GeoArabia, Vol. 11, No. 4, 2006
Gulf PetroLink, Bahrain

Permian Arabian Tectono-Stratigraphy Chart

Moujahed Al-Husseini

The enclosed *Permian Arabian Tectono-Stratigraphy Chart* presents a tentative regional correlation of the Permian and encompassing rock units (formations, members, units, subunits, and depositional sequences and cycles) in the Arabian Plate. The chart is calibrated to the approved International Commission on Stratigraphy (ICS) Geological Time Scale GTS 2004 (Gradstein et al., 2004) using a combination of biostratigraphic age dating and sequence stratigraphic interpretations of many rock units and surfaces. In GTS 2004, the Permian Period is divided into three formal epochs: (1) Russian Cisuralian (hereafter early Permian); (2) North American Guadalupian (hereafter middle Permian), and (3) Chinese Lopingian (hereafter late Permian).

The chart is also calibrated by the orbital second-order sequence stratigraphic framework AROS 2005 (Arabian Orbital Stratigraphy; Al-Husseini and Matthews, 2005a). In particular, for the Permian Period, the AROS calibration is from Oman (Al-Husseini and Matthews, 2005b), both in the subsurface (Osterloff et al., 2004a, b) and in Al-Haushi-Huqf outcrops (Angiolini et al., 2004, 2006). In the AROS model, for the Pennsylvanian Epoch (hereafter late Carboniferous), Permian Period and early Triassic Epoch, five second-order sequence boundaries (denoted SB^2 17 to SB^2 21) are interpreted to bound four second-order depositional sequences (denoted DS^2 18 to DS^2 21). Each DS^2 N is interpreted to have lasted c. 14.58 million years (My) and to consist of no more than six third-order depositional sequences (denoted from oldest to youngest as DS^3 N.1 to DS^3 N.6), each lasting 2.43 ± .405 My (i.e. 2.025, 2.43 or 2.835 My). Moreover, five third-order sequence boundaries (denoted SB^3 N.2 to SB^3 N.6) are predicted to occur within each DS^2 N.

The correlation starts in the late Carboniferous period following the pre-Unayzah hiatus. The pre-Unayzah hiatus was determined to occupy – at its briefest duration – the Carboniferous Serpukhovian, Bashkirian and early Moscovian stages (J. Filatoff *in* Al-Husseini, 2004). Because the age of the hiatus straddles the Mississippian (hereafter early Carboniferous) and late Carboniferous epochs, its age is here simplified by informal reference to a middle Carboniferous time. The correlation chart ends in the early Triassic after second-order sequence boundary SB^2 17. The chart is based on the correlation of numerous regional isochronous second and third-order sequence boundaries and glacio-eustatic depositional sequences that are briefly discussed below.

In the chart the terms "formation, member, unit, subunit, sequence, cycle", etc. are capitalized; however in this text they are shown within quotation marks (as per the author's nomenclature) so as not to imply a particular status for any rock units. The qualifiers "late, upper, middle, early, and lower" for the stages and epochs are not capitalized throughout the text. The names of the stages are written in full in the text but abbreviated by three letters in the chart.

Pre-Unayzah Unconformity, "middle" Carboniferous

The "pre-Unayzah unconformity" (so called "Hercynian unconformity", e.g. Wender et al., 1998) is manifested across the entire Arabian Plate by an angular unconformity below the subsurface "Unayzah Formation" and outcropping "Wajid Formation" in Saudi Arabia (Kellogg et al., 1986; Evans et al., 1991), "Al Khlata Formation" in Oman (Osterloff et al., 2004a), and elsewhere by other upper Carboniferous and lower Permian clastic units (Al-Laboun, 1988).

The plate tectonic interpretation of the pre-Unayzah unconformity is not fully understood. One interpretation is that this event represents the crustal response (in regional compression) to the initiation of a SW-directed subduction or obduction beneath the Middle East margin of Gondwana, by the oceanic Paleo-Tethys Plate (Husseini, 1992; Al-Husseini, 2004). This interpretation is consistent with the interpretation of a widespread middle Carboniferous episode of orogenic deformation along the Paleo-Tethys suture zone (Sengör, 1990). The evidence includes metamorphic rocks and arc-type, calk-alkaline magmatic complexes in the region of the Sanandaj-Sirjan Terrane in southeast Iran, and other smaller terranes in Iran and Turkey.

SB² 21: c. 305.5 Ma; Kasimovian stage, (Pennsylvanian Epoch) late Carboniferous period

Second-order sequence boundary SB² 21 has an orbital model age of c. 305.5 Ma and is correlated to the late Kasimovian stage according to GTS 2004 (Gradstein et al., 2004). Following the pre-Unayzah hiatus, the late Carboniferous late Moscovian-early Kasimovian “Al Khlata Production Unit 9 (AK P9)” was deposited in parts of Oman. SB² 21 is correlated to the boundary between “AK P9” and “Al Khlata Production Unit 5 (AK P5)” (i.e. “Al Khlata AK P5/P9 boundary”) in subsurface Oman (Osterloff et al., 2004a; Al-Husseini and Matthews, 2005b). The “AK P5/P9 boundary” is interpreted as a major melt-out (diamictite facies) that marks the base of the upper Kasimovian-lower Asselian “AK P5” (P. Osterloff, written communication *in* Al-Husseini and Matthews, 2005b). SB² 21 may be positioned near the base of the “Unayzah Formation” and base “Juwayl Member” of the “Wajid Formation” in Saudi Arabia (Al-Husseini, 2004).

