



Geological Mapping, Petrographic Characteristics and Grain-Size Analysis of Sandstone in Inachi, Lower Benue Trough, Nigeria

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KEYWORDS

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ABSTRACT

Geological mapping, petrographic examination and grain-size analysis were undertaken to characterise sedimentary rocks in Inachi, Lower Benue Trough, Nigeria, and assess their depositional and groundwater implications. Mapping covered approximately 20 km² within Otukpo Sheet 270SW, supported by thin-section examination and sieve analysis of three sandstone samples. Shale and sandstone were the principal lithologies. Fractures showed a dominant NW–SE orientation, while sandstone beds dipped 4–8° and ranged from 0.2 to 2.3 m in thickness. Reported petrographic estimates comprised 52–60% quartz, 30–35% feldspar and 5–18% accessory constituents; uncertainty in these estimates was not quantified. Grain-size statistics recalculated from previously recorded percentiles, rather than new measurements, yielded mean sizes of 2.567–2.800 ϕ and sorting values of 0.458–0.598 ϕ . The sandstone samples were fine-grained, with two classified as well sorted and one as moderately well sorted. Skewness ranged from 0.029 to 0.331 and kurtosis from 1.393 to 1.475, indicating nearly symmetrical to strongly fine-skewed, leptokurtic distributions. Contrasting fluvial and beach signatures from existing discrimination plots leave the depositional environment unresolved; a transitional setting remains a tentative interpretation. Local shallow groundwater abstraction indicates water occurrence, but seasonal well failure and the absence of direct petrophysical and hydraulic measurements prevent conclusions about aquifer productivity. The findings provide a preliminary geological baseline, with interpretations limited by the small sample set. Broader sampling, improved stratigraphic control and direct hydraulic testing are needed.

CITATION

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INTRODUCTION

Field mapping, petrography and grain-size analysis provide complementary evidence for characterising sedimentary rocks. Mapping establishes the distribution of lithologies and structures, while petrography documents mineral composition and grain relationships. Grain-size analysis quantifies sediment texture and supports depositional interpretation when considered alongside field evidence.

Together, these methods provide a geological baseline for investigating groundwater occurrence, although aquifer productivity requires direct hydraulic assessment. The Benue Trough is a major component of Nigeria's sedimentary framework. Its Cretaceous evolution involved continental extension associated with Atlantic opening, followed by deformation and sedimentation (Benkhelil, 1989; Obaje, 2009). Petrographic investigations of

Cretaceous sandstones in the Lower Benue Trough have documented carbonate cementation and diagenetic modification, demonstrating the importance of examining mineral relationships alongside sediment texture (Odigi & Amajor, 2008). In the neighbouring Anambra Basin, Tijani and Nton (2009) combined grain-size analysis with permeameter measurements to investigate the relationship between sandstone texture and hydraulic conductivity. These studies provide useful regional comparisons but do not establish the characteristics of individual sandstone exposures at Inachi.

At Inachi, sandstone and shale are exposed along drainage channels, road cuts and excavations, with vegetation and weathering restricting exposure elsewhere. The local relationship between lithological distribution, fracture orientation, sandstone mineral composition and grain-size characteristics requires clarification. In particular, it remains uncertain whether these observations consistently support a depositional interpretation and what they can establish about groundwater occurrence without direct hydraulic measurements.

This study therefore aims to characterise the exposed sedimentary rocks of Inachi through integrated field and laboratory observations. Its objectives are to describe the

principal lithologies and structural features, document sandstone mineral composition, quantify grain-size distributions and evaluate the depositional and groundwater implications within the limits of the available evidence.

MATERIALS AND METHODS

Study Area and Geological Setting

Inachi and its environs lie in Otukpo Local Government Area, Benue State, within the Lower Benue Trough. The mapped area occupies part of Otukpo Sheet 270SW, between latitudes 7°04'20"–7°06'32" N and longitudes 8°02'30"–8°05'16" E (Figure 1). Low-lying terrain and sandstone ridges characterise the landscape, which is drained by the Okpokwu River and its tributaries. Vegetation and weathered cover restrict outcrop continuity.

Sandstone and shale are the principal mapped lithologies. The original geological map identifies these as Otobi Sandstone, assigned to the Nkporo Formation, and Awgu Shale. These assignments are treated as provisional because independent age control and diagnostic stratigraphic evidence were not established. The units are therefore described primarily by lithology.

