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CASE STUDY

Fossil evidence in the Bimbila Limestones of the Oti Group in the Voltaian Basin of Ghana

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Abstract
This study investigates the presence of fossil in the Bimbila Limestones of the Oti Group of the Voltaian Basin of Ghana. Geological field mapping, petrographic and mineralogical analyses was used to investigate the organic matter (fossil) presence in the limestones. Results from the comprehensive study identified the Bimbila Limestones to have some microfolds and varve structures in outcrops as a result of marine depositional environment. Some are noted to be homogenous with no quartz or barite while others have quartz/barite. Petrographic analyses revealed that, the most abundant mineral is dolomite with other minerals present being micrite, chert, quartz, calcite, and iron oxide. Under the microscope, the Bimbila limestones were noted to be fossiliferous and hence providing inferred evidence of bioactivity preserved in the limestones. These fossils were inferred to be biogenic materials, possibly skeletal fossil and brachiopods remains probably derived from marine organisms.

Keywords: Fossil, Bimbila Limestones, Source Rock, Petroleum Exploration, Voltaian Basin

Introduction
The geology of Ghana largely comprises four sedimentary basins; Tano-Cape Three Point Basin (Western Basin), Saltpond (Central) Basin, Accra-Keta Basin (Eastern Basin) as well as volcanic belts, and extremely ancient crystalline rocks (Adda, 2013; Chudasama et al., 2016; Kesse, 1984; Petrocom, 2020). Interest in the sedimentary basins of the country heightened after oil seepages were discovered onshore Ghana in the Western Region in 1896 (Petrocom, 2020). However, of the four sedimentary basins, the Voltaian basin is yet to see detail investigation into fossils and source rocks characteristics in the basin. The hydrocarbon potential of the other three offshore sedimentary basins however have been studied leading to exploration work and discoveries in some of these basins (Leube *et al*., 1990; Milési *et al*., 1991;Eisenlohr and Hirdes, 1992; Brownfield and Charpentier, 2006; Koffi *et al*., 2016; Smith *et al*., 2016).

The Neoproterozoic to early Paleozoic rocks of the Voltaian Basin (Fig.1), underly the northern portion of the Volta Region, the central and eastern portions of the Northern and Brong-Ahafo Regions, and the north-eastern portions of the Ashanti and Eastern Regions (Adda, 2013). Under the auspices of the Ghana Geological Survey Department, Romanian and Soviet geologist survey team while drilling for water encountered viscous oily bitumen and oil spills in the drilled boreholes in the Voltaian Basin. This bitumen and oil spills were encountered in sandstone and carbonates rocks within the Oti Group of the Voltaian Basin in the Northern parts of the country (Boamah, 2017; Bozhko, 2008) suggesting that hydrocarbons may be present in the basin. This was not the only case of oil seeps observed. Boamah (2017) reported that bitumen was present in quartz veins and carbonate rocks of the Buipe quarry. The bitumen presence could be evidence of the fact that the limestones of the basin are possible source rocks. Analysis by Abu et al. (2021) even further confirmed that the limestones in the north-eastern region of the Voltaian basin are dolomitic and barite bearing due to hydrothermal mineralization of the carbonates (Abu et al., 2021). However, the presence of any biogenic materials (fossils) which may be responsible for the generation of the hydrocarbons behind these oil seeps is yet to be reported.

The presence of organic matter is keenly one of the parameters that defines a source rock. Pyrolysis is one of the methods used by organic geochemists to investigate the amount of organic matter, assess the quality of the organic matter and its thermal maturity (Katz, 1983; Delvaux et al., 1990; Disnar *et al*., 2003; Adenutsi et al., 2019; Quaye *et al*., 2023; Sun *et al*., 2022; Sykes and Snowdon, 2002; Yu *et al*., 2023). Petrography, on the other hand, is another ingenious technique used to classify and examine the presence of organic matter or fossils in source rock on a microscopic scale (Teerman *et al*., 1995; Suárez-Ruiz *et al*., 2012; Flores and Suárez-Ruiz, 2017; Su *et al*., 2019; Ghanizadeh *et al*., 2020; Yu et al., 2023). This method of petrographically studying organic matter presence through fossil evidence is applied in this study.

