Analyzing Sedimentary Rocks to Determine Hydrodynamic Conditions of Anambra Basin, South-Eastern Nigeria.

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Abstract

The Anambra Basin, situated in southeastern Nigeria, stands out as a significant sedimentary basin characterized by its intricate and multifaceted geological history. This complexity arises from a combination of marine, fluvial, and deltaic processes that have shaped the basin over geological time. Our study is dedicated to examining the sedimentary rock formations within this basin, with a particular focus on key units: the Nkporo, Mamu, Ajali, and Nsukka Formations. The primary aim is to reconstruct past hydrodynamic conditions and sediment transport mechanisms that influenced sediment deposition and distribution in the basin. Through a detailed analysis that incorporates both field observations and quantitative methods, we have estimated crucial paleohydrodynamic parameters. These include channel depth, bedform height, sediment transport modes, and flow velocities. By evaluating these parameters, we gain insights into the ancient environmental conditions and sedimentary processes that prevailed during the deposition of these formations. Our findings reveal a wide array of depositional environments within the Anambra Basin. The Nsukka Formation is associated with transitional flow conditions characterized by moderate sediment suspension. This indicates that the depositional environment experienced a balance between sediment being carried by the flow and sediment settling out of suspension. In contrast, the Ajali Formation is marked by a stable environment where sediment transport was predominantly in the form of bed load, suggesting a more consistent and less turbulent flow regime. The Mamu Formation is indicative of highly dynamic and turbulent flow conditions. This environment facilitated both bed load and suspended sediment transport, reflecting a setting with strong currents and significant sediment mobilization. Additionally, the Owelli Sandstone Formation displays transitional flow characteristics that point towards a coastal or shallow marine environment, where sediment transport and deposition were influenced by interactions between marine and continental processes. Overall, this study significantly contributes to our understanding of sedimentary processes within the Anambra Basin. By reconstructing past hydrodynamic conditions and sediment transport mechanisms, the research not only enhances our knowledge of the basin's geological history but also provides valuable insights into the broader sedimentary dynamics at play. This comprehensive analysis offers a foundation for future research and exploration, highlighting the intricate interplay between geological processes and sedimentary environments in the Anambra Basin

Keywords: Hydrodynamic conditions, Sedimentary Rocks, Anambra Basin, Paleohydraulic Parameters, Depositional Environments.

1. INTRODUCTION

The Anambra Basin, situated in southeastern Nigeria, is a significant sedimentary basin that has been the focus of various geological studies due to its rich and diverse sedimentological history. Covering approximately 40,000 square kilometers, the basin has a complex geological evolution influenced by its intracratonic setting and the tectonic activities associated with the Late Cretaceous period. This region is bounded by major geological structures such as the Benue Trough, the Abakaliki Anticlinorium, and the Niger Delta Basin (Reijers, 1996). The sedimentary fill of the Anambra Basin reflects a dynamic history of marine transgressions, regressions, fluvial processes, and deltaic depositional environments, making it an intriguing subject for sedimentological and hydrodynamic analysis.

This study aims to analyze the sedimentary rocks within the Anambra Basin to determine the hydrodynamic conditions that influenced sediment deposition throughout its geological history. By examining key formations such as the Nkporo Formation, Mamu Formation, Ajali Sandstone, and Nsukka Formation, this research seeks to reconstruct past hydrodynamic environments and sediment transport processes. These formations represent a range of depositional settings from shallow marine to deltaic and fluvial environments, each with unique sedimentary structures and characteristics.

Understanding the sedimentological and hydrodynamic dynamics of the Anambra Basin is crucial for several reasons. Firstly, it provides insights into the historical changes in sedimentary environments that have shaped the basin's geological framework. Secondly, it helps in reconstructing past river systems, which is essential for petroleum exploration, as these systems often act as significant hydrocarbon reservoirs. Lastly, the hydrodynamic analysis contributes to broader geological and geomorphological studies, enhancing our knowledge of sediment transport mechanisms and depositional processes in ancient riverine and deltaic systems.

