Petroleum Geology Conference series

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Petroleum Geology Conference series 2010; v. 7; p. 725-734
doi: 10.1144/0070725

Notes

Stratigraphic trapping potential in the Carboniferous of North Africa: developing new play concepts based on integrated outcrop sedimentology and regional sequence stratigraphy (Morocco, Algeria, Libya)

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Abstract: The lower Carboniferous (Tournaisian to Visean) of North Africa is characterized by cycle-stacks of predominantly shelfal to marginal marine sandstones and limestones, thick shelfal mudstones and less common but important interbedded fluvio-deltaic sandstones. The cyclic sedimentation pattern continues into the Mid Carboniferous (Serpukhovian to Bashkirian), when mixed siliciclastic–carbonate sequences give way to tropical carbonates, before an abrupt return to continental deposits in the upper Carboniferous (Bashkirian to Gzhelian). The alternation of widespread shallow marine and more discrete fluvial reservoirs with interbedded offshore mudstone seals is interpreted to result from high-frequency, high-amplitude Carboniferous glacio-eustatic sea-level changes. The large base-level changes during that time, combined with climatic conditions that produced high amounts of terrigenous mud, provided favourable conditions for the development of stratigraphic traps in the clastic-prone lower Carboniferous, while the advent of tropical carbonates produced reefal buildups in the Mid Carboniferous. Four stratigraphic trapping types are recognized: (1) truncation traps in which reservoir units were eroded on subaerially exposed proximal palaeohighs and thick underlying transgressive and highstand systems tract (TST and HST) mudstones form the bottom-seal and the rapid transgression of the offshore facies forms the top-seal; (2) pinchout traps of lowstand wedges on the flanks of distal palaeohighs, which were only affected by subaqueous reworking of previous TST–HST mudstones and were buried during the subsequent transgression; (3) incised valleys of the lowstand systems tract (LST), filled with thick fluvial and tidal sandstones, cutting either into TST–HST mudstones in the lower Carboniferous, or into exposed carbonate platforms in the Mid Carboniferous; (4) Waulsortian-type reefal buildups of the Mid Carboniferous. The four trapping types are discussed using selected outcrop examples, and are placed into regional sequence stratigraphic context of the Carboniferous depositional systems and sequence development of North Africa. These concepts can be readily applied to the subsurface and offer significant potential for new plays across North Africa.

Keywords: stratigraphic traps, sequence stratigraphy, Carboniferous, Morocco, Algeria, Libya

A tentative sequence stratigraphic scheme for the Carboniferous of North Africa has been developed to guide reservoir prediction in poorly explored areas and to provide a framework for further analysis of potential stratigraphic traps. Seven important outcrop sections across North Africa were reviewed and correlated. Of these, five sections have been interpreted based on published sources and two sections (SW Anti-Atlas, Morocco; NW Murzuk Basin, Libya) were logged for this study (Figs 1 & 2). All sections are located along the southern Palaeozoic outcrop belt, comprising exposures in the Anti-Atlas, the Bechar Basin, the Reggane, Ahnet and Mouydir Basins, the southern Illizi Basin, and the northern Murzuk to southern Ghadames Basins. The presented chronostratigraphic chart has been compiled based on a comprehensive review of a large amount of published literature, of which only selected key publications are referred to in this summary paper.

North African Carboniferous sequence framework

Over many decades of studies in North Africa there have been a number of publications on the stratigraphy and sedimentology of the Carboniferous; an excellent regional summary is provided by Diaz *et al.* (1985). However, of these studies, only a few attempt any sequence-type interpretation. In this paper we present the first regional sequence stratigraphic scheme, based on a large amount of available published biostratigraphic and sedimentological data, integrated with new field work.

Good quality sedimentological and biostratigraphic published work on a regional scale is very limited, despite the vast outcrops of fossiliferous Carboniferous sediments. The sequence stratigraphic scheme and correlation presented here must be considered a preliminary working document due to the vast area covered and the relatively widely spaced dataset currently available. In certain data-poor areas the scheme remains very conjectural at present. In addition to the limited dataset, different fossil groups used for biostratigraphic dating sometimes suggest very different ages (Wendt *et al.* 2009), exemplifying the need to continue and update the research on the extensive outcrops.

The regional correlation shows the general facies patterns and palaeogeography of the Carboniferous from Morocco to western Libya. This correlation allows assessment of the broad trends, although it should be emphasized that in detail, on a basin scale, the stratigraphy and sedimentology are undoubtedly more complicated than can be shown on the generalized correlation panel.

The following sections describe each phase of Late Devonian to Late Carboniferous deposition, ending with a comparison of these phases with global sea-level cycles.

Late Devonian ('Strunian') regression

A latest Devonian ('Strunian') regression is recognized across all of NW Africa, with the deposition of shelf sandstones in the Anti-Atlas (e.g. Kaiser *et al.* 2004), Bechar Basin, Ougarta Arch, northern Hoggar region and the Illizi and Ghadames Basins (Conrad *et al.* 1986; Lubeseder 2005; Fig. 3). A regionally extensive unconformity developed in the Murzuq Basin of Libya and across surrounding palaeohighs (the Gargaf Arch and Tihemboka Arch) and presumably reached far into the Ghadames Basin. The

VINING, B. A. & PICKERING, S. C. (eds) *Petroleum Geology: From Mature Basins to New Frontiers – Proceedings of the 7th Petroleum Geology Conference*, 725–734. DOI: 10.1144/0070725 © Petroleum Geology Conferences Ltd. Published by the Geological Society, London.

