Sedimentary units and Palaeoenvironments of an Upper Ordovician Reservoir from Mamuniyat Formation, NC174 concession, Murzuq Basin, Libya

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Abstract

Sedimentary successions of an Upper Ordovician (Ashgillian) Mamuniyat Formation characterize the main reservoir in the Elephant Oil Field, NC174 Concession, Murzuq Basin of Libya SW Libya. The Cambro-Ordovician reservoir is sealed by the shale of the Silurian Tanezzuft Formation. The main source rock in the NC174 is oil-prone mudstone in the lower part of the Silurian interval. Petrel multiwell correlation software have been used to determine the reservoir units and interpret the depositional environment and to gain knowledge about the history of the sediments. Mamuniyat Formation section of the NC174 *concession were subdivided into six sedimentary units based on measurements of electric log character (gamma ray and sonic log responses) and lithology correlation. These sedimentary units belonging to six interacting depositional environments: a braided alluvial plain, foreshore, and upper shoreface, shallow marine depositional and deltaic to shallow marine. The isopach map show a strong degree variation in thickness increasing from the part at Mamuniyat to north part, thickness very from 125 feet in western to 460 feet in the north-eastern.*

***Keywords**: Reservoir units, Mamuniyat Formation, Palaeoenvironments, Murzuq Basin, Libya*

Introduction

The Murzuq basin is located in SW Libya and covers an area of some 400,000 km^2, extending southwards into Niger (Thomas, 1995). The sedimentary fill is predominantly marine and continental Palaeozoic, with some Mesozoic and Cenozoic sediments overlying Precambrian crystalline basement. In the central part of the basin the total sediments thickness exceeds 3,500m (Thomas, 1995).

The Upper Ordovician (Ashgillian) sandstones of the Mamuniyat Formation assist as the primary oil reservoir in the Murzuq Basin's oil fields, with the Lower Silurian hot shales of the Tanezzuft Formation serving as the primary source and seal (Hassan and Kendall, 2014).

Allowing to (Davidson, et al. 2000), the Murzuq Basin is designated as an erosional remnant of a much larger Palaeozoic and Mesozoic sedimentary basin, which originally extended over much of North Africa.

Fello (2001) and Fello and Turner (2004) subdivided the Mamuniyat sandstone facies according to depositional environment into three members: lower, middle, and upper member. The lower member is dominated by a shallow marine coarsening-upward sandstone sequence; the middle is a fining-upward marginal marine sequence dominated with radioactive black shale's with fine- to medium-grained sandstones and coarse-grained siltstones; and the upper member is made up of coarsening-upward fluvial sandstone sequence.

The upper most Mamuniyat unit, is the main hydrocarbon producing interval of the Murzuq Basin being dominated by interbedded coarse sandstone and conglomeratic sediments. Such an interbedded succession is typical of sediments formed on glacially derived braiddeltas where channel bases and tops are rarely preserved and where regular melt water floods shape sediment dispersal on the delta (Cubit et al., 2011) .

The overlying Middle Mamuniyat is the most varied (in terms of rock types) of the three Mamuniyat Formation members with massive to low angle cross bedded sandstones, hetrolithics, and mudstones all encountered with shelf, sub-marine fan/channel, shoreface and deltaic depositional environments interpreted (Cubit et al., 2011). In addition dewatering features (dish and pillar) and hetrolithic soft sediment deformations are commonly noted at the Lower-Middle Mamuniyat boundary (Cubit et al., 2011)

Sandstone facies deposited unconformably up on the Lower Paleozoic lithostratigraphic units of the Al Hasawna, Mamuniyat and Tanzzuft Formations. These unconformities are attributed to the tectonic events prior to the Middle Devonian Age (Khalid et al., 2018).

Cuttings and sidewall cores are used in the identification of lithology, but their value in clastic facies analysis is limited to indicating lithology and grain size (De Ros and Goldberg, 2007). Cores provide the only means of directly observing and measuring facies (Reading and Levell, 1996

This paper aims to present a applied reservoir units scheme for the upper Ordovician reservoir and interpretation of their depositional environments. Data were collected from different wells (Fig. 1).

