PSEstimating The Permeability Of Carbonate Rocks From The Fractal Properties Of Moldic Pores Using The Kozeny-Carman Equation*

Adewale Amosu[1], Mohamed Imsalem[2], and Yuefeng Sun[2]

Search and Discovery Article #51481 (2018)**
Posted June 4, 2018

*Adapted from poster presentation given at AAPG 2018 Southwest Section Annual Convention, El Paso, Texas, April 7-10, 2018

[1]Department of Geology and Geophysics, Texas A&M University, College Station, Texas (adewale@tamu.edu)
[2]Department of Geology and Geophysics, Texas A&M University, College Station, Texas

Abstract

Reservoir modeling of carbonate rocks requires a proper understanding of the pore space distribution and its relationship to permeability. Fractal geometry is one way to characterize the distribution of pore spaces in rock samples. Pape et al. (1987) described a pigeonhole fractal model for characterizing the pore space in rock samples. They also extracted the fractal dimension and described its relationship to the tortuosity and the formation factor of the studied samples. In this study we apply the pigeonhole fractal model to moldic pore spaces observed in thin-section photomicrographs obtained from the Happy Spraberry Field in Garza County of the Midland Basin. The pigeonhole fractal model is particularly useful for approximating moldic pores due to their circular-like like shapes. We describe and use the Minkowski-Bouligand box-counting method to estimate the fractal dimension of the moldic pore spaces. We then combine the Kozeny-Carman equation together with the fractal theory of porous media to estimate the nonlinear increase in permeability at porosities increases and derive an empirical relationship between permeability and porosity expressed as $k = 4.3X10^{11} r_{grain}^{2} \Phi^{7/5}$ (where k is permeability and Φ is porosity and r_{grain} is average grain size radius). The permeability calculated using the empirical relationship shows a good match with measured permeability.

References Cited

Amosu, A., 2014, Elastic Deformation of the Earth’s Crust from Surface Loading Phenomena: PhD Thesis, University of Memphis, Memphis, TN.

Amosu, A., 2013, Parallel Computation Algorithm (PCA) for Large Geophysical Processes: Abstract, AAPG/SEG Student Expo, Houston, Texas, September 16-17, 2013, Search and Discovery Article #90182 (2013). Website accessed May 2018.

Amosu, A., and H. Mahmood, 2018, PyLogFinder: A Python Program for Graphical Geophysical Log Selection: Research Ideas and Outcomes, v. 4/e23676, 4 p.

Amosu, A., H. Mahmood, P. Ofoche, and M. Imsalem, 2018, Interactive Estimation of the Fractal Properties of Carbonate Rocks: arXiv preprint arXiv:1802.06276, 11 p.

Amosu, A., and R. Smalley, 2014, Crustal Deformation from Surface Loading in the Great Salt Lake Region: Seismological Research Letters, 85/2, p. 447.

Amosu, A., R. Smalley, and J. Puchakayala, 2013, Modeling Earth's Crustal Deformation in the Lower Mississippi River Basin: Seismological Research Letters, v. 84/2, p. 376.

Amosu, A., R. Smalley, and J. Puchakayala, 2012, Modeling Earth Deformation from the 2011 Inundation in the Mississippi River Basin Using Hydrologic and Geodetic Data: AGU Fall Meeting Abstracts.

Amosu, A., R. Smalley, T.J. Wilson, M.G. Bevis, I.W. Dalziel, E.C. Kendrick, S. Konfal, W.R. Magee, and J.E. Stutz, 2011, December. Automatic Processing of Antarctic POLENET GPS Data: Abstract G53B-0902, presented at 2011 Fall Meeting, AGU, San Francisco, California 5-9 December 2011.

Amosu, A., and Y. Sun, 2017, WheelerLab: An Interactive Program for Sequence Stratigraphic Analysis of Seismic Sections, Outcrops and Well Sections and the Generation of Chronostratigraphic Sections and Dynamic Chronostratigraphic Sections: SoftwareX, v. 6, p. 19-24.

