تقييم الصخر المصدري للعصر السيلوري السفلي للبئر H29 امتياز NC115 شمال غرب مرزق جنوب غرب ليبيا

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الملخص

يعتبر تكوين تنزوفت السفلي والتابع للعصر السيلوري السفلي والمعروف بـ (Hot Shale) بأنه صخر مشع وله استجابة عالية لأشعة جاما. ويرجع ذلك على الأرجح إلى ارتفاع نسبة اليورانيوم. ويعدُ تكوين تنزوفت ذو العصرالسيلوري هو المصدر الرئيسي للصخور في حوض مرزق.

ومن خلال دراسة العصرالسيلوري السفلي وتفسير النتائج الجيوكيميائية للبئر H29 والتابع للامتياز NC -115 تبين ان التكوين يتميز بسحنتين ريئسيتين، السحنة أ: وتضم الجزء السفلي من العصر السيلوري السفلي الذي يمتد عمقه مابين 1472 الى 1487 قدم، والذي يسمى بـ (Hot Shale). أما السحنة ب: وتضم الجزء العلوي من العصرالسيلوري السفلي الذي يمتد عمقه مابين 1426 الى 1468 قدم، والذي هو مختلف تماما ويسمى بـ (Tanezzuft Shale).

فمن خلال تقييم السحنة أ والتي تضم الجزء السفلي من العصرالسيلوري السفلي تتميز بأنها غنية جدا بالكربون العضوي (TOC) ونسبة عالية جدا من الهيدروجين وقلة الاكسجين مما يشير الى أنها بيئة مختزلة ، مما يعطي فرصة أكبر في حفظ المادة العضوية في البيئة المختزلة، والتي تمثل مرحلة نافذة الزيت أي الكيروجين النوع الثاني.
كذلك تم تقييم الجزء العلوي من السيلوري السفلي واستنادًا إلى المعلومات الجيوكيميائية ، حيث أشار التقييم إلى أن مؤشر الهيدروجين ضعيف مما أعطى نوع الكيروجين الثالث.

Evaluation of Lower Silurian Source rock H29- NC 115 NW Murzuq Basin SW Libya

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ABSTRACT

The basal Tanezzuft Formation (Hot Shale) is recognized as radioactive hot shale and has a high gamma ray response in wireline logs. This is most probably due to the high content of uranium. The lower most Silurian Tanezzuft Formation and Hot Shale are thought to be the main source rocks in the Murzuq Basin. The Lower Silurian Succession during this study and within H 29 - NC115, has been characterized by two main organic Facies, Facies A The Lower Part of the Lower Silurian Succession between intervals 1472 ft. to 1487 ft. which called (Hot Shale). Facies B the Upper Part of the Lower Silurian Succession between interval 1426 ft. to 1468 ft. which is completely different and called (Tanezzuft Shale). The Lower Part of the Lower Silurian Succession distinguished as very rich in organic carbon TOC and highly HI and low OI indicate anoxic environment, which gives opportunity to preserve the organic matter in reducing conditions. representing to Oil Window stage Kerogen type II. The Upper Part of the Lower Silurian Succession based on geochemical information have been evaluated Low Hydrogen Index (HI) which is indicate to the Kerogen type III.

1. INTRODUCTION

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The Murzuq Basin is one of the largest Paleozoic intracratonic basins in the North African Sahara. It covers an area of about 350,000 square kilometers in southwest Libya (Davidson et al., 2000), extending southwards into Niger (Fig. 1).

The Murzuq Basin has reserves with over five billion barrels of oil equivalent, while the NC115 Concession in A, B, C, (H - the focus of this study), and J oilfields, with reserves of about one billion barrels of oil. Many oilfields within the Murzuq Basin have very good production rates. For instance, the NC115 Concession has a maximum production rate of about 200,000 bpd, mainly from the A and B fields. The Sahara oilfield in the Murzuq Basin had a production capacity of about 400,000 bpd as of September 2011, while the Elephant Field, with estimated reserves of about 561 million barrels of oil, had a maximum production rate of 125,700 barrels of oil per day in 2010 (Petroleum Economist, 2011). The main focus of this study is the Lower Silurian Tanezzuft Formation and its basal part, the Hot Shale in a major oilfield H within the NC115 Concession, Murzuq Basin, SW Libya.

The basal Tanezzuft Formation (Hot Shale) is recognized as radioactive hot shale and has a high gamma ray response in wireline logs. This is most probably due to the high content of uranium (Fello et al., 2006). The lower most Silurian Tanezzuft Formation and Hot Shale are thought to be the main source rocks in the Murzuq Basin (Echikh and Sola, 2000; Sikander et al., 2000; Craig et al., 2008).

The Silurian organic-rich shale is estimated to be the origin of 80-90% of all Paleozoic sourced hydrocarbons in North Africa. Hydrocarbons generated from these source rocks migrated into various reservoir horizons, from Cambrian to Triassic sandstones and sealed by shale. In the Murzuq Basin, the Ordovician sandstones are the main reservoir rocks (Lüning et al., 2000).

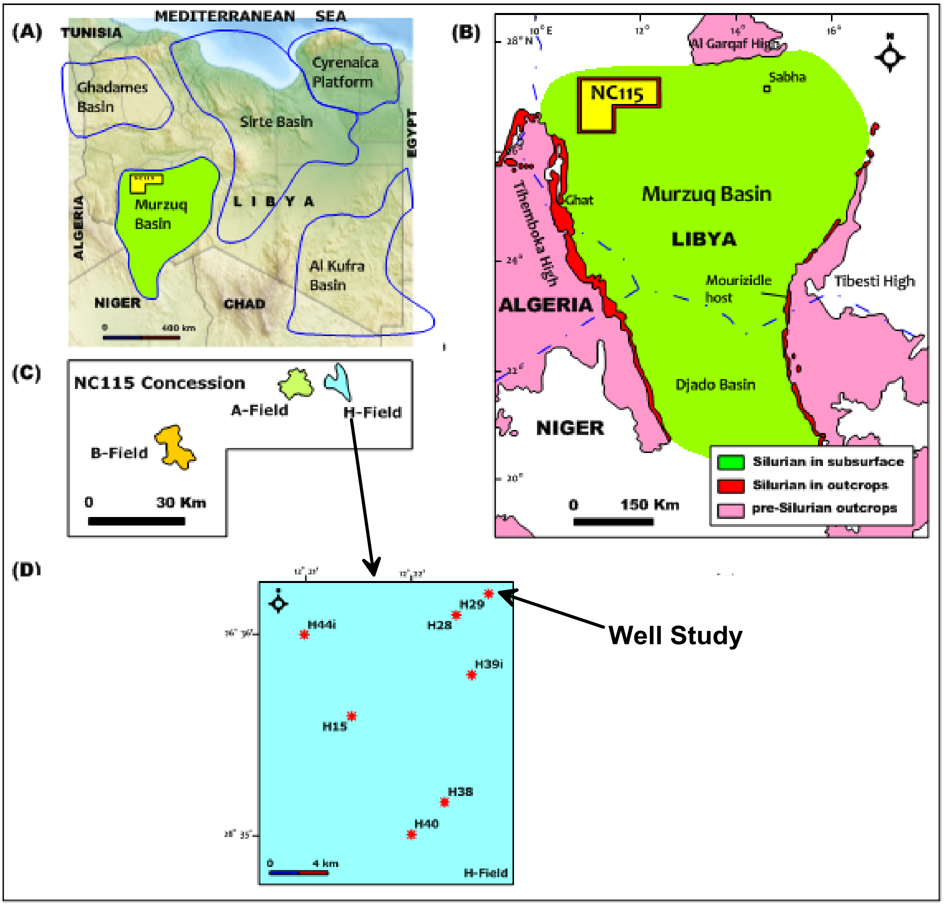

Figure 1. (A) The regional location of the Murzuq Basin in Libya. (B) Map showing distribution of the Silurian Tanezzuft Formation in the Murzuq Basin (modified after Lüning et al., 2003). (C) Map showing the distribution of the three A, B and H oilfields in the NC115 Concession, Murzuq Basin. (D) The location of the exploration well (H 29– that used in current study).