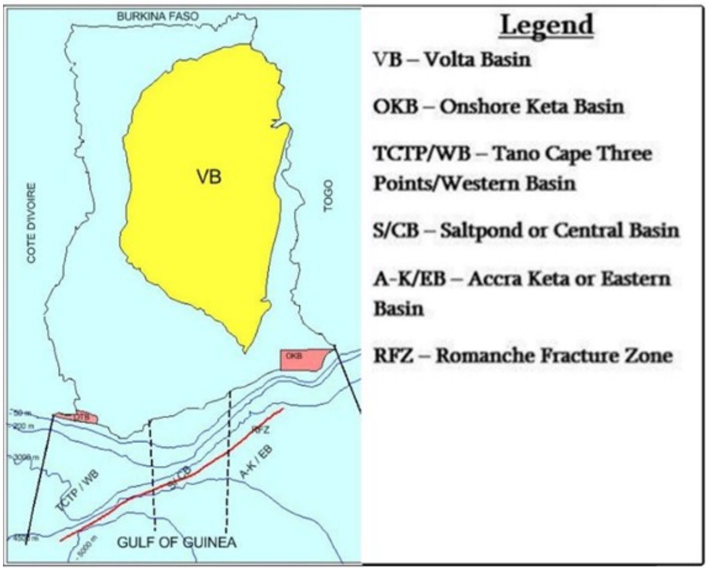

Figure 1 The four sedimentary basins of Ghana (not to scale) modified after Adda (2013). This shows the Tano-Cape Three Point Basin (Western Basin), Saltpond (Central) Basin, Accra-Keta Basin (Eastern Basin) and Voltaian Basin.

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Effective petrographic identification of specific components in sedimentary organic matter can explain source rock attributes, offer insight into depositional conditions, and determine thermal maturity (Powell *et al*., 1982; Teichmüller, 1986; Flores and Suárez-Ruiz, 2017; Wang et al., 2019; Singh *et al*., 2020; Osli *et al*., 2022; Quaye *et al*., 2022). Undoubtedly, Rock-Eval pyrolysis has developed into a standard technique for the chemical evaluation of source rocks, with the ability to also infer kerogen types. Howbeit, with the advancement in research, microscopy/petrography is universally applied to study rock pores and organic matter (fossils) to define reservoir and source rocks respectively.

In this study, petrographic thin section analysis is used to investigate the presence of any organic matter (fossils), which may further mature into kerogen which then generate oil and/ or gas (hydrocarbon) in rocks. Organic matter (fossils) is thus key in hydrocarbon source rocks, making its petrographic identification and characterization crucial.

Materials and Method

A 30-day field mapping of the various rock types in the study area was employed to deduce the attitudes (strike and dip) of the limestones in the area and the geological features at a macroscopic scale. The field sheet of the study area (Field sheets 1002D1 and part of 1002D3 encompassing the North East and Upper East Regions of Ghana, specifically the Mamprugu-Moagduri District and Builsa South District) were obtained from the Survey Department. The field sheets cover Ghana's latitudes 9°55'N and 10°35'N and longitudes 0°35'W and 1°45'W.

Petrographic analysis

Laboratory petrographic thin section analyses further performed on the limestone samples are used to investigate the grain sizes, shapes, arrangement, texture, minerals present and more importantly fossil evidence to deduce the source rock potential of the limestones. Fifteen (15) limestones were separately prepared through cutting to trimming and finishing (0.03 mm/30 microns) and observed for fossil evidence under the petrographic microscope.

