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RESEARCH ARTICLE

STRUCTURAL MAPPING AND INTERPRETATIONS OF SOME OUTCROPS AT KUNTENASE : IMPLICATIONS FOR TECTONICS

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ABSTRACT

This study focuses on the structural mapping and interpretation of some outcrops at Kuntenase and its surroundings and how these structures may be indicative of deformational and tectonic activities and also to understand the potential influence of the lake on rock tectonics. Structural measurements including strike, dip and dip direction data of planar and linear structures were collected to characterize the deformational patterns in the study area. The main rock type identified from the petrographic analysis is a metasediment specifically phyllite and metagreywacke with mineral compositions of pyroxene, biotite, quartz and some amount of plagioclase. Field observations and data analysis was conducted to identify and analyse structural features such as faults, folds, joints, foliations and cleavage, providing insight into the deformation history of the rocks. A particular emphasis was placed on the relationship between the structures and the proximity to the lake Bosumtwi. By comparing the structural characteristics and the orientation of outcrops closer to the lake and those located farther away, variations in deformation intensities were identified. Beds of outcrops closer to the lake were more vertical in orientation compared to the ones farther away. Micro-structures observed included microlithon, quartz veinlets and stringers and also a micro level deformational rock cataclasite. Using the law of cross-cutting relationship - since dating has not been done to tell specifically which one is older- the structures being cut across are relatively older and the ones cutting being relatively younger. Thus, new structures may have been formed due to the impact crater. The flow pattern of water in the area is along strike of most of the structures NE-SW thus the drainage system is controlled by the structures in the area.

KEYWORDS

structural mapping, rock deformation, micro-structures

1. INTRODUCTION

Approximately 98% of the Ashanti region is comprised of Birimian and Voltaian rock formations. The Tarkwaian system and the basic intrusive rocks constitute the remaining 2% of the underlying geology in the region (Kesse, 1985). Birimian rocks account for around 54% of this and are made up of Precambrian igneous and metamorphic rocks. These primarily include phyllites, schists, migmatites, granites, granite gneiss, and quartzites, predominantly found in the North-Western and South-Western areas of the region (Owusu et al., 2013). The Tarkwaian system comprises a thick series of rudites, arenites, and argillites from the Precambrian era, with the main rock types being conglomerates, grits, and quartzites. The geological setting of Kuntenase is characterized by Precambrian rocks of the Birimian and Tarkwaian formations associated with granites and metamorphosed sediments of phyllites and schists (District profile of Bosumtwi, 2007).

Geological structures refer to the arrangement of rocks in the earth crust. Some of these structures form at the time of formation of the rock mass in which they are found. These are called primary structures. Examples are beds and laminae in sedimentary rocks like sandstone, or shale, and lava pillows in extrusive igneous rocks like basalt (John and Morgan, 2024). Secondary structures form due to the later deformation of primary formations. Initially, many layered rocks—such as sedimentary rocks, certain lava flows, and pyroclastic deposits—are deposited in nearly horizontal layers. Geological studies have been going on in the Bosomtwi crater from the 1930's and these have led to a large storage of geological knowledge of the area. Work done by most of researcher, have all focused on defining the geological framework of the Bosomtwi impact crater (Boamah et al., 2003; Hastings et al., 1981; Junner, 1937). According to a study, the area immediately around the crater rim is strongly deformed based on the study of road cuts; the crater rim zone has been subjected to impact induced faulting as well as folding which our study area (Kuntenase) may also be part of, yet a comprehensive structural analysis is lacking (Boateng et al., 2012). This research reports on the mapping of Kuntenase for tectonic and deformational activities in outcrops and the structures they come with.

Structural mapping is the identification and characterization of structural expressions. These structures include faults, folds, joints, etc. Understanding structures is the key to interpreting crustal movement that have shaped the present terrane in this case Kuntenase (Canada, 2015). Structural analysis proceeds through three linear stages: 1)

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description of the structural geometry of a deformed field area (bedding attitudes, planar fabrics, linear fabric, joints, etc); 2) kinematic analysis (movements responsible for the movement of structures [translation, rotation, distortion and dilation] and relative timing) and 3) dynamic analysis (interpretation of forces and stresses responsible for the deformation) (Lageson, 1977). To conduct geological-structural mapping, it is essential to understand the tectonic and geological context in which the structure evolved.