1.1 Study area

The NC115 Concession is located in the northwestern part of the Murzuq Basin, southwest Libya, It covers an area of about

25,850 square kilometers. It covers approximately three quarters of the area latitudes 26°08' and 26°38'N and longitudes 11°30' and 12°30'E. Within the NC115 Concession, a major oilfield (the focus of this study); NC115-H, has been developed in this part of the Sahara Desert. (See location map, Fig.1). (RRI, 1998).

1.2 Objectives

This work attempts to apply petroleum geochemistry on source rocks of the Silurian Hot Shale and Tanezzuft Formation in the NC115 Concession, Murzuq Basin, Libya to:

1. Characterize the organic matter using organic geochemical data.
2. Assess and investigate the hydrocarbon generation potential of the studied source rocks.
3. Identify the sedimentary environment in which organic matter was produced and preserved.

1.3 Material and methodology

Thirteen samples were registered from exploratory well from different depth intervals within the Tanezzuft Formation and the basal 'Hot Shale' in the H29 - NC115 southwest Libya. In order to evaluate the geochemical results of the Rock-Eval 6 pyrolysis of this formation. In order to assess the hydrocarbon potential and organic geochemical signature of this formation.

Methods adopted here in are discussed as follow:

1.3.1 Pyrolysis analysis

Pyrolysis is the decomposition of organic matter by heating in the absence of oxygen to yield organic compounds (Peters, 1986). Organic geochemists use pyrolysis to measure richness, quality and maturity of potential source rocks. The most widely used pyrolysis technique is the Rock-Eval.

1.3.2. Rock-Eval pyrolysis

The purpose of Rock-Eval pyrolysis (Figs. 2) is to quickly obtain information on hydrocarbon generation potential, presence or absence of non-indigenous hydrocarbons, organic matter type and thermal maturity of a rock.

Rock-Eval pyrolysis was performed on 70 mg pulverized whole rock samples using a Rock-Eval 6 apparatus. In order to determine these parameters: TOC= Total organic carbon, wt % / Tmax = Temperature at maximum / HI: Hydrogen index / OI= Oxygen index, PI= Production index. (Table1). With S1, S2, S3, PP, that we not used in this study.

Figure 2. Illustrative picture showing the Rock-Eval 6 apparatus

All these parameters are explaining and interpreting in Table (1).

1. **Total Organic Carbon Content, TOC% Weight of rock**

Very Poor	Poor	Fair	Rich	Very Rich
0.01-0.20	0.21-0.5	0.51-1.0	1.01-3.00	Over 3

2. Petroleum Potential (PP), S1+S2, mg/g of rock

Very Poor	Poor	Fair	Rich	Very Rich
0.01-0.5	0.51-2.0	2.01-5.0	5.01-20.0	Over 20.0

3. Hydrogen Index (HI), S2/TOC*100

Very Low	Low	Medium	High	Very High
0-50	50-100	101-300	301-600	Over 600

4. Oxygen Index (OI), S3/TOC*100

Very Low	Low	Medium	High	Very High
0-50	50-100	101-200	201-400	Over 400

5. S1, mg/g

Poor	Fair	Good	Very Good
0 - 0.5	0.5 – 1.0	1.0- 2.0	Over 2.0

6. S2, mg/g

Poor	Fair	Good	Very Good
0 – 2.5	2.5-5.0	5.0 – 10	Over 10.0

7. Hydrocarbon Generative Potential in Terms of HI:

Type	Gas	Gas and Oil	Oil
HI	0 - 150	150 – 300	Over 300

Thermal Maturation Levels:

Parameter	Immature	Mature	Over-mature
Tmax, deg. C	Below 430	430-470	Over 470

PI=S1/S1+S2.	**Below 0.1**	**0.1 – 0.4**	**Over 0.4**

(Ref: After Beicip, 1991; K.E Peters, 1986).

2. Geologic setting

2.1 Geology of Libya

Libya is located on the Mediterranean coast of North Africa, and has an area of about 1,775,500 square kilometers. It extends about 1,525 kilometers east and west and as much as 1,450 kilometers north and south, except for the northernmost parts, where the country lies entirely within the Sahara.

Libya is divided into three Palaeozoic, and two Mesozoic-Cenozoic basins (Gumati et al., 1996). These basins in order of importance are as follows: the Sirte Basin (Mesozoic-Cenozoic), the Ghadames and Murzuq basins (Palaeozoic), Tripolitana Basin (Mesozoic-Cenozoic), and the unexplored Kufra Basin (Palaeozoic) (Fig.3).

The Murzuq and Kufra basins cover large areas in the south-west and southeast of Libya extending across the border into adjacent countries. The Ghadames Basin covers the NW part of Libya, whereas the Sirte Basin is located in the north central part of Libya and the Tripolitana Basin is situated in the northwest, offshore Libya.

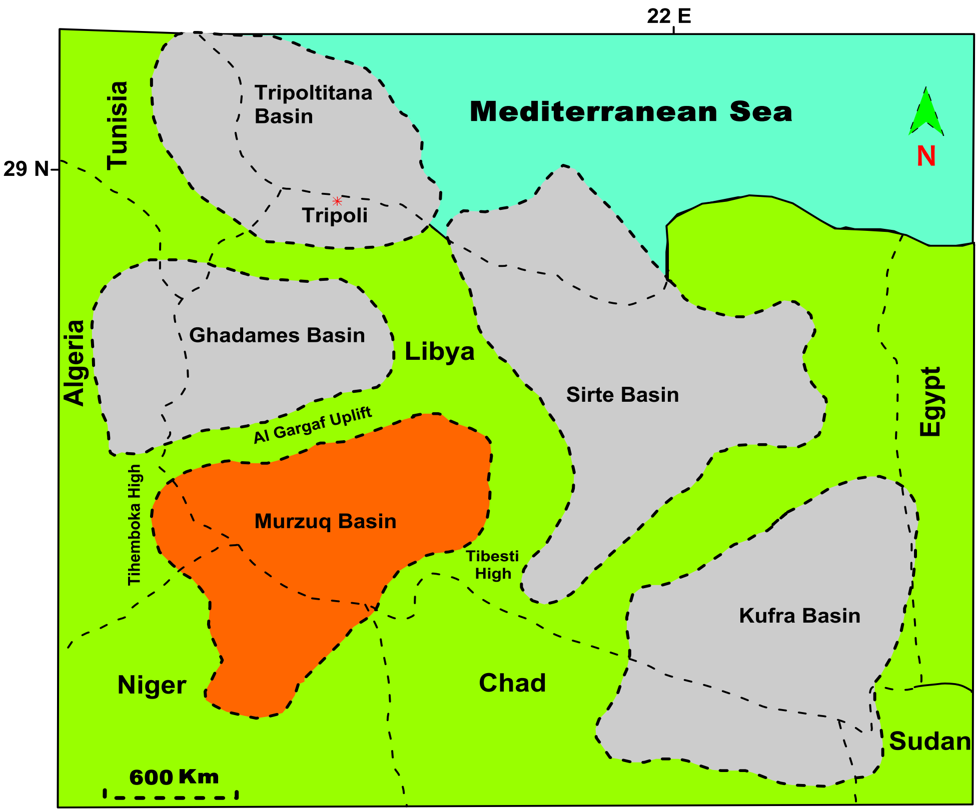

Figure 3. The geological basins of Libya (Gumati et al., 1996)

