Hydrocarbon Generation Indications from Source Rock to Reservoir Rock: Case Studies of Anambra and Abakaliki Basins, Southeastern Nigeria*

Rita U. Onolemhemhen[1], Samuel Salufu[1], and Sunday O. Isehunwa[1]

Search and Discovery Article #10911 (2017)**
Posted February 13, 2017

*Adapted from oral presentation given at AAPG/SPE Africa Energy and Technology Conference, Nairobi City, Kenya, December 5-7, 2016

[1]University of Ibadan, Ibadan, Nigeria (ritaonos@gmail.com)

Abstract

This article sought to use information from outcrop sections to characterise the source and reservoir rocks in a basin in order to give indication(s) for hydrocarbon generation potential to minimize uncertainty and risk allied with exploration, field development of oil and gas, using subsurface data from well logs, well sections, seismic and core data. Methods of study includes detailed geological and stratigraphic studies, geochemical study, petrographic, and sedimentological studies of rock units from outcrop sections within two basins - the Anambra Basin and Abakaliki Basin, used here as case studies. Thirty-eight (38) samples of shale were collected from the basins, a geochemical analysis (rockeval) was done on the samples to determine the total organic content (TOC) and to assess the oil generating window. The results were analyzed using Rock wares, Origin, and Surfer software to properly characterize the potential source rock(s) and reservoir rock(s) in the basins and factor(s) that can favour hydrocarbon traps.

Results of the geochemical analysis of shale samples from the Anambra Basin shows TOC values ≥1 wt%, Tmax ≥ 431°C, Vitrinite reflectance values ≥ 0.6%, and S1+S2 values ≥2.5 mg/g for the Mamu Formation, while shale samples from other formations within Anambra Basin fall out of these ranges. The shale unit in the Mamu Formation is the major source rock for oil generation in the Anambra Basin, while others have potential for gas generation with very little oil generation. Shale samples from the Abakaliki Basin shows that S1+S2 values range from <1-20 mg/g, TOC values ranges from 0.31-4.55 wt%, vitrinite reflectance ranges from 0.41-1.24% and Tmax ranges from 423°C-466°C. Result also shows that there is no source rock for oil generation in Abakaliki Basin; it is either gas or graphite. This observation indicates that all the source rocks within the Anambra Basin have exceeded the petroleum generating stage due to high geothermal heat resulting from deep depths, or the shale units have not attained catagenesis stage due to S1+S2 values lesser than 2.5 mg/g, TOC values ≥0.5 wt% and vitrinite reflectance values ≥ 0.6%. This study has shown that there is more oil in the Anambra Basin than previous authors claimed, and the distribution of oil and gas in the basins is controlled by two major factors - pattern of distribution of the materials of the source rock prior to subsidence and during the subsidence period, and the rate of tectonic activities in the basins.

References Cited

Akande, S.O., O.J. Ojo, and O.A. Adekeye, 2011, Stratigraphic evolution and petroleum potential of Middle Cretateous pediments in the Lower Benue and Middle Benue Trough, Nigeria: Insight from new source rock facies evaluation: Petroleum Technology Development Journal, v. 1, p. 1-34.

Bakin, S., 1999, Adaptive regression and model selection in data mining problems: PhD Thesis, Australian National University, Canberra.

deGroot-Hedlin, C., and S. Constable, 1990, Occam's inversion to generate smooth, two-dimensional models from magnetotelluric data: Geophysics, v. 55/12, p. 1613-1624.

Emujakporue, G.O., and A.S. Ekine, 2014, Determination of geothermal gradient in the Eastern Niger Delta sedimentary sasin from bottom hole temperatures: Journal of Earth Sciences and Geotechnical Engineering, v. 4/3, p. 109-114.

Okeke, H.C., I.P. Orajaka, Anthony Okoro, and E.N. Onuigbo, 2014, Biomarker Evaluation of the oil generative potential of organic matter, in the upper Maastrichtian strata, Anambra Basin, southeastern Nigeria: Journal of Scientific Research, 2/1, p. 16-25.

Salufu, S.O., and T.F. Ogunkunle, 2015, Source rock assessment and hydrocarbon prospects of Anambra Basin: Salient indications for maturity: The Pacific Journal of Science and Technology, v. 16/1, p. 336-344.

Hydrocarbon Generation Indication from Source Rock to Reservoir Rock: Case Studies of Anambra and Abakaliki Basins South-Eastern Nigeria

Presenter : Onolemhemhen, Rita
Co-authors : Salufu Samuel, Isehunwa, Sunday

University of Ibadan, Ibadan, Nigeria

Outline

1. **Introduction & Previous works**
2. **Aims of Study**
3. **Materials and Methods**
4. **Results and Discussion**
5. **Source Rock Characterization of Abakaliki Bain**
6. **Source Rock Characterization of Anambra Bain**
7. **Model for Hydrocarbon Maturation in Abakaliki and Anambra Bains**
8. **Conclusion**