2. Regional Geology

The Ashanti Region, situated in the south-western part of Ghana, encompasses an area of approximately 24,390 square kilometres accounting for about 10.2% of the country's total land

area (Owusu et al., 2013). The region's geology is characterized by three main geological systems: Birimian, Tarkwaian, and Voltaian formations. The Birimian Formation is the most extensive geological unit in the Ashanti Region, covering the majority of the area. It is divided into two main divisions: the lower and upper Birimian series, with the lower Birimian series dominating the entire area (Ofosu et al., 2014). The Birimian is intruded by large masses of granites and basic intrusive rocks, which are typically of post-Birimian and pre-Tarkwaian age (Ofosu et al., 2014). According to Goldfields annual report (2016) the Tarkwaian formation is a sequence of metasedimentary and metavolcanic rocks that overlie the Birimian formation. The Ashanti Belt, characterized by a north-easterly striking, broadly synclinal structure, comprises lower Proterozoic sediments and volcanics, which are underlain by the metavolcanics of the Tarkwaian formation. The Voltaian formation is a relatively minor geological unit in the Ashanti Region, consisting of metasedimentary rocks that are found in the north-western part of the region (Ofosu et al., 2014). The geological formations in the Ashanti Region are characterized by faults, fractures, and quartz veins, which contribute to the high water-bearing and yielding capacity of the region.

2.1 Local Geology

The Bosomtwi District is underlain by Precambrian rocks from the Birimian and Tarkwaian formations. These rocks are associated with granites and metamorphosed sediments such as phyllites and schists. The geology of the district is also influenced by tectonic events, including the formation of the Bosumtwi impact structure (features which are not fairly fresh and are altered by erosion), which is a result of a meteorite impact that occurred in the area. The local geology is characterized by northeast-southwest trends with steep dips either to the northwest or southeast. However, variations in this trend, due to folding, have been observed (Reimold et al., 1998). Lithology at and around Lake Bosumtwi is dominated by metagreywackes and metasandstones, but some shale and mica schist are found, especially in the north-eastern and southern rim sectors (Reimold et al., 1998). The rocks in the crater rim zone are usually only subjected to relatively low shock pressures (commonly <2 GPa) leading mostly to fracturing and brecciation. The presence of planar deformational features in rock-forming minerals (e.g., quartz, feldspar, or olivine) provides diagnostic evidence for shock deformation (Stoffler and Langenhorst ,1994). Recent rock formations include the Bosumtwi lake beds, as well as soils and breccias associated with the formation of the crater (Junner, 1937; Kolbe et al., 1967; Woodfield et al., 1966; Jones et al., 1981; and Reimold et al., 1998). Figure 1 presents the geological map of the Bosumtwi crater and its surrounding areas of which the study area is included.

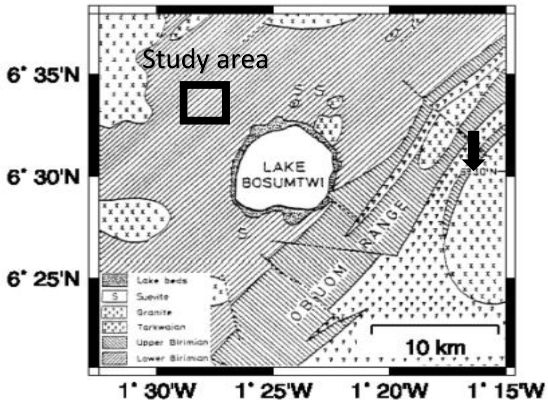

Figure 1: Schematic geological map of the Bosomtwe crater area showing the surrounding areas of the lake and the study area (after Jones et al., 1981).

3. Materials And Methodology

Fieldwork included conducting general geological field mapping and taking samples from various outcrops encountered. The subsequent laboratory analysis involved the petrographic examination of the collected samples. The field mapping was carried out at Kuntenase, the capital of the Bosomtwe District. The area is characterized by metasedimentary rocks like phyllite and schist, with structures such as faults, folds, joints, foliation, sills, dykes, and boudins. The field mapping exercise at Kuntenase involved a detailed examination of some massive outcrops and other smaller outcrops to understand their geological characteristics, tectonic activities, deformations and structural features. The type of mapping employed in the field work was exposure mapping.

During the fieldwork, we systematically documented various structural features such as folds, fractures and foliations, employing precise measurement techniques to capture their dimensions and orientations. Additionally, we collected rock samples for subsequent petrographic analysis to further analyse the texture of the rocks and also look for evidence of deformation at the micro level. Sampled rock samples were transported to the Geological Engineering Laboratory of Kwame Nkrumah University of Science and Technology for thin sections and petrographic studies.

