Tanzania Journal of Science 50(5): 917-928, 2024
ISSN 0856-1761, e-ISSN 2507-7961

Geochemical Characterization of Hydrocarbon Source Rocks in the Jurassic – Cretaceous Ruvu sub-basin- within the Coastal Basin of Tanzania; Implications for Petroleum Prospecting.

Hadija H Maumba and Charles H Kasanzu*
Department of Geoscience, School of Mines and Geosciences,
University of Dar es Salaam, Tanzania.
**Corresponding author: kcharls16@yahoo.com*
Received May 2023, Revised September 2024, Accept October 2024 Publ. 31 December 2024
https://dx.doi.org/10.4314/tjs.v50i5.2

Abstract

In this study, we characterize hydrocarbon source rocks from the Ruvu sub-basin's Kiwangwa well-1 using organic matter, total organic carbon (TOC), rock-eval pyrolysis and vitrinite reflectance data. Analytical results indicate fair to excellent TOC contents in the sub-basin, a feature suggesting conditions that favor organic matter production and preservation. Kerogen types II to IV are inferred for the Kiwangwa well-1 sediments. Using TOC vs S_2 for the Early Jurassic and Triassic of Kiwangwa well -1 at depth intervals, good to very good source rocks are inferred. This suggests high generative organic matter suitable for hydrocarbon production. None generative organic matter window is inferred for the Cretaceous, Middle Jurassic and Late Jurassic time intervals in the sub-basin. Generation potentiality of the source rocks employing the HI and TOC parameters show that the Late Jurassic source rocks interval in the Ruvu sub-basin are gas or oil-prone. Our findings from generation potentiality in the study area indicate that the Late Jurassic source rock interval in Ruvu can offer guidance for potential prospects and gas-exploration targets. Evaluation of the degree of thermal evolution of the sedimentary organic matter using vitrinite reflectance and production index suggest marginally matured source rocks for the Late Jurassic – Middle Jurassic that indicate reworked particles.

Keywords: Total Organic Carbon; Kerogen type; Ruvu sub-basin.

Introduction

The Ruvu sub-basin is located in the western margin of the hydrocarbon potential Coastal basin of Tanzania that is characterized by more than 4000 m thick sedimentary sequences (Kapilima 2003). After decades of geological investigations, this basin is now an important target for surveys of hydrocarbon source rocks (e.g. Mboya 2021, Godfray et al. 2021, Delvaux 2001, Mpanda 1997, Mbede 1991). The coastal basin is one of the East African extensive basins that formed during drifting and rifting of Gondwana supercontinent, leading into the formation of several sub-basins including Tanga, Ruvu, Mandawa, and Ruvuma (Mvile et al. 2020). Numerous investigations in the region have involved petrophysical, geochemical and spore coloration, organic matter quality, quantity and thermal maturity of the source rocks (Emmanuel et al. 2020, Sabuni et al. 2023) For instance, Emmanuel et al. (2020) contend that the Mandawa source rocks are mainly Type I, Type II, Type III, mixed Types II/III and Type IV kerogens, with a predominance of Type II, Type III and mixed Type II/III. They further conclude that the Triassic and possibly the Mid-Jurassic intervals have a higher potential for hydrocarbon generation.

On the other hand, Sabuni et al. (2023) indicate kerogen type for the Triassic shales are II (oil), III (gas pone), II/III (gas with minor oil), and IV (inert), using hydrogen index and TOC values. Jurassic interval suggests predominance of kerogen type III (gas prone) in the Tanga sub-basin.

An exploration well was drilled to investigate the hydrocarbon potentiality of the Ruvu sub-basin by TPDC (1992). Although previous studies have contributed into understanding hydrocarbon potential of other similar sub-basins in the region (e.g. Sabuni et al. 2023, Makarawe well 1 and references therein) the Ruvu sub-basin is under-explored and, thus, much remains to be investigated in order to broaden the database for the Coastal Basin. Therefore, since such investigations processes are vital in deciphering hydrocarbon potential fields, our work aims at evaluating the geochemical characteristics of the sub-basin. We used data from a 3514 m deep Kiwangwa well – 1 within the Ruvu sub-basin in the view of constraining geochemical characteristics of the area for hydrocarbon potentiality.

