems to be some degree of directionality around 100 degrees, as seen when using lag distance of 30m.

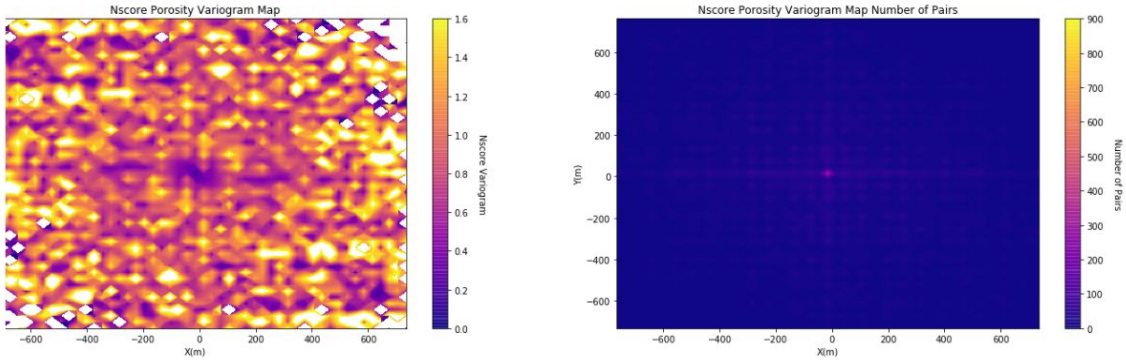


Figure 1. Nscore porosity variogram map and number of pairs with lag distance of 30 m in x and y direction

Isotropic and directional variograms of facies, porosity and permeability

To explore the spatial data directionality in more detail, multiple experimental variograms were calculated for different azimuths for facies, porosity and permeability data.

The results for the identified major and minor directions, and corresponding ranges can be summarized in the following table:

	Major Direction	**Minor Direction**
Facies	157.5 degree, Range 500m	67.5 degree, Range 200,
Porosity	120 degree, Range 525m	30 Degree, Range 200m
Permeability	70 Degree, Range 500m	160 degree, Range 250m

- Facies variograms

Since we are dealing with two facies, both isotropic and directional variograms of facies 1 (sand) and those of facies 0 (shale) will be the same. Therefore, in case of the directional variograms, we only display those of facies 1 (sand). Since facies is a categorical variable, the first step was performing indicator transformation to code the variable to a probability of realization of the facies. Figure below show the method used for this transformation.

```
In [34]: df['Is_sand'] = np.where(df['Facies']==1, 1, 0)
         df['Is_shale'] = np.where(df['Facies']==0, 1, 0)
```

➔ Isotropic facies variograms

The first step was generating isotropic variograms for the facies by setting the azimuthal tolerance 90 degree.

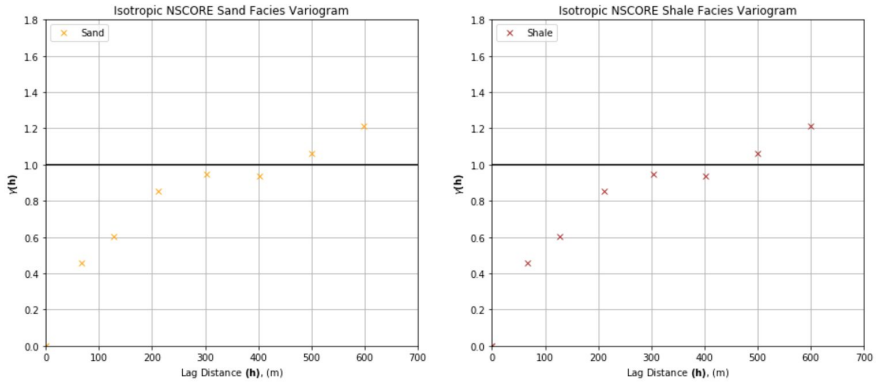


Figure 2. Isotropic facies variograms of sand facies(left) and shale facies(right)

➔ Directional facies variograms

The next step was generating directional variograms in multiple directions to explore the spatial data directionality in more detail. The parameters used for this were: lag distance = 80m, lag tolerance = 40m, azimuth tolerance 22.5 degrees for multiple azimuth angles..

