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Late Cretaceous (Campanian–Maastrichtian) marine reptiles from the Adaffa Formation, NW Saudi Arabia

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Abstract – Marine reptile remains occur in the Upper Cretaceous (lower Campanian to lower Maastrichtian) Adaffa Formation of NW Saudi Arabia. This is the first detailed report of late Mesozoic marine reptiles from the Arabian Peninsula. The fossils include bothremydid (cf. Taphrosphyini) turtles, dyrosaurid crocodyliforms, elasmosaurid plesiosaurs, mosasaurs (*Prognathodon*, plioplatecarpines) and an indeterminate small varanoid. The assemblage is compositionally similar to contemporary faunas from elsewhere in the Middle East/North Africa, and comprises taxa that are typical of the southern margin of the Mediterranean Tethys.

Keywords: marine reptiles, Late Cretaceous, Arabian Peninsula, Tethys, palaeobiogeography.

1. Introduction

The latest Cretaceous (Campanian–Maastrichtian) southern Tethyan platform of the Middle East and North Africa has an abundant and well-documented record of fossil marine reptiles. Currently, the richest assemblages have been reported from the phosphate basins of Morocco (e.g. Arambourg, 1952; Bardet *et al*. 2004, 2005*a*,*b*), and the eastern Mediterranean regions of Egypt (e.g. Werner & Bardet, 1996; Lapparent de Broin & Werner, 1998), Palestine and Negev (e.g. Raab, 1963; Christiansen & Bonde, 2002; Lewy & Gaffney, 2005), Jordan (recently summarized by Bardet & Pereda Suberbiola, 2002) and Syria (Bardet *et al*. 2000). Fragmentary remains are also known from contemporary deposits in the Arabian Peninsula–Iraq region (Arambourg *et al*. 1959).

In 2004, a palaeontological research team from the Saudi Geological Survey recovered vertebrate bone debris and fossil wood fragments from a series of limonitic sandstone cuestas in the vicinities of Aynunah and Wadi Azlam, both north of Duba on the Red Sea coast, NW Saudi Arabia (Fig. 1). Subsequent collecting in 2005 and 2006 yielded further material, including some diagnostic elements attributable to marine turtles, crocodiles, plesiosaurs and aquatic lizards (mosasaurs and small varanoids). Dinosaur, bony fish and shark fossils were also found at the site but are the subject of separate studies.

The Phanerozoic sedimentary sequences around Aynunah and Wadi Azlam have been extensively surveyed for their petroleum potential. They comprise part of a widely distributed Late Cretaceous to Neogene succession deposited in troughs of the Maqnah massif and Ifal Basin in the SE Midyan region between the Gulf of Aqaba and Red Sea (Remond & Teixido, 1980; Clark, 1986; Hughes *et al*. 1999; Hughes & Johnson, 2005). Clark (1986) defined the Late Cretaceous rocks at these localities as the Adaffa Formation, named after the small village of Adaffa in Wadi ash Sharmah; see Clark (1986, p. 5, fig. 3) for a detailed locality map.

Previous records of vertebrate fossils from the Adaffa Formation include a titanosaurid sauropod bone and indeterminate turtle shell fragments described in a confidential Saudi Aramco report 'A. Milner, N. Morris & P. Jeffery, unpub. report, Natural History Museum, London, 1993', and recently summarized by Hughes & Johnson (2005). Material subsequently recovered from the Adaffa Formation was assessed in 2006–2007 as part of a joint Saudi–Australian vertebrate palaeontology research program. This paper describes the marine reptile remains, the first documented Late Cretaceous assemblage from Saudi Arabia (the only other record is a reworked plesiosaur tooth fragment from the Paleocene–Eocene Lina Member of the Aruma Formation, NE Saudi Arabia: Thomas *et al*. 1999), and discusses their potential palaeobiogeographical relationships.