DS² 21: c. 305.5 to 290.9 Ma; Kasimovian stage, (Pennsylvanian Epoch) late Carboniferous period to middle Sakmarian (Cisuralian Epoch) early Permian period

Orbital second-order depositional sequence DS² 20 is tentatively interpreted, on the basis of biostratigraphic dating and stratigraphic position, to consist of “Al Khlata Production Unit 5 (AK P5)”, and the lower two units of “Al Khlata Production Unit 1A (AK P1A)”; namely: “AK P1A Unnamed Diamictite” and “AK P1A Early Lake”. The age of the two “AK P1A units” is interpreted to be late Asselian and ?Sakmarian (Osterloff et al, 2004b). A higher-order division of DS² 21 is not possible due to the complex stratigraphy of these glaciogenic units.

SB² 20: c. 290.9 Ma; middle Sakmarian stage, (Cisuralian Epoch) early Permian period

Second-order sequence boundary SB² 20 has an orbital model age of c. 290.9 Ma and correlates to the late Sakmarian stage according to GTS 2004 (Gradstein et al., 2004). SB² 20 is correlated to the regional melt-out represented by the base of “Al Khlata AK P1A Blanketing Diamictite” in subsurface Oman (Osterloff et al., 2004a; Al-Husseini and Matthews, 2005b). SB² 20 probably correlates to the boundary between the “Unayzah C Member” and “Unayzah B Member” (Al-Husseini, 2004).

DS² 20: c. 290.9 to 276.3 Ma; middle Sakmarian to late Artinskian stages, (Cisuralian Epoch) early Permian period

Second-order depositional sequence DS² 20 is interpreted to consist of six third-order depositional sequences (DS³ 20.1 to DS³ 20.6) separated by five third-order sequence boundaries (SB³ 20.2 to SB³ 20.6) (Al-Husseini and Matthews, 2005b). The following interpretation is based on the studies of Osterloff et al. (2004a, b) in Oman:

(1) DS³ 20.1: “AK P1A Blanketing Diamictite” and “AK P1 Rahab Lake 1 Unit”;
(2) DS³ 20.2: “AK P1 Intra-Rahab Glaciogenic and Delta Unit” and “AK P1 Rahab Lake 2 Unit”;
(3) DS³ 20.3: “Lower Gharif Member Cycle 1” consisting of the “Basal Sandstone” and marine “Maximum Flooding Shale” (Guit et al., 1995) containing MFS P10 (Sharland et al., 2001);
(4) DS³ 20.4: “Lower Gharif Member Cycle 2” corresponding to subsurface “Haushi Limestone” and outcropping “Saiwan Formation” of Al-Haushi-Huqf outcrops (Angiolini et al., 2004, 2006);
(5) DS³ 20.5: “Middle Gharif Member Cycle 3”;
(6) DS³ 20.6: “Middle Gharif Member Cycle 4”.

DS³ 20.3 and 20.4 may correlate to the lower part of the “Lower Unayzah A Submember” in subsurface Saudi Arabia (Al-Husseini, 2004), and to the marine clastics of the “Chal-e Shah Formation” (lower part of the “Faraghan Formation”, Szabo and Kheradpir, 1978) in Iran (R. Jones, written communication, 2000).

In Oman, third-order sequence boundary SB^3 20.3 marks the top of the "Rahab Shale Member" of the "Al Khlata Formation" (Osterloff et al., 2004b), and is correlated to the boundary between the "Saiwan Formation" and "Al Khlata Formation" in Al-Haushi-Huqf (Angiolini et al., 2004, 2006). The top of the "Rahab Member" is dated as late Sakmarian and corresponds to the boundary between the Oman-Saudi Arabia OSPZ2 and OSPZ3 palynozones (Stephenson et al., 2003). SB^3 20.3 is also correlated to the boundary between the "Unayzah A Member" and "Unayzah B Member" in subsurface Saudi Arabia (Stephenson et al., 2003; Al-Husseini, 2004).

Third-order sequence boundary SB^3 20.5 is correlated to the boundary between the "Lower Gharif Member" and "Middle Gharif Member" (also "Gharif Cycle 3/Cycle 2 boundary") in subsurface Oman, and the "Redefined Gharif/Saiwan boundary" in the Al-Haushi-Huqf outcrop (Angiolini et al., 2004, 2006; Al-Husseini and Matthews, 2005b). These boundaries are dated as late Sakmarian (Angiolini et al., 2004, 2006) or/and early Artkinsian (Stephenson et al., 2003), and correspond to the boundary between the Oman-Saudi Arabia OSPZ3 and OSPZ4 palynozones.

The change of depositional setting from marine ("Lower Gharif Member" and Saiwan Formation") to predominantly continental ("Middle Gharif Member") suggests that the region of the Oman Mountains may have become uplifted as an early Permian (c. Artkinsian-Kungrian) thermal bulge prior to the formation of the Neo-Tethys rift system in middle Permian (Wordian). This interpretation is consistent with the absence of most of the Paleozoic succession in the Oman Mountains due to erosion.

SB^2 19: c. 276.3 Ma; late Artinskian stage, (Cisuralian Epoch) early Permian period

Second-order sequence boundary SB^2 19 has an orbital model age of c. 276.3 Ma and correlates to the late Artinskian Stage according to GTS 2004 (Gradstein et al., 2004). SB^2 19 is correlated to the boundary between the "Middle Gharif Member" and "Upper Gharif Member" (Osterloff et al., 2004b). The "Upper/Middle Gharif boundary" corresponds to a major hiatus and the boundary between the OSPZ4 and OSPZ5 palynozones (Stephenson et al., 2003, 2006). The hiatus has an approximate age of late Kungurian-early Roadian (Stephenson et al., 2003, 2006) or c. 270–273 Ma, which is younger than the model age of SB^2 19 (276.3 Ma).

