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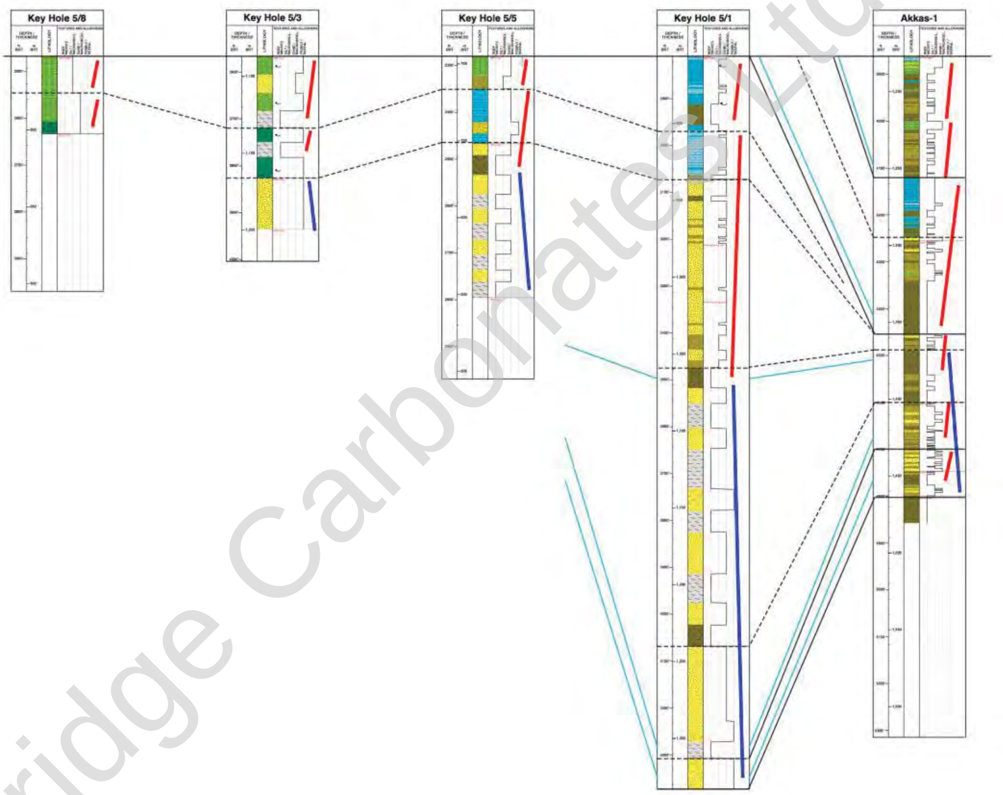

Regional Geology of the Western Desert of Iraq, Volume I: basin evolution

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Of importance in understanding the evolution of this basin system is its configuration in the InfraCambrian, of which little is known in detail because this interval is not penetrated by any wells. Gravity-magnetic data suggest that the Western Desert represents one of the few areas of Iraq that is thought to have any significant InfraCambrian deposition (Jassim, 2006c; Jassim and Buday, 2006a; Figure 5). These sediments were largely continental clastics and volcaniclastics in the main, western basin; but it is thought that salt deposition took place in the Nukhaib Basin to the SE (Jassim, 2006c). The orientation of this basin system was controlled by Precambrian structural geology, and this in turn, dicatated the orientation of later depocentres, such as that of the Permo-Carboniferous (AP5 megasequence)(see Figure 42 for example, and compare to Figure 3 and Figure 4).

