Architecture of Joints at Ago-Sunmonu, South Western Nigeria.

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ABSTRACT

The rock exposure at Ago-Sunmonu belongs to the Migmatized-Gneiss complex of Nigeria, a rock that has undergone polyphase deformation. Measurement was taken on forty five (45) joints on the outcrop and forty-three (43) others in surrounding exposures in order to understand their origin, architecture and regional connection. Parameters measured include the length and attitude (Strike and Dip) of the joints.

Fifteen (15) joint sets were identified with tip and intersection geometries ranging from branching, Y-shaped, gradual dying out, T-joint, and conjugate joint. These joints are extensional and shear joints produced by dominant NW-SE, NE-SW, and E-W tectonic forces. Regionally, the joints will enhance permeability of aquifers and knowledge of their orientation is crucial in planning construction works.

(Keywords: joints, polyphase deformation, conjugate, migmatized-gneiss)

INTRODUCTION

Joints are fractures in rocks with no measurable shear displacement, which are thought to represent Mode I fractures (tensile stress features). Joints are important to a aquifer (oil and water) because they enhance permeability in rock. An idea of joints present in an area would provide information on mass wasting surface, failure plane (slope stability, dam stability, tunnel stability, strength anisotropy), fracture porosity/permeability useful for hydraulic hydrologic modeling, mineralization, important geomorphic control, trellis drainage, lineaments, hydrocarbon migration, and interpretation of paleostress system.

The study was done within the area specified by $7^{0}21^{1}$N-$7^{0}24^{1}$N and $3^{0}41^{1}$-$3^{0}45^{1}$E and emphasis was placed on an outcrop exposure at Ago-Sunmonu which lies on $7^{0}23^{1}17^{11}$N and $3^{0}42^{1}45^{11}$ (Figure 1).

The aims of this study include identifying the different joints set present, their origin, architecture, their regional occurrence and most importantly their influence on aquifer properties in the area.

REGIONAL SETTING

The general geology of Nigerian has been studied by various researchers including Rahaman (1971), Oyawoye (1972), Cooray (1972), Elueze (1981), Caby (1981), and Dada (1998,1999). Nigeria is covered nearly in equal proportion by both crystalline and sedimentary rock. The crystalline rocks are divided into the basement complex, the younger granites, and Tertiary-recent volcanic. The basement complex is distributed in (i) a triangular area in south western Nigeria, (ii) a roughly circular area in North-central Nigeria and (iii) a rectangular area broken up into 3 zones by sedimentary rocks on the eastern border of Nigeria with Cameroon Republic.

The study area lies within the basement complex of south-western Nigeria. Rocks previously described in this region include A polycyclic Migmatized-Gneiss complex that is characterized by grey foliated Biotite Acid/Biotite Hornblende quartz feldspathic gneiss of tonalitic to granodioritic composition (Rahaman, 1981); Mafic to ultramafic component which outcrops as discontinuous boudinaged lenses or concordant sheet of amplibolites with minor amount of biotite-rich ultramafite; and Felsic component, a varied group comprised of pegmatite, aplite quartz-oligoclase veins, fine-grained granite gneiss, and porphyritic granite.