2.2 Murzuq Basin

Murzuq Basin is located in the southwestern part of Libya and abuts the border with Algeria, Niger and Chad. The basin is located to the south-east of the Ghadames Basin, from which it is separated by the Atshan Saddle, an anticlinal structure trending approximately ENE-WSW which leads into the western end of the Al Gargaf Uplift.

Oceanic anoxic events leading to oxygen depletion and deposits with a high total organic carbon (TOC) content have occurred in parts of the world's oceans several times in the past (Klemme and Ulmishek, 1991; Lüning et al., 2000; Lüning et al., 2003; Lüning et al., 2005). In North Africa and Arabia much of the Paleozoic oil resources derive from the maturation and migration of hydrocarbons generated from Silurian organic-rich marine shales (Klemme and Ulmishek, 1991; Boote et al., 1998; Lüning et al., 2000, Lüning et al., 2003; Peters and Creaney, 2004; Loydell et al., 2009; İnan et al., 2016). The intracratonic Murzuq Basin is no exception.

2.2.2 Stratigraphic succession of the Murzuq Basin

The sedimentary deposits in the Murzuq Basin range from Cambrian to Quaternary in age, and can be divided into several major sedimentary units. The Murzuq Basin contains a thick section of marine and continental Palaeozoic with some Mesozoic and Cenozoic sediments. These sediments are composed mainly of marine shale, siltstone, and sandstone overlying unconformably the Precambrian basement complex, their total thickness exceeds 3500 m in the central part of the basin (Thomas, 1995a).

Many researchers have discussed and interpreted the stratigraphic sequence of the Murzuq Basin (Mamgain, 1980; Bellini and Massa, 1980; Castro et al., 1985; Pierobon, 1991; Echikh and Sola, 2000; Davidson et al., 2000; Sutcliffe et al., 2000; Hallett, 2002; McDougall and Gruenwald, 2011). They divided the sequence of the Murzuq Basin into several sedimentary units and systems. These can be discussed as follow:

2.2.2.1 Ordovician

The Ordovician rocks of this area were first described by Massa and Collomb (1960). They are widespread over large portions of the North African craton (Pierobon, 1991). Four formations represent the system; these are Ash Shabiyat (Early Ordovician), Hawaz (Middle Ordovician), Melaz Shuqran and Mamuniyat (Late Ordovician) (Lüning et al., 2000). The Hawaz and Mamuniyat formations which are important reservoirs (Fig. 4).

Hawaz Formation: Middle Ordovician (Llandeilian/Llanvimian)

The Hawaz Formation which forms the secondary hydrocarbon reservoir in the Murzuq Basin was first described and named after Jebel Hawaz on the Al Garqaf High by Massa and Collomb (1960). In the NC115 Concession, it is overlain by the Ordovician Melaz Shuqran Formation (Fig. 4), where it reaches 150 m in thickness. Its probable mid- Ordovician age is based on palynological evidence (Hallett, 2002). The formation consists of fine- to medium-grained quartzitic sandstone that is moderately to well cemented by siliceous material. It is kaolinitic in parts, has poor visual porosity, and contains thin streaks of moderately- to well-compacted, sub-fissile to fissile shale (Hallett, 2002; Ramos et al., 2006). These deposits reflect the onset of the first major Palaeozoic marine transgression in the region (Echikh and Sola, 2000; Ramos et al., 2006; de Gibert et al., 2011).

Mamuniyat Formation: Late Ordovician (Ashgillian)

The name Mamuniyat Formation is derived from the type section Al Garqaf Arch as is the case for the names of most stratigraphic units in the Lower Palaeozoic of Libya, located either in Wadi (e.g. Tanezzuft Formation) or Arch (Mamuniyat Formation) as reported (Le Heron et al., 2010). The Late Ordovician glacially-related strata, as for underlying units, occur on the Al Garqaf Arch where two formations are formally recognized in both surface (Massa and Collomb, 1960) and subsurface (El-ghali, 2005) mapping, namely the Melaz Shuqran Formation and the overlying Mamuniyat Formation. This is predominantly a sandstone unit with subordinate siltstone and shale interbeds (Aziz, 2000; Davidson et al., 2000). The sandstone is fine-grained, off-white, medium hard to hard, and moderately to well cemented by siliceous material. It also includes thin layers of fissile to sub-fissile grey shales. The lower and middle parts of the formation represent glacial depositional systems associated with relative sea-level fall (El-ghali, 2005). The upper units of the formation comprise a prolific reservoir unit in the NC115 B oilfield, and are in direct contact with the overlying source rock, the Silurian (Llandovery–Wenlock) basal Tanezzuft Formation (Hallett, 2002). The sandstones of the Mamuniyat Formation are the primary reservoir in the Murzuq Basin.

