STRATIGRAPHIC NOTE

Permian–Triassic Transition and the Saiq/Mahil Boundary in the Oman Mountains: Proposed correction for lithostratigraphic nomenclature

Aymon Baud and Sylvain Richoz

INTRODUCTION

This note discusses the lithostratigraphic nomenclature used to characterise the Permian–Triassic transition at outcrop in the Oman Mountains, with emphasis on the position of the boundary between the Saiq and Mahil formations. Two inconsistent criteria for picking the Saiq/Mahil Boundary (SMB) prevail in the literature causing confusion regarding the correct position of the Permian/Triassic Boundary (PTB). The position of the PTB plays a central role in the correlation of these two formations from outcrop to the subsurface Khuff and overlying Sudair formations.

The Khuff Formation contains one of the world’s greatest reserves of non-associated gas, and its outcrop equivalent in the Oman Mountains is increasingly being studied for the purposes of regional correlations, reservoir characterisation and exploration. Therefore an agreement on the position of the SMB is a pre-requisite for precise communication among geoscientists. In this note we review the historical source of the confusion and recommend applying stratigraphic rules to resolve the position of the Saiq/Mahil Boundary (SMB).

CRITERIA FOR PICKING THE SAIQ/MAHIL BOUNDARY (SMB)

Glennie et al. (1974) introduced a new stratigraphic nomenclature for the outcrops in the Oman Mountains, in which the Middle Permian, Upper Permian and the Triassic succession is represented by the Saiq and Mahil formations of the Akhdar Group. They chose the type locality of the Saiq Formation on the Saiq Plateau, close to Saiq Village (Figures 1 and 2). They proposed Wadi Nakhl as the type area for the Mahil Formation (Figure 1), but did not specify its type locality. They characterised the Saiq/Mahil Boundary (SMB) with two lithological criteria, which subsequently resulted in two conflicting stratigraphic positions for the SMB, referred to here as the “lower SMB position” and “upper SMB position”.

“Upper SMB Position”

The criteria for picking the “upper SMB position” derive from the definition for the base of the Mahil Formation in the Wadi Nakhl area. It is based on the local occurrence of a breccia at the base of the Mahil Formation, and the description of the lowermost part of the Mahil Formation, in some wadis (valleys), as a “thinly bedded, unfossiliferous sequence of burrowed limestone, interbedded with porcellanite, laminated siltstone and shale” (Glennie et al., 1974, p. 147). These criteria for identifying the “upper SMB position”, when not overshadowed by faults, are recognised in all the wadis, and can be mapped along the entire northern side of Al Jabal al-Akhdar, and in Wadi Mu’aydin (Figure 1).

This position was adopted in the geological maps of Al Jabal al-Akhdar (Rabu et al., 1986; Villey et al. 1986; Beurrier et al., 1986), and several papers, theses, and field guides (Coy, 1997, 2004; Atudorei, 1999; Baud and Richoz, 2001, 2005; Baud et al., 2010; Richoz et al., 2005, 2010; Richoz, 2006) (Figure 2 and Table 1).

In Al Jabal al-Akhdar the “upper SMB position” has been dated by chemostratigraphy between the end of the Griesbachian to mid-Dienerian (Richoz, 2006), in the late Induan Age of the Early Triassic. It correlates to the Khuff/Sudair Boundary (Sudair Sequence Boundary) in subsurface Oman and other countries in the Arabian Peninsula. Detailed description of this boundary can be found in the above-mentioned references, as well as in Rabu (1987) and Pöppelreiter and Koehrer (2011; as base of the “middle Mahil member”, see below).
In the tectonically complex Saih Hatat Window the “Sq₃” unit consists of a dark limestone that crops out locally (Le Métour, 1987; Weidlich and Bernecker, 2003, 2007, 2010, 2011). It attains a maximum thickness of 120 m, and lies unconformably on the “Sq₂b” dolomite unit. It has been assigned a Late Permian age (Le Métour, 1987; Weidlich and Bernecker, 2003) and was correlated with the unfossiliferous upper part of the Saiq Formation (“Saiq unit C”) in Al Jabal al-Akhdar (e.g. Al-Husseini and Matthews, 2010). Recently, Weidlich and Bernecker (2011, their figures 1 and 3) published an Early Triassic Olenekian age (in part) for the Sq₃ unit, implying the “upper SMB position” has a younger age in the Saih Hatat Window (Table 1). Richoz et al. (in preparation) interpret the unconformity between the Sq₂b and Sq₃ units in the Saih Hatat Window as a hiatus that spans the late Changhsingian and early Induan (Table 1).