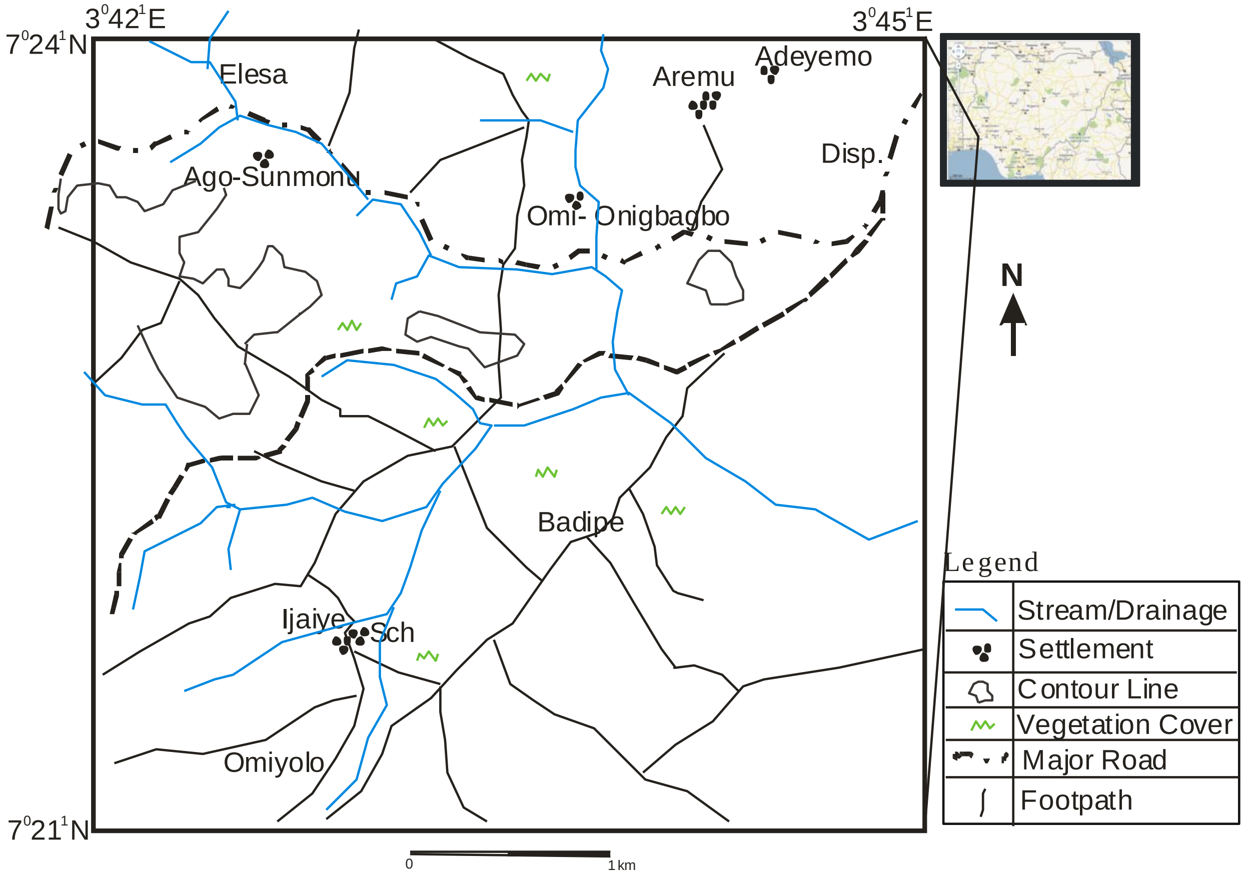

Figure 1: Topographical Map of the Study Area.

The outcrop exposure at Ago Sunmonu covers a length of ~1880cm from N-S and 1222cm from E-W, with an altitude of 197.4m asl. The area of study is located in south western Nigeria, some few meters to Bakatari.

Regionally, the geology of the area belongs to the basement complex of Nigeria, the area is characterized by metamorphic rocks which include Migmatized Gneiss, Banded Gneiss, and Porphyroblastic Gneiss. The MGn are restricted to the N and NNW part of the study area. These rock units are slightly foliated, displaying a medium degree of metamorphism with minerals such as Quartz, Feldspar, Hornblende, and Biotite. The strike of these rock units exhibit a NW-SE trend except in exposure along the main road some 350 meters SE of Bakatari that trend in the NE-SW direction. The BGn in the study area are strongly deformed. The foliation in the rock are conspicuously folded which attest to the degree of deformation recorded in the rocks.
The minerals in this rock are not different from those of the MGn. Apart from the strongly folded foliation on these rocks, the amount of extension of the rock is represented by the number joints found in this rock. This unit has undergone episodes of compression and extension has revealed by the structural features identified in the rock.

The PGn is from a porphyritic Granite protolith, with metamorphism consequently causing alignment of the feldspar phenocryst. These rock units belong to the Migmatized-Gneiss complex of Nigeria that is thought to be Achaean (3.5Ga) in age (Dada, 1989). Like other Achaean rocks elsewhere the Banded Gneiss occur as a window in the Porphyroblastic Gneiss (Figure 2).

The area is densely vegetated with an average annual temperature of 32°C / 89.6°F. The relief is undulating from the Northern end to the south; a common stream regionally drains the area.

