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Depositional Model for the Distribution of Silurian Hot Shale and Mamuniyat Reservoir Facies in the Al Kufrah Basin

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ABSTRACT

Previous accounts of the stratigraphy and petroleum geology of the Ordovician and Silurian succession of Al Kufrah Basin have drawn attention to the potential similarities of the Ordovician/Silurian succession of Murzuq Basin with that of the Al Kufrah Basin, acknowledging that far less is known about Al Kufrah Basin because of the limited drilling to date. One significant difference has been suggested, namely that the late Ordovician sediments of Al Kufrah may have been more peri-glacial than pro-glacial, the region having been dominated more by glacial outwash rivers and fans than by moraine and sub-glacial sediments. From regional considerations it is argued that this may be misleading. Evidence from western Libya is used to provide analogues of the type of depositional architecture postulated to be present in the subsurface of Al Kufrah. This comprises a landscape of some considerable palaeotopographic relief infilled with fluvioglacial and glacimarine sediments.

INTRODUCTION

Accounts of the stratigraphy and petroleum geology of the Ordovician and Silurian succession of Al Kufrah Basin have been presented by Luning *et al.* (2000, 2003) and Hallett (2002). Luning *et al.* (2000) provided a thorough account of the history of scientific research on Al Kufrah. Only four oil exploration wells have been drilled in the basin and exposures of the Ordovician and Silurian sedimentary rocks around the margins of the basin are neither extensive, nor thoroughly studied (Fig. 1). These factors together with the remoteness of the region make this a genuinely poorly explored basin. The Murzuq Basin, in SW Libya, by contrast, has been more thoroughly explored in recent years as a result of the discovery of significant hydrocarbon reserves in the NW part of the basin. Associated scientific research has allowed the development of a sophisticated understanding of the depositional settings of the late Ordovician and Silurian deposits of the basin (Sutcliffe *et al.*, 2000; Craig *et al.*, 2002, Le Heron *et al.*, 2004 and many others). These deposits comprise the glacigene Ordovician Mamuniyat and post-glacial Tanzuft formations (Fig. 2). This prior research has resulted in the construction of some tentative palaeogeographic reconstructions for the entire Sahara with important implications for the geology of Al Kufrah Basin which will be discussed below.

In this work the stratigraphic terminology used by Hallett (2002) has been adopted (Fig. 2) for the Melaz Shuqran Formation which is taken here to be Ashgillian in age (following Craig *et al.*, 2002). Failure to recognise this formation in Al Kufrah Basin may be related, therefore, more to depositional styles within the glacigene Ashgillian than to erosion or non-deposition.

DEPOSITIONAL ARCHITECTURE

Regional distribution of the Mamuniyat, Tanzuft and Akakus formations

The formations of the Ashgillian-Silurian second order sequence comprise the Mamuniyat, Tanzuft and Akakus (Fig. 3). In Murzuq Basin the Mamuniyat is typically between 50 m and 200 m thick whilst the Tanzuft ranges up to 350 m thick, with similar thicknesses for the Akakus. The recorded thicknesses for the Mamuniyat in Al Kufrah Basin (Fig. 1) are consistent with this except those for the A1- and B1-NC43 wells. In these wells the reported thicknesses (Luning *et al.*, 2003) seem rather large, possibly reflecting the difficulty of differentiating Cambro-Ordovician formations in the subsurface. The reported absence of Hawaz Formation sediments in