“Lower SMB Position”

The criteria for picking the “lower SMB position” are described by Glennie et al. (1974, p. 146 and 199) in the type locality of the Saiq Formation on the Saiq Plateau. They state that the Mahil Formation “can be distinguished from the underlying Saiq dolomites by its lighter colour and
massive bedding”. Recently, this lower position for the SMB was adopted in several papers and abstracts (Koehrer et al., 2010, 2011, 2012; Pöppelreiter et al., 2011; Zeller et al., 2011; Aigner and Pöppelreiter, 2012; Forke et al., 2012; Obermaier et al., 2012) (Figure 2 and Table 1).

The lower position corresponds to the disappearance of abundant microfossils and corals and the late Changhsingian (Dorashamian), end-Permian extinction event (Richoz, 2006; Baud et al., 2010). The colour change is easily identified from far away on the horizontally lying outcrops on the Saiq Plateau; but upon coming closer two superposed colour changes are observed (Figure 2). The first change is from dark grey to light grey at the “lower SMB position”, and the second from light grey to whitish, light yellow or pink at the “upper SMB position”. The second one is more easily distinguished in other parts of Al Jabal al-Akhdar (Figure 3).

“Saiq Unit C” and “Lower Mahil Member”

The correlation chart in Table 1 is modified from Al-Husseini (2006) and Baud et al. (2010, their figure 23). It shows the stratigraphic nomenclature of the Middle Permian–Lower Triassic in the Zagros Mountains, subsurface United Arab Emirates (UAE) and Oman with the two positions of the Saiq/Mahil Boundary (SMB) in Al Jabal al-Akhdar. The interval between the two positions is about 75 m thick on the Saiq Plateau, and is named “Saiq unit C” when the SMB is taken at the “upper SMB position”, or the “lower Mahil member” if the “lower SMB position” is followed (Figure 2 and Table 1).

In Saih Hatat the Sq3 Member was incorrectly correlated with our “Saiq unit C”, and according to the new dating of Weidlich and Bernecker (2011) and (Richoz et al., in press), it corresponds to our “lower Mahil member” (Table 1).
Table 1

| Age (Ma) | GTS 2012 | Iran | UAE | Subsurface | Al Huqf | Al Jabal al-Akhdar | Saihat Hatat |
|----------|-----------|------|-----|------------|--------|-------------------|------------|
| 245      |           |      | 2   | 3          | 4      | 6                 | 7a 7b       |
| 245.1    |           | Kangan Fm | Jilh Formation      | Jilh Formation |     |                  |             |
| 247.1    |           | Aghar Shale Mbr | Aghar Formation | Sudair Formation | Sudair Formation |       |
| 250.0    |           |      |     |            |        |                  |             |
| 252.2    |           |      |     |            |        |                  |             |
| 259.8    |           |      |     |            |        |                  |             |
| 265.1    |           |      |     |            |        |                  |             |
| 270      |           |      |     |            |        |                  |             |

Correlation chart modified and completed from Al-Husseini (2006). Data from: (1) Insalaco et al. (2006); (2–4) Al Husseini (2006); (5) Aigner and Pöppelreiter, (2012), Forke et al. (2012), Koehrer et al. (2010, 2012), Pöppelreiter et al. (2011), Zeller et al. (2011); (6) Béchennec et al. (1992), Rabu (1997), Coy (1997), Atudorei, (1999), Baud and Richoz (2001, 2005), Baud et al. (2010), Richoz et al. (2009), Richoz (2006) Richoz et al. (2010), Baud et al. (2010); (7a) Aqabat Amdah: Le Métour (1987), (7b) Wadi Aday: Weidlich and Bemecker (2010, 2011) with major modification (Richoz et al., in prep.).
PROPOSED TYPE SECTION FOR THE BASE OF THE MAHIL FORMATION AT WADI MISIN

Following the pioneering work by Glennie et al. (1974), the boundary between the Saiq and the Mahil formations in Al-Jabal al-Akhdar and Saih Hatat Window was mapped in the 1980s by the French geological survey, BRGM (Bureau de Recherches Géologiques et Minières), and the Directorate General of Minerals, Sultanate of Oman.