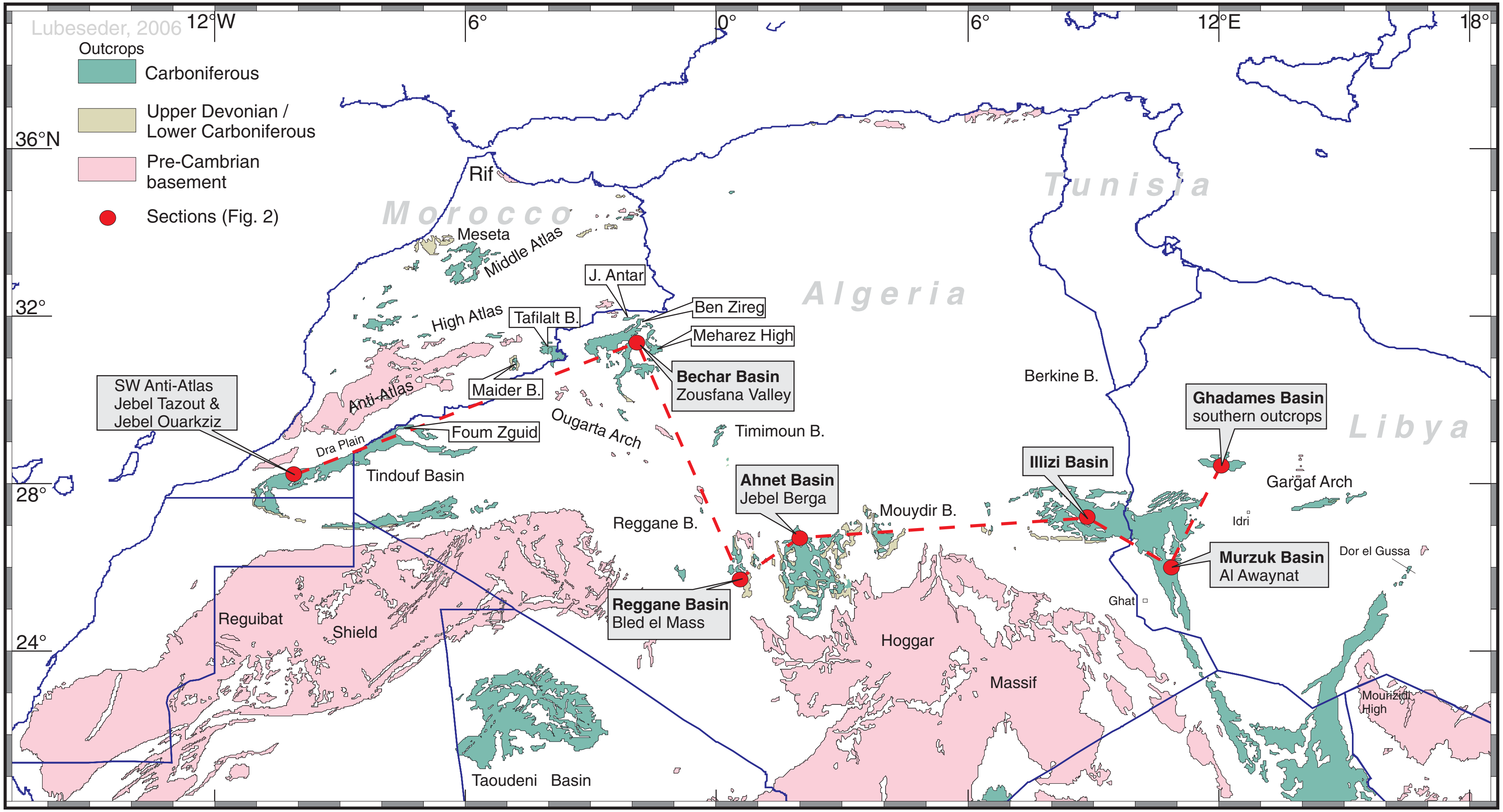

Fig. 1. Map of North Africa showing Carboniferous outcrops, location of sections (red dots), and line of correlation (shown in Fig. 2). Geological basemap after Persits *et al.* (1997).

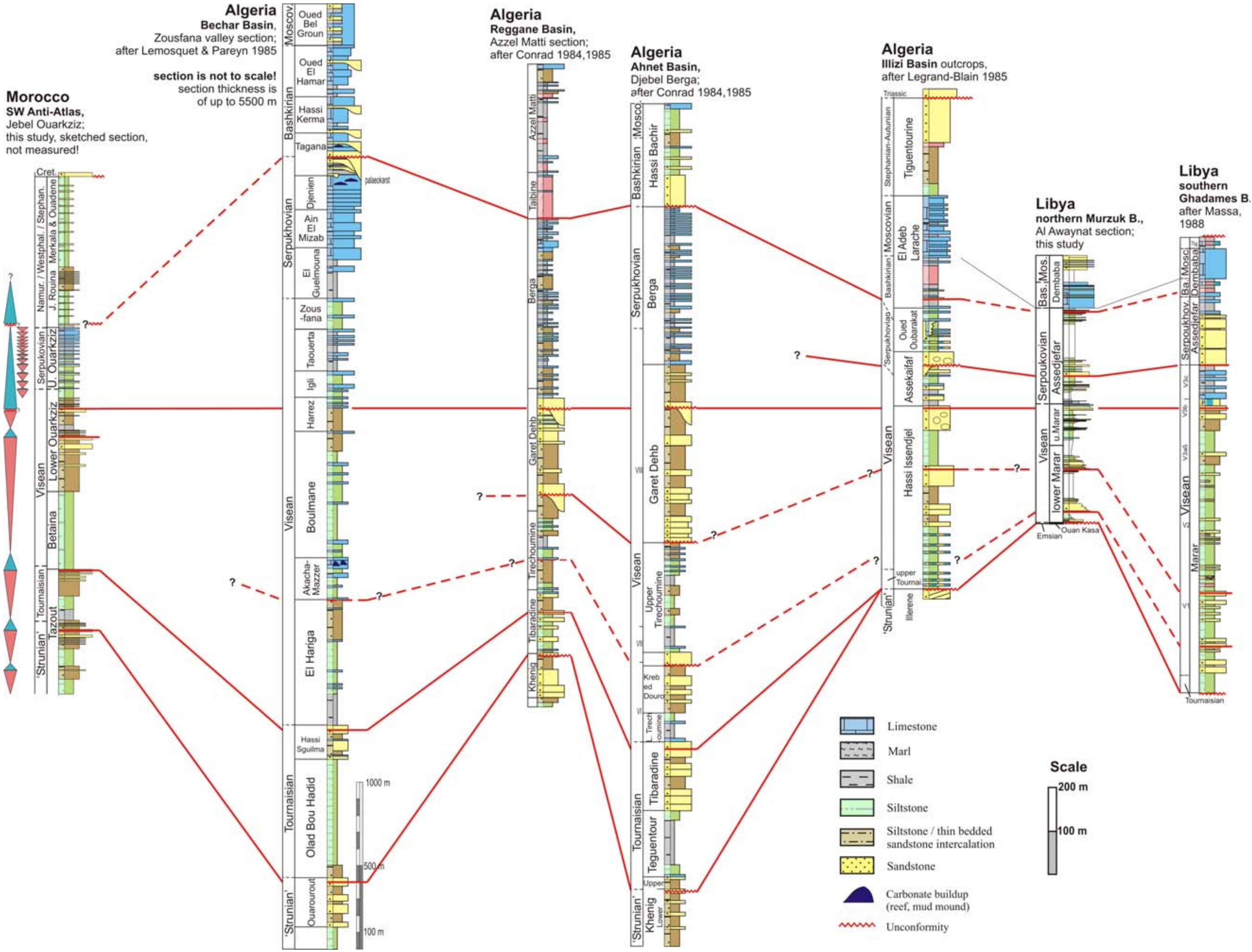

Fig. 2. Correlation of selected North African Carboniferous outcrop sections.