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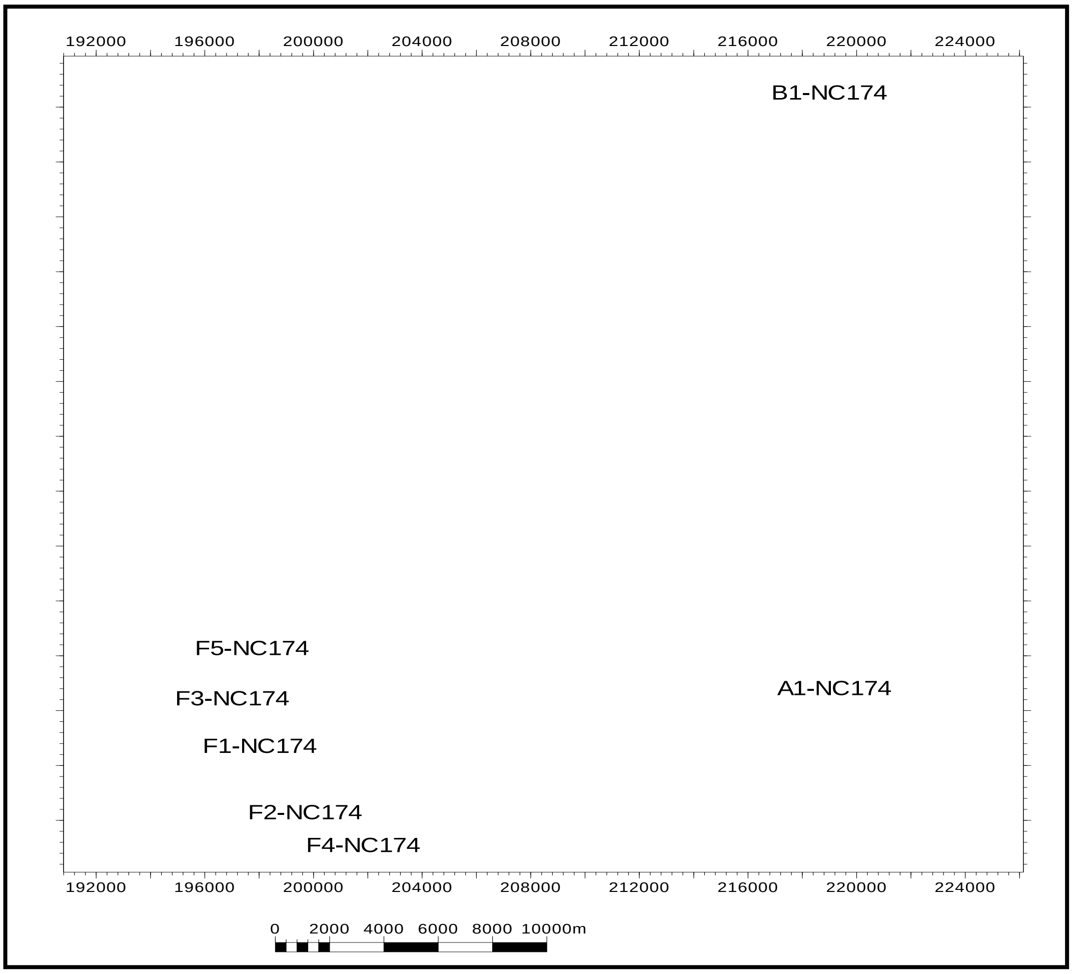

Fig. 1. Location map of correlated wells in the NC174 concession

2. Regional geology

2.1. Geological setting of the Murzuq Basin

The area of study for this paper is located within the Murzuq Basin SW Libya, one of a sequence of major intracratonic sag basins located across the North African platform or Saharan Metacraton (Brahimi et al., 2018).

The present-day boundaries of the Murzuq Basin (and of the Kufra and Ghadameis Basins in Libya) reflects Variscian (Hercynian) and Mesozoic orogenic overprint on the pre-existing structural relief. Uplifts bounding the basin include the Tihembokah, Tibisti and Qarqaf highs (arches) to the west, east and north, which mainly formed during the mid-Cretaceous to early Tertiary Alpine phase (Davidson et al., 2000; Badalini et al., 2002). Most hydrocarbon occurrences in the Murzuq Basin are located in the area of structurally high elements, whereas deeper portions are still unexplored. During the Late Ordovician glaciation major changes occurred in the paleogeography of the Murzuq Basin. This reflects the multiple advances and retreats of ice sheets which, together with resulting changes in the paleoclimate occasioned in the development of a wide range of depositional environments ranging from proximal glacial braidplain or deep glaciomarine (Grubic et al., 1991; Pierobon, 1991, Girard et al., 2012a,b).