The samples were mounted on the Leica DM 750P and Leica DM 4P transmitted light petrographic microscope and observed under crossed polarized light (XPL) and plane polarized light (PPL)for their physical and mineralogical properties and for fossil evidence. Various minerals were identified using the Michel-Levy Birefringence Chart and its corresponding mineral classes.
Fossils were also identified based on parameters proposed by earth science resources geological digressions.

Mineralogical analysis

The method for mineralogical analysis employed was the X-Ray Diffraction. The limestones samples were crushed to sixty -three (63) microns and sent to the X-Ray Diffraction Laboratory of the Regional Water and Environmental Sanitation Center, Kumasi (RWESCK), KNUST for the analysis to confirm the mineralogical composition of the samples. At the lab, the samples are prepared by using a glass rod or eye dropper to apply a drop of ethylene glycol directly to the surface of the sample mount after which samples are ready to be analyzed as soon as the glycol is uniformly absorbed on the sample mount. Excess ethylene glycol may be gently mopped up with a lab tissue.

In this method, a material is radiated with an incident x-ray to measure its intensity by scattering angles of the x-ray leaving the material. This helps to determine the crystallographic structure of the material and hence determine the minerals present. The minerals present are determined when the crystals scatter the incident x-ray through interaction with atoms' electrons. The scatter produces an array of spherical waves and show a specific direction to determine the intensity of the mineral present through Bragg's law (Bunaciu *et al*., 2015; Zhang *et al*., 2019).

Geology of the study area

The study area is in the Oti Group of the Voltaian Basin (Fig. 2). It has a flat, undulating terrane covering majority of it. The Oti Group formerly referred to as the Middle Voltaian outcrops in the northern sector of the basin but has minor occurrences in the southwest portion of the basin as well (Amedjoe, 2018; Kalsbeek et al., 2008; Zobah *et al*., 2022). It is about 2,500 m thick and rests unconformably on the Kwahu -Bombouaka Group of the Voltaian Basin. It is made up of predominantly shales, siltstones, and mudstones with intercalations of limestones sediments dating from the Precambrian and the Paleozoic age (Leprun and Trompette, 1969; Kesse, 1984; Affaton et al., 1991; Zobah et al., 2023).

The Carbonate rocks (limestones) encountered continue for over 12 kilometers along strike with an estimated depth of 330 meters. The Limestones were observed as being at the base of the Formation. These limestones marked in red (Fig. 2) were seen at Mugu, Fumbisi, Gbedemblisi, Yezezi, Yezibizi as well as occurring massively at waterlogged areas/marshy areas. They react with dilute HCL and some show ill-defined ripple marks with some others also being layered, wavy, and having micro folds.

Minor lithologies include less matured sandstones to greywacke beds and dolomitic carbonates and thin-bedded cherts defined as silexites (Affaton *et al*., 1980; Affaton *et al*., 1991; Carney, 2010; Couëffé, 2011). Some limestones are also reported to be barite bearing (Deynoux *et al*., 2006).

