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Full Length Research Paper

Determination of the Source and Depositional Environment of Sediments of Lake Bosumtwi using X-Ray Diffraction (XRD) Techniques

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The source and depositional environment of the top 2 – 8 cm of the sediments of Lake Bosumtwi in Ghana, West Africa, have been determined using x-ray diffraction (XRD) techniques. The sediment samples were collected at different locations in the lake using Ekman dredge. Oriented clay mineral studies using the XRD methods reveal clay mineralogies of smectite, vermiculite, chlorite, illite, kaolinite micas, and their interstratified derivatives, suggesting a warm wet climate with increased chemical weathering by hydrolysis. The presence of greigite at the central deep water part of the lake suggests sulphate reduction under anoxic conditions, which indicate deposition in deep water. This further supports the inference of a wet climate. Quartz, orthoclase, anorthosite, muscovite and illite, which emerged from powder XRD results, point to a probable Birimian Supergroup provenance, and therefore the source for these top sediments.

Keywords: Depositional Environment, Clay Mineralogy, X-Ray Diffraction, Birimian Supergroup.

INTRODUCTION

The Bosumtwi crater in Ghana is located about 30 km south-east of Kumasi (Figure 1.1). The crater is occupied by Lake Bosumtwi and has a rim-to-rim diameter of 10.5 km (Junner, 1931; Jones et al., 1985). It is the youngest large and well preserved impact crater on Earth. The lake itself has a diameter of 8 km and a maximum depth of 75 m (Scholz et al., 2000). The Bosumtwi crater was formed by a meteorite impact about 1.07 ± 0.05 Ma years ago in lower greenschist facies meta-sediments (i.e. low grade metamorphosed rocks) of the 2.1 – 2.2 Ga Birimian Supergroup (Storzer and Wagner, 1977; Koeberl et al., 1997a, Wright et al., 1985; Leube et al., 1990).

Several studies have shown that the location, structure, morphology, hydrology and state of preservation of the Lake Bosumtwi crater and sediment record are unique (Peck, 2004, Talbot and Delibrias,1980; Talbot and Johannessen, 1992). First, Lake Bosumtwi is not fed by water input from any major stream or river; neither does it lose significant water to any major stream or river. Hence it is said to be closed in terms of hydrology. In fact, 80% of the annual water input to Lake Bosumtwi is from direct rainfall upon it (Turner et al., 1996a, 1996b). Second, Lake Bosumtwi is situated in the atmospheric region that is seasonally affected by both the northeast (NE) continental trade winds (Harmattan trades) and southwest (SW) onshore winds, referred to as the intertropical convergence zone (ITCZ) (Peck et al., 2004). Third, the overall watershed of Lake Bosumtwi is relatively small, and restricted by the crater morphology and surrounding mountain ranges. The combination of these attributes of the lake makes it very sensitive to changes in the main components of regional water budget (precipitation, evaporation and transpiration) (Turner et al., 1996 a, 1996 b).

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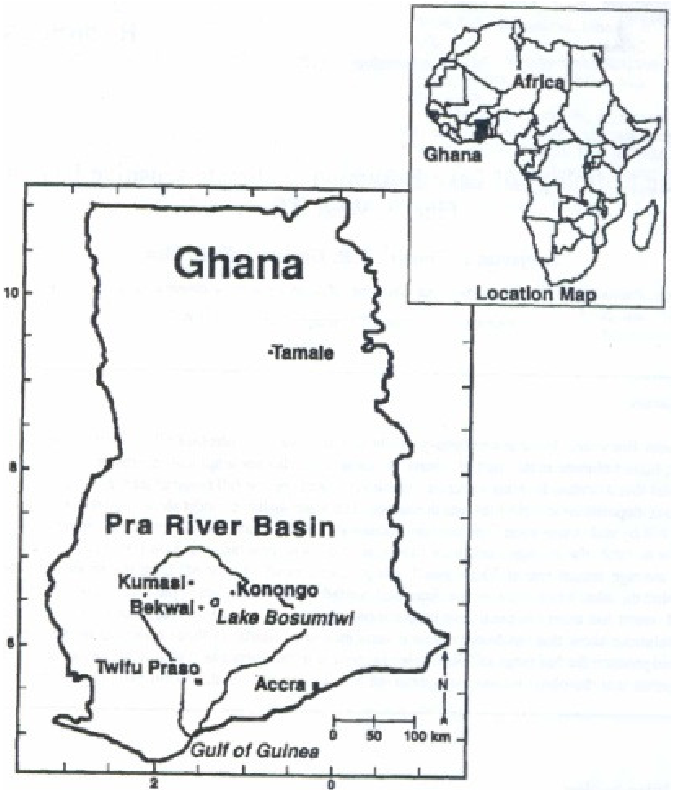

Figure 1. Map of Ghana showing the location of Lake Bosumtwi and the Pra River basin (solid line inside map)(after Turner et al.,1996).

Clay Mineralogy of Sediments as Climate Proxy

Clay minerals form from the hydrolysis of silicate rocks. The clay mineral content of sediments provides information on the climatic conditions under which they were formed. Hence clay mineralogy is a useful climate proxy. Clay minerals contain two patterns of layering (Nichols, 1999):

i. Two layers (the kandite groups) e.g. Kaolinite.
ii. Three layers (the smectite group) e.g. Montmorillonite, illite, chlorite, etc.