During the Ordovician, the North African part of West Gondwana established a passive margin and was rimmed by a wide, shallow-water marine platform (Sutcliffe et al., 2000; Kuhn and Barnes, 2005). Sedimentation in the eastern Sahara during the Early-Middle Ordovician was controlled by a Cambrian system of horsts and grabens (Boote et al., 1998; Klitzch, 2000). The grabens were sites of marine deposition during episodic transgressions, although the horsts, were subjected to erosion or were covered by thin layers of sediment. During periods of regression, the grabens were sites of nearshore marine to continental sedimentation (Klitzsch, 2000). Furthermost of Gondwana (including North Africa) was subjected to glaciation during the Late Ordovician (Ghienne, 2003; Monod et al., 2003; Young et al., 2004).(

The Taconic, Caledonian, Hercynian, Austrian, and Alpine tectonic events, mainly the Caledonian and Hercynian orogenies, have had a significant impact on the Murzuq Basin's tectonics and sedimentology (Belaid et al. 2010).

The present day borders of the Murzuq Basin were described mainly by erosional remnant of a much larger Palaeozoic sedimentary basin, which originally covered most of North Africa (Abouessa and Morad, 2009), that resulting from multiphasic tectonic uplifts. The flanks of the basin are comprised of the Tassili Plateau (Tihemboka High) in the west, the Tibesti High in the east, and the Gargaf Uplift in the north. These uplifts were generated by numerous tectonic movements, which were varying from Mid Palaeozoic through Facies Analysis of Lower Awynat Wanin Formations (Klitzsch, 2000).

The sedimentary fill within the Murzuq Basin is mainly Palaeozoic to Mesozoic and reaches a thickness of about 4000 m in the depocenter (Bertello et al., 2003). The sedimentary fill consists of Palaeozoic marine deposits which are truncated by Mesozoic to Quaternary continental deposits (Aziz, 2000; Davidson et aI., 2000; Echikh and Sola, 2000, Hallett, 2002).

Murzuq Basin has numerous concessions with oil Fields (Adel and Ahmed, 2022). The principle hydrocarbon play of the basin consists of an upper Ordovician glacio-marine sandstone reservoir sourced and sealed by overlying Silurian shale. Oil producing fields in the Murzuq Basin all produce from a sandstone reservoir of the Ordovician Mamuniyat and Hawaz Formations. The secondary play within the basin is Devonian sandstone. Devonian sandstones represent a high-risk secondary reservoir, with good lateral continuity but with generally poor reservoir characteristics. Ordovician sandstones (Mamuniyat and Hawaz Formations) contain the main discoveries (over 95% of reserves) and the totality of the commercial ones in the Murzuq Basin. They generally have good characteristics, lateral continuity, and thickness. In NC174, the reservoir can represent a risk as some wells found poor to very poor reservoir intervals. Early Paleozoic tectonism effectively controlled the distribution of late Ordovician reservoirs and distribution of Silurian hot shale, which laps onto early-formed fault blocks (Klitzsch, 1995; Fello et al., 2006).

The oldest Palaeozoic rocks outcrop on the external margins of the basin. Triassic, Jurassic and Cretaceous sediments form an escarpment in the middle part of the basin. Cenozoic sediments consist of about 100 m thick of Palaeocene marine limestone, dolomite and marl, which are preserved at the northern and northeastern margin of the Murzuq Basin (Khalid et al., 2018).

A stratigraphic column for the Murzuq Basin shown in Fig. 2. and includes the nomenclature of Repsol Oil Operations (Fello and Turner, 2004). The depositional history is relatively uncomplicated with some exposed characteristic facies patterns. During the complete of the Palaeozoic era the marine incursions came from the northwest. The major sedimentary deposits defined in the Ghadames Basin in subsurface areas and in the outcrops are found more to the south in the Murzuq Basin (Pierobon, 1991). The sedimentary section in the Murzuq Basin is marked by a number of unconformities. These are a result of epeirogenic movements, which occurred during the Palaeozoic. Late Hercynian and Mesozoic unconformities can be recognized in the subsurface (Gumati et al., 1996). These epeirogenic movements caused irregularities in the thickness of sedimentary beds in the Murzuq Basin (Conant and Goudarzi, 1967).