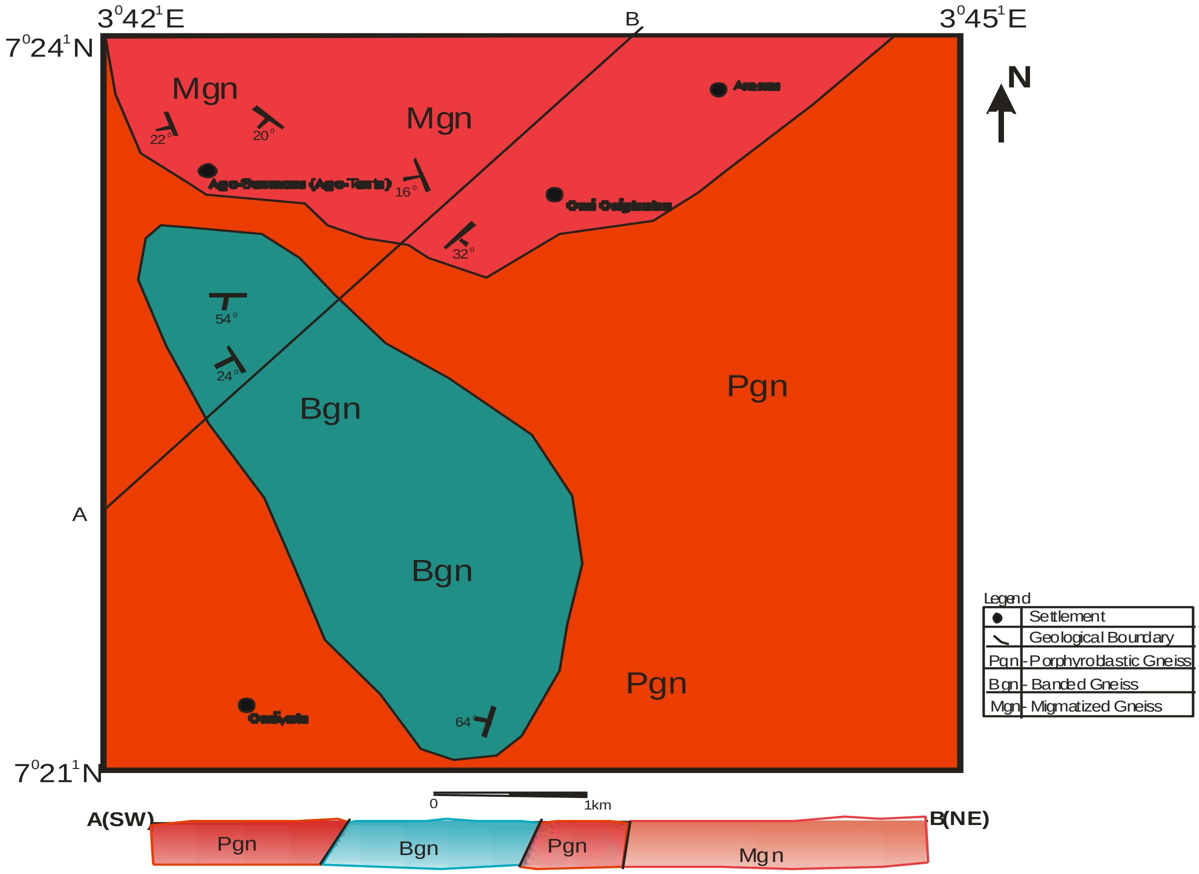

Figure 2: Geological Map of the Study Area

METHODOLOGY

Initial study of rock types was done by carrying out a detailed geological mapping of the entire region within the coordinate specified by Map 1 through traversing and positioning with the aid of GPS. This was done in order to understand the geology of the area and to appreciate the effect of joints on the rocks of the study area and its surroundings.

The rationale for studying the outcrop exposure at Ago-Sunmonu was the fact the outcrop exhibits pronounced jointing and folding. It may reflect the entire structural behavior of the entire region and may provide clues in mimicking larger regional structures (Pumpelly rule).

In mapping the joints at the study area, length and attitude of the joints were recorded from the NE-SE, SW to the NW part of the outcrop. The orientation of the joint relative to the entire outcrop is described in the table below. These measurements were made on the outcrop at Ago-Sunmonu and other exposures nearby in other establish a regional pattern.

Many of the joint planes are twisted and this made measurement of the joint orientation difficult, which invariably makes it difficult to determine whether the orientations are representative or not. The spacing between the joints was taken and the average perpendicular value was chosen as a representative for the joints spacing (Table 1).

The strike of the joints were taken along relatively straight surfaces. A generalization here is that the joint are assumed to have a straight surface when the orientation was measured. The orientation were plotted on rosette diagrams and histograms to understand the trend of the major tectonic force(s) in the region and as well as on the outcrop.

Table 1: Orientation of the Joints on the Outcrop at Ago-Sunmonu, SW, Nigeria.

S/N	Joints Name	Orientation (degrees)	Length(cm)	Location on Outcrop	Average Distance(cm)
1	J1	084	398	W-E	
2	J1a	124	18	NW-SE	
3	J1b	078	21	W-E	10.4
4	J1E1	092	68	W-E	
5	J1E2	038	50	NE-SW	43
6	J1E3	162	38	NW-SE	
7	J1E4	166	46	NE-SW	20.5
8	J2	168	153	N-S	J2&J3 = 5.5
9	J2E1	076	157	W-E	
10	J2E2	070	44	W-E	
11	J2E3	078	35		9.5
12	J2E4	124	38	NW-SE	
13	J2E5	122	30		36
14	J2E6	138	26		
15	J2E7	144	22		13.5
16	J3	162	780	N-S	
17	J3S1	126	84		57
18	J3E1(F)	046	10	E-W	
19	J3E2(F)	030	16	E-W	31
20	J3E3(F)	168	56	N-S	J3E3&J3E2= 22
21	J3ES1(F)	016	19	NE-SW	
22	JEES2(F)	022	22	NE-SW	20
23	J4	080	390	SE	
24	J5	080	390	SE	223
25	J51	096	93	W-E	J5&J51= 36.7
26	J52	022	24	NE-SW	
27	J6	110	276	NW-SE	
28	J7	080	79	NW-SE	9.5
29	J8	170	74	N-S	
30	J9	090	162	W-E	J7&J9= 38
31	J10	110	86	NW-SE	
32	J11	038	26	W-E	J11&J9 = 17
33	J12	036	63.5	NE-SW	
34	J13	110	337	SE	
35	J14	116	640	NW-SE	63
36	J14S	076	46	E-W	
37	J15	172	418.5	N-S	
38	J16	182	287	N-S	6.5
39	J17	123	155	NW-SE	J16&J17= 107.6
40	J18	106	224	NW-SE	J17&J18=45.5
41	J19	089	408	E-W	
42	J20	178	188	SW	
43	J21	168	138	SW	3.2
44	J22	142	151	NW-SE	
45	J23	142	181.5	NW-SE	26

Description of Abbreviations: J1a- means the first major joints and b means the minor one relative JIa; J1E1- means the first joint measured to the East of JI; J3ES1- means the first joints located south of the first eastern J3 joint, J4- means the fourth major joint. Cells are merged where the average perpendicular distance between the joints were established.

Where possible dip of the joints was plotted, not only this, orientation of veins and intrusion were measured where otherwise possible.