Geological Setting

Ruvu sub-basin is located in the northern and central parts of the Tanzanian coastal basin (Figure 1). Clastic to non-clastic lithologies present in Ruvu characterize the sedimentary successions, comprising different Formations such as the Sakura, Kipatimu (Kipumpwe), Bagamoyo, Amboni limestones, and Msata.

Kapilima (2003) contends that the Ruvu sub-basin is a rift basin that is related to the break-up of Gondwanaland in the Permo-Triassic to Early Jurassic, Cretaceous and Cenozoic times forming a north-easterly stretch of several sub-basins that are the typical sedimentary fill for the East African marginal sub-basins. The Gondwanaland sequences comprise the basal part of sedimentary fill which is related to the development of regional-scale epicontinental basins (Kasanzu 2014). This lower section belongs to sequence of sedimentary and volcanogenic rocks of the Karoo Group (Late Carboniferous-Early Jurassic) that underlay the Ruvu sub-basin (Kasanzu 2014).

Stratigraphically, the sub-basin comprises Triassic quartizic sandstones, Jurassic oolitic limestones, conglomerates, claystones and laminated shales that are capped by Cretaceous marls, claystones, limestones and shales (Godfray et al. 2023, Figure 2).

Figure 1: Location of the study area showing the sub-basin as star asteric Modified from Sabuni et al. (2023).

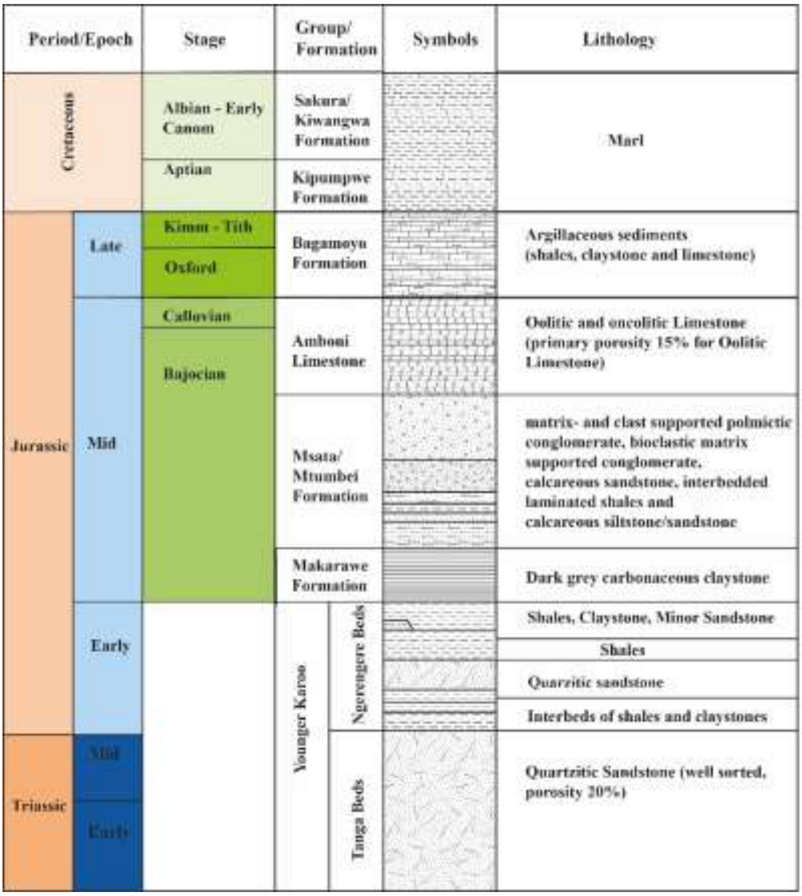

Figure 2: A schematic sketch showing the stratigraphy of the Ruvu sub-basin with different time intervals and respective lithologies (Adopted after Godfray et al. 2023).

Materials and Methods

Sampling was carried out with the support of drill hole geological information of the regions. Fifty-one (51) core samples from the Kiwangwa well -1 of Ruvu within intervals of 0 m – 3514 m were collected. The samples were used to investigate organic richness, type, maturity, and the depositional environment. Additionally, selected samples were analyzed for Rock-Eval pyrolysis.

