

Stratigraphic Note: Orbital-forcing calibration of the Late Jurassic (Oxfordian-early Kimmeridgian) Hanifa Formation, Saudi Arabia

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The Jurassic Period in Saudi Arabia is represented by the deposition of the Shaqra Group (Figure 1 after Fischer et al., 2001; Powers et al., 1966; Powers, 1968; Manivit et al., 1990). This group includes the prolific Arab reservoirs. In the Arabian Orbital Stratigraphy (AROS) framework, Al-Husseini and Matthews (2005) correlated model second-order sequence boundary SB² 11 (predicted at c. 159.7 Ma in the early Oxfordian Stage; i.e. younger than Oxfordian/Callovian = Late/Middle Jurassic = 161.2 ± 4.0 Ma; Gradstein et al., 2004) to the boundary between the Hanifa Formation and underlying Tuwaiq Mountain Limestone (denoted Hanifa/Tuwaiq) in Saudi Arabia and Oman. In the subsurface of eastern Saudi Arabia (C.D. Redmond, *in* Powers, 1968) and Oman (Rousseau et al., 2005; 2006), the signature of the maximum sea-level drop associated with SB² 11 is manifested as a regional unconformity that involved erosion of the Tuwaiq Mountain followed by Hanifa onlap.

Above the Hanifa/Tuwaiq Boundary, orbital second-order depositional sequence DS² 11 is interpreted to consist of the Hanifa, Jubaila, Arab and Hith formations (Figure 1), and to have been deposited in a period of about 14.58 million years (my) from c. 159.7 to 145.1 Ma (Al-Husseini and Matthews, 2005). This note focuses on the stratigraphic architecture of the Hanifa Formation. Unlike the erosional Hanifa/Tuwaiq Boundary, the Jubaila/Hanifa Boundary is apparently conformable (Powers, 1968) and is here interpreted as a third-order sequence boundary (SB³).

Hanifa Formation, Shaqra Group

Vaslet et al. (1983) divided the Hanifa Formation in the Wadi ar Rayn quadrangle, central Saudi Arabia, into two formal members: Hawtah Member (52.5 m thick) and overlying Ulayyah Member (53 m thick). The basal Ulayyah consists of a 4.5 m-thick bioclastic coral limestone (rich in echinoderm debris) with a carbonate-pebble conglomeratic base filling channels cut in the Hawtah Member. In the outcrops of Ar Riyad quadrangle the Hawtah (57 m) and Ulayyah (68 m) members (Vaslet et al., 1991; Mattner and Al-Husseini, 2002) each consists of 4 units (from base-up):

Hawtah Member

Unit 1: (15 m) Yellow fossiliferous (brachiopods, bivalves) clayey limestone and beige bioclastic limestone.

Unit 2: (22 m) Yellowish to gray clayey limestone interspersed with ocher bioclastic and pelletoidal calcarenite containing rare silicified stromatoporoids and with three massive meter-thick beds of beige to ocher bioclastic cherty limestone.

Unit 3: (10 m) Cream pelletoidal clayey limestone and ocher bioclastic and intraclastic calcarenite. This assemblage has yielded large nautili (1 m in diameter) and is capped by a hardground.

Unit 4: (10 m) Yellowish clayey limestone, bioclastic limestone containing rare ammonites, and gray bioturbated limestone in the upper part.

Ulayyah Member

Unit 1: (15 m) Yellow to gray clayey limestone with silicified corals and stromatoporoids; ocher bioclastic and pelletoidal calcarenite showing hummocky stratification.

Unit 2: (15 m) Cream reef limestone containing silicified corals and stromatoporoids, forming massive biostromal beds 50 cm thick; yellow to gray bioclastic limestone interrupted by several hard-grounds.

Unit 3: (15.5 m) Cream bioclastic massive reef limestone, containing silicified corals and stromatoporoids, either in growing position or broken; ocher oncolitic intraclastic calcarenite.