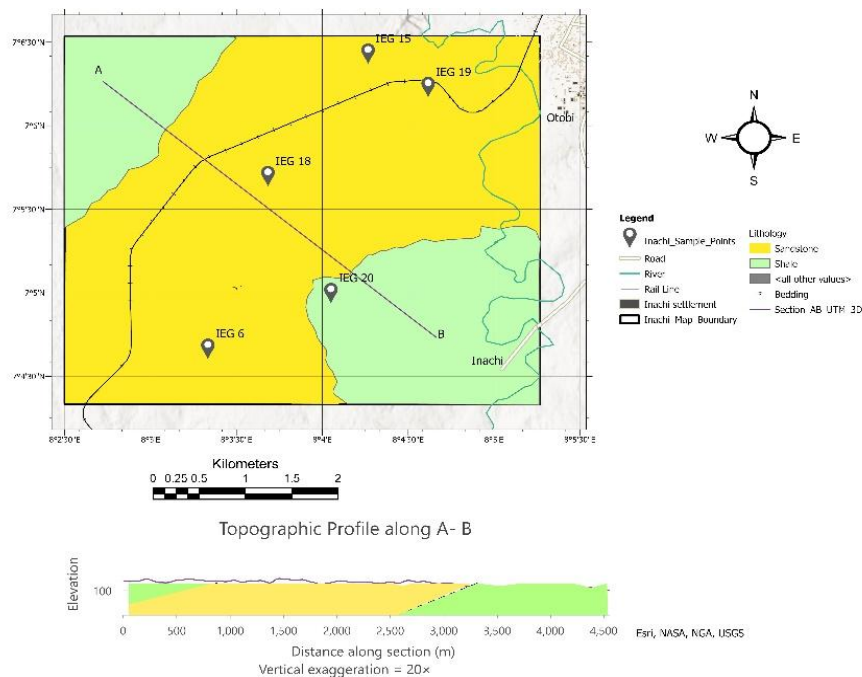


Figure 1: Geological map of Inachi and its environs showing lithological distribution, drainage, settlements and structural observations. Stratigraphic assignments in the original legend remain provisional

Field observations and sampling

Accessible exposures along stream channels, road cuts and excavations were examined for lithology, colour, grain size, bedding, weathering and structural features. Sandstone bed thickness and dip were recorded. Sixty-

seven fracture-orientation measurements were collected from accessible outcrops and grouped into six directional classes. The number of measurements varied between locations because limited exposure and possible

disturbance from road construction restricted suitable measurement surfaces. The photographed sandstone and shale outcrops occur at 7°05'58" N, 8°03'09" E and 7°04'56" N, 8°04'03" E, respectively, within the mapped boundaries. Selected rock samples underwent petrographic examination. Three sandstone samples—IEG 6, IEG 18 and IEG 19—were selected to represent the sandstone encountered at their

respective exposures and subjected to grain-size analysis. Their locations are shown in Figure 2. Sampling was guided by field observations and exposure accessibility rather than random selection. Consequently, the results characterise the sampled exposures, and the small sample set may not capture lithological and textural variability across the entire mapped area.