For rock eval pyrolysis, rock samples were subjected to 300 ℃ and subsequently S_1 values were detected as free hydrocarbon. At an increased temperature of 600 ℃ in an inert helium atmosphere, S_2 values were released as hydrocarbon that was expelled from the kerogen by cracking. At temperature intervals of between 300 ℃ - 390 ℃, the S_3 peak values were detected as the result of CO_2 produced from the cracking of the Kerogen following the procedure in Sabuni et al. (2023). In addition, vitrinite reflectance from 33 samples in the Kiwangwa well -1 were analyzed on polished resin-embedded whole rock blocks with a Leica MPV3 photomicroscope as in Xianming et al. (2000).

Production index (PI) was computed as [$PI = S_1 / (S_1 + S_2)$], this parameter refers to the hydrocarbon already generated relative to the total amount of the hydrocarbon that could be generated. The hydrogen richness parameter in the kerogen (S_2/S_3) with the genetic potential of the source rock was constrained as $GP = S_1 + S_2$.

Results

From the sample obtained in both Kiwangwa well-1, laboratory techniques were carried out to elucidate the various parameters as indicated in Appendix 1.

Analyzed Cretaceous samples from the Kiwangwa well-1 show average TOC, S_1, S_2, HI and VR between 0.47 wt%, 0.063 (mgHC/g Rock), 0.096 (mgHC/g Rock), 18.14 and 2.36, respectively. PI values range between 0.21 – 0.58 (mean = 0.42; Table 3). Average TOC, S_1, S_2, HI and VR for Jurassic time interval 1.32 wt.%; S1= 0.28 (mgHC/g Rock); S2 = 0.22 (mgHC/g Rock); PI = 0.38, HI = 26.4; and VR = 1.84, respectively. Similar parameters for sediments the Triassic are also indicated in Appendix 1.

.

The late Jurassic (1020 - 1050 m) of Kiwangwa well -1 suggests excellent TOC values ranging between 0.53 wt.% and 11 wt.% compared to its Triassic, Early Jurassic, late Jurassic and Cretaceous sequences (Appendix 1).

Discussion

Organic richness of the source rocks

Organic richness is the total amount of organic matter present in the source rock determined by measuring TOC and pyrolysis parameter S_2 (Sabuni et al. 2023). Good to very good source rocks are inferred from the plot of TOC vs S_2 (Figure 3) for the Early Jurassic and Triassic of Kiwangwa well -1 at depth intervals of 1020 m -1050 m. This suggests high generative organic matter suitable for hydrocarbon production. None generative organic matter window is inferred for the Cretaceous, Middle Jurassic and Late Jurassic time intervals in the sub-basin (Figure 3). This discrepancy in organic richness may be due to differential organic matter input into the Sub-basin and variations in organic matter preservation (e.g. (Peters and Cassa 1994).

Additionally, the variation in the analyzed TOC values could have resulted from different burial histories, deposition environments, type of organic matter such as amorphous structures, algae, wood and terrestrial plants (Peters and Cassa 1994, Tissot and Welte 1984).

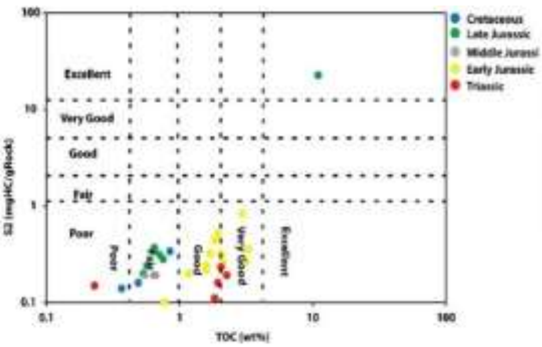

Figure 3: Geochemical correlations between content of total organic matter and Rock-Eval data S_2 of source rock intervals in the Ruvu sub-basin.

Quality of organic matter (Kerogen type).