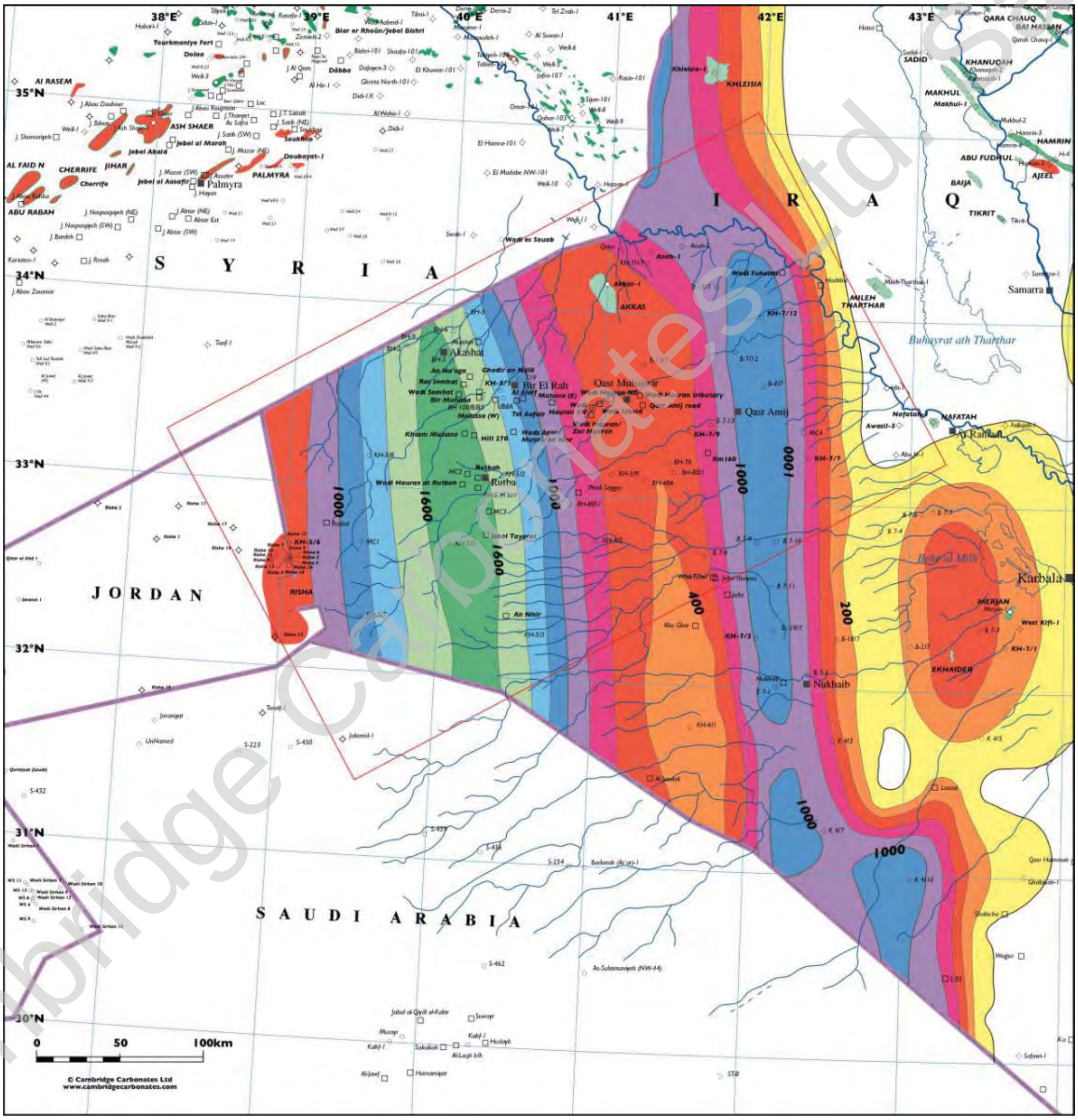


Figure 5 InfraCambrian isopach, derived from gravity magnetic data, from Jassim and Buday (2006a, their fig. 4 9A).