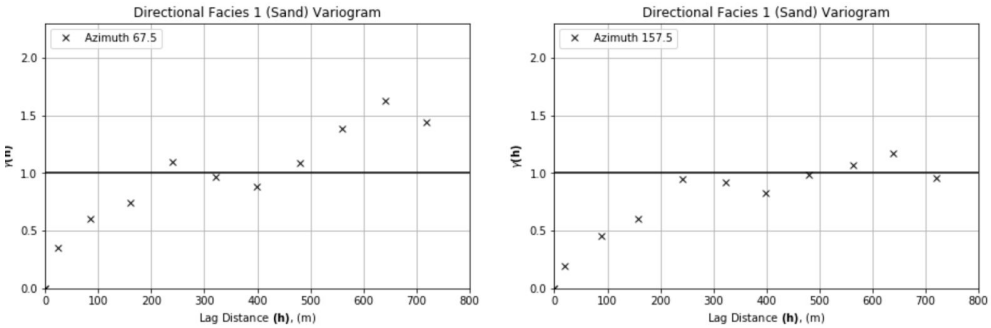


Figure 3. Directional facies variograms of sand facies for multiples azimuths.

Based on directional variograms, the variogram shows major directionality at 157.5 degree.
Also, there is degree of cyclicity for many azimuths, which is consistent with our previous interpretation of interbedded sandstones and shales facies

- Porosity variograms

Isotropic and directional variograms in multiple azimuth directions were generated for porosity data to get a better understanding of the spatial continuity.

➔ Isotropic porosity variograms

Isotropic variograms for porosity were generated by setting the azimuthal tolerance 90 degree.

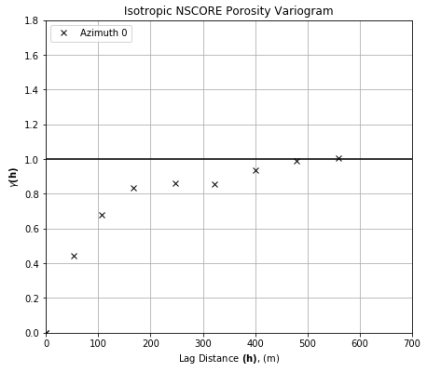


Figure 4. Isotropic Nscore porosity variograms of the overall reservoir.

➔ Directional porosity variograms

Porosity Variograms for different azimuthal angles were then constructed using a lag distance of 80m, lag tolerance of 80 m and azimuthal tolerance of 25 degrees.

Based on the different directional variograms, the major axis was identified to be around 120 degrees with a range of 525m, while the minor axis was then identified to be around 30 degrees with a range of around 200m. The major axis is consistent with the directional variogram based ocular identification of the major axis to be around 100 degrees.