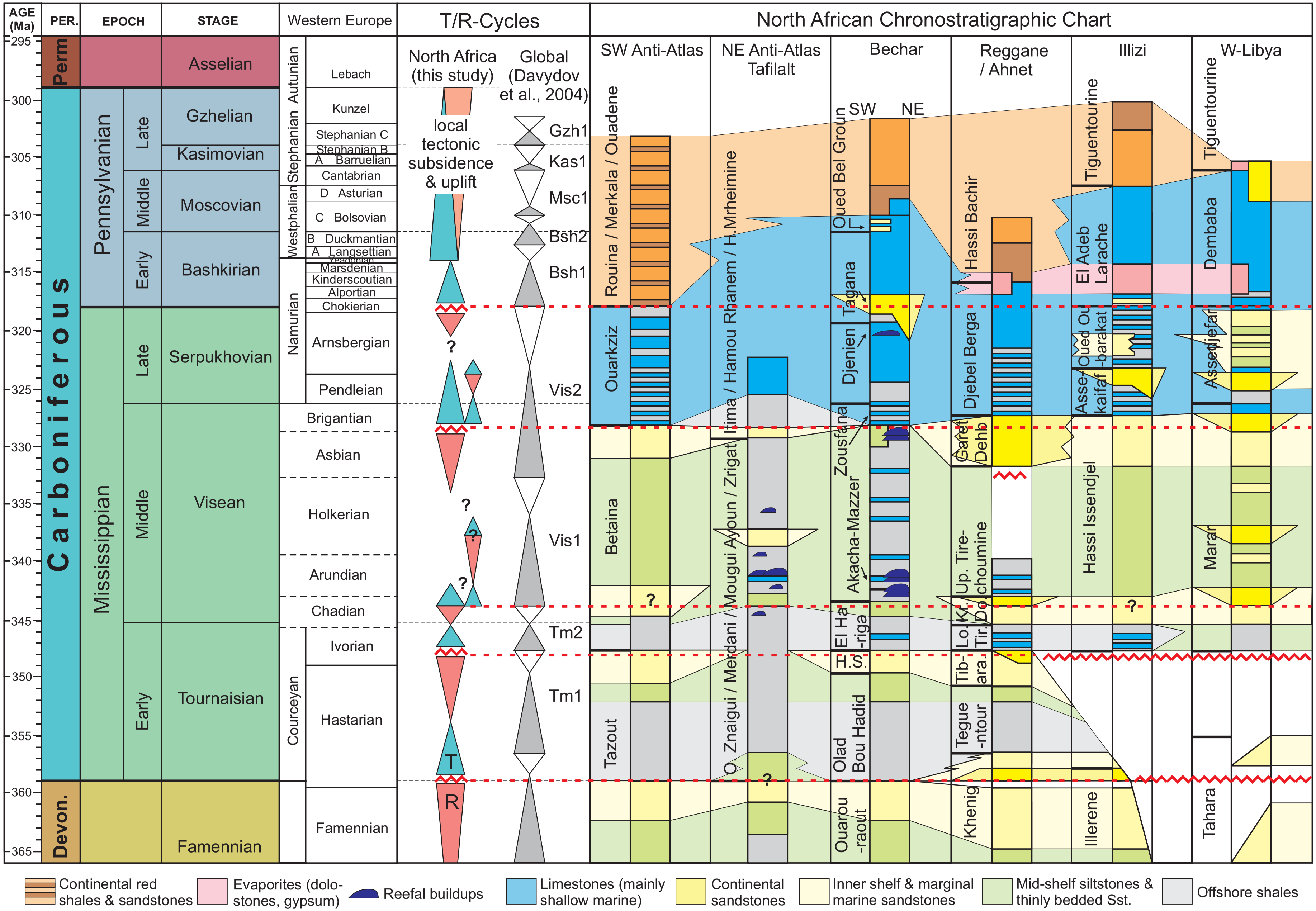

Fig. 3. Tentative chronostratigraphic correlation and transgressive-regressive (T/R) sequence framework of the Carboniferous of North Africa. Note that much more integrated biostratigraphic and sedimentological work on the Carboniferous sections of North Africa will have to be carried out before a satisfactory regional sequence framework can be achieved, and that the proposed scheme presented here is only a starting-point.

unconformity is also developed in the Reggane and Ahnet Basins of Algeria (Conrad 1984, 1985).

Early to Middle Tournaisian transgression

In the northwestern regions (the Anti-Atlas, Bechar Basin and Ougarta Arch), the subsequent transgression led to the deposition of marine shales with an Early Tournaisian fauna (the ammonoid *Gattendorfia* sp.). These shales are correlated to the shales of the Teguentour Formation in the Ahnet Basin, dated to the Mid to Late Tournaisian (Wendt *et al.* 2009). The emergence interpreted by these authors in the Ahnet Basin is interpreted here as a hiatus caused by non-deposition during maximum flooding. In the more proximal near-shore to continental dominated southwestern areas, transgressive sandstones were deposited bearing Early Tournaisian brachiopods (e.g. the upper Tahara and Ashkidah Formations of the Gargaf Arch; Mergl & Massa 2000).