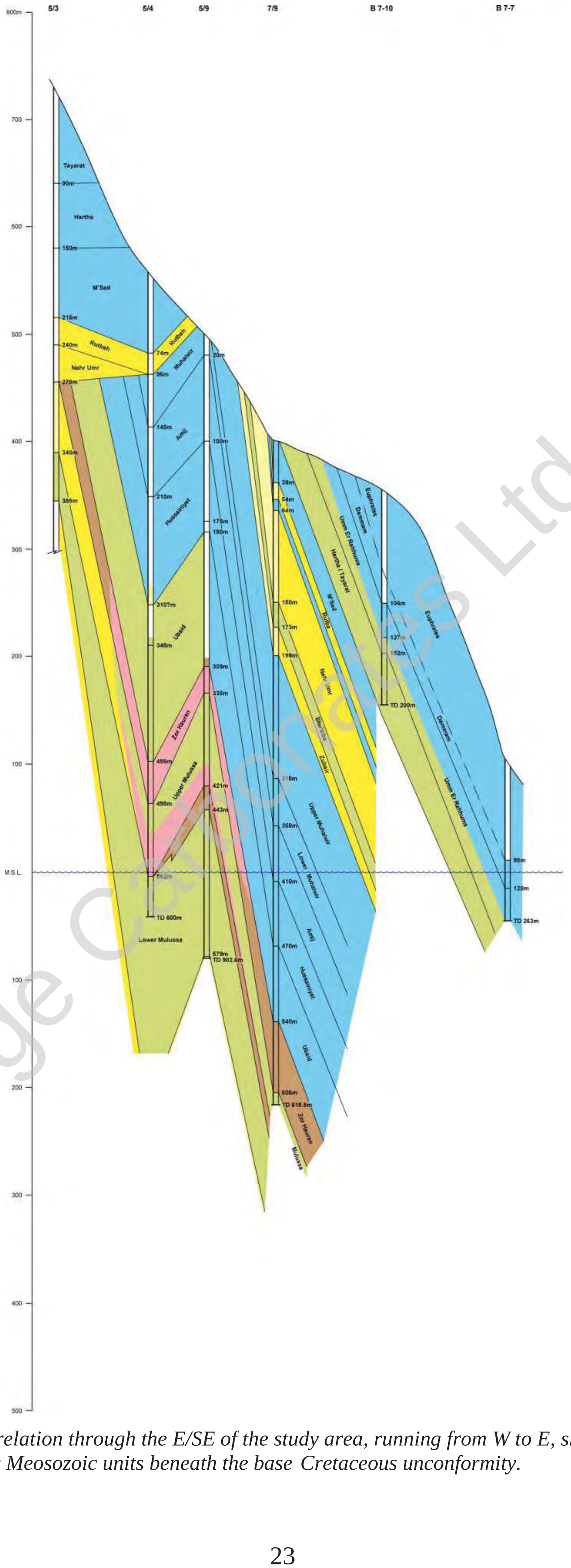


Figure 13 Dip correlation through the E/SE of the study area, running from W to E, showing notable truncation of older Meosozoic units beneath the base Cretaceous unconformity.

border (Figure 21). This is despite the top-Silurian Alna Formation in Risha-3, being only Wenlock/Ludlow in age (i.e. the Risha-3 stratigraphy is truncated/incomplete; Figure 21). Therefore, there is clearly major stratigraphic (depositional) thinning of the Silurian eastwards across the border into Iraq, regardless of later erosional effects. Across the Western Desert, the same interval is unbottomed in KH-5/1 such that a true thickness cannot be determined. In Akkas-1, the topmost Silurian, although eroded (contact at 1463m according to Al-Hadidy, 2007) whilst the most likely Wenlock/Llandovery transition is thought to be at about 1920m (corresponding to the double hot shales in the Risha area; Figure 22), making for approximately 460m of post-Llandovery stratigraphy in Akkas-1. As such within Iraq, the upper part of the Silurian actually thickens slightly eastwards and also shows stratigraphic condensation towards its top (Figure 21).

In terms of Devonian (Lower and Middle; uppermost AP3) stratigraphy in the Western Desert area of Iraq, perhaps the most significant control point for this unconformity is the Key Hole 5/6 well. Here Lochkovian (Gedinnian) age strata (lowermost Devonian) are preserved between 590 and 670m according to our interpretation of data in Al-Haba et al. (1994), Jassim (2006c) nd Al-Hadidy (2007) (see summary log). The stratigraphy is figured in a crude log (Figure 24) and is referred to in Al-Ameri et al. (1990,1991), but the accuracy of the log data is doubtful and it was found better to trust the written descriptions and thickneses when calculating picks. Description of this Lower Devonian interval is not to be found in Al-Ameri (2000) or Al-Ameri and Baban (2002); both instead place an “Upper Devonian” unit directly above the Pridoli. Neither was Gedinnian stratigraphy recognised by Al-Hadidy (2007). The lack of discussion of the apparent absence of this previously documented Lower Devonian stratigraphy in later publications is difficult to explain; it is possible that the original work was based on poor sampling and that re-definition of samples resulted in the older ages now presented. Unfortuately these revisions intentional or not, were not discussed and their origin is unclear: the Al-Ameri et al. 1991 paper is never mentioned in later publications, although results of the 1991 tudy are supported by comments in both Al-Haba et al. (1994) and Jassim (2006c) also supports the presence of Lower Devonian in KH-5/6. Regardless of the presence or absence of earliest Devonian in KH-5/6, the well penetrates a complete Silurian stratigraphy, and can therefore be compared to the Risha wells to the west (cited in Andrews et al., 1991).

The presence of some Devonian in the Iraqi stratigraphy of the border areas is supported by data in nearby Saudi Arabia, where the Jalamid-1 well prove a Middle Devonian age unit, the Jubah Formation, on the basis of palynology (Al-Ajmi, 2005). A synonymous formation (Sakaka Formation of Middle-Late Devonian age) is also present and widespread in areas of NW Saudi Arabia and is 215m thick in the Jauf area (Sharief and Moshrif, 1989). In Jalamid-1 a relatively complete succession was found of Jubah, Jauf and Tawil formations of Middle to Early Devonian age (Al-Ajmi, 2005). Generally in the stratigraphy of the Iraq-Saudi border area (Figure 25), about 200-300m is attributed to the Jubah/Sakaka Formations (of Middle-Late Devonian to possibly earliest Tournaisian age), about 150m to the Jauf Formation of Early-Middle Devonian age, and about 200m to the Tawil Formation of Early Devonian (Lochkovian/Pragian)-latest Silurian (Pridoli or even Ludlow) age (Al-

Unayzah Formation" occurrence is Middle Devonian in age and it is overlain by Upper Carboniferous/Lower Permian age Unayzah formation (Al-Laboun, 1986, his fig. 9); whilst in the nearby S-462 well, the equivalent Jubah Formation is of Frasnian age at its top, but is directly overlain by Wasia Formation (of Cretaceous age) (Loboziak, 2000). Therefore, there appears to be a hiatus with the absence of late Tournaisian and Viséan biozones VP, PO and OA in the border area with Iraq (Clayton et a., 2000; Al-Hajri and Owens, 2000). As such by the absence of 'lower' AP4 the Saudi stratigraphy contrasts strongly with that in Iraq. This makes it difficult to compare evolution of processes on unconformities of this age in the two countries.