Introduction

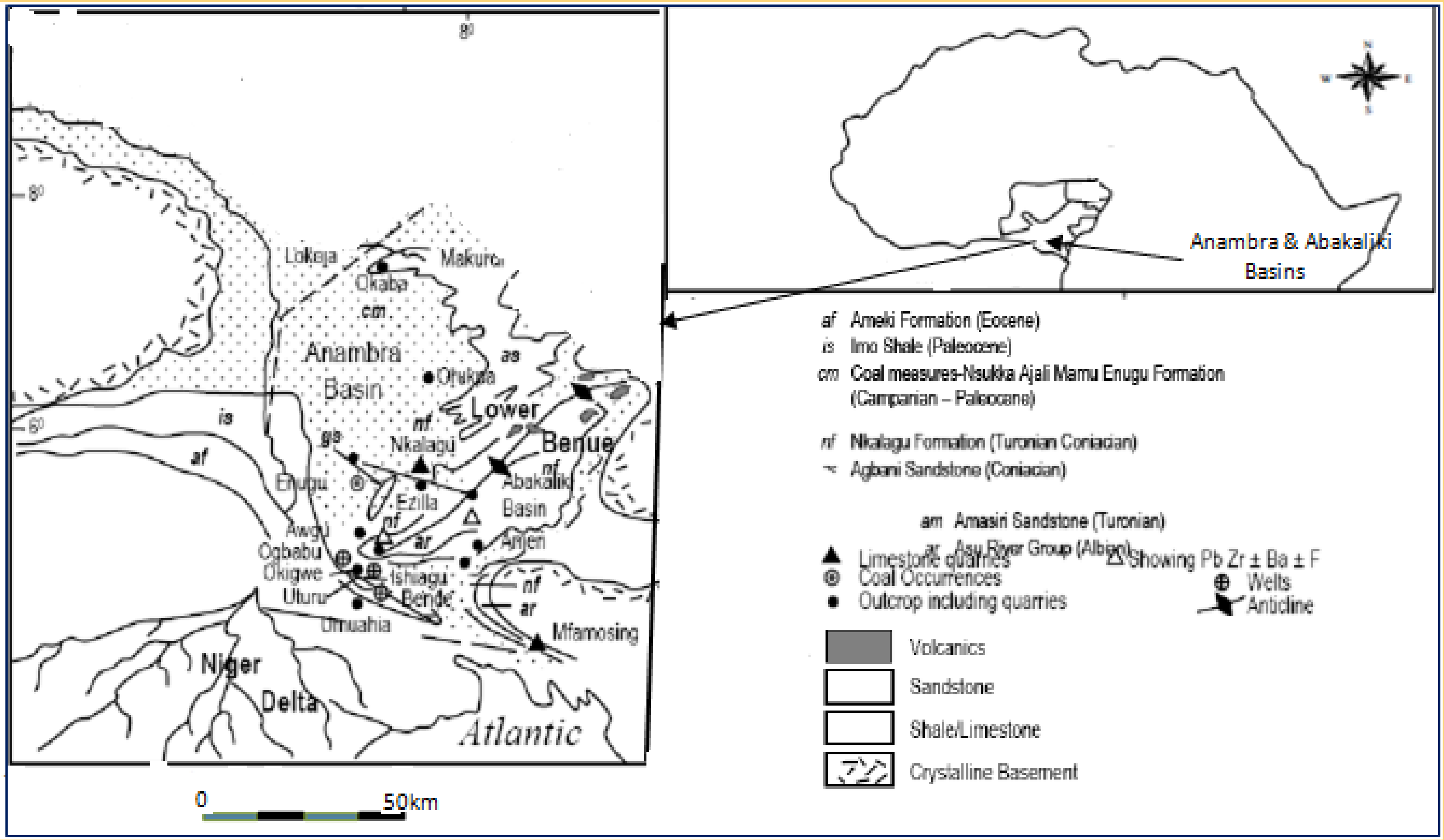


Figure 1: Map of southeastern Nigeria showing Abakaliki and Anambra Basin

Previous Work

- Okeke et al.(2014)
- Akande et al. (2011)
- Emujakporue and Ekine (2014)

Aims of Study

- To characterize the source rocks in the two basins
- To identify mature source, and to identify those ones that are gas or oil source rock(s).
- To characterise the reservoir rocks in the two basins.
- To develop a new model for classifying hydrocarbon maturation in the two basins, using information from the geological, geophysical, sedimentological, stratigraphical, petrological and geochemical studies in order to eliminate the uncertainty that are allied with exploration in these basins.

Materials and Method

- Thirty eight samples of shale were collected from the study area; thirteen samples were collected from Abakaliki Basin randomly at various locations within the basin while twenty five samples of shale were collected randomly from outcrop sections in different locations in Anambra Basin during detailed geologic mapping.
- The shale samples were crushed.
- LECO device was used to measure TOC.
- Hydrocarbon already generated within the source rock (S_1), residual petroleum potential (S_2), gas (S_0), temperature at which maximum in S_2 response (Tmax).
- The values of the measured Tmax were used to compute the vitrinite reflectance (%VRo) as well TOC with the equation below:

Materials and Method (Cont'd)

$$\%VRo = 0.01803Tmax - 7.16 \quad (1)$$

Where %VRo = calculated vitrinite reflectance

$$TOC = \frac{(0.83(S_0 + S_1 + S_2) + S_4)}{10(wt\%)} \quad (2)$$

$$HI = \frac{S_2}{TOC} \times 100 \quad (3)$$

$$PI = \frac{S_1}{(S_1 + S_2)} \quad (4)$$

Materials and Method (Cont'd)

- However, stratigraphical, sedimetological and petrographical studies of outcrops in the two basins were carefully carried out in other to get vital information about the geology and tectonic history of the basin in order to to integrate the information with geochemical information measured and computed using equations (1) to (4) above so as to properly model the tectonic model for hydrocarbon maturation for both Anambra and Abakaliki Basin.
- Electrical resistivity tomography (ERT) was carried out at selected locations within Anambra Basin base on information from outcrop observations in order to delineate if there are occurrence of structures that favours hydrocarbon traps.
- The ERT was done using dipole-dipole array.
- Smoothness constrained inversion method was used after the method of deGroot-Hedlin and Constable (1990) as follows:

Materials and Method (Cont'd)