In this article, we will discuss the methodology used for field observations and data collection, including sedimentological analysis and hydrodynamic parameter estimation. By employing empirical formulae and sedimentological data, we aim to provide a comprehensive evaluation of the paleohydrodynamic conditions within the Anambra Basin. This analysis will offer valuable insights into the sediment transport dynamics and depositional environments of the region, contributing to the broader understanding of its geological history and sedimentary processes.

2. THE STUDY AREA LOCATION, STRATIGRAPHY AND SEDIMENTOLOGY

The Anambra Basin is a prominent sedimentary basin located in southeastern Nigeria, covering approximately 40,000 square kilometers. It is an intracratonic basin that developed during the Late Cretaceous period and is bounded by the Benue Trough to the north, the Abakaliki Anticlinorium to the east, the Niger Delta Basin to the south, and the West African Craton to the west (Reijers, 1996). The basin's geological history is closely linked to the tectonic evolution of the Benue Trough and the Niger Delta.

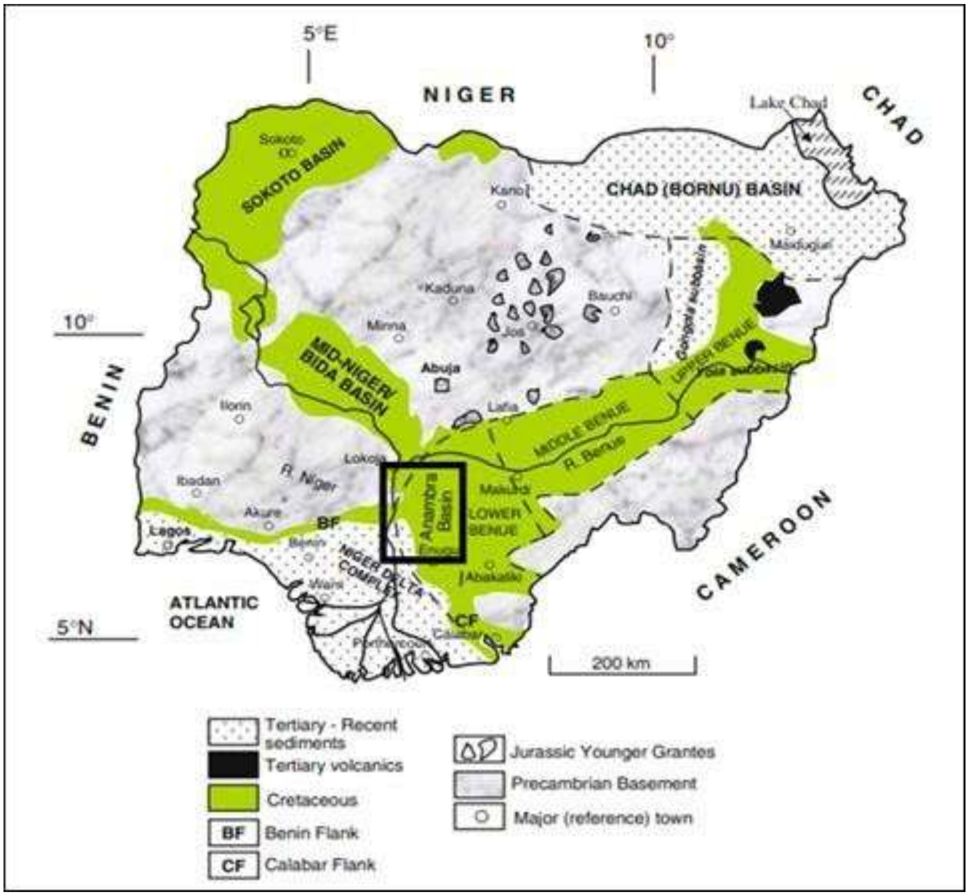

Figure 1. Map of Nigeria Showing the Location of Anambra Basin(After NGSA, 2001)

Geological Setting

The formation of the Anambra Basin is attributed to the Santonian tectonic event, which caused significant uplift and folding of the Abakaliki Anticlinorium, leading to the subsidence of the adjacent areas and the creation of the Anambra Basin. The basin's sedimentary fill records a complex history of marine transgressions and regressions, fluvial processes, and deltaic deposition (Murat, 1972).

