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Facies Analysis and Reservoirs Characterization of the Ordovician Hawaz and Memouniyat Formations and the Devonian Awainat Wanin Formation, Area 176-4, Murzuq Basin, SW Libya

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Moustafa Abdullah[1*], Alsharef Albaghday[2], Osama Hlal[3]

Mohamed Targhi[4]

[1] Geology Department, Faculty of Science, Sebha University, Sebha, Libya.
[2] Libyan Academy for Graduate Studies, Janzour, Abudjalil Street, Tripoli, Libya.
[3] Department of Geology, Faculty of Science, University of Tripoli, Tripoli, Libya.
[4] Earth Science Department, Mellitah Gas Company, Tripoli, Libya.

*Corresponding author email: mous.ahmad@sebhau.edu.ly

ABSTRACT
The Ordovician to Devonian succession in the in Murzuq Basin represents the most important part of the lower Paleozoic terrigenous Al Gargaf siliciclastic group, which consists of several formations such as the Ordovician Hawaz, Melaz Shuqran and Mamuniyat Formations and the Devonian Tadrart and Awainat Wanin Formations.
Different integrated methods were used and implemented in order to understand lithology and sedimentary structures of the Ordovician, Silurian and Devonian formations.
Firstly, intensive geological field trips were carried out and special attention was focused on Ordovician and Devonian reservoir sandstones and the Silurian source rocks. Secondly facies analysis and sequence stratigraphy methods were applied to figure out a

simple sequence stratigraphic division of the Ordovician to Devonian succession based on outcrop sections, well logs and interpreted seismic sections. As a result of the petrographic field investigation and facies analysis based on seismic interpretation of the several seismic lines in the study area.
Sequence boundaries of the Ordovician and Devonian succession on all seismic sections were identified by using specific reflection terminations such as onlap and erosional truncations features. 13 seismic facies were recognized, divided and classified for each of the examined stratigraphic formations (4 facies in Hawaz, 5 facies in Melaz Shuqran and Mamuniyat formations and 4 facies in the Tadrart and Awainat Wanin). A seismic facies classification chart was made on the basis of the classified seismic facies scheme, since depositional systems and types of seismic facies differ in each stratigraphic succession.
Depositional sequences of sedimentary environments were identified from well logs and available 2D seismic sections and sequence stratigraphic frameworks were constructed for the Ordovician and Devonian formations.
Based on the facies analysis and sequence stratigraphy interpretations, two different order sequences in the Ordovician to Devonian succession have been found and identified:
The major sequences are possibly 2nd-order sequences in time duration. They are clearly traceable on all seismic sections. May be minor sequences are possibly 3rd-order sequences, and they are not traceable on all seismic sections clearly, but are recognized on well logs or outcrop sections. Eventually, all obtained information and that results were plotted on the different maps for each examined section to construct a depositional model and to estimate the maximum distributions of each formation separately on the basis of depositional system interpretations.
Keywords: Murzuq Basin, Al Gargaf siliciclastic group, Ordovician to Devonian succession, depositional system and seismic facies

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تحليل السحنات الرسوبية وتوصيف الخزانات لتكوينات حواز والمومنيات من العصر الأوردوفيشي وتكوين عوينات وأنين من العصر الديفوني، منطقة 176-4، حوض مرزق، جنوب غرب ليبيا

مصطفى عبدالله[1*]، الشارف البغدادي[2]، اسامة هلال[3]، محمد تارقي[4]

[1] قسم علوم الأرض، كلية العلوم، جامعة، سبها، سبها، ليبيا

[2] قسم علوم الأرض، الاكاديمية الليبية للدراسات العليا، جنزور، ليبيا

[3] قسم علوم الأرض، كلية العلوم، جامعة طرابلس، طرابلس ليبيا

[4] قسم علوم ألرض، شركة مليتة غاز، طرابلس، ليبيا

[*]البريد الإلكتروني للكاتب المراسل: mous.ahmad@sebhau.edu.ly

الملخص

يعد التتابع الطبقي من الأوردوفيشي إلى الديفوني في حوض مرزق من اهم الاجزاء في مجموعة القرقاف الفتاتية الرملية التابعة لحقبة الحياة القديمة، وهي تتكون من عدة تكوينات مثل تكوينات حواز، ملزشقران، والمومنيات من العصر الأوردوفيشي، وتكويني تادرات وعوينات ونين من العصر الديفوني.

تم استخدام وتطبيق طرق مختلفة لفهم التركيب الصخري والبنيات الرسوبية للتكوينات الأوردوفيشية والسيلورية والديفونية. أولاً، تم القيام برحلات حقلية جيولوجية مكثفة، وكان التركيز بشكل اساسي على الحجر الرملي لخزانات الأوردوفيشي والديفوني، وصخور المصدر من العصر السيلوري. ثانياً، تم تطبيق تحليل السحنات الرسوبية وطرق التتابع الطبقي لوضع تقسيم بسيط للتتابع الطبقي من العصر الأوردوفيشي إلى العصر الديفوني استناداً للمكشف ا السطحية، وتسجيلات الآبار، والقطاعات السيزمية المفسرة. وكنتيجة للعمل الحقلي البتروجرافي وتحليل السحنات الرسوبية بواسطة التفسيرات السيزمية لعدة خطوط في منطقة الدراسة.