In the explanatory notes of the 1:100,000 scale geological map of the Nakhl Quadrangle Rabu et al., (1986, p. 17) defined the SMB by “a conspicuous, whitish-colored recessive step in the slope profile”, and they described the basal part of the Mahil Formation as follows: “At the base of the formation, the succession commonly includes decimeter-thick beds of dolomite with quartz and intraformational breccia with a sandstone-dolomite cement (Wadi Mu‘aydin), beds of maroon siltstone (Wadi Misin), and a close succession of hardgrounds separating the dolomite beds and reflecting periodic emergence. However, the passage between the Saiq and Mahil formations is not always identifiable.” Their definition is meant to correspond to the “upper SMB position”, which is the conspicuous step shown in Figures 2 and 3 and in field observations. The “lower SMB position” is also a whitish coloured recessive step in the slope profile on the Saiq Plateau, but is more discrete.

In the Fanjah Quadrangle covering the eastern end of Al-Jabal al-Akhdar, Villey et al. (1986) reported that the Mahil Formation “conformably overlies the Saiq Formation, is some 500 m thick, and is easily distinguished from the underlying dark-coloured Saiq by its pale pinkish beige colour.” In the Rustaq Quadrangle, covering the western part of Al Jabal al-Akhdar, Beurrier et al. (1986) wrote: “On a regional scale, the base of the Mahil is marked by a yellowish retreating slope, which is fairly clear in the cliffs bordering the Amq depression to the south, but difficult to identify in the sections exposed in Wadi Bani Awf and Wadi Sahtan.” In regards to the age they wrote: “the upper part of the [Saiq] is assigned to the Djulfian. [Wuchiapingian]” ... “The regional data concerning this unit [Mahil] (Rabu et al., 1986; Villey et al., 1986) and the results obtained from the Rustaq map area in particular, suggest an overall Triassic age for the Mahil Formation; Early to Middle Triassic for the basal part.”

During the mapping of the Nakhl Quadrangle, Rabu noticed that the boundary between the Saiq and Mahil formations in Wadi Nakhl was partly faulted. He therefore proposed in his doctoral thesis and book on the geology of Al Jabal al-Akhdar, that Wadi Misin, located a few kilometres away, must be taken as the type locality for the Mahil Formation (Rabu, 1987, p. 157, his figure IV.15, redrawn here in Figure 4). He reported that in Wadi Misin, the Mahil Formation is 500–530 m thick and consists entirely of dolomite. The basal part of the formation occurs at a ledge in the huge dolomite cliff, and consists of thin-bedded yellow to pink dolomite, locally conglomeratic, with terrigenous input of dark red to green silt and clay amongst the beds.

Rabu (1987) documented many sections of the Saiq and Mahil formations and referred to an 80 m-thick “upper Saiq unit” as an unfossiliferous light-coloured dolomite, and the concordant basal part of the Mahil Formation as a pinkish dolomite containing terrigenous red silt and clay interbeds. The lowermost silt deposit overlies a semi-regional breccia level and is followed by an exposure surface with desiccation cracks as illustrated by Baud et al. (2010, their figure 32, p. 46). This “upper Saiq unit” corresponds to “Saiq unit C” or the “lower Mahil member” depending on the chosen position of the SMB (Figure 2 and Table 1).