Stratigraphy

The stratigraphy of the Anambra Basin comprises several key formations, each representing different depositional environments and geological periods:

Nkporo Formation (Campanian-Maastrichtian):

The Nkporo Formation is the oldest stratigraphic unit in the Anambra Basin, consisting primarily of dark shales, mudstones, and siltstones, with occasional interbeds of sandstone. This formation represents a transgressive marine sequence, indicating deposition in a shallow marine environment. The shales are often rich in organic matter, making them potential source rocks for hydrocarbons (Reyment, 1965).

Mamu Formation (Maastrichtian):

Overlying the Nkporo Formation, the Mamu Formation is characterized by alternating beds of sandstone, shale, and coal. The sandstones are typically fine to medium-grained and exhibit sedimentary structures such as cross-bedding and ripple marks, indicative of deposition in fluvial to deltaic environments. The presence of coal seams suggests swampy conditions with abundant vegetation during periods of low energy (Simpson, 1954).

Ajali Sandstone (Maastrichtian):

The Ajali Sandstone is a prominent and laterally extensive formation, composed of well-sorted, coarse-grained sandstones with high-angle cross-bedding. This formation represents high-energy fluvial and shallow marine environments, likely influenced by tidal currents. The sandstones are typically quartzose, indicating a high degree of mineralogical maturity (Nwajide, 2013).

Nsukka Formation (Maastrichtian-Paleocene):

The Nsukka Formation consists of fine to medium-grained sandstones, shales, and coal beds. The presence of coal beds suggests deposition in swampy, deltaic environments with periodic marine incursions. The sandstones often exhibit sedimentary structures such as planar and trough cross-bedding, indicative of fluvial processes (Akaegbobi & Schmitt, 1998).

Sedimentary Structures and Depositional Environments

The Anambra Basin exhibits a variety of sedimentary structures that provide insights into the depositional processes and paleoenvironments. These structures include:

- Cross-bedding: Indicative of high-energy fluvial and tidal environments, commonly observed in the Ajali Sandstone and Mamu Formation.
- Ripple marks: Suggestive of shallow marine and fluvial settings, found in the sandstones of the Mamu Formation and Nsukka Formation.
- Mud cracks: Indicative of periodic exposure and desiccation in a deltaic environment, often observed in the shales and mudstones of the Nkporo Formation and Nsukka Formation.

- Bioturbation: Evidence of biological activity, indicating relatively low-energy environments with sufficient oxygenation, commonly found in the shales of the Imo Shale and Ameki Formation.

Depositional Environments

The depositional environments of the Anambra Basin range from shallow marine to deltaic and fluvial settings:

- Shallow Marine Environments: Represented by the Nkporo Formation, Imo Shale, and parts of the Ameki Formation, characterized by low-energy conditions and the presence of fine-grained sediments.
- Deltaic Environments: Dominant in the Mamu Formation and Nsukka Formation, with alternating beds of sandstone, shale, and coal, indicating dynamic fluvial processes and swampy conditions.
- Fluvial Environments: Evident in the Ajali Sandstone, characterized by well-sorted, coarse-grained sandstones with high-angle cross-bedding, indicative of high-energy river channels and tidal influences.

3. METHODOLOGY

Field Observations and Basic Data Collection

Sedimentological data were collected from eight locations, each featuring vertical sections ranging from 5 to 10 meters, primarily observed along road-cut exposures across the four study areas. At each outcrop, multiple measurements were taken, including set thickness, average grain size, and total thickness. Cross-bed set thicknesses were specifically measured using a 30 cm scale. The cross-bedding sets in the study area were interpreted predominantly as dunes based on several observations: the cross-bedding sets exhibit truncation, the paleocurrent directions display significantly less variability than typically seen in bar formations, even when bars are present within the data, they generally consist of numerous layers of truncated dunes, all observed ripples on the outcrops flowed in the same direction as the cross-bedding sets, rather than in divergent directions.