The variation in TOC values could have resulted from different burial histories, deposition environments, type of organic matter such as amorphous structures, algae, wood and terrestrial plants (Peters and Cassa 1994, Tissot and Welte 1984). The organic richness also depends on three factors that are productivity, deposition, and preservation.

This attribute involves the type of organic matter that influences the nature of hydrocarbon that is generated or expected to be produced (Law 1999, Elyasi 2016, and Dembicki 2022). It is important to constrain the organic richness as it is vital for elucidating hydrocarbon generation potential, which can be done by TOC and S_1 + S_2 values (Lai et al. 2020). Kerogen types I, II, III, and IV are categorized as different types of hydrocarbons generated by organic matter (Tissot et al. 1974, Peters and Cassa 1994, Law 1999). Ahmed et al (2004) report that nature of hydrocarbon from the organic matter is reliant on the contents of hydrogen present as inferred from the hydrogen index (HI). Furthermore, characterization of potential source rocks also uses the pyrolysis parameter (S_2/S_3) to indicate organic matter quality in a given sample-set (Peters and Garrey 2015).

From Appendix 1, the Late Jurassic source rocks at depth intervals between 1020 m -1050 m of the Kiwangwa well-1 show HI of 204.5 mgHC/gTOC, suggesting Kerogen type II and III (oil and gas prone). Kerogen types II and III point to the presence of generative organic matter contrary to Early Cretaceous, Middle Jurassic, Early Jurassic and Triassic source rock intervals that indicate Kerogen type IV which is interpreted as non-generative organic matter.

The cross plot of S_2 vs TOC in Figure 4 shows Kerogen type IV in the Late Jurassic source rocks at depths between 870 m - 1680 m of the Ruvu sub-basin. At depths between 1020 m - 1050 m an abrupt increase of both TOC and S_2 is depicted, although the source rocks are inert.

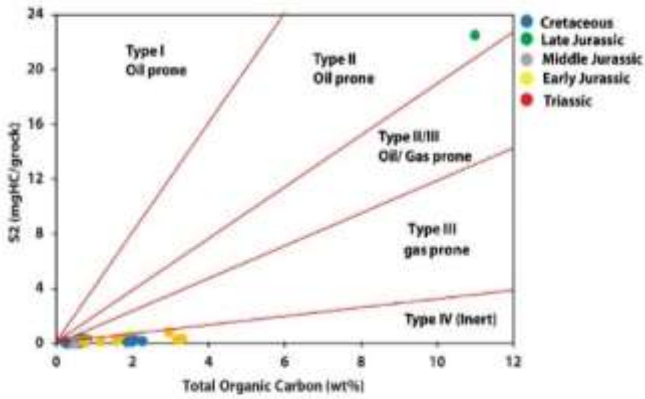

Figure 4: A plot of TOC vs S2 for expected types of hydrocarbons to be generated at maturity in the Ruvu sub-basin.

Hydrocarbon generation potential

Hydrocarbon generation potential parameter measures the capacity of source rock types to generate hydrocarbon (Xianming et al. 2000). A plot of the Pyrolysis parameter (S_1+S_2) versus TOC is used to evaluate hydrocarbon generation potential of source rocks (Sabuni et al, 2023) The Jurassic-Triassic- Cretaceous of the Ruvu sub-basin show poor generation potential of hydrocarbons (Figure 5). On the overall, the TOC contents are lower than 0.7 wt.%, suggesting that the analyzed shales have insufficient organic matter to be considered a source rock as indicated by prior researchers elsewhere such as the Early Cretaceous Sembar Formation, southern Indus Basin, Pakistan. Tissot et al. (1974) consider that TOC > 0.5% is necessary for a source rock to generate hydrocarbons and *vice versa*.

However, TOC content alone is not enough to satisfy all the requirements of a generative potential; it must be substantiated with other parameters such as the Rock-Eval pyrolysis data (e.g. Peters 1986, Peters and Cassa 1994). We found that the TOC contents of the analyzed samples correlate with both Rock-Eval S1 and S2. The petroleum potential, however, of the analyzed samples are confined within the poor source rock field (Figure 5).