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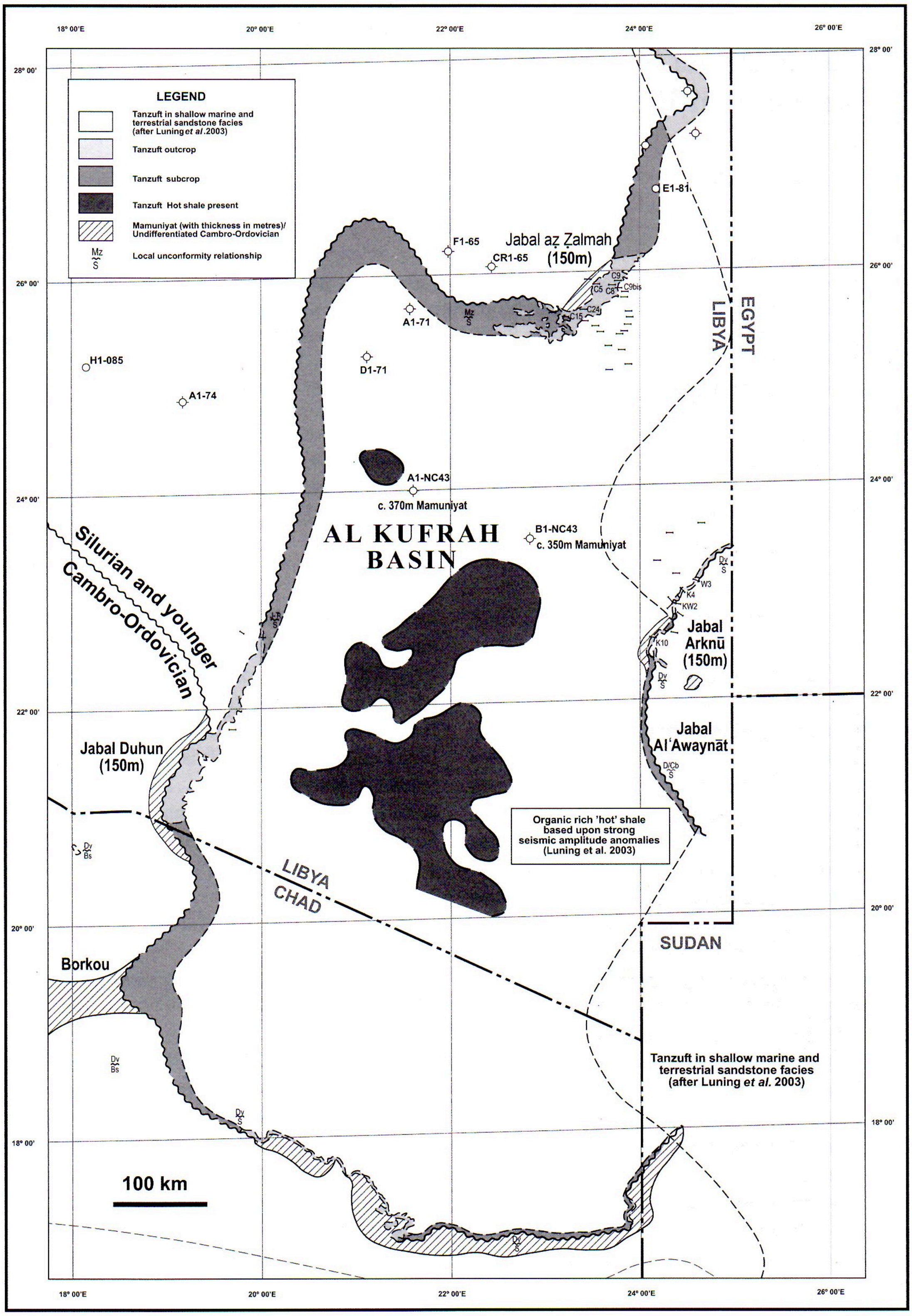

Fig. 1. Sketch map of Al Kufrah Basin showing distribution of Mamuniyat and Tanzuft formations.

