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STRATIGRAPHIC NOTE

Revised ages (Ma) and accuracy of Arabian Plate maximum flooding surfaces

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Assigning an age in million years before present (Ma) to maximum flooding surfaces (MFS, or any other isochronous sequence stratigraphic surface) can be a misleading practice unless the level of accuracy is adequately quantified.

Nonetheless, many authors (e.g. Haq et al., 1988; Sharland et al., 2001, 2004; Haq and Al-Qahtani, 2005; Simmons et al., 2007) have assigned precise ages to MFS and sequence boundaries using different vintages of the geological time scale (GTS). This practice remains useful because it provides very approximate constraints on rates of deposition, durations of sequences and their orders, and hiatuses. This note compares how age revisions in GTS affect the numerical age assignment of Arabian Plate MFS.

Sharland et al. (2001, 2004, Table 1) published the biozones, their corresponding stages and estimated age values of 65 Arabian Plate MFS based on the GTS 1996 (Gradstein and Ogg, 1996). These authors also correlated the ages of their Cenozoic and Mesozoic MFS to those of Haq et al. (1988). Haq and Al-Qahtani (2005) adopted the 63 Phanerozoic MFS of Sharland et al. (2001, 2004), but did not consider Neoproterozoic Pc10 and Pc20. They positioned the remaining 63 MFS (with minor modifications) in the stratigraphic column of Saudi Arabia, and revised their ages based on GTS 2004 (Gradstein et al., 2004; *see* GTS 2004 *in* GeoArabia, 2007, v. 12, no. 1, p. 208-209).

GTS 2004 has been ratified by the International Commission on Stratigraphy (ICS) and includes stage names that are recommended for global correlations (Gradstein et al., 2004; Gradstein and Finney, 2007). The estimated ages of the stage boundaries have been compared by the ICS across various vintages of the Geological Time Scale, starting with the GTS 1937 of Holmes and ending with GTS 2004. These comparisons were reprinted by permission of the ICS *in* Al-Husseini (2005, see Cenozoic Comparison Chart on p. 140; Mesozoic Comparison Chart on p. 142; and Paleozoic Comparison Chart on p. 144).

Most recently Simmons et al. (2007) revised the age estimates of the 63 Phanerozoic MFS of Sharland et al. (2001, 2004) using GTS 2004. Changes in the age estimate for an MFS mostly occur because the bounding ages of stages were revised due to better radiometric and other age-dating techniques. The dating of an MFS may also change because either (1) the reference section pick was revised (i.e. it is placed in a different body of rock belonging to a different biozone), or (2) the biostratigraphy of the reference section was revised by, for example, the discovery of new fossils offering a more correct biozonal assignment.

In Table 1 the 63 Phanerozoic MFS age estimates (Sharland et al., 2001, 2004) are compared to those of Haq et al. (1988), Haq and Al-Qahtani (2005) and Simmons et al. (2007). The comparison does not account for changes due to revised positions or biozones (stage) of the MFS, and mostly reflects GTS revisions. Column (1) of Table 2 compares the age differences between Haq et al. (1988) and Haq and Al-Qahtani (2005) for the 38 Mesozoic-Cenozoic MFS that were identified in Arabia. Of these 38 MFS, 13 have ages that shifted by less than 3.0 My, 11 shifted by 3.0–6.0 My and 14 shifted by more than 6.0 My.

Shifts in age of 3.0 My or more are significant because the duration of a third-order sequence is generally estimated to be 2.0, 2.4 or 2.8 My (Matthews and Frohlich, 2002). Age shifts of more than 3.0 My are substantial and reflect the inherent inaccuracy of GTSs from vintage-to-vintage.

Column (2) of Table 2 compares the age differences between Sharland et al. (2001, 2004) based on GTS 1996 and Simmons et al. (2007) based on GTS 2004 for the 63 Phanerozoic Arabian MFS. Nearly half (27) have changed ages by one-or-less million years (My), approximately one quarter (15) MFS shifted in age by 1.0–3.0 My. One-third (21) of the MFS shifted in age by more than 3.0 My. In some cases, several MFS were closely spaced in Sharland et al. (2001, 2004) and the large shifts imply a different order. For example, the Permian MFS P20, P30 and P40 (Khuff sequences) only spanned 3.5 My in Sharland et al. (2001), suggesting fourth-order MFS; whereas in Simmons et al. (2007) they span 13.0 My, thus implying they are third-order MFS.

