GeoArabia, Vol. 10, No. 3, 2005
Gulf PetroLink, Bahrain

Stratigraphic Note: Orbital-forcing calibration of the Late Cretaceous and Paleocene Aruma Formation, Saudi Arabia

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The Aruma Formation, in the outcrops of central Saudi Arabia, represents a part of a regional Late Cretaceous-Paleocene transgression that flooded the entire Arabian Platform. In many parts of the Arabian Peninsula, the transgression was preceeded by a long-lasting time hiatus that spanned much of Late Cretaceous (Turonian, Coniacian, Santonian and Campanian stages). This hiatus corresponds to the Pre-Aruma Unconformity, and is attributed to regional eastward tilting of the Arabian Plate and tectonism along the Tethyan margin.

The Aruma Formation is divided from oldest to youngest into three members (Figure 1): Cretaceous Khanasir and Hajajah members, and Paleocene Lina Member (Vaslet et al., 1988, 1991; Le Nindre et al., 1990; Philip et al., 2002). According to biostratigraphic studies the Lina/Hajajah Boundary represents the Paleogene/Cretaceous (Cenozoic/Mesozoic or Tertiary/Cretaceous: KT) Boundary (Philip et al., 2002). The biostratigraphic age of the Cretaceous part of the Aruma is variably reported as late Campanian-Maastrichtian (Vaslet et al., 1988, 1991; Le Nindre et al., 1990; Le Nindre, personal communication, 2005) or late Maastrichtian (see Philip et al., 2002 for a full discussion of biostratigraphy).

The Base Aruma Boundary was interpreted by Al-Husseini and Matthews (2005) as an orbital second-order sequence boundary (denoted SB^2 5) with an age of c. 72.2 Ma (late Campanian). This interpretation was based on a simplified orbital-forcing model of the Phanerozoic sea level that predicted second-order sequence boundaries to be periodic at 14.58 million years (my). Above SB^2 5, the second-order depositional sequence DS^2 5 was interpreted to have lasted from c. 72.2 to 57.6 Ma (Paleocene, late Thanetian according to the Geological Time Scale GTS 2004, Gradstein et al., 2004), and to consist of the Aruma and the Paleogene Lower Umm er Radhuma formations (Figure 2).

Another prediction of the orbital-forcing model is that a second-order depositional sequence should consist of no more than six third-order depositional sequences (DS^3) each having a period of 2.43 $\pm$ .405 my. In turn the six DS^3s should each consist of 5, 6 or 7 fourth-order depositional sequences (DS^4), each having a period of 0.405 my (referred to as the "geological tuning fork" by Matthews and Frohlich, 2002). In this note we apply this orbital template to calibrate the sequence and chronostratigraphy of the Cretaceous part of the Aruma Formation in the outcrops of Saudi Arabia.

Philip et al. (2002) interpreted the Aruma Formation in terms of a "large accomodation" cycle that encompasses the entire formation (Figure 1). In turn, these authors interpreted the large cycle in terms of four "medium" cycles names Ar1 to Ar4. The Ar1 to Ar3 cycles are further divided into 13 "small" cycles or parasequences.

The first striking observation in applying the orbital template to the Aruma Formation (Figure 1), is that the terminal Cretaceous Ar3 cycle was interpreted by Philip et al. (2002) as six parasequences numbered Ar3a to Ar3f. These parasequences are of comparable thickness (ranging from about 5 to 13 m), and each represents a high-frequency trangessive-regressive cycle. According to Phillip et al., Sequence Ar3 is separated from the underlying Sequence Ar2 (Ar3/Ar2 Boundary) by "a major erosional surface that has a relief of about 10 m. The geometry of the surface suggests that an irregular channel-like erosional pattern developed after cementation of the underlying rudist carbonate platform, probably during a sea-level lowstand." The Lina/Hajajah (Aruma Ar4/Ar3) Boundary is described as a sequence boundary represented by an "erosion surface" and "disconformity" that according to Thomas (*in* Philip et al., 2002) "probably corresponds to a hiatus of several million years."

The interpretation of six parasequences (Ar3a to Ar3f) within two sequence boundaries (Ar3/Ar2 and Ar4/Ar3) suggests that Sequence Ar3 is an orbital third-order depositional sequence (DS^3 = 2.43 my) consisting of apparently six fourth-order depositional sequences (DS^4 = 0.405 my).