Kaolinite is the commonest member of the kandite group. It is formed in soil profiles in warm humid environments in acid waters and intensely leached bedrock lithologies such as granite. The smectite group clays are swelling clays, and absorb water within their structure. Montmoritlonite forms in moderate temperature conditions in arid climates. Chlorite forms most commonly in sediments with moderate leaching under fairly acidic ground water conditions. Illite and chlorite form from weathering products of volcanic rocks (Nichols, 1999).

The global distribution of clay minerals reveals a latitudinal zonation that strongly reflects the pedogenic and climatic zonation (Biscaye, 1965; Griffin et al., 1968; Windom, 1976; Chamley, 1989). In tropical to subtropical environments, both lacustrine and marine clay-mineral assemblages have often been a useful guide to paleoclimatic settings, because hydrolysis of rock-forming silicates in tropical conditions can change rapidly in response to climatic phenomena (Stoffers and Hecky, 1978; Kalinderafe et al., 1996; Gingele, 1996). Lakes are especially sensitive, because they have repeatedly formed closed basins during more arid times, increasing the alkalinity and salinity of the water mass and inducing diagenetic alteration of the clays (Stoffers and Hecky, 1978).

In cold temperate to polar regions, the chemical weathering reactions producing clay minerals have generally been viewed as too insensitive (kinetically slow) to provide much assistance in interpreting climatic change. Under these conditions, clay minerals have been regarded primarily as source-area indicators (Windom, 1976; Chamley, 1989). In the Antarctic Ocean for example, direct paleoclimatic information from clay-mineral assemblages can be derived from sediments older than Oligocene, prior to the Antarctic glaciation (Ehrmann et al., 1992). In Neogene and Quaternary sediments in contrast, temporal and spatial variations in clay minerals were traced back to different source areas and transport processes, the latter leading to indirect paleoclimatic conclusions (Ehrmann et al., 1992, Melles et al., 1995b).

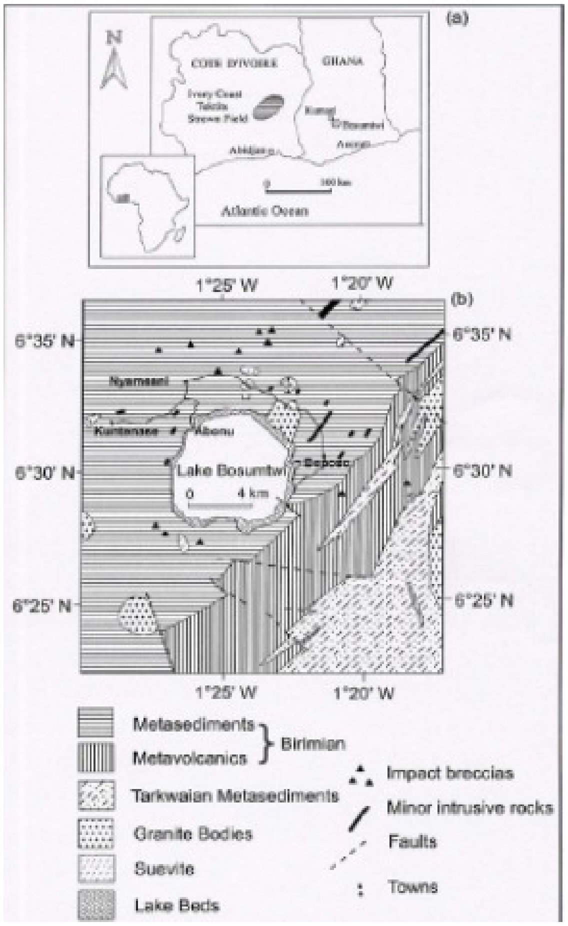

Figure 2(a). Location of Lake Bosumtwi in relation to tektites of the Ivory Coast. (b): Schematic geological map of the study area, and surroundings (after Koeberl et al., 1997a).

Two independent research teams examined the clay mineral content of sediment cores recovered from Lake Baikal, south-central Siberia (Yuretich et al., 1999). The independent analytical results of abundance changes and correlation with other data from the cores show that the clays respond to two influences (Yuretich et al., 1999):

i. Climatic fluctuations, particularly in the upper 40 cm of the sedimentary record, which show the relative amount of illite-smectite (and sometimes kaolinite) increasing during warmer climate episodes.
ii. Source area changes.

These clay mineral-based climate fluctuations were shown to be correlative with the marine oxygen-isotope record.

The paleoclimate and depositional environment can be studied using different proxies, including clay mineralogy, which is the focus of this paper. This study seeks to identify the clay minerals in the sediments and to determine the depositional environment and sediment sources.

