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# Effect of Chemical Composition of Sandstone on Deformation of Reservoir Rocks

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**Abstract:** ***Deformation bands appreciably alter the parochial petro-physical characteristics of reservoirs rocks. Notwithstanding, the effect of the ingrained unstable mineralogy, grain size and sorting of sandstones on the nature and distribution of deformation bands is yet to be understood. To identify the effect of chemical composition of the sandstone on band, cataclastic deformation bands in the matrix of oil bearing rock, sandstone at Abakaliki anticlinorium, were studied using the mineralogy of the outcrop. The scanning electron images were analyzed. In the coarse sample the deformation bound was more than the fine-grained section. The microscopic image and SEM were analyzed for grain size effect. Current observations show that close to the fault, more of the dipping conjugates of cataclysmic bands occurred. The grain sizes generated indicated that the primary grain size determines the intensity of deformation band which significantly reduces porosity of the sandstone. The lost in porosity affects permeability which constitute barriers to fluid flow in the reservoir. The XRD analysis revealed the preference of cataclastics of feldspar grains inside the host sandstone and deformation band. The bands develop before carboniferous source rock mature or petroleum migrates.***

**Keywords:** Reservoir, sandstone, fault, deformation band, feldspar

## 1. Introduction

One of the current concerns in the Nigerian petroleum sector involve understanding deformation bands because they are sub seismic, tabular zones of strain localization that can cause large changes to a reservoir's petrophysical properties (Ballas et al. 2013). Example of permeability alteration include the Abakaliki anticlinorium where deformation bands paved a conduit to reservoir fluid flow at the onset of deformation band which induced porosity. At the Abakaliki anticlinorium, deformation bands demarcate clean sandstones and oil-stained sandstones, indicating a significant impact on oil migration. The investigation on the effect of mineral composition on sandstone deformation can predict near-term reservoir quality in the Triassic reservoirs in Nigeria.

Outcrop analysis of field sample defines deformation bands as an isolated structure, connected systems, complex zones of multiple, interlinked arrangement in fault locations (e.g. Aydin & Johnson 1983; Hesthammer & Fossen 2001). In laboratory studies Mair et al. (2000) have reported the number of distinct deformation bands varies directly with strain in rock materials. The comprehensive mapping of outcrops of faulted cataclastic deformation bands reveals that slip surfaces precede the nucleation of small patches in the deformation band that build-up, link up, and changes into through-going slip surfaces with strain concentration. The developed through-going slip surface is associated with ultra cataclasite thin core (e.g. Aydin & Johnson 1978; Parnell, et al., 2004). Before the occurrence of slip-surface development, a densed localized grain crushing also occurs within the location of deformation bands (Johansen et al. 2005), implying that grain crushing is an incipient stage in the development of slip surfaces. Rock deformation is yet to be fully understood because of the complex mineralogy and matrix which they contain by nature. Thus, the extent of deformation bands formed locally at the period when slip-surfaced is developed is probably sensitive to all physicochemical properties of the rock which also include porosity, morphology, the cementation materials and overburden pressure. Deformation in the north sea sandstone is a small-scale (5–20 m throw) which faults in fluvial to shallow marine and at a thousand meters depth usually exhibit about 12 deformation bands on any side of the slip surface (Hesthammer and Fossen 2001), while deformation in the aeolian sandstones a small fault occur a two thousand meters depth having about 80 bands (Aydin 1978). Therefore at deeper burial more substantial fault damage locations are formed (Mair et al. 2002a). The length of deformation ahead of fault tip is affected by lithology. The more porous the sandstone is the wider the damage zones in even minor faults. The fragments of the pre-faulting and syn-faulting are the structural elements of damage location surrounding the damage band (Schultz and Siddharthan 2005). Therefore the permeability structure is affected by this orientation of deformation bands in these locations. Conjugate sets exist in reservoirs in Nigeria similar to the Colorado plateau (Fossen et al. 2005). While a conjugate set being sub-parallel to some main slip planes and another dipping in an opposite direction. According to Olsson et al. (2004), conjugate set structures contemporaneously occur due to mutual cross-cutting relationship. Reservoir fluid flow parallel to the strike of conjugate band is predicted to flow easily than the flow across damage locations. Phyllosilicate bands can form in sandstone having a composition of about 12% platy minerals. If the clay content is up to 40% then deformation bands with clay smearing are formed (Fossen et al. 2007 Cerveny et al., 2004, Cowie and Scholz, 1992). Grains can also be broken causing rearrangement of the granular assembly through porosity reductions this is the cataclstic band caused by the degradation of clay minerals binding the grains in the sandstone. (Fossen 2010). Minimum cataclastic are found in shallow depth formed at these are solution bands formed by chemical compaction. As the grain boundaries slides during chemical compaction, fresh mineral surfaces are exposed and sites for cementations are activated and cementation bands are formed (Fossen et al. 2007). Therefore this current research presents a study on the effect of chemical composition on the deformation of sandstone in Nigerian oil wells. By surveying an out crop location to obtain three dimensional view of deformation band, cataclastic deformation bands is addressed within fine- and coarse-grained to provide the quality of a reservoir in Abakaliki anticlinorium (Southern Benue Trough, Nigeria).