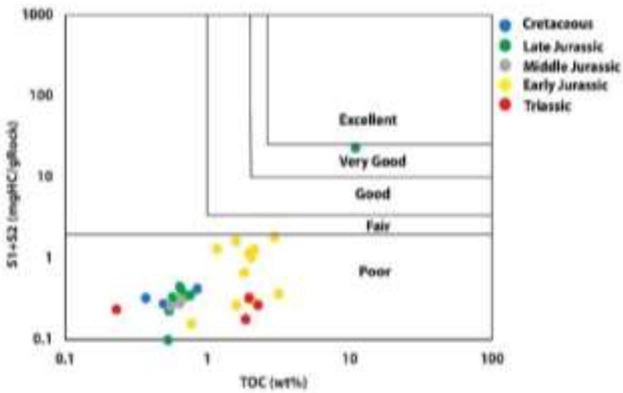

Figure 5: Hydrocarbon generation potential of source rocks in the Ruvu sub-basin.

We furthermore elucidate generation potentiality of the source rocks employing the plot of HI versus TOC. This discrimination diagram shows that the Late Jurassic source rock intervals between 1020 m - 1050 m in the Ruvu sub-basin is gas or oil-prone source (Figure 6). The lower HI values during the Early Jurassic – Mid-Jurassic can be attributable to the existence of a large number of terrigenous plants in the parent source (Lai et al. 2020). On the other hand, all other investigated in these intervals in the sub-basin, using the criterion of Espetalie et al. (1977) have no hydrocarbon generation potential (Figure 6). Nonetheless, findings from generation potentiality in the study area indicate that the Late Jurassic source rock interval in Ruvu can offer guidance for potential prospects and gas-exploration targets.

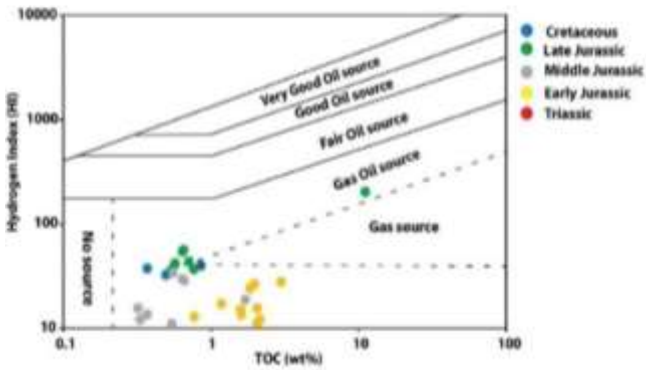

Figure 6: Generation potentiality of source rock intervals of Ruvu sub-basin.

Maturity of organic matter

Maturity of organic matter must reach a grade of thermal evolution in order for organic matter to expel hydrocarbon in a given basin (Tissot and Welte 1984). Several factors influence thermal maturity such as organic matter contents, burial depth, age of the source rocks, and geothermal gradient (Dembicki 2022). Maturation of organic matter is classified into three stages, namely diagenesis, catagenesis and metagenesis (Ahmed et al. 2004, Shalaby et al. 2012, Edilbi et al. 2019). The degree of thermal evolution of the sedimentary organic matter can be evaluated from vitrinite reflectance and production index (Sabuni et al. 2023)

From the plot of PI versus vitrinite reflectance depict a bimodal pattern, indicating the presence of two populations of vitrinite particles (Figure 7). The first population with lower mean vitrinite reflectance is attributed to autochthonous whereas the other category with relatively higher vitrinite represent reworked particles (Nzoussi-Mbassani et al. 2005). The later population is revealed by samples from the Late Jurassic and Middle Jurassic source rocks from the Kiwangwa well -1 that generally suggest a marginally mature zone. The former population is statistically minor for making any inference to. Although most of the samples plot in the mature window but they characterize a dry gas window (Figure 7).