To ensure thoroughness, each outcrop was meticulously examined, and data were systematically recorded to provide a comprehensive understanding of the sedimentological characteristics and depositional environments of the study area.

Cross-Set Measurements and Grain Size Analysis

Cross-set heights were measured to reconstruct the original bedform heights and formative flow depths. Both trough and planar cross-bedding, indicative of bed load transport, were observed at nearly all field sites. These structures were predominantly found in sand-grade deposits but were also present in the pebble-grade deposits of Owelli Sandstones. To establish mean cross-set heights, the sampling strategy outlined by Harms et al. (1982) was followed.

Grain sizes were measured at each outcrop using a standard 10x hand lens and a grain size card. Grains were classified according to the Udden-Wentworth grain size scale. Grains within each set were generally unimodal or largely represented by a single size, facilitating the determination of the average size within cross-bedding sets. This average size was used as a proxy for D50, representing the median grain size distribution.

The sedimentological data collected from the outcrop exposures included grain size, cross-bedding height, and bar-form height. These data were subsequently used to determine multiple channel geometry, paleohydraulic parameters, and paleo-dynamics, including mean bedform height, channel depth and width, channel belt width, paleoslope, boundary shear stress, Darcy-Weisbach friction factor, paleoflow velocity, paleodrainage, and overall drainage area, following the methodologies outlined by Rubin and McCulloch (1980).

Quantitative Paleo-hydrodynamic Formulae

The Paleo-Channel Depth (Dc) and Bedform Height (Hm)

The paleo-channel depth (Dc) and bedform height (Hm) – such as cross set thickness - are crucial parameters in understanding the flow dynamics of ancient river systems. The bedform height (Hm) can be estimated from the mean cross-set thickness (Sm) using the empirical relationship given by Leclair and Bridge (2001):

$$Hm = 2.90 \times 0.70 \times Sm \qquad 3.5$$

Hm is the mean dune height; Sm is the mean cross-set thickness. The mean dune height (Hm) is typically 8 to 10 times the mean cross-set thickness (Sm). The channel depth (Dc) can be estimated from the bedform height (Hm) using the empirical relationship:

$$Dc = 11.6 \times Hm^{0.8} \qquad 3.6$$

The paleo-channel flow depth (Dc) can also be estimated from the thickness of lateral macroforms using the equation:

$Dc = D*/0.9$ 3.7

where D∗ is the maximum channel bankfull flow depth, which is represented by the thickness of the sandstone macroform.The empirical equation above is prefereed in this work.

3.5.2 Paleo-Channel Slope

Paleo-channel slope (Sc) is an important parameter in reconstructing the paleoenvironmental conditions of ancient river systems. Slope affects river plan form and facies boundaries, and paleoslope can be calculated using physics-based methods or empirical equations.
One empirical equation used to estimate paleoslope is:

$Sc = \tau bf50 \ RD50 / Dc$ 3.8

where Sc is the paleoslope, τbf50 is the bankfull Shields number for dimensionless shear stress, Dc is the mean bankfull channel flow depth, R is the submerged dimensionless density of sand-gravel sediment, ρs is the grain density, ρw is the fluid density, and D50 is the median grain size.
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3.5.3 Boundary Shear Stress and Critical Shear Stress in Open Channels

The boundary shear stress (τb) is a critical parameter in understanding the dynamics of sediment transport and the movement of bed materials in open channels. The boundary shear stress can be calculated using the following equation:

$\tau b = \rho gDcSc$ 3.9

where τb is the boundary shear stress, ρ is the fluid density, g is the gravitational acceleration, Dc is the averaged channel flow depth, and Sc is the averaged water-surface paleoslope. Both field and laboratory experiments have shown that initial motion of bed materials in coarse-medium grained rivers typically occurs at a transport stage that is moderate (Andrews, 1984). This relationship between the flow and its container can be applied to all natural channels with some error and has been recently applied in ancient fluvial deposit (Ninke, 2002)

3.5.4 Critical Shear Stress

The critical shear stress (τcr) represents the necessary boundary shear to move the bed-load materials, based upon their grain size, grain shape, effective density, and roughness. For non-cohesive sand, the critical shear stress can be calculated using the equation provided by Shield (1939) as follows:

$$tcr = \tau*(\rho s - \rho w) \qquad 3.10$$

where τcr is the critical shear stress, τ∗ is the Shield number for the given particle, ρs is the grain density (assumed to be quartz with a density of 2650 kg/cm^3), ρw is the fluid density (1000 kg/m^3), g is the acceleration due to gravity in m/sec^2, and D50 is the median particle size in meters.