$$(J^T J + \mu F)d = J^T g \qquad (5)$$

$$F = \mathbb{f}_x \mathbb{f}_x T + \mathbb{f}_z \mathbb{f}_z \qquad (6)$$

Where $\mathbb{f}_z$ = vertical flatness

$\mathbb{f}_x$ = horizontal flatness

μ= damping factor

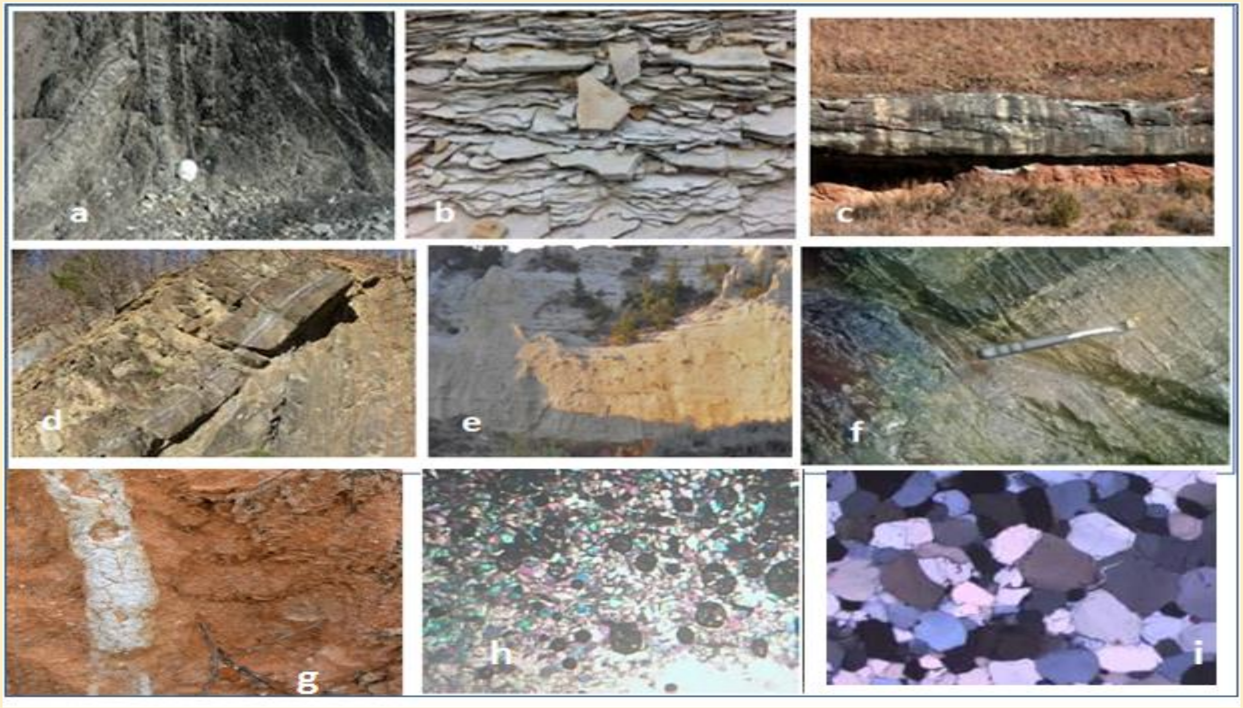
d= model perturbation vector

g=discrepancy vector

The results of the geological, stratigraphical, sedimentological, geochemical, and structural studies were integrated and used to develop a new model for hydrocarbon generation in the Basins

Results and Discussion

Presentation of Geological Result



Figuere.2: (a) Tilted Asu River Group (b) Baked shale unit within Bakaliki Basin (c) Dolerite sill intrusion within the sedimentary rock at Lokpatan (d) Gabbro dyke intusion (e) Aureole contact at Abakaliki within Asu River Group (f) Faulted unit of Imo Shale at the Edo State portion of Anambra State(g) Ophiomorpha burrows within the sandstone units in Anambra Basin (h) Thin section of sandstone unit of Abakaliki Basin (i) Thin section of sandstone unit of Anambra Basin

Presentation of Geophysical Result

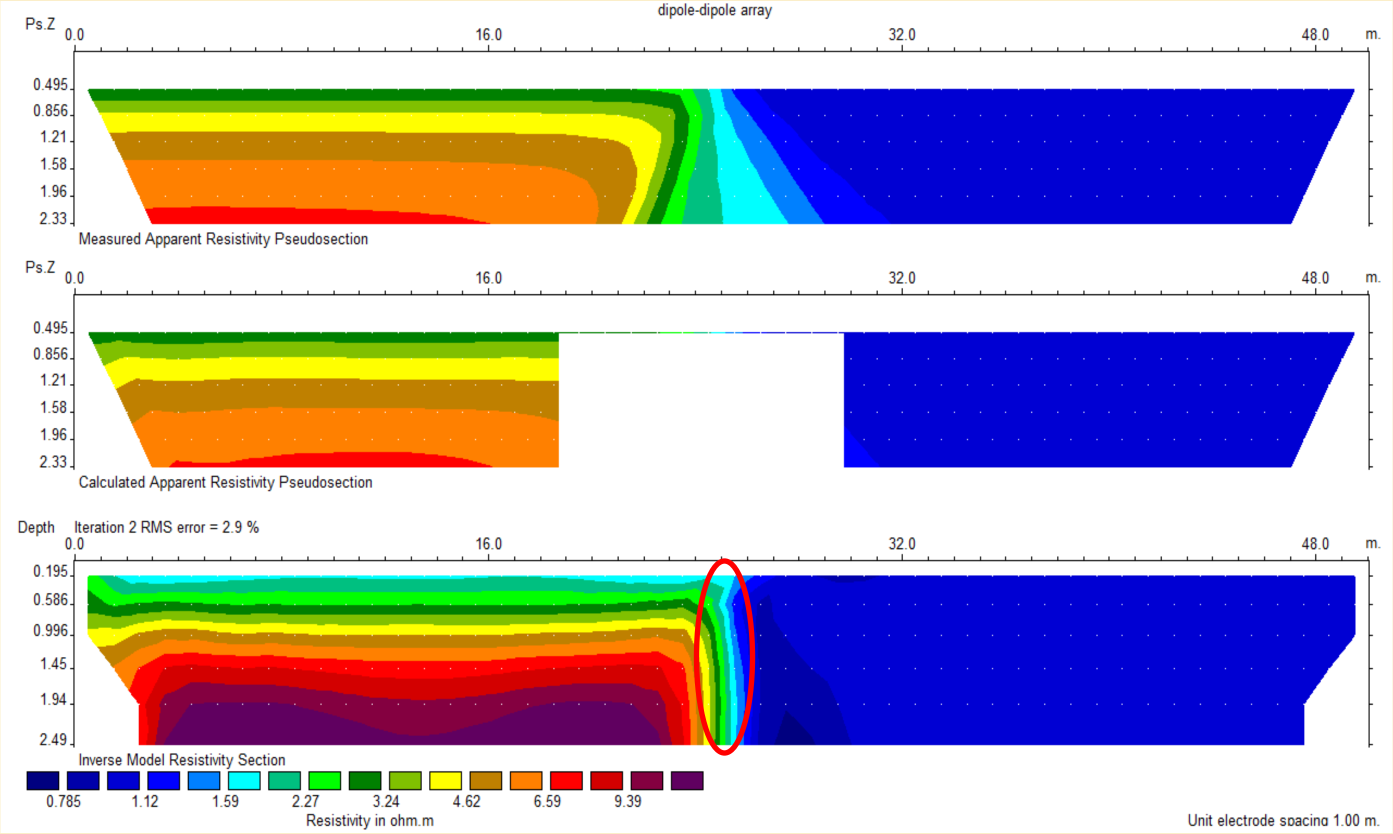


Fig.3: ERT result taken at the Proda in Enugu, showing faulted sections of Mamu and Ajali Formations in Anambra Basin

Presentation of Geophysical Result (Cont'd)