2. Geological setting

The Late Cretaceous Adaffa Formation is a thick (up to 200 m) accumulation of yellow to pale reddish cross-bedded quartz arenite sandstone grading upwards to thin marl, siltstone and fine-grained sandstone beds (Remond & Teixido, 1980; Clark, 1986; Hughes *et al*. 1999; Hughes & Johnson, 2005). A conglomeritic layer

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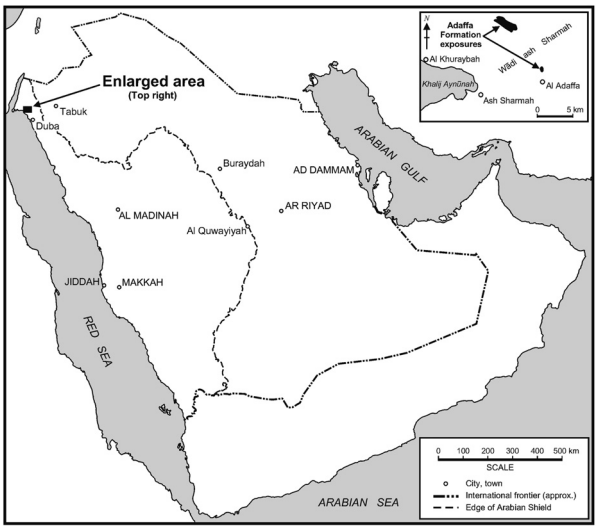

Figure 1. Map of the Arabian Peninsula showing geographical location of the field study area (enlarged) relative to the Palaeozoic Arabian Shield boundary and approximate international borders.

containing granite cobbles and phosphatic nodules forms the base of the sequence; ferricrete/silcrete horizons are locally abundant in areas of epigenetic enrichment (Remond & Teixido, 1980; Clark, 1986; Hughes *et al*. 1999; Hughes & Johnson, 2005). The Adaffa Formation forms the lowermost unit of the Late Cretaceous to Palaeogene Suqah Group, a series of pre-Red Sea rift strata that extend from the Usfan region in the Jiddah Basin, north into the Ifal Basin of the Mydian region, NW Saudi Arabia (Filatoff & Hughes, 1996; Hughes *et al*. 1999; Hughes & Johnson, 2005). Filatoff & Hughes (1996, p. 539, fig. 2) and Hughes & Johnson (2005, p. 57, fig. 5) have published detailed stratigraphical columns showing the disposition of Suqah Group units in the Red Sea area.

The Adaffa Formation has been correlated with lower Campanian to lower Maastrichtian strata on the basis of pollen and dinoflagellate remains (Filatoff & Hughes, 1996). It represents the oldest Suqah Group unit cropping out in the Midyan and rests unconformably on Proterozoic basement rocks of the Arabian Shield. The uppermost layers of the Adaffa Formation are thought to contact strata of the middle Tertiary Tayran Group (Sharik Formation *sensu* Clark, 1986); however, this boundary is poorly defined and largely obscured by Quaternary sands and gravels (Hughes *et al*. 1999; Hughes & Johnson, 2005). In the Aynunah and Wadi Azlam areas (SE Midyan), the Adaffa Formation mainly occupies basement lows in the Maqnah massif and two small graben structures called the Sharmah and Aynunah troughs (*sensu* Remond & Teixido, 1980). Macrofossils from these outcrops are found in thin limonitic beds towards the top of the main sandstone sequence. Lithological features together with palynological evidence suggest deposition under marginal marine conditions, probably linked to minor transgressive episodes extending southeast from the Gulf of Suez (Brown, 1970; Filatoff & Hughes, 1996). The frequent occurrence of non-marine vertebrate remains, including dinosaur bones, ceratodont lungfish toothplates, together with large quantities of wood, support this inferred close proximity to land. Coarse clastic sediments form the remaining bulk of the Adaffa Formation and are thought to derive from coastal (predominantly supratidal) outlet channels emptying a moderately high-energy braided river complex possibly fed by flash-flood events (Filatoff & Hughes, 1996).