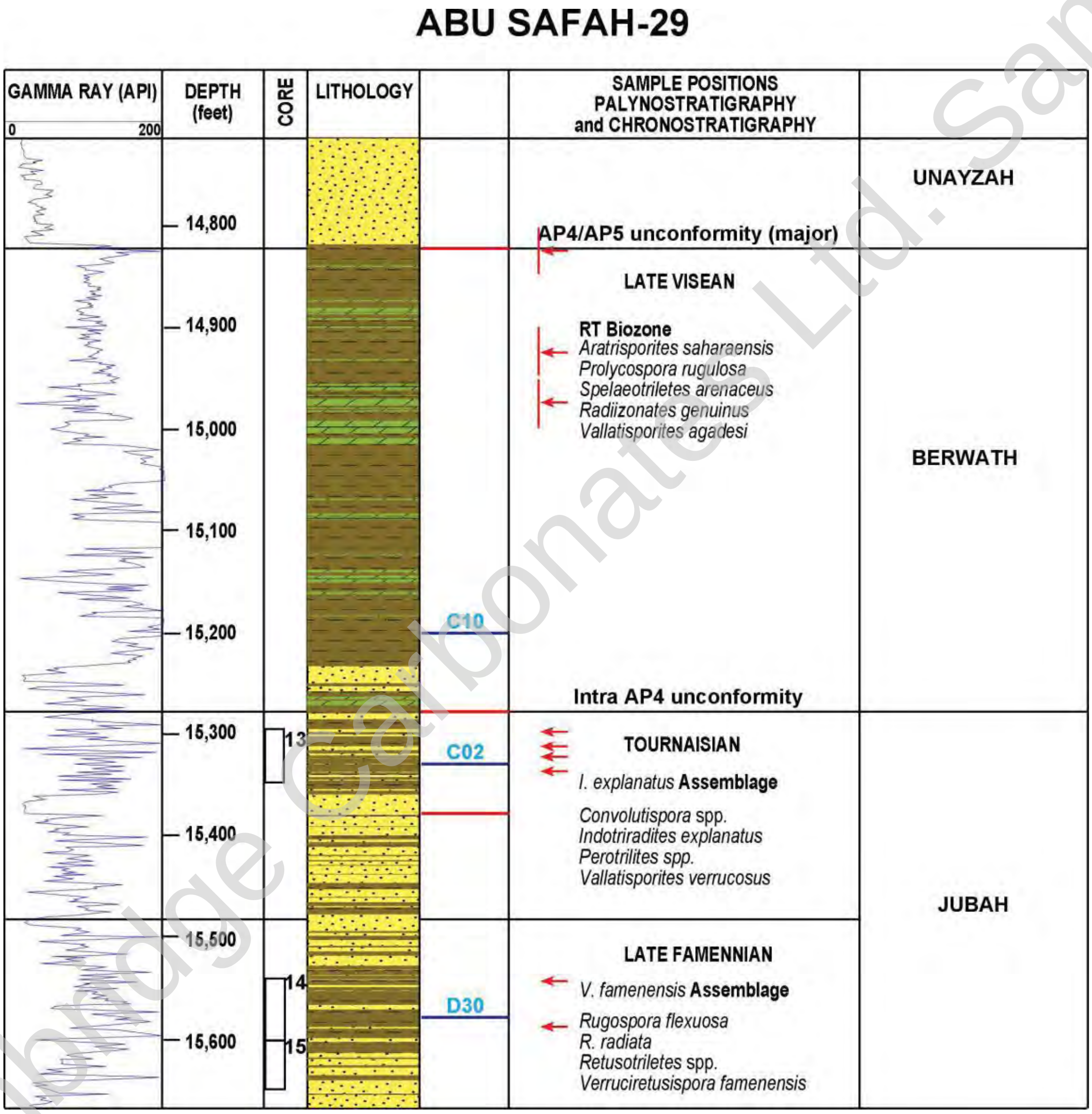


Figure 29 Stratigraphy of the Abu Safah 29 well. The significance of this well is that it demonstrates the presence of a major intra Viséan unconformity, where Berwath Formation sits upon Jubah Formation. CC figure after Clayton et al. (2000).

