The Petroleum Geology and Prospectivity of the Neo-Proterozoic, Paleozoic and Cretaceous Sedimentary Basins in Ghana*

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Abstract

Ghana has four sedimentary basins (Figure 1) namely: the Voltaian Basin (Neo-Proterozoic, inland), Saltpond or Central Basin (Paleozoic, offshore), Accra-Keta or Eastern Basin (Cretaceous, offshore with onshore extension), and Tano-Cape Three Points or Western Basin (Cretaceous, offshore with onshore extension). The Paleozoic and Cretaceous basins form Ghana's continental margin, which stretches from the Ghana-Togo border in the east to the Ghana-Cote D'Ivoire border in the west. The margin is part of the Gulf of Guinea Province. The Tano-Cape Three Points Basin extends from Cote D'Ivoire in the west and is the eastern extension of the Cote D'Ivoire-Ghana Basin. The Accra-Keta Basin is the western extension of the Dahomey Embayment. The margin is also part of the Equatorial Segment of the South Atlantic Ocean and thus bounded to the east and west by the Chain and St. Paul fracture zones respectively. Ghana's margin formed at the height of Late Jurassic to Early Cretaceous tectonism during which Africa and South America separated.

In the Early Cretaceous (~ 125 Ma), northern South America and southern West Africa started to rift and small basins opened as the thick continental crust was stretched and thinned (Brownfield and Charpentier, 2006). Basin infill was sourced from eroded upland continental areas. The tectonism caused both block and transform faulting, and newly formed basins deformed along the transform faults (later became the fracture zones after active movements). As the continental crust was further thinned, sea floor spreading was initiated between Late Aptian and Early Albian (~110 Ma). New oceanic crust formed at the trailing edges of the two continental plates as they began separating during Late Albian (~100 Ma). The two plates finally separated by Late Santonian to Early Campanian (~85 Ma). The above movements were superimposed on an extensive Paleozoic basin, which existed along the margin prior to the extension and breakup.

The Saltpond Basin

The Saltpond Basin is a Paleozoic wrench modified pull-apart basin centrally located between the Tano-Cape Three Points and Accra-Keta basins. It covers an area of approximately 12,294 sq km. Sediments in the basin were deposited in non-marine to coastal marine environments, and range in age from Ordovician to Cretaceous. The basin has been stratigraphically divided into formations based on lithofacies and depositional environments (Asiedu et al., 2005). These are from oldest to youngest: Elmina Sandstone (Late Ordovician-Early Silurian), Takoradi Sandstone (Devonian), Takoradi Shales (Middle Devonian-Early Carboniferous), Efia Nkwanta Beds (Late Carboniferous-Permian), Sekondi Sandstone (Triassic-Early Jurassic) and the Lower Cretaceous sediments. The structure of the basin is characterized by multiple faulting, which has resulted in a complex set of horsts and grabens.

The only known and proven petroleum system in the Saltpond Basin is the Lower Paleozoic Petroleum System. This system has Devonian source rocks and Devonian to Carboniferous reservoirs. The two main source rocks are the Lower and Upper Takoradi Shales. These are dark grey shales with predominantly Type II kerogen and moderate to good TOC and HI values. The reservoirs are sandstones of the Takoradi Sandstone Formation. Trapping is both structural (fault-bounded blocks) and stratigraphic (sandstones interfingering into shales) with sealing provided by the Takoradi Shale Formation. Burial history reconstruction and geochemical analysis indicate the source rock was mature for hydrocarbon generation in the Middle Cretaceous.

The Saltpond Field was discovered in 1970 by the Signal-Amoco 10-1 well. The well recovered light crude oil from the Devonian Takoradi Sandstones. The maximum production attained was 4800 bopd from 1978 to 1984. Production declined from 4,800 bopd and by 1985 the field was no longer economical to produce and operations were stopped. In 2000, the Ghana National Petroleum Corporation (GNPC) and Lushann-Eternit Energy Ltd entered into a joint venture to form the Saltpond Offshore Producing Company Ltd (SOPCL). This venture enabled them attract the needed investment to redevelop the field and provide for its decommissioning. The current production average is 300 bopd from 2 wells.