3. Survey of the marine reptile material

The Adaffa Formation marine reptile remains are represented by isolated bones and teeth. Most of the specimens are indeterminate fragments and exhibit extensive surface corrosion (e.g. edge rounding) consistent with damage by wave action and/or currents prior to burial. Typically, individual elements do not occur within concentrated masses (e.g. bone beds) but are randomly distributed throughout the exposed horizons. All of the fossil material is housed in the Paleontological Collection of the Saudi Geological Survey (SGS), Jiddah, Kingdom of Saudi Arabia.

3.a. Chelonians

The current collection of Adaffa Formation marine turtle remains includes mainly indeterminate shell fragments and a femur attributable to the marine-littoral pleurodiran group Bothremydidae. The frequently recovered shell pieces are thick (up to approximately 20 mm) with a smooth surface that displays no distinct dorsal ornamentation. A large section (105.4 mm long) comprising two incomplete fused plates (SGS 004-10; Fig. 2a) with an acutely angled edge and flat, slightly eroded surface probably represents part of a posterior plastron (see Gaffney, Tong & Meylan, 2006 for comparisons). The large femur (128.6 mm long; SGS 006-84; Fig. 2b–d) has a sigmoid diaphysis and evidence of an intertrochanteric fossa present between the distal tibia and fibula facets. Bardet *et al*. (2000) reported a closely comparable specimen from the Maastrichtian phosphates of Syria and attributed it to a '*Nigeremys* group' bothremydid (incorporated into Taphrosphyini *sensu* Gaffney, Tong & Meylan, 2006).

3.b. Crocodyliforms

Crocodilian remains are rare and represented by a single cranial fragment together with some isolated vertebrae. The cranial fragment (37.2 mm long; SGS 004-32; Fig. 2e, f) cannot be attributed to a specific taxon. The vertebrae include a laterally constricted cervical centrum (22.3 mm long; SGS 006-204; Fig. 2g, h) missing the neural arch but with amphicoelous articular faces and a prominent crest-like hypophysis (broken off near its base). A small dorsal centrum (27.7 mm long) with unfused neural arch (SGS 006-16; Fig. 2i, j)