Coy (1997, p. 48 and 50) reported that an 80 m-thick “upper Saiq unit” that is devoid of fossils occurs on the Saiq Plateau. He picked the Saiq/Mahil Boundary at the base of a sandy pink silty dolomite above a breccia where palaeokarsts occur; this definition corresponds to the “upper SMB position”. Also the geological map in Coy (2004) shows the “upper SMB position” along the Jayl road and his lower Mahil description (his location 3 on p. 10) corresponds to the area above the “upper SMB position”.
In 2003, the opening of a large quarry in the Saiq Plateau permitted a detailed bed-by-bed correlation of the Permian–Triassic transition between the plateau and Wadi Sahtan (Figure 5). Above the breccia level, the red or green mudstone and the pinkish dolomite, which characterise the upper part of the 75 m-thick interval between the two SMB positions in the wadis, was here again present (Baud et al., 2010; Pöppelreiter et al., 2011). The access to this quarry is easy and so it would provide an excellent reference section for the Khuff/Sudair Boundary (Sudair Sequence Boundary).

PERMIAN/TRIASSIC BOUNDARY (PTB)

“Upper SMB Position” Miscorrelated to the Permian/Triassic Boundary

Glennie et al. (1974), Rabu (1987), Coy (1997), and Béchennec et al. (1992) described the 75–100 m-thick interval between the two SMB positions as “uppermost Saiq Formation without fossil”. They interpreted the lack of fossils to be due to harsher environmental conditions during the deposition of this interval in comparison to other parts of the Saiq Formation. Because the youngest fossils found below this interval were dated by biostratigraphy as Djulfian (Wuchiapingian)
Figure 4: The type section of the Mahil Formation in Wadi Misin proposed by Rabu (1987, his figure IV.15), located approximately at 23°18'54.39"N and 57°49'20.18"E.

(Montenat et al., 1976; Beurrier et al., 1986), this unfossiliferous interval was incorrectly interpreted as latest Permian. This error in age assignment persisted in the literature from the 1970s to the 1990s with the “upper SMB position” correlated to the PTB. In Saih Hatat the Sq3 Member, when outcropping, was also incorrectly interpreted as latest Permian by Le Métour (1987), Weidlich and Bernecker (2003) and Al-Husseini and Matthews (2010).

The incorrect correlation of the PTB to the “upper SMB position” appeared in the first subsurface lexicon of Oman by Hughes Clark (1988) who wrote: “At outcrop in the Oman Mountains, the Saiq Formation (Glennie et al., 1974) is the lateral equivalent of the Permian part of the Khuff.” … “The Saiq passes upwards conformably into Triassic Mahil dolomites, locally with a conglomerate marking the boundary (see Glennie et al., 1974). The upper Khuff is laterally equivalent to the lower part of the Mahil Formation.” … “Equivalents of the Sudair may be in the middle part of the Mahil Formation of the Central Oman Mountains.”

**Discovery of the PTB near the “Lower SMB Position”**

In the 1990s, we chose Wadi Sahtan (Figure 1) to conduct isotope studies on the Permian–Triassic outcrops in the Oman Mountains. In this wadi the “upper SMB position” is characterised by the pinkish terrigenous input and was believed to be the PTB. Carbon-isotope values were measured starting from the last fossiliferous beds (Djulfian = Wuchiapingian) in the Saiq Formation (top of Saiq unit B sensu Atudorei, 1999; Baud and Richoz, 2001; Richoz 2006) and continuing upwards. Surprisingly, the characteristic carbon-isotope negative shift of the PTB was identified in this section about 90 m below the “upper SMB position” (Atudorei, 1999), some metres above these last fossiliferous beds (Figure 3). A detailed description of this section and carbon-isotope curve with a discussion on the PTB position was published by Baud and Richoz (2001, 2005), Baud et al. (2010), Richoz (2006), Richoz et al. (2005, 2010) and Koehrer et al. (2010).
Now the position of PTB is well constrained in the lithological column at the base of the “Saiq unit C” near the base of Khuff Sequence KS2.

**RECENT STUDIES ON THE SEQUENCE STRATIGRAPHY OF THE KHUFF AND SUDAIR FORMATIONS**

B. Koehrer (written communication, 2013) explained that an extensive study by Germany’s University of Tübingen started in 2007, initially on the Saiq Plateau. The main objective of this project was to interpret the sequence stratigraphy and chronostratigraphy of the outcrop-equivalents of the Khuff, Sudair and Jilh sequences.