The Tano-Cape Three Points Basin

The Tano-Cape Three Points Basin is a Cretaceous wrench modified pull-apart basin bounded by the Saltpond Basin in the East and the St. Paul Fracture Zone in the West. The basin is the eastern extension of the Cote d'Ivoire-Ghana Basin and formed as a result of trans-tensional movement during the separation of Africa and South America, and the opening of the Atlantic Ocean in the Albian. Active rifting and subsidence during this period resulted in the formation of a deep basin. Prevailing conditions at the time were ideal for the deposition of shales, thus thick organic rich shale was deposited in the Cenomanian and Turonian.

Several river systems contributed significant clastics into the deep basin and led to deposition of large turbidite fan/channel complexes. The working play type is the Cretaceous Play, which consists of Cenomanian-Turonian and Albian shales as source rocks with Turonian slope fan turbidite sandstones and Albian sandstones in tilted fault blocks as reservoirs. Trapping is both stratigraphic and structural. The hydrocarbon potential of Ghana's portion of the basin has been known since the 1890's based on onshore oil seeps but the first major discovery was made in

2007 by Tullow Oil PLC (Jubilee Field) with oil production commencing in 2010. The hydrocarbon prospectivity of the basin is also well known in Cote d'Ivoire where there are producing fields including Baobab, Belier, Espoir, Foxtrot, Lion and Panthere.

The Accra-Keta Basin

The Accra-Keta Basin is a Cretaceous wrench modified pull-apart basin structurally bounded by the Chain Fracture Zone in the east and the Romanche Fracture Zone in the west. It covers an area of approximately 33,900 sq km of which 1900 sq km is onshore. The basin's formation history has been divided into:

- Pre-Rift Stage - comprising Precambrian to Late Jurassic rocks
- Syn-Rift Stage - comprising Lower Cretaceous rocks
- Post Rift Stage - represented by Upper Cretaceous to Tertiary sequences

Studies by Abu et al. (2010) suggest the presence of a working Cretaceous Petroleum System, with at least two key mature source rocks: Early Cretaceous lacustrine shales with Types II and III kerogen, and Turonian-Coniacian organic rich shales. Numerous syn-rift Albian, Late Cretaceous and Tertiary reservoirs exit. Both stratigraphic and structural trapping mechanisms are present, with the former predominating. Several horizons mapped and interpreted on seismic sections as Cretaceous-Tertiary shales could provide sealing. Potential exploration plays such as basin floor fans and ponded turbidites exist in the Upper Cretaceous and Tertiary.

The Voltaian Basin

The Voltaian Basin is an asymmetrical epicontinental interior sag basin covering about 40% of Ghana's continental landmass. It stretches into Togo, Benin and Burkina Faso. The basin formed during the Pan African Orogeny about 600 Ma (Tairou et al., 2012) as a result of the collision between the stable West African Craton, known as Birimian Supergroup in Ghana, and the Pan African Mobile Belt, known as Dahomeyan System in Ghana (GNPC, 2007). Sediments are of shallow marine to continental origin and comprise sub-horizontal beds of sandstones, shales, mudstones and conglomerates which range in age from Precambrian to Paleozoic. The thickness of sediments exceeds 6000 m in the deepest portion of the basin. The basin has been stratigraphically divided into:

- Upper Voltaian - which comprises massive and thinly bedded sandstones with some shales
- Middle Voltaian - which comprises sandstones with limestone intercalations (Upper Greenish-Grey Series), shales with limestone intercalations, siltstones, silty sandstones (Variegated Series) and conglomerates
- Lower Voltaian - which comprises sandstones, shales and siltstones (Lower Greenish-Grey Series)

and quartz sandstone (Basal Sandstone Series).