In the Al Haushi–Huqf region, SB^2 19 is correlated to the boundary between the "Lower Unit" and "Upper Unit" of the "Redefined Gharif Formation" (Angiolini et al., 2004, 2006; Al-Husseini and Matthews, 2005b). In subsurface Saudi Arabia, SB^2 19 is correlated to the top of the red siltstone or corresponding top of the "Upper Unayzah A Submember" (Al-Husseini, 2004) or top of the "Unnamed Middle Unayzah Unit" (Melvin and Sprague, 2006).

DS^2 19: c. 276.3–261.8 Ma; late Artinskian stage, (Cisuralian Epoch) early Permian period to middle Wordian stage, (Guadalupian Epoch) middle Permian period

Second-order depositional sequence DS^2 19 is interpreted to consist of six third-order depositional sequences (DS^3 19.1 to DS^3 19.6) separated by five third-order sequence boundaries (SB^3 19.2 to SB^3 19.6) (Al-Husseini and Matthews, 2005b) based, in part, on the interpretation of Osterloff et al. (2004b):

(1) DS^3 19.1: "Upper Gharif Member Cycle 5";
(2) DS^3 19.2: "Upper Gharif Member Cycle 6";
(3) DS^3 19.3: "Upper Gharif Member Cycle 7";
(4) DS^3 19.4: "Upper Gharif Member Cycle 8" together with "Lower Khuff Member P17 Sequence";
(5) DS^3 19.5: "Lower Khuff Member P18 Sequence";
(6) DS^3 19.6: "Lower Khuff Member P19 Sequence" containing the "Khuff Marker Limestone (KML)" interpreted as maximum flooding interval MFI P19.

In Saudi Arabia subsurface, DS[3] 19.1 to 19.3 probably correspond to "Upper Unayzah A Submember" that is predominantly comprised of fluviatile sandstones and siltstones (Al-Husseini, 2004).

During the deposition of DS[3] 19.4, in the Middle Permian Wordian times, the eastern margin of the Arabian Plate was flooded by the newly formed Neo-Tethys Ocean, as represented by the "Chia Zairi Formation" in Iraq, "Dalan Formation" in Iran, and "Khuff Formation" in the Arabian Gulf. Wordian SB[3] 19.4 is interpreted as the final third-order sequence boundary to have occurred prior to the onset of the transgression. In subsurface Oman, SB[3] 19.4 is represented by the boundary between "Cycles 7 and Cycle 8 of the Upper Gharif Member" (Osterloff et al., 2004b). In the Al-Haushi-Huqf outcrops it is correlated to the base of "Subunit B, Upper Unit of the Redefined Gharif Formation" (Angiolini et al., 2004, 2006; Al-Husseini and Matthews, 2005b). In the Oman Mountains, Wadi Sahtan, Al Jabal al Akhdar, SB[3] 19.4 is represented by the base of the "Saiq A1 basal clastics" of the "Saiq Formation" (Glennie, 1977; Rabu et al., 1993). SB[3] 19.4 is correlated to the boundary between OSPZ5 and OSPZ6 of middle Wordian age (Stephenson, 2006).

In the Oman Mountains, Saih Hatat region, the collapse of the uplifted thermal bulge may have occurred in the middle Permian times allowing the carbonates and volcanics of the Saiq Formation to be deposited above much older Paleozoic rock units (Le Métour et al., 1995). In this region SB[3] 19.4 was accompanied (or followed) by Wordian rifting along the Oman margin as manifested by the horst and graben structural style and the "Saiq Sq_1V" limestone-volcanic unit (Le Métour et al., 1986, 1995; Rabu et al., 1993). The "Saiq Sq_1V" volcanic unit consists of carbonates with inter-layered basalts and provides evidence for the Neo-Tethys proto-rift and the breakaway of the Cimmeria Superterrane. The rift collapse along the Arabian Plate and the Cimmeria Superterrane boundary probably caused rapid subsidence of the eastern margin (and the Rub' Al-Khali Basin) of the Arabian Plate, and the rapid development of substantial accommodation space. The formation of the Neo-Tethys rift may have been accompanied by regional eastward tilting of the Arabian Plate.

The Neo-Tethys rift-collapse model implies that the middle Permian transgression ("Chia Zairi, Khuff, Saiq and Dalan formations") was, in part, driven by the rapid extensional subsidence along the eastern margin of the Arabian Plate. The rapid Wordian-Capitanian subsidence is represented by the thick carbonate units such as the "Lower Khuff Member" of subsurface Oman (Osterloff et al., 2004b), "Saiq A2 and A3 Cycles" (Baud et al., 2001) and "Saiq Sq_1L Unit" (Le Métour et al., 1986; Rabu et al., 1993) in the Oman Mountains, "Lower Dalan Member" in Iran (Szabo and Kheradpir, 1978), Zinnar Member of the Chia Zairi Formation in Iraq (van Bellen et al., 1959), and possibly coeval units elsewhere.

The Oman-Cimmeria rift segment of the Neo-Tethys Ocean may have terminated along a NE-trending, left-lateral strike-slip (transform) fault. A second Neo-Tethys rift system between the region of the Zagros Mountains (Arabian Plate) and Sanandaj-Sirjan Terrane (Cimmeria), may have started to evolve in the middle Permian times, or later in late Permian and Triassic times.

SB[2] 18: c. 261.8 Ma; middle Capitanian stage, (Guadalupian Epoch) middle Permian period

Second-order sequence boundary SB[2] 18 has an orbital model age of c. 261.8 Ma and is correlated to the middle Capitanian stage according to GTS 2004 (Gradstein et al., 2004). SB[2] 18 is correlated in the subsurface of Oman to the boundary between the "Lower Khuff Member" and "Middle Khuff Member" (Osterloff et al., 2004b). In other regions the position of SB[2] 18 is not interpreted and can only be approximately positioned in the chart.