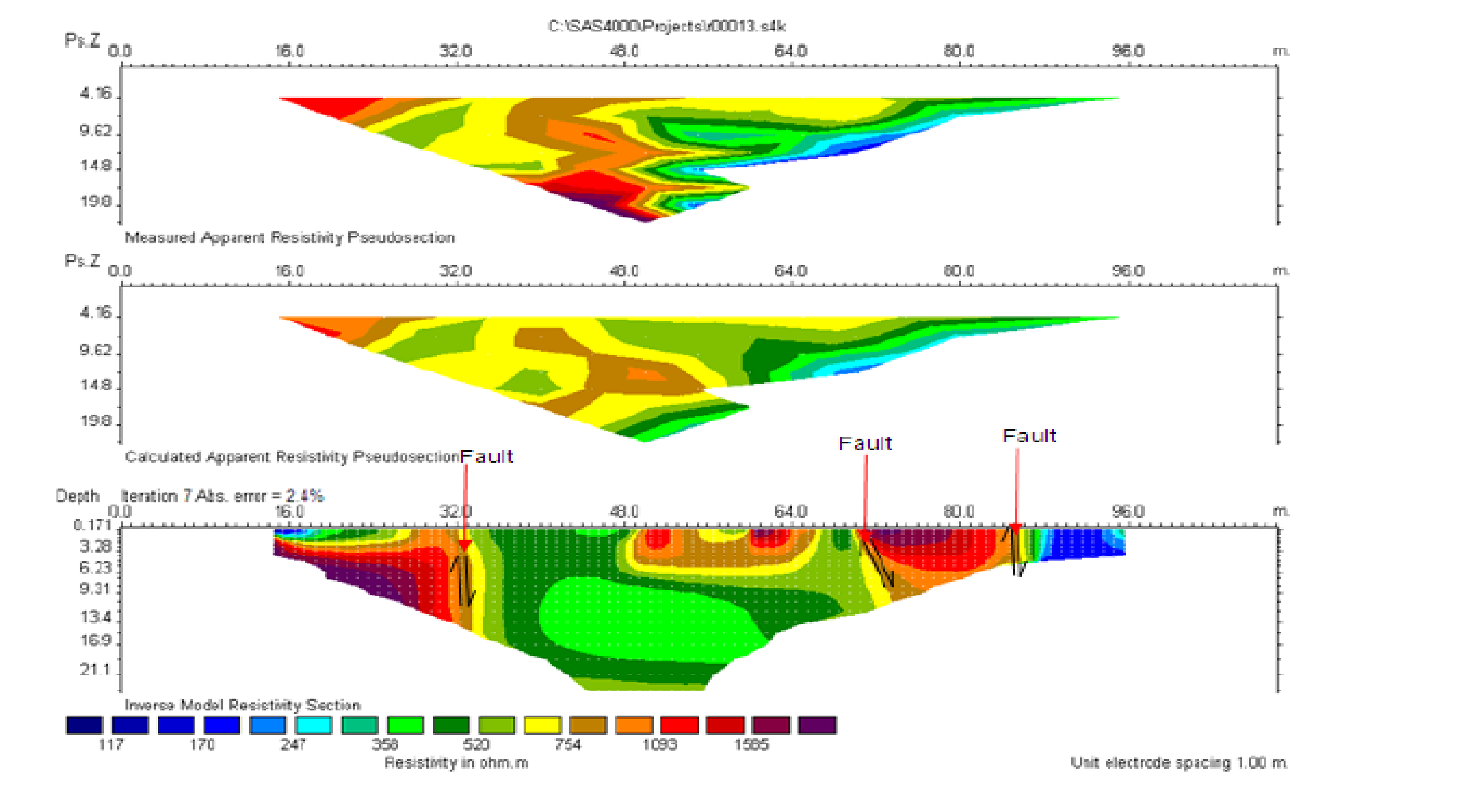


Fig.4: ERT result taken in Ekpoma, showing faulted sections of Bende-Ameki Formation in Anambra Basin

Presentation of Geophysical Result (Cont'd)

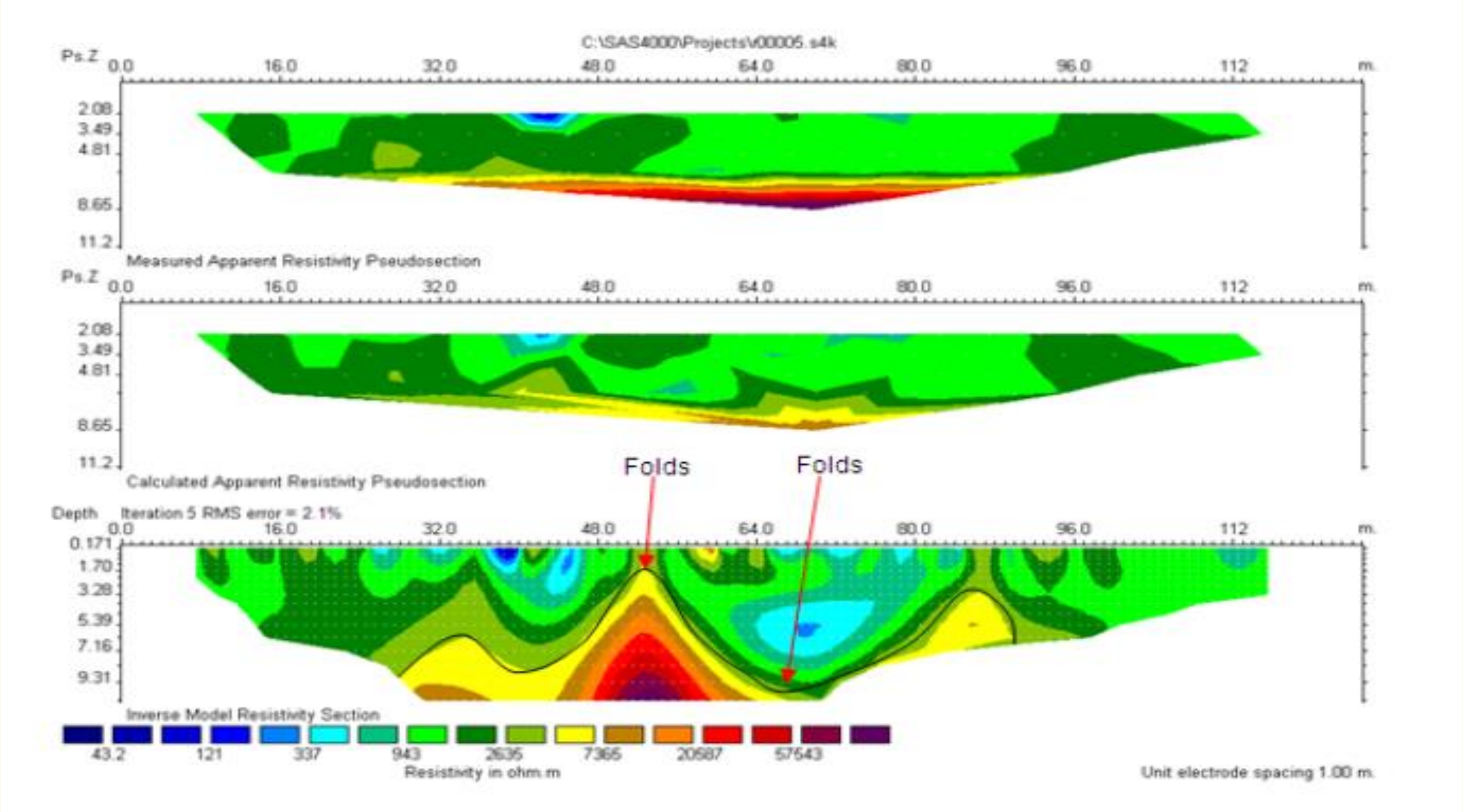


Fig.5: ERT result taken at Uromi in Edo State of Nigeria, showing folded sections of Imo Shale in Anambra Basin