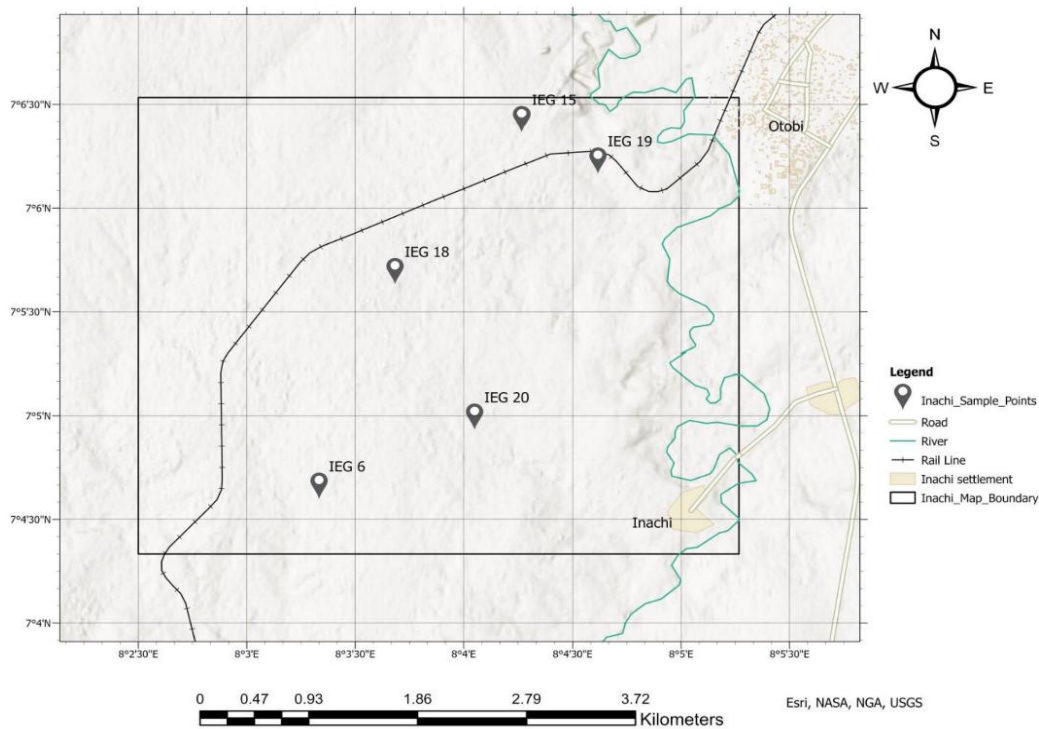


Figure 2: Locations of sandstone samples IEG 6, IEG 18 and IEG 19 used for grain-size analysis within the mapped area of Inachi

Petrographic Examination

Thin sections of sandstone samples IEG 15, IEG 18 and IEG 19 and shale sample IEG 20 were examined under plane-polarised and cross-polarised light to identify mineral constituents and describe grain relationships. Photomicrographs were recorded at a reported magnification of ×40. Mineral proportions were estimated visually from the thin sections; systematic point counting was not performed. The reported percentages are therefore approximate, with unquantified estimation uncertainty, and are used for descriptive comparison rather than quantitative provenance interpretation.

Grain-Size Analysis

Three sandstone samples—IEG 6, IEG 18 and IEG 19—were disaggregated, and a 200 g portion of each was mechanically sieved for 10 minutes. The sieve openings were 2.000, 1.000, 0.500, 0.250, 0.125 and 0.063 mm, with a collecting pan for material finer than 0.063 mm. Retained fractions were weighed to determine their mass distributions. Sample locations are shown in Figure 2. The sieve-analysis results for samples IEG 6, IEG 18 and IEG 19 are presented in Tables 1–3. Recovered masses were 173.4, 182.4 and 192.8 g, corresponding to recoveries of 86.7%, 91.2% and 96.4%, respectively. Grain-size terminology follows Wentworth (1922).

Table 1: Sieve-Analysis Results for Sandstone Sample IEG 6

S/N	Mesh size(mm)	Phi(ϕ)	Weight of sieve (g)	Weight of sieve +sample (g)	Retained weight	Corrected weight	% weight retained	% Weight cumulative
1	2	-1	399.3	400.0	0.7	0.783	0.4	0.40
2	1	0	408.0	408.3	0.3	0.335	0.17	0.58
3	0.5	1	359.7	360.4	0.7	0.783	0.40	0.98
4	0.25	2	352.5	360.0	7.5	8.385	4.33	5.31
5	0.125	3	329.0	446.2	117.2	135.179	67.59	72.90
6	0.063	4	320.6	366.5	45.9	52.941	26.47	99.37
7	<0.063	5	318.2	319.3	1.1	1.269	0.63	100
TOTAL					173.4	197.216	100%	

Initial mass: 200 g; recovered mass: 173.4 g; recovery: 86.7%; loss: 26.6 g (13.3%). Percentages and cumulative percentages were calculated before rounding.

Table 2: Sieve-Analysis Results for Sandstone Sample IEG 18

S/N	Mesh size(mm)	Phi(ϕ)	Weight of sieve (g)	Weight of sieve +sample (g)	Retained weight	Corrected weight	% weight retained	% Weight cumulative
1	2	-1	399.7	399.9	0.2	0.218	0.11	0.11
2	1	0	407.9	408.3	0.4	0.435	0.22	0.33
3	0.5	1	359.6	360.8	1.2	1.306	0.66	0.99
4	0.25	2	352.6	359.8	7.2	7.824	3.94	4.93
5	0.125	3	329.0	485.0	156.0	169.728	85.5	90.43
6	0.063	4	320.7	337.8	17.1	18.605	9.38	99.81
7	<0.063	5	318.2	318.5	0.3	0.16	0.16	99.97
TOTAL					182.4	198.442	99.97%	

Initial mass: 200 g; recovered mass: 182.4 g; recovery: 91.2%; loss: 17.6 g (8.8%). Percentage values are retained as recorded.