Exploration in the basin to determine its hydrocarbon potential has been minimal. Earlier works include those by the Gold Coast Geological Survey (now Geological Survey Department) and Soviet geologists in the 1960's. The team drilled 10 hydrogeological wells to study the hydrodynamics of the basin. Two of these wells, Nasia and Prang drilled to an average depth of about 700 m, encountered traces of hydrocarbons and natural gas. Viscous black oily bitumen was observed in core samples of sandstones, shales and siltstones of the Oti Group in Middle Voltaian. Palynological studies of core samples from the group also suggest a wide distribution of organic matter in the greenish and variegated shales (Bozhko, 2008).

The Lower Voltaian hosts sandstones and limestones, which could serve as reservoirs (Apesegah, 2010). The basal sandstones in particular are reported to have good reservoir quality (Bozhko, 2008). The tectonic history of the basin has resulted in a variety of features, including compressional structures and faults. These in combination with some stratigraphic features could provide traps for hydrocarbons, with the shales of the Middle Voltaian acting as seals.

Prospectivity

The prospectivity of Ghana's continental margin has been established based on previous and recent oil discoveries in the Saltpond Basin and the Tano-Cape-Three Points Basin respectively, and active ongoing exploration activities in the Accra-Keta Basin. The risk initially associated with the Upper Cretaceous Stratigraphic Fan play in the Tano-Cape Three Points Basin has been lowered following various discoveries made by Tullow Oil PLC (Tweneboa, Owo, Ntomme, etc.), ENI Ghana Exploration & Production (Sankofa and Gye Nyame), Kosmos Energy (Mahogany, Odum, Teak, Akasa), and Hess (Paradise, Beech, Hickory North, Pecan, etc.). Discoveries in the same play have also been made in other nearby countries, notably the Venus and Mercury discoveries in Sierra Leone, offshore in the Sierra Leone-Liberian Basin (Jewell, 2011) and Paon-1X discovery in block CI-103 offshore Cote d'Ivoire. With the Jubilee Field's world-class discovery containing an expected 600 MMbbls of recoverable light crude oil, and about 305 MMboe of petroleum expected to be recovered from the combined development of the Tweneboa, Enyenra and Ntomme (TEN) fields and other upcoming developments, the Tano-Cape Three Points Basin could potentially hold some of West Africa's significant petroleum accumulations.

Exploration interest in the Saltpond Basin has been marred by marginal discoveries. The in-place reserves for the Saltpond Field were estimated at 34.4 Mbbls of oil and 34.3 Bscf of gas. The trapping mechanism is fault dominated, and the sizes of the fault blocks significantly influenced the size of the reserves (Aryeetey, 2011). Advances in seismic acquisition and processing have greatly improved the quality of seismic data. Investment could be made in acquiring new seismic data or re-processing and re-interpreting vintage seismic. Acquisition of 3D seismic data could greatly improve the chances of identifying larger fault traps and hence larger reserves. This approach, according to Hanagan (2003), has been used successfully in Chaves County, New Mexico to locate structures in Siluro-Devonian reservoirs and also increase success rates from an initial pre-3D seismic rate of 10% to 50%.

The Voltaian Basin discussed earlier has great potential to hold significant petroleum resources. Direct observations of gas and bitumen suggest the presence of a working petroleum system in the basin. Thus there is renewed interest in the basin. Reconnaissance surveys are being

organized in order to collect data to update the existing database and increase geological knowledge. The Geological Survey Department (GSD) and the European Union (EU) have recently conducted gravity and aeromagnetic surveys in the basin. The Ghana National Petroleum Corporation (GNPC) has also earmarked some funds for geological expedition and acquisition of 2D seismic data. The new data is expected to help attract investment into exploration.

The Accra-Keta Basin has also received considerable attention in recent time. Exploration activity has also shifted from shallow water and onshore areas, which targeted Tertiary plays, to the deepwater areas. International oil companies, including ENI Ghana Exploration and Production and Ophir Energy, are currently exploring the basin to establish its prospectivity.