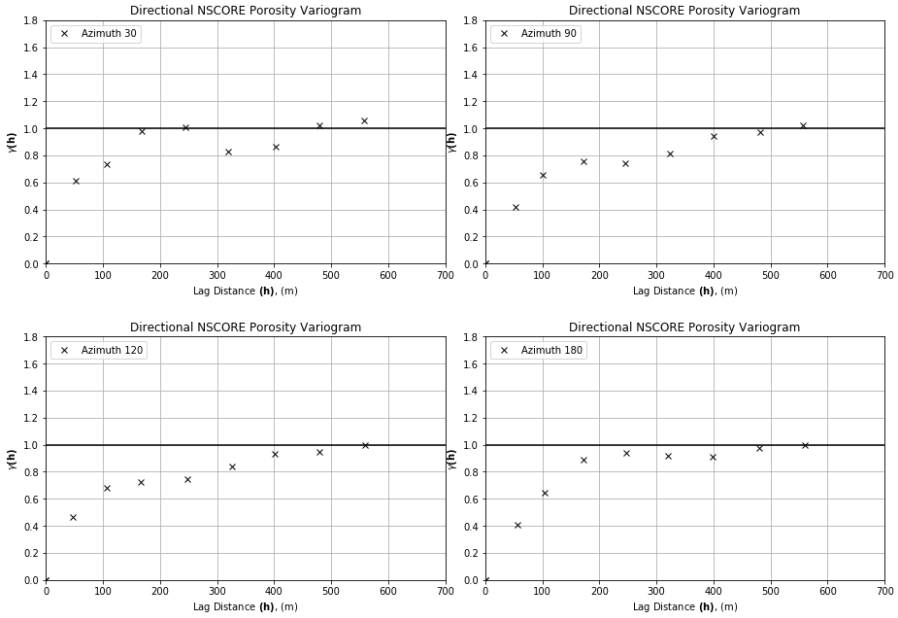


Figure 5. Directional Nscore porosity variograms of the overall reservoir for multiple azimuths.

- Permeability variograms

Similar isotropic and directional variograms were then generated for permeability data.

➔ Isotropic permeability variograms

Isotropic variograms for permeability were generated by setting azimuthal tolerance 90 degrees.

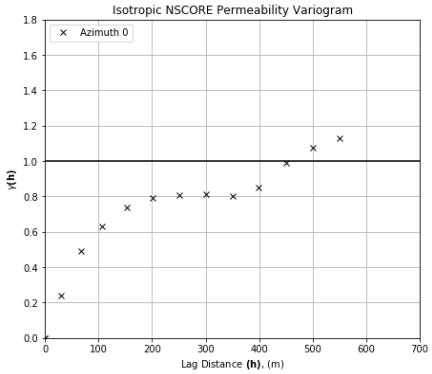


Figure 6. Isotropic Nscore permeability variograms of the overall reservoir for multiple azimuths

➔ Directional permeability variograms

Permeability Variograms for different azimuthal angles, constructed using a lag distance of 80m, lag tolerance of 80 m and an azimuthal tolerance of 20 degrees.

Based on the different directional variograms, the major axis was identified to be around 70 degrees with a range of 500m, while the minor axis was then identified to be around 160 degrees with a range of around 250m.

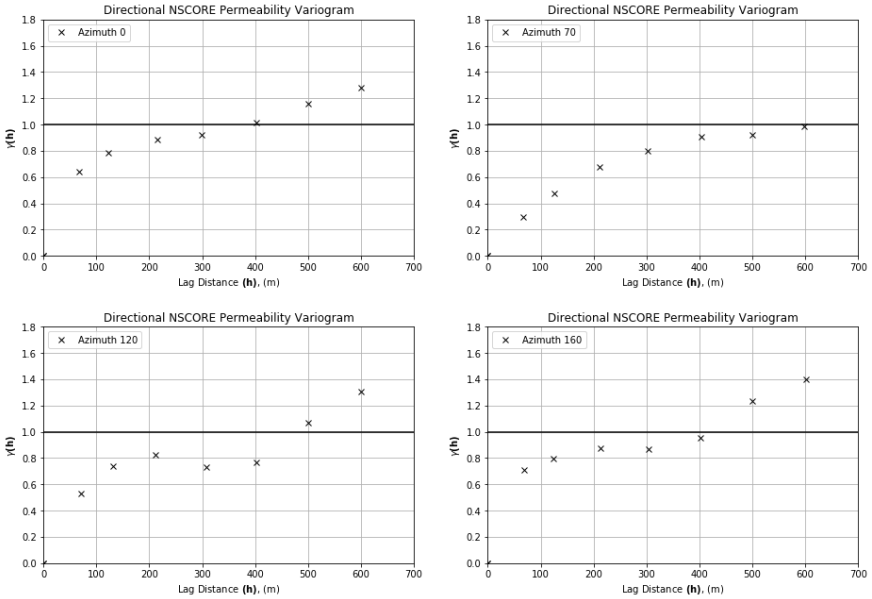


Figure 7. Directional Nscore permeability variograms of the overall reservoir for multiple azimuths