DS[2] 18: c. 261.8 to 247.3 Ma; middle Capitanian stage, (Lopingian Epoch) late Permian period to middle Olenekian stage, early Triassic period

Second-order depositional sequence DS[2] 18 is interpreted to consist of six third-order depositional sequences (DS[3] 18.1 to DS[3] 18.6) separated by five third-order sequence boundaries (SB[3] 18.2 to SB[3] 18.6) (Al-Husseini and Matthews, 2005b) based, in part, on the interpretation of Osterloff et al. (2004b) and Insalaco et al. (2006). DS^3 18.1 and DS^3 18.2 are not separately defined and consist in subsurface Oman of the "Middle Khuff Member" up to the top of the "Middle Anhydrite Unit"; i.e. depositional sequences "P20, P23 and P27" of Osterloff et al. (2004b). DS^3 18.1 and DS^3 18.2 probably correlate to the carbonate-volcanic "Saiq Sq_2V Unit" (Le Métour et al., 1986; Rabu et al., 1993).

DS^3 18.3 and DS^3 18.4 correlate to "Upper Dalan Cycle IV" and "Upper Dalan Cycle III" (Insalaco et al., 2006). In the Oman Mountains DS^3 18.3 and DS^3 18.4 probably correlate to the "Saiq A4 Cycle" (Baud et al., 2001), and probably to the "Saiq Sq_{2a} Unit" (Le Métour et al., 1986; Rabu et al., 1993).

In Saudi Arabia, the Wordian and ?early Capitanian stages are not clearly identified (Vaslet et al., 2005; Vachard et al., 2005). This period may correspond to non-deposition or/and an arid setting involving erosion and dune deposition as characterized by the "Upper Unayzah A Subunit" consisting of aeolian deposits (Evans et al., 1997). In outcrop, either DS^3 18.1-18.2 or DS^3 18.3-18.4 may correlate to the depositional sequences "Khuff DS^3 PKh" ("Ash Shiqqah and Huqayl members") and "Khuff DS^3 PKm" ("Duhaysan and Midhnab members") of Vaslet et al. (2005), respectively. Vaslet et al. (2005) tentatively dated the "Ash Shiqqah Member" as ?Capitanian, and correlated it to the subsurface "Khuff D Anhydrite". In the AROS model (Al-Husseini and Matthews, 2005b) and in the present chart, the subsurface "Khuff D Anhydrite" is correlated to SB^3 18.3 ("Midhnab/Duhaysan boundary") in middle Wuchiapingian (as calibrated by GTS 2004), thus implying the "Ash Shiqqah Member" is younger than Capitanian and correlates to the "Basal Khuff Clastics".

Third-order SB^3 18.3 at c. 242.3 Ma (middle Wuchiapingian) is correlated to the top of a regional anhydrite bed, some 10–20-meters-thick, which is correlated across Arabia and Iran (Al-Jallal, 1995):

(1) Either base of "Ash Shiqqah Member of Khuff Formation" in outcrop in Saudi Arabia (Vaslet et al., 2005), or the sequence boundary between the "Duhaysan Member" and "Huqayl Member" (as in the chart);
(2) Top of "Khuff D Anhydrite" capping the "Khuff D Member" in subsurface Saudi Arabia (Al-Jallal, 1995);
(3) Top of "Khuff K III Unit" in Bahrain (Janahi and Dakessian 1985);
(4) Top "Median Anhydrite of Khuff Formation" in Qatar (Sugden and Standring, 1975; Hamam and Nasrulla, 1989);
(5) Top of "Middle Khuff Member" in Kuwait (Khan, 1989);
(6) Top of "Satina Evaporite Member" of the "Chia Zairi Formation" in Iraq (van Bellen et al., 1959);
(7) Top of "Nar Member" of the "Dalan Formation" in Iran (Szabo and Kheradpir, 1978; Insalaco et al., 2006);
(8) Top of "Middle Anhydrite" of the "Middle Khuff Member" in subsurface Oman (Osterloff et al., 2004b).
(9) Top of "Middle Anhydrite" of the "Khuff Formation" in subsurface United Arab Emirates (El-Bishlawy, 1985; Alsharhan, 2006).

In the Oman Mountains, the anhydrite bed is not present. SB^3 18.3 is tentatively correlated to the boundary between "Saiq Sequences A and B" in Al Jabal al Akhdar (Baud et al., 2001), and the boundary between "Saiq Sequences Sq_{2a} and Sq_2V" in Saih Hatat (Le Métour et al., 1986; Rabu et al., 1993). SB^3 18.5 may correlate to the boundary between "Saiq Sequences B and C" (Baud et al., 2001) and "Saiq Sequences Sq_{2b} and Sq_{2a}" (Le Métour et al., 1986; Rabu et al., 1993).

DS^3 18.5 and DS^3 18.6 are respectively correlated to "Kangan Cycle I" and "Upper Dalan-Kangan Cycle II" in Iran (Insalaco et al., 2006), and correspond to the "Khartam Member" of the "Khuff Formation" in outcrop in Saudi Arabia. Late Permian SB^3 18.5 is correlated to the stratigraphic discontinuity represented by the incised channels in the upper part of the "Midhnab Member" of the "Khuff Formation" in Saudi Arabia's outcrops (Vaslet et al., 2005), the boundary between the "Khuff B and C members" in the subsurface of Saudi Arabia (Al-Jallal, 1995), and "Khuff Sequences KS2 and KS3" in subsurface Qatar (Hamam and Nasrulla, 1989), Upper Dalan Cycle II and Cycle III" in Iran (Insalaco et al., 2006), and "Upper and Middle Khuff members" in subsurface Oman (Osterloff et al., 2004b).