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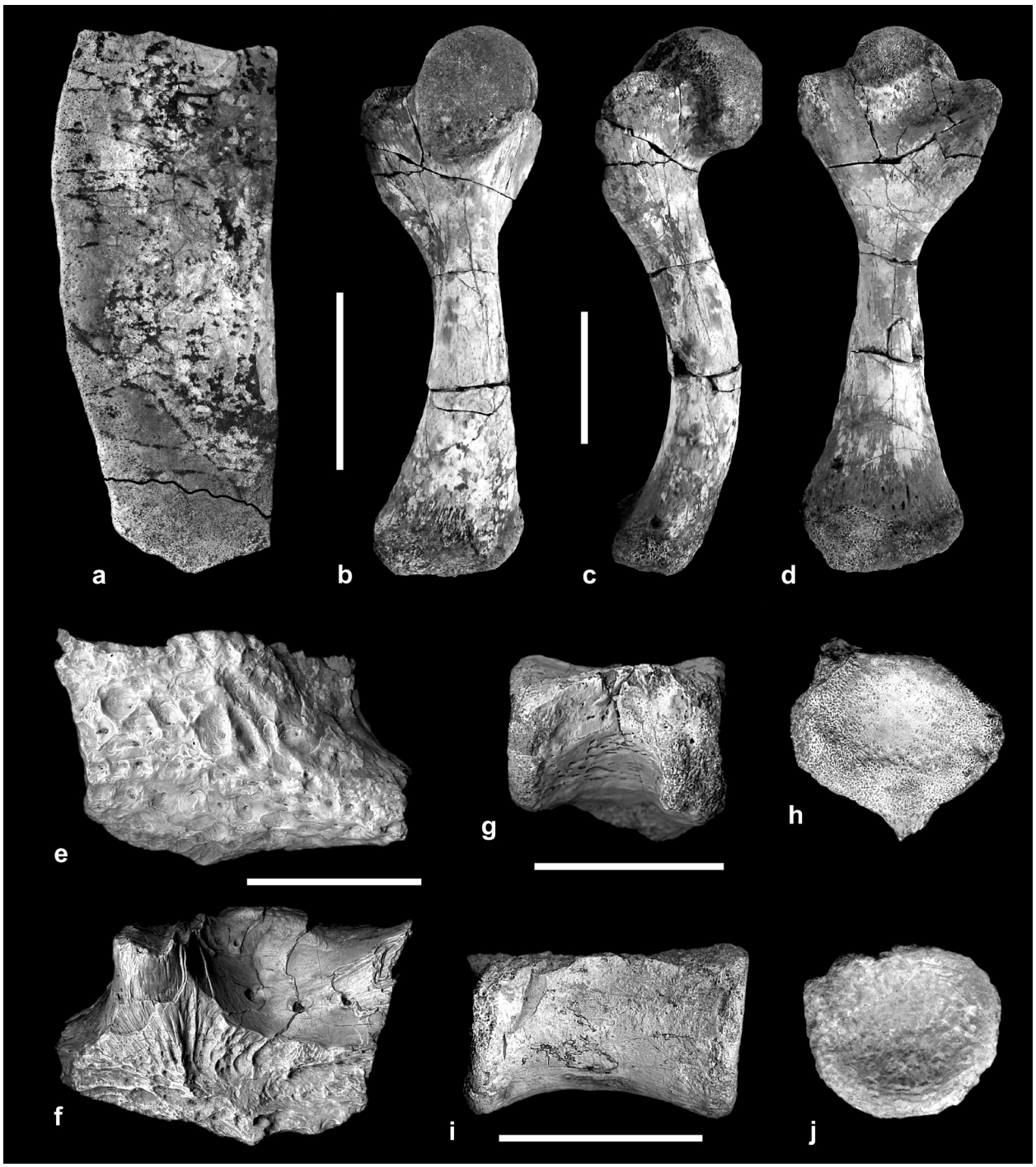

Figure 2. Chelonian and crocodyliform remains from the Adaffa Formation of Saudi Arabia. (a) Bothremydid plastron fragment with highlighted inter-plate suture (SGS 004-10) in ventral view. Bothremydid right femur (SGS 006-84): (b) ventral; (c) lateral; (d) dorsal views. Crocodyliform cranial fragment (SGS 004-32): (e) dorsal; (f) ventral views. Dyrosaurid cervical centrum (SGS 006-204): (g) lateral; (h) anterior views. Dyrosaurid dorsal centrum (SGS 006-16): (i) lateral; (j) anterior views. Scale bar represents 30 mm in (a–d) and 20 mm in (e–j).

also displays amphicoelous articular faces; both of these are here referred to indeterminate dyrosaurid crocodyliforms (see Jouve, Bouya & Amaghzaz, 2006; Schwartz, Frey & Martin, 2006 for comparisons).

3.c. Plesiosaurians

The only recognizable plesiosaur fossil currently recovered from the Adaffa Formation (found at Wadi Azlam) is the rostral section of a small skull (122.9 mm long, 77.6 mm wide; SGS 006-20; Fig. 3a–c), which is severely weathered and heavily encrusted with gypsum. The short preorbital segment (formed by the premaxillae), including up to five pairs of premaxillary teeth, enlarged maxillary fangs, and short mandibular symphysis (50.6 mm long as preserved) suggests attribution to an indeterminate elasmosaurid (see Kear, 2005).