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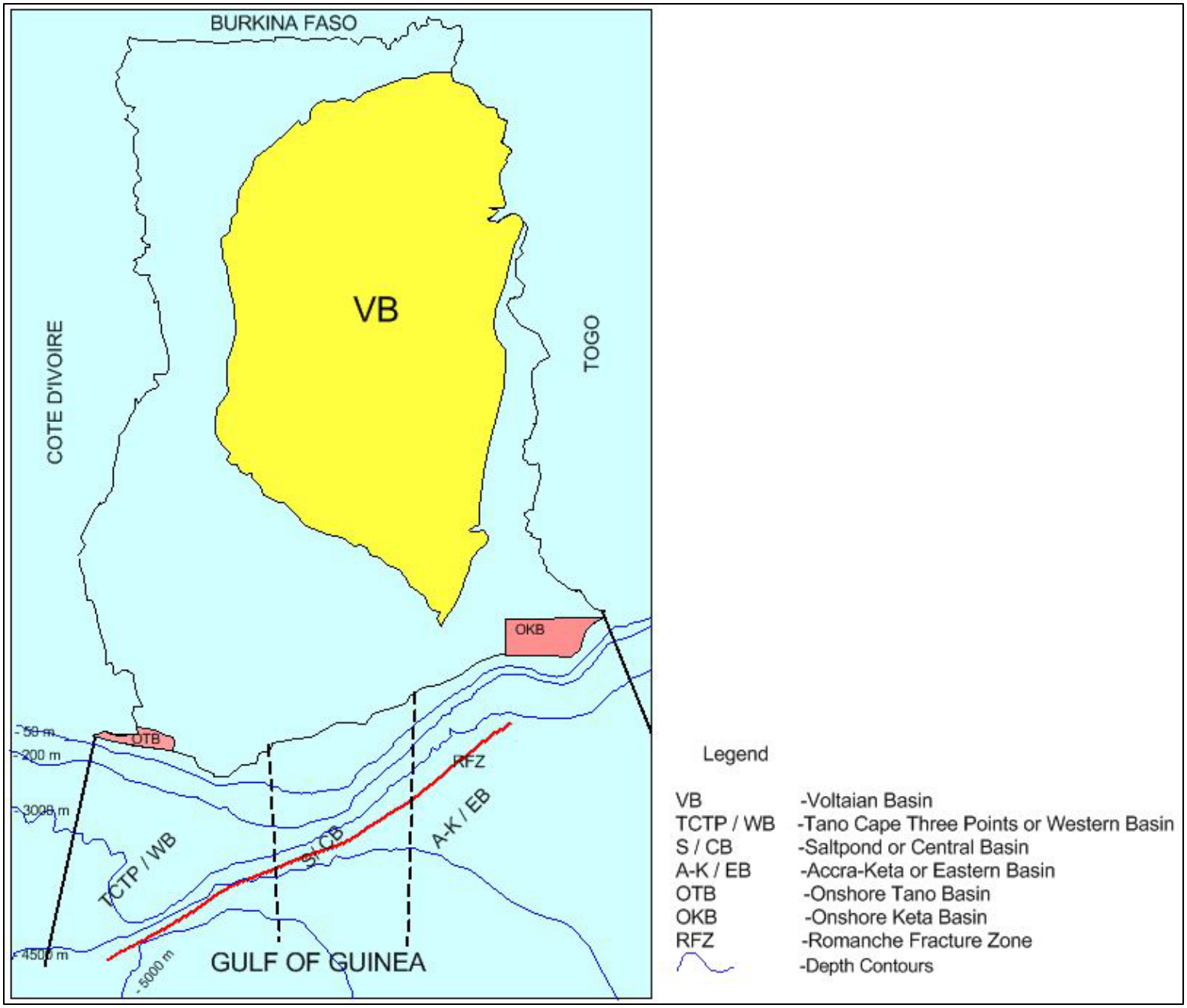

Figure 1. Map of Ghana (not to scale) showing the four sedimentary basins. Modified after GNPC.