The orientation of the joints was plotted on a rosette diagram, and a histogram was used to analyze the behavior of joints in the area. The joints were later described based on the following criteria:

(1) Whether the joints are systematic or non-systematic

(2) The orientation of joints present

(3) The number of joints sets present

(4)Their cross cutting relationship

(5) Overall appearance of the joints

(6) The dimension of the joints

(7) Joint spacing and density

(8) The relationship of joints and petrological units

(9) Variation of joints with petrological units

(10) Relationship of the Joints to other geological structures

(11) Whether joints are isolated or connected to regional network.

RESULTS AND DISCUSSION

The longer joints are systematic with a relatively constant separation between them; other joint sets are located within the longer joints. The systematic joints are parallel and sub parallel to each, they occur on different scales, microscopic and megascopic relative to the size of the exposure itself.

The non-systematic joints have no observable spatial relationship (they have irregular average perpendicular distance/ spacing) (Table 1).

Because the rock units is a mixture of metamorphic and igneous rock, it may indicate a variation in strength of the outcrop exposure in this area, this may account for the irregular spacing between the non-systematic joints because the rock is supposedly less stiff in this area. The low tensile strength of the rock may be responsible for the amount of joints found in this exposure relative to other exposures within the larger mapped area.

The different joint sets relative to the outcrop are oriented in virtually all directions, N-S, NW-SE, E-W, S, & NE-SW. In Ago-Sunmonu forty-five (45) joints were mapped, the microfractures are located on the eastern part of the outcrop, with a larger number of the joints present in the SE and SW part of the outcrop. About fifteen (15) joint sets were identified, each with its own characteristics joint relationship; these joint sets have orientations in the NE-SW, NW-SE, and E-W direction.

The dominant joint orientation is created by two principal tectonic forces, a NW-SE oriented tectonic force and another oriented in the NE-SW direction. The orientation is dominant in the whole study and we could conclude that the model of polyphase deformation entails the two principal tectonic forces be operative at different time in the history of the area. An E-W oriented force may correspond to shear stress which is responsible for the compression of the structures, in this instance the conjugate joints set. Joint orientations were taken in other places or outcrop exposures visited in the area. This was done in other areas to regionally correlate the direction of major tectonic force responsible for the different structures, and it was obvious that the major tectonic stresses in this region are those earlier mentioned.

T junction is a common intersection geometry (Figure 7.5.). A T-junction was seen at the intersection of J7 with J8, and J9 with J8. This geometry has great implication for fluid transmission through the rock, as it enhances permeability through the rock. Near Conjugate relationships were exhibited by J11, J12 & J13 (Figure 7.3). By this definition we estimated the angle to be ~ 60^0. We reluctantly call this a strike-slip fault. Horizontally, this joint set may appear has a strike–slip fault but with deep consideration of the fact that the geometry exists along veins and later fractured by younger joints, a strike-slip model may be inappropriate. However, in compression, joints develop in the conjugate shear directions (the orientation of symmetric fracture planes) making the lower angle with the major principal stress direction.

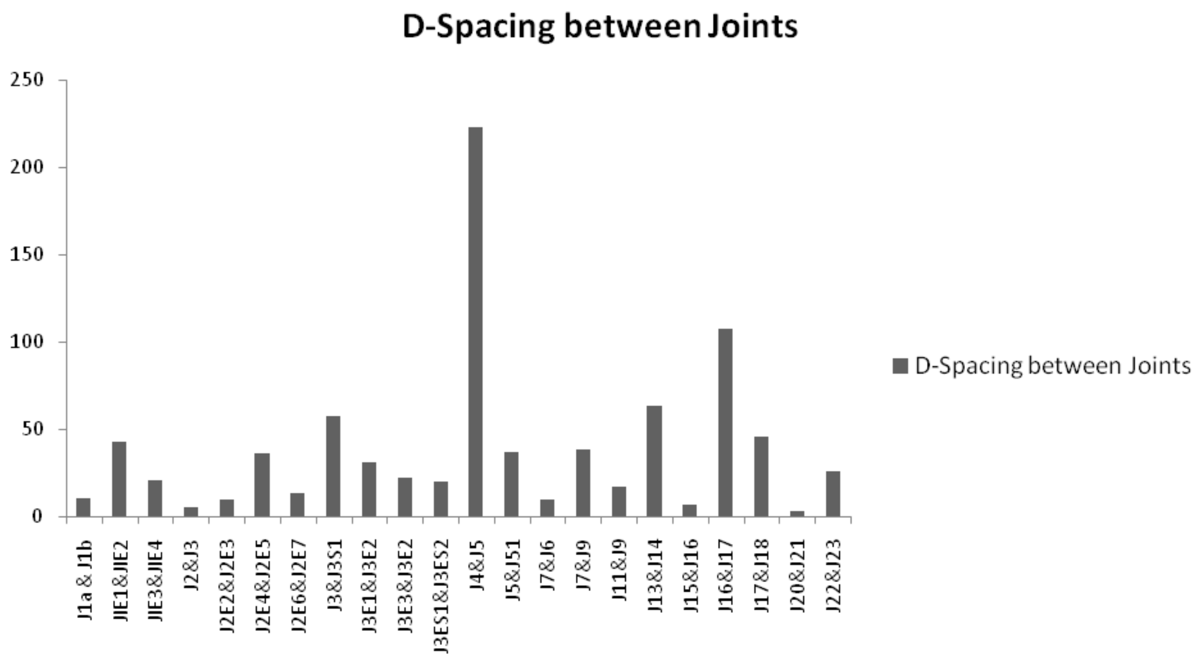

Figure 3: Average Perpendicular Distance between Non-Systematic Joints.