Table 3: Sieve-Analysis Results for Sandstone Sample IEG 19

S/N	Mesh size(mm)	Phi(ϕ)	Weight of sieve (g)	Weight of sieve +sample (g)	Retained weight	Corrected weight	% weight retained	% Weight cumulative
1	2	-1	399.7	399.8	0.1	0.104	0.05	0.05
2	1	0	407.9	408.2	0.3	0.311	0.16	0.21
3	0.5	1	359.6	363.4	3.8	3.937	1.97	2.18
4	0.25	2	352.6	363.7	11.1	11.450	5.73	7.91
5	0.125	3	329.0	489.0	160.0	165.76	83.01	90.92
6	0.063	4	320.7	338.0	17.3	17.923	8.98	99.9
7	<0.063	5	318.2	318.4	0.2	0.207	0.10	100
TOTAL		Phi(ϕ)			192.8	199.69		

Initial mass: 200 g; recovered mass: 192.8 g; recovery: 96.4%; loss: 7.2 g (3.6%). Percentage values are retained as recorded.

Table 4: Recorded Grain-Size Percentiles used to Recalculate Statistical Parameters

Sample	ϕ_5	ϕ_{16}	ϕ_{25}	ϕ_{50}	ϕ_{75}	ϕ_{84}	ϕ_{95}
IEG 6	2	2.2	2.5	2.7	3	3.5	3.8
IEG 18	2	2.2	2.3	2.5	2.8	3	3.7
IEG 19	1.8	2.2	2.3	2.6	2.8	3	3.5

Graphic mean, inclusive graphic standard deviation, inclusive graphic skewness and graphic kurtosis were recalculated using the Folk and Ward (1957) expressions below. Here ϕ_p denotes the phi value at cumulative percentile

$$M_z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

$$\text{Standard Deviation, } \sigma = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6}$$

$$\text{Skewness } S_k = \frac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_5 - 2\phi_{50}}{2(\phi_{95} - \phi_5)}$$

$$\text{Kurtosis } (K_g) = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})}$$

RESULTS AND DISCUSSION

Lithology and Field Relationships

Shale and sandstone were the principal lithologies mapped in Inachi. The shale was grey to greyish brown,

fissile and thinly laminated, with variable weathering between exposures. Sandstone occurred as ridges, exposed beds and boulders within stream channels, displaying reddish-brown to yellowish-brown weathered surfaces (Figure 3). Field estimates indicated fine- to medium-grained textures, while the three samples selected for sieve analysis were fine-grained. Sandstone beds dipped 4–8° and ranged from 0.2 to 2.3 m in thickness. Joints and fractures were observed, together

with features described in the field records as mud cracks and possible bioturbation. These features suggest variability in sedimentary conditions but require further documentation to support a specific depositional interpretation. The brown sandstone surfaces may reflect weathering-related oxidation and do not independently establish depositional conditions. The mapped lithologies alone are insufficient to confirm their provisional assignment to the Awgu and Nkporo formations.



Figure 3: Field exposures of shale (left; 7°04'56" N, 8°04'03" E) and sandstone (right; 7°05'58" N, 8°03'09" E) in Inachi. Geological hammers provide a visual indication of scale; their dimensions were not recorded

Fracture orientations

The fracture-frequency distribution is presented in Table 5 and illustrated by the rose diagram in Figure 4. Of the 67 recorded measurements, 26 (38.81%) fall within the 121°–150° class and its reciprocal direction, indicating a dominant NW–SE orientation. The 61°–90° and 91°–120° classes account for 20.90% and 16.42%, respectively, demonstrating additional fracture orientations. Uneven

outcrop exposure limits the regional representativeness of this pattern. Open and interconnected fractures may provide secondary groundwater pathways. However, fracture aperture, connectivity and mineral infilling were not quantified. The observed orientations therefore do not establish hydraulic conductivity or groundwater productivity.