Semivariograms models and their heterogeneity and spatial interpretation

- Facies variogram model

Three nested structures were used to fit the variograms: one nugget effect and two spherical type variogram structures. These structures were modeled using the following parameters:

Nugget effect Variogram structure: nug = 0.1

Spherical Variogram structure 1: cc1 = 0.65; azi1 = 157.5; hmaj1 = 250; hmin1 = 250

Spherical Variogram structure 2: cc2 = 0.25; azi2 = 157.5; hmaj2 = 500; hmin2 = 500

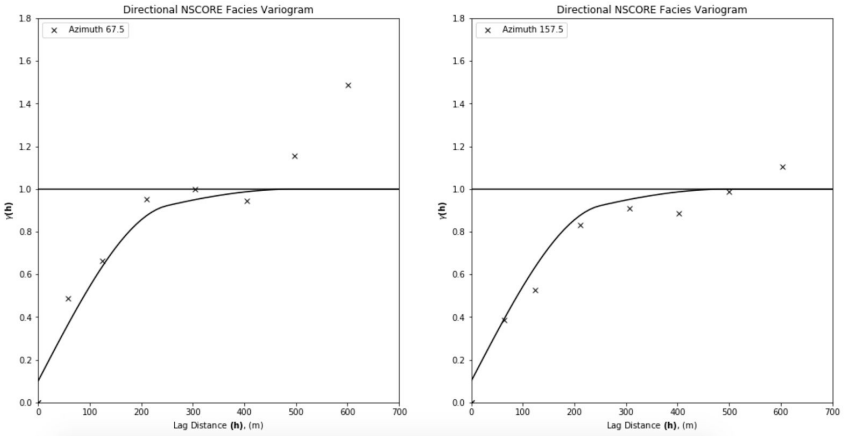


Figure 8. Facies variogram models of major direction (left) and minor direction (right)

- Porosity Variogram Models

Three nested structures were used to fit the variograms: one nugget effect and two spherical type variogram structures.
Nugget effect Variogram structure: nug = 0.1
Spherical Variogram structure 1: cc1 = 0.6; azi1 = 120; hmaj1 = 200; hmin1 = 100
Spherical Variogram structure 2: cc2 = 0.3; azi2 = 120; hmaj2 = 650; hmin2 = 200

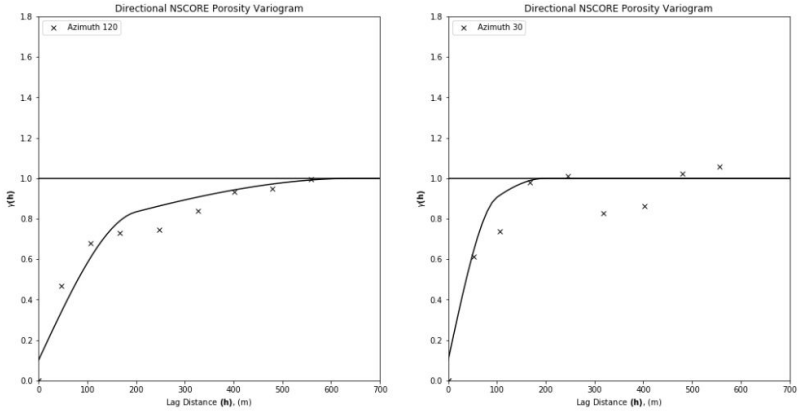


Figure 9. Porosity variogram models of major direction (left) and minor direction (right)