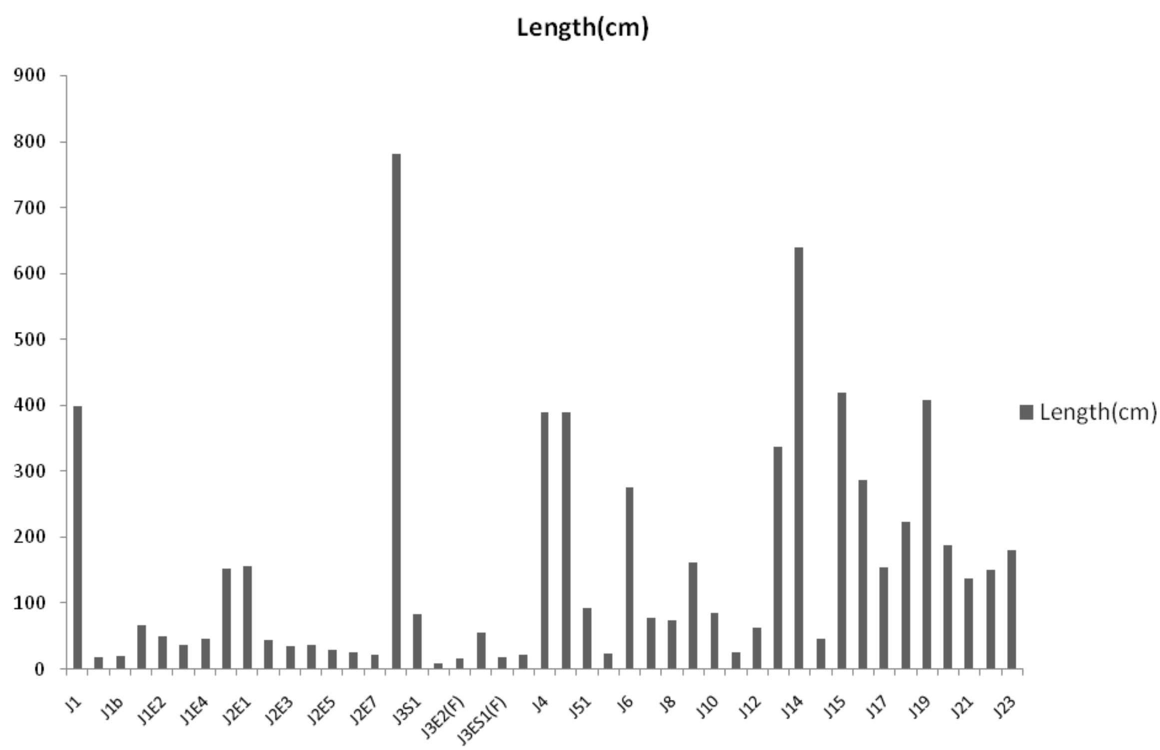

Figure 4: The Dimension of Joints (length) Mapped at Ago-Sunmonu, SW, Nigeria.

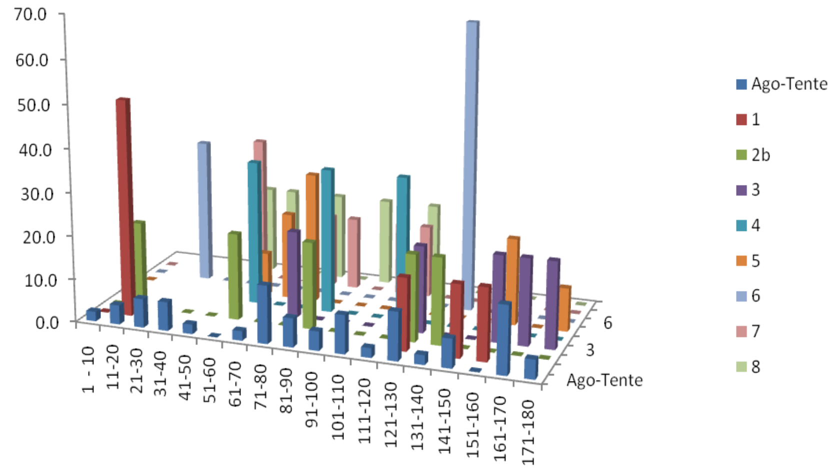

Figure 5: Orientation of Eighty-Eight (88) Joints in the Entire Study Area.