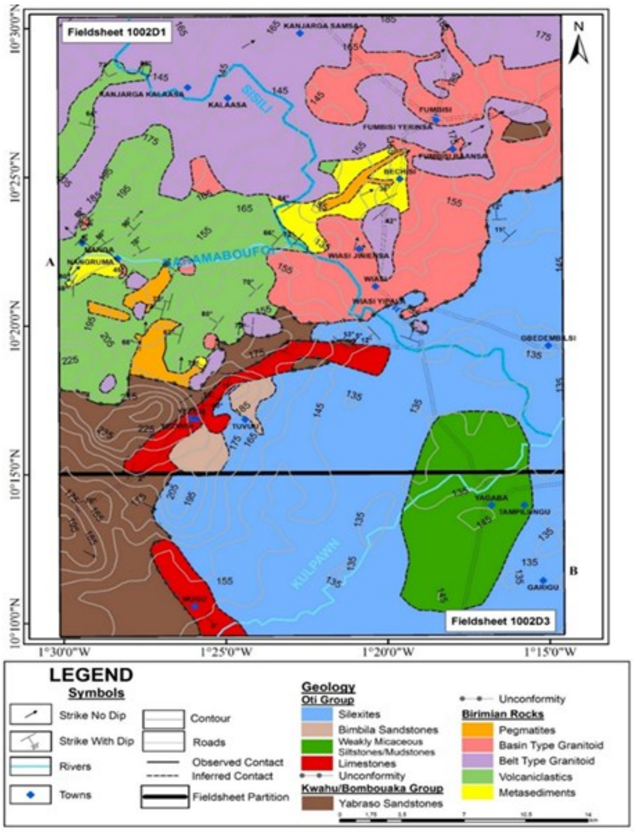

Figure 2 Geological map of the project area showing limestones outcropping in the area

Results and Discussions

Macroscopic characteristics of the Bimbila Limestones

The carbonate rocks (limestones) were observed as being at the base of the Bimbila Formation in the Oti Group. These limestones (Fig. 3) were seen at Mugu, Fumbisi, Gbedemblisi, Yezezi, Yezibizi as well as occurring massively at waterlogged areas/marshy areas. The limestones continue for over 12 km along strike with an estimated depth of 330 m. They react with dilute HCl and some show ill-defined ripple marks with some others also being layered, wavy, and having micro folds. Two distinct types were observed, the homogenous limestones (Fig. 3a) and the limestones with quartz veins or barite (Fig. 3b).

(Fig. 4b). The micrite are very fine grained (Fig. 4e). The cherts occur as nodules, and they are associated with the dolomite grains (Fig. 4f). The quartz grains are coarse to medium grained, and anhedral (Fig. 4a and b). Monocrystalline and polycrystalline quartz types occur.

The mean modal analysis of the limestone by visual estimation (Table 2) confirmed the average percentage of dolomite as 30 %, micrite as 57 %, chert 1 %, fossil 2 %, quartz 5 % and iron oxide cement as 5% based on Terry and Chilingar (1955) defining the rock type as a sedimentary rock and the rock name as a Dolostone-Limestone-Quartz Succession.

Figure 3 Limestones observe at Mugu, Fumbisi, Gbedemblisi, Yezezi, and Yezibizi: (a) homogenous (without quartz veins/ barite) limestones and (b) limestone with quartz veins/barite

Table 1 Minerals present in the Bimbila Limestone and the concentration levels

Limestone

Compound Name	**Dolomite**	**Gypsum**	**Quartz**	**Calcite**	**Illite**	**Ettringite**
S-Q	56.0%	32.2%	2.0%	5.3%	3.2%	1.4%
Concentration Level	Major	Major	Minor	Major	Minor	Minor

Limestone

Compound Name	**Dolomite**	**Ankerite**	**Normandite**	**Illite**	**Calcite**	**Quartz**	**Ettringite**
S-Q	33.9%	23.6%	27.1%	13.2%	1.3%	0.3%	0.6%
Concentration Level	Major	Major	Major	Major	Minor	Trace	Trace

Mineralogy of the Bimbila Limestones

Mineralogical analysis was conducted to further confirm the minerals present as revealed by petrographic analysis. The coupled two theta X-ray diffractometer test (Table 1) on the Bimbila Limestone samples revealed that the clay minerals present are illite and gypsum. Illite occurs in minor concentration level of 3.2 % (S-Q) and Gypsum occurs in major concentration of 32.2 % (S-Q).