Presentation of petrographical Result

Table 1: Petrographical Result of formations in Abakaliki and Anambra Basins

Formations	Q (%)	F (%)	Rf (%)	Heavy minerals (%)
Ajali	95.5	1.5	4	0.1(Z,R)
Ajali	95	1.7	3.2	0.1((Z,R)
Ajali	93	2.9	4	0.1(Z,R)
Mamu	95	1.00	4.00	0.1(Z,R)
Mamu	94.5	1.5	5.00	0.15(Z,R)
Mamu	96	1	2.9	0.1(Z,R)
Nkporo	96	1	2.9	0.1(Z,R,A)
Nkporo	95.5	1.1	3.3	0.1(A,R)
Nkporo	94.5	2.1	3.8	0.1(A,R)
Awgu	80	2.9	17	0.1(Z,T)
Awgu	81	1.9	17	0.1(Z,T)
Eze-aku	80	19	0.9	0.1(O,T)
Eze-aku	80	2.9	17	0.1(Z,T)
Eze-aku	81	2.9	16	0.1(Z,T)
Asu River	58.2	25.7	17	0.1(Z,T)
Asu River	24.5	59.4	16	0.1(O,Z.T)

Presentation of Geochemical Result

Table 2: Geochemical Result of shale samples within Abakaliki Basin

S/N	Formations	TOC (wt%)	S_1 (HC/t)	S_2 (HC/t)	Tmax (°C)	%VRo	HI	PI
1	Awgu	1.49	0.11	1.63	423	0.46	109	0.04
2	Awgu	0.71	0.2	0.08	466	1.24	13	0.07
3	Awgu	0.51	0.2	0.17	435	0.68	33	0.54
4	Awgu	0.65	0.19	0.35	434	0.67	54	0.35
5	Ezeaku	1.88	0.59	10.30	422	0.45	548	0.05
6	Ezeaku	0.86	0.01	0.09	426	0.52	10	0.10
7	Ezeaku	1.59	0.33	6.94	426	0.52	435	0.05
8	Ezeaku	1.91	0.33	0.87	420	0.41	46	0.03
9	Ezeaku	0.76	0.01	0.39	432	0.6	52	0.03
10	Ezeaku	0.57	0.09	0.19	448	0.92	33	0.3
11	Asu River	0.31	0	0.03	464	1.2	9	0
12	Asu River	0.16	0	0.05	440	0.77	33	0
13	Asu River	0.22	0	0.06	441	0.79	23	0

Table 3: Geochemical Result of shale samples within Anambra Basin

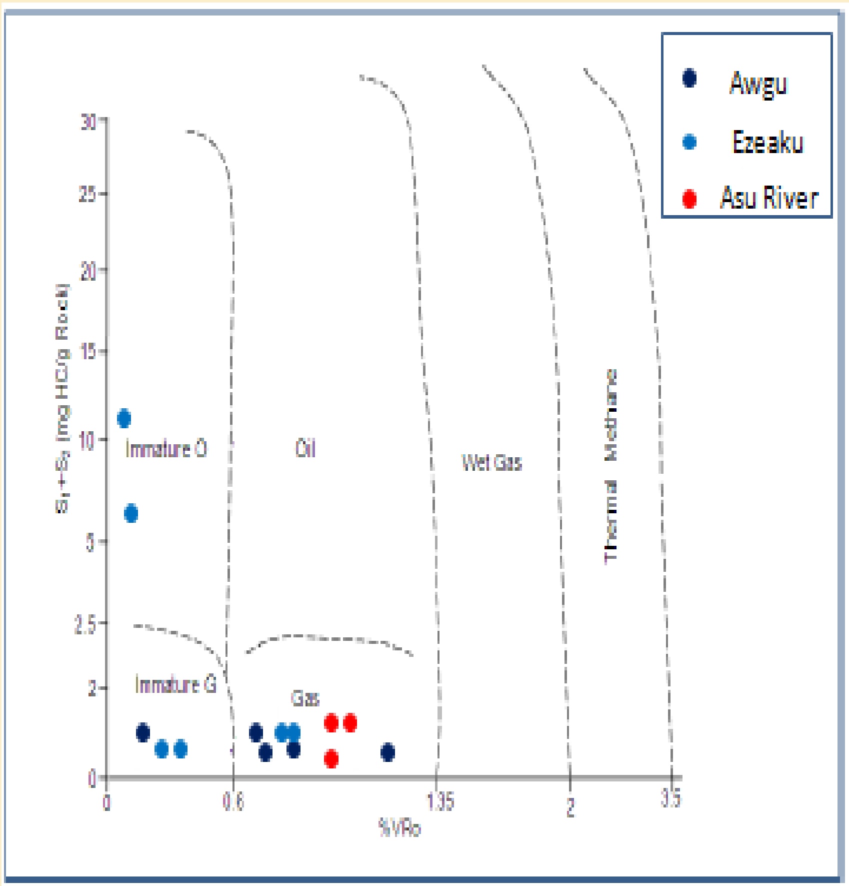
S/N	Formations	TOC (wt%)	S_1 (HC/t)	S_2(HC/t)	Tmax (°C)	%VRo	HI	PI
1	Ogwashi	1.64	0.05	0.59	422	0.45	35.98	0.04
2	Ogwashi	1.76	0.07	0.14	414	0.30	7.95	0.33
3	Ameki	1.55	0.03	0.15	410	0.23	7.1	0.17
4	Ameki	1.5	0.04	0.65	416	0.34	43	0.06
5	Imo	1.6	0.01	0.26	420	0.41	16.25	0.04
6	Imo	1.5	0.04	0.52	426	0.52	35	0.07
7	Nsukka	0.5	0.03	0.21	421	0.42	42	0.13
8	Nsukka	0.85	0.03	0.26	430	0.58	31	0.1
9	Nsukka	1.6	0.07	0.74	430	0.58	64	0.09
10	Nsukka	1.05	0.07	0.71	432	0.62	68	0.09
11	Nsukka	18.67	0.43	18.25	431	0.6	98	0.02
12	Mamu	5.08	0.24	9.96	432	0.6	196	0.02
13	Mamu	1.45	0.09	153	432	0.62	106	0.06
14	Mamu	4.73	0.3	11.87	433	0.63	251	0.02
15	Mamu	6.1	0.27	11.62	432	0.62	260	0.03
16	Mamu	3.79	0.33	9.86	433	0.63	251	0.02
17	Enugu	2.04	0.09	0.8	425	0.49	69	0.05
18	Enugu	0.74	0.07	1.18	428	0.54	159	0.1
19	Enugu	2.34	0.05	1.29	434	0.65	55	0.09
20	Enugu	2.95	0.07	1.29	427	0.53	42	0.04
21	Nkporo	3.21	0.01	3.56	434	0.65	111	0.03
22	Nkporo	0.97	0.07	0.3	439	0.74	31	0.03
23	Nkporo	2.29	0.03	1.18	424	0.47	48	0.04
24	Nkporo	1.07	0.03	1.1	425	0.49	36	0.07