Unit 4: (22.5 m) Ocher pelletoidal, bioclastic, and lithoclastic (reworking of mudstone pebbles) calcarenite forming massive beds 50 cm thick, interspersed with cream clayey limestone (mudstone). This assemblage is capped by a massive meter-thick bed of ocher pelletoidal cross-bedded calcarenite.

Jurassic Shaqra Group, Saudi Arabia

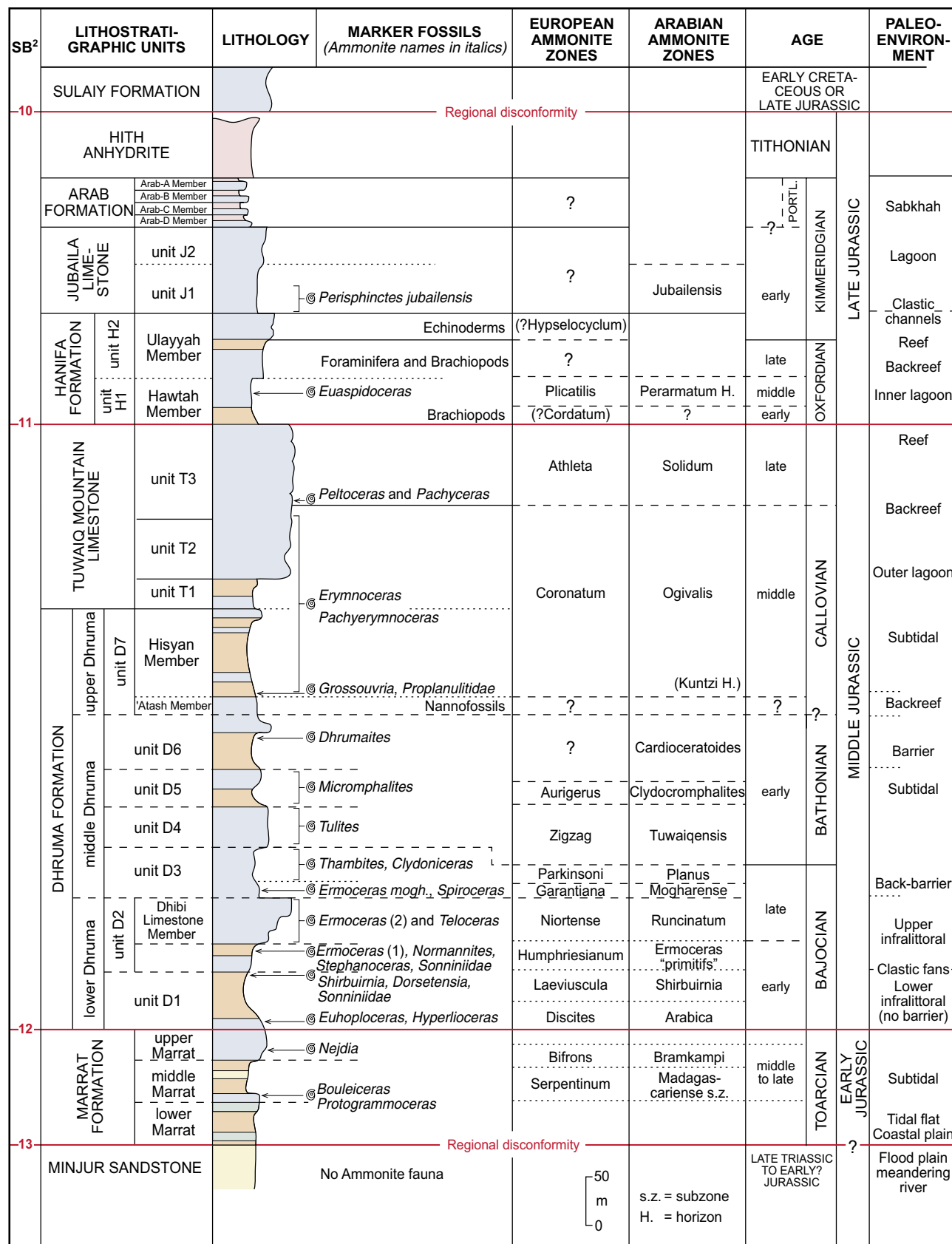
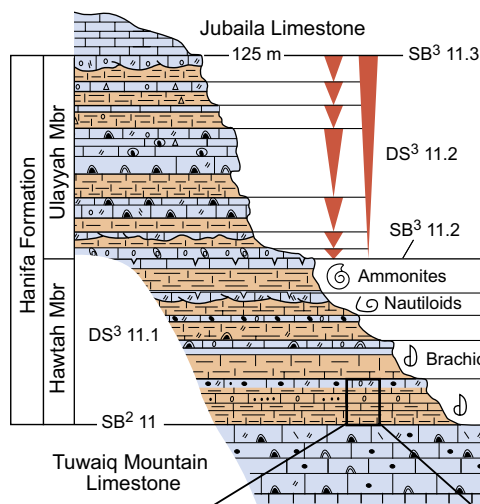