Amosu, A., and Y. Sun, 2017, FischerLab: An Interactive Program for Generating Dynamic Fischer Plots from Wireline Logs and Stratigraphic Data: AAPG Annual Convention and Exhibition, Houston, Texas, United States, April 2-5, 2017, Search and Discovery Article #70260 (2017). Website accessed May 2018.

Amosu, A., and Y. Sun, 2017, WheelerLab: An Interactive Program for Sequence Stratigraphic Analysis of Seismic Sections and the Generation of Dynamic Chronostratigraphic Sections: AAPG Annual Convention and Exhibition, Houston, Texas, United States, April 2-5, 2017, Search and Discovery Article #42053 (2017). Website accessed May 2018.

Amosu, A., and Y. Sun, 2017, FischerLab: An Interactive Program for Generating Fischer Plots and Stepwise Fischer Plots from Wireline Logs and Stratigraphic Data: SoftwareX (Under Review).

Amosu, A., and Y. Sun, 2017, Visualization of Angular Unconformities and Tectonic Angular Discordance Measurement Constraints by Structural Geometrical Flattening: Case Studies in the Permian (California), Grand Canyon (Arizona), Chad Basin (Nigeria), Algarve Basin (Iberia) and the Aegean Sea Basin (Turkey): Gulf Coast Association of Geological Societies Transactions, v. 67, p. 13-21.

Amosu, A., and Y. Sun, 2017, Sequence Stratigraphy, Chronostratigraphy and Spatio-Temporal Stratigraphic Thickness Variation of the Agbada Formation, Robertkiri and Delta Fields, Niger Delta, Nigeria: Gulf Coast Association of Geological Societies Transactions, v. 67, p. 3-12.

Amosu, A., and Sun, Y., 2018, MinInversion: A Program for Petrophysical Composition Analysis of Geophysical Well Log Data: Geosciences, v. 8/65, 12 p.

Amosu, A., Y. Sun, and D. Agustianto, 2016, Coherency- Based Inversion Spectral Decomposition of Seismic Data: 2016 SEG International Exposition and Annual Meeting. Society of Exploration Geophysicists Extended Abstracts, p. 1706-1711.

Crossley, D.J., and O.G. Jensen, 1989, Fractal Velocity Models in Refraction Seismology: Pageoph, v. 131, p. 61-76.

Hein, F.J., 1999, Mixed ("Multi") Fractal Analysis of Granite Wash Fields/Pools and Structural Lineaments, Peace River Arch Area, North-Western Alberta, Canada; A Potential Approach for Use in Hydrocarbon Exploration: Bulletin of Canadian Petroleum Geology, v. 47, p. 556-572.

Imsalem, M., P. Pondthai, and A. Raymond, 2018, Preliminary Establishment of Al-Athrun, Uwayliah and Apollonia Formations Based on Magnetostratigraphic Investigation, NE Libya.

Imsalem, M., and A. Raymond, 2018, Pollen Analysis from Ecological and Latitudinal Gradient in Morocco: gsa-2018SC-1494-6800-6929-3335.

Mandelbrot, B.B., 1983, The Fractal Geometry of Nature: WH Freeman and Co., New York, 495 p.

Pape, H., C. Clauser, and J. Iffland, 1999, Permeability Prediction Based on Fractal Pore-Space Geometry: Geophysics, v. 64/5, p.1447-1460.

Pape H., L. Riepe, and J. Schopper, 1987, Theory of Selfsimilar Network Structures in Sedimentary and Igneous Rocks and Their Investigation with Microscopical and Physical Methods: Journal of Microscopy, v. 148/2, p. 121-147.

Turcotte, D.L., 1992, Fractals and Chaos in Geology and Geophysics: Cambridge University Press, Cambridge, 221 p.