3.1 Petrographic Analysis

3.1.1 Megascopic sample description

Observations of the physical properties of the samples were made with the bare eye together with the aid of the hand lens. These observed physical properties were recorded. The magnification of the hand lens is ×10 making it easier to identify structures and minerals that are not readily seen with the naked eye. Some of the megascopic properties that were readily observed include; deformational features, colour, texture and mineralogy.

3.1.2 Thin section preparation

The process begins with sample selection and sorting. Representative rocks of the samples collected from the field were selected ensuring that they capture some key features for investigation. Using the rock cutting machine which has a diamond saw, the selected samples were trimmed in a way that will ensure that some features of interest will be maintained and then flattened into rectangular slabs that are smaller in dimensions compared to the petrographic glass slide. The samples were then placed in an oven at a temperature of 105° in order to dry. The surface of the glass slides onto which the samples will be bonded was gritted on a louver blade together with silicon carbide and a little water until the glass slide exhibits a cloudy surface, ensuring effective bonding. The gritting is done to achieve a smooth polished surface that is optically flat for effective bonding. Gritting was done in order of sheets P60, P80, P120, P180, P240, P400, P600, P1000, and P1200 with P60 being the roughest and P1200 being the smoothest. After gritting, the smooth (gritted) surface is then bonded onto the frosted slide using epoxy glue. This was done by impregnating the smooth surface of the slab with epoxy resin and then carefully placing the frosted glass onto the surface. It was then left to dry for further cutting. After the bonding, a rock cutting and grinding machine with a diamond-coated grinding wheel was used to gradually cut, reduce and thin the sample on the slides while monitoring the thickness and transparency of the rock sample on the slide. This is done using the cutting machine. The polishing is continued until a thickness of 30μm of the rock sample is achieved. That preferred size, is to allow light to pass through the slide for easy visibility of the minerals and structures in the sample when placed under the microscope. The microscopic properties in the prepared thin sections were then observed under microscope to identify the minerals present, their relative abundance and visible micro structures with their implications.

4. Results And Discussions

4.1 Field Observations

The outcrops within the study area primarily consist of Birimian metasediments, which are predominantly grey and reddish-brown in colour. The metasediments encountered were randomly dispersed with few being massive with widths and heights of approximately 200m and

15m respectively whiles others are highly weathered and barely outcropping. Outcrops closer to the lake Bosomtwe exhibit near vertical beds of outcrops with variable orientations in NE-SW direction while others are oriented NW-SE. Most of the outcrops near the lake presents a folded structure, specifically an antiform indicating significant deformation. Within unusually large exposures of the metasediments located at significant distance away from the lake are minor anticlinal and synclinal folds, such as is indicated in Figure 2 (a) and (b) respectively, with a fault running through both the phyllitic and highly jointed rock material. Intrusions of quartz veins were observed in the outcrops. The rocks are heavily jointed and foliated. The grain size of the sediments ranges from medium to fine and the predominant mineral visible within the rock is quartz.

The outcrop (massive) in Figure 2(a) is located at coordinates Lat 6° 31′ 8.76″ N, Long 1° 26′ 49.42″ W at a significant distance from the lake, revealing a complex relationship of rock types and structural features. Spanning approximately 195 meters in width and standing 13 meters tall. The massive outcrop which is moderately weathered provides a vast space for detailed examination due to extensive excavation. The whole exposure is primarily made up of two distinct rock types: a dark to light grey fine-grained phyllitic material and a reddish-brown competent medium grain size metagreywacke. The reddish-brown colour of the competent rock (metagreywacke) is as a result of oxidation which indicates the presence of iron in the rock. In Figure 2(a), there is evidence of ductile and brittle deformation displayed with well-defined series of folds and faults. These are indications that the entire rock is/was subjected to extreme pressure and heat. Brittle deformation is predominantly observed in the metagreywacke through fault, joint systems and fractures. The alignment of mineral grains within foliated layers (Figure 3) offers clues to the geological conditions such as extreme pressure under which these rocks were formed and subsequently altered into different foliation patterns, namely, S_1, S_2, and S_3. The general trend of most structures measured is NE-SW. Throughout most of the massive outcrops, there are intermittent highly weathered materials which are intruding vertically into the exposure. The phyllites exhibit a curve of previous foliations such that the original foliations appear to be inscribed by a later foliation indicative of crenulation. S_1 is at an oblique angle with S_2, whilst S_2 is also at an oblique angle with S_3.