Geology of the study area

The Birimian Rocks

Heavily brecciated greywackes and phyllites dominate the geology of the study area, with less ubiquitous occurrences of strongly weathered dike- and pod-like granitoid intrusions (Junner, 1937; Moon and Mason, 1967; Reimold et al., 1998). Graywackes predominate, and appear in many lithological variations between a silty, tufaceous phyllite and tufaceous grits. They are fine- to coarse-grained, light to dark grey impure fragmental arenaceous rocks, often containing clastic and tuffaceous materials. The finer variety exhibits good cleavages; while the coarser types are more massive with few, often obscured cleavages. The Bosumtwi crater is the source crater of the Ivory Coast Tektites (Figure 2a). Figure 2b shows the geological map of the study area.

The coarser grained varieties grade into pebbly grits and conglomerates containing sub-angular to rounded pebbles of quartz and squeezed pebbles of phyllite and lava; and the fine-grained types grade into phyllite. The coarse types typically contain high proportion of feldspar (feldspathic graywacke). Quartz veining, quartz stockwork and silicification are common in the graywackes. Graywacke outcrops exposed in road cuts are heavily fractured, shattered and appear cataclastic.

The phyllites are grey to black, fine grained and mainly argillaceous, but tuffaceous in places. Silicification is present in the phyllites in places, in bands. Silicified bands are sheared and crumbled to an apparently higher degree than the non-silicified zones (Boamah and Koeberl, 2003). Lenses and stringers of clear vein quartz occur in the foliae of both the silicified and non-silicified phyllites. These quartz veins are found in the same localities as the silicified phyllites, and by inference believed to have some origin as the silicifying silica, but are slightly younger since veinlets of the clear quartz cut the silicified phyllites.

The Birimian metasediments strike generally NE-SW and dip steeply (~80^0) to either NW or SE. Local disturbances exist around the crater rim, giving rise to irregular strikes and dips. These irregularities are believed to have been caused by the meteoritic impact event.

Intrusive Bodies

Several Proterozoic granitic intrusions occur in the region around the crater, and some strongly weathered granitic dikes occur around the crater rim (Junner, 1937; Woofield, 1966; Moon and Mason, 1967; Jones, 1985a; Reimold et al., 1998). These granitic complexes and dikes probably belong to the Kumasi-type granitoid intrusions for which an age of 2.0 – 2.1 Ga has been obtained (Taylor et al., 1992; Hirdes et al., 1992). Additional to granitic dikes with granophyric texture in places (Reimold et al., 1998), some of the dikes appear aplitic in the field. Some of the granites are highly shattered and greatly weathered like those outcropping in the road cut from Asisiriwa towards Boamadumasi. Other granite outcrops include foliated types penetrated by small dikes of aplite and quartz veins. The foliations in the granites trend NE and the most prominent joints have a NW-SE direction.

Most of the granite dikes conform to the foliation or bedding planes of the Birimian rocks into which they are intruded. The Pepiakese granite complex to the northeast of the crater is composed of a range of rock types, including hornblende diorite, biotite-muscovite granite and an almost pure albite (Jones, 1985b). Reimold et al. (1998) estimates the overall granitoid component in the region at no more than 2%. In addition, a few occurrences of dikes of dolerite, amphibolite, and intermedicte rocks have been noted.

Impact Breccia

Numerous breccia exposures have been mapped around the crater (Junner, 1937; Moon and Mason, 1967; Woodfield, 1966). However it is not certain as to whether all these breccias represent impact breccia. Reimold et al. (1998) opines that at least some of the breccias, likely, are the results of lateritisation and secondary mass-wasting processes, in this tropical and topographically varied environment where weathering can obtain thicknesses in excess of 50 m.

Using composition and texture as yardsticks, the Bosumtwi breccias could be grouped into three categories comprising an autochthonous monomict breccia, a probably allochthonous polymict lithic breccia, and suevitic breccias (Boamah and Koeberl, 2003).

In a roadcut to the northeast of the crater, outside the crater rim (from Asisiriwa to Boamadumasi), occurs an excellent exposure of partly consolidated breccia. This consists of unsorted angular fragments of graywackes (~60%), phyllite (~30%), schist (~7%), and granite (~3%) in a matrix of smaller fragments and dust derived from the same rocks. Most of the clasts are highly weathered and up to 30 cm in size. Clast shapes range from angular to subrounded. Based on comparison with local weathering products (lateritic surfaces), this exposure is interpreted to represent a mixture of impact breccia and locally accumulated products of secondary mass-wasting processes along the steeply dipping outer rim slopes. Coarse pieces of quartz are rare, but fine-grained quartz occurs in the matrix. From the thickness of the roadcut (about 2 m) and core samples recovered from drill hole (sunk during the 1999 shallow drilling program executed by the University of Vienna in collaboration with the Ghana Geological Survey Department), the thickness of this impact breccia is estimated at >20 m. Similar breccias outcrops occur in roadcuts along the same road (from Boamadumasi toward Asisiriwa). Clast sizes are large towards the Nyameani–Asisiriwa main road, up to 60 cm compared to about 30 cm in the breccia farther to the north from the crater towards Boamaduamasi (Boamah and Koeberl, 2003).

The monomict breccia often grades, on a metre scale, into unbrecciated rock. The rocks are shattered more or less in situ without much displacement. Shattered rock consists of angular fragments of different sizes, which are irregularly distributed and recemented in a matrix of the same material. This category is found on the road from Nyameani to Asisiriwa and along the crater wall as was described by Moon and Mason (1967), as having formed by changes of the surface elevation without much lateral displacement.