Description of Unconformity In the Western Desert, Tournaisian CM zone carbonates are demonstrably absent (at 855m) in KH-5/1 (Figure 31) (and presumably in the rest of the Western Desert by correlation) since the Raha Formation which is most probably Tournaisian CM zone at its very base, sits sharply and most probably unconformably on top of the PC zone carbonates of sequence C04. The stratigraphy

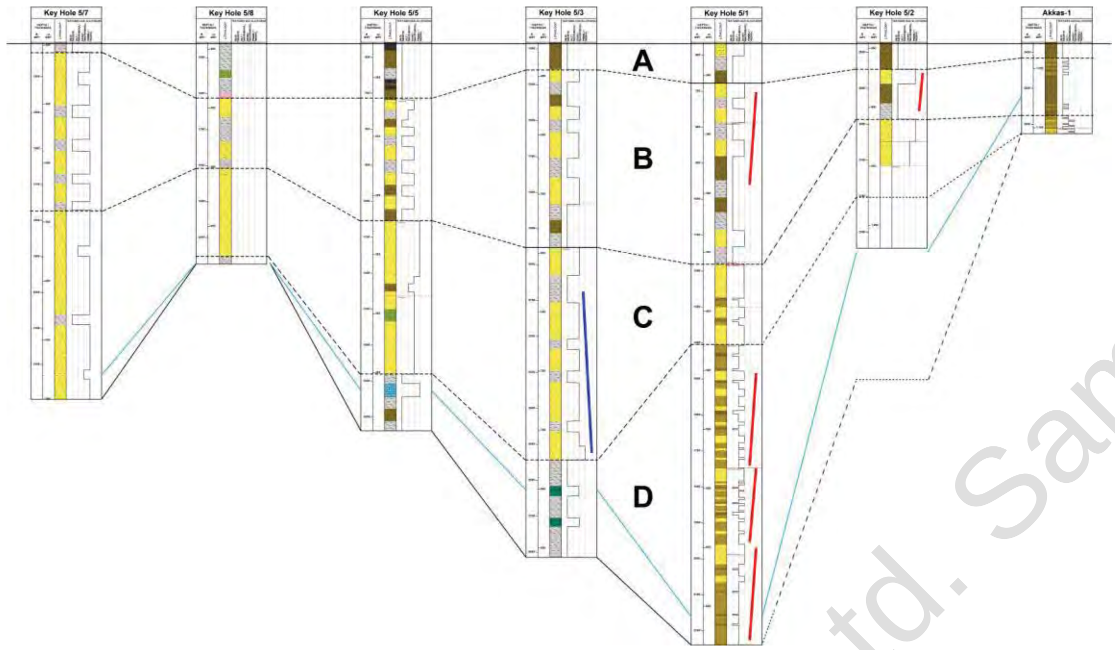


Figure 36 Correlation of lowermost Ga'ara Formation (latest Westphalian earliest Permian) stratigraphy in the Key Hole Wells and Akkas 1. Blue line within Unit D is th C30 MFS, dashed lines are lithostratigraphic correlation lines. A: upper lacustrine member (dated as Early Permian), B: meandering fluvial member (probably Stephanian); C: deltaic sa dstones (probably Stephanian); D: basal marine clastics and thin carbonates (probably Westphalian D'). Note that Akkas 1 would appear to prove a more shaly and condensed facies than noted in the Key Hole Wells and the facies divisions cannot be carried through to this well with any co fidence. Facies in the west are generally sandier than facies in the east. CC figure reformatted after various data sources, mostly Kaddouri (1992) and Al Hadidy (2007).

Further evidence for relative conformity of deposition and lack of significant erosion specifically in Western Iraq on the top-AP4 surface, is that immediately younger (later Carboniferous and Lower Middle Permian) sediments of AP5 are best-developed in the whole country, in a successor basin that shows optimum development in the same are (Jassim 2006c; Figure 42). Thus, it is the margins of the AP5 basin that show most uplift and erosion at the end of AP4.

by a coarser-grained member, as noted in Al-Laboun (1986, fig. 13); these are subdivided into the Unayzah B and C sandstones of Figure 46. Widespread siltstone of Unayzah A (Figure 46) may be the equivalent of the lacustrine interval in the Western Desert that was noted by Al-Hadidy (2007). Uppermost Unayzah sandstone (A) are probably equivalent to the P10 sequence massive braided sandstones of Al-Hadidy (2007). Uppermost beds of the Unayzah are more carbonate-dominated and silty, in common with the Ga'ara Formation of Iraq; they are a transitional facies up into the overlying Khuff Formation (Figure 48).