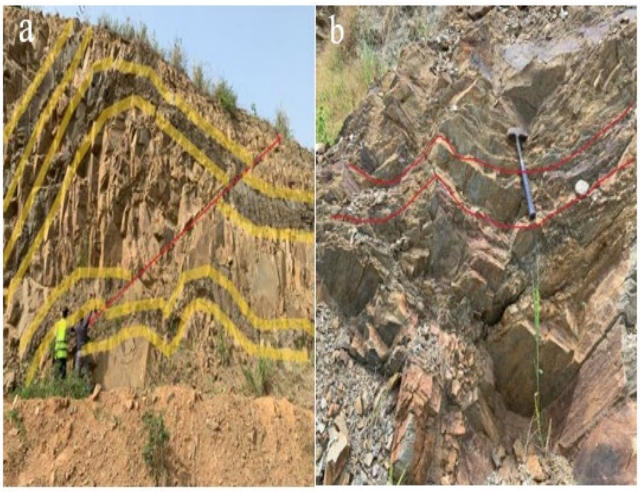

Figure 2: (a) a massive highly jointed and folded metasedimentary rock with a fault running across **(b)** a metasedimentary rock with anticlinal folds at Kuntenase.

At coordinate Lat 6° 32′ 34.91″ N, Long 1°26′ 21.44″ W is another massive outcrop (Figure 4) which is much closer to the lake compared to the other outcrops. It has outcrops whose beds are nearly vertical Figure 4(a) and it is predominant of phyllite with the whole exposure folding but a missing fold hinge as a result of intense erosion at the top. At coordinates Lat 6° 32′ 36.35″ N, long 1°26′ 21.44″ is a shear zone with pulverized rocks of both metagreywacke and phyllitic fragments which are 2cm to 5cm in sizes shown in Figure 4(b). The rock is slickenside and with grooves on some surfaces Figure 4 (c) and (d) respectively. There are igneous intrusions (sills) of 0.5cm to 1cm in width within the metagreywackes (Figure 5).

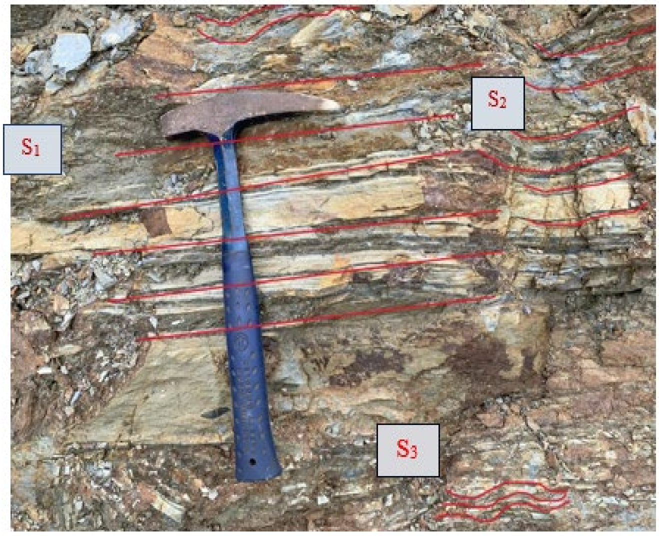

Figure 3: Foliation within a metasedimentary rock layer at Kuntenase.

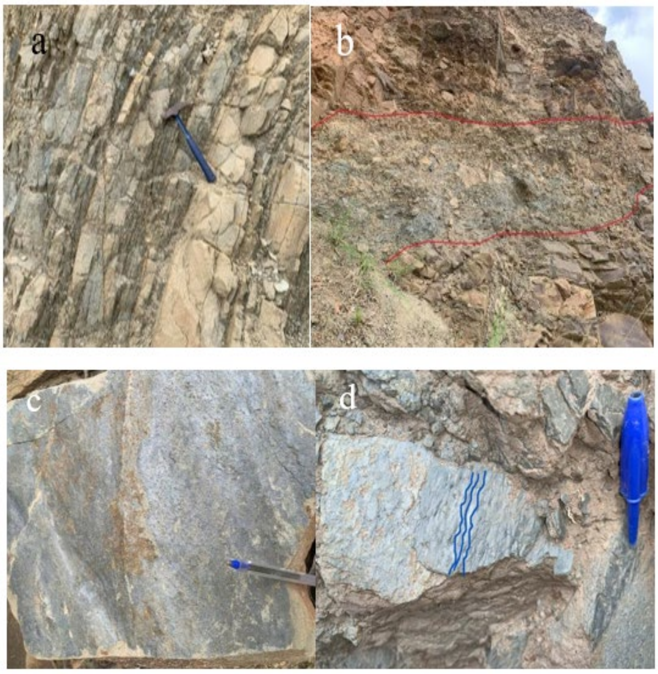

Figure 4: Metasedimentary outcrops encountered close to the lake Bosomtwi few meters from Kuntenase Township. (a) Shows the near vertical nature of the outcrops (b) shear zone with pulverized rocks sizes of about 2cm-5cm (c) slickenside surface of some rock material around the shear zone and (d) a grooved surface.