تم تحديد حدود التسلسل لتتابعات الأوردوفيشي والديفوني على جميع المقاطع السيزمية باستخدام خصائص انعكاسية معينة مثل التراكب واسطح عدم التوافق. تم التعرف على

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13 سحنة سيزمية تم تقسيمها وتصنيفها لكل من التكوينات الطبقية التي تمت دراستها (4 سحنات في تكوين حواز، 5 سحنات في تكويني ملزشقران والمومونيات، و4 سحنات في تكوين تادرات وعوينات ونين). وقد صنفت السحنات السيزمية بناءً على مخطط تصنيف السحنات السيزمية، حيث تختلف أنظمة الترسيب وأنواع السحنات السيزمية في كل تتابع طبقي.

وتم تحديد التتابعات للبيئات الرسوبية من سجلات الآبار والقطاعات السيزمية ثنائية الأبعاد المتوفرة، و بناء إطار للتابع الطبقي لتكوينات العصر الاردوفيشي والديفوني .استنادًا إلى تحليل السحنات الرسوبية وتفسيرات التتابع الطبقي، تم التعرف على نوعين مختلفين من التتابعات. التتابعات الرئيسية: يُحتمل أن تكون تتابعات من الرتبة الثانية من حيث المدة الزمنية ويمكن تتبعها بوضوح في جميع القطاعات السيزمية. التتابعات الثانوية: قد تكون تتابعات من الرتبة الثالثة وهذه لا يمكن تتبعها بوضوح في جميع القطاعات السيزمية، لكنها معروفة من تسجيلات الآبار أو المكاشف الصخرية.

في النهاية، تم رسم جميع المعلومات والنتائج على خرائط مختلفة لكل قسم تم فحصه، وذلك لبناء نموذج ترسيبي وتقدير أقصى توزيعات كل تكوين على حدة استنادًا إلى تفسيرات النظام الترسيبي.

الكلمات المفتاحية: حوض مرزق، مجموعة القرقاف الفتاتية، تتابع الاوردفيشي – الديفوني، نظام التوضع والسحنات السيزمية

Introduction

Murzuq Basin located in SW Libya is approximately between 23° - 27° N and 11° - 16° E (Fig.). This basin is one of the several endorheic Intracratonic basins of the North African platform, and covers an area over 350 000 km2 (Aziz, 2000 and Davidson et al., 2000).

The recently borders of the basin are the Gargaf Uplift to the north, the Tassili Plateau to the west, the Haruj volcanic complex and the Tibesti Uplift to the east. To the south, the basin extends into the Djado Basin in Niger.

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According to Davidson et al. (2000), the Murzuq Basin is most exactly described as an erosional remnant of a much larger Palaeozoic and Mesozoic sedimentary basin, which was originally extended over much of North Africa (Echikh & Sola, 2000 and El-Hawat et al., 1998).
The current borders of the Murzuq Basin were delineated mainly by erosion resulting from multiphased tectonic uplifts the flanks comprising the Tassili Plateau (Tihemboka High) to the west, the Tibesti High to the east, and the Gargaf Uplift to the north.
All these uplifts were generated by numerous tectonic movements, which were ranging from mid Palaeozoic through to Tertiary times Gundobin, 1985; Parizek, Klen, & Rohlich, 1984; Radulovic, 1984 and Hallett, Clark-Lowes, (2017).
The sedimentary rocks in the middle part of the basin have a thickness more than 4000 m, comprised mainly of Palaeozoic and Mesozoic sandstones and shales.
The oldest Palaeozoic Gargaf group crops out on the external margins of the basin, whereas Triassic, Jurassic and Cretaceous sediments form an escarpment in the middle part of the basin. Cenozoic sediments consist of about 100 m thick Paleocene marine limestone, dolomite and marl, which are preserved at the northern and north-eastern margin of the Murzuq Basin (Fig. 1). Cambrian, Ordovician, Silurian and Devonian formations are classified the lower Paleozoic succession comprises the terrigenous Cambrian–Ordovician Gargaf Group consisting of at least five formations; from bottom to top, they are the following:
Hasawnah, Ash Shabiyat, Hawaz, Melaz Shuqran, and Mamuniyat Formations all of them crops out in western Gargaf uplift area and subside under a thick cover of upper Palaeozoic, Mesozoic and recent deposits (Abouessa & Morad, 2009; Anfray & Rubino 2003 and Vos, 1981).. The special attention was focused on Ordovician and Devonian reservoir sandstones and Silurian source rocks such as Tanezzuft shale formation in our main targeted Area 176-4 in central part of Murzuq Basin.
Our surface geological survey started by Intensive field trip was carried out in order to observe lithology and sedimentary structures

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of the Ordovician, Silurian and Devonian formations in western side of Gargaf uplift area (Fig.1) shown geological map of the Gargaf Uplift with the field trip stations in the western part of Gargaf Arch . This paper provides a simple sequence stratigraphic division of the based on outcrop sections, well logs and interpreted seismic sections.