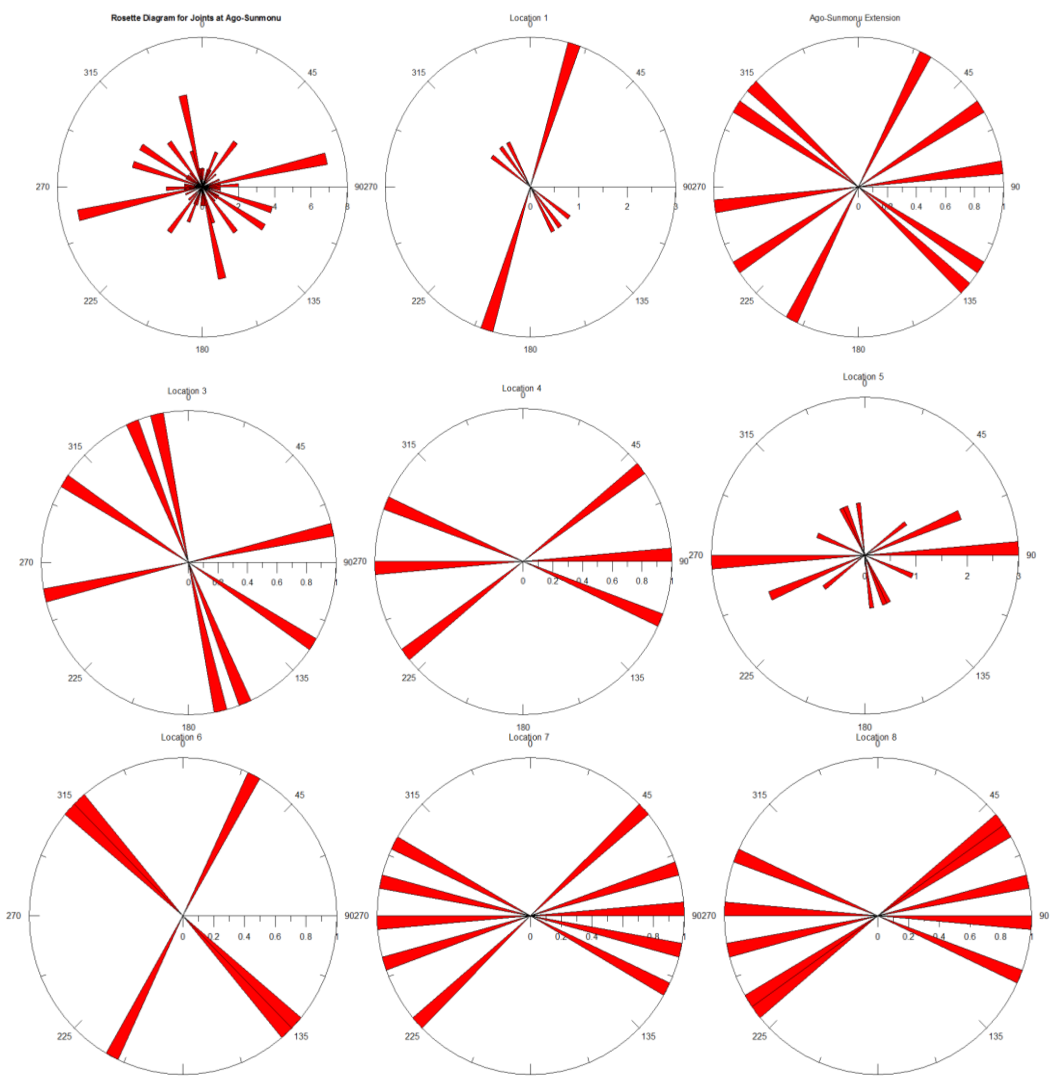

Figure 6: Rosette Diagrams for the Orientation of the Outcrop Exposure at Ago-Sunmonu and Other Outcrop Exposures in the Study Area.