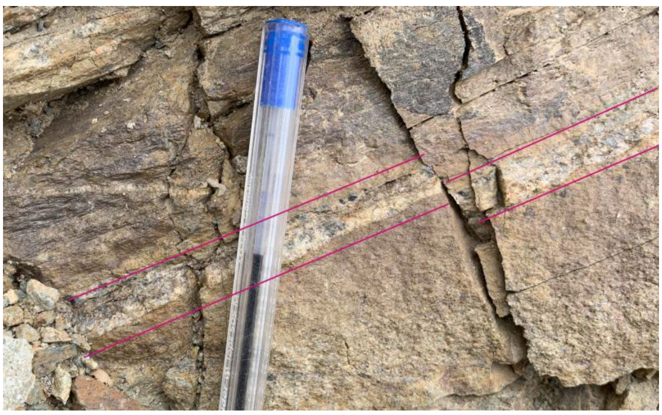

Figure 5: A faulted Igneous intrusion (sill) in a metasedimentary rock few meters from the lake.

4.2 Petrographic Analysis

4.2.1 Macroscopic Description of the Rock Samples

Samples collected from the field were sorted and described macroscopically to identify some physical observable features. Some of these features include colour, texture, minerals and state. Table 1 illustrates a brief summary of these descriptions.

Table 1: A brief description of the selected few samples from the field.

PHYLLITE (sample P) 	The rock has a distinct layered appearance with alternating light and dark bands. It has well sorted grains. The overall colour varies from grey, brown to green tone. With the brown tone indicating some rusting which further implicates the presence of iron. The rock feels hard and dense to touch. The grains are fine and tightly compacted. There are small flakes of mica visible on some of the layers of the rock. The edges of the rock are sharp and angular.
METAGREYWACKE (sample M) 	It has a predominantly reddish brown to grey colour and some reddish patches. It is poorly sorted with medium-grained particles. There are visible bands of quartz intrusions running through the rock. The rock has a somewhat smooth surface with rough edges. There are no noticeable large mineral grains present and the rock appears to be resistant to weathering as evidenced by the smooth surface.

4.2.2 Microscopic Analysis

4.2.2.1 Sample P (Phyllite)

Observations made on the sample under the microscope shows the following minerals and their properties. Some observed minerals include quartz (Qz), biotite (Bt), pyroxene (Px) and plagioclase (Pl) with some elements of opaque (Opq) minerals. Most of the mineral grains are medium to fine grain, predominantly fine grains. The grains are well sorted with some sort mineral alignment. The observed mineral quartz appears to be broken and scattered across the whole of the entire space. Due to the extent of alteration of some of the minerals it is difficult to distinctively point them out. The photomicrographs presented in both XPL and PPL below provides some information about the said rock, Figure 6.

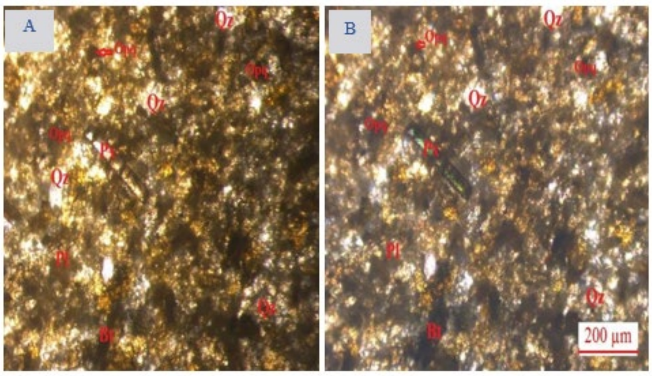

Figure 6: A photomicrograph (x10) of a phyllite showing minerals such as quartz, pyroxene and plagioclase under both **(A)** PPL and **(B)** XPL.

4.2.2.2 Sample M (Metagreywacke)

Observations made on the specimen under the microscope indicates the following minerals and their properties. The minerals include quartz (Qz), plagioclase feldspar (Pl), orthoclase feldspar (Or) some traces of opaque (Opq) minerals with the matrix (Mtx) forming a major part of the space. The mineral grains appear to be grading from coarse grains to fine grains. Most of the grains are angular implying that the rock is immature. The dark patches on the slides were classified as opaque minerals since they transmit no light. A photomicrograph that describes the features of the said rock is displayed in Figure 7.