Late Tournaisian regression

In the Anti-Atlas and the Bechar, Reggane and Ahnet Basins, a Late Tournaisian regression formed a shale-to-sandstone coarsening-upward hemi-cycle comparable to those of the latest Devonian. It is likely that this hemi-cycle also developed in the subsurface of several other basins (e.g. the Timimoun, Ghadames and Berkine Basins) and may have been incorporated into the 'Strunian' reservoir interval by some workers. In the southern Ahnet Basin, fluvial sandstones occur locally within the Late Tournaisian Tibaradine Formation (Conrad 1985). In the Murzuq Basin and in the southern Illizi Basin outcrops, Late Tournaisian strata were eroded or sediments bypassed these basins during this regressive phase.

Latest Tournaisian to earliest Visean transgression

The Late Tournaisian shelf sandstones are succeeded by a thick interval of outer-shelf shales in the Anti-Atlas and the Bechar Basin (Betaina Formation; El Hariga Formation), which contain latest Tournaisian faunas at their bases. In the Ahnet Basin, the shales and limestones of the Lower Tirechoumine Formation (Iridet Formation *sensu* Wendt *et al.* 2009) are dated by conodonts, ammonoids and foraminifera to the Late Tournaisian to Early Visean (Conrad 1985; Wendt *et al.* 2009). This latest Tournaisian transgression also led to the deposition of marine sediments directly above the basal Hassi Issendjel Formation unconformity (Legrand-Blain 1985) and above the basal Marar Formation unconformity in the southern Illizi and Murzuq Basins. The very bases of these two formations have been assigned to the latest Tournaisian.

Visean transgressive–regressive cycles

Most of the Visean essentially forms one large-scale regressive phase (seen in the SW Anti-Atlas Betaina Formation, more poorly developed in the Ahnet and Illizi Basins, and well developed in the Marar Formation of Libya), which ended with the onset of widespread carbonate deposition during the latest Visean. Correlation of several intra-Visean cycles across the Saharan Platform, however, is uncertain (Fig. 2). It is proposed that the Visean large-scale regression is subdivided into two, or possibly three, higher-order cycles (Fig. 3).

Two well developed Visean cycles are evident in the Betaina Formation of the Anti-Atlas and are possibly represented by the El Hariga Formation, and (partially) by the Akacha–Mazzer Formation (lower cycle), and by the Boulmane and the Harrez Formations (upper cycle), in the Bechar Basin.

In the Ahnet Basin, the regressive deltaic-marine to fluvial sandstones of the Kreb ed Douro Formation are well dated to the Early Visean by the under- and overlying marine shales and limestones with ammonoids, conodonts and foraminifera (Conrad 1985; Wendt *et al.* 2009). We suggest a different interpretation from that of Wendt *et al.* (2009), placing the subsequent fluvially dominated and undated Garet Dheb Formation into the Late Visean, not the Early Visean. Fluvial channels that are reported to have incised several tens of metres within this formation (Conrad 1985) correlate better with the Late Visean major regressive phase than with the relatively minor regression in the Early Visean. The long-lasting Visean hiatus proposed by Wendt *et al.* (2009) would, in this re-interpretation, underlie a Late Visean unconformity.

At least two higher-order cycles also occur in the Hassi Issendjel Formation of the southern Illizi Basin (Legrand-Blain 1985), but there is little detailed information available on this section. In the western Libyan outcrops, the Marar Formation shows three well developed Visean sequences, the upper two starting with incised fluvial channels at the base that grade upwards into shelf sandstones and shale (sequences LC1, LC2 and LC3 of Fröhlich *et al.* in press; biostratigraphic data mainly based on Massa & Vachard 1979 and Massa 1988).

Latest Visean to Serpukhovian transgression

In all of the reviewed sections the start of the regionally widespread carbonate deposition above the Late Visean clastics was proposed to occur in the latest Visean. In the west (the Anti-Atlas and the Bechar, Reggane and Ahnet Basins), deposition of the carbonate-rich interval continued throughout the Serpukhovian, while siliciclastics remained important in the SE (the Murzuk, Ghadames and southern Illizi Basins).

In the Anti-Atlas (Jebel Ouarkziz section) the uppermost Visean to Serpukhovian forms a well-expressed cyclic succession of shallow marine limestones, siltstones and sandstones with an overall long-term transgressive trend from lagoonal to open-shelf carbonates and a gradual disappearance of intercalated siliciclastics (Fig. 4). Similar cyclic Serpukhovian strata are recorded from the Bechar, Reggane and Ahnet Basin sections (Fig. 2). In the Libyan outcrops, oolitic and stromatolitic limestones (Collenia Beds) are part of these Serpukhovian mixed depositional systems. It appears that relative sea-level during the latest Visean and Serpukhovian rose gently, punctuated by many high-order fluctuations.

It must be noted that biostratigraphic dating in this interval is very controversial. In the Ahnet Basin, Wendt *et al.* (2009) proposed that the carbonates of the Jebel Berga Formation date entirely to the Bashkirian based on conodont data, yet foraminifera suggest a Late Visean to Serpukhovian age (Conrad 1985; Wendt *et al.* 2009). We follow the foraminifera dating since most of the other Algerian and Libyan sections were also dated using foraminifera.

Early Bashkirian regression

It appears that the gently rising Serpukhovian sea-level fell abruptly around the Serpukhovian–Bashkirian boundary, around which time a marked regression is observed that terminated the shelf carbonate deposition in the Anti-Atlas, the Reggane Basin and the Ahnet Basin. In these areas, the Bashkirian commenced with deposition of continental sandstones, marginal-marine gypsum deposits and dolomites as well as lacustrine carbonates. In the Bechar Basin, sea-level fall exposed the carbonate platform and a palaeokarst surface developed, into which sandstone-filled channels up to 150 m deep were cut (Lemosquet & Pareyn 1985). This major regression is less evident in the Libyan sections, where shelf carbonate deposition continued into the Bashkirian. Clearly, the palaeogeography and facies patterns across North Africa became more complicated across the Saharan Platform during the Bashkirian, suggesting that Variscan tectonics began