They used the position of the Saiq/Mahil Boundary (SMB) according to their understanding of the geological map and explanatory notes of the Nakhl Quadrangle; i.e. “conspicuous, whitish-colored recessive step in the slope profile on the Saiq Plateau” (Rabu et al., 1986). They also followed the chronological interpretation of a Permian Saiq Formation and a Triassic Mahil Formation (e.g. Glennie et al., 1974), as well as their interpretation of the work by Coy (1997, 2004, unpublished report for Petroleum Development Oman). They published their studies on the Saiq Plateau using the “lower SMB position” (Koehrer at al., 2010, 2011, 2012; Pöppelreiter et al., 2011; Zeller et al., 2011; Obermaier et al., 2012) and referred to the 75 m-thick interval between the two SMB positions as the “lower Mahil member”.

With ongoing outcrop documentation of the wadi sections in Al Jabal al-Akhdar, Koehrer et al. (2012) correlated the sections from the wadis to the reference section on the Saiq Plateau. In this regard their results are entirely consistent with the subsurface nomenclature but not with the lithostratigraphic nomenclature at outcrop. These papers are also consistent with the correlations in the “Stratigraphic Lexicon of Subsurface Oman” by Forbes et al. (2010) that states: “In outcrops of Al Jabal Al Akhdar in North Oman, the Upper Saiq Formation and overlying Mahil Formation (lower part) are time-equivalent to respectively the Lower/Middle and the Upper Khuff Formation.”
RECOMMENDATIONS

According to the rules of stratigraphic practice, a lithological or chronological unit is defined at a type locality by a type section and its basal boundary (Murphy and Salvador, 2000). We propose that the Oman Stratigraphic Committee considers adopting the definition for the base of the Mahil Formation (Sudair Sequence Boundary) at a same level as the one proposed in Wadi Misin by Rabu (1987, Figures 1 and 4) and on the easily accessible quarry on the Saiq Plateau, corresponding to the “upper SMB position” of Glennie et al. (1974).

The type section at Wadi Misin for the Mahil Formation was proposed 25 years ago and has been carried in the geological maps of Oman. It is grounded on a regional early Dienerian (late Induan Age of the Early Triassic) event: the first input of fine terrigenous sediments on the carbonate platform at the Khuff/Sudair Boundary. The base Mahil can be recognised by the first appearance of red (or green, or yellow according to the alteration) silt, locally quartz, and clay interbeds in pinkish dolomite. It overlies a breccia (“Top Khuff Breccia” in Koehrer et al., 2010) symptomatic of the top Saiq (top Khuff) Formation. Its main advantage is its easy usage for mapping and for regional correlations with the Upper Member of the Saiq Formation corresponding to the Khuff Formation. It is easily found in a monotonous dolomite section and is useful for the field and structural geologist. Agreement on this definition will avoid future confusion.

The correlation of the Mid-Permian to lowermost Triassic Khuff and equivalent formations is now well established in the many studies that are cited (Table 1). The subsurface nomenclature (Khuff, Sudair and Jilh formations) is applied not only in Oman but also in the other countries of the Arabian Peninsula (Bahrain, Kuwait, Qatar, Saudi Arabia and the United Arab Emirates, Al-Jallal, 1995). We suggest that where appropriate authors add clarifications for lithostratigraphic nomenclature referring to this note; for example: “upper Saïq/Mahil Boundary of Glennie et al., 1974”, “lower Mahil member sensu Koehrer et al. (2010, 2012)”, “Saiq unit C” sensu Baud and Richoz (2013); and so forth.

ACKNOWLEDGEMENTS

Thanks to Benoit Beauchamp (Calgary) for carefully reading a first version of the manuscript and improving the English. We are grateful to Moujahed Al-Husseini for rewriting of the text more concisely and to Bastian Koehrer for all his very useful comments. And thanks also to Arnold Egdane for preparing the figures and Kathy Breining for the careful proof reading.

REFERENCES

Aigner, T. and M. Pöppelreiter 2012. The Khuff outcrop project in the Oman Mountains: Framework and research approach. In The Permo–Triassic Sequence of the Arabian Plate, Abstracts of the EAGE’s Third Arabian Plate Geology Workshop, Kuwait. Abstract, GeoArabia, v. 17, no. 1, p. 185-189.