Xie, S., Q. Cheng, Q. Ling, B. Li, Z. Bao, and P. Fan, 2010, Fractal and Multifractal Analysis of Carbonate Pore-Scale Digital Images of Petroleum Reservoirs. Marine and Petroleum Geology, v. 27/2, p.476-485.

Estimating the Permeability of Carbonate Rocks from the Fractal Properties of Moldic Pores using the Modified Kozeny-Carman Equation

AAPG Southwest Section Convention, April 7-11 2018, El Paso, TX

Author(s): Adewale Amosu, Mohamed Imsalem, Yuefeng Sun, *Department of Geology & Geophysics, Texas A&M University*

Department of
GEOLOGY & GEOPHYSICS
COLLEGE OF GEOSCIENCES

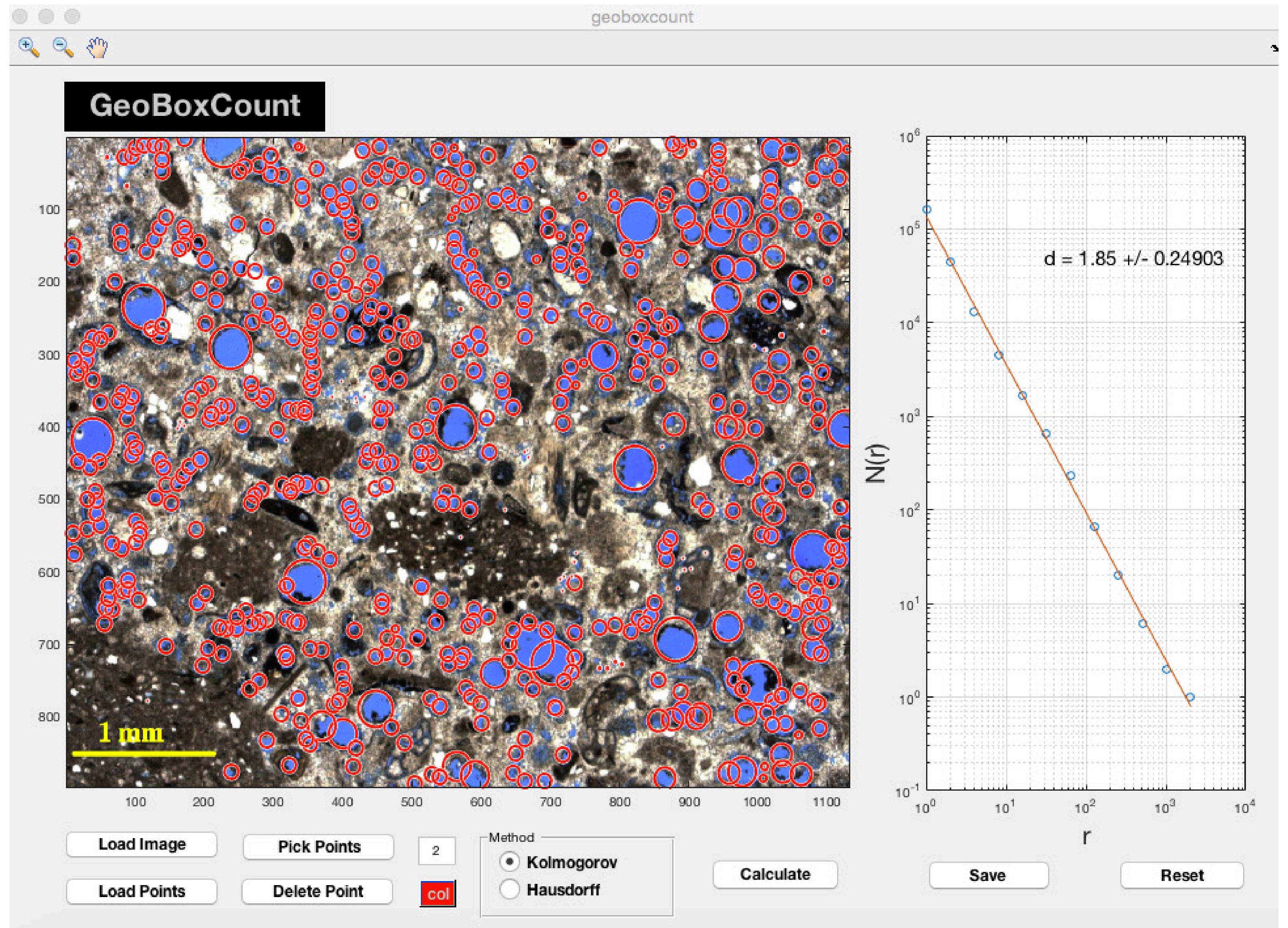
OBJECTIVES

- Reservoir modeling of carbonate rocks requires a proper understanding of the pore space distribution and its relationship to permeability.
- Fractal geometry is one way to characterize the distribution of pore spaces in rock samples.
- In this study we apply the pigeonhole fractal model to moldic pore spaces observed in thin-section photomicrographs and extract the fractal dimension.
- We apply the Kozeny-Carman equation and equations relating the tortuosity and the porosity to the fractal dimension to derive an empirical relationship between permeability and porosity.

INTRODUCTION

- The concept of fractals was introduced by Benoit Mandelbrot (1983) and can be observed extensively in many areas of geology and geophysics (Turcotte, 1992; Xie, 2010).
- Scale invariance of intrinsic patterns is an important concept in geology that can be observed in numerous geological objects and phenomena.
- These geological objects and phenomena are described as containing statistically self- similar patterns often modeled with fractal geometry.