Sediment mobility for a given particle size occurs when the boundary shear stress exceeds the critical shear stress, i.e.

$\tau b > \tau cr$.

This relationship has been observed in the Ajali sandstones of the present study.

3.5.5 Paleoflow Velocity in Open Channels

Paleoflow velocity is the velocity of the ancient sediment flows that occurred in a specific region or basin. Paleoflow velocity (Vc) is a critical parameter in understanding the dynamics of sediment transport and the movement of bed materials in open channels. Two methods are commonly used to compute the threshold mean velocity (Vc): the Manning roughness coefficient (n) and the Darcy-Weisbach friction factor (f).

Manning Roughness Coefficient

The Manning roughness coefficient (n) is used to compute the threshold mean velocity (Vc) as follows:

$$Vc = R^{0.67}\ Sc^{\ 0.50}\ n \qquad 3.11$$

Where

Vc is the paleoflow velocity, R is the hydraulic radius, Sc is the channel slope, and n is the Manning roughness coefficient.

3.5.6 Darcy-Weisbach Friction Factor

The Darcy-Weisbach friction factor (f) is used to compute the threshold mean velocity (Vt) as follows:

$$Vc = (8gR(Sc/f))^{0.50} \qquad 3.12$$

Where Vc is the paleoflow velocity, g is the gravitational acceleration, R is the hydraulic radius, Sc is the channel slope, and f is the Darcy-Weisbach friction factor. Unlike the Manning empirical equation, the Darcy-Weisbach equation uses a dimensionless friction factor, has a sound theoretical basis, and exact accounts for the acceleration from gravity; moreover, the relative bed roughness does not influence the exponents of hydraulic radius and channel slope. For these reasons, the DarcyWeisbach equation is preferred over the Manning approach as discussed by Kleinhans (2005).

3.5.7 Rouse Number (Z) for Sediment Transport

The Rouse number (Z) is a non-dimensional scale parameter used to determine the dominant mode of sediment transport. It is calculated as:

$$Z = Ws / \beta \kappa U_* \qquad 3.13$$

where β is a constant (taken as 1), κ is the von Karman constant (taken as 0.40), U_* is the boundary shear velocity, and Ws is the sediment settling velocity. Rouse Number and Sediment Transport. The Rouse number (Z) is used to determine the dominant mode of sediment transport. For $Z > 2.5$, the dominant mode is typically bed load, while for $1.2 < Z < 2.5$, it is 50% suspended load (mixed load).

3.5.8 Sediment Settling Velocity

The sediment settling velocity (Ws) is calculated as a function of grain size according to Ferguson (2004) as:

$$Ws = Rg(D50)^2 / C1v + (0.75C2Rg(D50)^3)^2 \qquad 3.14$$

where g is the Earth's gravitational acceleration, D50 is the median diameter of a particle, v is the kinematic viscosity of water, v is the kinematic viscosity of water (110^{-6} for water at 20^{o} C and C1 = 18 and C2 = 1 are constants associated with grain sphericity and roundness.

3.5.9 Boundary Shear Velocity

The boundary shear velocity (U) is determined as:

$$U_* = \sqrt{\tau b} / \rho w \qquad 3.15$$

where τb is the boundary shear of the fluid and ρw is the mass density of the fluid.

3.5.10 Reynolds Particle Number (Rep)

The Reynolds particle number (Rep) is a dimensionless number used to collaborate inferred sediment transport modes. It is calculated as:

$$Rep = \sqrt{RgD50}D50/v \qquad 3.16$$

where R is the hydraulic radius, g is the gravitational acceleration, D50 is the median diameter of a particle, and v is the kinematic viscosity of water.