Table 5: Fracture Orientation Frequencies Recorded during Mapping

Orientation class (°)	Frequency	Percentage (%)
0–30 / 181–210	6	8.96
31–60 / 211–240	6	8.96
61–90 / 241–270	14	20.90
91–120 / 271–300	11	16.42
121–150 / 301–330	26	38.81
151–180 / 331–360	4	5.97
Total	67	100

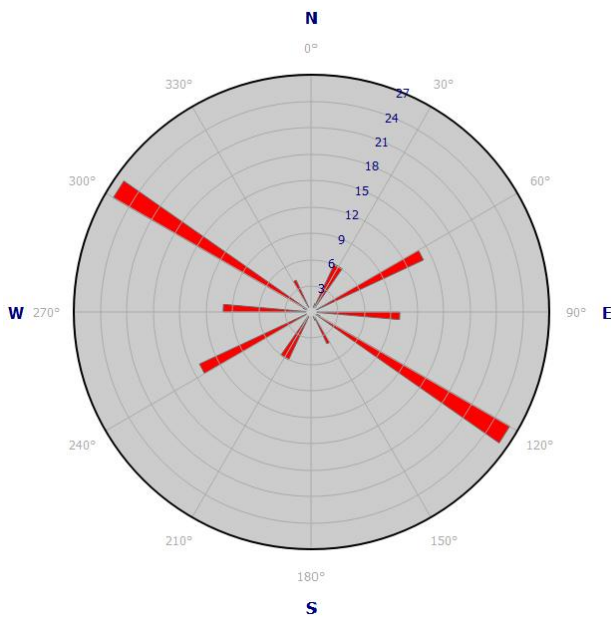


Figure 4: Rose diagram showing the frequency distribution of measured fracture orientations in Inachi

Mineral Composition and Grain Relationships

Visual estimates of mineral composition are summarised in Table 6. Quartz was the dominant constituent in the sandstone samples (52–60%), followed by feldspar (30–

35%) and accessory constituents (5–18%). The shale sample comprised approximately 80% clay minerals, 15% quartz and 5% accessory constituents. Individual clay species were not resolved by optical examination.

Table 6: Reported Modal Composition of the Examined Rock Samples

Sample	Lithology	Quartz (%)	Feldspar (%)	Clay (%)	Accessory (%)
IEG 15	Sandstone	55	35	—	10
IEG 18	Sandstone	60	35	—	5
IEG 19	Sandstone	52	30	—	18
IEG 20	Shale	15	—	80	5

Values are approximate visual estimates. A dash indicates that the constituent was not separately quantified.

The appreciable feldspar content indicates that the sandstones are not composed exclusively of resistant quartz grains. Their grain-size sorting should therefore be distinguished from compositional maturity. Because systematic point counting and separate quantification of

matrix and lithic fragments were not undertaken, these estimates support descriptive comparison but do not establish a rigorous sandstone classification or provenance interpretation.

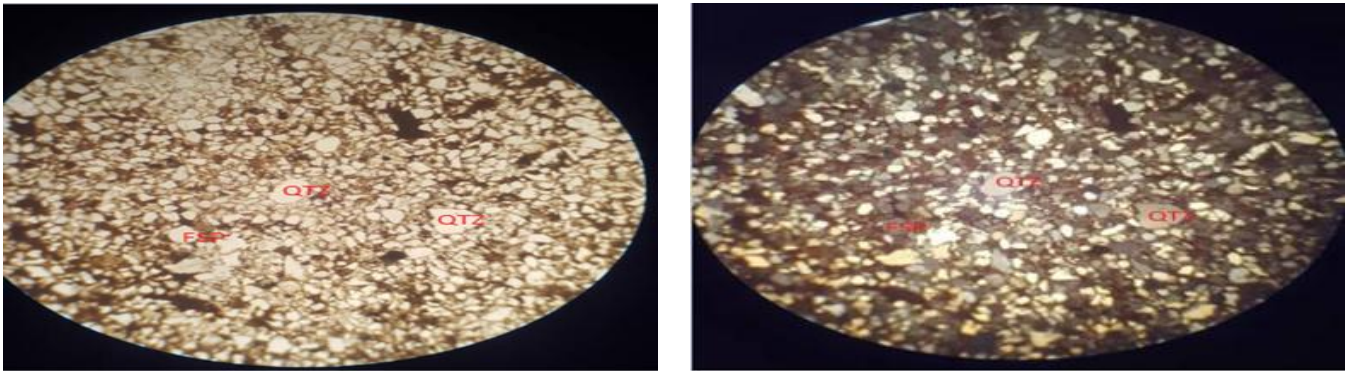


Figure 5: Photomicrographs of sandstone sample IEG 15 under plane-polarised light (left) and cross-polarised light (right), as identified in the project. QTZ = quartz; FSP = feldspar. Reported magnification ×40; a calibrated scale bar was not supplied

Grain-size distributions

The recalculated grain-size statistics are presented in Table 7. Graphic mean values range from 2.567 to 2.800 ϕ , indicating fine-grained sandstone in all three samples.