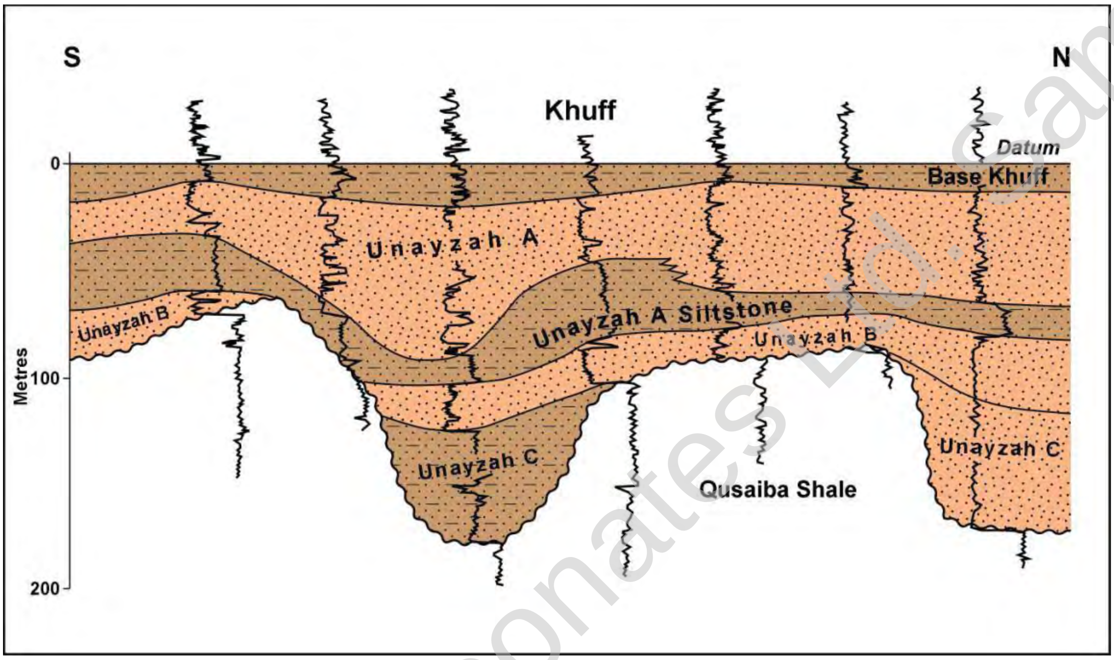


Figure 46 Correlation of Unayzah Formation sandbodies draping the pre Unayzah Unconformity. Cambridge Carbonates figure after Al Labo n (1986).

In Syria, rocks of this age appear to be absent in the Swab-1 borehole (Best et al., 1993). In Tanf-1, they re present (as the Amanus Formation) (Best et al., 1993). These data points therefore appear somewhat inconsistent with the isopach trends in Jassim (2006c) which suggest a deep basin to be developing within Syria (Figure 42); instead according to our data, the east of the Hamad (Tanf-Swab) Uplift may have positive at this time Similarly, Al-Bassam et al. (2000) figures that Cretaceous sits unconformably above Devonian (Jubah Formation?) in the Jalamid-1 well in NW Saudi Arabia immediately south of the KH-5/7 location, indicating perhaps the continuation of non-deposition or erosion in the Risha area of Jordan towards the south (Figure 42).

Dunnington et al., 1959). The unconformity is therefore likely to show a westward increase in magnitude.

Northwards into Syria, Triassic rocks are completely absent in Tanf-1 and Swab-1 over the Hamad Uplift, where they are cut out beneath the M'sad Formation equivalent stratigraphy (Judea Limestone)(Best et al., 1993). They are also absent in the Akkas-1 well on the flanks of the Anah Graben within Iraq, where Lower Permian rocks are overlain by the Tayarat Limestone of Maastrichtian age (Al-Hadidy, 2007; Figure 30). Erosion in these cases is thus likely to be a Cretaceous event, rather than intra-Jurassic.

In Saudi Arabia, the Al-Jawf Graben within the Nafud Basin contains remnants of Jurasic and Triassic stratigraphy (Aoudeh and Al-Hajri, 1995). These remnants suggest (although they cannot prove definitively) that there was little intra-Triassic/Jurassic erosion in this area prior to development of the pre-Wasia Unconformity surface during the Albian-Cenomanian.

Degree of Erosion Erosion clearly increases in magnitude locally to the west. There is loss of the Liassic stratigraphy in the order of 134m in eastern Jordan on this or subsequent surfaces (the likely thickness of this unit where it appears to have been locally preserved nearby in KH-5/6; from drilled depths 276 down to 410m).

3.7. TOP-JURASSIC UNCONFORMITY (TOP-AP7)

Pre-Unconformity Stratigraphy Rocks of this age in the Western Desert are best developed in the deeper KH-7 series wells in the east of the study area. The stratigraphy reaches a thickness of at least 263m in KH-7/12, whilst 159m is established in the KH-7/9 well and over 135m in KH-7/7 (Radoicic, 1981). Some of this stratigraphy is present further west, but it is much thinner due to condensation and onlap onto the top-AP6 high (47m in KH-5/4 and only 20m at spud and the very top hole of KH-5/9); derived from data in Kaddouri 1992 and Jassim and Buday, 2006d.