## 2. Methodology

Main method involves sampling and sample analysis. Rock samples were collected from outcrop located at Abakaliki anticlinorium in the Southern Benue Trough, Nigeria. The zone has conjugate sets of deformation bands within the damage location of two slip surfaces. The orientation, density and thickness of deformation bands were recorded with close to this slip surfaces (over a 300mm scan line orthogonal to faulting), within fine-grained having a mean grain size of c. 120 mm. The overlying coarse-grained sandstone is of c 440mm in the mean grain size.

Table 1 presents the list of the equipment employed in the determinations of grain properties and the microstructure nature of the sandstone. The equipment has been tested on preliminary studies and is found precise for the measurement carried out in this work.

**Table 1:** List of Equipment/Apparatus used in this Study

| S/N | Equipment | Model | Manufacturer | Measurement |
|---|---|---|---|---|
| 1 | Optical microscope | Meiji 9000 | Rex Shanghai China | Field view of Sub-parallel and bedding plane |
| 2 | HRSEM | Zeiss Auriga | Sco Tech.Germany | Back Scatter images |
| 3 | XRD | XRD-6000 | Shimadzu scientific instrument | Mineralogy and elemental mapping |

Beneath the intermediate group of the lower Benue, Murat (1972), no stratigraphic or paleontological details. The Keana sandstone and Wukari group (KWU) are found in the lower Benue trough. The presence of deformation bands at Benue trough is been considered, thus, this paper provides the analysis of deformation band distribution on core sample. The petrographic description and interpretation are also provided.