Al-Husseini, M.I. 2006. Permian Arabian tectono-stratigraphy chart. GeoArabia, v. 11, no. 4, p. 95-102.

Al-Husseini, M.I. and R.K. Matthews 2010. Middle East Geologic Time Scale 2010: Calibrating Mid-Permian to Early Triassic Khuff sequences with orbital clocks. GeoArabia, v. 15, no. 3, p. 171-206.

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-Huseini (Ed.), Middle East Petroleum Geosciences Conference, GEO’94. Gulf PetroLink, Bahrain, v. 1, p. 103-119.

Atudorei, V. 1999. Constraints on the Upper Permian to Upper Triassic marine carbon isotope curve. Case studies from the Tethys. PhD Thesis, University of Lausanne, Switzerland, 161 p.

Baud, A. and S. Richoz 2001. The Permian-Triassic shallow carbonate Platform in Wadi Sathan (Jabal Akhdar). In A. Baud, F. Béchennec, F. Cordey, L. Krystyn, J. Le Métour, J. Marcoux, R. Maury and S. Richoz (Eds.), Permo-Triassic Deposits: from the Platform to the Basin and Seamounts. International Conference on the Geology of Oman, Field guidebook, Excursion No. A01, Muscat, Oman, p. 40-48.
Baud, A. and S. Richoz 2005. The Permian-Triassic shallow carbonate Platform in Wadi Sathan (Jabal Akhdar). In A. Baud, H. Droste, F. Guilloucheau, P. Razin and C. Robin (Eds.), Mesozoic Evolution of the Tethyan margin of Oman. 24th IAS regional Meeting, Field guidebook BF4, Muscat, Oman, p. 1-25.

Baud, A., B. Beauchamp, C.M. Henderson and S. Richoz 2010. The Permian-Triassic transition on the Saiq Plateau. In A. Baud and M. Bernecker (Eds.), IGCP 572 Field Guide Book 2: The Permian-Triassic transition in the Oman Mountains. GUtech, Muscat, p. 34-47.

Béchennec, F., J. Roger, J. Le Métour and R. Wyns 1992. Explanatory notes to the Geological map of Seeb. Sheet NF40-03. Muscat, Oman Ministry of Petroleum and Minerals, 104 p.

Beurrier, M., F. Béchennec, D. Rabu and G. Hutin 1986. Explanatory notes to the geological map of the Rustaq Quadrangle, Sultanate of Oman. Geoscience map, scale 1:100,000, sheet NF 40-3D. Ministry of Petroleum and Minerals, Directorate General of Minerals, Sultanate of Oman, 69 p.

Coy, G.A. 1997. Dolomitisation of the Akhdar Group: The Arabian Platform of Oman. Unpublished PhD thesis, University of Cambridge, 164 p.

Coy, G.A. 2004. Geological excursion to the Saiq Plateau. Geological Society of Oman, Field Guide No. 8, 10 p.

Forbes, G.A., H.S.M. Jansen and J. Schreurs 2010. Lexicon of Oman subsurface stratigraphy: Reference guide to the stratigraphy of Oman’s hydrocarbon basins. GeoArabia Special Publication 5, Gulf PetroLink, Bahrain, 371 p.

Forke, H., M. Pöppelreiter, T. Aigner, B. Koehrer, L. Walz, D. Bendias and M. Haase 2012. Integrated biostratigraphy of the Saiq Formation (Al Jabal al-Akhdar, Oman Mountains) and its implication for the regional correlation of Khuff time-equivalent deposits. In Third Arabian Plate Geology Workshop, Part I The Permo-Triassic Sequence of the Arabian Plate, GeoArabia, v. 17, no. 1, p. 230-234.

Glennie, K.W., M.G. Boeuf, M.H.W. Hughes-Clarke, M. Moody-Stuart, W.F. Pilaar and B.M. Reinhardt 1974. Geology of the Oman Mountains. Verhandelingen van het Koninklijke Nederlands Geologisch Mijnbouwkundig Genootschap, no. 31, 423 p.