Rarer is the Bosumtwi suevite, a glass-bearing breccia similar to the suevite of the Ries crater in Germany. The occurrence of suevite in the north and southwest of the Bosumtwi crater, outsite the crater rim, was first mentioned by Junner (1937), who referred to the deposit

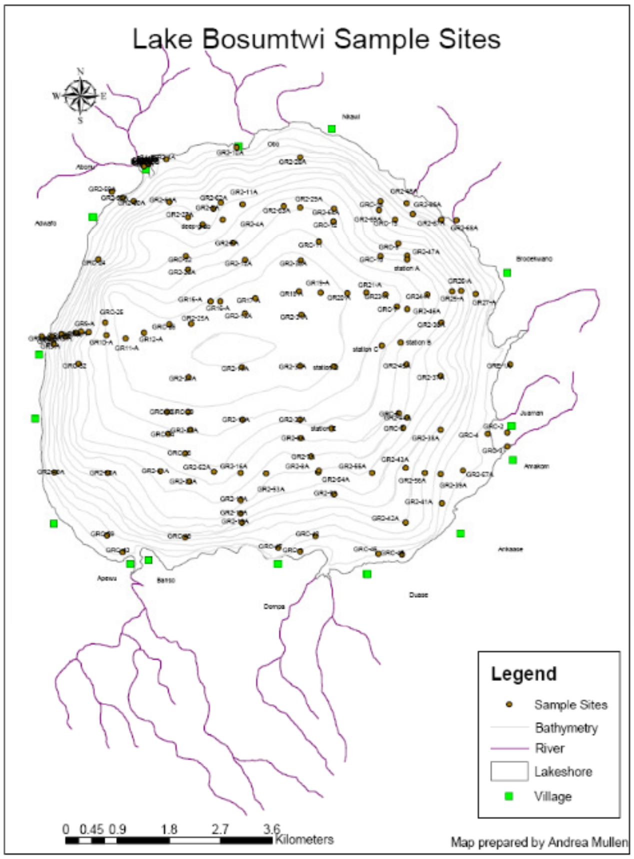

Figure 3. A map showing the GPS locations where the samples were collected.

as volcanic tuff and conglomerates. Suevite is defined as polymict impact breccia including cogenetic impact melt particles, which are in a glassy or crystalline state, included in a clastic matrix containing littic and mineral clasts in various stages of shock metamorphism (Stöffler and Grieve, 1994). The Bosumtwi suevite is greyish in colour with abundant glass and clast up to about 40 cm in size.

The suevite is the most interesting deposit of the Bosumtwi crater formation. It represents that type of ejecta formation that contains target rocks in all stages of shock metamorphism, including vitreous and devitrified impact glasses. The Bosumtwi suevite occurs as large blocks of up to several metres width as patchy massive deposits more or less covered by thick vegetation in a marginal zone (~1.5 km^2) outside the rim of the crater in the north, ~2.5 km from the lakeshore (location area of $1^0 23.5^1$-$1^0 24.5^1$W and $6^0 33.5^1$-$6^0 34.2^1$N) (Boamah and Koeberl, 2003).

One of these outcrops is a massive suevite exposed ~2 m in thickness. It contains melt inclusions and rock fragments (greywacke, phyllite, shale, granite) up to 40 cm in size, with greywacke dominating. Most of the rock fragments are subangular in shape and less than 20 cm long and are arranged in a disordered fashion. Individual and isolated grains of quartz and feldspar are also present. The matrix is essentially composed of fine-grained particles of predominantly quartz, feldspar, and highly vesicular glass (Boamah and Koeberl, 2003).

MATERIALS AND METHODS

Overview of the Methods

The top 2 – 8 cm of sediment samples were collected at specific global positioning system (GPS) locations (as shown in Figure 3) from the lake with Ekman dredge and used for the analysis.

X-Ray Diffraction Techniques (XRD)

The samples for the x-ray diffraction (XRD) studies were selected from various locations in the lake as follows: the central deep part; the northeast (NE) part (near the granites; see Figure 2), the southwest (SW) part (opposite the granites), the Abonu transect in the northwest (NW) and the Duase transect in the southeast (SE).

Quick and Dirty XRD Analyses

Seven samples representing central deep, NE (near granites), SW (opposite granites) and generally shallow water regions were analysed using the quick and dirty powder XRD technique. The samples were air-dried and grounded into fine powder. Circular XRD analytical glass slides were washed and dried with paper towel and set on clean white sheet. By means of a spatula, small quantity of the fine sample powder (just enough to uniformly coat the surface of the circular glass slide) was fetched onto the clean glass slide. A few drops of acetone was added to the dry powder sample on the glass slide and spread uniformly on it. The sample was allowed to dry in acetone, in open air, at room temperature. The sample slide was now stuck onto a metal sample plate by means of plasticine, and set into the slide holder. Slide holders containing the samples were then loaded into the magazine of the Philips PW1710 BASED diffractometer, and analysed through a continuous scan. The XRD mineral identification was done through comparison of the resulting diffractogram with standard reference patterns and measurements.