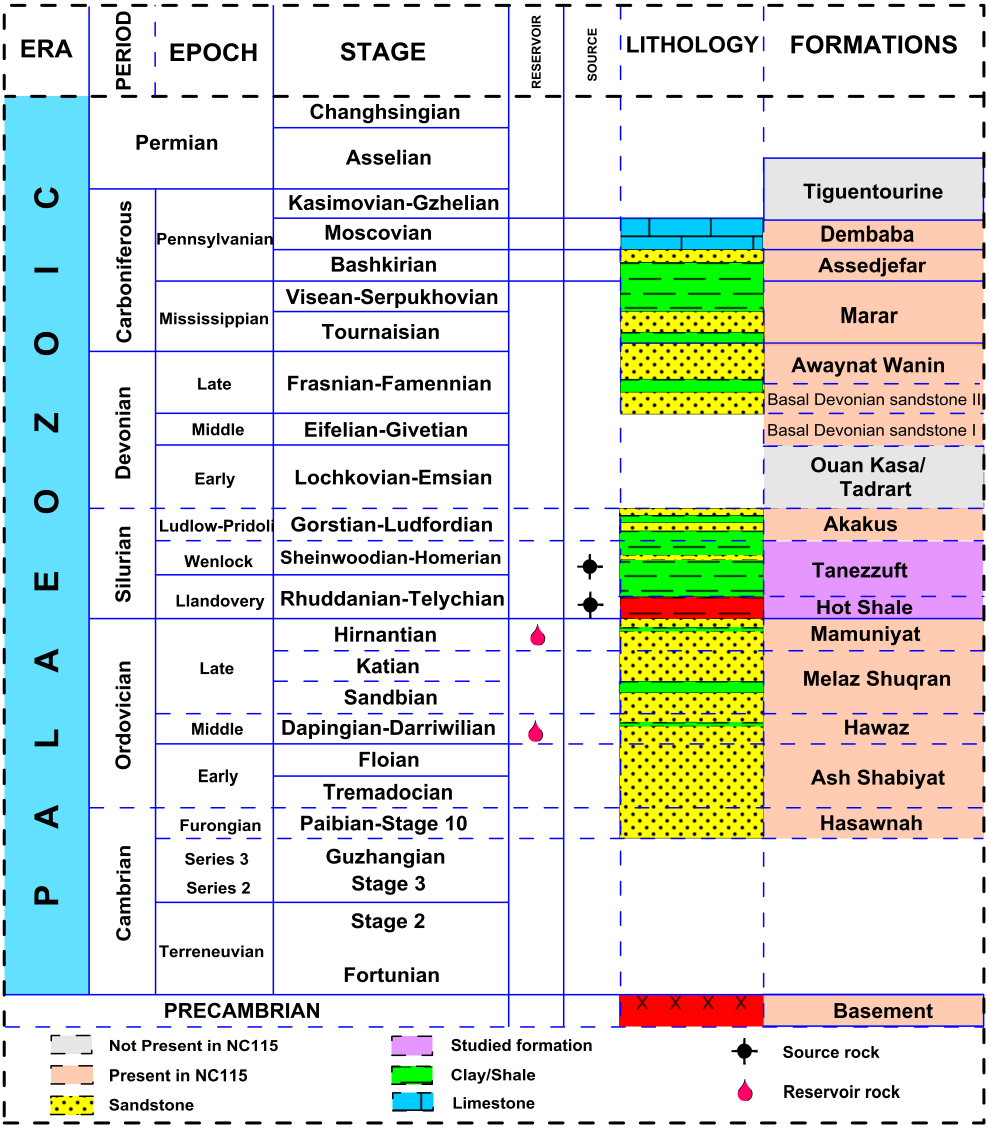

Figure 4. Compiled lithostratigraphic column in the NC115 Concession, Murzuq Basin, SW Libya (Modified after Aziz, 2000)

2.2.2.2 Silurian

The first major marine transgression covering the greater part of the North African craton started in the Early Silurian period as a result of melting of ice sheets that covered the Hoggar, Tibesti, Jabal Al Awaynat and probably Jabal AI Hasawnah massifs (Mamgian, 1980). The transgression produced thin, locally developed, basal silty sandstones in some areas, after which thick, "hot" black, radioactive, graptolitic-shale were deposited. This organic-rich shale forms one of the principal petroleum source rocks in Libya and Algeria (Hallett, 2002).

Hot Shale: Early Silurian (Llandoverian)

The basal part of the Tanezzuft Formation is an Early Silurian, Rhuddanian, black shale known as the Hot Shale Member. This constitutes the most important source rock within the Murzuq Basin, but its extent is limited as a result of Hercynian erosion (Lüning et al., 2000; Hallett, 2002). In southern Libya the anoxic event that led to this deposit was confined to depressions in the eroded Ordovician surface (Parrish, 1982; Finney and Berry, 1997; Lüning et al., 1999, Lüning et al., 2000, Lüning et al., 2003). It resulted from a favourable combination of marine upwelling associated with abundant organic productivity and preservation in oxygen-deficient conditions (Waples, 1985; Finney and Berry, 1997). These factors could affect the distribution of source richness and kerogen type. This is consistent with a dominance of amorphous kerogen in the central part of the basin whereas in areas toward the southwest and south, the organic matter has a more continental character with a high coarse Clastic content, resulting in poor to non-source rock quality (Meister et al., 1991). It is present only in B42, H15, H28, H29, and H39 wells in the NC115 Concession. Its maximum thickness is about 45 m in the southeast (Aziz, 2000).

The Hot Shale deposits are commonly black, dark brown to dark grey, micaceous, and pyritic. Isopach maps show that in North

Africa they are thickest and most extensive in western Libya, Algeria and Tunisia, whereas in Arabia they are most prolific in Saudi Arabia. They are absent from Egypt, which was a structurally high region at this time (Echikh and Sola, 2000; Lüning et al., 2000; Fig. 5).

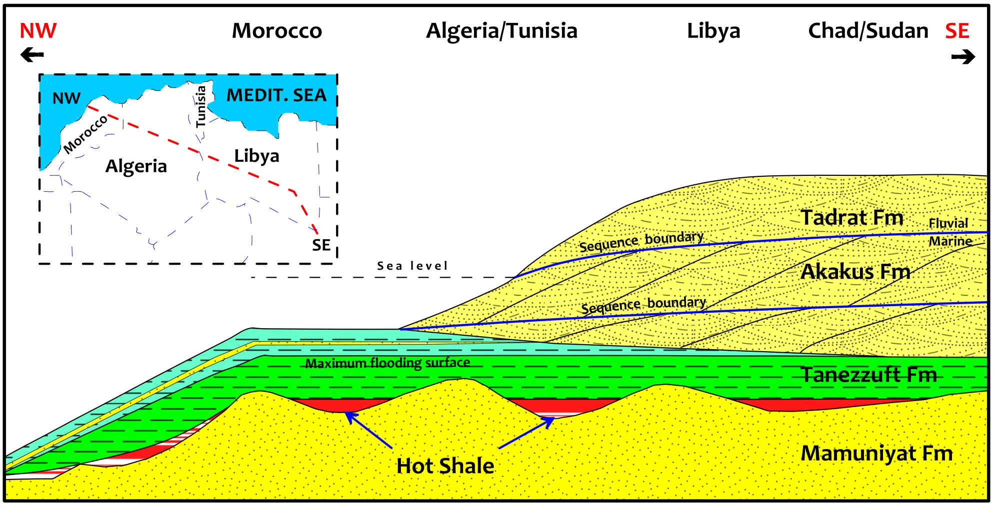

Figure 5. General depositional model for Late Ordovician to Early Devonian sediments in North Africa with emphasis on the lowermost Silurian Hot Shales (after Lüning et al., 2000)

The term 'Hot Shale' refers to the high level of natural radioactivity in certain shales owing to an increase in authigenic uranium, thorium and potassium, and can be easily recognized on the wireline logs (Lüning et al., 2000; Armstrong et al., 2005). High gamma ray values have also been recorded for the Hot Shales in Tunisia (Vecoli et al., 2009), Qusaiba in Saudi Arabia (McGillivray and Husseini, 1992; İnan et al., 2016), and Jordan (Butcher, 2009).

Tanezzuft Formation: Early Silurian (Llandoverian/Wenlock)

The Tanezzuft Formation was named after Wadi Tanezzuft by Desio (1936). It overlies the Mamuniyat Formation and underlies the Late Silurian (Ludlow–Pridoli) Akakus Formation (Fig. 5). It is an important stratigraphic unit from the petroleum exploration standpoint as it represents the most proven Palaeozoic source rocks in North Africa and northern Gondwana (Hallett, 2002). It reflects a widespread marine transgression of the Silurian sea over the North African craton (Mamgain, 1980), although it's a real extent has been reduced by later, mid-Devonian and post-Hercynian erosion.