Petrographic characteristics of the Bimbila Limestones

The Bimbila Limestones as observed under the petrographic microscope are composed of micrite, chert, quartz, dolomite, calcite, fossils and iron oxide (Fig. 4a-e). The dolomite grains are coarse grained and crystalline, cloudy and brown (Fig. 4b, c, d and f). They occur as subhedral to anhedral rhombs, with relicts of calcite crystals coated with developing dolomitization

Table 2 Mean modal analysis of Limestones by visual estimation

Mineral	**Modal %**
Dolomite	30
Quartz	57
Chert	1
Fossil	2
Iron cement	10

Fossil evidence in the Bimbila Limestones

Some fossils were observed and seen to have close associations with the quartz grains (Fig. 4a). These fossils are suspected to be remains of brachiopods (Fig. 4a). The iron oxides occur in association with the dolomite grains (Fig. 4d). These fossils

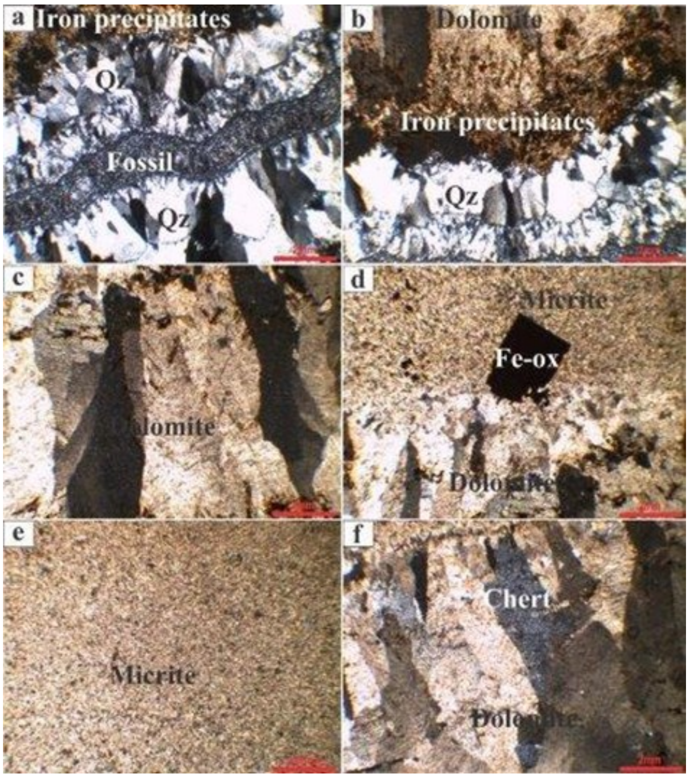

Figure 4 Photomicrographs of Limestones showing (a): quartz grains and a skeletal fossil, grey coloured showed by scratches with iron precipitates defining its boundary (xpl, x4). (b): iron precipitate defining the boundary between dolomite and quartz (xpl, x4). (c): dolomite grains, with relics of calcite (d): iron-oxides, (e): micrite and (f): chert (dark ash under the microscope)

mainly occur at the boundaries in contact with quartz and micrite. Few coarse grained and euhedral type iron oxides occur and they are suspected to be pyrite due to the crystal shape (Fig. 4d).

Fossils evidence (possibly brachiopods) in the limestones (Figs. 5) suggest that there is an organic matter constituent in the limestones. These fossils/biogenic materials spotted may further be studied to define specifically the type of organic constituents they are. Furthermore, the Bimbila limestone can be targeted as a possible rock for Rock-Eval pyrolysis to assess the quantity, quality and thermal maturity of the organic matter present.

Also, in another thin section slide of the Bimbila Limestones, some whitish occurrences which could not be

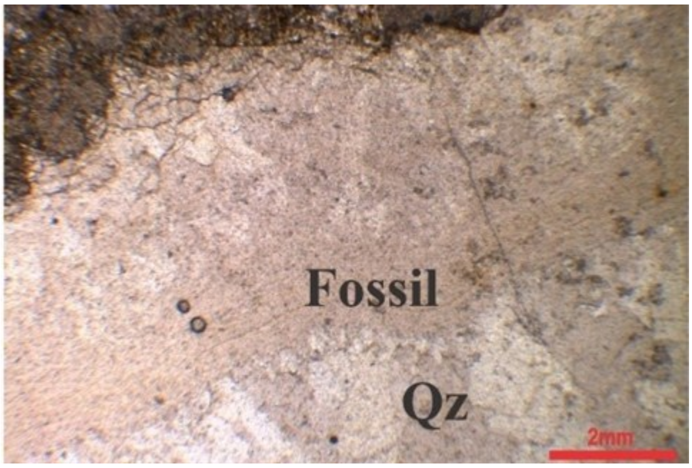

Figure 5 Photomicrographs of Limestones showing a fossil with iron precipitates defining its boundary (ppl, x4)