The Triassic/Permian Boundary is biostratigraphically interpreted to occur within the "Khartam Member of the Khuff Formation" (Vaslet et al., 2005) and within the "Khuff B Member" in Saudi Arabia (Al-Jallal, 1995); between the Chia Zairi and Mirga Mir formations in Iraq (van Bellen et al., 1959); between the "Kangan Formation" and "Dalan Formation" in Iran (Insalaco et al., 2006); and within "Saiq Cycle C" in the Oman Mountains (Baud et al., 2001).

SB^2 17: c. 247.2 Ma; middle Olenekian stage, early Triassic period

Orbital second-order sequence boundary SB^2 17 has a model age of c. 247.2 Ma and is correlated to the early Triassic Olenekian stage according to GTS 2004 (Gradstein et al., 2004). It is correlated to the regional stratigraphic discontinuity represented by the onset of shale deposition above carbonates as represented by the "Sudair/Khuff boundary" in Saudi Arabia (Vaslet et al., 2005), Bahrain and Qatar (Al-Jallal, 1995), subsurface Oman (Osterloff et al., 2004b), and the United Arab Emirates (El-Bishlawy, 1985; Alsharhan, 2006). In Iraq it correlates to the boundary between the "Beduh Shale" and "Mirga Mir Formation" (van Bellen et al., 1959). In Iran, it correlates to the boundary between the "Aghar Shale" and "Kangan Formation" (Szabo and Kheradpir, 1978; Insalaco et al., 2006). SB^2 17 may correlates to the boundary between the "Mahil and Saiq formations" in the Oman Mountains, although many authors correlate the Triassic/Permian Boundary to the "Mahil/Saiq boundary" (e.g. Glennie, 1977).

FUTURE UPDATES OF THE CHART

The Permian Tectono-Stratigraphy Chart shows the correlations between the most recent global geological time scale (Gradstein et al., 2004), orbital-forcing calibrations (Al-Husseini and Matthews, 2005a, b), the depositional sequences of the Middle East and regional plate tectonics. It provides, at a glance, a framework that can be refined through the addition of new data and interpretations. The ages and stratigraphic correlation of the rock units carry significant uncertainties. The uncertainty in age derives from inaccurate (and often conflicting) biostratigraphic dating of many rock units that can vary by a biostratigraphic stage or more. The chart attempts to adopt biostratigraphic age interpretations wherever possible, but also takes into account sequence stratigraphic and orbital calibrations. The spatial correlations also carry uncertainty, largely because of the sparse subsurface control (wells and seismic) between the studied localities. These various sources of uncertainty can be reduced or even eliminated with additional data, interpretations and discussions. Accordingly the Permian Chart (and similar charts for other periods) will be revised and reprinted when new papers provide amendments and corrections.

ACKNOWLEDGEMENTS

The author thanks Robley K. Matthews, Joerg Mattner and Denis Vaslet for their useful comments.

REFERENCES

Al-Husseini, M.I., 2004. Pre-Unayzah unconformity, Saudi Arabia. In Carboniferous, Permian and Early Triassic Arabian Stratigraphy. GeoArabia Special Publication 3 (Ed. M.I. Al-Husseini). Gulf PetroLink, Bahrain, p. 15-59.

Al-Husseini, M.I. and R.K Matthews, 2005a. Arabian Orbital Stratigraphy: Periodic second-order sequence boundaries. GeoArabia, v. 10, no. 2, p 165-184.

Al-Husseini, M.I. and R.K Matthews, 2005b. Tectono-Stratigraphic Note: Time calibration of late Carboniferous, Permian and Early Triassic Arabian stratigraphy to orbital-forcing predictions. GeoArabia, v. 10, no. 2, p 189-192.

Al-Jallal, I.A. 1995. The Khuff Formation: its regional reservoir potential in Saudi Arabia and other Gulf countries; depositional and stratigraphic approach. In, M.I. Al-Husseini (Ed.), Middle East Petroleum Geosciences Conference, GEO'94. Gulf PetroLink, Bahrain, v. 1, p. 103-119.

Al-Laboun, A.A. 1988. The distribution of Carboniferous-Permian siliciclastic rocks in the greater Arabian platform. Geological Society of America Bulletin, v. 100, no. 3, p. 362-373.

Alsharhan, A.S. 2006. Sedimentologiacl character and hydrocarbon parameters of the Middle Permian to Early Triassic Khuff Formation, United Arab Emirates. GeoArabia, v. 11, no. 3, p. 121-158.

Angiolini, L., S. Crasquin-Soleau, J.-P. Platel, J. Roger, D. Vachard, D. Vaslet and M.I. Al-Husseini 2004. Saiwan, Gharif and Khuff formations, Haushi-Huqf Uplift, Oman. In, M.I. Al-Husseini (Ed.), Carboniferous, Permian and Early Triassic Arabian Stratigraphy. GeoArabia Special Publication 3, p. 149-183.

Angiolini, L., M.H. Stephenson and E.J. Leven 2006. Correlation of the Lower Permian surface Saiwan Formation and subsurface Haushi limestone, Central Oman. GeoArabia, v. 11, no. 3, p. 13-78.

Baud, A., F. Béchennec, F. Corder, L. Krystyn, J. Le Métour, J. Marcoux, R. Maury and S. Richox 2001. Permo-Triassic deposits: from the platform to the basin seamounts. Excursion no. A01 in the Oman Mountains, January 8-11, 2001. International Conference on the Geology of Oman, Pangea Symposium and Field Meeting, 56 p.