Melting of the Late Ordovician ice sheets led to a major marine transgression from the north, and culminated in a high stand with deposition of the Tanezzuft Formation, a consistent argillaceous succession interbeded with very thin sandstone layers, the total thickness of which may reach more than 700 m in some wells in the NC115 Concession. The lower part of the formation, which has been dated as early Llandovery (Davidson et al., 2000), consists predominately of grey to dark grey, fissile to sub-fissile, occasionally micaceous shales. The upper part begins with a light grey shale that is usually soft to firm, fissile to sub-fissile, micaceous and silty.

3. Source rock evaluation using TOC /Rock-Eval data

Rock-Eval pyrolysis gives information on the quantity and quality of organic matter in a sedimentary rock, in addition to the level of organic maturation (Espitalié et al., 1977). TOC occurs in petroleum source rocks and represents the amount of organic matter in a rock sample (Peters and Cassa, 1994).

The results of the TOC analysis and Rock-Eval pyrolysis parameters; Temperature at Maximum (Tmax) , Hydrogen Index (HI) , oxygen index (OI), production index (PI) of selected thirteen cores and cuttings samples from the Hot Shale and Tanezzuft Formation are listed in Table (2).

Table. 2 . Showing the Geochemical results of the study well (H29-NC115) by using the Rock-Eval 6 pyrolysis.

No.	Well	Stratigraphic Age	Depth (ft)	Tmax C⁰	PI mgHC/g rock	TOC %Wt	HI mgHC/g TOC	OI mgo2/g TOC
	H29 – NC 115	L.Silurian(TZ)	1426	442	0.1	0.41	206	98
		L.Silurian(TZ)	1452	443	0.12	0.43	162	113
		L.Silurian(TZ)	1468	441	0.22	1	117	57
		L.Silurian(HS)	1472	447	0.15	5.66	249	9
		L.Silurian(HS)	1473	446	0.17	3.93	232	8
		L.Silurian(HS)	1474	441	0.13	8.37	285	2
		L.Silurian(HS)	1475	442	0.12	5.84	275	1
		L.Silurian(HS)	1476	445	0.13	10.95	259	3
		L.Silurian(HS)	1477	444	0.12	8.6	262	3
		L.Silurian(HS)	1479	443	0.12	11.08	278	6
		L.Silurian(HS)	1480	437	0.11	21.86	299	1
		L.Silurian(HS)	1482	438	0.11	20.90	285	2
		L.Silurian(HS)	1487	438	0.18	1.71	228	10

(TZ) = Tanezzuft shale, **(HS)** = Hot Shale, **TOC**= Total organic carbon, wt % / **T_{max}** = Temperature at maximum / **HI**: Hydrogen index / **OI**= Oxygen index , **PI**= Production index.

Kerogen Type

Based on the geochemical analyses of the key Well H29 – NC 115, Table (2).the Hydrogen Index(HI)Values range between 299 - 228 (mgHC/gTOC), within the interval from 1472 ft to 1487 ft, indicate that the significant hydrocarbon potentiality occur within the Lower Part of the Lower Silurian Succession (Hot Shale Member). In Contrast the Upper Part of the Lower Silurian Succession (Tanezzuft Shale) have (HI) value range between 206 to 117 (mgHC/gTOC), with high (OI) values were plotted the Upper Part of the Lower Silurian Succession in modified van krevlen diagram (Fig No. 6) in oxidizing area Type III Kerogen. However the Lower Part of the Lower Silurian Succession characterized by good values of Hydrogen Index indicate Kerogen Type II Oil prone with respect maturity (Fig No.6) (Peters, 1986).

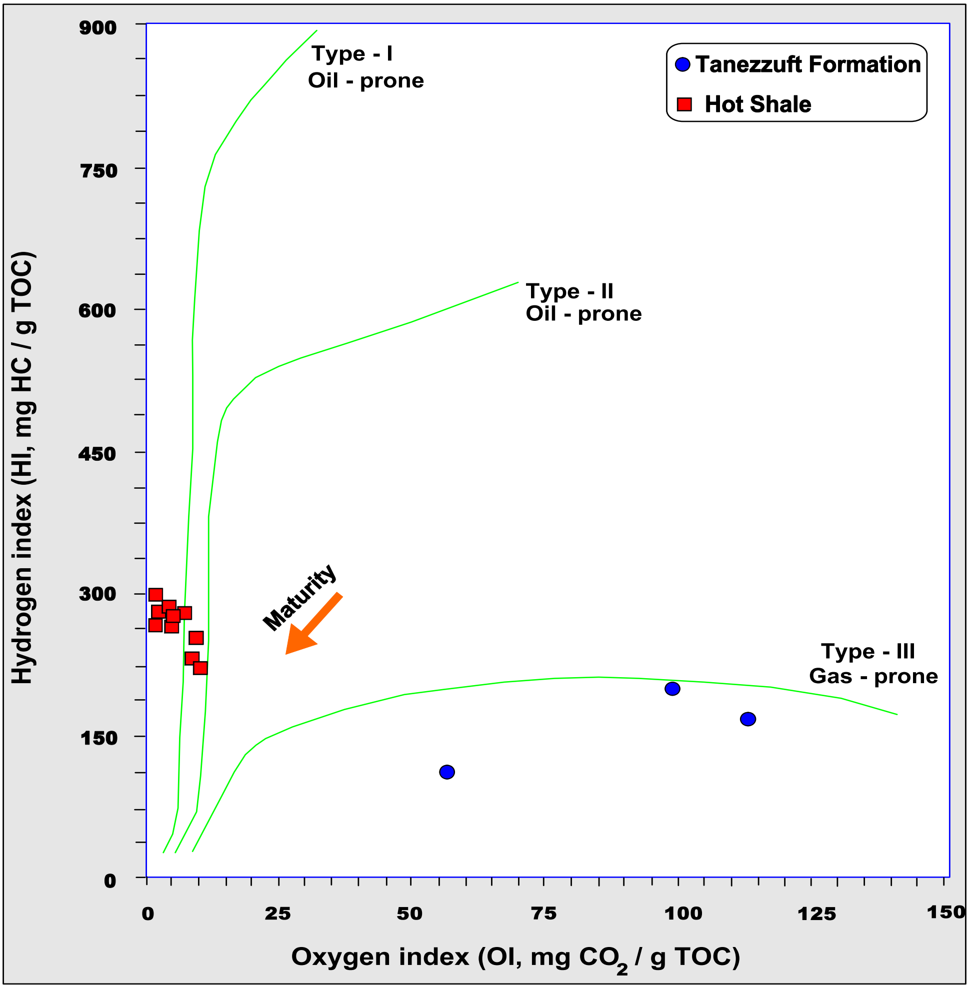

Fig No.6 Showing: Hydrogen Index vs. Oxygen Index.

Maturity-Level

The Production Index PI of the Lower Silurian Succession remains near (0.1 mgHC/g rock) in the Immature zone to the depth 1426 ft. (Upper Part of the Lower Silurian Succession), The maturity-level start increase and source rocks entiried to generation zone of hydrocarbons below the interval 1472 ft, Tmax 447 and PI (0.15 mgHC/g rock) (Fig. No. 7). The PI start increase up to (0.15 – 0.18 mgHC/g rock) and Tmax more than 437 in mature zone, which is the peak of the Oil-generation window (Hunt 1981).