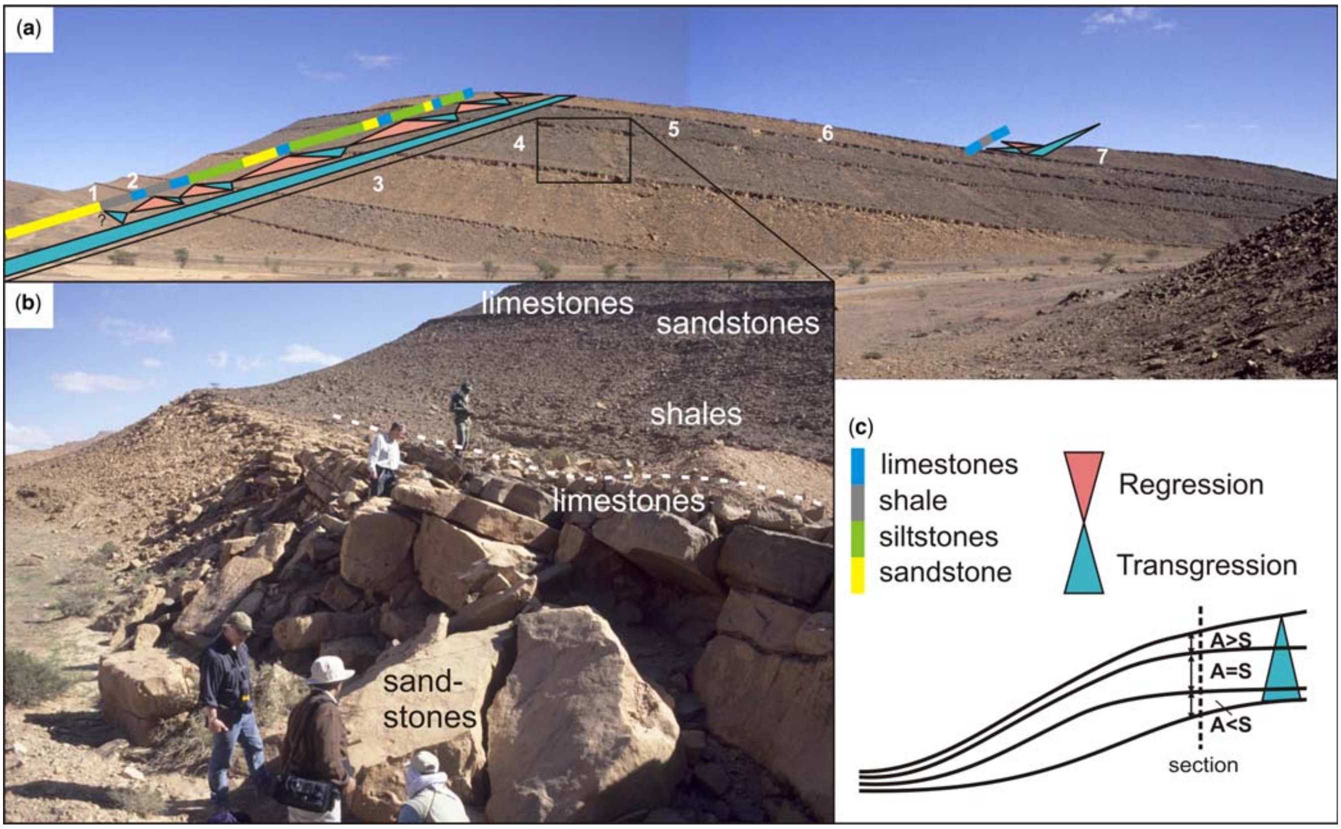

Fig. 4. (**a**) Serpukhovian transgressive succession of the SW Anti-Atlas (Ouarkziz Formation south of Assa) consisting of several higher-order transgressive limestone–regressive shale, siltstone, sandstone cycles (numbered 1–7). Note the overall transgressive sequence that is expressed in the upward decrease of terrigenous supply and increase of carbonate deposition as well as in the cyclical thin (cycles 1 and 2) to thick (cycles 2 and 3) to thin (cycles 4–7) stacking pattern. The section continues above the last crest with at least the same thickness of carbonate-dominated cycles. (**b**) Close-up view of cycle 4. (**c**) Legend and sketch to illustrate the interpretation of the stacking pattern as an upward passage through changing accommodation to sediment supply ratios (A/S) due to transgression (cycles 1 and 2, near-shore A < S; cycles 2 and 3, mid-shelf A = S; cycles 4–7, offshore A > S).

to destabilize the platform more effectively than the subtle tectonic movements that had prevailed since the Middle Devonian.

Late Carboniferous

Following the major end-Early Carboniferous regression, the Late Carboniferous sections vary across the region. Whilst in the Anti-Atlas (Tindouf Basin) and the Reggane and the Ahnet Basins, continental sandstones, mudstones and gypsum were deposited during the Late Carboniferous, carbonate deposition continued in the Bechar Basin, the southern Illizi Basin, and the Libyan basins during the early Late Carboniferous (Bashkirian to Moscovian). In the latter regions, continental red beds were deposited during the late Late Carboniferous (middle Moscovian to Gzhelian; middle Westphalian to Stephanian), although the full extent of their deposition is unclear, since the Hercynian Unconformity cuts down through the area. Upper Carboniferous cycles are difficult to constrain in terms of their sedimentology and biostratigraphy from the literature descriptions and are likely only to be valid locally.

Comparison of North African and global transgressive–regressive cycles

Four Early Carboniferous second-order transgressive–regressive (T/R) cycles are recognized in North Africa, which is the same as the number of cycles shown on the global scheme (Davydov *et al.* 2004; Fig. 3). Three out of nine North African hemi-cycle boundaries (maximum regressions and maximum transgressions) differ in age from the global scheme. Of the remaining six boundaries, four show a good correlation with the global scheme, but two are biostratigraphically too poorly constrained to allow a comparison. An additional Mid Visean cycle in North Africa is at present speculative.

The first Early Carboniferous cycle of North Africa, comprising the Devonian–Carboniferous boundary maximum regression, the Early Tournaisian transgression and the Late Tournaisian regression, compares well with the global T/R cycle Tm1 of Davydov *et al.* (2004) (Fig. 3). A fundamental difference between the schemes, however, exists in the preceding latest Devonian cycle. On global T/R schemes, the latest Devonian is considered to be transgressive (Johnson *et al.* 1985) and the following regressive phase is thought to fall entirely into the earliest Tournaisian. Yet, in North Africa, a wealth of biostratigraphic data suggest a latest Devonian ('Strunian') regression, succeeded by an Early Tournaisian transgression.

The interpreted second and third Early Carboniferous T/R cycles fit well with those of the global scheme (Tm2, Vis1; Fig. 3), although the Late Visean maximum regression appears to be younger in North Africa, constrained mainly by the age of the overlying transgressive limestones.