- Permeability Variogram Models

Three nested structures were used to fit the variograms: one nugget effect and two spherical type variogram structures.
Nugget effect Variogram structure: nug = 0.1
Spherical Variogram structure 1: cc1 = 0.6; azi1 = 70; hmaj1 = 400; hmin1 = 90
Spherical Variogram structure 2: cc2 = 0.3; azi2 = 70; hmaj2 = 750; hmin2 = 300

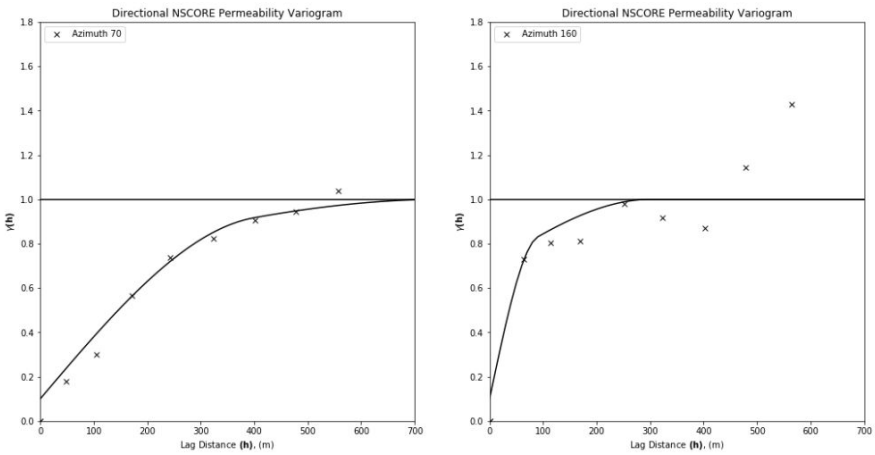


Figure 10. Permeability variogram models of major direction (left) and minor direction (right)

Facies Based Analysis

Individual facies variogram maps were constructed for both facies 0 and facies 1. However, due to limited number of data points, 56 sparsely distributed points for facies 0 and 112 points for facies 1, there does not seem to be sufficient directional information from facies 0 variogram map.

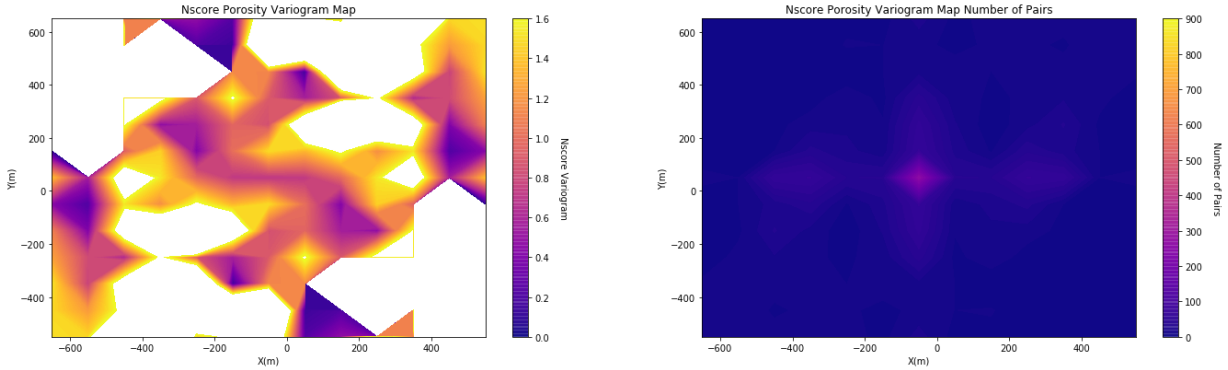


Figure 11. Nscore porosity variogram map and its number of pairs for facies 0

However, facies 1 do seem to provide good information for building a variogram model, as discussed below.