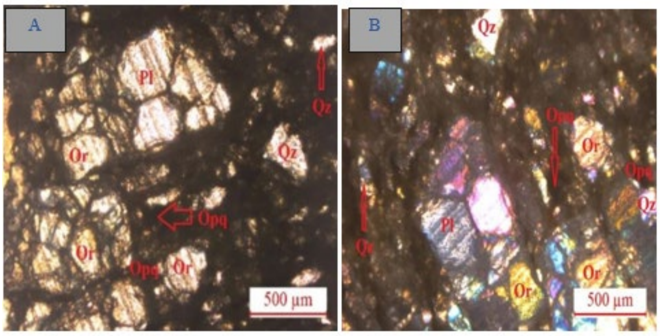

Figure 7: A photomicrograph (x10) of a metagreywacke showing minerals such as quartz, orthoclase and plagioclase feldspars under both **(A)** PPL and **(B)** XPL.

Table 2: Microscopic description of phyllites encountered at Kuntenase

	Properties	1	2	3	4
Plane polarized light (PPL)	Colour Shape Pleochroism Cleavage Relief Habit	Colourless Anhedral No No Low Prism	Yellowish-brown Subhedral Yes 1 directional Moderate Tabular	Yellowish brown Euhedral Yes Perfect 90^0 High Needle-like	Colourless Subhedral No 90^0 Low Prism
Cross polarized light	Interference colour Birefringence Extinction Twinning	White-grey Low Undulose No twinning	Green, blue (2nd order) Low Parallel extinction No twinning	Green (3rd order) High Oblique extinction No twinning	White Low Inclined extinction Albite twinning
Mineral percentages (%)		55%	10%	15%	20%
Mineral name		**Quartz**	**Biotite**	**Pyroxene**	**Plagioclase**
	Phyllite (sample P)				

Table 3: Microscopic description of Metagreywackes at Kuntenase

	Properties	1	2	3	4	5
Plane polarized light (PPL)	Colour Shape Pleochroism Cleavage Relief habit	Colourless Anhedral No No Low Prism	light-green (1st order) Subhedral No Perfect 90^0 Low Tabular	Colourless Subhedral No 90^0 Low Prism	Dark brown ----- No ----- ----- -----	Black Anhedral No No High -----
Cross polarized light	Interference colour Birefringence Extinction Twinning	Grey Low Undulose No	Pale-yellow (1st order) Low Simple Extinction Carlsbad	White-grey (1st order) Low Parallel Extinction Albite	Yellowish brown ----- No No twinning	No No No No twinning

Table 3 (cont): Microscopic description of Metagreywackes at Kuntenase						
Mineral percentages (%)		50%	10%	5%	15%	20%
Mineral name		**Quartz**	**Orthoclase**	**Plagioclase**	**Matrix**	**Opaque**
	Metagreywacke (sample M)					

4.2.3 Micro-Structures

Analysis done on the few samples collected from the field indicated that some structures observed on the field physically, appear to be manifesting at the micro level. These structures include quartz veinlets and stringers. Microlithons were also observed together with micro deformational activities in a cataclasite rock. Some of these observed micro-structures are interpretative of the level of deformation and stresses that have caused those deformations. Below are some results obtained from the micro tectonics.

4.2.3.1 SPECIMEN 1

The rock is highly fractured with quartz veins and veinlets cutting across each other which depicts brittle deformation. Each vein and veinlets relatively represent different episode of deformation and hence different ages. There is a very close proximity between where the rock was sampled and the Lake making it possible to establish that the rock may have been affected by the impact of the crater under high temperature and pressure condition. The older vein has been superimposed by the younger vein as shown in Figure 8. It may then be concluded using cross cutting relations that, the older veins might have existed before the impact crater and the younger ones came resulting from the impact crater.

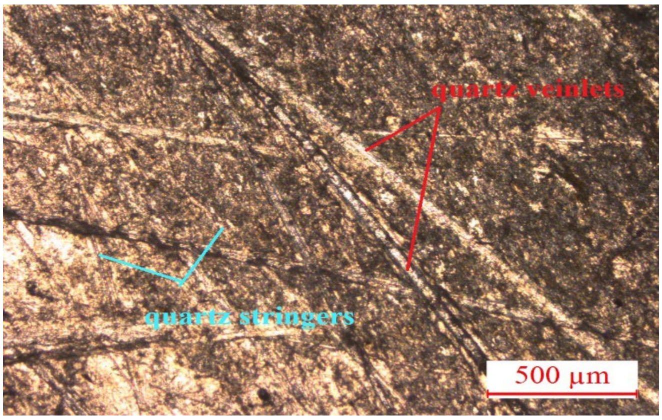

Figure 8: A photomicrograph under PPL with a magnification of ×10 indicating quartz veinlets and stringers cutting across each other.