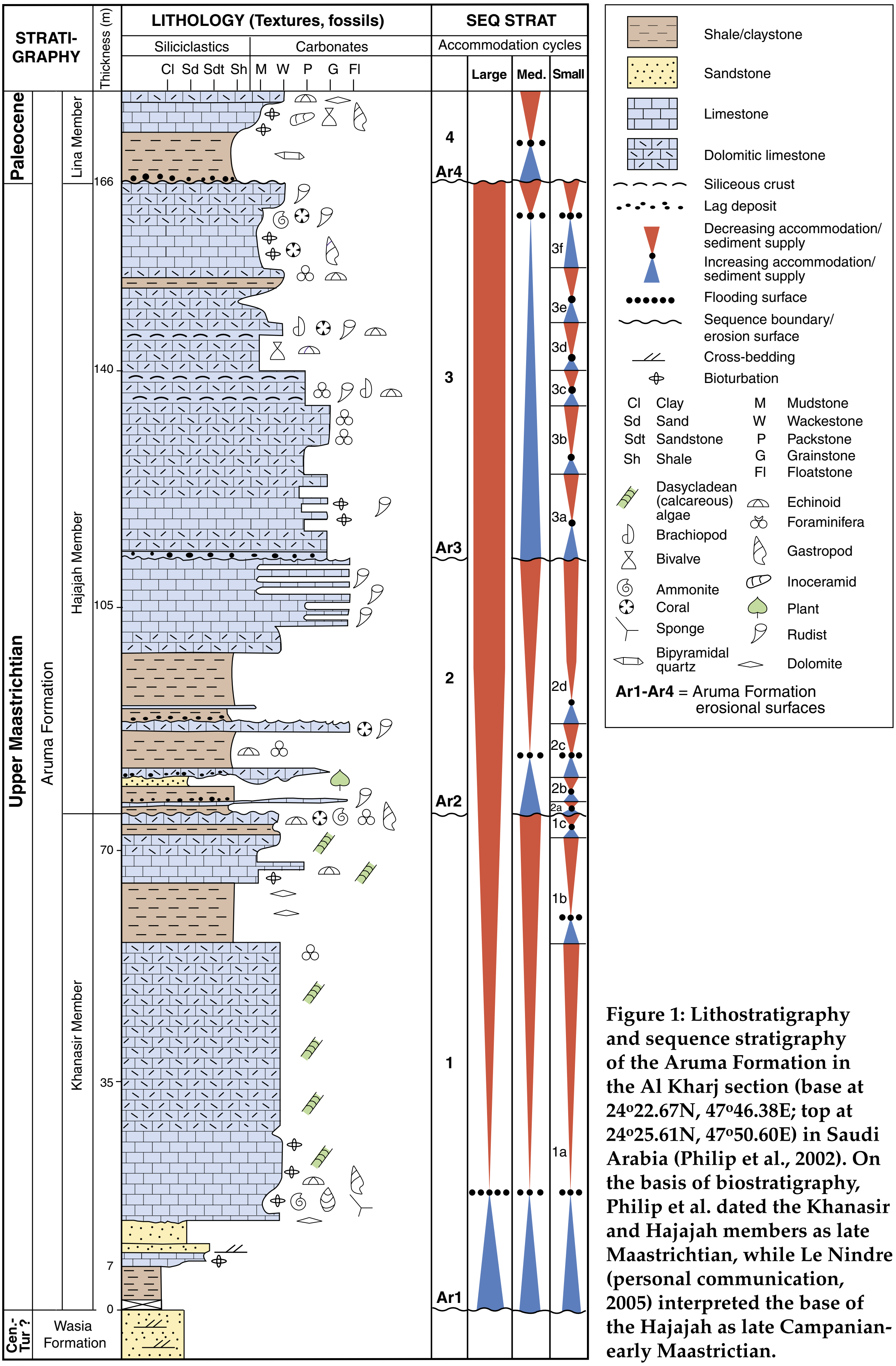

Figure 1: Lithostratigraphy and sequence stratigraphy of the Aruma Formation in the Al Kharj section (base at 24°22.67N, 47°46.38E; top at 24°25.61N, 47°50.60E) in Saudi Arabia (Philip et al., 2002). On the basis of biostratigraphy, Philip et al. dated the Khanasir and Hajajah members as late Maastrichtian, while Le Nindre (personal communication, 2005) interpreted the base of the Hajajah as late Campanian-early Maastrictian.

A second striking observation (Figure 1) is that the Cretaceous cycles Ar1 and Ar2 have comparable thicknesses to that of the Ar3 cycle; thus suggesting they too are orbital third-order sequences. Cycles Ar1 and Ar2 are separated by a "conspicuous hardground" (Ar2/Ar1 Boundary, Philip et al., 2002). Unlike the Ar3 cycle, cycles Ar1 and Ar2 consist of parasequences that have substantially uneven thickness (e.g. Ar1a is about 10 times thicker than Ar1c; Ar2d is about 10 times thicker than Ar2a). The uneven thickness of the Ar1 and Ar2 parasequences suggests that within the thick limestone and dolomite intervals (e.g. Ar1a and Ar2d) the signatures of some of the fourth-order cycles are not distinct nor easily recognizable.