Powder Pack XRD Method

Three samples, namely, GRC-13A, GR2-32A and GR-8A representing NE (near granites), central deep and SW (opposite granites) respectively, were analysed using the powder pack XRD method on the PW1710 BASE diffractometer. In preparation of the powder pack sample, each sediment sample was grounded into very fine powder (<10 micron particle size) and loaded in the powder pack holder. The prepared samples in respective holders were then loaded into the diffractometer and scanned.

Mineral identification was also achieved by comparison of scan diffractograms with standard patterns. The comparison work was done by typing the code of suspected minerals in turn, into the diffractometer software, so the software searched for the mineral.

The Oriented Clay Mineral Mount XRD Method.

Twenty-six (26) samples comprising subsets representing central deep, NE (near granites), SW (opposite granites), Abonu transect (NW) and Duase transect (SE) were analysed for oriented clay minerals. The sample preparation for the oriented clay minerals was rather elaborate and rigorous. The process involved the following steps:

Air-drying and grinding

Sediment samples (wet) were air-dried for about a month. The dried samples were ground to very fine powder particles (<10µ*m* particle size).

Preparation of clay-particle size suspension.

The grounded samples were transferred into 50 ml polyethylene centrifuge bottles, and distilled (de-ionised) water added. The suspension was shaken for uniform mixing. 5% sodium metaphosphate was added to the sample suspensions and shaken. The sodium mataphosphate serves as a deflocculant.

Ultrasonic disaggregation and dispersion

The sample suspensions were exposed to ultrasonic vibration for 3 hours, so the sediments were disaggregated and dispersed ultrasonically. This treatment released all clay minerals complexly attached to other minerals or stuck to organic matter. Otherwise the clay/clay size material will remain attached to organic matter, and settle during centrifugation.

Centrifugation

The slurry containing the fine fraction was separated by decantation into 50 ml glass centrifuge tubes. This is centrifuged at 2000 rpm for 1 minute 10 seconds to cause all grains >2µm to settle out, according to Stoke’s law determinations. The settling times, t (in minutes), was determined from the relation (Jackson, 1975) below:

$$t = \frac{63 \times 10^8 n \log_{10} \frac{R}{s}}{(N_m)^2 (D_n)^2 (\Delta S)},$$

where N_m = number of revolutions per minute (rpm)
D_n = diameter in microns
n = viscosity in poises at 25^0C = 0.00894
ΔS = difference in specific gravity (relative density) at 25^0C = 1.653,
R = constant for 50 ml glass tube filled to the 50 ml mark = 12
s = constant for remaining empty space on top of the 50 ml mark of the 50 ml centrifuge tube = 4.
The supernatant liquid was transferred into a clean glass centrifuge tube.

Slide preparation

The density of the supernatant clay suspension (in a clean tube) was determined by placing the centrifuge tube in the optical clay-suspension densitometer, and recording the frequency in number of counts. The frequency (number of counts) is converted to

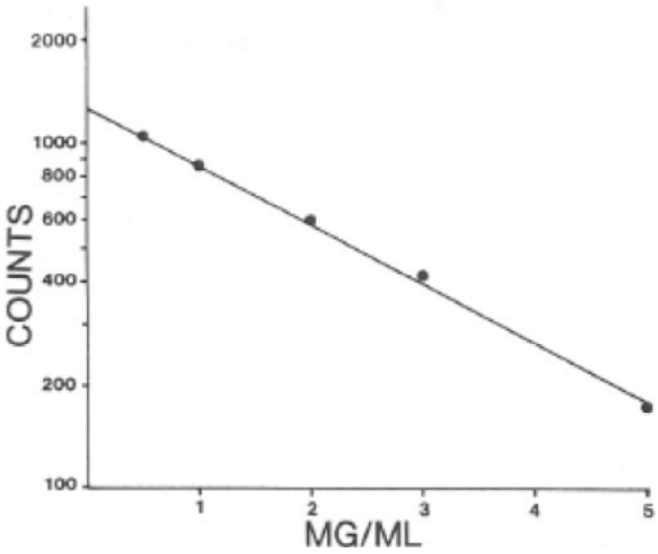

Figure 4. Calibration curve showing the relationship between frequency (counts) and concentration (after Foos and Quick, 1988).

concentration of clay suspension in mg/ml by referring to the calibration curve in Figure 4.

Determination of the number of millilitres of clay suspension required for the final thickness of the oriented clay mount was made based on the standard that, 50 mg clay = 10 mg/cm^2 for a 25 mm filter. So depending on the frequency of the clay suspension and hence its concentration, a pipette was used to deliver the right volume of clay suspension required to prepare the mount on a 25 mm filter.

The measured volume of clay suspension was vacuum filtered onto a membrane filter. While the filter (carrying the clay mount) was still moist, it was placed with the clay-side down on a clean glass slide. The filter membrane was then gently peeled back, to leave the oriented clay mineral mount on the glass slide. This was then left to dry in air at room temperature, for 24 hours. Dry oriented clay mineral mounts were then set in slide holders, and loaded in the diffractometer magazine and scanned. The sample analysis was done via XRD with Cu radiation using the Phillips PW 1710 BASE type goniometer updated with Databox digital processing system. Diffractograms were scanned at 20 to 35^0 2ϑ values, with a step size of 0.020 and a counting time of 1 s.