El-Bishlawy, S.H. 1985. Geology and hydrocarbon occurence of the Khuff Formation in Abu Dhabi, UAE. Proceedings of the 4th Society of Petroleum Engineers Middle East Oil Show, Paper SPE 13678, p. 601-606.

Evans, D.S., R.B. Lathon, M. Senalp, and T.C. Connally 1991. Stratigraphy of the Wajid sandstone of southwestern Saudi Arabia. Proceedings of the Society of Petroleum Engineers Middle East Oil Show, Bahrain, 16-19th November 1991, SPE paper 21449, p. 947-957.Oct30/02

Evans, D.S., B.H. Bahabri and A.M. Al-Otaibi 1997. Stratigraphic trap in the Permian Unayzah Formation, central Saudi Arabia. GeoArabia, v. 2, no. 3, p. 259-278.

Glennie, K.W. 1977. Outline of the Geology of Oman. Memoire h. ser. Société Géologique France, v. 8, p. 25-31.

Gradstein, F.M., J.G. Ogg, A.G. Smith et al. 2004. A geological time scale 2004, Cambridge University Press.

Guit, F.A, M.H. Al-Lawati and P.J.R. Nederlof 1995. Seeking new potential in the early-Late Permian Gharif play, west central Oman. In, M.I. Al-Husseini (Ed.), Middle East Petroleum Geosciences Conference, GEO'94. Gulf PetroLink, Bahrain, v. 2, p, 447-462.

Hamam, K.A. and I.M. Nasrulla 1989. Drilling operations and evaluation of Matbakh-2 a deep formation test in Qatar offshore. In, Country Reports and Case Studies presented at the seminar on Deep Formations in the Arab Countries: Hydrocarbon Potential and Exploration Techniques. Organisation of Arab Petroleum Exporting Countries, E229-E241.

Husseini, M.I. 1992. Upper Palaeozoic tectono-sedimentary evolution of the Arabian and adjoining plates. Journal of the Geological Society, London, v. 149, no. 5, p. 419-429.

Insalaco, E., A. Virgone, B. Courme, J. Gaillot, M. Kamali, A. Moallemi, M. Lotfpour and S. Monibi 2006. Upper Dalan/Kangan Formation between the Zagros Mountains and offshore Fars: depositional system, biostratigraphy and stratigraphic architecture. GeoArabia, v. 11, no. 2, p. 75-176.

Janahi, I.A. and B.A. Dakessian 1985. Development of the Khuff Gas Reservoir, Bahrain field. Society of Petroleum Engineers SPE 13679. Proceedings of the SPE 1985 Middle East Oil Show, Bahrain, p. 25-31.

Kellogg, K.S., D. Janjou, L. Minoux and J. Fourniguet 1986. Explanatory notes to the geologic map of the Wadi Tathlith Quadrangle, Kingdom of Saudi Arabia. Geoscience Map GM-103C, scale 1:250,000, sheet 20G. Deputy Ministry for Mineral Resources, Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia. 27 p.

Khan, A. 1989. Stratigraphy and hydrocarbon potential of the Permo-Triassic sequence of rocks in the State of Kuwait. Organization of Arab Exporting Countries Seminar on Hydrocarbon Potential of Deep Formations in Arab Countries, Abu Dhabi, p. 3-29.

Le Métour, J., M. Villey and X. de Gramont 1986. Geologic Map of Masqat, sheet NF-40-4D, scale 1:100,000, with Explanatory Notes. Directorate General of Minerals, Ministry of Petroleum and Minerals, Oman.

Le Métour, J., F. Béchennec, J.-P. Platel and J. Roger 1995. Late Permian birth of the Neo-Tethys and development of its southern continental margin in Oman. In, M.I. Al-Husseini (Ed.), Middle East Petroleum Geosciences Conference, GEO'94. Gulf PetroLink, Bahrain, v. 2, p. 643-654.

Melvin, J. and R.A Sprague 2006. Advances in Arabian stratigraphy: Origin and stratigraphic architecture of glaciogenic sediments in Permian-Carboniferous lower Unayzah sandstones, eastern central Saudi Arabia. GeoArabia, v. 11, no. 4, p. 105-152.