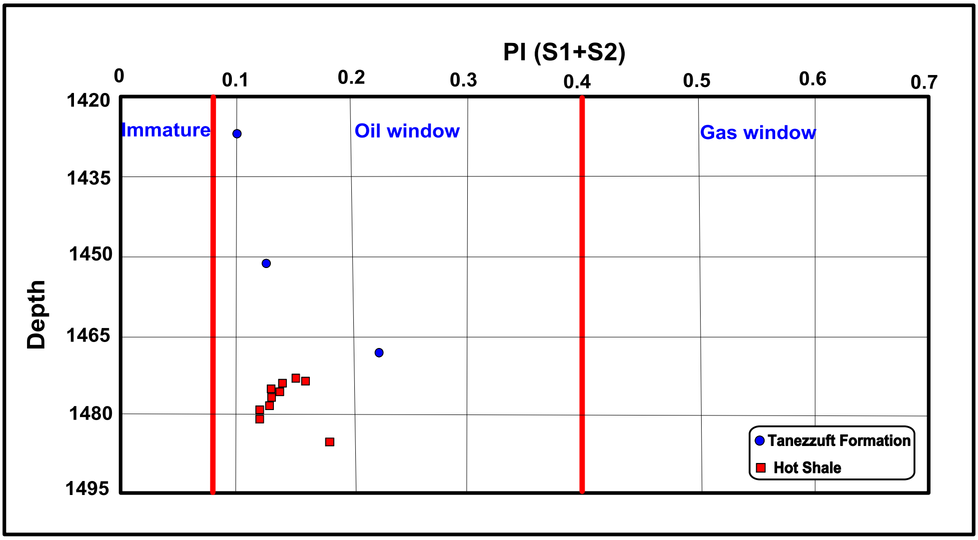

Fig. No. 7 Showing: Productivity Index vs. Depth

Preservation and Depositional Environment

The Lower Part of the Lower Silurian Succession characterized by hydrogen index HI values over than 250 mgHC/g TOC (Fig No. 8) and Low oxygen index OI values with high TOC more than (3.9 to 21 Wt%) very rich (Fig No. 9). The depletion of oxygen with rich of hydrogen indicate that the reducing environment was predominated referring to Anoxic environment. This environment is considered as the best condition of organic matter preservation with hydrogen content. represent to Oil Window Stage.

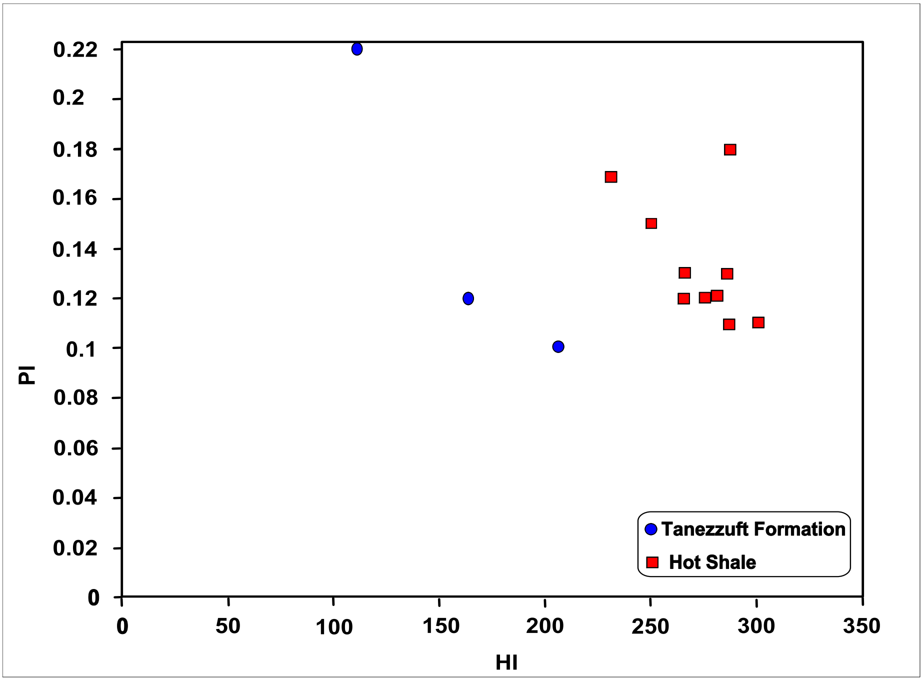

Fig No. 8: Hydrogen Index vs. Productivity Index.