Additionally it clarifies the environmental conditions that have accompanied to establishing Ordovician to Devonian succession in the Murzuq Basin during the lower Palaeozoic era.

Seismic facies analysis and sequence stratigraphy methods were applied to figure out a simple sequence stratigraphic division of the Ordovician to Devonian succession based on outcrop sections, well logs and interpreted seismic sections. Nine well log data with total 2053.35 km line length of seismic lines have been measured, described, investigated and interpreted.

As a result of the petrographic field investigation and facies analysis based on seismic interpretation of the all seismic lines in the study area.

Sequence boundaries of the Ordovician and Devonian succession on all seismic sections were identified by using specific reflection terminations such as onlap and erosional truncations features. 13 seismic facies were recognized, divided and classified for each examined stratigraphic formations (4 facies in Hawaz, 5 facies in Melaz Shuqran and Mamuniyat formations and 4 facies in the Tadrart and Awainat Wanin).

Based on seismic facies analysis and sequence stratigraphy interpretations, two different order sequences in the Ordovician to Devonian succession have been found and identified:

The major sequences are possibly 2-nd-order sequences in time duration. They are clearly traceable on all seismic sections. Minor sequences are possibly 3rd -order sequences, and they are not traceable on all seismic sections clearly, but are recognized on well logs or outcrop sections.

Finally, all obtained information and results were plotted on the different maps for each examined section to construct a depositional model and to estimate the maximum distributions of each formation

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separately on the basis of depositional system interpretations.

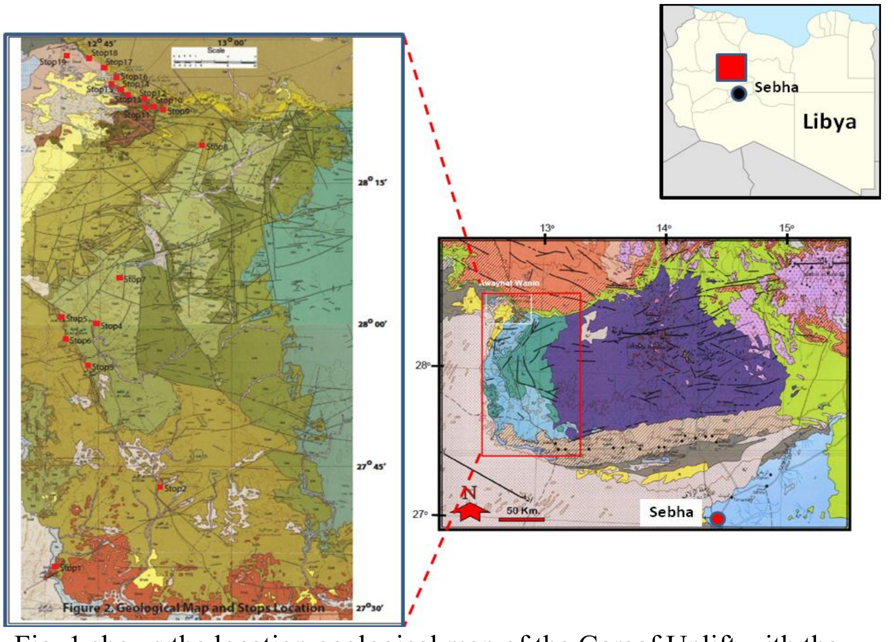

Fig. 1 shows the location geological map of the Gargaf Uplift with the field trip stations in the western part of Gargaf Arch

Geological Setting

The Gargaf Group crops out extensively in boundaries of Gargaf Uplift and in the neighboring Tihemboka and Tibesti uplifts and has been recognized in the subsurface of the Murzuq, Ghadames and Kufra Basins.

The Gargaf Group consists of lithological differentiated formations such as Hasawnah, Ash Shabiyat, Hawaz, Melaz Shuqran, and Mamuniyat Formations all of them crops out locally in western Gargaf uplift area and subside under a thick cover of upper Palaeozoic, Mesozoic and recent deposits.

The summary of the geological setting of these formations can summarized is as shown on figure (2) follows:

The Lower Ordovician Hawaz Formation consists mainly of fine to coarse grained quartzite sandstones. It is assigned to fluvial to shallow marine environment.

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Hawaz Formation thickness reaches more than 100 meters at maximum. It crops out in the western side of the Gargaf Uplift. The Hawaz Formation is classified as one of the best reservoir rocks in the Murzuq Basin. According to several workers such as Klitzisch, 1970 and others after the deposition of the Lower Ordovician, the Murzuq Basin area was exposed and subjected to intensive glacial erosion processes. During the glacial phase a major sea transgression has been happened and the Melaz Shuqran Formation unconformably overlies the Hawaz Formation. The Melaz Shuqran Formation is composed of green and grey claystone and siltstones in the Upper Ordovician age with maximum thickness of 50 meters at. It deposited in the neritic to deep marine environment. After the deposition of the Melaz Shuqran Formation a relative marine regression has been reported from several areas in Murzuq Basin.