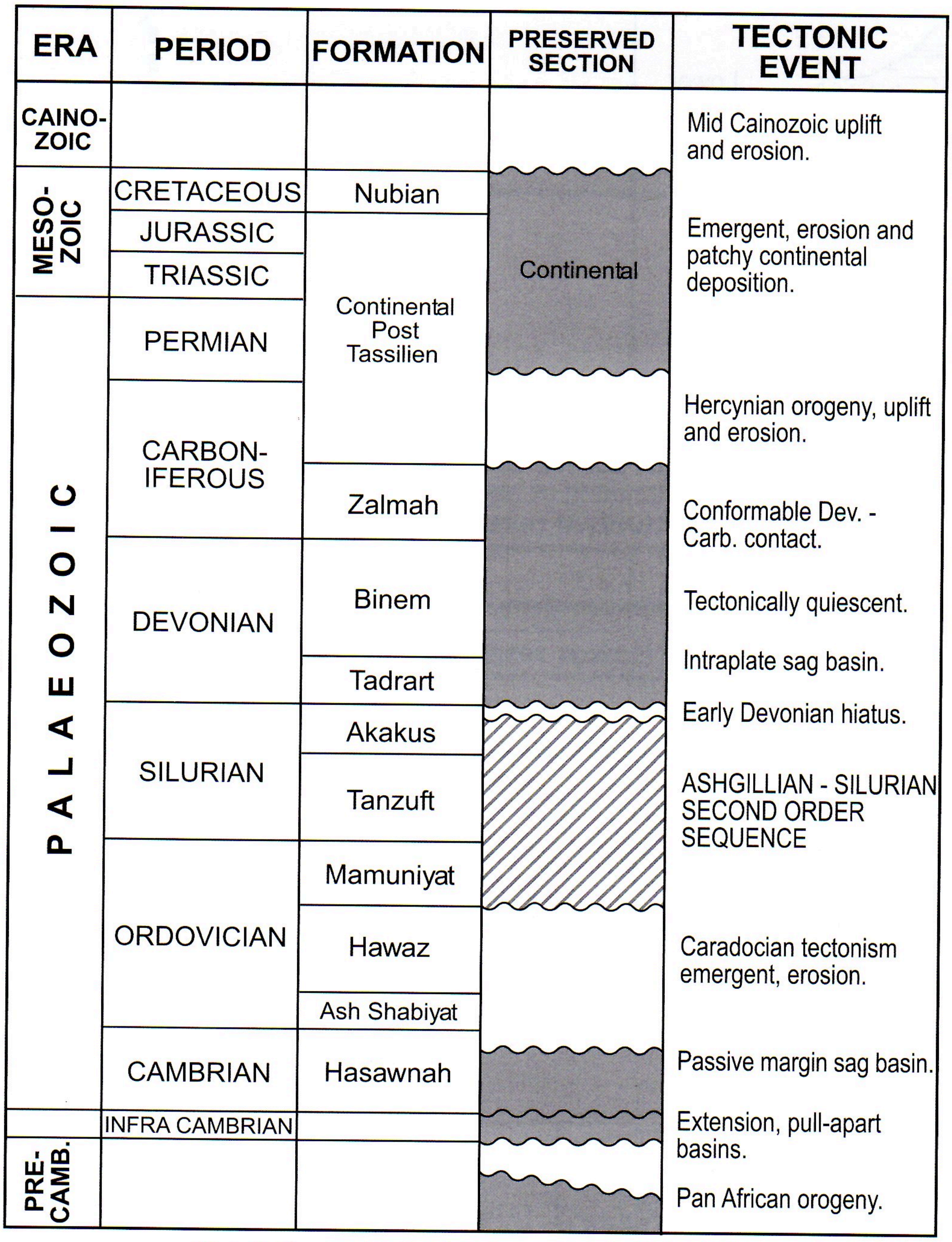

Fig. 2. Stratigraphy of Al Kufrah Basin (modified after Hallett, 2002).

Al Kufrah Basin (Hallett, 2002) suggests strong intra-Ashgillian pre-glacial erosion. This contrasts with Murzuq Basin and is perhaps consistent with a stable position on the Saharan platform where preservation potential is low. Intra-Devonian erosion and subsequent erosional events (Fig. 2) resulted in the truncation of the Silurian section leading to the widespread removal of the Akakus and the reduction in thickness of the Tanzuft. Typical distributions of these three formations are given in Fig. 4 where the great lateral variability of the Mamuniyat is illustrated. Palaeovalley complexes, characteristically up to 100 km in width, are shown to be of critical importance in localising and then preserving the Ashgillian glacigene deposits. The orientation of these palaeovalley complexes in Al Kufrah Basin is not yet established. Following Le Heron *et al.* (2004) it might seem reasonable to assume a south to north orientation. However, the strong SE to NW grain of the