Source Rock Characterization of Abakaliki Bain

Table 4: Interpreted result of Rock-Eval Pyrolyiss for shale samples in Abakaliki Basin

S/N	Formations	TOC (wt%)	Tmax (°C)	%VRo	S_1+ S_2	Source Rock	Maturity	%Maturity	Hydrocarbon yield
1	Awgu	1.49	423	0.46	1.74	Good	Immature		Gas potential
2	Awgu	0.71	466	1.24	0.1	Fair	Mature		Gas
3	Awgu	0.51	435	0.68	0.37	Fair	Mature	75%	Gas
4	Awgu	0.65	434	0.67	0.54	Fair	Mature		Gas
5	Ezeaku	1.88	422	0.45	10.89	Good	Immature		Oil potential
6	Ezeaku	0.86	426	0.52	0.1	Fair	Immature	33%	Gas potential
7	Ezeaku	1.59	426	0.52	7.27	Good	Immature		Oil Potential
8	Ezeaku	1.91	420	0.41	1.2	Good	Immature		Gas potential
9	Ezeaku	0.76	432	0.6	0.4	Fair	Mature		Gas
10	Ezeaku	0.57	448	0.92	0.28	Fair	Mature		Gas
11	Asu River	0.31	464	1.2	0.03	Poor	Mature		Gas
12	Asu River	0.16	440	0.77	0.05	Poor	Mature	100%	Gas
13	Asu River	0.22	441	0.79	0.06	Poor	Mature		Gas

Source Rock Characterization of Abakaliki Bain (Cont'd)



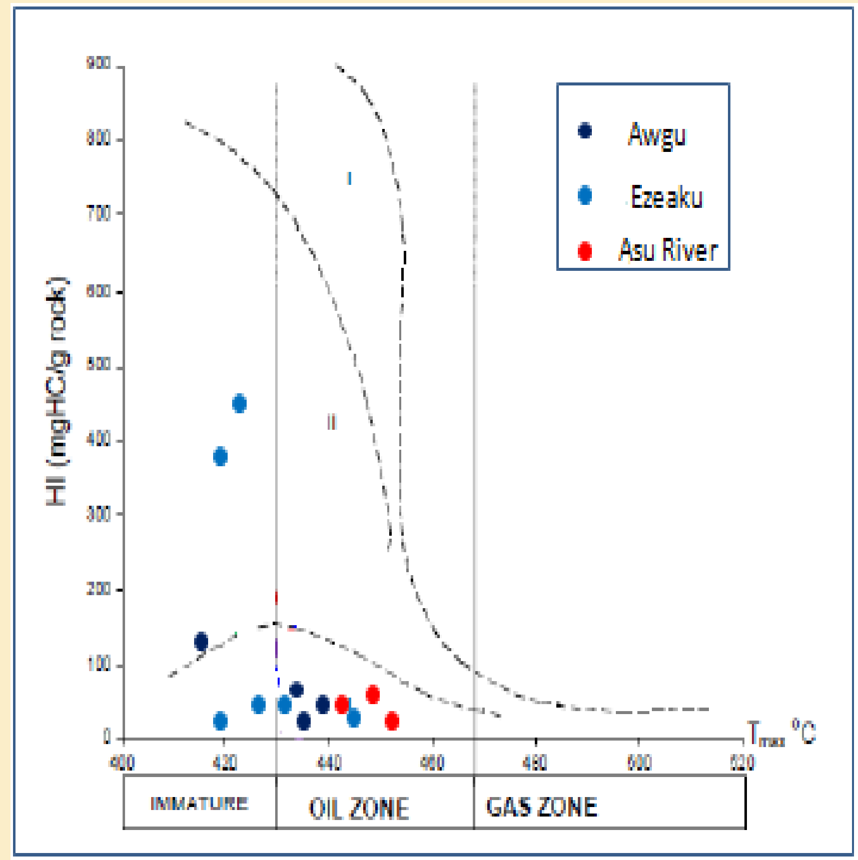


Figure 6: Hydrocarbon yield curve for source rock in Abakaliki Basin (After Salufu and Ogunkunle, 2015)

Figure 7: Kerogen type curve for source rock in Abakaliki Basin (After Bakin, 1999)

Source Rock Characterization of Anambra Basin

Table 5: Interpreted result of Rock-Eval Pyrolyiss for shale samples Anambra Basin

S/N	Formations	TOC (wt%)	Tmax (°C)	%VRo	S_1+ S_2	Source Rock	Maturity	%Maturity	Hydrocarbon yield
1	Ogwashi	1.64	422	0.45	0.64	Good	Immature	0%	Gas potential
2	Ogwashi	1.76	414	0.30	0.21	Good	Immature		Gas potential
3	Ameki	1.55	410	0.23	0.18	Good	Immature	0%	Gas potential
4	Ameki	1.5	416	0.34	0.69	Good	Immature		Gas potential
5	Imo	1.6	420	0.41	0.27	Good	Immature	0%	Gas potential
6	Imo	1.5	426	0.52	0.56	Good	Immature		Gas potential
7	Nsukka	0.5	421	0.42	0.24	Fair	Immature		Gas potential
8	Nsukka	0.85	430	0.58	0.29	Fair	Immature	40%	Gas potential
9	Nsukka	1.6	430	0.58	0.81	Good	Immature		Gas potential
10	Nsukka	1.05	432	0.62	0.78	Good	Mature		Gas
11	Nsukka	18.67	431	0.6	18.68	Excellent	Mature		Oil
12	Mamu	5.08	432	0.6	10.10	Excellent	Mature		Oil
13	Mamu	1.45	432	0.62	153.09	Good	Mature		Oil
14	Mamu	4.73	433	0.63	11.9	Excellent	Mature	100%	Oil
15	Mamu	6.1	432	0.62	11.89	Excellent	Mature		Oil
16	Mamu	3.79	433	0.63	2.40	V. good	Mature		Gas
17	Enugu	2.04	425	0.49	0.17	Good	Immature		Gas potential
18	Enugu	0.74	428	0.54	1.25	Fair	Immature		Gas potential
19	Enugu	2.34	434	0.65	1.34	V. good	Mature	25%	Gas
20	Enugu	2.95	427	0.53	1.36	V. good	Immature		Gas potential
21	Nkporo	3.21	434	0.65	3.57	V. good	Mature		Oil
22	Nkporo	0.97	439	0.74	0.10	Fair	Mature		Gas
23	Nkporo	2.29	424	0.47	1.21	V. good	Immature	60%	Gas potential
24	Nkporo	1.07	425	0.49	1.13	Good	Immature		Gas potential
25	Nkporo	5.75	432	0.62	19.39	Excllent	Mature		Oil