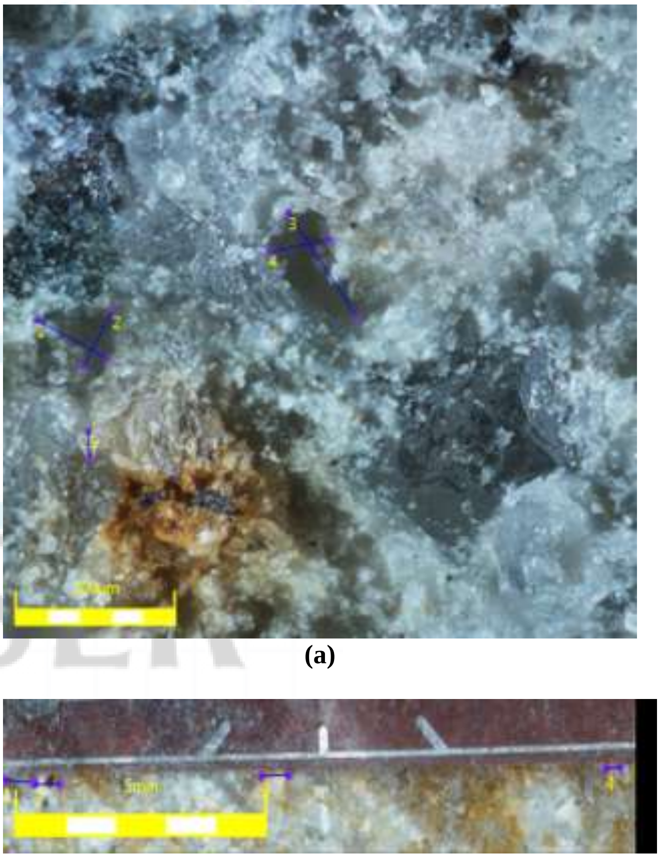
Samples from Abakaliki anticlinorium, allowed for a more extensive study of the relationship between slip surface proximity and deformation band density within coarse-grained sandstone. Two 20 m linear north–south transects orthogonally to the strike of main slip surface. Therefore fault, deformation band density, spacing and orientation were indicated so that $1m^2$ of photo exposures taken at field (sub-parallel to bedding). The photo images were used to present the deformation band and its anastomosing geometry. The grain size distribution of five fine and coarse samples were determined for field data using Particle size analyzer. Sample disaggregation was analyzed under an optical microscope. The disaggregated sample was sorted using the procedure of Cheung et al (2012). The values of D10 and D90 were chosen for both fine and coarse grain to obtain the grain size range. X-ray diffraction was carried out on disaggregated sandstone to obtain mineralogical composition using PANalytical X'pert Pro MPD.

### Microstructural Characterization

Along the north-south plane, the oriented sample was taken. The sample was thin sectioned and SEM images were captured. Next a Philips XL model SEM was used to obtain back scatter electron images. The XRD technique was employed for elemental mapping of each element. The images of the Scanning Electron Microscope (SEM) were imported into image J and data were generated to obtain Volume percentage of grains, grain distribution on sample surface, number of grains counted on deformation bands.

### Discussion of Results

Typical sample of the sandstone results are presented in Figure 1a and b.



(a)

(b)

**Figure 1:** (a) Optical Microscope Image of Coarse Sandstone

**(b) Optical Microscope Image of Fine-grained Sandstone**

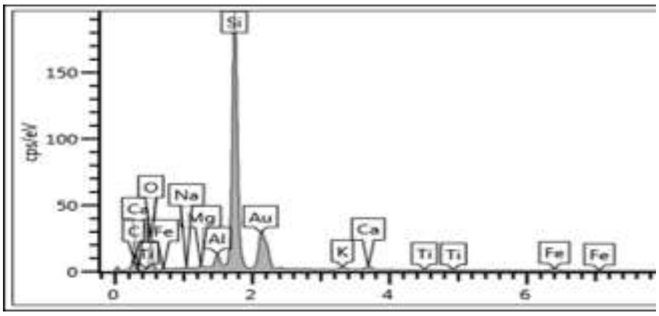



**Figure 2:** EDS- Layered Image Analysis of Niger Delta Sandstone

Figure 1 and 2 presents the deformation band as viewed under the optical Microscope. The grain sizes, grains area and standard deviation are obtained by further analysis of Figure 1 using image J, major and minor distribution of sizes were obtained from image J. The plots of generated data are provided in Figure 3 to 5. The deformation band indicated the crushed minerals which were identified by the elemental mapping. The XRD elemental mapping of the SEM is presented in Figure 2. Peaks of cps/ev revealed the presence of the potassium, sodium, aluminium, iron and calcium. The iron, Calcium, potassium are equally sparsely present in the sandstone. These elements constitute the chemical composition of the sandstone besides the major quartz (silicon oxide) indicated as the highest peak of Si component.