- Fractal geometry has been used extensively to characterize pore space and fracture distribution of both carbonate and clastic rocks as well as the transport properties of porous media and fluid flow in reservoirs.
- The fractal properties are usually estimated from thin-section photomicrograph images or scanning electron microscope images.

METHODOLOGY



- We develop a workflow for applying the box-counting method to thin-section photomicrographs.
- Box-counting methods are commonly applied to thin-section photomicrographs or scanning electron microscope (SEM) images in order to estimate the fractal dimension.
- This procedure involves recognizing every instance of a certain feature everywhere it occurs in the image, then super-imposing boxes of varying size and counting how many boxes cover the features of interest.
- Due to complexity of certain rocks, such as carbonate rocks that are often affected by facies selective diagenesis, automatic detection of features, such as pore spaces, fractures, or specific fossil types, is often inaccurate. Interactive interpretation of the images ensures all features of interest are captured.

$$k = \frac{\phi}{8T} r_{eff}^2$$

$$T = 1.34 \left(\frac{r_{grain}}{r_{eff}}\right)^{0.67(D-2)}$$

$$\phi = 0.5 \left(\frac{r_{grain}}{r_{eff}}\right)^{0.39(D-3)}$$

Modified Kozeny-Carman equation (Pape et. al., 1987; 1999) and equations (obtained using the pigeon-hole fractal model) relating Tortuosity and Porosity to the Fractal Dimension D.

T is tortuosity, r_{grain} is average grain size, r_{eff} is the effective pore radius, D is the fractal dimension, k is permeability and Φ is porosity.

The fractal dimension obtained is approximately 2.05; we substitute it in the 2nd and 3rd equations and combine the results with the first equation to obtain:

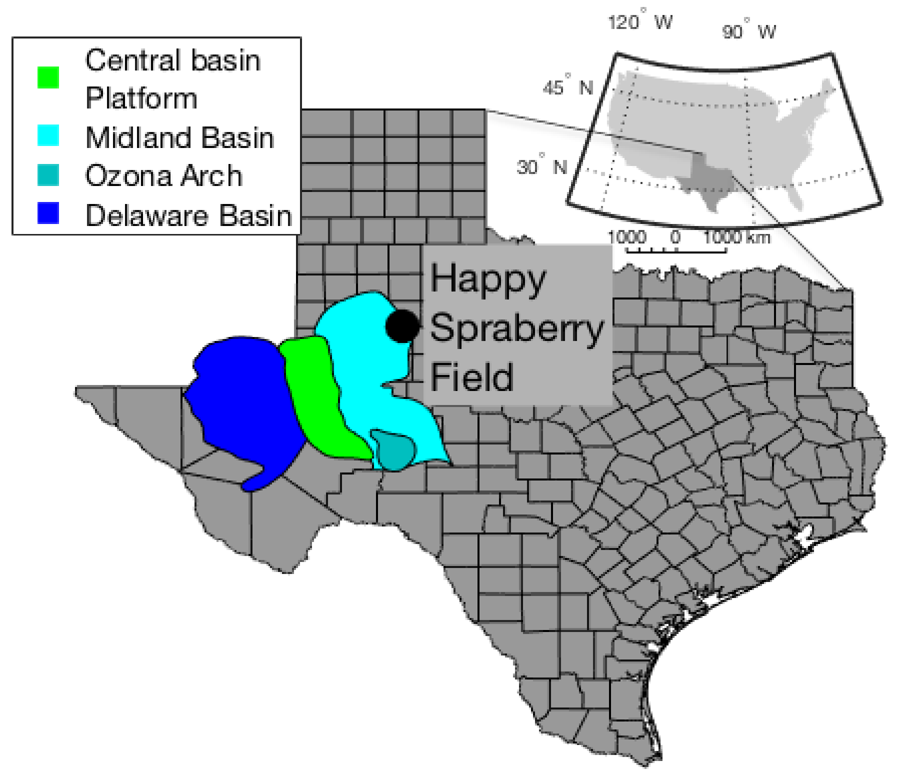
$$T = 1.34 \left(\frac{r_{grain}}{r_{eff}}\right)^{0.07}$$

$$\phi = 0.5 \left(\frac{r_{grain}}{r_{eff}}\right)^{-0.35}$$

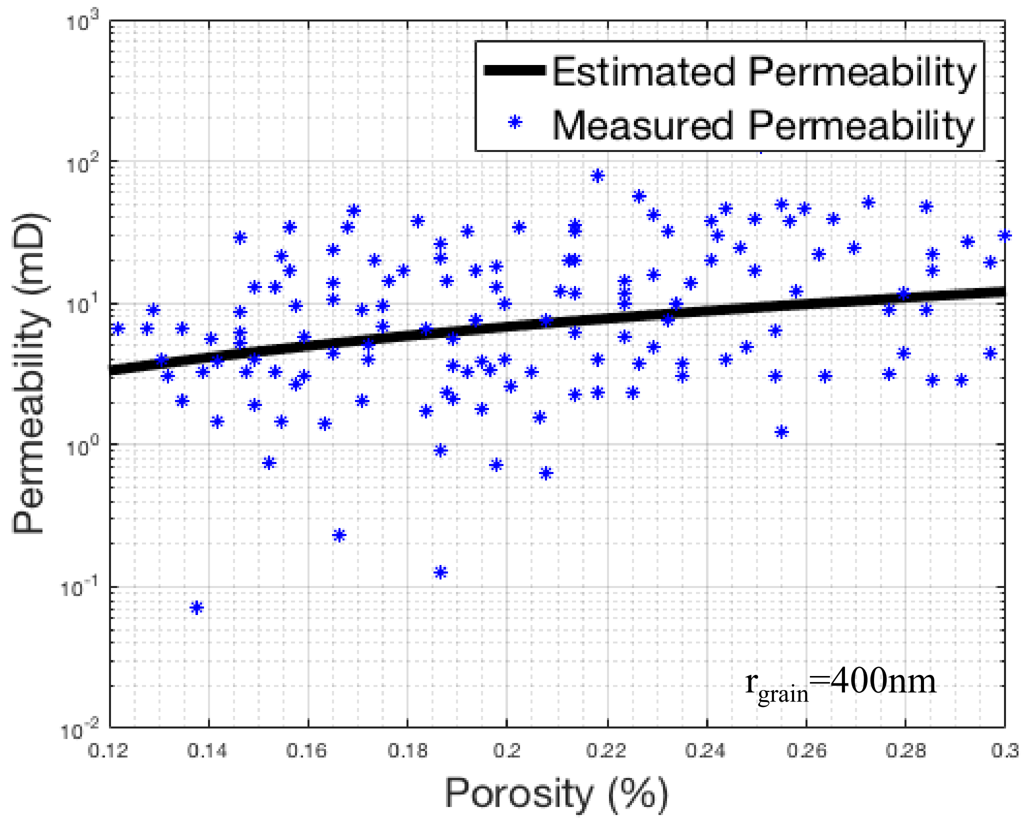
$$k = 4.3 * 10^{11} r_{grain}^2 \phi^{7/5}$$