The Reynolds Particle Number (Rep) can take on a wide range of values depending on the specific conditions of the fluid flow and the particle being studied. Here are some general ranges of values for Rep:

- **Low Reynolds Numbers**: Typically below 10, indicating laminar flow. This range is often associated with smooth, predictable flow patterns.
- **Transition Region**: Between 10 and 2000, indicating the onset of turbulence. This range is characterized by a transition from laminar to turbulent flow.

- **High Reynolds Numbers**: Typically above 2000, indicating fully turbulent flow. This range is often associated with chaotic and unpredictable flow patterns

3.5.11 Froude Number (Fr)

The Froude number (Fr) is a dimensionless parameter that describes different flow regimes in open channel flows. It is a ratio of inertial and gravitational forces. The Froude number (Fr) is a ratio of the inertial force (proportional to the square of the velocity) to the gravitational force (proportional to the depth). When the Froude number is greater than unity, the flow is supercritical, and when it is less than unity, the flow is subcritical.

The Froude number (Fr) is calculated as:

Fr = gDcVc 3.17

where:

Vc is the water flow velocity, Dc is the bankfull channel depth, g is the acceleration due to gravity (approximately half of the present during Permian times, i.e., 4.9 m/sec^2).

The range of values for the Froude number indicates the type of flow:

- **Subcritical Flow**: $<1 Fr<1$
  - Gravitational forces dominate.
  - Flow is slow and tranquil.
  - Both upstream and downstream disturbances propagate.
  - Examples: rivers, lakes, and slow-moving streams.
- **Critical Flow**: $Fr=1$
  - Inertial and gravitational forces are balanced.
  - Flow is unstable and often sets up standing waves.
  - Examples: hydraulic jumps, where the flow transitions from subcritical to supercritical.
- **Supercritical Flow**: $Fr>1$
  - Inertial forces dominate.
  - Flow is fast and rapid.
  - Disturbances are transmitted downstream.

- Examples: rapids, waterfalls, and fast-moving streams

4. RESULTS:

Quantitative Results to Paleohydrodynamic Conditions

Table 1. Results of Paleohydrodynamic Conditions Based on Empirical Formulae

	Mean crossbed thickness(m)	Mean particle size(D50)	Bedform height (Hm)	Flow depth (Hm)	Channel slope	Average Velocity	Manning Constant	Sediment Setling Velocity	Boundary shear stress	Rouse number	Reynolds Particle Number (Rep)	Froude Number (Fr)
Nsukka FM	0.47	0.75	1.36	15.05	0.15	0.55	0.04	17.37	11.28	3.85	953.71	18.22
Ajali FM	0.62	0.68	1.80	18.99	0.11	0.46	0.04	25.69	10.23	6.28	864.70	19.49
Mamu Fm	0.41	0.83	1.19	13.42	0.19	0.61	0.04	11.58	12.48	2.32	1055.44	18.10
Owelli SSt	0.52	0.69	1.51	16.38	0.13	0.50	0.04	24.24	10.38	5.84	877.41	18.23

Table 2. Interpretation of Hydrodynamic Results Based On Empirical Formulae

Formation	Flow Depth (m)	Channel Slope	Average Velocity (m/s)	Rouse Number (Z)	Reynolds Particle Number (Rep)	Froude Number (Fr)	Transport Type	Flow Regime	Likely Environment of Deposition
Nsukka	15.05	0.15	0.55	3.85	953.71	18.09	Bed load transport with some suspension	Transitional	Fluvial or deltaic
Ajali	18.99	0.11	0.46	6.28	864.69	18.97	Predominantly bed load transport	Transitional	Fluvial or shallow marine
Mamu	13.42	0.19	0.61	2.33	1055.44	19.49	Bed load transport with some/incipient suspension	More turbulent	Fluvial or fluvio-deltaic
Owelli Sandstone	16.38	0.13	0.50	5.84	877.41	18.89	Predominantly bed load transport	Transitional	Coastal or shallow marine

The Nsukka Formation features a flow depth of 15.05 meters and a channel slope of 0.15, which indicates moderate hydrodynamic conditions. The average flow velocity of 0.55 meters per second suggests a transitional flow regime, where sediment transport is influenced by both bed load and suspended sediment. According to the Rouse number of 3.85, sediment transport involves some degree of suspension, though bed load transport remains predominant (Rouse, 1937). The Reynolds particle number of 953.71 and a Froude number of 18.09 further indicate that the flow conditions are consistent with a fluvial or deltaic environment, where varying energy levels support both bed load and suspended sediment transport (Leopold & Maddock, 1953; Einstein, 1950).