Source Rock Characterization of Anambra Basin Continuous

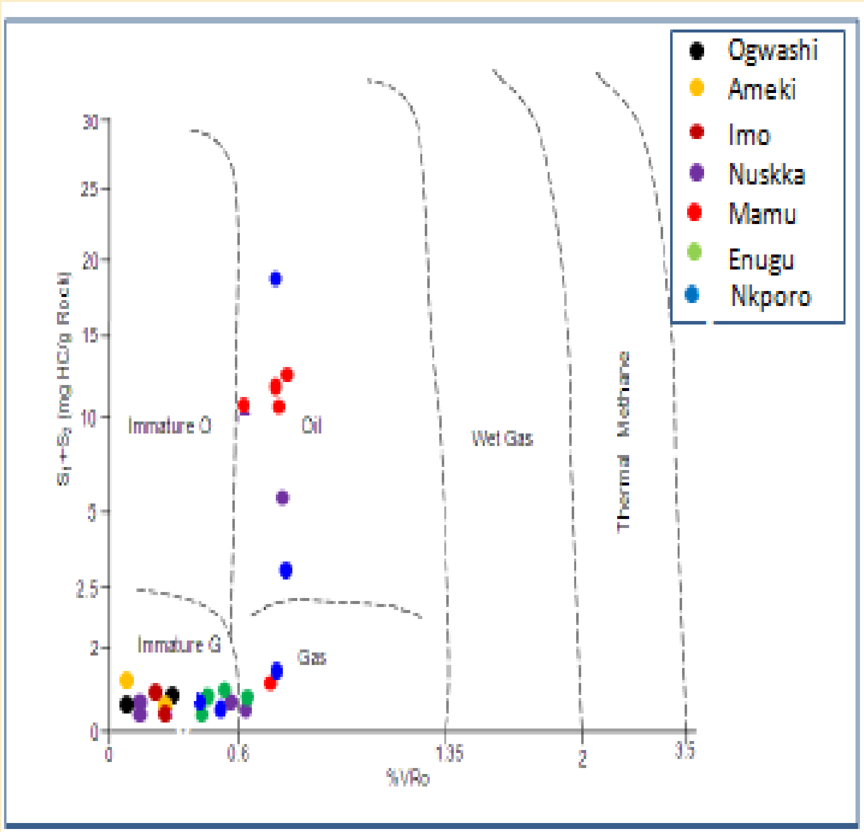


Figure8: Hydrocarbon yield curve for source rock in Anambra Basin (After Salufu and Ogunkunle, 2015)