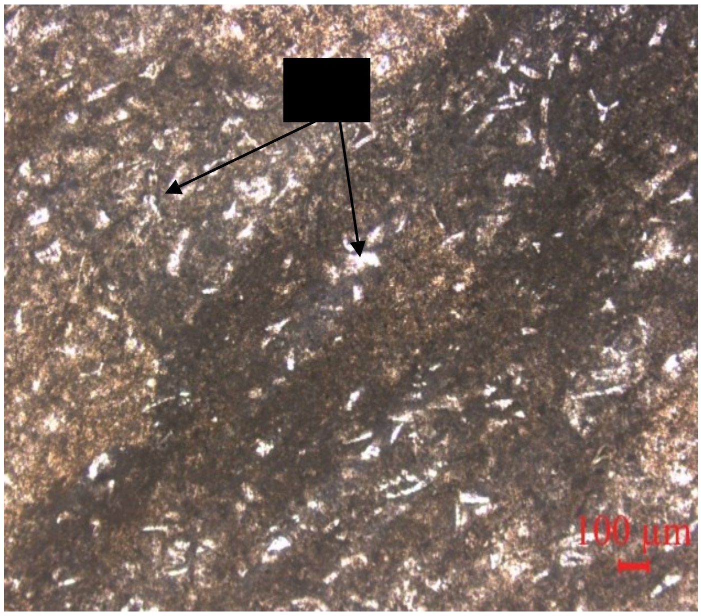

Figure 6 Photomicrographs of Limestones showing fossil evidence (ppl, x4): biogenic materials possibly skeletal fossils (Sf)

classified under any group of minerals were spotted and investigated. These whitish occurrences were thought to be biogenic materials and possibly skeletal fossil remains (Fig. 6) which further confirmed fossils presence. The type of biogenic material can be further confirmed through a more detailed analyses of the Bimbila Limestones. The Bimbila limestones are thus fossiliferous (having fossils or traces of fossils) providing inferred evidence of bioactivity preserved in the limestones.

Implication for petroleum source rocks

The limestone samples are studied through petrography for source rocks characteristics to infer the possible source rocks that will influence a good petroleum reserve. Fossil features observed in the limestones (Figs. 4, 5 and 6) are important in deducing the presence of biogenic activity and possibly the presence of organic matter in the limestones. These fossils were inferred to be biogenic (primarily composed of plant and animal remains) materials, possibly skeletal fossils and remains of brachiopods probably derived from marine organisms. Further analyses on the limestones for fossil presence will however provide more information on the fossils type present. The quantity of organic matter must be investigated in future studies by Rock-Eval pyrolysis to assess the total organic carbon (TOC) content. If the TOC content is high enough further analysis will be required to ascertain the quality of organic matter and its thermal maturity.

Conclusions

This study employed geological field mapping, petrographic and mineralogical analysis to investigate the organic matter (fossil) presence in the Bimbila Limestones. The Bimbila Limestones observed on the field have some microfolds and varve structures. Some are homogenous with no quartz or barite while others have quartz/barite. The presence of varve structures infers the marine play of marine depositional environment in the formation of the rocks and hence the fossils may be of marine origin.

Under the microscope, the Bimbila limestones were noted to be fossiliferous (having fossils or traces of fossils) and hence providing inferred evidence of bioactivity preserved in the limestones. These fossils were inferred to be biogenic materials, possibly skeletal fossil remains and remains of brachiopods probably derived from marine organisms.

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Conflict of Interest Declarations

The authors declare no competing interests

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