The Ajali Formation is characterized by a greater flow depth of 18.99 meters and a channel slope of 0.11, combined with a lower average velocity of 0.46 meters per second. This suggests a transitional flow regime with predominantly bed load transport and minimal suspension (Graf, 1971). The Rouse number of 6.28 supports this observation, indicating that sediment suspension is limited (Rouse, 1937). With a Reynolds particle number of 864.69 and a Froude number of 18.97, the conditions are indicative of a fluvial or shallow marine environment where bed load transport is dominant (Chien & Wan, 1999; Knighton, 1998).

The Mamu Formation exhibits a flow depth of 13.42 meters and a channel slope of 0.19, which suggests a more turbulent environment. The higher average velocity of 0.61 meters per second, along with a Rouse number of 2.33, indicates that sediment transport includes both bed load and incipient suspension (Ackers & White, 1973). The Reynolds particle number of 1055.44 and a Froude number of 19.49 suggest dynamic flow conditions that enhance sediment suspension (Simons & Richardson, 1966; Lane, 1955). This turbulent flow regime is typical of a fluvial or fluvio-deltaic environment where increased velocity and slope contribute to higher sediment suspension potential.

The Owelli Sandstone Formation features a flow depth of 16.38 meters and a channel slope of 0.13, with an average velocity of 0.50 meters per second. This transitional flow regime suggests that sediment transport is predominantly along the bed with some potential for suspension (Williams, 1980). The Rouse number of 5.84 indicates that while bed load transport is predominant, there is some level of sediment suspension (Rouse, 1937). The Reynolds particle number of 877.41 and a Froude number of 18.89 are consistent with a coastal or shallow marine environment where bed load transport is the primary mechanism, but varying flow conditions can influence sediment suspension (McLean, 1981; Allen, 1984).

These formations reveal distinct characteristics that highlight the variability in sediment transport and depositional environments. The Nsukka and Owelli Sandstone formations both exhibit transitional flow regimes with significant bed load transport, but the Nsukka Formation shows a greater potential for sediment suspension. The Ajali Formation, with its lower velocity and higher Rouse number, shows predominantly bed load transport and a more stable flow regime. The Mamu Formation, with its higher velocity and more turbulent conditions, suggests a dynamic environment where both bed load and suspended sediment transport are important.

Overall, the variations in flow depth, velocity, and sediment transport mechanisms across these formations underscore the diversity of depositional environments represented. This data enhances our understanding of how sediment transport and deposition are influenced by flow conditions and provides insights into the geological history and sedimentary processes of these regions. The differences in flow dynamics and sediment transport characteristics support interpretations of fluvial, deltaic, and marine environments, each with unique sedimentary processes.

CONCLUSION

The examination of hydrodynamics and sedimentary rocks within the Anambra Basin offers a comprehensive understanding of the region's ancient environmental conditions and geological evolution. By meticulously analyzing paleohydraulic parameters, researchers can reconstruct past flow dynamics and sediment transport processes that played a crucial role in shaping the basin's sedimentary framework. This detailed insight into the historical water flow and sediment deposition patterns enhances our grasp of how the geological features of the Anambra Basin were formed.

Additionally, this research has broader implications for predicting future sedimentary processes and resource distribution in the region. Understanding the interplay between hydrodynamic forces and sedimentary deposition can inform models that forecast how similar environments might evolve under different conditions. Such knowledge is invaluable for geological surveys, resource exploration, and environmental management strategies. Overall, this study not only enriches our geological knowledge of the Anambra Basin but also provides a foundation for future research and practical applications in sedimentology and basin analysis.

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