Glycolation

After scanning, the oriented clay mineral mounts were placed in desiccators containing ethylene glycol and solvated in the glycol-rich atmosphere at 60^0 for 24 hours. These glycolated samples were analysed again in the diffractometer, at the same specifications, as was the case for the air-dried unglycolated set. Ethylene glycol salvation causes clay minerals to have expansion of the d-spacing between atomic planes, while producing no effect in certain clay minerals. The effect as revealed by XRD analysis aids clay mineral identification.

Heating

Six (6) glycolated samples representing the central deep part of the lake, the NE (near granites), SW (opposite granites), and the transects in the NW and SE were subjected to further treatment by heating. The glycolated clay mineral mounts on glass slides were heated by means of an electronic oven to exactly 400^{0}C for 30 minutes. Heating dehydrates the sample, causing disappearance, of some peak diffractions, or collapse/reduction in the d-spacing of some minerals while producing no change in certain others. These changes are characteristic of specific clay minerals and could be used as an identification index. So, after heating to 400^{0}C, the set was re-analysed on the diffractometer at the same settings.

A second heating treatment was also conducted on the 400^{0}C heat set of samples. In this second heating phase, the samples were heated to 550^{0}C for 30 minutes. Upon removal, and cooling, the samples were analysed again using the diffractometer. The phase-two heating to 550^{0}C causes increase in intensity, additional collapse, or no change in the fingerprint d-spacing in the crystalline structures in the minerals. These changes also are important characteristic identification indices for clay minerals.

Table 1. Samples from central deep part of the lake

Sample	Mineral Present
1. GR2-32A	i. Corrensite
	ii. Rectorite (regularly interstratified mica-smectite)
	iii. Vermiculite-mica or illite-vermiculite
2. GR-16A	i. Rectorite
	ii. Mica, muscovite, dioctahedral vermiculite
	iii. Kaolinite-smectite (interstratified)
3. GRC-24A	i. Dioctahedral vermiculite
	ii. Palygoskite (attapulgite)
	iii. Chlorite-smectite (regularly interstratified) (also called Tosudite)
4. GR2-24A	i. Vermiculite
	ii. Muscovite
5. GR8A	i. Vermiculite-mica or illite-chlorite
	ii. Muscovite

Table 2. Samples from the NE part of the lake (near the granites)

Sample	Mineral Present
1. GRC-8A	i. Mica, muscovite (various polymorphs)
	ii. Chlorite
2. GR2-68A	i. Mica (muscovite) or vermiculite-mica
	ii. Rectorite (mica-smectite)
3. GRC-11A	i. Tosudite (regularly interstratified chlorite-smectite)
	ii. Vermiculite-mica or illite-vermuculite (regularly interstratified)
	iii. Mica, muscovite
	iv. Kaolinite-smectite (interstratified)
4. GRC-14A	i. Rectorite (regularly interstratified mica-smectite)
	ii. Vermiculite
	iii. Mica, muscovite
5. GRC-13A	i. Chlorite-mica or chlorite-illite (randomly interstratified)
	ii. Vermiculite-mica or illite (regularly interstratified)
	iii. Mica-muscovite

Table 3. Samples from the SW part of the lake (opposite the granites)

Sample	Minerals Present
GR2-50A	i. Vermiculite
	ii. Mica-muscovite (various polymorphs)
GR2-18A	i. Vermiculite-mica or illite-vermiculite (regularly interstratified) or chlorite-mica-illite- chlorite
	ii. Muscovite, or lepidolite
	iii. Chrysotile or antigorite or lizardite or kaolinite (disordered)
GR2-49A	i. Vermiculite-mica or illite-vermiculite (regular interstratified) or chlorite-mica or illite-chlorite (regular interstratified)
	ii. Muscovite or lepidolite or biotite or roscoelite
	iii. Kaolinite (disordered), antogorite or chrysolite or lizardite
GRC-40A	i. Rectorite
	ii. Vermiculite-mica, illite-vermiculite or illite-chlorite
	iii. Mica (muscovite or biotite) (various polymorphs
GR2-50A	i. Rectorite
	ii. Mica (muscovite or biotite) or lepidolite
	iii. Kaolinite (disordered) or chrysotile

Table 4. Samples from the Abonu Transect in the NW part of the lake

Sample	Mineral Present
BA-1B	i. Chlorite or dioctahedral chlorite, or vermiculite or dioctahedral vermiculite ii. Muscovite or biotite or lepidolite
BA-3A	i. Chlorite or vermiculite or dioctahedral types of either one ii. Mica, muscovite or lepidolite
BA-6A	i. Rectorite ii. Vermiculite-mica or illite-vermiculite iii. Kaolinite – smectite
GR2-4A	i. Vermiculite or dioctaheral vermiculite ii. Mica, muscovite or lepidolite iii. Rectorite
GR2-27A	i. Chlorite or vermiculite, or dioctahedral type either one ii. Mica, muscovite or lepidolite
GRC-22A	i. Kaolinite-smectite ii. Mica, muscovite or lepidolite iii. Chlorite or vermiculite; or dioctahedral type of either one
GR2-3A	i. Kaolinite-smectile ii. Chlorite or vermiculite; or dioctahedral types of either one iii. Mica, muscovite or lepidolite

