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From the Editor

Launch of the Middle East Geologic Time Scale

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SUMMARY

With this issue of GeoArabia the first version of the *Middle East Geologic Time Scale* is launched. It provides the *time-rock language* by which geoscientists can communicate across the boundaries of countries, or from outcrop to subsurface, and with stratigraphers worldwide. Unlike previous stratigraphic charts for this region, this one will evolve in the scientific public domain through frequent revisions. These updates will be based on the documentation of the most recent published data and interpretations by stratigraphers working in different countries, whether for companies, universities or surveys.

GEOLOGIC TIME SCALE 2004

The three enclosed charts correlate Middle East rock units to time (million years before present – Ma) using two geologic scales. The first, the Geologic Time Scale *GTS 2004* of the International Commission on Stratigraphy – ICS (Gradstein et al., 2004), represents the current international agreements on the naming conventions for rock successions as defined by biostratigraphy. In the charts the stages are abbreviated by three letters (e.g. Apt for Aptian Stage), and formal geological divisions are written in full (e.g. Early Epoch of the Cretaceous Period, Mesozoic Era, Phanerozoic Eon, corresponding to the Lower Series of the Cretaceous System, Mesozoic Erathem, Phanerozoic Eonethem). Adopting GTS 2004 in the Middle Eastern charts not only offers numerical age estimates for biostages, but also provides the means for international geological communication.

For some periods GTS 2004 does not use the qualifiers "late, middle and early" but rather more cumbersome terms that render geological narratives and chart designs difficult to present. Some examples are the Carboniferous Period with its Mississippian and Pennsylvanian epochs. If used literally then one would have to write about the *Late Mississippian-Early Pennsylvanian pre-Unayzah hiatus* instead of the *mid-Carboniferous hiatus*. In order to retain more familar time connotations, the Middle East Scale is shown throughout with both formal and informal qualifiers, the latter being in quotation marks.

SEQUENCE STRATIGRAPHY AND TIME-ROCK UNITS

The second time scale, *AROS 2008* (Arabian Orbital Stratigraphy, Al-Husseini and Matthews, 2008), presents a framework for sequence stratigraphy, which is based on a tuned model of orbital forcing. It shows transgressive-regressive depositional sequences (DS), sequence boundaries (SB) and their ages in million years before present (Ma). This scale predicts that second-order sequence boundaries (denoted SB^2) occur every 14.58 million years starting with SB^2 1 at 16.1 Ma. Each second-order sequence (denoted DS^2) is predicted to contain six third-order sequences and these are uniquely numbered where observed sequences are tentatively recognized.

The *Haq et al. (1988)* column approximately positions their eustatic cycles in GTS 2004 and AROS 2008. The *Arabian Plate* column shows the maximum flooding surfaces (MFS) of Sharland et al. (2001, 2004) and Davies et al. (2002) according to GTS 2004 stages/ages (Simmons et al., 2007; Al-Husseini, 2007).

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Launch of the Middle East Geologic Time Scale (continued from p. 11)

by Moujahed I. Al-Husseini

Middle Eastern rock units (supergroup, group, formation, member) are listed in columns by country with simplified lithology colors. These units are correlated to geological stages by biostratigraphy or other age-dating methods using nomenclature from many papers, lexicons and books. In general, the stratigraphic interpretations of these units continue to rapidly evolve since their introduction in the literature many decades ago. Accordingly, lexicon-style papers are welcomed by GeoArabia and they will be used to update sections of the charts as appropriate. Indeed, in the case of subsurface Oman, Petroleum Development Oman and GeoArabia are currently preparing a revised Stratigraphic Lexicon for this country.

Also, where possible, the charts identify possible transgressive-regressive (T-R) sequences indicated by the *hourglass* symbol. Sequences may ultimately prove to be natural units for geological time scales and regional correlations because they are mostly controlled by orbital-forcing. In the charts rock units are shown to occupy a continuous time interval for graphical purposes; it is implicitly understood that short-lived hiatuses (about one or less million years) undoubtedly occur between and within them. Long-lived hiatuses are shown where recognized and their corresponding local unconformities are named.