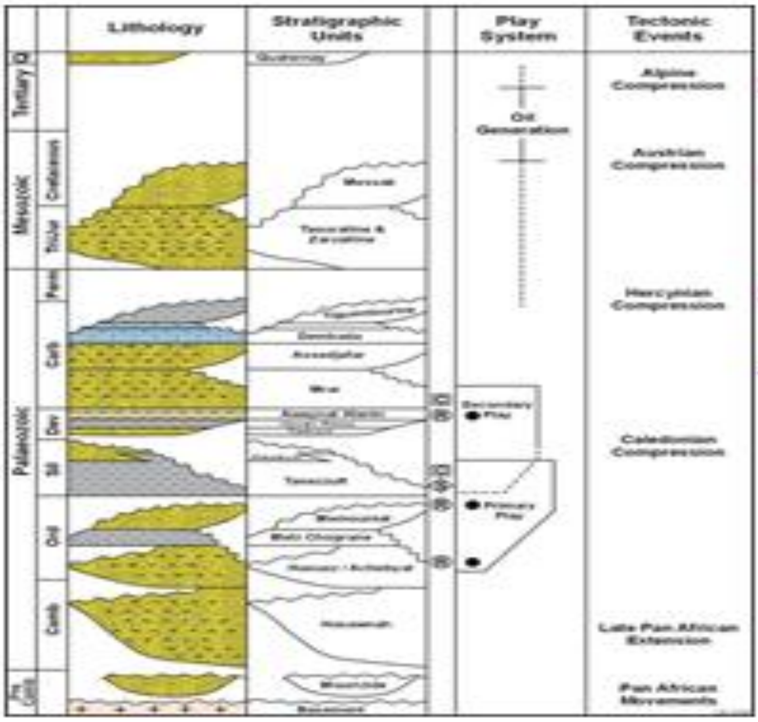

Fig. 2. Stratigraphic section of Murzuq Basin

2.2. Structure style within NC174 block

Seismic lines and the resulting structure maps for the NC174 block show a regional south easterly dip towards the basin centre, and a structural style dominated by faulting (Fig. 3). The faults share several common characteristics. Nearly all are high angle reverse faults with a roughly north-south orientation. Many of the faults show evidence of more than one phase of movement and some show indications of strike-slip movement, which may have occurred on most of the faults (Buck, 1995).

The dominant north-south orientation of the faults indicates that they have followed old Pan-African trends, and on a few faults thinning of the Cambro-Ordovician interval onto basement indicating late Pan-African movement. The main displacement on most of the faults occurred during Caledonian movement. The faults generally cut the top of the Cambro-Ordovician section. Reactivation of the faults during Hercynian and Alpine movements were common, and generally resulted in the propagation of tip-line folds up through the section (Buck, 1995). In the western part of the NC174 block, the numbers of faults are more than in the eastern part (Fig. 3).