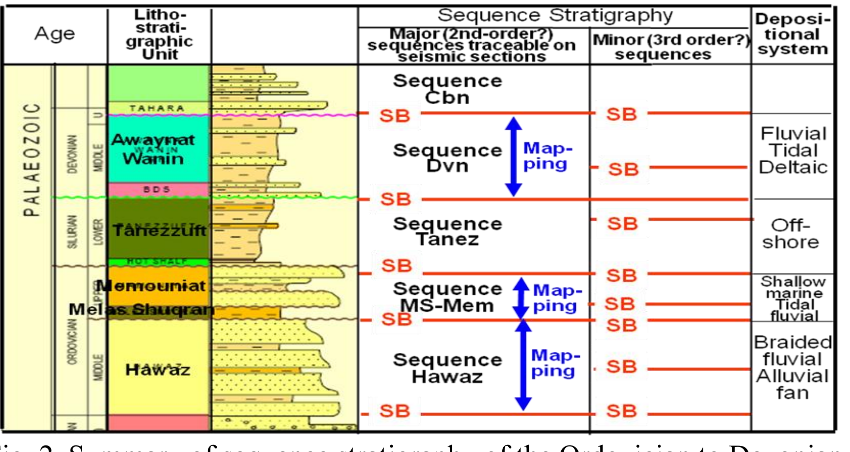

Fig. 2 Summary of sequence stratigraphy of the Ordovician to Devonian succession in the Area 176-4.

The next one is the Mamuniyat Formation, which is unconformably deposit above the both Melaz Shuqran and Hawaz Formations. Mamuniyat Formation consists mainly of fine to coarse grain sandstone. Its depositional environment ranges from tidal, fluvial to shallow marine environments.
The thickness of the Mamuniyat Formation is about 100 meters at maximum. Mamuniyat Formation widely distributes in the western

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part of the Gargaf Uplift. This Formation is considered as a main reservoir in the Murzuq Basin. The Silurian period started by largest marine transgression in whole North Africa. The Silurian succession is represented by the Tanezzuft Formation in the Gargaf Uplift area. Tanezzuft Formation unconformably covers the Mamuniyat Formation and consists of siltstones and claystone very rich with graptolites. Tanezzuft Formation has locally limited distribution at the isolated outcrops in southwestern and northwestern edge of the Gargaf Uplift arch. Tanezzuft Formation has 30 meters in thickness at maximum and pinches out toward the east. The Tanezzuft Formation has been deposit in a relative deep marine to neritic environments. Claystone of the Tanezzuft Formation represents the main source rock in Murzuq Basin.

The Devonian deposit includes Tadrart, Ouan Kasa, Awainat Wanin, and Tahara Formations. They consist of several cycles of siliciclastic sediments of sandstone, siltstone and mudstone. Their total thickness is more than 300 meters in Murzuq Basin. They represent a various range of depositional environment from proximal fluvial to offshore marine shelf. These successions are subdivided into cyclic stacks of sequence unit with 30 to 80 meters in thickness. Each sequence is bounded by unconformity surface.

All Lower Devonian (the Tadrart and Ouan Kasa Formations) unconformably overlie the Tanezzuft Formation with the erosional surface of the Caledonian unconformity. The Lower Devonian is about 50-80 meters in thickness and locally distributes in the northwest part of the Gargaf uplift arch. The sedimentary environment is dominantly tidal fluvial with little shoreface and offshore marine. Sandstones in the Lower Devonian have good reservoir potential. The Middle to Upper Devonian (the Awainat Wanin and Tahara Formations) conformably overlies the Lower Devonian and is 150 to 200 meters in thickness. It distributes in the northwestern edge of the Gargaf uplift. The sedimentary environment is dominantly shoreface, offshore marine and little fluvial environment. Mudstones in the Middle to Upper Devonian are good source rocks and seal potential in same time.

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Methodology

Different integrated methods were used and implemented in order to figure out the lithology and Sedimentary structures of the Ordovician, Silurian and Devonian formations.

Firstly intensive geological field trips were carried out and special attention was focused on Ordovician and Devonian reservoir sandstones and Silurian source rocks. Cuttings logs and log patterns of the upper Ordovician to Devonian interval were examined from the standpoint of depositional systems and sequence stratigraphy. Nine well log data with total 2053.35 km line length of seismic lines have been measured, described, investigated and interpreted.

Secondly facies analysis and sequence stratigraphy methods were applied to figure out a simple sequence stratigraphic division of the Ordovician to Devonian succession based on outcrop sections, well logs and interpreted seismic sections.

A seismic facies classification chart was made on the basis of the classified seismic facies scheme, since depositional systems and types of seismic facies differ in each stratigraphic succession. Depositional sequences of sedimentary environments were identified from well logs and available 2D seismic sections and sequence stratigraphic frameworks were constructed for the Ordovician and Devonian formations.