- Variogram Analysis for Facies 1

➔ Variogram Map for Porosity

Multiple variogram maps were built for the porosity data based on different configurations of the cell size/lag distance and the number of cells in each direction. As with the case of the entire dataset, by ocular inspection there does not seem to be an apparent directionality. However there seems to be some degree of directionality around 120 degrees, as can be seen when using lag distance of 40m. One such map with lag distance of 40m and shape of 33 by 33 boxes is shown.

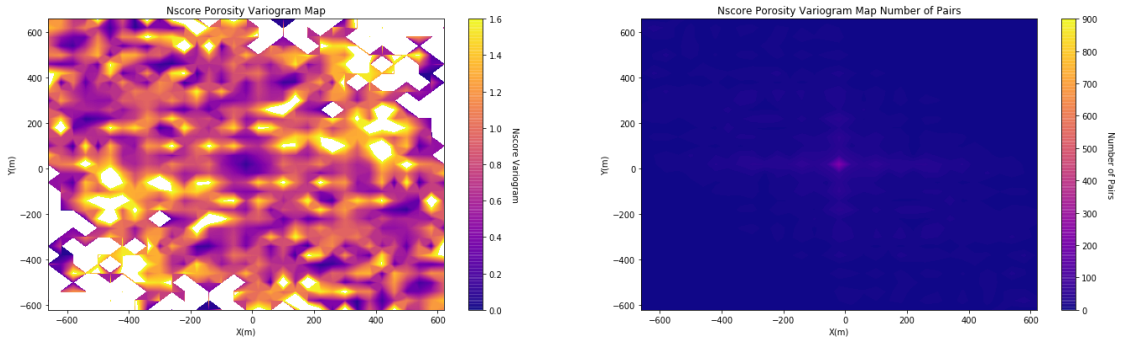


Figure 12. Nscore porosity variogram map and its number of pairs for facies 1

➔ <u>Isotropic Variogram for Porosity and Permeability</u>

Using an azimuthal tolerance of 90 degrees, the variograms for both porosity and permeability were developed.

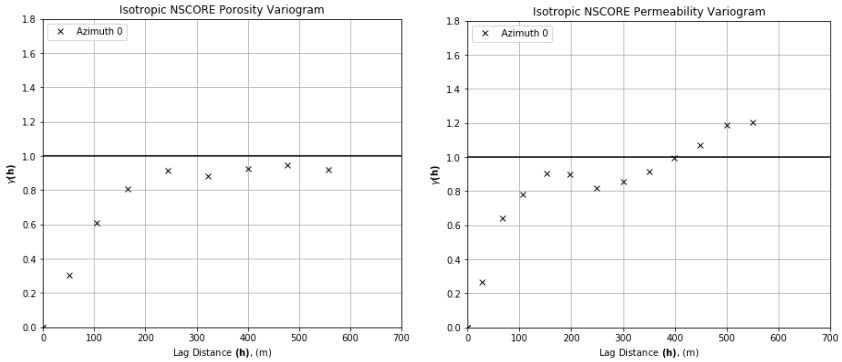
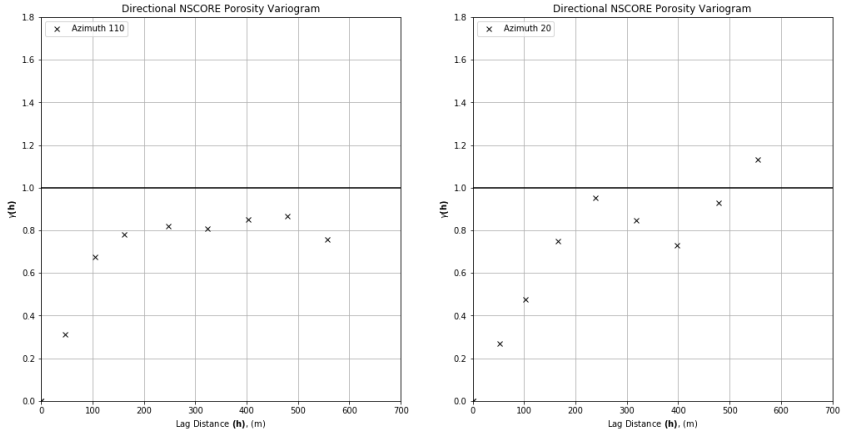