Figure 1: The Jurassic succession in Saudi Arabia is represented by the Shaqra Group (compiled in Fischer et al., 2001). Al-Husseini and Matthews (2005) interpreted orbital second-order sequence boundaries (shown in red) at SB² 13 = Marrat/Minjur, SB² 12 = Dhruma/Marrat, SB² 11 = Hanifa/Tuwaiq Mountain and SB² 10 = Sulaiy/Hith. In this note the Oxfordian-Kimmeridgian Hanifa Member is interpreted in terms of two third-order sequences deposited in a period of 4.86 million years.

Age of Hanifa Formation: The age of the Hanifa Formation is Oxfordian-early Kimmeridgian (Vaslet et al., 1991; Figure 1 after Fischer et al., 2001). At its base, the Hawtah Member is early Oxfordian (?*Cordatum* zone) based on brachiopods (Boullier, *in* Manivit et al. 1990, and *in* Fischer et al., 2001). The middle and upper parts of the member are middle Oxfordian (*Plicatilis* zone) according to the *Euaspidoceras* ammonite fauna (Enay et al., 1987, *in* Fischer et al., 2001), nautiloids (Tintant, 1987, *in* Fischer et al., 2001) and nannoflora (Manivit, 1987, *in* Fischer et al., 2001). The Ulayyah Member is late Oxfordian in its basal part, based on the occurrence of foraminifera *Alveosepta jaccardi* (Andreieff, *in* Manivit et al., 1990, and *in* Fischer et al., 2001), and brachiopods (Boullier, *in* Manivit et al., 1990, and *in* Fischer et al., 2001). The upper part of the Ulayyah Member yielded echinid faunas (Clavel, *in* Manivit et al., 1990, and *in* Fischer et al., 2001) that suggest an early Kimmeridgian age (?*Hypsolocyclum* zone).

Hanifa Stratigraphy and Stacking of Depositional Cycles in Outcrop

a) Stratigraphy



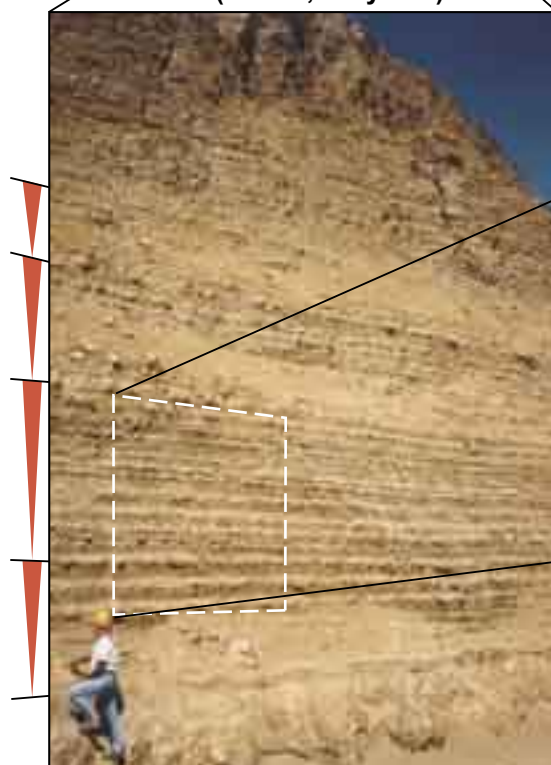
Third, Fourth and Higher-order Depositional Sequences