HAPPY SPRABERRY FIELD

- The Happy Spraberry Field Texas is located in Garza County on the northern part of the Midland Basin.
- It produces oil from heterogeneous shallow shelf carbonates of the Permian-aged Lower Clear Fork Formation. .
- The reservoir facies have cemented and dissolution enhanced pore types caused by facies selective diagenesis. Moldic pores are the most abundant across the field and dominate the oolitic skeletal grainstone packstone facies.
- We make use of thin section photomicrographs of the reservoir facies from a well in the Happy Spraberry Field.



RESULTS & CONCLUSIONS



- The pigeonhole fractal is used to successfully characterize the moldic pores in the reservoir facies of carbonate rocks and extract the fractal dimension.
- We apply the Kozeny- Carman equation and equations relating the tortuosity and the porosity to the fractal dimension to establish an empirical relationship between permeability and porosity.
- A good match is observed between modeled and measured permeability for r_{grain}= 400nm.

Some of the results in this study were generated using the GeoBoxCount program (Amosu et al., 2018). For more free software and research work from the authors, see: Amosu (2013, 2014), Amosu and Sun (2017 a-e), Amosu et al., (2011, 2012, 2013, 2016, 2018a-b), Amosu and Mahmood (2018), Imsalem et al., (2018).

REFERENCES

- Mandelbrot, B.B., 1983. The fractal geometry of nature (Vol. 173). New York: WH freeman.
- Crossley, D. J., and Jensen, O. G., 1989, Fractal velocity models in refraction seismology: Pageoph, 131, 61-76.
- Hein, F.J., 1999. Mixed ("multi") fractal analysis of granite wash fields/pools and structural lineaments, Peace River Arch area, north- western Alberta, Canada; a potential approach for use in hydrocarbon exploration. Bulletin of Canadian Petroleum Geology 47, 556-572.
- Turcotte, D.L., 1992. Fractals and Chaos in Geology and Geophysics. Cambridge University Press, Cambridge 221pp.
- Pape H., Riepe L., Schopper J., 1987. Theory of selfsimilar network structures in sedimentary and igneous rocks and their investiga- tion with microscopical and physical methods. Journal of Microscopy 148 (2): 121-147.
- Pape, H., Clauser, C. and Iffland, J., 1999. Permeability prediction based on fractal pore-space geometry. Geophysics, 64(5), pp.1447-1460.
- Xie, S., Cheng, Q., Ling, Q., Li, B., Bao, Z. and Fan, P., 2010. Fractal and multifractal analysis of carbonate pore-scale digital images of petroleum reservoirs. Marine and Petroleum Geology, 27(2), pp.476- 485.
- Amosu A., Y. Sun, WheelerLab: An interactive program for sequence stratigraphic analysis of seismic sections, outcrops and well sections and the generation of chronostratigraphic sections and dynamic chronostratigraphic sections SoftwareX 6 (2017), pp 19-24.
- Amosu A., Y. Sun, FischerLab: An Interactive Program for Generating Dynamic Fischer Plots From Wireline Logs and Stratigraphic Data, AAPG Annual Convention (2017).