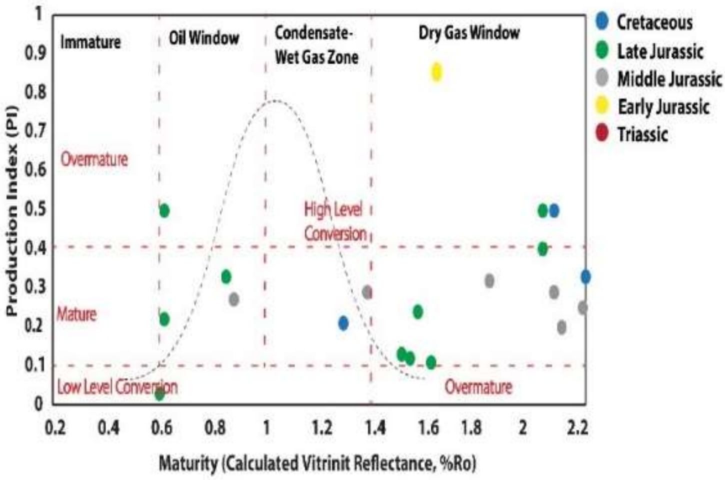

Figure 7: Plot of production index versus maturity indicating the maturity levels of Ruvu sub-basin sediments.

Conclusions

Good to very good source rocks are inferred from TOC vs S_2 for the Early Jurassic and Triassic of Kiwangwa well -1 at depth intervals of 1020 m -1050 m. This suggests high generative organic matter suitable for hydrocarbon production. None generative organic matter window is inferred for the Cretaceous, Middle Jurassic and Late Jurassic time intervals in the sub-basin. The Late Jurassic source rocks at depth intervals between 1020 m -1050 m of the Kiwangwa well-1 show HI of 204.5 mgHC/gTOC, suggesting Kerogen type II and III (oil and gas prone) whose inference point to the presence of generative organic matter contrary to Early Cretaceous, Middle Jurassic, Early Jurassic and Triassic source rock intervals that indicate Kerogen type IV which is non-generative organic matter.

Generation potentiality of the source rocks employing the HI and TOC parameters show that the Late Jurassic source rock intervals in the Ruvu sub-basin is gas or oil-prone source. The lower HI values during the Early Jurassic – Mid-Jurassic are inferred to be due to the existence of a large number of terrigenous plants in the parent source. All other intervals in the sub-basin have no hydrocarbon generation potential. Our findings from generation potentiality in the study area indicate that the Late Jurassic source rock interval in Ruvu can offer potential prospects and gas-exploration targets. The degree of thermal evolution of the sedimentary organic matter was evaluated from vitrinite reflectance and production index. The data depict a bimodal pattern, indicating the presence of two populations of vitrinite particles: the first population (minor) with lower mean vitrinite reflectance is attributed to autochthonous; and the second (Late Jurassic and Middle Jurassic) with relatively higher vitrinite possibly indicating reworked particles but marginally matured.

Acknowledgement

Petroleum Upstream Regulatory Authority (PURA) and Tanzania Petroleum Development Corporation (TPDC) are highly acknowledged for data provision in this study.

References

Ahmed W, Alam S and Jahandad S 2004 Techniques and Methods of Organic Geochemistry as Applied to Petroleum Exploration. *Pakistan J. Hydr. Res. (*14): 69-77.

Delvaux D 2001 Karoo rifting in western Tanzania: Precursor of Gondwana break-up? Edited by Klerkx, J. In Contributions to geology and paleontology of Gondwana. In honor of Helmut Wopfner. *Geol. Inst. Univ. Col.* 111-125.

Dembicki H 2022 Practical petroleum geochemistry for exploration and production. *Elsevier.* 25-40.

Edilbi A, Kolo K, Muhammed NR, Yasin SR, Mamaseni WJ and Akram R 2019 Source rock evaluation of shale intervals of the Kurra Chine Formation, Kurdistan Region-Iraq: An organic geochemical and basin modeling approach. *Egypt. J. Petrol.* 28(4): 315-321.

Elyasi S 2016 Petroleum source-rock potential of the Piranj oil field, Zagros basin. *Mar. Petrol. Geol.* 78: 448-454.

Emmanuel A, Kasanzu CH and Kagya M 2020 Geochemical characterization of hydrocarbon source rocks of the Triassic-Jurassic time interval in the Mandawa basin, southern Tanzania: Implications for petroleum generation potential. *S. Afr. J. Geol*. 123(4): 587-596.