The fourth identified cycle, comprising the latest Visean and Serpukhovian transgression and the regression at the Serpukhovian–Bashkirian boundary, corresponds approximately to the global T/R cycle Vis2.

Although Early Hercynian tectonic activity is known to have started during the Middle Devonian and continued throughout the Late Devonian and Carboniferous in North Africa, the close match of North African and global T/R cycles suggests that Early Carboniferous sedimentary sequences were mainly controlled by eustatic sea-level fluctuations rather than tectonics. In contrast, the Late Carboniferous sequence ages, architectures and depositional systems are likely to have been controlled predominantly by regional to local tectonics and climate changes; however, the increasingly continental nature of the depositional environment means that research to date has struggled to constrain these sequences, making any conclusion regarding controls somewhat tentative.

Potential stratigraphic trapping types

Four potential stratigraphic trapping mechanisms are recognized within the Carboniferous interval. Two of the four stratigraphic trap types (truncation traps and depositional pinchout traps, Fig. 5) are controlled by the topography of palaeohighs and basins during the Carboniferous. Many of these highs are old structures that already influenced sediment distribution during the Early Palaeozoic. The structures were re-activated during the Middle to Late Devonian, and subsequently the syn-depositional relief became more and more pronounced until Hercynian uplift and peneplanation, especially in the northern basins (e.g. Bechar Basin; Malti *et al.* 2008). The other two potential trapping types are more related to depositional architecture (incised valleys, carbonate buildups, Fig. 5).

Truncation traps

Truncation, and subsequent onlap by a sealing lithology, is a proven trapping mechanism in Algeria. In several places the 'Strunian'–Tournaisian sandstones have been eroded on palaeohighs (e.g. the western Meharez High flanking the Bechar Basin, the Timimoun Basin margins and the Tihemboka Arch separating the Illizi Basin from the Ghadames Basin) either shortly after deposition (within-sequence) or later by the Hercynian Unconformity. Top-seals are either Visean shales or Triassic–Liassic shales and evaporites. The bottom-seal is provided by the Frasnian–Famennian shales. Risk of top-seal failure occurs in the case of within-sequence truncation, since laterally continuous sandstones of the following transgression may overlie the unconformity and trapping may therefore rely on sealing faults. However, the fault offsets required to give seals may only be small, since the thicknesses of the stacked transgressive sandstones are expected to be limited due to high-amplitude Carboniferous sea-level fluctuations.

Depositional pinchout of lowstand wedges on palaeohigh flanks

This stratigraphic trapping concept is probably the least-known and least-documented type in North Africa. It is similar to the truncation trap and may have been misinterpreted as such in some cases, but differs in the genetic sense and the predicted reservoir facies.

Topographic relief on the Saharan Platform influenced the facies patterns in all depositional environments, including outer shelf settings. This is well documented in the Middle to Upper Devonian carbonate facies (e.g. Wendt *et al.* 2006). In distal mid-shelf to outer-shelf dominated settings, siliciclastic supply into the basin either directly bypassed the highs or was subsequently removed by bottom-currents or storm reworking. This led to the deposition of only thinly bedded, rippled sandstones and siltstones on the highs and thickly bedded storm-induced siliciclastic turbidites and distal storm beds in the adjacent basin.

An example of this sediment partitioning is found in the 'Strunian'–Tournaisian of the Maider and Tafilalt Basins (Morocco), which are separated by a regional palaeohigh. In the centre of the Maider Basin, sandstones with large flute-marks

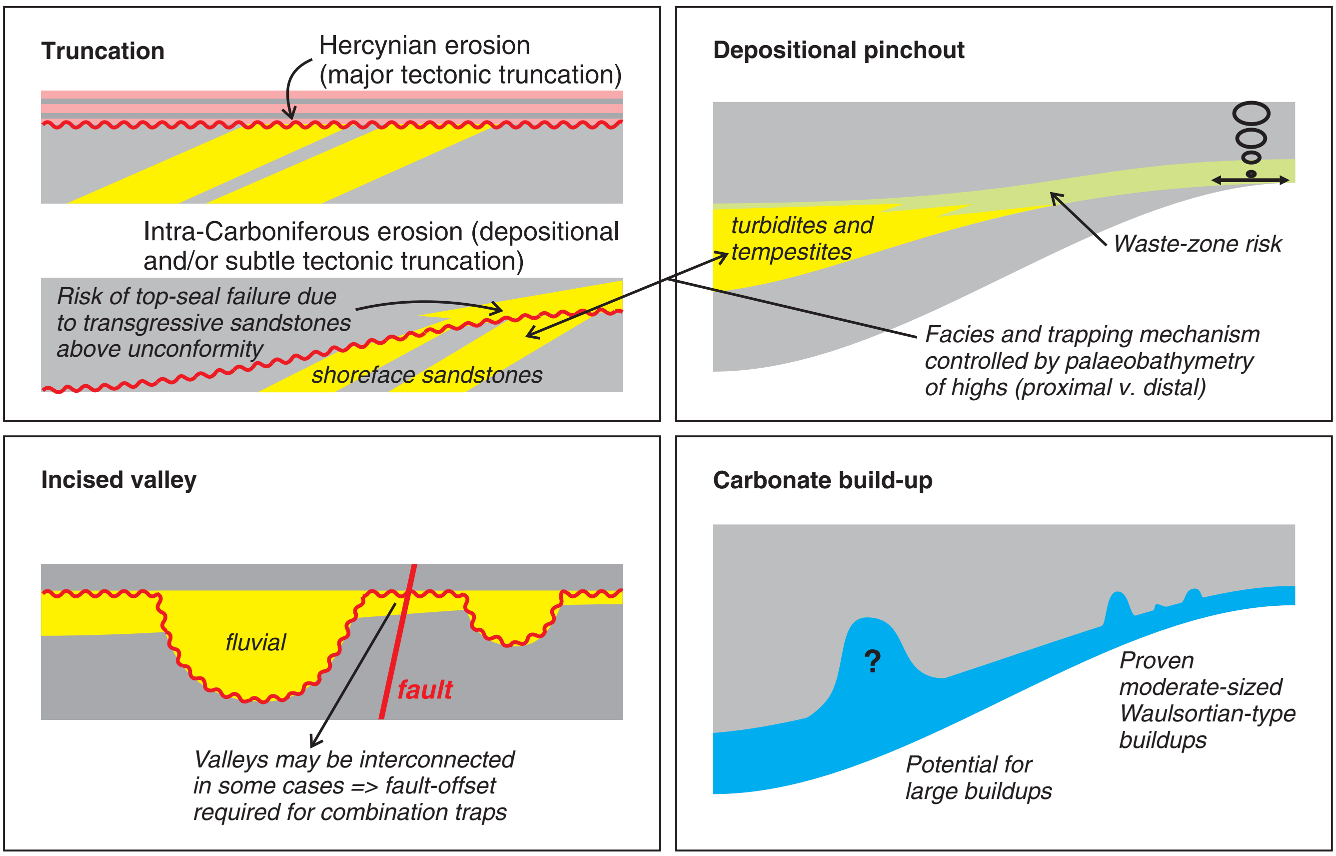

Fig. 5. The four main stratigraphic trapping types recognized in Carboniferous plays in North Africa. See text for explanations.