Results

Based on intensive field investigation, seismic facies analysis and sequence stratigraphy interpretations of the Ordovician to Devonian succession:-

All obtained information was plotted on the map for each examined interval to construct a depositional model as shown on figure (3) depict the workflow applied for seismic facies mapping and depositional system interpretation. Two different order sequences in the Ordovician to Devonian succession have been found and identified. Finally, reservoir distributions were interpreted on the basis of the obtained results.

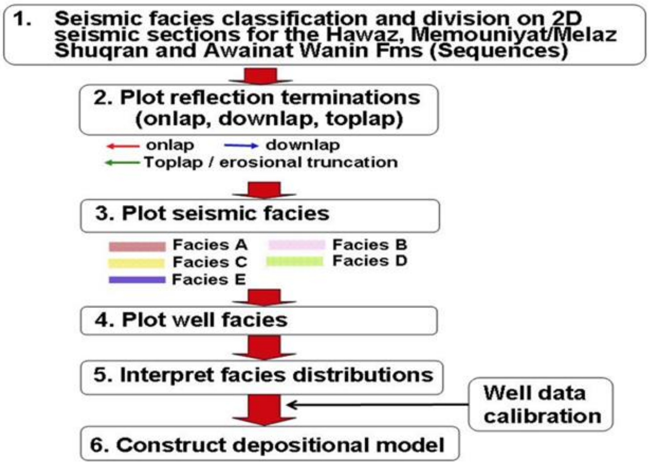

Fig. 3 a workflow chart showing the methods of seismic facies mapping and depositional system interpretation in Area 176-4

Sequence division on seismic sections

Sequence boundaries on a seismic section can be identified using specific reflection terminations such as on lap and erosional truncations (Arato and Takano, 1995). The on lap surface, which is determined as a surface just below on laps, can be determined as a sequence boundary Figure (4).

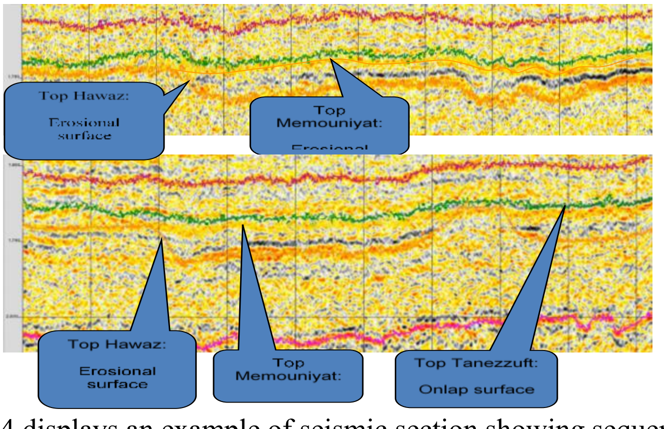

Fig.4 displays an example of seismic section showing sequence boundary (SB)

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First, seismic facies were classified for each examined stratigraphic interval. Likewise, erosional truncation surface, below which erosional truncation patterns are seen, can also be determined as a sequence boundary

Sequence stratigraphy of the Ordovician to Devonian in the Area 176-4

As a summary of sequence stratigraphic division based on outcrop sections, well logs and seismic sections. Figure (5) depicts the result of plotting reflection terminations and classified seismic facies on the shot point map of the Area 176-4. depicts generalized sequence stratigraphy of the Ordovician to Devonian succession in the Area 176-4. As a consequence of sequence interpretation, it is evident that there are two different order sequences in the Ordovician to Devonian succession: major sequences and minor sequences.

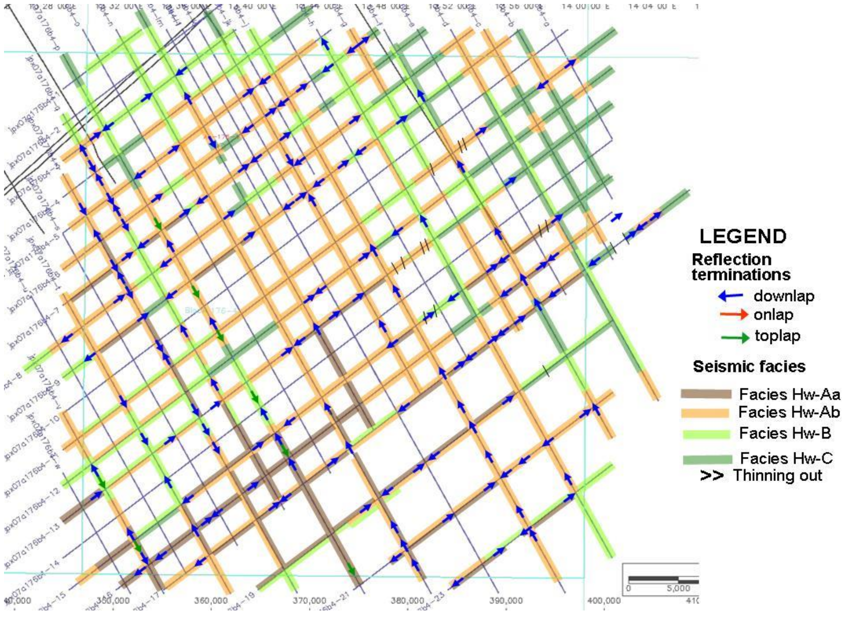

Fig.5 shows the results of seismic facies/reflection termination plotting for the Sequence Hawaz formation as example of seismic facies characterization and distribution within Hawaz formation.