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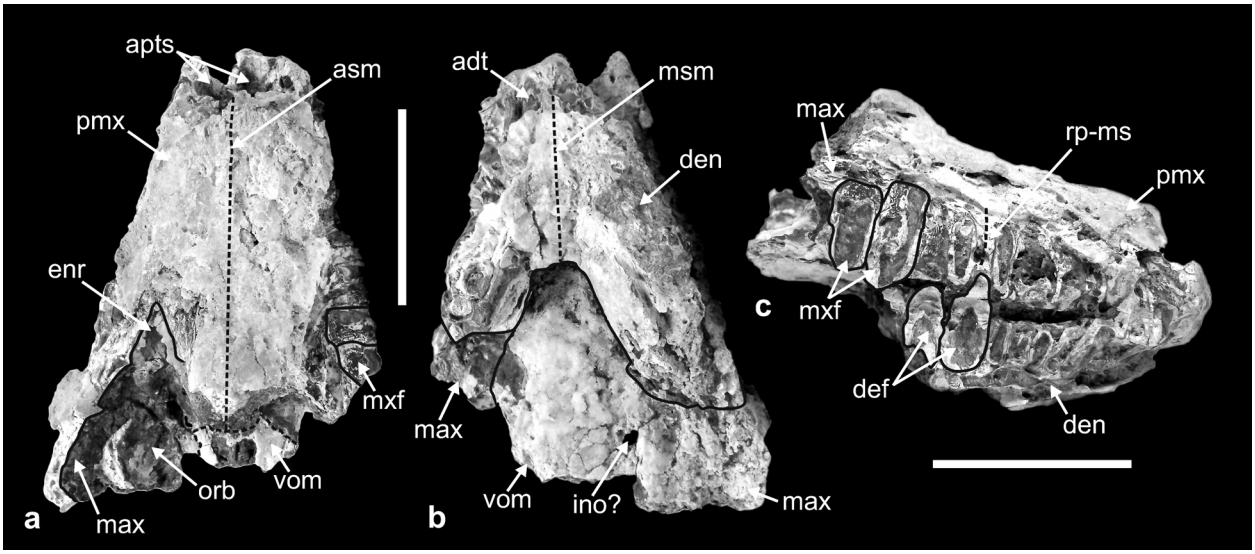

Figure 3. Plesiosaur remains from the Adaffa Formation of Saudi Arabia. Elasmosaurid skull rostrum and mandibular symphysis (SGS 006-20): (a) dorsal; (b) ventral; (c) right lateral views. Abbreviations: adt – anterior dentary teeth; apts – anterior premaxillary tooth sockets; asm – approximate snout midline; def – dentary fang; den – dentary; enr – external naris region; ino? – possible internal narial opening; max – maxilla; msm – median symphysis midline; mxf – maxillary fang; orb – orbit; pmx – premaxilla; rp-ms – reconstructed premaxillary-maxillary suture; vom – vomer. Scale bars represent 50 mm.

3.d. Aquatic squamates

Mosasaur remains are abundant in the Adaffa Formation and include diagnostic teeth and vertebrae. The teeth are represented by large (34.7–76.7 mm high, 15.4–29.3 mm basal mesodistal length) shed crowns (Fig. 4a) that are either straight or slightly recurved. The enamel (where preserved) is thin (~0.5 mm) and smooth with very weak striations; unusually there is no evidence of strong carinae. The circular basal cross-sections and sub-equal, convex labial and lingual faces are consistent with the mosasaurine genus *Prognathodon* Dollo, 1889 (Bardet *et al*. 2005*a*).

Identifiable vertebrae include a distinctly plesiomorphic (*sensu* Debraga & Carroll, 1993; Bell, 1997) mosasaurid pygal (SGS 006-542; Fig. 4b, c) with centrum length > height (86.8 mm long, 68.4 mm high), equidimensional (sub-circular) condyle/cotyle and anteriorly positioned, inclined transverse process (broken off on left side). A dorsal vertebra (54 mm long, 28.3 mm high; SGS 006-340; Fig. 4h–j) with dorsoventrally compressed, weakly heart-shaped condyle/cotyle, anteriorly positioned, vertically elongate synapophyses and no apparent accessory zygantral articulations (prezygopophyseal region damaged) is reminiscent of plioplatecarpines (*sensu* Bell, 1997; Bell & Polcyn, 2005). Several other indeterminate vertebrae (approximately 11 mm long, 10 mm proximal width, 4.5 mm high; Fig. 4d–g) with obliquely oriented (visible ventrally), weakly reniform condyles/cotyles and inclined zygopophyses are comparable to small aquatic varanoids; these have been reported elsewhere from Maastrichtian deposits in Syria (Bardet *et al*. 2000) and North Africa, the latter attributed to *Pachyvaranus crassispondylus* by Arambourg (1952).