Mattner and Al-Husseini (2002) interpreted the two members of the Hanifa Formation as two third-order sequences (Figure 2a). In turn, these authors interpreted the lower Hawtah Member in terms of five cycles. Each of the Hawtah cycles is about

b) 10-20 m Shallowing-upward 405,000 year Cycles



c) Bedding Bundles (95-125,000 years)



d) 30 cm (20-40,000 years) Cycles

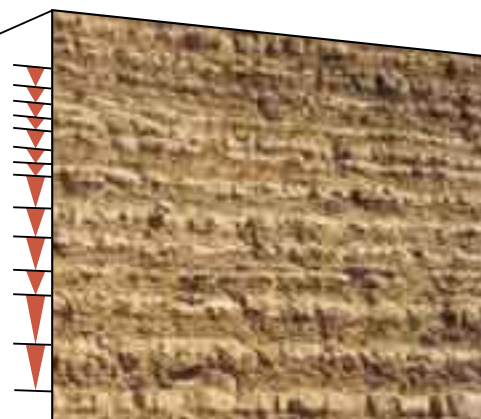


Figure 2: Stratigraphy of the Hanifa Formation showing the Hawtah and Ulayyah members (modified after Vaslet et al., 1991; Mattner and Al-Husseini, 2002). The members are here interpreted as third-order orbital sequences DS³ 11.1 (Hawtah) and DS³ 11.2 (Ulayyah).

10–20 m thick and consists of clayey limestone capped by a bioclastic limestone some one meter thick (Vaslet et al., 1991). In some cycles (e.g. Hawtah cycle 4 = unit 3 of Vaslet et al., 1991) the top of the capping limestone is a hard ground, indicating probable subaerial exposure and a fourth-order sequence boundary.

In the AROS framework, the Hawtah Member (denoted DS³ 11.1) appears to consist of five fourth-order orbital cycles (DS⁴ 11.1.1–11.1.5) that were deposited in a period of 2.025 my (5 × 0.405 my) between c. 159.7 and 157.7 Ma. This age span implies an Oxfordian age (161.2–155.7 ± 4.0 Ma, Gradstein et al., 2004) for the Hawtah Member, as consistent with its biostratigraphic age (Fischer et al., 2001).

The Ulayyah Member appears to consist of seven cycles that are similar in thickness and lithology to those of the Hawtah Member (Figure 2a). The Ulayyah Member (DS³ 11.2) apparently consists of seven fourth-order orbital cycles (DS⁴ 11.2.1–11.2.7) that were deposited in a period of c. 2.835 my (7 × 0.405 my) between c. 157.7 and 154.8 Ma (i.e. late Oxfordian and early Kimmeridgian; Kimmeridgian: 155.7–150.8 ± 4.0 Ma, Gradstein et al., 2004). An Oxfordian and early Kimmeridgian age for the Ulayyah Member is consistent with its biostratigraphic age (Fischer et al., 2001).

In the Hanifa outcrops (Figure 2a, b), the basal Hawtah fourth-order cycle can be further divided into four “bedding bundles” that are each some 2–4 m thick (Figure 2c, Mattner and Al-Husseini, 2002). According to the orbital calibration, these bundles would each have a period of c. 95–125 ky. The 30-cm cycles may be related to precession and tilt and have periods of 20–40 ky.

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