DEFINING DEPOSITIONAL SEQUENCES

Recognizing, naming and defining T-R sequences is difficult for a variety of reasons, whether in the Middle East or elsewhere. Foremost is converging on a common geological interpretation. For example, when interpreting the *same* succession at outcrop, in a well or seismic image, many geoscientists have *agreed-to-disagree* on many fundamental aspects of how to characterize stratigraphic cycles in terms of sequences. Typical issues include: *What are the orders of the cycles? What surfaces represent sequence boundaries and which one is the MFS? What stage, age and duration can be attributed to the cycles?*

In the last issue of GeoArabia, Homewood et al. (2008) explained many of the challenges involved in describing the sequence stratigraphic architecture of the Cretaceous Natih Formation of Oman. In the Mesozoic chart shown here, the Natih Formation is interpreted to consist of six third-order orbital sequences (Matthews and Frohlich, 2002).

Natih I-1 to Natih I-6 are interpreted as fourth-order orbital sequences (each with a duration of 0.405 My) that group to form the oldest Natih third-order sequence (denoted DS^3 7.1 with a total depositional duration of 2.43 My). Natih I-7 is bounded by two sequence boundaries (incision surfaces IS1 and IS2) and apparently consists of six seismic clinoforms. It is interpreted as another third-order sequence (DS^3 7.2 lasting 2.43 My). Natih II to IV are mapped in outcrop and subsurface, whereas Natih V is only recognized in outcrop and completes the second-order sequence DS^2 7. The positioning of the Natih Sequences in the Mesozoic Chart shows they occupy the Upper Albian to Turonian stages with the uppermost ones truncated by the Turonian unconformity. This assignment is consistent with the radiometric dating of the initial emplacement of the Semail Ophiolite in Oman in mid-Turonian (Searle, 2007).

HINTS OF MANY MORE SEQUENCES

Very few Middle East sequences have been published in the detail presented by Homewood et al. (2008) for the Natih Formation. Nevertheless, many aspects of third-order eustatic cycles have already been recognized in many regions and informally named in papers; some examples are:

- Biozones GOS S10 to S80 separated by paleontological terraces GOS T00 to T70 in the Miocene-Pliocene of the Gulf of Suez in Egypt (Wescott et al., 1996; Krebs et al., 1997);
- Palani to Injana formations/sequences of Iraq (van Bellen et al., 1959-2005);
- Rus 1–3 and Dammam 1–3 Sequences of Qatar (Dill et al., 2003; 2007);

- Aruma Sequences 1–4 of Saudi Arabia (Philip et al., 2002; Le Nindre et al., 2008);
- Habshan I–III and Zakum IV Sequences of the United Arab Emirates (Aziz and El-Sattar, 1977) and Habshan 1–6 of Oman (Droste and van Steenwinkel, 2004);
- Ulayyah and Hawtah Sequences of Saudi Arabia (Al-Husseini et al., 2006; Hughes et al., 2008).

Other sequences and regional boundaries are shown in the charts based only on conference abstracts. With supporting data and analysis, some of these could provide important constraints to the charts; for example, to name just a few:

- Arabian Gulf Sequence Boundaries AG1 to AG9 (Steinhauff et al., 2004);
- Kolosh, Sinjar and Sagerma Sequences of Iraq (Lawa and Albayati, 2008);
- Marrat Sequences of Kuwait (Dey et al., 2008).

For the Middle East, the Triassic, Permian and upper Carboniferous naturally group into one chart bounded by the Early Jurassic and mid-Carboniferous hiatuses. The Permian and upper Carboniferous sequences were previously discussed together with their possible regional correlations (Al-Husseini, 2006) and these are shown here with minor revisions. The reported position of the Permian-Triassic (PTr) Boundary is shown in several columns but remains unresolved regionally. The correlation of the Triassic rock units is considered in terms of second-order orbital sequences DS^2 14 to 17, with the Carnian Salt Crisis offering a potential marker for regional correlations.