Table 1: Comparison of Ages of Maximum Flooding Surfaces

Sharland et al. (2001, 2004*)						Haq et al. (1988)	Haq and Al-Qahtani (2005)	Simmons et al. (2001)	
MFS	**Era**	**Period**	**Epoch**	**Stage**	**Age**	**Age**	**Age**	**Age**	**Stage**
Ng40	Cenozoic	Neogene	Miocene	Late Serravalian	12.0	11.6	14.6	14.5	Late Langhian
Ng30	Cenozoic	Neogene	Miocene	Late Langhian	15.0	15.0	15.9	15.9	Early Langhian
Ng20	Cenozoic	Neogene	Miocene	Mid-Burdigalian	18.0	18.5	18.5	17.5	Mid-Burdigalian
Ng10	Cenozoic	Neogene	Miocene	Aquitanian	23.0	24.8	20.0	20.0	Early Burdigalian
Pg50*	Cenozoic	Paleogene	Oligocene	Chattian	24.5	NA	24.0	24.5	Chattian
Pg40*	Cenozoic	Paleogene	Oligocene	Rupelian-Chattian	29.0	NA	29.0	29.0	Late Rupelian
Pg30	Cenozoic	Paleogene	Oligocene	Early Rupelian	33.0	35.0	33.0	33.0	Early Rupelian
Pg20	Cenozoic	Paleogene	Eocene	Late Ypresian	49.0	49.0	48.6	50.0	Late Ypresian
Pg10	Cenozoic	Paleogene	Paleocene	Late	58.0	56.5	59.0	59.0	Selandian
K180	Mesozoic	Cretaceous	Late	Mid-Maastrichtian	68.0	69.5	68.0	70.0	Early Maastrichtian
K170	Mesozoic	Cretaceous	Late	Mid-Campanian	78.0	79.5	78.0	78.0	Mid-Campanian
K160	Mesozoic	Cretaceous	Late	Santonian	85.0	86.0	85.0	85.0	Santonian
K150	Mesozoic	Cretaceous	Late	Early Coniacian	88.0	89.0	88.0	88.0	Early Coniacian
K140	Mesozoic	Cretaceous	Late	Early Turonian	93.0	91.5	93.0	93.0	Early Turonian
K130	Mesozoic	Cretaceous	Late	Mid-Cenomanian	95.0	94.7	95.0	95.5	Mid-Cenomanian
K120	Mesozoic	Cretaceous	Late	Early Cenomanian	98.0	95.75	98.0	99.0	Early Cenomanian
K110	Mesozoic	Cretaceous	Early	Late Albian	101.0	97.0	101.0	100.5	Late Albian
K100	Mesozoic	Cretaceous	Early	Mid-Albian	106.0	104.0	106.0	108.0	Mid-Albian
K90	Mesozoic	Cretaceous	Early	Early Albian	111.0	107.0	111.0	110.0	Early Albian
K80	Mesozoic	Cretaceous	Early	Mid-Aptian	116.0	?111.0	117.0	119.0	Mid-Aptian
K70	Mesozoic	Cretaceous	Early	Early Aptian	120.0	?111.0	122.5	124.5	Early Aptian
K60	Mesozoic	Cretaceous	Early	Late Barremian	123.0	114.0	126.0	125.5	Late Barremian
K50	Mesozoic	Cretaceous	Early	Early Barremian	126.0	116.5	129.0	129.0	Early Barremian
K40	Mesozoic	Cretaceous	Early	Late? Hauterivian	129.0	118.0	132.0	134.5	Early Hauterivian
K30	Mesozoic	Cretaceous	Early	Early Valanginian	136.0	127.5	139.0	140.0	Early Valanginian
K20	Mesozoic	Cretaceous	Early	Late Berriasian	138.0	128.75	141.0	142.0	Late Berriasian
K10	Mesozoic	Cretaceous	Early	Early Berriasian	143.0	132.5	144.0	145.0	Early Berriasian
J110	Mesozoic	Jurassic	Late	Mid-Tithonian	147.0	137.0	147.0	147.0	Mid-Tithonian
J100	Mesozoic	Jurassic	Late	Late Kimmeridgian	150.75	NA	150.75	151.0	Late Kimmeridgian
J90	Mesozoic	Jurassic	Late	Late Kimmeridgian	151.25	NA	151.5	151.4	Late Kimmeridgian
J80	Mesozoic	Jurassic	Late	Late Kimmeridgian	151.75	NA	152.50	151.8	Late Kimmeridgian
J70	Mesozoic	Jurassic	Late	Late Kimmeridgian	152.25	138.50	154.0	152.2	Late Kimmeridgian

Table 1 (Continued):