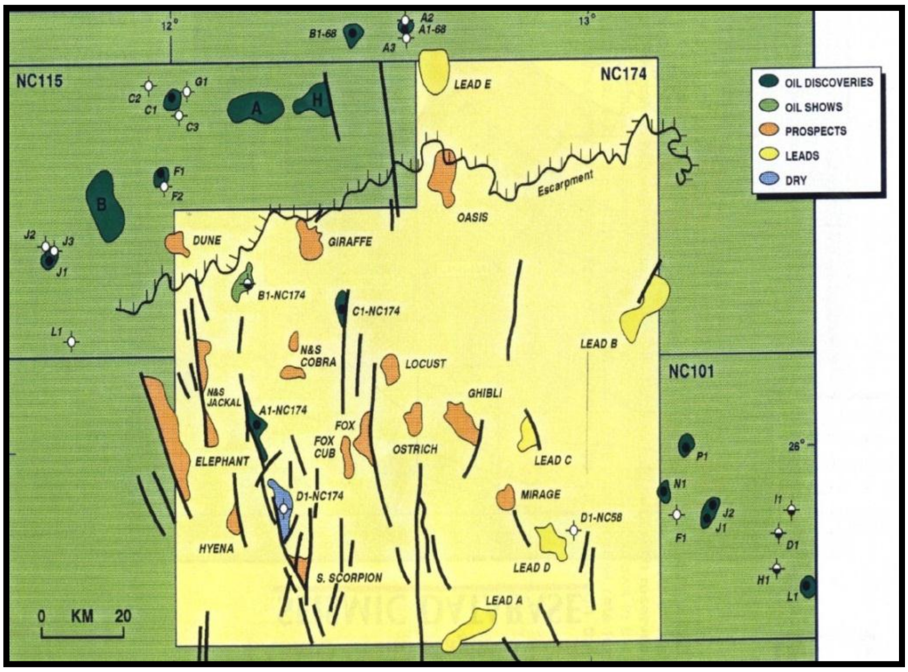

Fig. 3. Oil fields, exploration of NC174 and faults orientations (Buck, 1995).

In area of NC174, the tectonic phases developed anticlines and fault bounded anticlines generally super-imposed on each other and re-actived through time. The resulting structural style is characterized mainly by multi-phase sub-vertical reverse faults with different directions (N-S, NNW-SSE and NNE-SSW) and locally with opposite vergence. The faults bounding most of the prospects are apparently superimposed on subtle anticlines oriented SSW-NNE along which the culminations are aligned.

The Tibesti and Tihemboka Highs respectively (Fig. 4) form the eastern and western margins of the Murzuq Basin. These highs relate to a north south trending Pan-African basement fault system. Substantial strike-slip movement has probably occurred along these fault systems throughout the basin’s long history, the faults accommodating stress generated by movement of the African plate. The Gargaf Arch forms the northern margin of the basin whereas the southern part of the basin extends down into Niger (Buck, 1995).

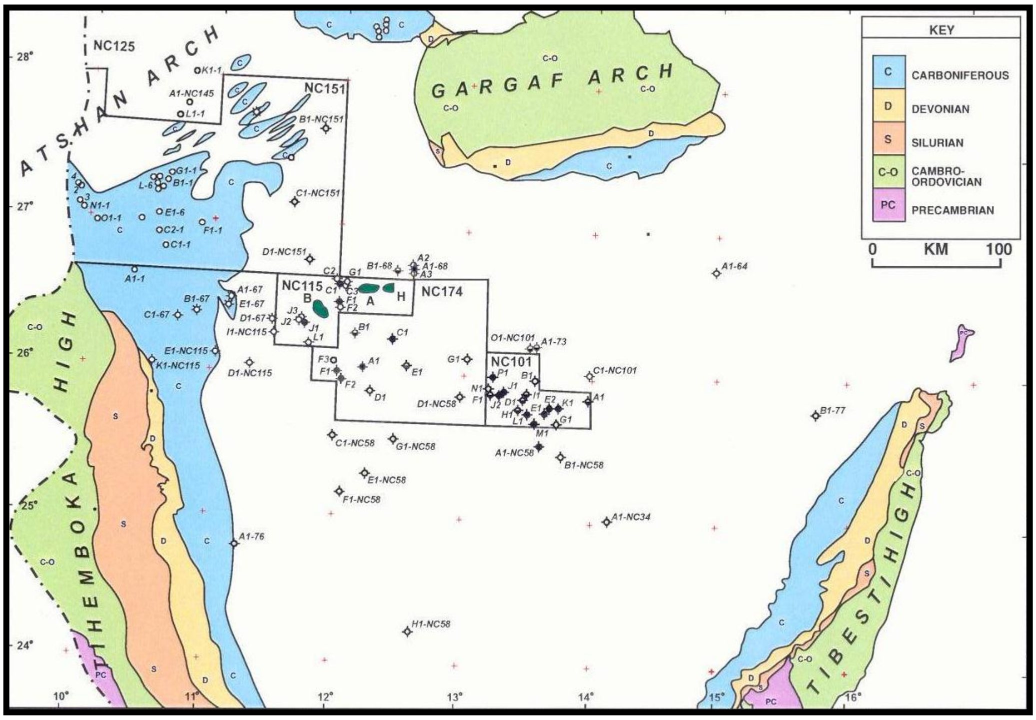

Fig. 4. Surface geology map showing the eastern and western margins of the Murzuq Basin (Buck, 1995).