The sequence stratigraphy of the mid-Carboniferous to Neoproterozoic is least understood and most of their rock units are best represented as lithostratigraphic units. A notable exception is the progress in identifying sequences in subsurface Oman (e.g. Droste, 1997; Cozzi and Al-Siyabi, 2004). Regional correlation of these oldest Omani sequences, however, requires better age control. For example, the three columns dedicated to Iran were submitted by Vachik Hairapetian (written communication, 2008) based on studies published in the Farsi language. The resulting correlations between Iran and Oman differ significantly from those in Allen (2007). In the latter paper, the Iranian Soltanieh Formation is mostly correlated to Oman's Nafun Group rather than the much younger Ara Salt Group. This is a good example of how a proposal for one country's column has ramifications for regional correlations across the Middle East. This particular example, and many others, will require much further evaluation with the results presented in published notes and revised charts.

CAN GEOLOGICAL TIME BE ESTABLISHED IN THE MIDDLE EAST?

To confidently define T-R sequences requires the type of multidisciplinary data and interpretative rigor as, for example, documented by Homewood et al. (2008). To assign their Natih sequences unambiguously to stages is another matter – and well beyond the resolution of biostratigraphy. Indeed the stage assignment of most rock units in the Middle East remains unresolved nearly a century after oil was first discovered in this region. With a few exceptions of radiometric dating of igneous rocks (e.g. Ara Group of Oman, Amthor et al., 2003), the Middle East Geological Time Scale cannot be constrained in absolute age. Moreover, correlations to various reference isotope curves are generally equally ambiguous in constraining biostage/age assignments. This predicament is an empirical fact that cannot be circumvented.

This is why the charts are purpose-built with *pigeon boxes* that adopt the orbital scheme proposed by Al-Husseini and Matthews (2008). Testing the accuracy and practicality of this scheme is not trivial because orbital-forcing modeling (Laskar et al., 2004) and its application to sequence stratigraphy (Matthews and Frohlich, 2002) remains empirically untested. Most stratigraphers who have studied cyclostratigraphy have focused on periodicities of c. 20–40 thousand years (Ky) (precession and obliquity) and c. 100 Ky (so-called *short eccentricity*). But these are not stable periods and cannot therefore be used to convert rock cycles to time intervals. Indeed the only predicted orbital chronometer runs at 0.405 My/cycle (back to at least the Permian Period, Laskar et al., 2004), and it is the one that builds third-order sequences (e.g. 2.025, 2.43, 2.835 My cycles) and prominent combinations of these, mainly 4.86 (12 x 0.405 My) and 14.58 My (36 x 0.405).

MIDDLE EAST GEOLOGICAL TIME SCALE 2009 AND BEYOND

Middle Eastern geoscientists recognize the importance of interpreting the high-resolution stratigraphy of their producing reservoirs and exploration targets. However, comparing their interpretations to those in other countries and regions continues to be a challenge. This can be achieved – step-by-step – by improving the accuracy and resolution of the geological time scales that are launched here. For example, a major upgrade to the Aptian Stage will accompany the publication of GeoArabia Special Publication 4 in 2009. This book is in progress with more than 15 papers dedicated to the Shu'aiba Formation.

The present 2008 launch is therefore only a modest start at presenting this complex stratigraphic matrix. Undoubtedly many iterations will be required to make it more accurate and useful. These will involve moving rock units up-or-down in time; or adding new columns for better spatial control; or including more rows to depict higher temporal resolution. Additionally, tectono-structural events will need to be distinguished by highlighting regional angular unconformities. So please send your proposed moves with scientific justification to me at geoarabi@batelco.com.bh.

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