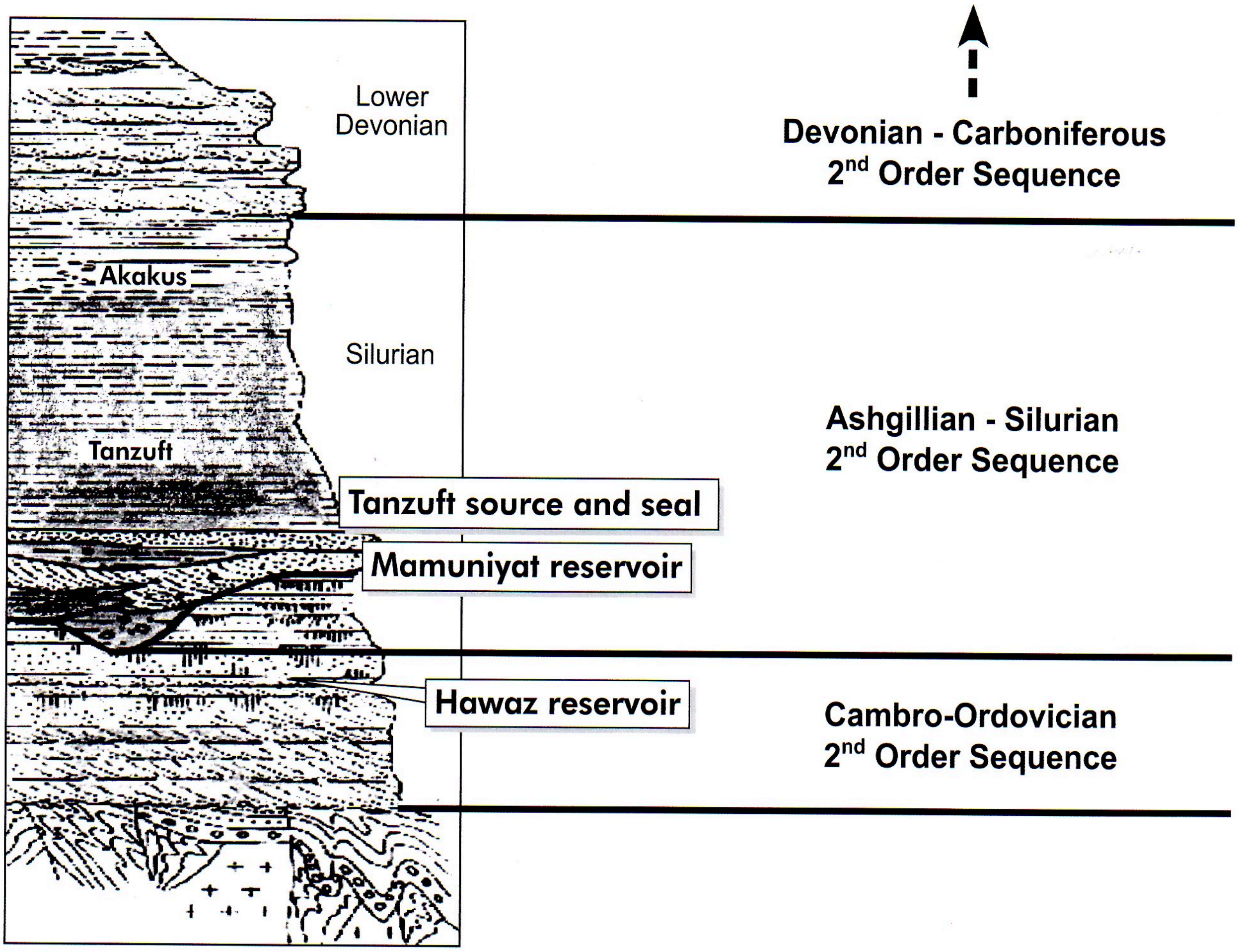

Fig. 3. Stratigraphy of the lower Palaeozoic of the Central Sahara showing second order sequence boundaries and main petroleum reservoirs and source rocks (modified after Beuf *et al.*, 1971).