Hughes Clarke, M.W. 1988. Stratigraphy and rock unit nomenclature in the oil-producing area of interior Oman. Journal of Petroleum Geology, v. 11, no. 1, p. 5-60.

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

Koehrer, B., M. Zeller, T. Aigner, M. Poeppelreiter, P. Milroy, H. Forke and S. Al-Kindi 2010. Facies and stratigraphic framework of a Khuff outcrop equivalent: Saiq and Mahil formations, Al Jabal al-Akhdar, Sultanate of Oman. GeoArabia, v. 15, no. 2, p. 91-156.

Koehrer, B., T. Aigner and M. Pöppelreiter 2011. Field-scale geometries of Upper Khuff reservoir geobodies in an outcrop analogue (Oman Mountains, Sultanate of Oman). Petroleum Geoscience, v. 17, no. 1, p. 3-16.

Koehrer, B., T. Aigner, H. Forke and M. Pöppelreiter 2012. Middle to Upper Khuff (Sequences KS1 to KS4) outcrop-equivalents in the Oman Mountains: Grainstone architecture on a subregional scale. GeoArabia, v. 17, no. 4, p. 59-104.

Le Métour, J. 1987. Géologie de l’autochtone des Montagnes d’Oman: La fenêtre du Saih Hatat. PhD thesis, University Pierre et Marie Curie, Paris VI, France, 425 p. (Document Bureau de Recherches Géologiques et Minières no. 129, Orléans, France, 1988, 430 p.)

Montenat, C., A.F. de Lapparent, M. Lys, H. Termier, G. Termier and D. Vachard 1976. La transgression Permienne et son substratum dans le Jabal Akhdar (Montagnes d’Oman, Péninsule Arabique): Annales de la Société Géologique du Nord, Lille, France, v. 96, no. 3, p. 239-258.

Murphy, A.M. and A. Salvador 2000. International Subcommission on Stratigraphic Classification of IUGS International Commission on Stratigraphy. International Stratigraphic Guide-an abridged version. GeoArabia, v. 5, no. 2, p. 231-266. Reprinted with permission from Episodes, v. 22, no. 4, p. 255-271.
Pöppelreiter, M.C., C.J. Schneider, M. Obermaier, H.C. Forke, B. Koehrer and T. Aigner 2011. Seal turns into reservoir: Sudair equivalents in outcrops, Al Jabal al-Akhdar, Sultanate of Oman. GeoArabia, v. 16, no. 1, p. 69-108.

Rabu, D. 1987. Géologie de l’autochtone des montagnes d’Oman: La fenêtre du Jabal Akhdar. La semelle métamorphique de la Nappe ophiolitique de Semail dans les parties orientales et centrale des Montagnes d’Oman: Une revue. PhD thesis, University Pierre and Marie Curie, Paris VI. (Document Bureau de Recherches Géologiques et Minières, no. 130, Orléans, France, 1988, 582 p.)

Rabu, D., F. Béchennec, M. Beurrier and G. Hutin 1986. Explanatory notes to the geological map of the Nakhl Quadrangle, Sultanate of Oman. Geoscience map, scale 1:100,000, sheet NF 40-3E. Ministry of Petroleum and Minerals, Directorate General of Minerals, Sultanate of Oman. 42 p.

Richoz, S. 2006. Stratigrapie et variations isotopiques du carbone dans le Permien supérieur et le Trias inférieur de quelques localités de la Néo-Téthys (Turquie, Oman et Iran). Mémoire de Géologie de Lausanne, v. 46, 284 p.

Richoz, S., A. Baud, L. Krystyn, R. Twitchett and J. Marcoux 2005. Permo-Triassic Deposits of the Oman Mountains from Basin and Slope to the Shallow Platform. In 24th IAS Regional Meeting, Post-Conference Excursion A13, Muscat, Oman, p. 1-57.

Richoz, S., A. Baud, B. Beauchamp, S. Grasby, C.M. Henderson and L. Krystyn in press. Khuff margin: Slope to oceanic deposits (Permain-Triassic Allochthons and Exotics, Oman). In EAGE (Ed.), Khuff outcrop analogues across the Arabian Platform.