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The major sequences are possibly 2nd-order sequences in time duration, and they are clearly traceable on seismic sections. The minor sequences are possibly 3rd-order sequences, and they are not traceable on seismic sections clearly, but are recognized on well logs or outcrop sections. The Ordovician Hawaz Formation corresponds to a major (2nd-order) depositional sequence: Sequence Hawaz, and can be divided into at least two 3rd-order depositional sequences. The top sequence boundary is a glacial erosional surface, which created topographic undulation including buried hill structures and incised valleys. (see Figure (5))

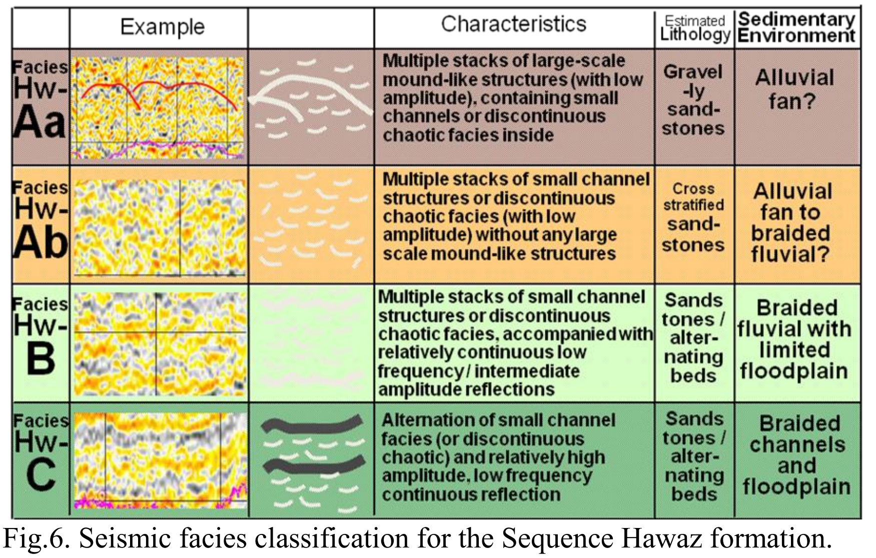

Fig.6. Seismic facies classification for the Sequence Hawaz formation.

Workflow of seismic facies mapping and depositional system interpretation

As the next step, seismic facies mapping was conducted for three stratigraphic intervals: Sequence Hawaz, Sequence MS-Mem and Sequence Dvn., since depositional systems and types of seismic facies differ in each stratigraphic interval, and seismic facies classification chart was made. Then, seismic facies was recognized and divided on all available 2D seismic sections in the Area 176-4 on the basis of the classified seismic facies scheme

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Seismic facies classification of Hawaz Sequence

In Sequence Hawaz (Hawaz Formation), four seismic facies were identified: Facies Hw-Aa, Hw-Ab, Hw-B and Hw-C (Figure 5).

Facies Hw-Aa is characterized by multiple stacks of low-amplitude large-scale mound-like structures, containing low-amplitude small channels or discontinuous chaotic facies inside. Since the basic element is low amplitude obscure small channel structures, it is interpreted that this facies is mainly composed of sandy or gravelly channels. Large-scale mound structures suggest that multiple stacks of sandy or gravelly channels form a large mound such as an alluvial fan or colluvium. Consequently, this facies is interpreted to represent an alluvial fan to the proximal part of a braided fluvial system.

Mapping and depositional system interpretation of the Hawaz Sequence

Figure (5) depicts the result of plotting reflection terminations and classified seismic facies on the shot point map of the Area 176-4. Bi-directional downlaps representing a mound facies are dominant in the Area 176-4, except the northeastern margin. Combination of unidirectional downlap and opposing toplap, indicating a progradation pattern, can be seen in the south central to west central part of the Area 176-4. With regard to the seismic facies, Facies Hw-Aa can be seen in the south central part, and Facies Hw-Ab is distributed widely in the area, except in the northeastern part, where Facies Hw-C is dominant. It seems that Facies Hw-B accompanies with Facies Hw-Ab.

Seismic facies classification of the Mamuniyat / Melaz Shuqran Sequence

In the Sequence MS-Mem (Melaz Shuqran and Mamuniyat Formations), seismic facies are classified into five: Mm-A, Mm-B, Mm-C, Mm-D and Mm-E (Figure 7).