Table 5. Samples from the Duase Transect in the SE part of the lake

Sample	Minerals Present
GR2-9A	i. Kaolinite-smectite (interstratified) ii. Mica, muscovite or lepidolite iii. Chlorite or vermiculite; or dioctahedral type of either one iv. Tosudite (regularly interstratified Chlorite-smectite)
GR2-7A	i. Vermiculite or dioctahedral vermiculite ii. Vermiculite-mica or illite-vermiculite (regularly interstratified) iii. Mica, muscovite or lepidolite iv. Chrysotite or antigorite or kaolininite
GRC-46A	i. Kaolinite – smectite ii. Muscovite (various polymorphs)
GR2-33A	i. Kaolinite-smectite ii. Muscovite (various polymorphs) iii. Chlorite or vermiculite; dioctahedral type of either one
GRC-45A	i. Muscovite or lepidolite ii. Kaolinite-smectite

The standard flow chart for clay-mineral identification

The clay minerals present in the oriented mounts were identified using the clay mineral identification chart of the U.S Geological Survey Department, Bulletin 153.This flow chart for clay mineral identification is a standardized system for identification of clay minerals universally.

RESULTS AND DISCUSSIONS

Oriented Clay Mineral XRD Results

Using the Bragg equation (2d sin θ = n λ), and the standard flow chart for clay mineral identification, the oriented clay minerals identified in the samples are presented in Table 1.

Generally, by comparing the interatomic d-spacings, it was found that the deeper water samples contain higher amounts of smectites (interstratified with vermiculite, kaolinite and micas). Shallower water samples contain more of vermiculites and micas interstratified with chlorite and illite. At the central deep part of the lake, the clay minerals identified are predominantly mica-smectite, mica-vermiculite chlorite, kaolinite and illite. In the northeastern (NE) part of the lake (near the granites), the clay minerals basically include muscovite, smectites (often interstratified with vermiculite, chlorite or kaolinite).

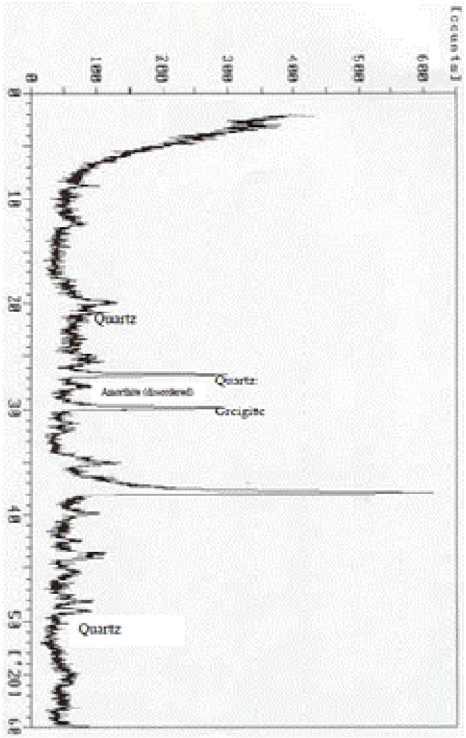

Figure 5. Powder pack diffractogram for sampe GR2-32A from the central deep part of the lake

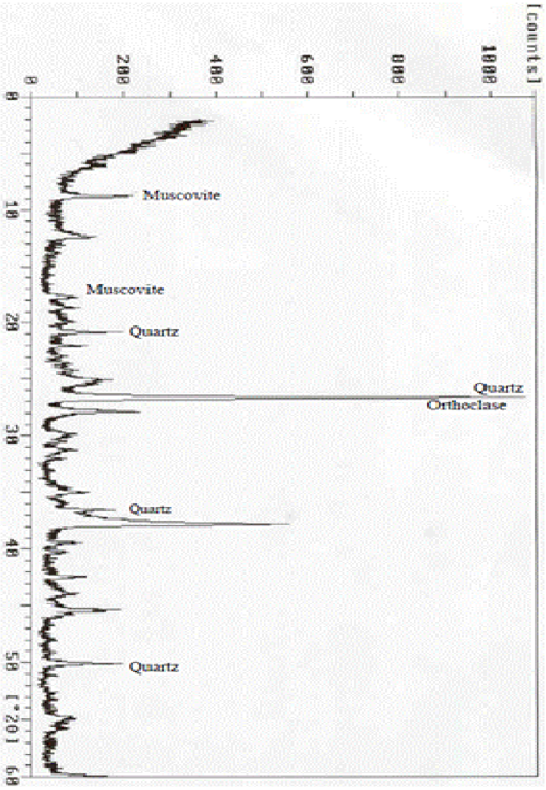

Figure 6. Powder pack diffractogram for sampe GRC-13A from the NE part of the lake near the granites