Richoz, S., L. Krystyn, A. Baud, R. Brandner, M. Horacek and P. Mohtat-Aghai 2010. Permain–Triassic boundary interval in the Middle East (Iran and N. Oman): Progressive environmental change from detailed carbonate carbon isotope marine curve and sedimentary evolution. Journal of Asian Earth Sciences, v. 39, no. 4, p. 236-253.

Villey, M., J. Le Métour and X. de Gramont 1986. Explanatory Notes to the Geological map of Fanjah Quadrangle, Sultanate of Oman. Geoscience map, scale 1:100,000, sheet NF 40-03F. Ministry of Petroleum and Minerals, Directorate General of Minerals, Sultanate of Oman, 68 p.

Weidlich, O. and M. Bernecker 2003. Supersequence and composite sequence carbonate platform growth: Permian and Triassic outcrop data of the Arabian platform and Neo-Tethys. Sedimentary Geology, v. 158, p. 87-116.

Weidlich, O. and M. Bernecker 2007. Differential severity of Permian–Triassic environmental changes on Tethyan shallow-water carbonate platforms. Global and Planetary Change, v. 55, p. 209-235.

Weidlich, O. and M. Bernecker 2010. The Permian-Triassic transition at Wadi Aday, Saih Hatat, Capital area. In A. Baud and M. Bernecker (Eds.), IGCP 572 Field Guide Book: The Permian-Triassic transition in the Oman Mountains. GUtech, Muscat, p. 17-33.

Weidlich, O. and M. Bernecker 2011. Biotic carbonate precipitation inhibited during the Early Triassic at the rim of the Arabian Platform (Oman). Palaeogeography, Palaeoclimatology, Palaeoecology, v. 308, p. 129-150.

Zeller, M., B. Koehrer, E.W. Adams, M. Pöppelreiter and T. Aigner 2011. Near well-scale heterogeneities in a Khuff outcrop equivalent (Saiq Plateau, Jebel Al Akhdar, Sultanate of Oman). Journal of Petroleum Geology, v. 34, no. 3, p. 241-260.
ABOUT THE AUTHORS

Aymon Baud earned his MSc in Geology, Palaeontology and Geophysics from Lausanne University, Switzerland, and his PhD in 1984 from Lausanne Geological Museum. His PhD dissertation focused on the Middle Triassic carbonate of the Prealps and Western Alps. Aymon was the Head of the Lausanne Geological Museum from 1986 until 2003. He was Chairman of the International Sub-commission on Triassic Stratigraphy between 1989–1996. He is currently working on the Committee on International Geological Correlation Program (IGCP), on past Tethys and Peri-Tethys programs and is a member of several geological societies (AGS, IAS, SGS, GSA and EAGE). Aymon has led or participated in field studies of 100s of stratigraphic sections all over the world, including many to the Sultanate of Oman during the past 24 years. He has published or co-published more than 150 articles (papers, books-guidebooks, maps, explanatory notes, etc.). Aymon is a specialist on Permian–Triassic carbon-isotope stratigraphy and carbonate sedimentology, and is actively engaged as a Geological Consultant.

aymon.baud@unil.ch

Sylvain Richoz studied Geology and Geochemistry at Lausanne University and was then Research Scientist at the Lausanne Geological Museum in Switzerland. He obtained his PhD in 2004 on sedimentology and stratigraphy of the Permian/Triassic Boundary interval in Oman, Turkey and Iran. Since then Sylvain worked on several projects at Vienna and Frankfurt universities. He is now Research Scientist at the Austrian Academy of Sciences in Graz and manages the light isotope labs of the Institute of Earth Sciences at Graz University. He was involved in several projects about chemostratigraphy, sedimentology and on the interaction between life evolution and ocean chemistry during the Late Permian to Early Jurassic. His main research interests are on the Permian–Triassic Boundary interval, the Middle Carnian Crisis and the End-Triassic mass extinction in the Neo-Tethys Realm (Austrian Alps to Himalaya).

sylvain.richoz@uni-graz.at

Manuscript submitted February 1, 2013;
Revised February 10, 2013;
Accepted March 4, 2013