Sharland et al. (2001, 2004)						Haq et al. (1988)	Haq and Al-Qahtani (2005)	Simmons et al. (2001)	
MFS	**Era**	**Period**	**Epoch**	**Stage**	**Age**	**Age**	**Age**	**Age**	**Stage**
J60	Mesozoic	Jurassic	Late	Early Kimmeridgian	154.0	144.5	155.0	155.25	Late Oxfordian
J50	Mesozoic	Jurassic	Late	Mid-Oxfordian	156.0	150.0	158.0	159.0	Early Oxfordian
J40	Mesozoic	Jurassic	Middle	Mid-Callovian	162.0	153.5	163.0	162.5	Mid-Callovian
J30	Mesozoic	Jurassic	Middle	Early Bathonian	168.0	163.5	167.0	167.5	Early Bathonian
J20	Mesozoic	Jurassic	Middle	Early Bajocian	175.0	170.0	170.0	171.0	Early Bajocian
J10	Mesozoic	Jurassic	Early	Mid-Toarcian	185.0	183.5	180.0	181.0	Mid-Toarcian
Tr80	Mesozoic	Triassic	Late	Norian	215.0	223.0	211.0	208.0	Norian
Tr70	Mesozoic	Triassic	Late	Carnian	222.0	225.5	220.0	220.0	Carnian
Tr60	Mesozoic	Triassic	Late	Carnian	226.0	229.5	226.0	227.0	Carnian
Tr50	Mesozoic	Triassic	Middle	Ladinian	233.0	235.0	234.0	233.0	Ladinian
Tr40	Mesozoic	Triassic	Middle	Anisian	238.0	238.0	241.0	242.0	Anisian
Tr30	Mesozoic	Triassic	Early	Mid-Scythian	245.0	241.0	249.75	249.7	Olenekian/Induan
Tr20	Mesozoic	Triassic	Early	Scythian	246.0	243.0	250.0	250.0	Induan
Tr10	Mesozoic	Triassic	Early	Scythian	248.0	245.5	250.5	250.5	Induan
P40	Paleozoic	Permian	Late	Late Tatarian	249.0	NA	254.0	253.0	Lopingian, Changsingian
P30	Paleozoic	Permian	Late	Late Tatarian	250.0	NA	255.0	256.0	Lopingian, Wuchiapingian
P20	Paleozoic	Permian	Late	Late Kazanian	252.5	NA	261.0	266.0	Guadalupian, Wordian
P10	Paleozoic	Permian	Early	Late Sakmarian	272.0	NA	287.0	286.0	Late Sakmarian
C10	Paleozoic	Carboniferous	Early	Late Visean	333.0	NA	333.0	330.0	Late Visean
D30	Paleozoic	Devonian	Late	Late Famennian	355.0	NA	361.0	363.0	Late Famennian
D20	Paleozoic	Devonian	Early	Late? Emsian	393.0	NA	401.0	400.0	Emsian
D10	Paleozoic	Devonian	Early	Late Pragian	402.0	NA	408.0	408.0	Pragian
S20	Paleozoic	Silurian	Late	Late Pridoli	418.0	NA	418.0	417.5	Pridoli
S10	Paleozoic	Silurian	Early	Mid-Aeronian	440.0	NA	440.0	437.0	Aeronian
O40	Paleozoic	Ordovician	Late	Late Caradoc	453.0	NA	454.0	453.0	Katian
O30	Paleozoic	Ordovician	Middle	Late Llanvirn	465.0	NA	469.0	464.0	Darriwilian
O20	Paleozoic	Ordovician	Early	Late Tremadocian	487.0	NA	483.0	480.0	Tremadocian
O10	Paleozoic	Ordovician	Early	Early Tremadocian	494.0	NA	486.0	488.0	Tremadocian
Cm30	Paleozoic	Cambrian	Late	Early Dolgellian	502.0	NA	496.0	498.0	Furongian, Paibian
Cm20	Paleozoic	Cambrian	Middle	Middle Minevian	510.0	NA	506.0	505.0	Series 3, Drumian
Cm10	Paleozoic	Cambrian	Early	not specified	540.0	NA	538.0	542.0	Base Cambrian
Pc20	Precambrian	Vendian	Late	not specified	550.0	NA	NA	NA	NA
Pc10	Precambrian	Vendian		not specified	570.0	NA	NA	NA	NA

Table 2: Differences in Age Estimates of MFS

Time Shift (My)	(1) Haq et al. (1988) and Haq and Al-Qahtani (2005)	(2) Sharland et al. (2001) and Simmons et al. (2007)	(3) Haq and Al-Qahtani (2005) and Simmons et al. (2007)
1.0	7	27	45
> 1.0 to 3.0	6	15	14
> 3.0 to 6.0	11	14	2
> 6.0	14	7	0
Total MFS	**38**	**63**	**61**

The estimated ages of MFS can also differ when different authors interpret the same sequences using the same GTS. The magnitude, in this case, is much less but still significant. This can be illustrated when comparing the age estimates of Haq and Al-Qahtani (2005) to those of Simmons et al. (2007); both are based on Arabia's sequence stratigraphy and GTS 2004 (Table 2, Column 3). In this comparison, 45 MFS have ages that differ by one or less million years. About a quarter (14) differ by 1.0–3.0 My and two differ by more than 3.0 My.

Any apparent convergence in estimated ages between different authors using the same GTS and/or sequences is not, however, an indication of chronostratigraphic *accuracy*. It reflects the level of *precision* in estimating age values using the same data. Therefore it is important not to refer to an MFS by its estimated age value alone. This is because an MFS (or isochronous surface), as defined in a particular study, has a well-defined position in the rock column and/or biozone. The absolute age value, however, should carry an error bar that reflects the age extent of the biozone in which the MFS occurs and the uncertainty of absolute age values for that interval of geological time.

Applying numerical error analysis to geological time may not be straightforward. Consider, for example, the cited one standard deviation for the age of the Aptian/Barremian boundary. It was recalibrated from 121.0 ± 1.4 Ma in GTS 1996 to 125.0 ± 1.0 Ma in GTS 2004; but a shift of 4.0 My (121.0 to 125.0 Ma) exceeds the standard deviation cited for both estimates (1.0 and 1.4 My).

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