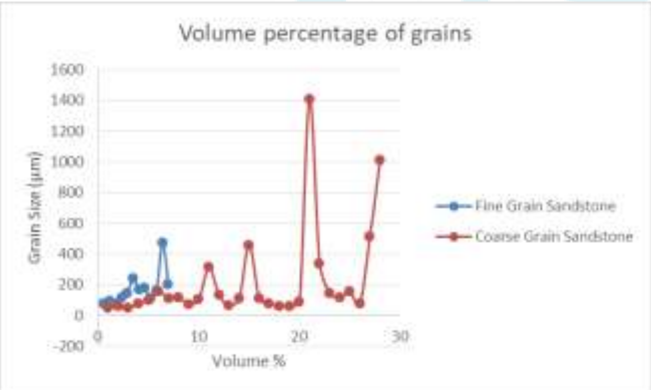



**Figure 3:** Volume Percentage of Grains

Figure 3 is the plotted data generated from the sandstone sample. The data were obtained by image J analysis performed on the micrograph image of the sandstone. The coarse grains were more than that of the fine grains so making the sandstone a coarse–grained sandstone which explains that the deformation bands in the sandstone are within on the larger mineral grains. Whereas the analysis of Figure1b the grain distribution on the sample surface was made because the grains very fine. The data was plotted in Figure 4.

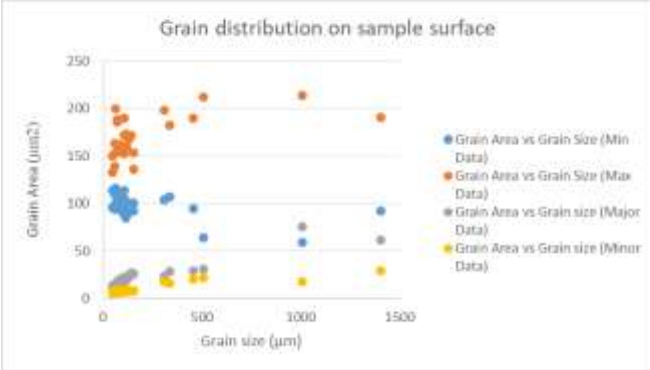



**Figure 4:** Grain Distribution on Sample Surface

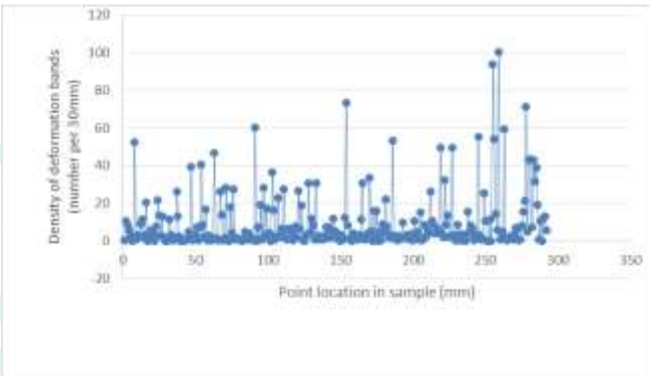



**Figure 5:** Number of Grains Counted at Deformation Band

Figure 5 illustrates the relationship between the density of deformation band of the sandstone layer region and the point location in sample. An average of 3bands were within 30mm in the sample at point location up to 280mm. Highest density of band was observed at a point where the proximity to slip surfaces is about 250mm. Deformation bands broadly increase in density with proximity to the faults although there is no correlation between deformation band density and the magnitude of fault offset. Deformation bands were mostly within the overlying coarse-grained sandstone, and commonly end abruptly at the fine-grained sandstone boundary.