3. Data base and Method of study

3.1.The data set is outlined below

1- Hard copies of the wireline logs suite from exploration wells which includes A1-, B1, FI-, F2-, F3-, F4-, F5 and FA7-NC174 wells (Fig 1). The well-logging data for eight exploratory wells (Fig. 1). Each of the 8 study wells also has a high-quality wireline log dataset.

However, gamma-ray logs measure the natural radioactive properties in different lithologies such as sandstone and shale in units of API (American Petroleum Institute). Shale is characterized by the strongest radiation (Rider, 1986). Readings (1986), listed potassium, uranium, and thorium as common sources of gamma-ray radiation and attributed the radioactive (shaly response of sandstone to K-bearing minerals like clays, micas, K-feldspars, heavy minerals and Glauconite). Miall (1984) demonstrated that the gamma-ray log acts as an indicator of the clay mineral content of a unit, which correlates to grain size. In contrast, texturally and mineralogically matured quartz arenite and clean carbonate give a low gamma-ray log reading. Therefore, the log is considered as an excellent tool for differentiating shale/mud from rocks like clean sandstone and dolostone in the subsurface.

2- Sample cuttings of the Upper Ordovician in the subsurface, which acts as the calibration point for image log interpretation. Review of core descriptions, high resolution core photographs has been used to generate a selection, from across all 8 study wells, of key sedimentological features, which were subsequently used as a guide for the development of a units association scheme.

2.3 . Methodology

Petrel muItiwell correlation software was used on the digitized well data to investigate possible correlations between data from different wells.

4. Results

The wells in the Mamuniyat Formation section of the NC174 concession were subdivided into six units based on measurements of electric log character (gamma ray and sonic log responses), cores images and cutting description and lithology correlation (Fig. 5 and Fig.6) and units intervals and interpretation see (Tables 1and 2).

Wells	Unit 1 Top (Ft)	Unit 2 Top (Ft)	Unit 3 Top (Ft)	Unit 4 Top (Ft)	Unit 5 Top (Ft)	Unit 6 Top (Ft)
Al-NC174	6362.0	6400.0	–	6618.0	6662.0	6692.0
Bl-NC174	7070.0	7172.0	7264.0	7417.0	–	–
Fl-NC174	–	5040.0	5150.0	5170.0	–	–
F2-NC174	–	5057.0	5192.0	5275.0	–	5420.0
F3-NC174	5103.0	5177.0	–	5240.0	–	–
F4-NC174	–	5272.0	5365.0	5400.0	–	5482.0
F5-NC174	5493.0	5499.0	5562.0	5603.0	–	5618.0
FA7-NC174	–	5732.0	5880.0	5952.0	–	6172.0

Table 1. Tabulated units intervals by depth (depth on MD).

Unit 1 Unit 2 Unit 3

Unit 4 Unit 5 Unit 6

Fig. 5. Core units scheme.

Unit Top to bottom	Description	Depositional processes and interpretation
1	Light gray, light brown, off white, fine to medium occasionally coarse grained of sandstone, hard, angular to subangular, clay matrix, stacked upward, sequence of increasing gamma ray strength (fining upwards sequence).	The deposition environment of this unit is interpreted as braid-delta. Comprising channel sandstone deposited in subaqueous channels probably at the channel margin.
2	Quartzite, light brown, clear, translucent, off white, moderate hard, very fine to coarse grained in some parts, angular to subangular, stacked coarsening up wards sequence.	This unit was probably deposited as a stacked coarsening up wards sequence. Sandstone may be deposited by low-density turbidity currents as pro gradation and abandonment of mouth bars.
3	Quartzite, light brown, clear, translucent, off white friable to medium hard, very fine to fine grained of sandstone, argillaceous sandstone, subangular to subrounded grain size.	Low energy prodelta environments offshore from braid-delta.
4	This unit is represented in all the wells studied, Quartzite, clear, translucent, white, light grey medium hard, fine to medium grained of sandstone, slightly argillaceous and pebbly sandstones, subangular to subrounded, occasionally subrounded. The gamma ray traces increasing upwards values that shows coarsening upwards sandstone, these are capped by thin argillaceous sandstone horizon.	Thick dewatered sandstone deposited rapidly or dumped by glacial outwash streams on the braid-delta front during a period of a low sea level characterised by high rates of sand supply.