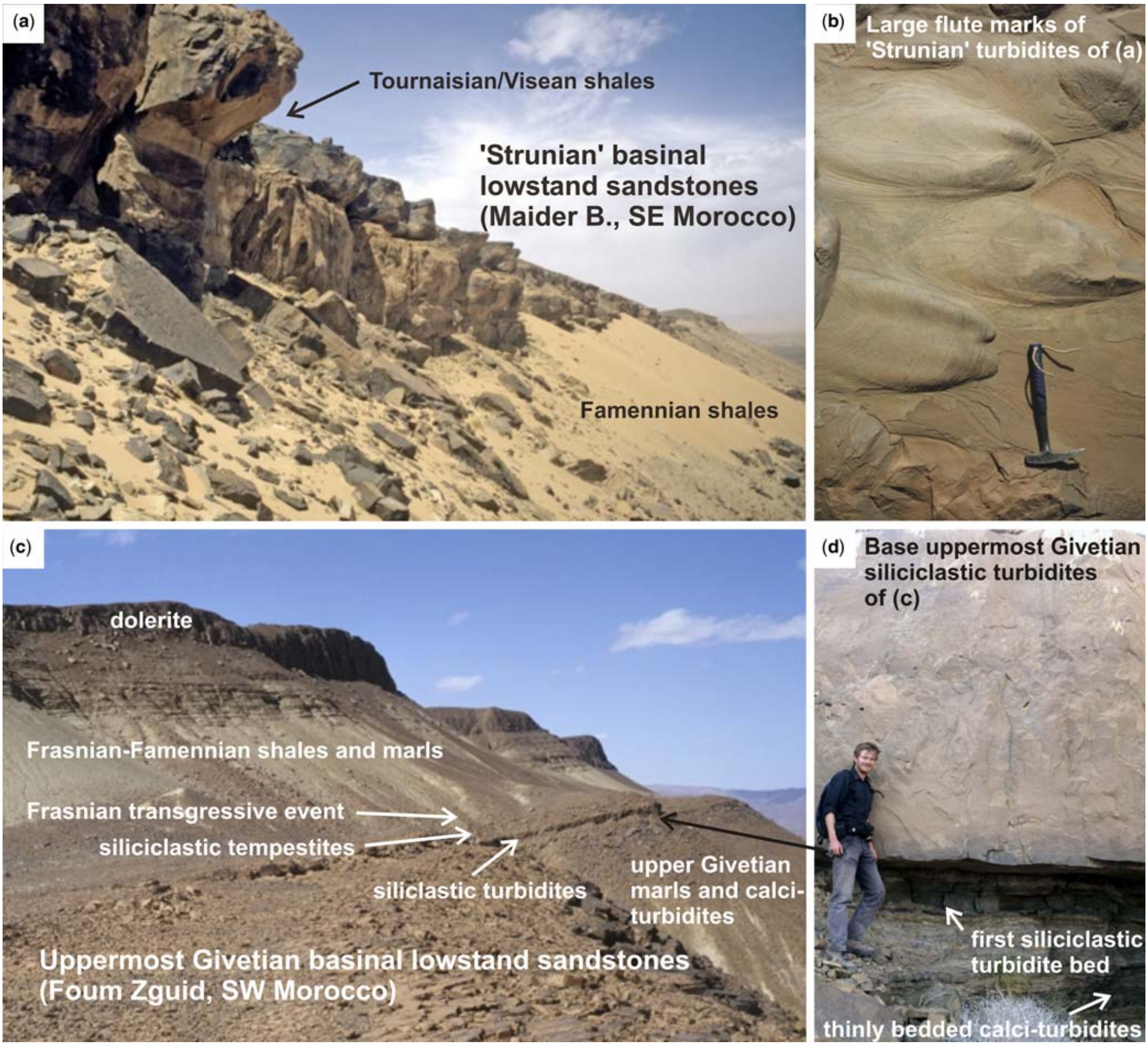

Fig. 6. Examples of basin-centred, distal lowstand sandstones that pinch out towards adjacent palaeo-structures thus forming potential pinchout traps on their flanks. The sandstones form 5–8 m thick bodies consisting of massive siliciclastic turbidites that pass upwards into storm deposits. The first example is the uppermost Devonian ('Strunian') sandstone exposed in the Maider Basin of Morocco (**a**) exhibiting large flute marks (**b**); note that the flute marks are filled by cross-beds and that the turbidites start at the base with the Bouma–Tc sequence. The second example is from the uppermost Givetian of the NE Dra Plain (Morocco) (**c**, **d**), where the sandstone is sandwiched between upper Givetian marls to thinly bedded calci-turbidites and Frasnian 'black' shales. Both examples are from the Middle and Upper Devonian, but very similar basin-centred lowstand sandstones are expected to occur in the NW African Carboniferous basins.

(Fig. 6) sharply overlie upper Devonian (Famennian) dark-coloured shales and are interpreted as turbiditic lowstand wedges. The sandstones pinch out onto the Tafilalt ridge and re-appear in the Tafilalt Basin. Another example of these lowstand basin-centred sandstones is the uppermost Givetian Megsem–Medersam Sandstone at Foum Zguid (SW Morocco) (Fig. 6). This sandstone sharply overlies upper Givetian thinly bedded calciturbidites, and its lower 4 m are entirely structureless. In its upper part there is a transition to hummocky cross-stratification. The transitional contact with the overlying Frasnian dark shales (related to a base Frasnian transgressive event, and elsewhere a proven source rock interval) is characterized by levels enriched in large corals and wood fragments (Meyer-Berthaud *et al.* 2004).