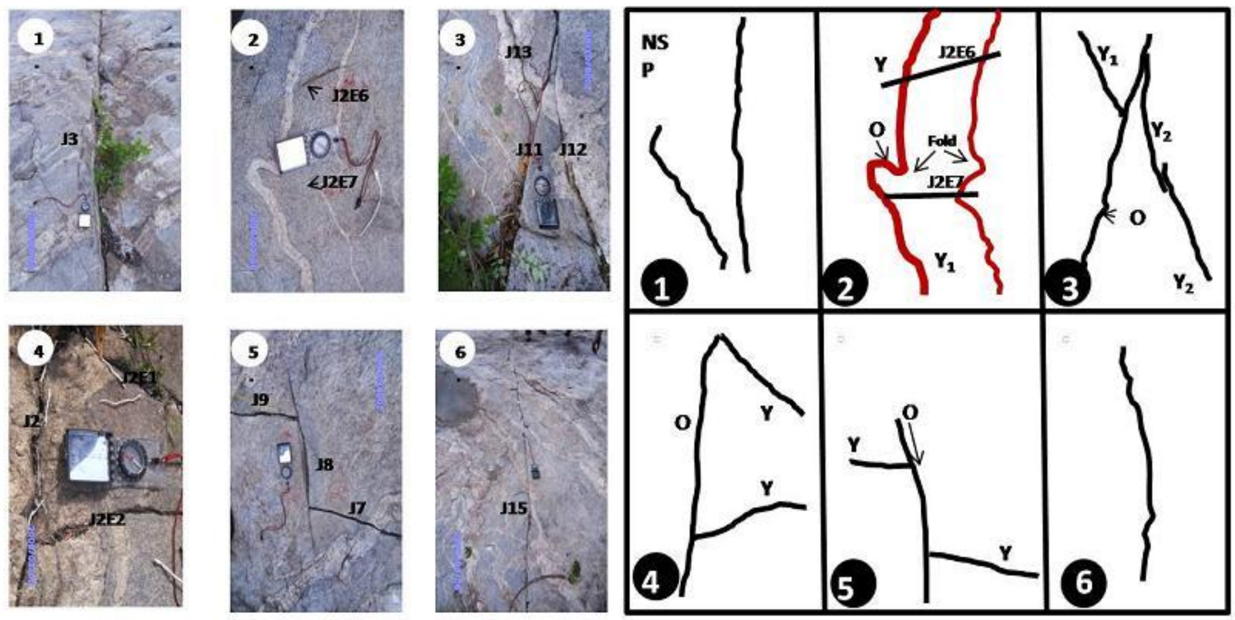

Figure 7: (1) Isolated J3 Joint that Trends N-S of the Exposure; **(2)** Micro Fracture J2E6 & J2E7 that Exhibits some sense of Shear (these joints postdates the fold); **(3)** Exhibits a Near Conjugate Relationship in which they Intersect a QtzF Vein; **(4)** J2 is the Second Major Joint described but because J2E1 & J2E2 Terminates on it and they are Located East of it, They are so Named J2E1 & J2E2; **(5)** T-Joints between J9 & J8, J8 & J7; **(6)** J15 Runs N-S, it Trends from N-S and measures ~ 418.5cm, It significantly Cross-cuts most of the QtzF Veins and is Isolated from other Joints and Joint Sets.

The compass was aligned to the North before pictures were taken. O-Older Joint; Y- Younger Joint, P- Parallel Joint, NS- Non-systematic joints, Quartzo-feldspathic.

These conjugate joints are not grooved, striated, polished or slicken-sided. They lack the characteristics of a shear joints though they show small amounts of shear displacement. We propose a shear joint model for these joint geometry.

In terms of their tip geometry, most of the joints die out gradually, some curve and die out, others branch and dye out. A few of the joints curve towards a parallel and perpendicular intersection towards another. The intersection or behavior of these joints at their tips affords us the opportunity to relatively determine the timing of these joints.

In Figure 7 some of these age relationship have been assigned (Y and O) to differentiate the older joint form the younger ones. The conjugate pair is not mutually perpendicular but mutually cross cutting without any certain age relationship. Elsewhere, some of the joints are mutually perpendicular. At certain points, some of the joints branch out in smaller set of joints exhibiting a Y-shaped geometry at the tip. Only J14 is bent at the tip.

The joint lengths were measured. J3 is the longest joint on the exposure. It divides the outcrop into two equal halves, measures ~780m in the N-S direction. Apart from this, J14 measures ~640 cm and J1, J4, J5, J15 & J19 measure ~398, 390, 390, 418.5, and 408 cm, respectively. This longer joints, on the average, measure ~400cm in length and were described as the Master joints on this outcrop. J3 is a good joint for characterizing the joint set, and it represented the reference point for the mapping exercise.

The joint spacing was measured perpendicularly between the joints, with values taken at different points along the separation. These values were averaged and a plot of the average perpendicular distance was taken to represent the joint spacing (Figure 3). The average spacing ranged between 3.2cm (between J20&J21) and 107.6cm (between J16 and J17).

The petrological unit identified in the study area is Migmatized Gneiss, in which the degree of metamorphism varies from the northern part of the rock to the south. This means there is no variation *per se* across the rock exposure except for mineral variation from north to south. However, joints are seen across the whole rock exposure. Changes in the mineral composition of the rock do not pronouncedly affect the orientation/population of joints throughout the exposure. Most of the longer joints are isolated, most especially J3, J4, J5, J14, and J19. These joints are systematically maintaining a relatively constant separation between themselves; the non-systematic joints are enslaved by these longer joints.

No plumose marks or hackle structures were seen on the joint surface, this does not mean the joints are not extension fractures, it shows how lithology controls the behavior of the joints surfaces, plumose structures would have been obvious in sedimentary rock units not hard rocks. Plumose structure is present on joints in a variety of rock types, but it is most clearly displayed in rocks of uniform fine-grained texture (Twiss and Moores, 2007). In relationship to other structures, the joints are seen cutting across most of the Quartzo-feldspathic veins, pegmatite intrusion, and folds in the field (Figure 8 a-e). None of the joints are parallel to foliation. The implication for this is that the joints seen in the rocks are the youngest events recorded in the area. This signifies a series of extension-compression-extension. Initial extension of the rock provided opening for mineralization of the Quartzo-feldspathic and pegmatite intrusion, later compression caused folding in the rock and the last episode of tectonic activity witnessed extension which produced the joints.