Osterloff, P., R. Penney, J. Aitken, N. Clark and M. Al-Husseini 2004a. The Al Khlata Formation in Interior Oman. GeoArabia Special Publication 3. Gulf PetroLink, Bahrain, p. 61-81.
Osterloff, P.L., A. Al-Harthy, R. Penney, P. Spaak, F. Al-Zadjali, N.S. Jones, R.W.O.B Knox, M.H. Stephenson, G. Oliver and M.I. Al-Husseini 2004b. Depositional sequence of the Gharif and Khuff formations, subsurface Interior Oman. GeoArabia Special Publication 3, Gulf PetroLink, Bahrain, p. 83-147.
Rabu, D., P. Nehlig, J. Roger, F. Bechennec, M. Beurrier, J. Le Métour, C. Bourdillon de Grissac, M. Tegyey, J.-J. Chauvel, C. Cavelier, H. Al-Hazri, T. Juteau, D. Janjou, B. Lemiere, M. Villey and R. Wyns 1993. Stratigraphy and structure of the Oman Mountains. Document du Bureau de Recherches Géologiques et Minières, no. 221, 262 p.
Sengör, A.M.C. 1990. A new model for the late Palaeozoic-Mesozoic tectonic evolution of Iran and implications for Oman. In, A.H.F. Robertson, M.P. Searle and A.C. Ries (Eds.), The Geology and Tectonics of the Oman Region. Geological Society, London, Special Publication no. 49, p. 797-831.
Sharland, Peter R., Ray Archer, David M. Casey, Roger B. Davies, Steve H. Hall, Alan P. Heward, Andrew D. Horbury and Michael D. Simmons 2001. Arabian Plate Sequence Stratigraphy. GeoArabia Special Publication 2, Gulf PetroLink, Bahrain, 371 p., with 3 charts.
Stephenson, M.H., P.L. Osterloff and J. Filatoff 2003. Palynological biozonation of the Permian of Oman and Saudi Arabia: progress and challenges. GeoArabia, v. 8, no. 3, p. 467-496.
Stephenson, M.H. 2006. Update of the standard Permian palynological biozonation: definition and description of OSPZ5 and 6. GeoArabia, v. 11, no. 3, p. 173-178.
Sugden, W. and A.J. Standring 1975. Qatar Peninsula. In, Lexique Stratigraphique International, v. III Asie, Centre National de la Recherche Scientifique, Paris, fasc. 10b3., 120 p.
Szabo, F. and A. Kheradpir 1978. Permian and Triassic stratigraphy, Zagros basin, south-west Iran. Journal of Petroleum Geology, v. 1, no. 2, p. 57-82.
Vachard, D., J. Gaillot, D. Vaslet and Y.-M. Le Nindre 2005. Foraminifers and algae from the Khuff Formation (late Middle Permian-Early Triassic) of central Saudi Arabia. GeoArabia, v. 10, no. 4, p 137-186.
van Bellen, R.C., H.V. Dunnington, R. Wetzel and D.M. Morton 1959. Iraq. Lexique Stratigraphique International Centre National de la Recherche Scientifique, III, Asie, Fasc. 10a, Paris, 333 p.
Vaslet, D., Y.-M.Le Nindre, D. Vachard, J. Broutin, S. Crasquin-Soleau, M. Berthelin, J. Gaillot, M. Halawani and M.I. Al-Husseini 2005. The Permian-Triassic Khuff Formation of central Saudi Arabia. GeoArabia, v. 10, no. 4, p. 77-134.
Wender, L.E., J.W. Bryant, M.F. Dickens, A.S. Neville and A.M. Al-Moqbel 1998. Paleozoic (pre-Khuff) hydrocarbon geology of the Ghawar area, eastern Saudi Arabia. GeoArabia, v. 3, no. 2, p. 273-302.

ABOUT THE AUTHOR

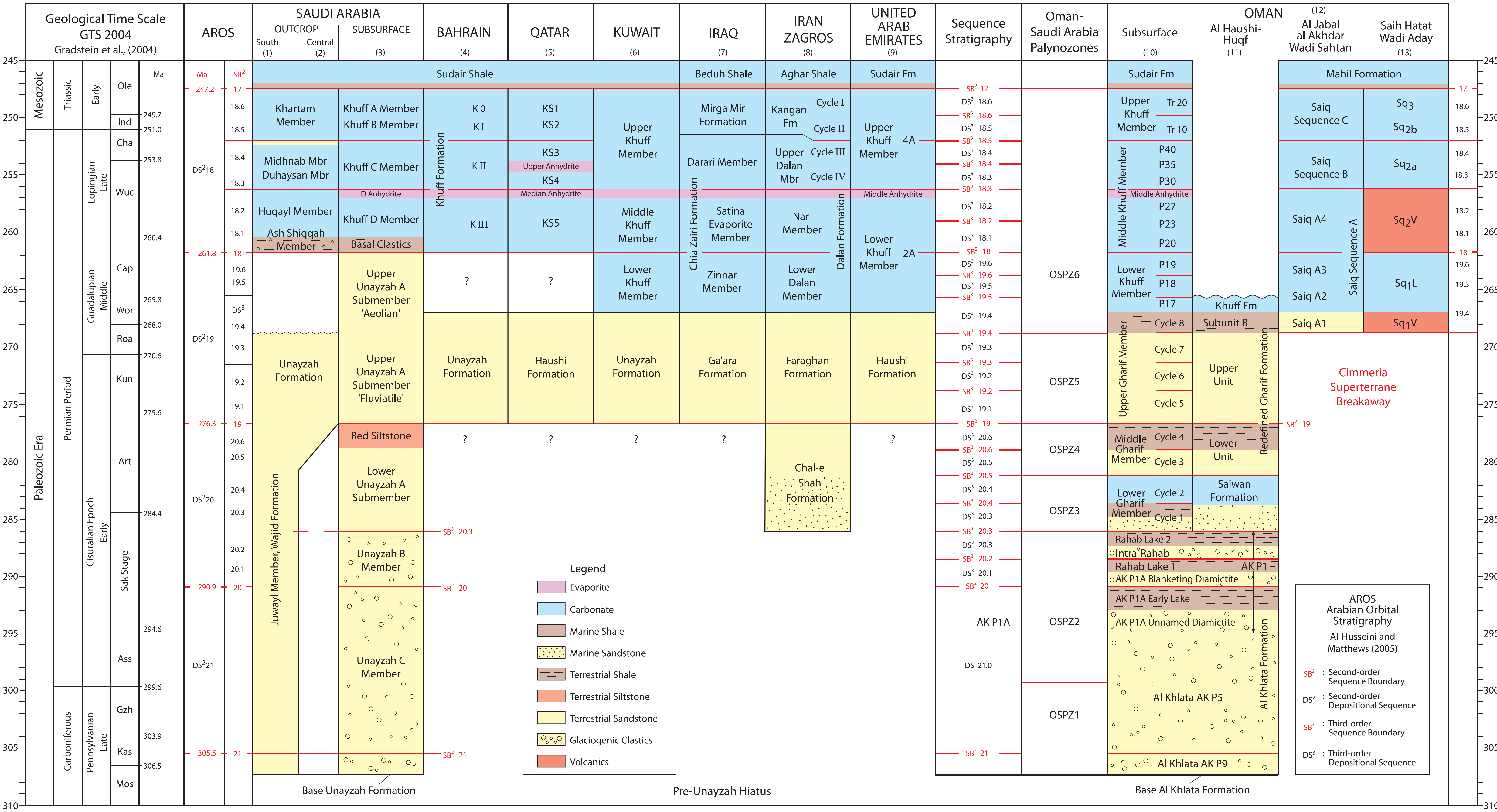
Moujahed Al-Husseini *founded Gulf PetroLink in 1993 in Manama, Bahrain. Gulf PetroLink is a consultancy aimed at transferring technology to the Middle East petroleum industry. Moujahed received his BSc in Engineering Science from King Fahd University of Petroleum and Minerals in Dhahran (1971), MSc in Operations Research from Stanford University, California (1972), PhD in Earth Sciences from Brown University, Rhode Island (1975) and Program for Management Development from Harvard University, Boston (1987). Moujahed joined Saudi Aramco in 1976 and was the Exploration Manager from 1989 to 1992. In 1996, Gulf PetroLink launched the journal of Middle East Petroleum Geosciences, GeoArabia, for which Moujahed is Editor-in-Chief. Moujahed also represented the GEO Conference Secretariat, Gulf PetroLink-GeoArabia in Bahrain from 1999-2004. He has published about 30 papers covering seismology, exploration and the regional geology of the Middle East, and is a member of the AAPG, AGU, SEG, EAGE and the Geological Society of London.*