The sequence stratigraphic architecture suggested by the Ar1 to Ar3 cycles is that they are three orbital third-order sequences that spanned a time period of c. 7.29 million years (3 x 2.43 my) between c. 72.2 and 64.9 Ma. In this calibration the top of the youngest Cretaceous Sequence Ar3 would fall at 64.9 Ma, or within 0.3–0.9 my (based on one standard deviation of 0.3 my) from the age of the Paleogene/Cretaceous Boundary (65.5 $\pm$ 0.3 Ma, Gradstein et al., 2004). This calibration is consistent with the correlation of the Aruma Ar4/Ar3 (Lina/Hajajah) Boundary to the Paleogene/Cretaceous Boundary (Philip et al., 2002).

Figure 2 summarizes the orbital-forcing interpretation and implied chronostratigraphy of the Aruma Formation in terms of GTS 2004 (Gradstein et al., 2004). In the proposed interpretation, the Base Aruma is correlated to SB^2 5 at 72.2 Ma (Al-Husseini and Matthews, 2005) in late Campanian as consistent with the interpretation of Le Nindre (2005, personal communication). Aruma Sequences Ar1 to Ar3 are correlated to orbital third-order sequences DS^3 5.1 to DS^3 5.3, with the Ar3 parasequences (Ar3a to Ar3f) correlated to orbital fourth-order sequences DS^4 5.3.1 to DS^4 5.3.6. The Aruma Ar4/Ar3 Boundary (Lina/Hajajah Boundary) is correlated to SB^3 5.4 predicted at c. 64.9 Ma, and c. the Paleogene/Cretaceous Boundary at 65.5 Ma (Philip et al., 2002).

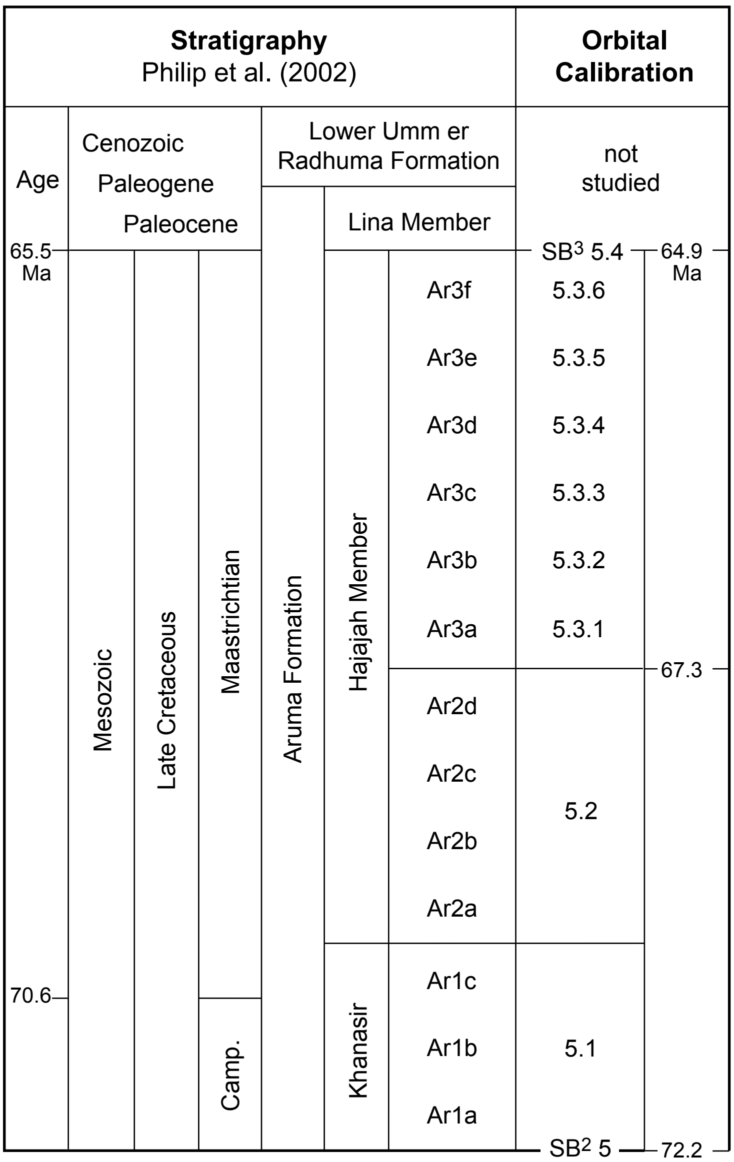

Figure 2: Orbital-forcing model of the Aruma Formation proposes correlating the Cretaceous Sequences Ar1 to Ar3 (Philip et al., 2002) to three orbital third-order sequences, DS^3 5.1, DS^3 5.2 and DS^3 5.3, that were deposited between about 72.2 Ma in late Campanian, and 64.9 Ma (i.e. close to the age of the Cenozoic/ Mesozoic Boundary dated at 65.5 Ma, Gradstein et al., 2004). Terminal Cretaceous Sequence Ar3 consists of 6 parasequences (Ar3a to Ar3f) that are correlated to fourth-order sequences DS^4 5.3.1 to DS^4 5.3.6

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