4.2.3.2 SPECIMEN 2

The photomicrograph shows a rock of different sizes of mineral grains. The quartz mineral is of angular and sub-rounded shapes showing grain sizes of fine, medium and coarse. The different grain sizes of the quartz and the nature of the brokenness depicts that the quartz mineral has undergone straining and deformation. The type of deformation of this rock demonstrates brittle behaviour. The rock may thus be a cataclasite (Figure 9).

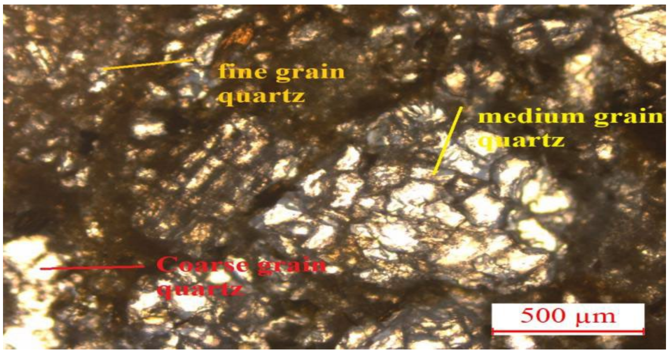

Figure 9: A photomicrograph of ×10 magnification under PPL of a cataclasite rock.

4.2.3.3 SPECIMEN 3

Under the microscope the specimen shows quartz with different grain sizes, these grains are surrounded by dark coloured minerals which are foliated, known as domain (i.e. foliation). The foliation is as a result of first deformation (D_1) caused by compressive force. The quartz grains surrounded by the dark coloured minerals are also referred to as microlithons. Microlithons are small minerals, relatively undeformed sections of rock that are found between zones of foliation or cleavage in a metamorphic rock. These zones called shear bands or cleavage domains are areas where the rock has been more heavily deformed and exhibit a strong alignment of minerals. Microlithons retain more of the original structure and texture of the rock prior to deformation and can provide important information about the rock's pre-deformation history.

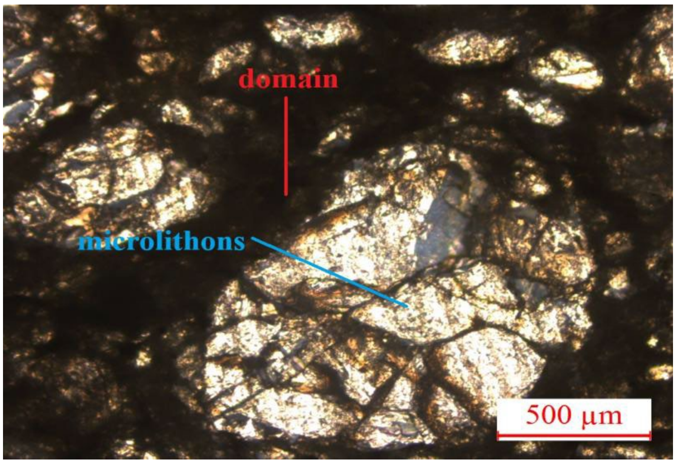

Figure 10: A photomicrograph of ×10 magnification for a broken quartz surrounded in dark coloured minerals.

4.3 Generation of Maps

4.3.1 Outcrop Map

The outcrop map shows the various locations of outcrops discovered in our study area. The three outcrops located along the road on the map are massive and much closer to the lake compared to the rest which are greatly weathered. The outcrops are all metasediments. Few outcrops could only be encountered farther away from the lake because they were barely outcropping. The general trend of the outcrops is NE-SW.