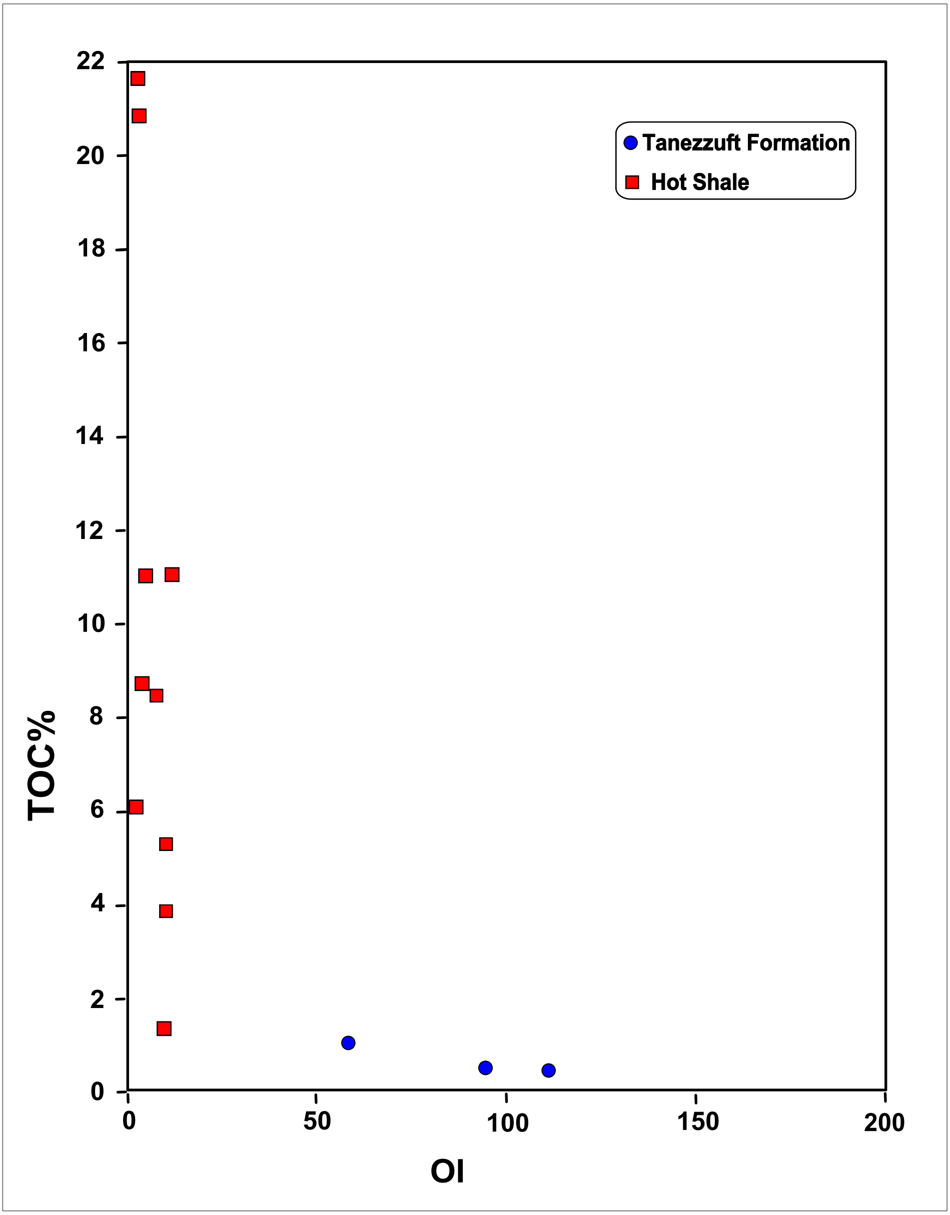

Fig No. 9: Total Organic Carbon vs. Oxygen Index

Conclusion

The Murzuq Basin, an intracratonic sag basin, is a huge ladle-shaped structural basin covering an area more than 350.000 km^2 and has a roughly triangular shape, narrowing toward the south from Libya into Niger. The sedimentary fill is predominately marine and continental Palaeozoic with some Mesozoic and Cenozoic sediments overlying Precambrian crystalline basement in the central part of the basin the total sedimentary thickness exceeds 3500 m thick (Thomas, 1995). The Lower Silurian shales in Murzuq Basin, SW Libya are termed the Tanezzuft Formation and are underlain by the Ordovician sandstones of the Mamuniyat or Hawaz Formations and overlain by the upper Silurian sandstones of the Akakus Formation. The term 'Tanezzuft Formation' was introduced by Desio (1936) who named the formation after Wadi Tanezzuft which is situated between Ghat and Al Awaynat (Luning *et al.*, 2000). The Silurian system records the first major marine transgression in SW and NW Libya. (Conant and Goudarzi, 1967).

The Lower Tanezzuft shale in the NC115 wells is dated as early Silurian (early Llandovery). The major Silurian transgression initially resulted in a relatively shallow anoxic sea and the deposition of a thin transgressive sequence tract overlain by organic rich, Lowermost Silurian hot shales indicator as an excellent source rock qualities. The early Silurian bottom waters were dense and very anoxic which, coupled with very low sedimentation rates, allowed the preservation of very high concentrations of organic matter.

Based on the Geochemical analysis of the Lower Silurian Succession in this well (H29 –NC 115) has two main organic Facies:-

- Facies A The Lower part of the Lower Silurian Succession between intervals 1472 ft. to 1487 ft. which called (Hot Shale).

- Facies B The Upper part of the Lower Silurian Succession between interval 1426 ft. to 1468 ft. is completely different which called (Tanezzuft Shale).
- Organic content varies widely between the organically-lean Tanezzuft Formation and the basal Rhuddanian Hot Shale samples, which are rich in organic matter.
- Rock-Eval Tmax and PI maturity data show that the analyzed samples from the basal Hot Shale and overlying Tanezzuft Formation have reached a well-defined maturity level to generate oil and gas in the NC115 Concession of the Murzuq Basin.
- The Lower Part the Lower Silurian Succession exhibits very good Production Index (PI) , very rich in organic carbon (TOC) and highly Hydrogen Index (HI) and low Oxygen Index (OI) that indicate to anoxic environment which gives opportunity to preserve the organic matter in reducing conditions. Then characterized by high values of hydrogen index (HI) and low oxygen index (OI), which is represent to Oil Window stage Kerogen type II with respect maturity.
- The Upper Part of the Lower Silurian Succession based on geochemical information have been evaluated Low Hydrogen Index (HI) which is indicate to the Kerogen type III.

References

Armstrong, H.A., Turner, B.R., Makhlouf, I.M., Weedon, G.P., Williams, M., Al Smadi, A., Abu Salah, A., 2005. Origin, sequence stratigraphy and depositional environment of an upper Ordovician (Hirnantian) deglacial black shale, Jordan. Palaeogeography, Palaeoclimatology, Palaeoecology 220, 273–289.

Aziz, A., 2000. Stratigraphy and hydrocarbon potential of the Lower Paleozoic succession of license NC-115, Murzuq Basin, southwest Libya. In: Sola, M., Worsley, D. (Eds.), Geological Exploration in Murzuq Basin. Elsevier, Amsterdam, pp. 349–368.

Bellini, E., Massa, D., 1980. A stratigraphic contribution to the Palaeozoic of the southern basins of Libya. In: Salem, M.J., Busrewil, M.T. (Eds.), The Geology of Libya. Academic Press, London, pp. 3–56.

Boote, D.R.D., Clark-Lowes, D.D., Traut, M.W., 1998. Palaeozoic petroleum systems of North Africa. In: MacGregor, D.S., Moody, R.J.T., Clark-Lowes, D.D. (Eds.), Petroleum Geology of North Africa, Geological Society London, Special Publication 132, pp. 7–68.

Butcher, A., 2009. Early Llandovery Chitinozoans from Jordan. Palaeontology 52, 593–629.

Castro, J.C., Della Favera, J.C., El-Jadi, M., 1985. Palaeozoic sedimentary facies, Murzuq Basin. SPLAJ, Internal report, Braspetro-Petrobras, Rio De Janeiro, 117 p.

Conant, L. C. and Goudarzi, G. H, 1967. Stratigraphic and tectonic framework of Libya. *American Association of Petroleum Geologists Bullet.* Vol. 51, P. 719-730.

Craig, J., Rizzi, C., Said, F., Thusu, B., Lüning, S., Asbali, A.I., Keeley, M.L., Bell, J.F., Durham, M.J., Eales, M.H.,

Beswetherick, S., Hamblett, C., **2008**. Structural styles and prospectivity in the Precambrian and Paleozoic hydrocarbon systems of North Africa. In: Salem, M.J., Oun, K.M., Essed, A.S. (Eds.), The Geology of East Libya, 4. Gutenberg Press, Malta, pp. 51–122.

Davidson, L., Beswetherick, S., Craig, J., Eales, M., Fisher, A., Himmali, A., Jhoon, J., Mejrab, B., Smart, J., 2000. The structure, stratigraphy and petroleum geology of the Murzuq Basin, southwest Libya. In: Sola, M.A., Worsley, D. (Eds.), Geological Exploration in the Murzuq Basin. Elsevier, Amsterdam, pp. 295–320.

de Gibert, J.M., Ramos, E., Marzo, M., 2011. Trace fossils and depositional environments in the Hawaz Formation, Middle Ordovician, western Libya. Journal of African Earth Sciences 60(1-2), 28–37.

Echikh, K., Sola, M.A., 2000. Geology and hydrocarbon occurrences in the Murzuq

Basin, SW Libya. In: Sola, M.A., Worsley, D. (Eds.), Geological Exploration in Murzuq Basin. Elsevier, Amsterdam, pp. 175–222.

El-ghali, M.A.K., 2005. Depositional environments and sequence stratigraphy of paralic glacial, paraglacial and postglacial Upper Ordovician siliciclastic deposits in the Murzuq Basin, southwest Libya. Sedimentary Geology 177(3-4), 145–173.

Espitalié, J., LaPorte, J.L., Madec, M., Marquis, F., LePlat, P., Paulet, J., Boutefeu, A., 1977. Rapid method for source rocks characterization and for determination of petroleum potential and degree of evolution. Oil and Gas Science and Technology 32, 23–42.