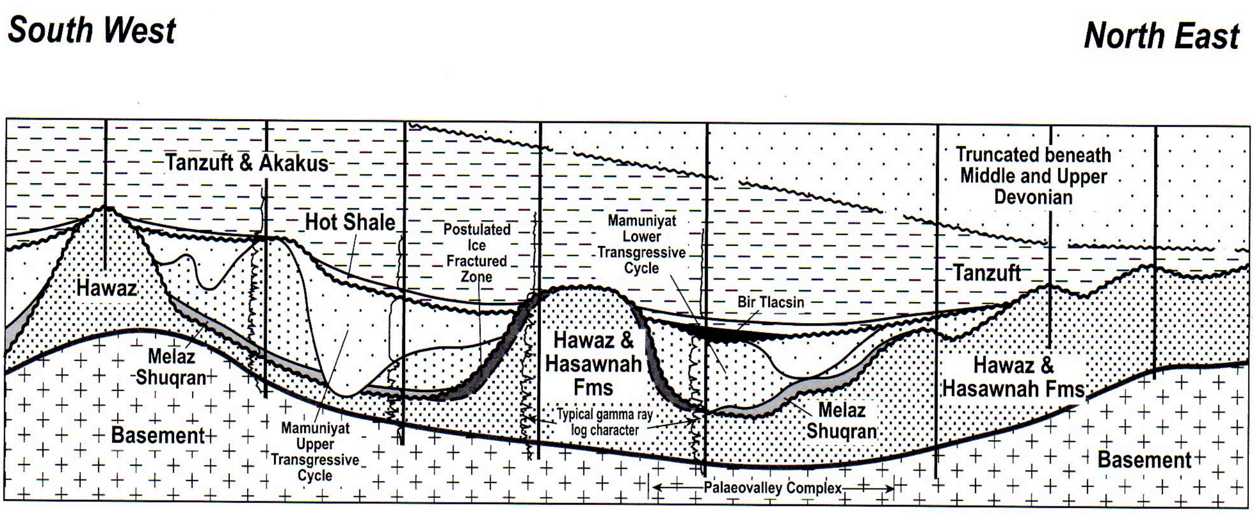

Fig. 4. Schematic cross-section to show typical architecture of the Ashgillian – Silurian second order sequence of southern Libya with typical well positions shown.

palaeovalleys of Block NC174 in Murzuq Basin (Smart, 2000), established in contradiction to expected south to north orienations, gives one pause for thought and has encouraged the current author to suggest tentatively that the orienation may be similar in Al Kufrah Basin.

Ashgillian succesion

Figure 5 illustrates the main characteristics of the four transgressive cycles that have been recognised in the Ashgillian succession of southern Libya. The erosional boundary at the base of an Upper Ordovician sandstone has been recognised throughout the Sahara since the early 1970s (Beuf *et al.*, 1971) – its identification as an Hirnantian second order sequence boundary is more recent (Sutcliffe *et al.*, 2000). This boundary is thought to have both tectonic and eustatic origins – glacial scouring of the landscape exploiting zones of weakness and ice loading and unloading events encouraging movement on existing faults.

Three glacial-period facies associations are defined (see left hand column of Fig. 5). Ice contact deposits (facies association 1), glacial outwash fans (facies association 2) and submarine fan/glacimarine shelf deposits (facies association 3). A fourth facies association (not illustrated) comprises an ice-distal shelf facies association composed of clean highly bioturbated shoreface sandstones with common *Skolithos* representing deposition on a shallow shelf some distance from glacial influence.

In this interpretation of the Ashgillian (Fig. 5) the Melaz Shuqran is incorporated at the base as a part of the glacigene succession. Each transgressive cycle displays an erosional base. The transgressive cycles may be interpreted as high frequency periglacial sequences, or para-sequence sets of the lowstand systems tract. The Upper Transgressive Cycle is perhaps the most significant from a petroleum reservoir point of view, being deposited during the retreat of what was probably the maximum ice advance. The Melaz Shuqran Formation is interpreted as the deposits of a minor glacial advance and retreat. The formation, which is dominated by marine shales with thinner interbedded sandstones, is generally constrained to the lower parts of the incised erosional topography of the bounding unconformity surface. The sequence is characterised by floating pebbles and boulders of often striated granite, gneiss and quartzite, with common subaqueous slump, liquefaction and turbidity flow structures.

Evidence for restriction of Memouniat reservoir sandstones, and also the hot shale source rock facies, to palaeotopographic depressions comes from many sources, both in the subsurface and at outcrop. An outcrop example is given in Fig. 6 where a palaeovalley system filled with Melaz Shuqran, Tasghart and Mamuniyat (Lower Transgressive Cycle) deposits is overlain erosively by an offset erosional palaeovalley filled with sediments of the Upper Transgressive Cycle.

The Bir Tlacsin Formation lies above the 'top Mamuniyat unconformity' and is composed of microconglomeratic shales, thought to be the deposits of the waning ice sheet. These deposits are the lateral equivalent of the persculptus shales which Echikh and Sola (2000) have suggested might provide a barrier to downward charge of Tanzuft-generated oil into the Mamuniyat. This is considered to be less of a real problem than envisaged because the Bir Tlacsin is likely to be very localised in its distribution.