4. Palaeobiogeographical implications of the assemblage

Although fragmentary, the Adaffa Formation marine reptile remains represent the first documented Late Cretaceous assemblage from Saudi Arabia, and are thus an important new addition to the late Mesozoic record for the Arabian Peninsula. Recognizable taxa include bothremydid turtles, dyrosaurid crocodilians, elasmosaurid plesiosaurs, mosasaurine and plioplatecarpine mosasaurs and small aquatic varanoids, all of which are typical of the southern Tethyan realm (e.g. Bardet *et al*. 2000), and have been previously reported from Campanian–Maastrichtian deposits elsewhere in the Middle East (e.g. Arambourg *et al*. 1959; Raab, 1963; Werner & Bardet, 1996; Lapparent de Broin & Werner, 1998; Bardet *et al*. 2000; Bardet & Pereda Suberbiola, 2002; Christiansen & Bonde, 2002; Bardet *et al*. 2004; Zalmout, Mustafa & Wilson, 2005) and North Africa (e.g. Arambourg, 1952; Bardet *et al*. 2004, 2005*a*,*b*). Bothremydid turtles and dyrosaurid crocodilians in particular are diagnostic elements of Late Cretaceous faunas throughout the Mediterranean Tethys (see Hua & Buffetaut, 1997; Gaffney, Tong & Meylan, 2006 for respective summaries) and are consistent with the inshore depositional setting of the Adaffa Formation; the retention of weight-bearing limbs (rather than paddles) and probable benthic-oriented lifestyle in bothremydids is thought to have necessitated occupation of littoral habitats (Lapparent de Broin & Werner, 1998).

Elasmosaurid plesiosaurs are well documented from Late Cretaceous coastal marine palaeoenvironments in the Middle East and elsewhere around the globe (e.g. Welles, 1962; Werner & Bardet, 1996; Bardet *et al*.