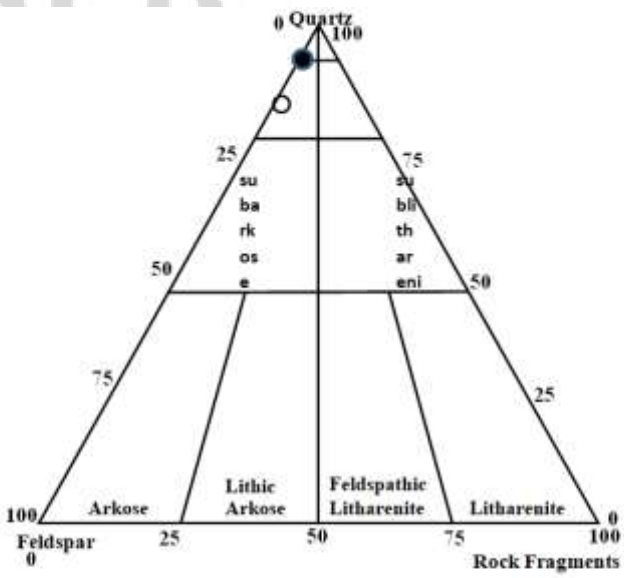



**Figure 6:** Triangular relationship of major minerals in Sandstone

In Figure 6 (triangular relationship) the mineralogy of the sandstone is represented in a relationship to deformation. An Aeolian facies is found in an upward fining sequence observed within overlying cross-stratified foresets of the sandstone. This grain size changes from medium to coarse grained but an intense deformation results into the loss of structure in pre-existing primary deposition. A facies was found in the underlying zone exhibiting sub-horizontal with a fine size-scale. They are purely fine-grained sandstone wavy laminae with insignificant change in grain sizes.

Quartz (95%), Feldsper4.5% and a trace of illite were found in the analysis of the coarse-grained sandstone which falls into the class of subarkose. Whereas 84%quartz, 10%Feldsper and 7% illite were found in the second sample and it is classified as quartzarenite mixed with another class called sandy (or calclithite) (Figure 6 ). The classification made are based on the work of Folk et al. (1970) which uses the quartz, feldspars and rock fragments (QFR) classification.

Therefore at points where quartzs grains slipage began, the grains disagreggate, the offset emerge and deformation begins. The deformation band appears. The ease with which the grains disaggregate is due to little or no cementation materials in the subarkose sandstone. The cementation materials between the grain to grain is the quartz which are very brittle because these materials constitute a friable property. The effect of the cementation of the quartz and feldspar strengthen the pore system of the quartzarinite sample which moderately reduces the friabable property of the rock. However the localized commination of the grain allow the formation of the deformation bands.(Figure 2). Therefore feldspar ($KSi_4O_8$) component crushes with preference to quartz within the rock system. The deformation indicated a fairly stronger bond between the grain contacts of the rock compared to the quartz in the subarkose rock. The shear component is the $KSi_4O_8$ is entrained into the deformation band. $KSi_4O_8$ is the chemical composition of feldspar which is easily fractured.

The deformation bands are clearly seen after considerable stresses after rock's response to the induced velocity and displacement field. These are small scale structures occurring in the sandstone. The feldspar shears (entrained) are captured in the Figure 1.

However at the field, the neighboring slip surfaces were observed to have sliped, this occurs close to sample point. Therefore the spike in deformation band at the Benue trough is originally due to the altered cohesion in the host-rock caused by the neighboring slip in the zone. By using the geometric model of Nicol et al., (2013) Deformation band were developed in the sandstone by reason of the fact that strain are formed in the rock and the rock becomes weakened forming a cluster at the geometric complexity or irregular lines of faults. Therefore if the slip surface is identified at the onset, the appropriate geometric model at Benue trough can be determined.

## 3. Conclusions

The reservoir scale impact depends on the intrinsic host-rock properties, permeability, orientation, connectivity and abundance of mineral present. This is in agreement with the findings of Sternlof et al. (2004) and Brandenburg et al. (2012). The possibilities of reservoir compartmentalization exist due to the presence of quartz cement which lowers the porosity in the core and ultimately the chemical composition of the core.

The results presents a schematic process of the likely dispersal of deformation bands and rock's porosity drop linked with conjugate sets of deformation bands between sandstones with varying intrinsic host-rock properties. If found within a core, the analogue studies in can be used to predict the extent of sub-seismic deformation bands through the effect of chemical composition of rock on reservoir performance. Sub-seismic fault-growth is described by the intrinsic geometry of damage zones linked to the mechanism of fault growth. This is in agreement with the theory of fault development by Schueller et al. (2013).

Deformation bands at Benue trough increases in numbers per unit area with proximity to fault Deformation bands are more abundant in the overlying matrix of coarse-grained sandstone. Feldspar is preferentially fractured in fine-grained sandstone.

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