Silurian succesion

In the Al Kufrah Basin this is dominated by the Tanzuft Formation. This was deposited as sea level rose at the end of the glacial episode and the North African platform was flooded and blanketed by a transgressive marine shale with a basal transgressive sand developed in places. Luning *et al.* (2000) identified a maximum flooding event at the Rhuddanian-Aeronian boundary (early to middle Llandovery) with regressive high stand sedimentation commencing above.

A brief intra-Rhuddanian anoxic event (graptolite zones 16/17) is marked by deposition of thin but regionally extensive organic-rich shales. Although of widespread geographical extent, it is locally confined to still under-filled incised valley systems. This is illustrated in Fig. 7 where the onlap relationships to adjacent palaeotopographic highs is evident.

De Lestang (1968) reported the existence at outcrop of Silurian graptolitic shales overlying sandstones that may belong to the Mamuniyat at Borkou in western Al Kufrah (Fig. 1). Graptolites collected well up in the section appeared to belong to zone 19. It seems probable that the underlying shales may belong to zones 17 and 18 and to contain, therefore, the hot shale. Such are the problems of recognising hot shale in outcrop (Luning *et al.*, 2003) that no direct evidence was obtained as to whether these shales comprised the organic-rich facies. However, on indirect evidence, it seems likely. If this is correct this outcrop location probably represents an axial palaeovalley position.