For a pinchout trap to be effective, it requires rapid pinchout of reservoir facies against the high; change from reservoir to non-reservoir facies must ideally happen over a short distance to minimize the potential for a mixed-facies 'waste-zone'. Such clear separation of reservoir-quality lowstand wedge deposits from non-reservoir deposits on the palaeohigh may require reasonable palaeo-relief, and may therefore limit this trapping style to the northwestern and northern Saharan Platform basins with, for example, known elevated subsidence rates during the Famennian.

Incised valley-fills

Fluvial channels interpreted to occur within incised valleys have been reported from several outcrop localities and stratigraphic levels of the uppermost Devonian and lower Carboniferous; and occasionally also from subsurface data. Because of the predominantly mud-rich lithologies of under- and overlying strata, these incised valley-fills may have good trapping potential, unless they pass laterally into extensive shoreline successions.

'Strunian' to Tournaisian incised valleys

Fluvial sandstones of the 'Strunian' and Tournaisian have been described (e.g. the Khenig Formation of the Ahnet and Reggane Basins, Conrad 1985; the Tazout Formation of the SW Anti-Atlas, Vos 1977), but no examples of isolated incised systems have been found in the literature. In the SW Anti-Atlas, on the northern flank of the Tindouf Basin, coarse-grained delta plain deposits occurring in up to 55 m thick and 60 km wide belts, pass laterally into extensive shoreface deposits (Vos 1977). These belts may significantly increase net reservoir thickness in structural traps, but because of the juxtaposition to the extensive shoreface deposits, they have low stratigraphic trapping potential.

Visean incised valleys

Fluvial sandstones of Visean age are widespread in the Ahnet and Reggane Basins (Garet Dehb Formation) and channels cut down several tens of metres into the underlying strata. Two main channel systems have been logged, one in the lower and one in the upper part of the formation (Azzel Matti section, Fig. 2).

Similar delta distributary channels cutting into underlying strata also occur in the southern Illizi Basin outcrops ('Gres de Champinngons Superieur'). In the northern Murzuk Basin, the Marar Formation contains recently recognized incised valleys about 0.5–3 km wide and 15–50 m thick (this study).

Serpukhovian–Bashkirian incised valleys

A different stratigraphic trapping potential may exist in the Bechar Basin. A sea-level drop towards the end of the Serpukhovian exposed the carbonate platform of the Bechar Basin, and a palaeokarst surface developed, into which cut sandstone-filled channels up to 150 m deep (Lemosquet & Pareyn 1985).

According to these authors, the fluvial sandstones were derived from the SW (Arlal Land) from the area of the future Kenadza and Abadla 'coal basins' (Colombo & Bensalah 1991).

The channels are filled with coarse, plant-bearing sandstones and occasional conglomerates. Each channel-filling episode was followed by deposition of well stratified shales and limestones containing marine faunas. The cycle of incision, fluvial sandstone deposition and open marine carbonate sedimentation suggests high-amplitude sea-level fluctuations at this time.

Carbonate buildups (Waulsortian reefs)

Visean Waulsortian-type carbonate buildups are exposed along the margins of the larger Bechar Basin (the Meharez High to the east, the Ben Zireg and Jebel Antar outcrops to the north and the Tafilalt Basin to the west). On the Meharez High, the sponge-bryozoan mounds grew vertically during times of high relative sea-level. Growth terminated when the buildups were covered by crinoidal and oolitic limestones during falling sea-level and lowstand stages (Bourque *et al.* 1995).

In the Tafilalt, approximately 100 Visean carbonate mud mounds are exposed (Wendt *et al.* 2001). However, several of these have also been interpreted as channels, filled with calcarenitic and finer-grained material, and not representing true mud mounds (Klug *et al.* 2006).

On the Meharez High, the exposed buildups are 50 m (locally up to 120 m) high and 2–3 km broad (Bourque *et al.* 1995). It may well be that even larger buildups exist in the subsurface. The size distribution of the Devonian mud mounds shows that it is inadvisable only to consider the well known examples as analogues. Most of the famous Devonian mounds in Morocco and Algeria (Brachert *et al.* 1992; Kaufmann 1998; Wendt & Kaufmann 1998) are rather small (few metres to tens of metres high and wide), economically unattractive buildups, but the less well-known Middle Devonian reefal mounds of the Zemour in the SW Tindouf Basin (Dumestre & Illing 1967) show that buildups at this time were also capable of accumulating 80 m thick coral-stromatoporoid-rich limestones with good reservoir potential, with aerial extents of up to 2 km.

Conclusions

A preliminary sequence stratigraphic framework is presented for the Early Carboniferous of North Africa that shows a good correlation with published global sequences and eustatic sea-level curves. However, the relatively sparse sedimentological database available regionally, and the limited biostratigraphic control, further hampered by contradictory published biostratigraphic interpretations, emphasize the need for further work in the region to develop a more robust regional synthesis of the Carboniferous sequence development in North Africa.

Four types of potential stratigraphic traps are recognized (truncation traps, depositional pinchout traps, incised valley-fills and carbonate buildups). Of these, truncation plays have the highest potential as exploration targets. Depositional pinchout traps of basin-centred sands may have been overlooked in the past and offer a higher risk but potentially volumetrically significant target. These may be imaged on future high-quality 3D seismic. Such reservoirs are believed to be a particular feature of the middle to upper Palaeozoic succession, as the basins changed from low-relief intra-cratonic sag basins (Late Cambrian to Early Devonian) to ramps with locally steepened profiles (Middle Devonian to Carboniferous). High-amplitude sea-level falls in the Carboniferous provided a mechanism to deliver clastics into the distal parts of the basins and may even have led to detached lowstand accumulations (the latter being a hypothesis that is not yet confirmed). Incised valley-fills also provide opportunities for thickened and stratigraphically discrete reservoir sections, and require a detailed knowledge of the sequence stratigraphic framework for prediction.

This study was funded by the North Africa Research Group (University of Manchester) sponsored by Anadarko, BG Group, ConocoPhillips, Hess, Maersk, Oxy, Petro-Canada, PlusPetrol, RepsolYPF, RWE, Wintershall and Woodside.

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