Espitalié J, Laporte J, Madec M, Marquis F, Leplat P, Paulet J and Boutefeu A 1977 Méthode rapide de caractérisation des roches de méres de leur potentiel pétrolier et de leur degré d'évolution. *Institut Francais. Pétrol. Rev*. 32: 23-42.

Godfray G, Kabohola J and Msabi M 2023 Sedimentology and compositional characteristics of siliciclastic and associated sediments in Ruvu basin: implication on paleo-depositional environment, provenance, and tectonic setting. *Geol. Ecol. Landscap. 7*(4): 356–368. https://doi.org/10.1080/24749508.2021.2022447.

Kapilima S 2003 Tectonic and sedimentary evolution of the coastal basin of Tanzania during the Mesozoic times. *Tanz. J. Sci.* 29(1): 1–16.

Kasanzu 2014 Apatite fission track and (U-Th)/He thermochronology from the Archean Tanzania Craton: Contributions to cooling histories of Tanzanian basement rocks**.** *Geosci. Front.* 8(5): 999-1007.

Lai H, Li M, Mao F, Liu J, Xiao H, Tang Y and Shi S 2020. Source rock types, distribution and their hydrocarbon generative potential within the Paleogene Sokor-1 and LV formations in Termit Basin, Niger. *Energy Explor. Exploit.* 38(6): 2143-2168.

Law CA 1999 Treatise of Petroleum Geology/Handbook of Petroleum Geology: Exploring for Oil and Gas Traps. Chapter 6: *Eval. Sour. Roc.*

Mbede E 1991 The sedimentary basins of Tanzania-reviewed. *J. Afr. Earth Sci.* 13(3–4): 291–297.

Mboya EI 2021 Sedimentary Basins Prospective for Hydrocarbons. Eur. Assoc. of Geosci. & Eng. 27: 1-2. DOI: https://doi.org/10.3997/2214-4609.201702431

Mpanda S 1997 Geological development of the East African coastal basin of Tanzania. *Acta Universitat Stockholmiensis***.** pp. 223.

Mvile BN, Abu M, Osinowo O, Marobhe IM and Olayinka AI 2020 An overview of the geology of Tanga onshore basin: implication for hydrocarbon potential, Tanzania, East Africa. *J. Sedim. Environ.* 5(3): 267-277.

Nzoussi-Mbassani P, Copard Y and Disnar J R 2005 Vitrinite recycling: diagnostic criteria and reflectance changes during weathering and reburial. *Int. J. Coal Geol.* 61: 223–239.

Peters D and Garrey P 2014 Source rock evaluation and hydrocarbon potential in the Tano basin, South Western Ghana, West Africa. *Int. J. Oil Gas Coal Eng.* 2(5): 66-77.

Peters KE and Cassa MR 1994 Applied source rock geochemistry. In: Magoon LB and Dow WG (eds) The Petroleum System e from Source to Trap, 60. Tulsa: *Am. Assoc. Petr. Geol. Mem.* 93–120.

Sabuni R, Kagya M and Mtelela C 2023 Petroleum systems and hydrocarbon potential of the Ruvuma Basin, Tanzania. *Geoen. Sci. and Engin.* 223: p.211588.

Shalaby MR, Hakimi MH and Abdullah WH 2012 Organic geochemical characteristics and interpreted depositional environment of the Khatatba Formation, northern Western Desert, Egypt. *AAPG Bull.* 96(11): 2019-2036.

Tanzania Petroleum Development Cooperation (TPDC) Geological internal report 1992 Fairway. Tanz. Petrol. *Explor. Potent. (Unpublished).*

Tissot B, Durand B, Espitalie J and Combaz A 1974 Influence of nature and diagenesis of organic matter in the formation of petroleum. *AAPG Bull.* 58(3): 499-506.

Tissot BP and Welte DH 1984 Composition of crude oils in Petroleum Formation and Occurrence S*pring. Berl. Heidel.* pp. 375-414.

Xianming X, Wilkins RWT, Dehan L, Zufa L and Jiamu F 2000 Investigation of thermal maturity of lower Palaeozoic hydrocarbon source rocks by means of vitrinite-like maceral reflectance—a Tarim Basin case study. *Org. Geochem.* 31(10): pp.1041-1052.