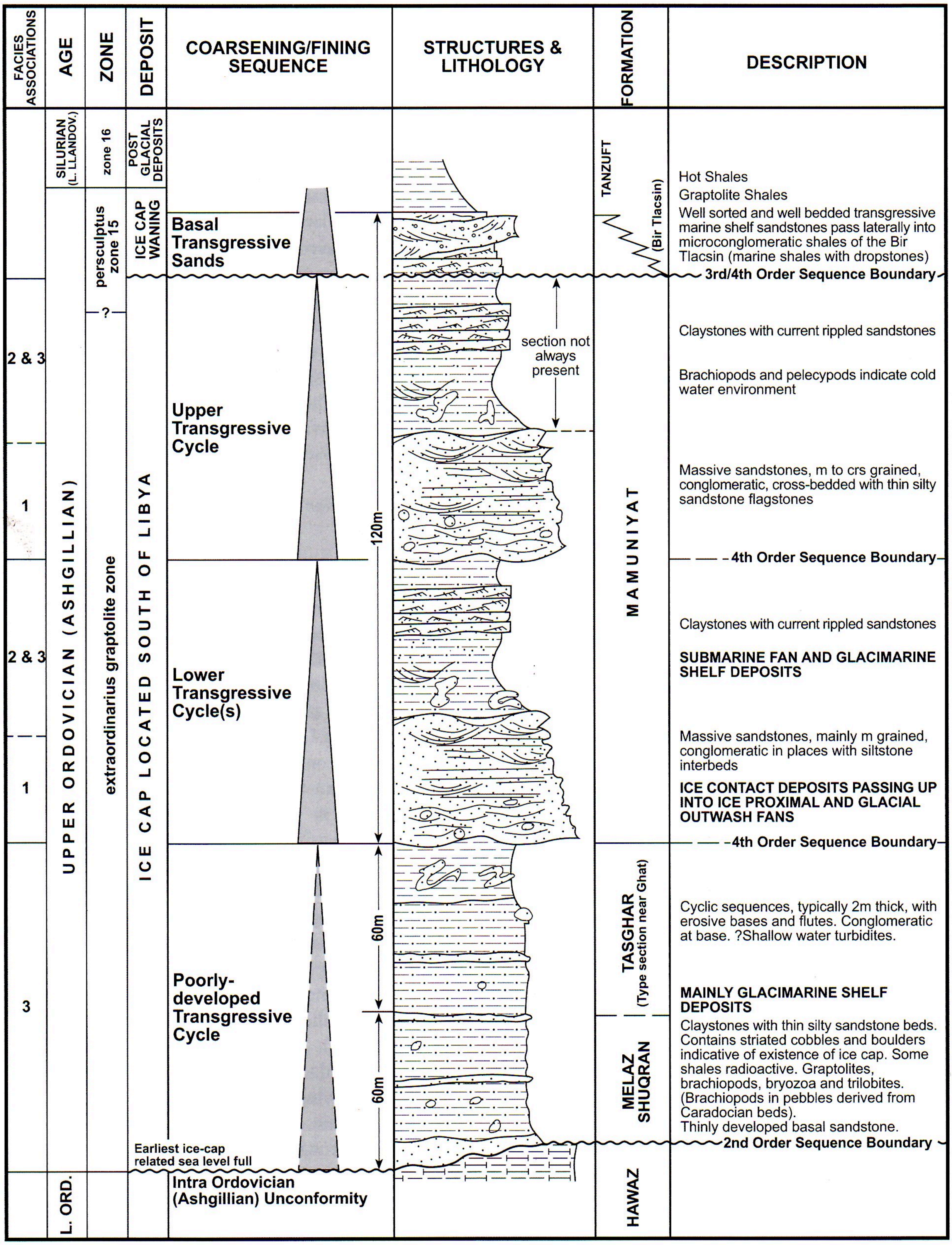

Fig. 5. Schematic Ashgillian to Early Silurian succession of southern Libya; four distinct transgressive (ice retreat) cycles are illustrated (succession based primarily on outcrop and subsurface data from Murzuq Basin).

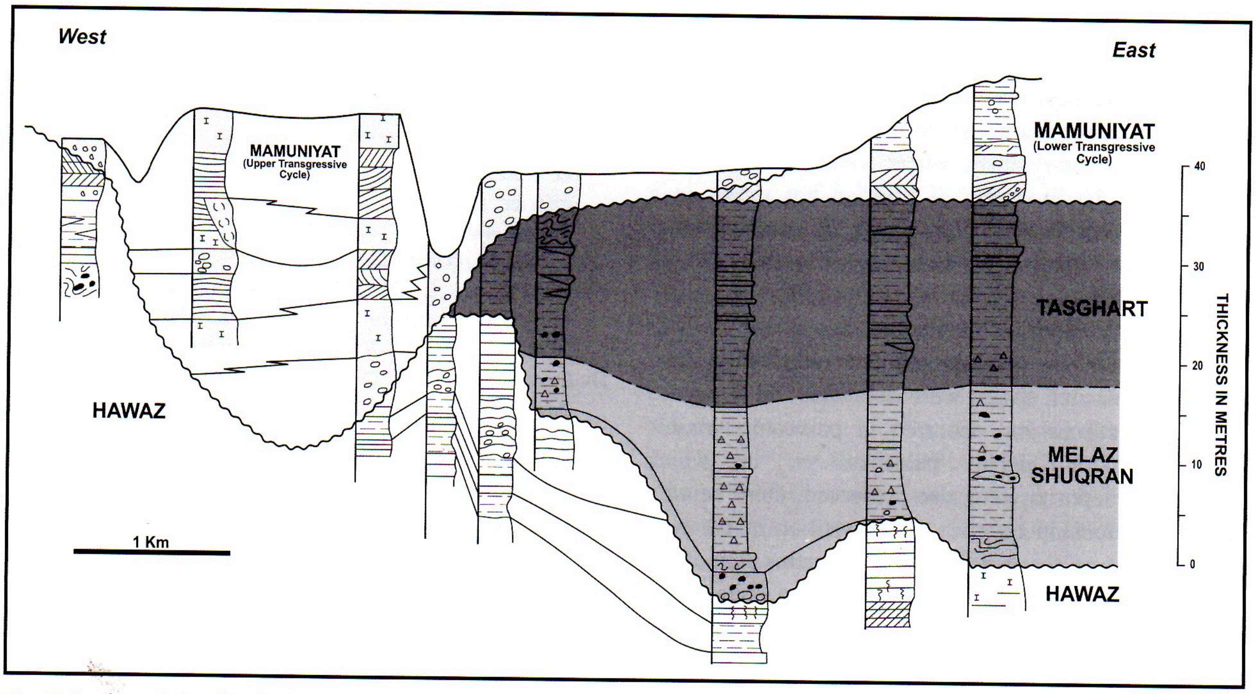

Fig. 6. Outcrop relationships in the Ashgillian succession of Al Qarqaf region (modified after Beicip, 1973, evidence also from El-Mehdi, 1992).