Sorting values range from 0.458 to 0.598 ϕ ; IEG 18 and IEG 19 are well sorted, whereas IEG 6 is moderately well sorted.

Table 7: Grain-Size Statistics Recalculated from the Recorded Percentiles

Sample	Mz (ϕ)	σ_I (ϕ)	Skl	KG	Sorting
IEG 6	2.800	0.598	0.226	1.475	Moderately well sorted
IEG 18	2.567	0.458	0.331	1.393	Well sorted
IEG 19	2.600	0.458	0.029	1.393	Well sorted

Mz: graphic mean; σ_I : inclusive graphic standard deviation; Skl: inclusive graphic skewness; KG: graphic kurtosis.

IEG 6 is fine-skewed, IEG 18 strongly fine-skewed and IEG 19 nearly symmetrical. Kurtosis values of 1.393–1.475 indicate leptokurtic distributions in all three samples. These classifications follow Folk and Ward (1957). The results demonstrate textural variation among the sampled exposures, but the small sample set limits generalisation across the mapped area. Grain-size characteristics alone do not establish a unique depositional environment.

Depositional interpretation

The bivariate plots yielded contrasting environmental indications. Mean grain size versus sorting suggested a fluvial influence, whereas skewness-based comparisons suggested beach or wave-influenced conditions. Such differences require caution because textural characteristics can overlap between depositional environments (Friedman, 1961). Sorting and skewness therefore do not independently establish a unique transport or depositional mechanism.

Fluvial sediment supply followed by shoreline reworking offers a possible explanation for these mixed signatures. However, a transitional setting remains tentative because the available facies descriptions, palaeocurrent data, fossil evidence and stratigraphic control are insufficient to substantiate this interpretation. Fine grain size alone does not establish transport distance or suspension-dominated transport. The evidence supports the occurrence of fine-grained, well-sorted to moderately well-sorted sandstone, while its depositional environment remains unresolved.

Groundwater Implications and Study Limitations

Local hand-dug wells reportedly obtain water from sandstone, indicating its contribution to shallow groundwater supply. Seasonal drying of some wells and streams suggests variable water availability. Residents were also observed waiting to purchase water during the peak dry season (Figure X). These observations illustrate seasonal water-supply difficulties but do not quantify recharge, groundwater storage or sustainable abstraction.



Figure 6: Residents waiting to purchase water in the study area during the peak dry season

Groundwater movement depends on pore connectivity, cementation, clay content and fracture characteristics, as well as sediment texture. Porosity, permeability and

hydraulic conductivity were not measured; consequently, the observed sorting and fracture orientations do not establish aquifer productivity. Shale may restrict vertical

flow where continuous, but confinement requires confirmation through subsurface investigations and hydraulic-head measurements.

The principal limitations are the three-sample grain-size dataset, visually estimated mineral proportions, incomplete exposure and uneven structural sampling. Sample losses during sieving introduce uncertainty because the composition of the unrecovered material is unknown. Stratigraphic assignments also remain provisional.

Further work should combine broader sampling and measured geological sections with repeat sieve analysis, petrographic point counting and quantification of cement and matrix. Direct petrophysical measurements, pumping tests and seasonal groundwater monitoring are required to assess aquifer performance and sustainable groundwater use.

CONCLUSION

The Inachi area contains exposed shale and sandstone with gently dipping beds and a dominant NW–SE fracture preference in the measured dataset. The examined sandstones are quartz- and feldspar-bearing and have fine-grained, well-sorted to moderately well-sorted distributions. Recalculated mean size, sorting, skewness and kurtosis reproduce the reported percentile-based statistics, with two well-sorted samples and one moderately well-sorted sample. The available evidence does not uniquely distinguish fluvial from beach deposition. A transitional interpretation remains provisional pending broader sedimentological and stratigraphic evidence. Local sandstone-hosted wells indicate groundwater relevance, but direct measurements are required to establish porosity, permeability and sustainable yield. The study provides a preliminary geological and textural baseline for targeted follow-up

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