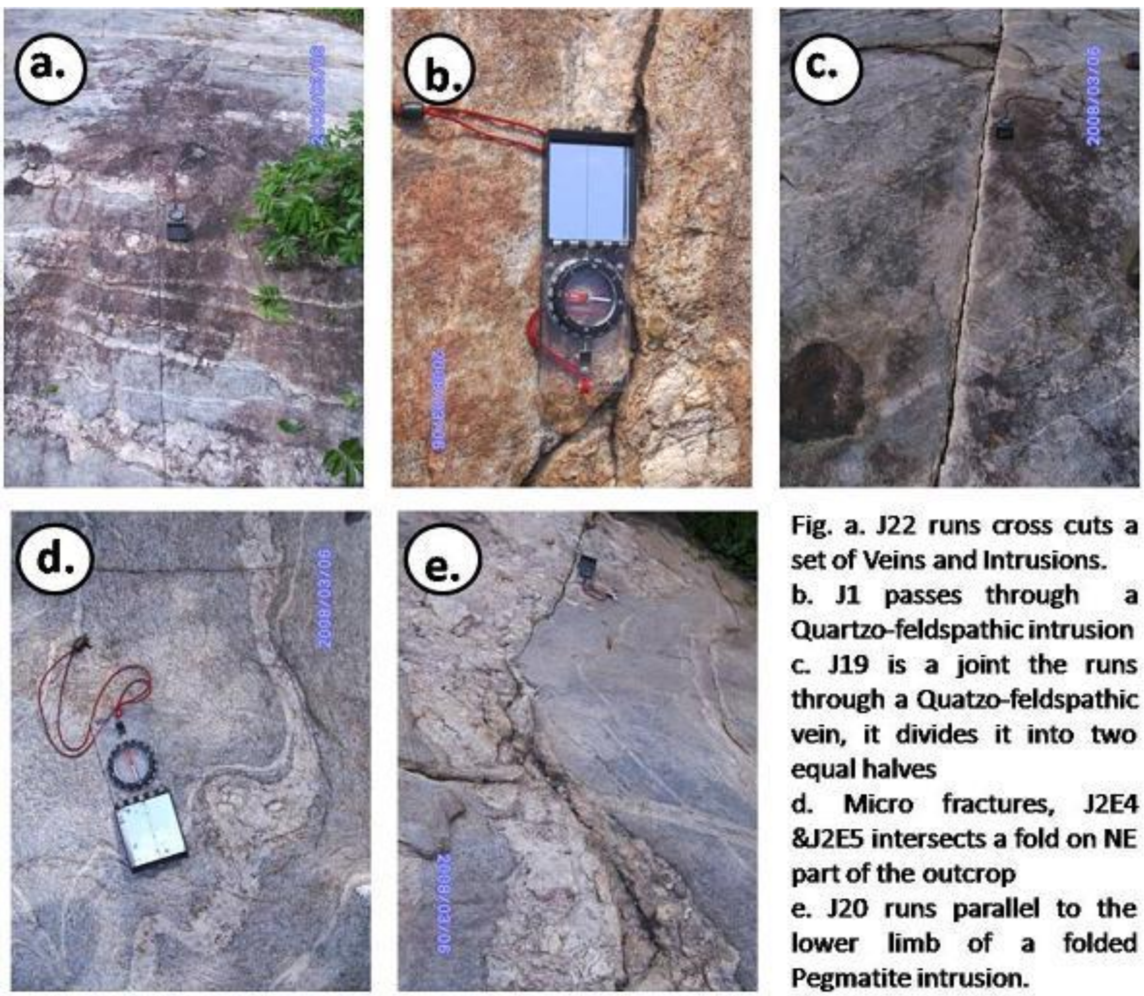

Fig. a. J22 runs cross cuts a set of Veins and Intrusions.
b. J1 passes through a Quartzo-feldspathic intrusion
c. J19 is a joint the runs through a Quatzo-feldspathic vein, it divides it into two equal halves
d. Micro fractures, J2E4 &J2E5 intersects a fold on NE part of the outcrop
e. J20 runs parallel to the lower limb of a folded Pegmatite intrusion.

Figure 8: Relationship of Joints with Other Geological Structures at Ago-Tente.

Regionally it may be realistic to consider the joints that are oriented in this same direction to be connected. Most of the major tectonic forces that fractured the rock at Ago-Sunmonu are seen responsible for the deformation recorded in other outcrop mapped in the region. It is obvious from the aforementioned that the rock exposure at Ago-Sunmonu is a good guide to understanding the regional tectonic behavior of rocks.

CONCLUSION

The joints in Ago-Sunmonu were produced as a result of extension and shearing; extension in the isolated, parallel and sub-parallel joints with shearing in the conjugate joints. In terms of origin, it is appropriate to invoke a tectonic denudation rather hydraulic fracturing or uplift and unroofing for these joints. The joints system in Ago-Sunmonu provides a hint to understanding the regional tectonic pattern, as the joints are evidence to a stress regime coming from different directions. Virtually all the major tectonic forces identified in the rocks mapped in the other locations are represented in this exposure. In conclusion, the rock has undergone a polyphase deformation as evident by the amount of deformation recorded in the rock which tally with previous suggestion that the Migmatized Gneiss complex in south-western Nigeria is polycyclic in nature.

Though the absolute age of the joints was not determined, we propose that the rock experienced extension (which acted as conduits for the emplacement of the veins and intrusion), compression (when the rock was foliated, folded, and the previous structures were folded), then extension (that produced the non-conjugate joints) and lastly a period of compression (which we suppose was not so intense producing the conjugate joint set). The different joints identified in the area (based on their geometries, tip and intersection), on a regional scale will enhance aquifer properties, as permeability will improve in places where there is T-Joint geometry and other intersection geometries; their orientation should be given priority during foundation investigations as this may prevent future foundation failure.

RECOMMENDATION

We recommend that future analyses should be encouraged for student mapping exercises, so that a joint trajectory map of the entire south western Nigeria can be produced.

ACKNOWLEDGEMENT

We acknowledge the assistance of Fashola Gbotemi, Ehinmowo, Eze Kingsley, Falana Louis, Ebrimoni Samuel, Oguneye Shola, Bolade Odugbesan Dayo, Kunle, and the Department of Earth Sciences Olabisi Onabanjo University, Ago-Iwoye during the mapping exercise.

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SUGGESTED CITATION

Omosanya, K., O. Ajibade, and A. Akintola. 2010. “Architecture of Joints at Ago-Sunmonu, South Western Nigeria”. *Pacific Journal of Science and Technology*. 11(2):625-635.

Pacific Journal of Science and Technology