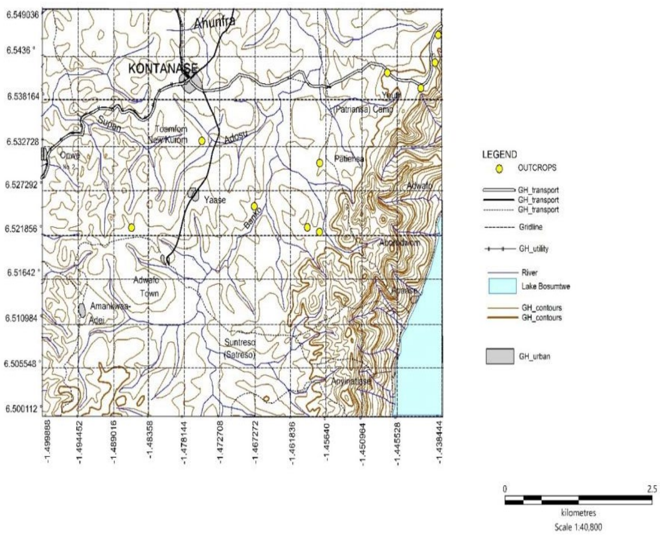

Figure 11: Outcrop map of Kuntenase and its environs showing the locations of some outcrops

4.3.2 Structural Map

The structural map shows the spatial distribution, orientation and relationship between the structures in Kuntenase and its surroundings. The structures observed are more prominent in the massive outcrops by the road closer to the lake, this is indicated by the red section. A magnification of the section is indicated in Figure 12 as the structures measured were closer to each other.

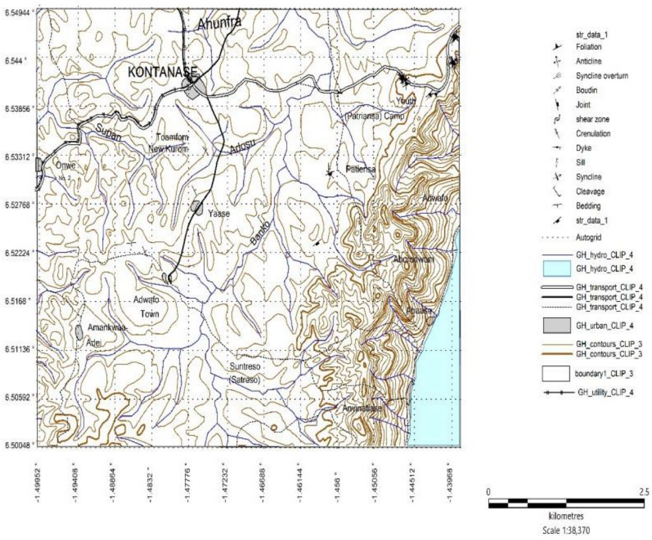

Figure 12: Structural map of Kuntenase and its environs showing the spatial distribution of structures

5. Conclusion

This work involves the study of geological structures at Kuntenase and its surrounding through structural mapping and microscopic analysis. A mapping exercise was conducted in some parts of Kuntenase and its environs during which the predominant structures observed in most outcrops were joints, faults, folds and foliations. This was established through traversing, identifying, describing and taking attitudes of structures. Outcrops that were farther away from the lake had less structures as compared to the ones that were closer to the lake. Geological structures of varying ages (i.e. relative ages) representing different episodes of deformation were identified through the principle of cross-cutting relationship.

On analysing the samples based on petrography, it was established that the samples belong to the metasedimentary rock units specifically metagreywacke and phyllite. The mineralogical composition of the phyllite include pyroxene, biotite, quartz and some amount of plagioclase with quartz been the dominant mineral and that of the metagreywacke include orthoclase, plagioclase, quartz and some opaque minerals with quartz and feldspar being dominant. Lines of evidence of deformation were seen in thin section under the microscope as shown in Figures 8, 9 and 10. The presence of quartz veinlets and stringers intersecting each other as shown in Figure 8 and the Cataclasite nature of the rock in Figure 9 are supporting lines of evidence of brittle deformation of the rocks in the study area.

The presence and spatial distribution of varieties of structures observed in the outcrops on the field shows that the intensity of deformation that Kuntenase and its environs have suffered is very high. Structures that maybe of relatively different ages make it possible to establish that the area has undergone different episodes of deformation and this has shaped the structural geology of the area. Since there is a close proximity between the lake and the area under study, it can be inferred that the impact crater may have caused a disturbance and some of the deformations registered in the rocks as structures might be as a result of this impact. Also, the results from the petrographic and microstructural analysis confirms some of these lines of evidence seen on the field. The presence of a high temperature and pressure mineral in the phyllite which was sampled at about 300m away from the lake implies that the rate of metamorphism increases as one moves towards the lake and this also supports the hypothesis that the rocks in the area have been affected greatly by the genesis of Lake Bosumtwi. The brokenness of mineral grains in Figure 9 also depicts the high rate of strain that the rocks in the area have suffered. Overall, the drainage patterns in the area are controlled by these geological structures and this was established based on the fact that these patterns follow the general strike of the structures in the study area, NE-SW.

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