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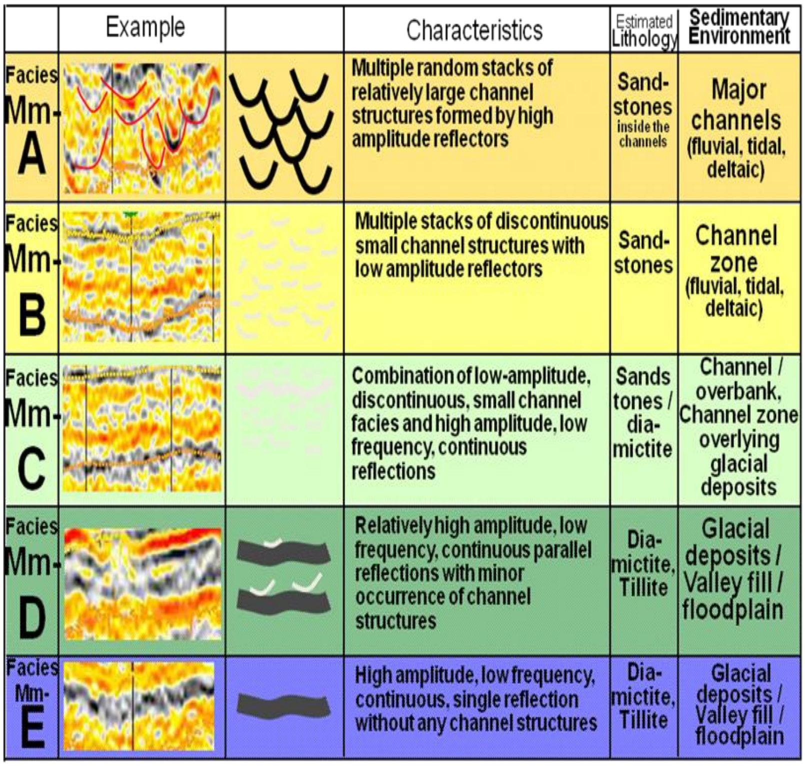

Fig.7 Seismic facies classification for the Sequence Melaz Shuqran/Memouniyat

Facies Mm-A is characterized by multiple random stacks of relatively large channel structures formed by high amplitude reflections. Relatively large channel structures indicate that these functioned as major sediment supply paths at the time of deposition. These channel facies are shown on figure (8) by high amplitude reflections, suggesting high impedance contrast between inside and outside the channel. It is estimated that channel fill deposits are more or less composed of sandstones and some amount of shale or diamictic materials are intercalated inside or outside the channels.

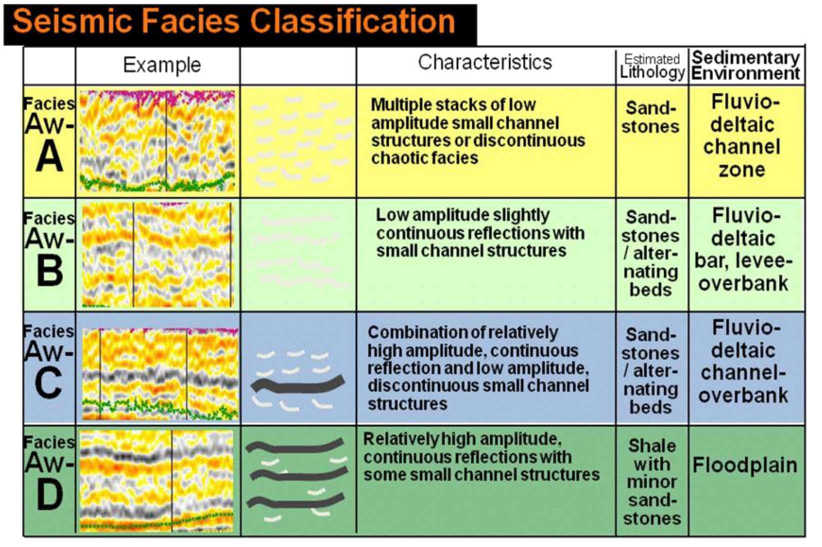

Fig.8 Seismic facies classification for the Sequence Tadrart/Awainat Wanin

Facies Mm-B is characterized by multiple stacks of discontinuous small channel structures with low amplitude reflections. This facies shows mostly the same character as Hw-Ab of the Hawaz Formation. Stacks of low amplitude small channel structures indicate sandy braided channel deposits without any impedance contrast. Therefore, this facies is interpreted to represent a sandy channel zone of fluvial, tidal or deltaic environments.

Facies Mm-C is characterized by combination of low amplitude, discontinuous, small channel facies and relatively high amplitude, low frequency, continuous reflections. This facies resembles Facies Hw-B of Sequence Hawaz (Hawaz Formation) in terms of combination of small channel facies and continuous reflections. As interpreted for Facies Hw-B, Facies Mm-C is inferred to represent channel/overbank couplet, since the relatively high amplitude continuous reflection indicates overbank deposits.