Fello, N., Lüning, S., Štorch, P., Redfern, J., 2006. Identification of early Llandovery (Silurian) anoxic palaeo-depressions at the margin of the Murzuq Basin, (southwest Libya), based on gamma-ray spectrometry in surface exposures. GeoArabia 11(3), 101–118.

Finney, S.C., Berry, W.B.N., 1997. New perspectives on graptolite distributions and their use as indicators of platform margin dynamics. Geology 25, 919–922.

Gumati, Y.D., Kanes, W.H., Schamel, S., 1996. An evaluation of the hydrocarbon potential of the sedimentary basins of Libya. Journal of Petroleum Geology 19(1), 95–112.

Hallet, D., 2002. Petroleum Geology of Libya. Elsevier, Amsterdam, 503 p.

Hunt, M. 1981. Source rock characterization by thermal distillation and pyrolysis. In G. Atkinson and .1.3. Zuckerman (eds.), Origin and chemistry of petroleum. Oxford: Pergamon Press, pp. 57-65.

İnan, S., Goodarzi, F., Mamm, A.S., Arouri, K., Qathami, S., Ardakani, O.H., İnan, T., Tuwailib, A.A., 2016. The Silurian Qusaiba Hot Shales of Saudi Arabia: An integrated assessment of thermal maturity. International Journal of Coal Geology 159, 107–119.

Klemme, H.D., Ulmishek, G.F., 1991. Effective petroleum source rocks of the world: stratigraphic distribution and controlling depositional factors. American Association of Petroleum Geologists Bulletin 75, 1809–1851.

Le Heron, D.P., Armstrong, H.A., Wilson, C., Howard, J.P., Gindre, L., 2010. Glaciation and deglaciation of the Libyan Desert: the Late Ordovician record. Sedimentary Geology 223, 100–125.

Loydell, D.K., Butcher, A., Frýda, J., Lüning, S., Fowler, M., 2009. Lower Silurian “hot shales” in Jordan: A new depositional model. Journal of Petroleum Geology 32(3), 261–270.

Lüning, S., Craig, J., Fitches, W.R., Mayouf, J., Busrewil, A., El Dieb, M., Gammudi, A., Loydell, D.K., McIlroy, D., 1999. Re-evaluation of the petroleum potential of the Kufra Basin (SE

Libya, NE Chad): does the source rock barrier fail? Marine and Petroleum Geology 16, 693–718.

Lüning, S., Craig, J., Loydell, D.K., Štorch, P., Fitches, B., 2000. Lower Silurian 'hot shales' in North Africa and Arabia: regional distribution and depositional model. Earth-Science Reviews 49, 121–200.

Lüning, S., Kolonic, S., Loydell, D.K., Craig, J., 2003. Reconstruction of the original organic richness in weathered Silurian shale outcrops (Murzuq and Kufra basins, southern Libya). GeoArabia 8, 299–308.

Lüning, S., Shahin, Y.M., Loydell, D., Al-Rabi, H.T., Masri, A., Tarawneh, B., Kolonic, S., 2005. Anatomy of a world-class source rock: Distribution and depositional model of Silurian organic-rich shales in Jordan and implications for hydrocarbon potential. American Association of Petroleum Geologists Bulletin 89(10), 1397–1427.

Mamgain, V.D., 1980. The pre-Mesozoic (Precambrian to Palaeozoic) stratigraphy of Libya: A reappraisal. Industrial Research Centre Bulletin 14, 104 p.

McDougall, N.D., Gruenwald, R., 2011. Ice in the Sahara: The Upper Ordovician glaciation in southwest Libya- a subsurface perspective. In: Gutiérrez-Marco, J.C., Rábano, I., García-Bellido, D. (Eds.), Ordovician of the World. Spain, pp. 347–352.

McGillivray, J.G., Husseini, M.I., 1992. The Paleozoic petroleum geology of central Arabia. American Association of Petroleum Geologists Bulletin 76, 1473–1490.

Meister, E.M., Ortiz, E.F., Pierobon, E.S.T., Arruda, A.A., Oliveira, M.A.M., 1991. The origin and migration fairways of petroleum in Murzuq Basin, Libya, an alternative exploration model. In: Salem, M.J., Busrewil, M. T., Ben Ashour, A.M. (Eds.), the Geology of Libya. Elsevier, Amsterdam, pp. 2725–2741.

Parrish, J.T., 1982. Upwelling and petroleum source beds, with reference to Paleozoic. American Association of Petroleum Geologists Bulletin 66, 750–774.

Peters, K.E., Cassa, M.R., 1994. Applied source rock geochemistry. In: Magoon, L.B., Dow, W.G. (Eds.), The Petroleum System–from Source to Trap. American Association of Petroleum Geologists Memoir 60, pp. 93–120.

Peters. K.E, 1986. Guidelines for evaluating petroleum source rocks using programmed pyrolysis. Bull.Am. Assoc.
Petrol. Geol. 70. p. 318-329.

Peters, K.E., Creaney, S., 2004. Geochemical differentiation of Silurian from Devonian crude oils in eastern Algeria. In: Geochemical Investigations in Earth and Space Science: A Tribute to Isaac R. Kaplan. The Geochemical Society Special Publication Series 9, pp. 287–301.

Petroleum Economist. 2011. Libya's Sharara field ready for exports within two weeks. www.petroleum-economist.com

Pierobon, E.S.T., 1991. Contribution to the stratigraphy of the Murzuq Basin, SW Libya. In: Salem, M. J., Belaid, M.M. (Eds.), The Geology of Libya. Elsevier, Amsterdam, pp. 1767–1783.

Ramos, E., Marzo, M., de Gibert, J.M., Tawengi, K.S., Khoja, A.A., Bolatti, N.D., 2006. Stratigraphy and sedimentology of the Middle Ordovician Hawaz Formation (Murzuq Basin, Libya). American Association of Petroleum Geologists Bulletin, 90(9), 1309–1336.

RRI, 1998. Source rock geochemistry and burial history study, NC115 Concession, Murzuq Basin, Libya. Project no. Ic/GN229, internal report, 384 p.

Sikander, A.H., Basu, S., Rasul, S.M., 2000. Geochemical source-maturation and volumetric evaluation of Lower Palaeozoic source rocks in the west Libyan basins. In: Salem, M.J., Oun, K.M., Seddiq, H.M. (Eds.), The Geology of Northwest Libya 3, pp. 3–53.

Sutcliffe, O. E., Adamson, K., Ben Rahuma, M. M., 2000. The geological evolution of the Palaeozoic rocks of western Libya: a review and field guide. Second Symposium on the Sedimentary Basins of Libya, Geology of northwestern Libya. Field Guide. Earth Sciences Society of Libya, 93 p.

Thomas, D., 1995a. Geology, Murzuq oil development could boost SW Libya prospects. Oil and Gas Journal 6, 41–46.

Vecoli, M., Riboulleau, A., Versteegh, G.J.M., 2009. Palynology, organic geochemistry and carbon isotope analysis of a latest Ordovician through Silurian clastic succession from borehole Tt1, Ghadamis Basin, southern Tunisia, North Africa: Palaeoenvironmental interpretation. Palaeogeography Palaeoclimatology, Palaeoecology 273, 378–394.

Waples, D.W., 1985. Geochemistry in petroleum exploration**.** International Human Resources Development Corporation, Boston, USA, 232 p.