Figure 13. Isotropic Nscore porosity and permeability variograms for facies 1

➔ <u>Directional Variograms for Porosity and Permeability</u>

For both the porosity and permeability data for the facies type 1, experimental variograms were generated for multiple azimuth angles, with the goal of identifying the principal major and minor axis and the corresponding ranges in the two directions. For brevity only the major and minor axis plots are shown for both porosity and permeability.



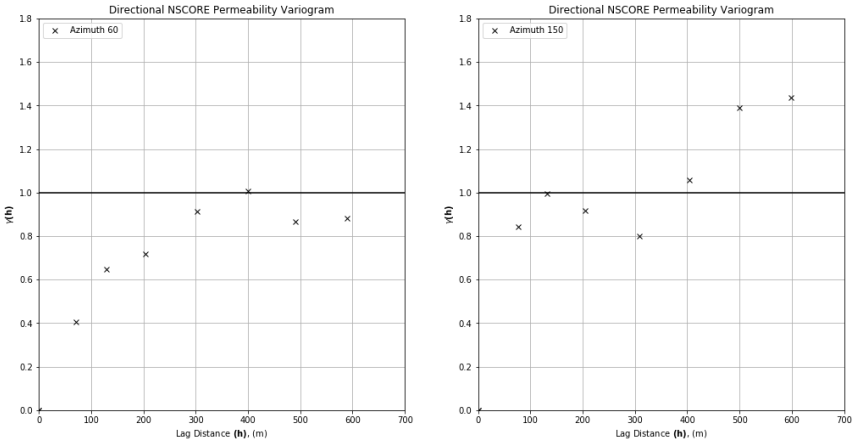


Figure 14. Directional Nscore porosity and permeability variograms for facies 1, for multiple azimuths

Therefore to summarize:

	Major Direction	**Minor Direction**
Porosity	110 degrees, zonal anisotropy	20 degrees, Range 240m
Permeability	60 degrees, Range 400m	150 degrees, Range 125m

➔ Porosity and Permeability variogram model of facies 1

For facies 1, both porosity and permeability variogram models were built using a combination of one nugget effect and two spherical type variogram structures for the major and minor axis.

For porosity:

Nugget effect Variogram structure: nug = 0.1

Spherical Variogram structure 1: cc1 = 0.7; azi1 = 110; hmaj1 = 175; hmin1 = 300 (minor should be less than major)

Spherical Variogram structure 2: cc2 = 0.2; azi2 = 110; hmaj2 = 9999; hmin2 = 320