In Syria, rocks of AP7 megasequence are absent in both the Tanf-1 and Swab-1 boreholes (Best et al., 1993); this is also the case for the Akkas-1 borehole within Iraq (Figure 30) and in Saudi Arabia, where in the Jalamid-1 well no Jurassic is preserved (Al-Bassam et al., 2000), nor in the outcrop belt where the Upper Cretaceous Aruma Formation rests directly upon older Mesozoic units (Al-Laboun, 1986).

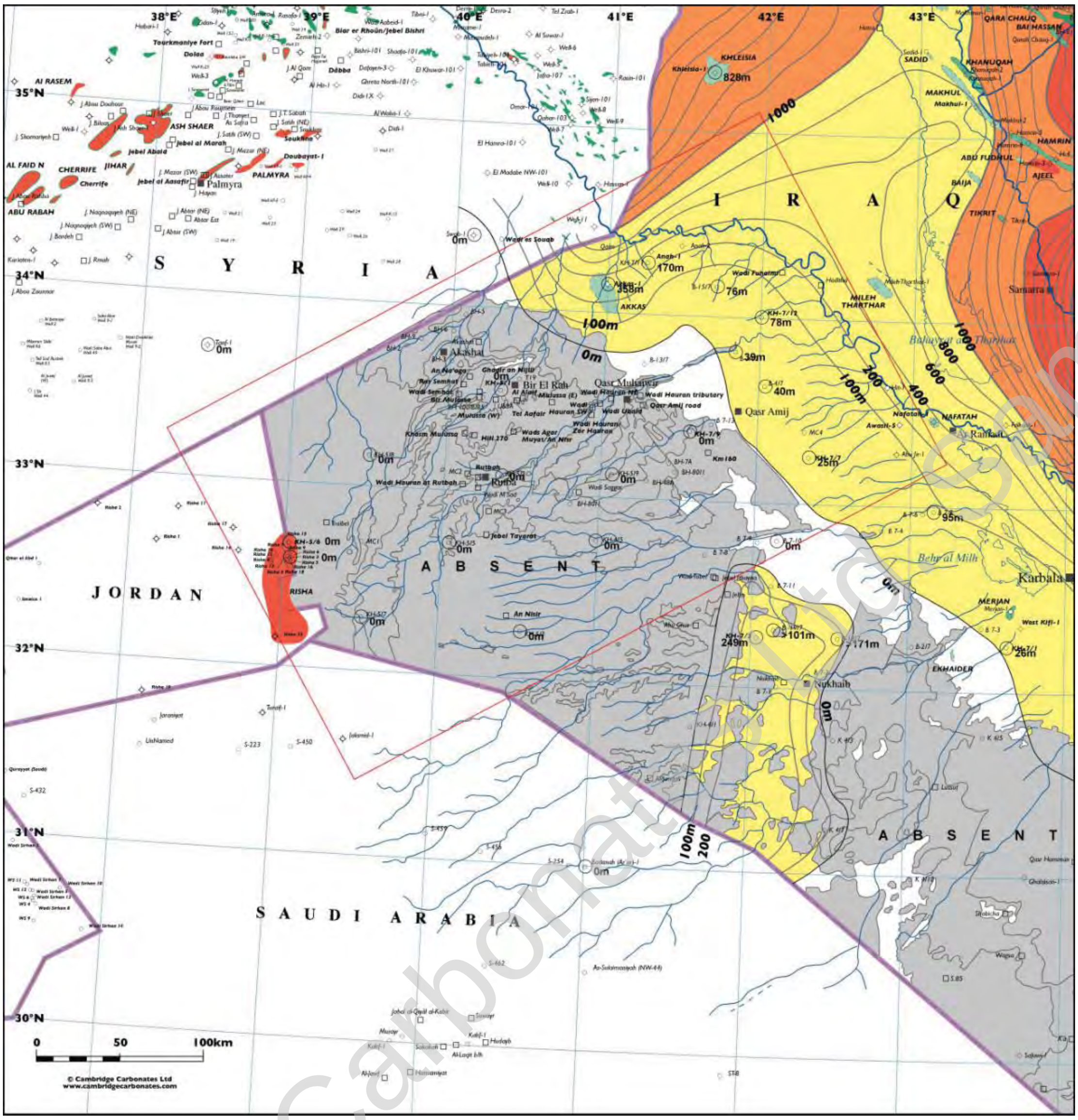


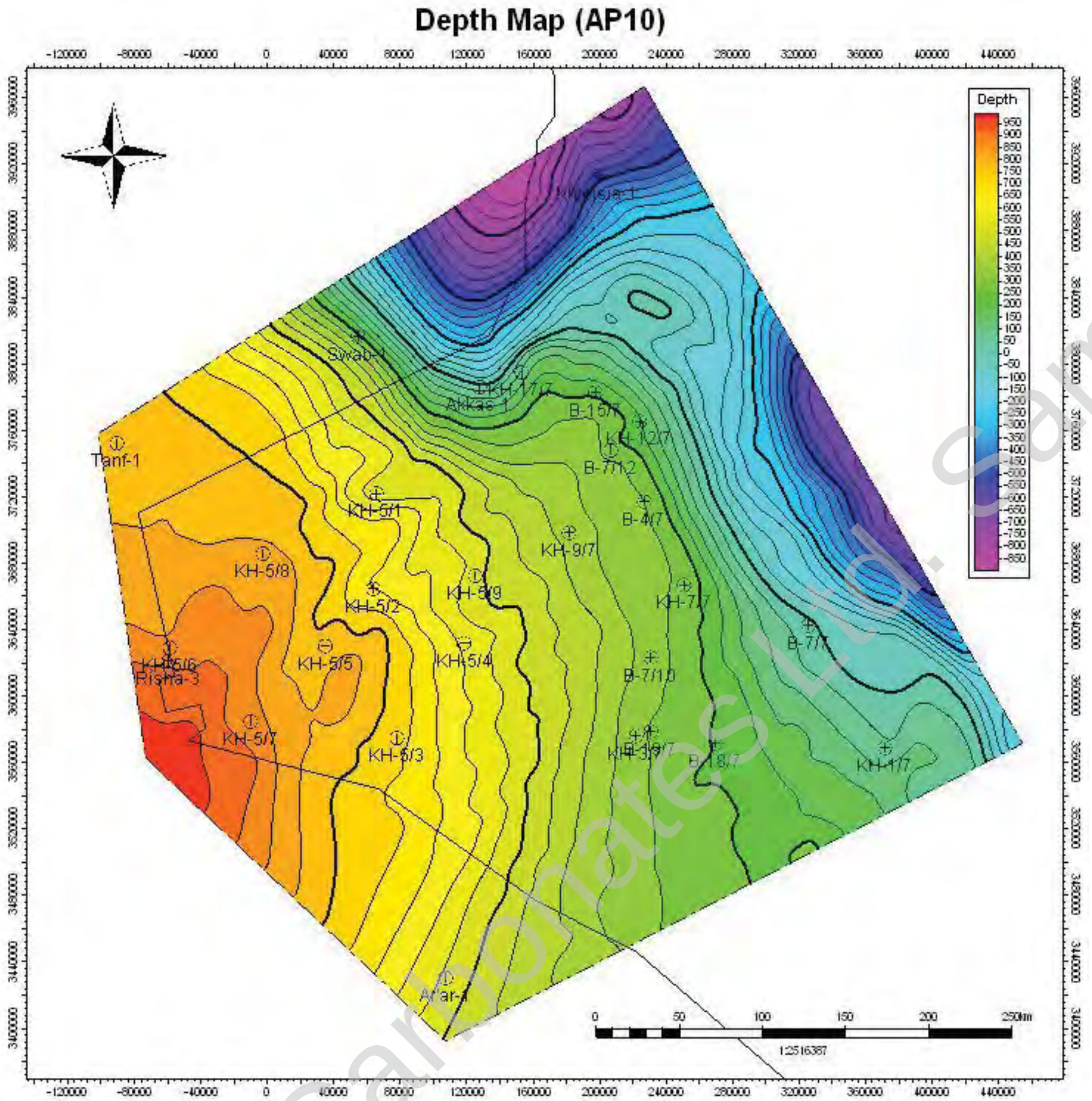
Figure 57 Isopach of Oligocene Recent (Megasequence AP11) in western Iraq. Cambridge Carbonates figure after Jassim and Buday (2006h).

Description of Unconformity Overlying Lower Neogene rocks of the Euphrates, Jeribe and Lower Fars formations show a general SW onlap onto the Eo-Oligocene and then offlap to the NE, on the NE flank of the study area.

Degree of Erosion If the Oligocene is eroded, this does not require a major change in relative sea-level; a drop of 50m would be sufficient to remove much of the unit where it was once present. Its localised loss SW of Abu Jir however, is suggestive of a structural uplift that may have resulted in a greater loss of stratigraphy than just the Oligocene.

3.12. INTRA-MIOCENE UNCONFORMITY (INTRA-AP11)

Pre-Unconformity Stratigraphy Rocks of Early Neogene age (usually the Euphrates Formation) are generally thin, with the thickest reported section being in the northeast, in KH-7/17 with 170m, but with under 100m in other wells in the east of the study area (B-7/12, B-7/4, KH-7/12, B-7/15, KH-7/7, B-7/7, KH-7/1).



Map 2: Top-AP10 (top Dammam) in depth

In this map the most positive feature is the Risha area. A structural nose trends to the NE (Khleisia High). Otherwise, dips are steady down to the east in to the Mesopotamian Basin or into the Euphrates basin towards the north.