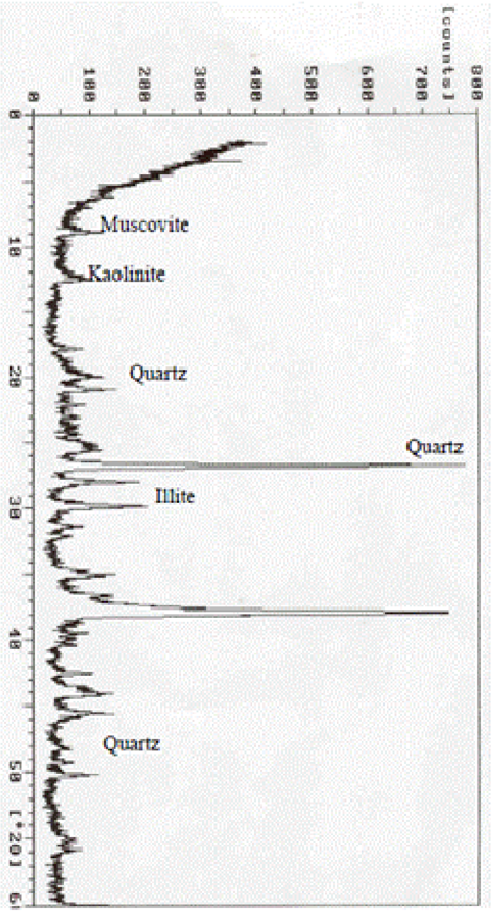

Figure 7. Powder pack diffractogram for sampe GR8A from the SW part of the lake opposite the granites

Table 6. Powder Pack XRD Results

Sample	Location	Minerals Present
GR2-32A	Central deep part of the lake	i. Quartz ii. Anorthite iii. Greigite
GRC-13A	Northeastern (NE) part of the lake (near the granites)	i. Quartz ii. Muscovite iii. Orthoclase
GR-8A	Southwestern (SW) part of the lake (opposite the granites)	i. Quartz ii. Muscovite iii. Kaolinite iv. Illite

However, in the southwest (SW) part (opposite the granites), the samples mainly contain micas (such as muscovite, biotite) and vermiculite often intestratified with illite or chlorite; lepidolite is also present.

For the Abonu transect in the northwest (NW), the samples display a rather wide variety of clay minerals; for example, micas and vermiculite interstratified often with illite or chlorite abound in the shallow waters, while interstratified smectites become more pronounced in the deeper waters. The deeper water samples also possess lepidolite. A similar mineralogy is displayed by the Duase transect in the southeast (SE) with interstratified smectites becoming more pronounced in the deeper waters. Note that Montmorillonite, which forms often in moderate temperature conditions in arid climates, is probably absent in the Bosumtwi sediments.

Powder Pack XRD Results

Diffractograms generated from scans on powder packs of three samples representing central deep, NE (near the granites) and SW (opposite the granites) are presented above in Figures 5, 6 and 7.

The central deep sample, GR2-32A, revealed powder pack results of quartz, disordered anorthite ($CaAl_2Si_2O_8$) and greigite (Fe_3S_4). Quartz is a silicate, and anorthite Ca-rich plagioclase feldspar. Greigite is an iron-sulphide, belonging to the ferromagnetic mineral group. The presence of greigite is probably due to reductive diagenesis under anoxic conditions, indicating that it was formed during a high lake stand (>15-18 m deep). The Quartz (silica) and anorthite (Ca-rich plagioclase feldspar) are probably derived from the catchment area of the lake (within the crater), which is covered by Birimian metasediments rich in quartz and plagioclase feldspars.

The results of sample GRC-13A from the NE (near the granites) show quartz, muscovite (white mica) and orthoclase (K-feldspar). These minerals are abundant in the granitic intrusions into the Birimian. Hence it is inferred that these top sediments were derived from the granites. Representative sample GR-8A from the SW (opposite the granites) revealed a powder pack XRD mineralogy of muscovite, kaolinite, illite and quartz. The clays, kaolinite and illite, are probably weathered products of feldspar. But the mineralogy is clearly different for those near the granites (as revealed by sample GRC-13A). Hence mineralogy differences exist from the NE (near the granites) through the central deep part of the lake to the SW (opposite the granites).

CONCLUSIONS

X-ray diffraction (XRD) methods have been used to analyse the top sediments of Lake Bosumtwi to determine the sediment provenance and depositional environment. The XRD techniques focused on oriented clay minerals and powder pack methods.

It was found out that the sediments analysed most probably have Birimian Supergroup provenance. The sediments were derived from weathered products and clasts of the surrounding Birimian Supergroup metamorphic rocks and intrusions associated with them. Some minerals in the sediments were formed as a result of post-depositional processes such as diagenesis and authigenesis. Because of the wet climate, Bosumtwi lake waters had high stands. The high lake stands naturally gave rise to stratification into a well-mixed (aerated) epilimnion, which was oxic, and an anoxic hypolimnion (Turner et al., 1996a). Sulphate reduction under these anoxic conditions gave rise to the ferromagnetic mineral greigite.

It is inferred that the top 2 – 8 cm of the sediments were deposited in the last few decades during relative lake high stands. The sediments have lots of clay minerals such as vermiculite, illite, smectite, kaolinite and their stratified derivatives, which were formed due to chemical weathering (hydrolysis) of silicate rocks and minerals under warm and wet conditions.

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