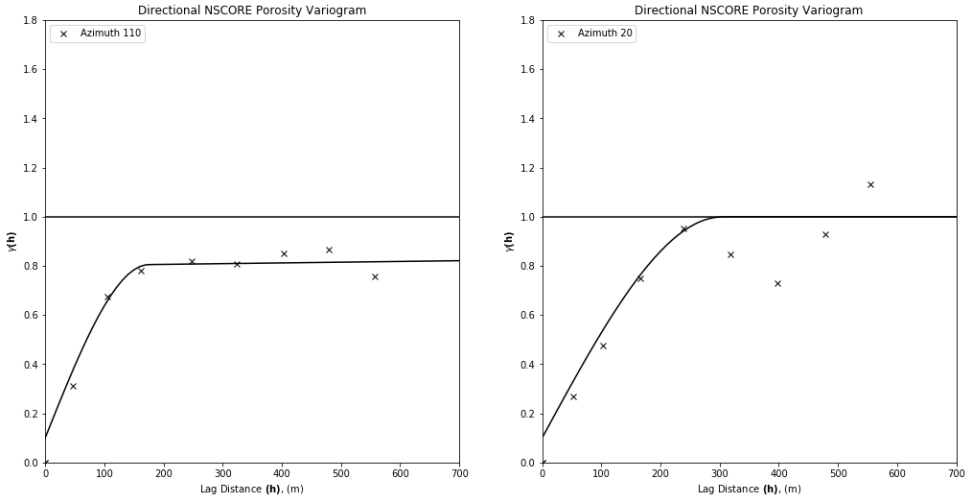


Figure 15. Porosity variogram models of major direction (left) and minor direction (right) for facies 1

For Permeability:
Nugget effect Variogram structure: nug = 0.1
Spherical Variogram structure 1: cc1 = 0.8; azi1 = 60; hmaj1 = 320; hmin1 = 80
Spherical Variogram structure 2: cc2 = 0.1; azi2 = 60; hmaj2 = 640; hmin2 =200

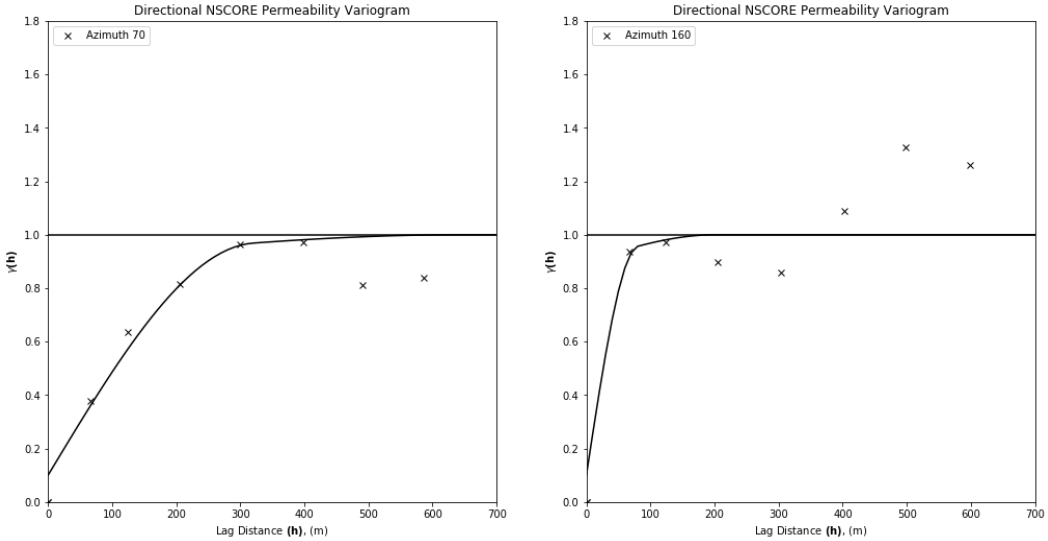


Figure 16. Permeability variogram models of major direction (left) and minor direction (right) for facies 1

Conclusions

- There is no clear directionality in the variogram maps generated for porosity. However, if some is occurring, it probably is at a 100° angle
- Major facies continuity direction at an azimuth of 67.5°
- There is zonal anisotropy in porosity at the 135° direction
- For facies 1 there seems to be zonal anisotropy as indicated by flat-lining of the variogram to a value lower than the range and some cyclic trends in other azimuthal directions
- For facies 0 we need more data to build a better variogram map, and thus develop better and more representative variogram model.
- The reservoir rock itself (interbedded sandstone - mix of sand and shale) can potentially be a cause of reservoir heterogeneity as we cannot see a clear directionality, plus we see some degree cyclicity over multiple azimuths in facies vaiograms.

Future Work

- Develop a full 3D spatial continuity model
- Possible collection of more data for facies 0 to develop a better understanding of the spatial continuity of facies 0