5	This unit is present only in well AI-NCI74, Quartzite, clear, translucent light grey, off white medium hard, very fine to fine grained of sandstone, subangular to sub rounded, occasionally subrounded.	Fine to very fine grained and spike in the gamma rays at the base of the unit that defines the base of the unit and it is composed of silty and shaly mudstone suggests low energy outer shelf environment
6	This unit is not present in the wells B 1, F 1, and, F3-NCI74. Quartzite, clear, translucent, light grey off white, medium hard, very fine to medium grained of sandstone, argillaceous sandstone associated with silty mudstone, subangular to subrounded.	Deposited shelf environment below storm wave base.

Table 2. Unit description;

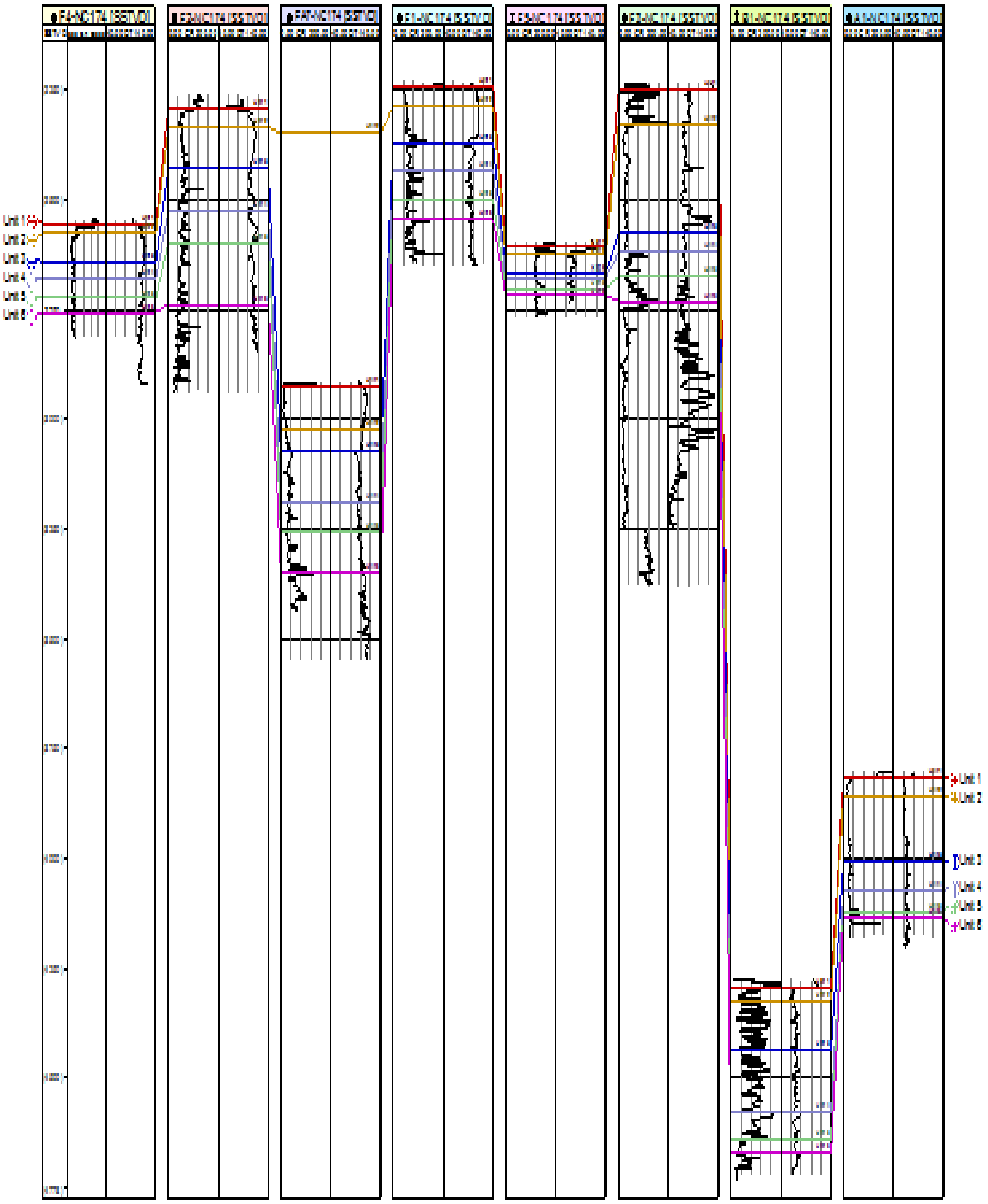

Fig. 6. Well correlations based on unit subdivision (SSTVD subsurface true vertical depth).