As indicated by El-ghali (2005), the Melaz Shuqran Formation is mainly composed diamictite of glacial origin, suggesting that the overbank deposits comprise glacial poorly sorted diamictite deposited beside the channel zones. Facies Mm-D is characterized by relatively high amplitude, low frequency, continuous, parallel reflections with minor occurrences of channel structures. According to well data/seismic facies calibration using several wells in the Ghadames and the Murzuq Basins, it is confirmed that relatively high amplitude, low frequency, continuous reflections indicate poorly sorted glacial diamictite or shale. Consequently, Facies Mm-D is interpreted to represent glacial to paraglacial diamictic sediments deposited outside channels or inter-channel zones. Occasional small channel structures seen in this facies indicate minor branch channels of crevasse avulsion from a channel zone, developed on an overbank environment. Since this facies tends to be cut by channel facies of Facies Mm-A, -B and –C, this facies may represent the Melaz Shuqran Formation underlying the Memouniyat Formation, which is mainly composed of diamictite, according to outcrop data by El-ghali (2005) figure (9).

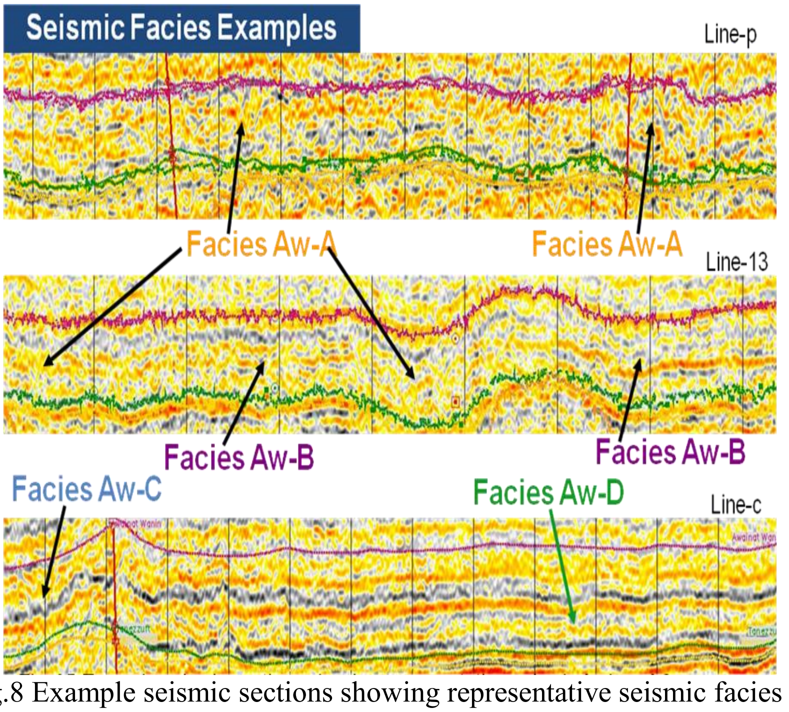

Fig.8 Example seismic sections showing representative seismic facies in the Sequence Tadrart/Awainat Wanin

Facies Mm-E is characterized by high amplitude, low frequency, continuous, single reflection without any channel structures. The basic element of this facies is mostly the same as Facies Mm-D, but Facies Mm-E shows a single reflection, and does not include channel structures, suggesting that Facies Mm-E represents relatively thin glacial diamictic sediments deposited in an overbank environment without any minor channel or crevasse supply.

Conclusion

The Ordovician, Silurian and Devonian formations were investigated to clarify and figure aout the lithology, sedimentary structures and seimic facies at A-164 Area, in Murzuq Basin. Different integrated methods were used and implemented.

Firstly intensive geological field trips were carried out and special attention was focused on Ordovician and Devonian reservoir sandstones and Silurian source rocks.

Secondly seismic facies analysis and sequence stratigraphy methods were applied to figure out a simple sequence stratigraphic division of the Ordovician to Devonian succession based on outcrop sections, well logs and interpreted seismic sections.

As a result of the petrographic field investigation and facies analysis based on seismic interpretation of the several seismic lines in the study area.

Sequence boundaries of the Ordovician and Devonian succession on all seismic sections were identified by using specific reflection terminations such as onlap and erosional truncations features. 13 seismic facies were recognized, divided and classified for each examined stratigraphic formations (4 facies in Hawaz, 5 facies in Melaz Shuqran and Memouniyat formations and 4 facies in the Tadrart and Awainat Wanin).

Depositional sequences of sedimentary environments were identified from well logs and available 2D seismic sections and sequence stratigraphic frameworks were constructed for the Ordovician and Devonian formations. Two different order sequences in the Ordovician to Devonian succession have been found and identified:

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The major sequences are possibly 2 nd -order sequences in time duration. They are clearly traceable on all seismic sections. Minor sequences are possibly 3 rd -order sequences, and they are not traceable on all seismic sections clearly, but are recognized on well logs or outcrop sections.
The obtained information and results were plotted on the different maps for each examined section to construct a depositional model and to estimate the maximum distributions of each formation separately on the basis of depositional system interpretations

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