Appendices

Appendix 1. Pyrolysis data of Kiwangwa well -1 with its attributes (51 samples were collected).

Age		Depth (m)	TOC (wt %)	S_1 (mgHC/g Rock)	S_2 (mgHC/ g Rock)	PI	HI	VR
Cretaceous	Early Cretaceous	305	0.34	0.03	0.03	0.5	8.8	2.83
		420	0.21	0.02	0.02	0.5	9.5	
		445	0.3	0.01	0.02	0.33	6.7	2.41
		480 - 510	0.37	0.19	0.14	0.58	37.8	
		540 - 570	0.49	0.12	0.16	0.43	32.7	3.37
		675	0.53	0.02	0.02	0.5	3.8	2.08
		740	0.69	0.02	0.04	0.33	5.8	2.2
		810 - 804	0.85	0.09	0.34	0.21	40	1.29
Jurassic	Late Jurassic	870 - 900	0.76	0.08	0.28	0.22	36.8	0.62
		937	0.61	0.04	0.04	0.5	6.6	0.62
		960 - 990	0.57	0.1	0.24	0.29	42.1	
		1020-1050	11	0.81	22.5	0.03	204.5	0.6
		1110-1140	0.71	0.04	0.31	0.11	43.7	1.62
		1260-1290	0.65	0.05	0.37	0.12	56.9	1.54
		1350-1380	0.54	0.03	0.2	0.13	37	1.51
		1500-1530	0.64	0.11	0.35	0.24	54.7	1.57
		1650-1680	0.53	0.05	0.05	0.5	9.4	2.04
		1650-1680	0.61	0.04	0.06	0.4	9.8	2.04
	Middle Jurassic	1710-1740	0.59	0.04	0.24	0.14	40.7	
		1800-1830	0.3	0.03	0.06	0.33	20	0.85
		1800-1830	0.31	0.01	0.02	0.33	6.5	
		1920-1950	0.32	0.02	0.05	0.29	15.6	1.38
		1920-1950	0.37	0.02	0.05	0.29	13.5	
		2010-2040	0.31	0.01	0.03	0.25	9.7	2.27

Jurassic	Middle Jurassic	2010-2040	0.4	0.01	0.03	0.25	7.5	
		2130-2160	0.49	0.01	0.04	0.2	8.2	2.11
		2130-2160	0.33	0.01	0.04	0.2	12.1	
		2220-2250	0.54	0.02	0.06	0.25	11.1	2.19
		2220-2250	0.47	0.01	0.04	0.2	8.5	
		2380-2410	0.55	0.07	0.19	0.27	34.5	0.88
		2560-2590	0.64	0.09	0.19	0.32	29.7	1.84
		2620-2650	0.66	0.13	0.19	0.41	28.8	
	Early Jurassic	2650-2680	1.7	0.18	0.32	0.36	18.8	
		2725	3.3	0.15	0.36	0.29	10.9	2.08
		2740-2770	2.96	1.04	0.83	0.56	28	
		2796	3.17	0.11	0.26	0.3	8.2	3.3
		2800-2830	1.82	0.24	0.44	0.35	24.2	
		2830-2860	1.96	0.65	0.52	0.56	26.5	
		2875	1.17	1.12	0.2	0.85	17.1	1.64
		2892.5	1.58	1.43	0.24	0.86	15.2	1.64
		2942.5	1.6	0.05	0.22	0.19	13.7	3.62
		3035	2.05	0.72	0.32	0.69	15.6	2.95
		3103	0.77	0.06	0.1	0.38	13	3.58
		3117.5	2.13	1.04	0.26	0.8	12.2	2.96
Triassic		3250-3280	2.05	0.09	0.23	0.28	11.2	3.79
		3280-3310	0.23	0.09	0.15	0.38	65.2	
		3310-3340	1.95	0.17	0.16	0.52	8.2	
		3370-3400	1.85	0.07	0.11	0.39	5.9	3.72
		3460-3490	2.27	0.08	0.19	0.3	8.4	
		3509.55	0.25	0.02	0.02	0.5	8	6.64