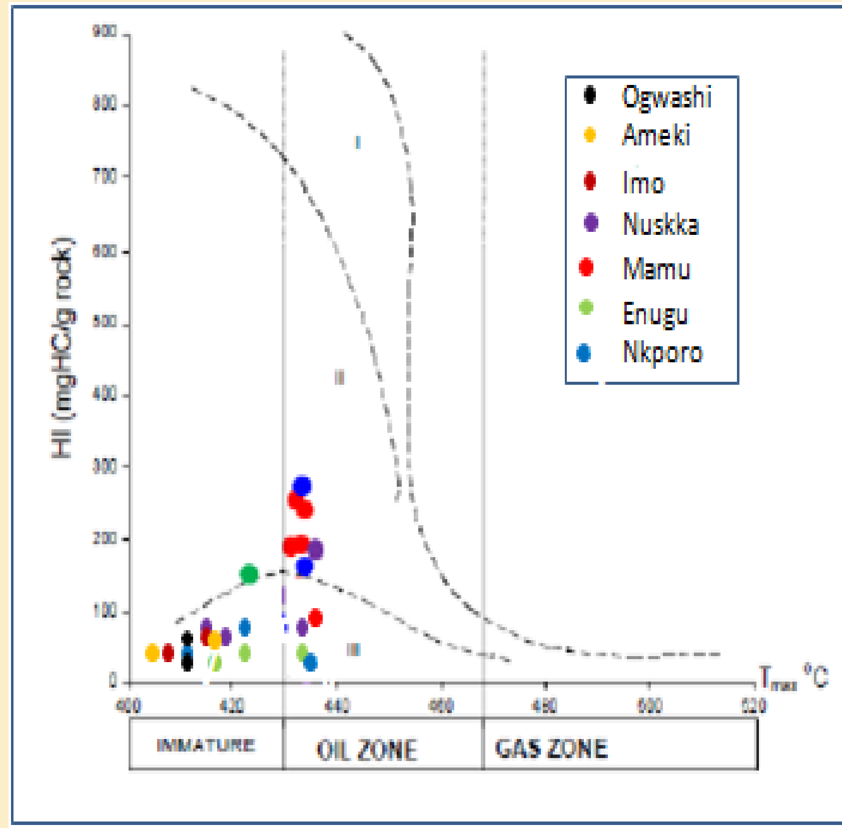


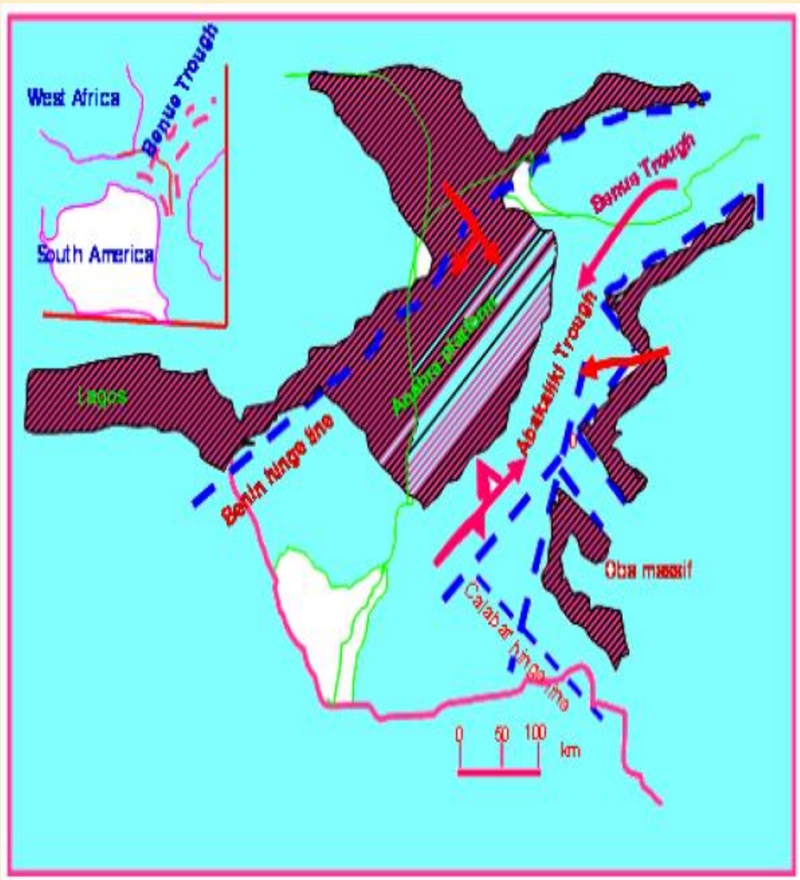
Figure 9: Kerogen type curve for source rock in Anambra Basin (After Bakin, 1999)

Reservoir Characterization and Traps

Table 5: Interpreted Petrographical Result of formations in Abakaliki and Anambra Basins

Formations	Q (%)	F (%)	Rf (%)	Reservoir Quality
Ajali	95.5	1.5	4	Quartz Arenite - Good
Ajali	95	1.7	3.2	Quartz Arenite - Good
Ajali	93	2.9	4	Quartz Arenite - Good
Mamu	95	1.00	4.00	Quartz Arenite - Good
Mamu	94.5	1.5	5.00	Quartz Arenite - Good
Mamu	96	1	2.9	Quartz Arenite - Good
Nkporo	96	1	2.9	Quartz Arenite - Good
Nkporo	95.5	1.1	3.3	Quartz Arenite - Good
Nkporo	94.5	2.1	3.8	Quartz Arenite - Good
Awgu	80	2.9	17	Arenite - Poor
Awgu	81	1.9	17	Arenite - Fair
Eze-aku	80	19	0.9	Arenite -Fair
Eze-aku	80	2.9	17	Arenite -Fair
Eze-aku	81	2.9	16	Wacke - Poor
Asu River	58.2	25.7	17	Wacke - Poor
Asu River	24.5	59.4	16	Wacke - Poor

Model for Hydrocarbon Maturation in Abakaliki and Anambra Bains



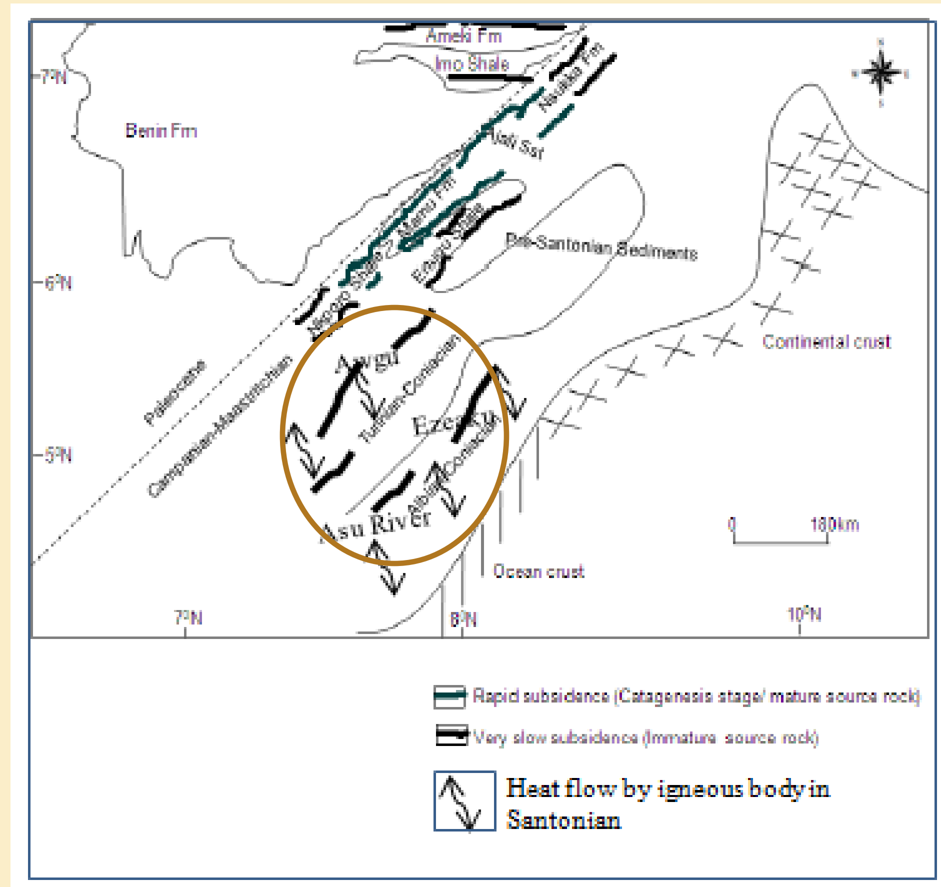


Figure. 10 : Model for hydrocarbon Maturation in Abakaliki and Anambra Basins

Conclusion & Recommendation

- This study has shown that there are indications for oil and gas generation from the source rocks in the Anambra Basin while only gas can be generated from the source rocks within Abakaliki Basin.
- Hydrocarbon maturation in the Abakaliki Basin was by burial and heat flow while rapid subsidence caused hydrocarbon maturation in the Anambra Basin.
- The good reservoir quality associated with Anambra basin is as a result of second cycle sediments.
- The presence of localized structures (faults and folds) within the Anambra Basin and regional faults and folds by Santonian tectonism within Abakaliki Basin gives evidence of structural traps occurrence within the two basins respectively , to trap hydrocarbon that must have been generated from the source rocks in the two basins.
- Effort should be geared toward identifying these traps at deep depth in order to effectively explore for the hydrocarbons within these basins using sophisticated 2D and 3D seismic.