5. Isopach map of the Mamuniyat Formation distribution within studied area

This map was produced to give some idea of the thickness variations within the Mamuniyat sandstone. However, the thickest sandstone is at the north-eastern part of the map, where it is 460 feet thick. From the isopach map (Fig. 7) show a strong degree variation in thickness increasing from the part at Mamuniyat to north part, thickness very from 125 feet in western to 460 feet in the north-eastern. That thickness variation reveals strong tectonic control on sedimentation.

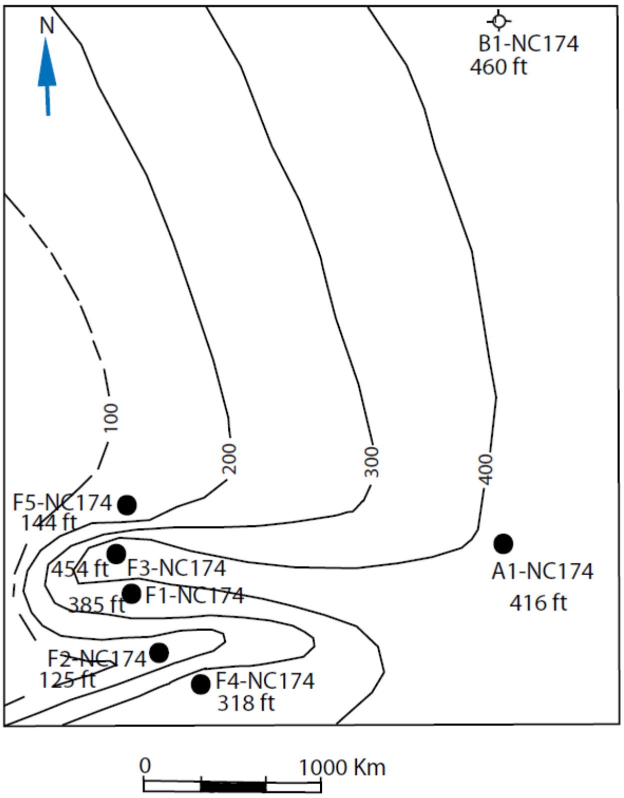

Fig. 7. Isopach map of the Mamuniyat Formation.

6. Discussions

Six sedimentary units were recognized based on their electric log character (gamma ray and sonic log responses) and lithology correlation that conferring to the regional geology, the overall sedimentary setting can be attributed to flood-dominated glacial fluvial systems. Thickness variation reflects strong tectonic control on sedimentation. In addition, the Mamuniyat Formation shows laterally systematic changes in grain size, lithology, and sedimentary structure. These changes are related to a decrease in depositional gradient passing outward from the source terrain with concomitant decrease in stream capacity and competence. The entire units interpretation of the Mamuniyat Formation within the study wells is consistent with a braided alluvial plain, foreshore, and upper shoreface, shallow marine depositional and deltaic to shallow marine.

The Mamuniyat Formation shows an increase in marine influence toward the northeast. It is dominated by a proximal-distal braided plain in the southwest giving way to fluvial and marginal marine-to-marine shelf deposits in the northeast. Paleocurrent was from the SW, probably from the uplifted Ghat/Tikiumit Arch to the southwest and the concession area (Fello and Turner, 2004).

Several geologists have discuused the deposition environment modelling based on facies interpretation. (Voss, 1977; Turner, 1980; Fello, 2001), suggests that the Mamuniyat Formation was deposited under high energy, low sinuosity braided streams in which vertical channel aggradations, and rapid channel shifting were important depositional processes. Possibly the rivers drained an extensive alluvial plain, which may have been built on the (proximal and distal) slopes of an alluvial fan complex to the southwestern part of the NC174 concession..

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