geoarabi@batelco.com.bh

GeoArabia 2006

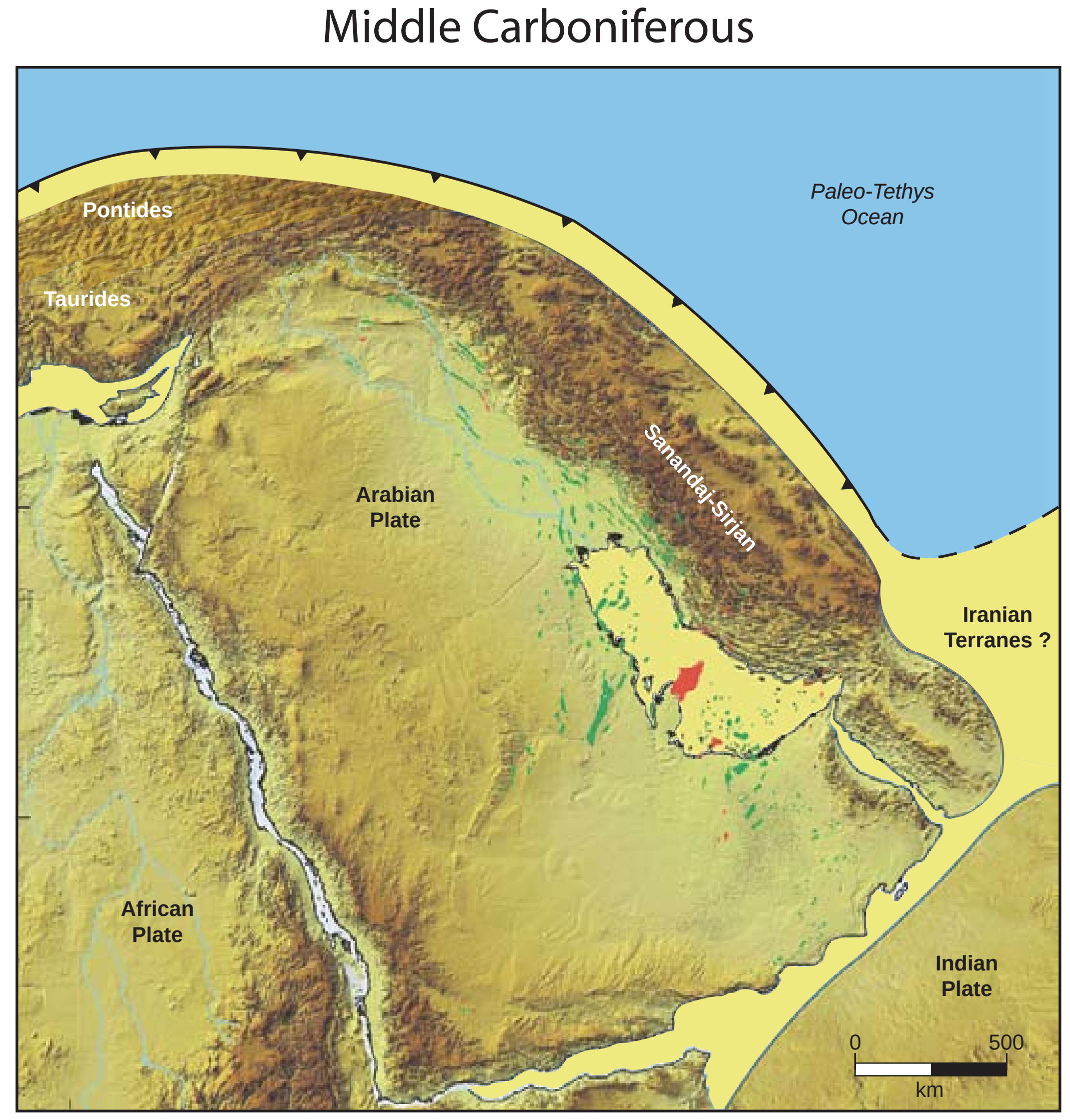
Permian Arabian Tectono-Stratigraphy

Moujahed I. Al-Husseini
GeoArabia, Vol. 11, No. 4, 2006.
Gulf Petrolink, Bahrain



Today

Middle Carboniferous



Middle and Late Permian