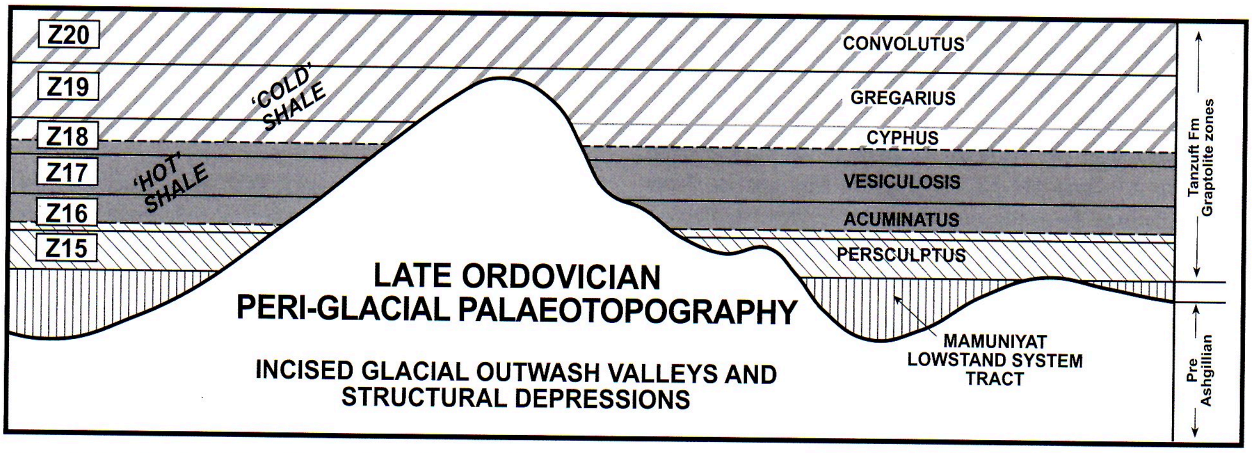

Fig. 7. Schematic relationship of Tanzuft Formation graptolite zones with underlying palaeotopography (modified after Luning *et al.*, 2000).

CONCLUSIONS

The proximal position of Al Kufrah Basin, in terms of depositional setting of the Late Ordovician to Silurian second order sequence, has been taken to provide evidence for a likely dominance, in the poorly explored subsurface, of terrestrial and sand/silt dominated clastic facies in the Mamuniyat and Tanzuft formations; in particular to suggest the likely absence of Tanzuft source/seal rocks. The palaeogeographic reconstruction of Luning *et al.* (2003) suggests that the position of the palaeocoastline in the Early Silurian (the maximum flooding surface is thought to have been at the end of the Rhuddanian-graptolite zones 18/19) may have been located to the south and east of Al Kufrah Basin. Deposition distally or seaward from this coastline in the late Ashgillian and early Silurian was controlled by major and relatively rapid glacioeustatic sea-level changes. Consequently, although preservation potential may be poor, it is probable that significant marine shale deposits were laid down both in the late Ashgillian (Mamuniyat) and early Silurian (Tanzuft) during periods of maximum ice retreat and post-glacial marine transgression. Just such a situation is known to exist in the southern part of the Murzuq (Djado) Basin, where well data from Niger demonstrate the existence of Silurian hot shales in a region predicted to be too proximal for anything other than sand/silt Tanzuft deposition (see for instance Echikh and Sola, 2000).

The early Silurian maximum transgression was associated with the development of anoxic 'sub-basins' where organic-rich shales were deposited. It is argued that these 'sub-basins' occurred in palaeotopographic depressions, or glacial palaeovalleys, in which Mamuniyat deposits were also preserved, there being a genetic relationship between the deposition of the two. Identification of these palaeovalley systems, therefore, is of critical importance in locating good source and reservoir rocks. Information from modern seismic data in Murzuq Basin demonstrates that not only may the hot shale be recognised (by amplitude anomalies) but that the erosional palaeovalleys may also be recognised on seismic. There is no necessary relationship between the location of these palaeovalley systems and present-day structural 'deeps' in the basin, although of course sufficient source rock burial is required to establish a petroleum system.

The possible presence of hot shale in the region south of wells A1- and B1-NC43 (Fig. 1) but not in those two wells may be explained if the wells were drilled on palaeotopographic highs, palaeovalley systems lying to the south and NW with a SE to NW orientation. The possible presence of the hot shale at Jabal Duhun supports the concept of a paleovalley system lying in the southern part of the basin, located in Chad.

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