- Amosu A., Y. Sun, WheelerLab: An Interactive Program for Sequence Stratigraphic Analysis of Seismic Sections and the Generation of Dynamic Chronostratigraphic Sections, AAPG Annual Convention (2017).
- Amosu A., Y. Sun, FischerLab: An interactive program for generating Fischer plots and stepwise Fischer plots from wireline logs and strati- graphic data: SoftwareX (Under Review).
- Amosu A., Y. Sun, Visualization of Angular Unconformities and Tec- tonic Angular Discordance Measurement Constraints by Structural Geometrical Flattening: Case Studies in the Permian (California), Grand Canyon (Arizona), Chad basin (Nigeria), Algarve Basin (Iberia) and the Aegean Sea Basin (Turkey), Gulf Coast Association of Geological Societies Transactions (2017).
- Amosu A., Y. Sun, Sequence Stratigraphy, Chronostratigraphy and Spatio-Temporal Stratigraphic Thickness Variation of the Agbada Formation, Robertkiri and Delta Fields, Niger Delta, Nigeria, Gulf Coast Association of Geological Societies Transactions (2017).
- Amosu, A. and Mahmood, H., 2018. PyLogFinder: A Python Program for Graphical Geophysical Log Selection. Research Ideas and Outcomes, 4, p.e23676.
- Amosu, A., 2014. Elastic Deformation of the Earth's Crust from Sur- face Loading Phenomena (Doctoral dissertation, University of Memphis).
- Amosu, A. and Sun, Y., 2018. MinInversion: A Program for Petrophysical Composition Analysis of Geophysical Well Log Data. Geosciences, 8(2), p.65.
- Amosu, A., Smalley, R., Wilson, T.J., Bevis, M.G., Dalziel, I.W., Kendrick, E.C., Konfal, S., Magee, W.R. and Stutz, J.E., 2011, December. Automatic Processing of Antarctic Polenet GPS Data. In AGU Fall Meeting Abstracts.
- Amosu, A., Smalley, R. and Puchakayala, J., 2013. Modeling Earths Crustal Deformation In the Lower Mississippi River Basin. Seismological Research Letters, 84(2), p.376.
- Amosu, A., 2013. Parallel Computation Algorithm (PCA) for Large Geophysical Processes. American Association of Petroleum Geologists, AAPG/SEG Expo, Article, 90182.
- Amosu, A. and Smalley, R., 2014. Crustal Deformation from Surface Loading In the Great Salt Lake Region. Seismological Research Letters, 85(2), p.447.
- Amosu, A., Sun, Y. and Agustianto, D., 2016, January. Coherency- based inversion spectral decomposition of seismic data. In 2016 SEG International Exposition and Annual Meeting. Society of Exploration Geophysicists.
- Amosu, A., Smalley, R. and Puchakayala, J., 2012, December. Modeling Earth deformation from the 2011 inundation in the Mississippi river basin using hydrologic and geodetic data. In AGU Fall Meeting Abstracts.
- Amosu, A., Mahmood, H., Ofoche, P. and Imsalem, M., 2018. Interactive Estimation of the Fractal Properties of Carbonate Rocks. *arXiv preprint arXiv:1802.06276.*
- Imsalem, M., Pondthai, P., Raymond, A., 2018. Preliminary establishment of Al-Athrun, Uwayliah and Apollonia Formations based on Magnetostratigraphic investigation, NE Libya.
- Imsalem, M., Raymond, A., 2018. Pollen Analysis from Ecological and Latitudinal Gradient in Morocco. gsa-2018SC-1494-6800-6929-3335.