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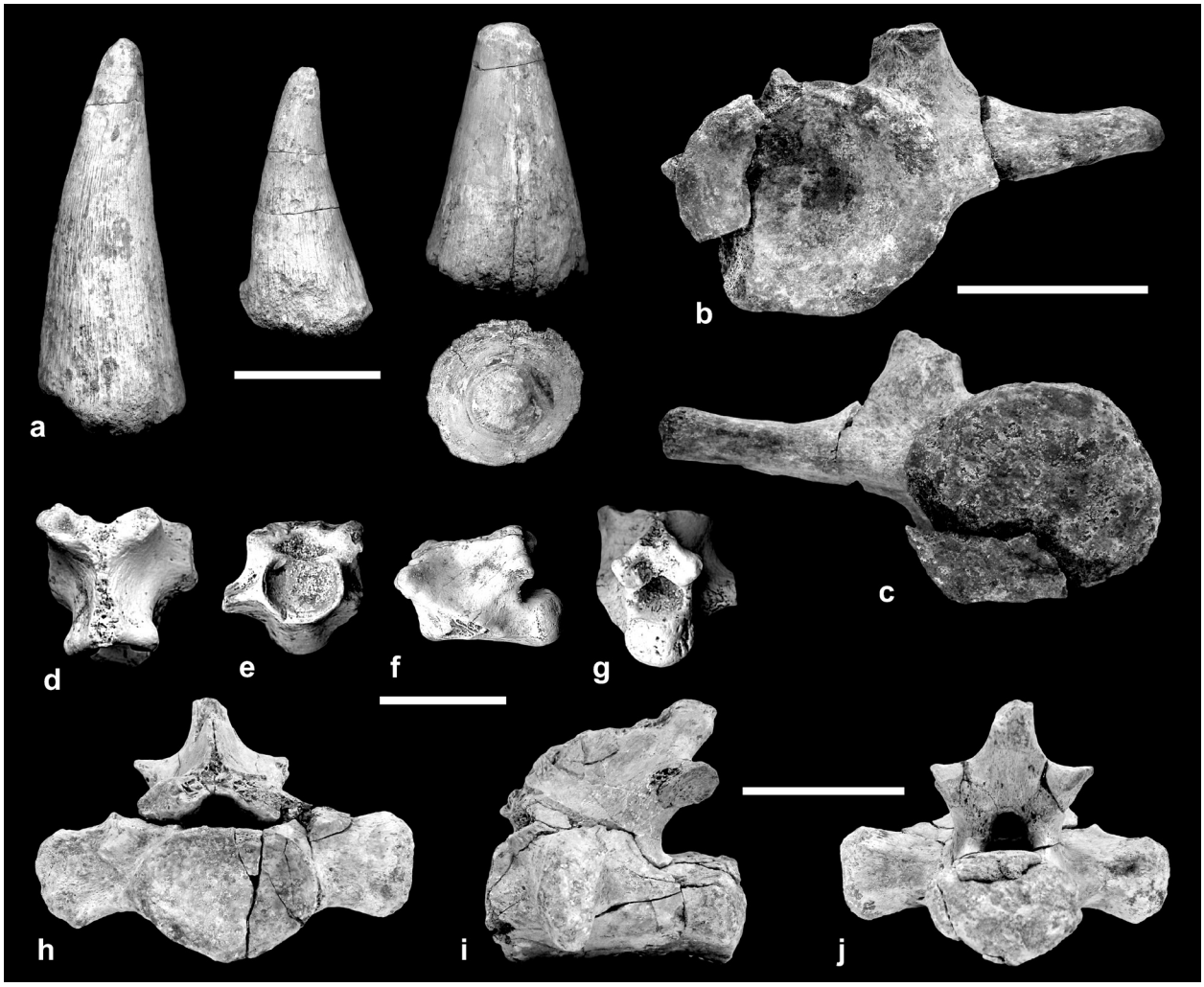

Figure 4. Aquatic squamate remains from the Adaffa Formation of Saudi Arabia. (a) *Prognathodon* teeth (SGS 006-217) in labial and apical (bottom right) views. Mosasaurid pygal vertebra (SGS 006-542): (b) anterior; (c) posterior views. Indeterminate small varanoid dorsal vertebra (SGS 004-70): (d) dorsal; (e) anterior; (f) left lateral; (g) posterior views. Plioplatecarpine mosasaurid dorsal vertebra (SGS 006-340): (h) anterior; (i) lateral; (j) posterior views. Scale bar represents 30 mm in (a, h–j), 50 mm in (b, c) and 10 mm in (d–g).

2000; Bardet & Pereda Suberbiola, 2002; Gasparini, Salgaldo & Casadío, 2003). Unfortunately, remains from the Adaffa Formation are too incomplete to draw any meaningful palaeobiogeographical comparisons.

The Adaffa Formation aquatic squamates are represented by widespread high-level taxa (e.g. mosasaurine and plioplatecarpine mosasaurids) and one identifiable genus: the ubiquitous mosasaurine *Prognathodon*. This pandemic taxon has been described from Campanian–Maastrichtian strata in New Zealand (Welles & Gregg, 1971; Wiffen, 1990), Europe (Lingham-Soliar & Nolf, 1989; Dortangs *et al*. 2002; Bardet, Corral & Pereda Suberbiola, 1997; Bardet *et al*. 1997; Lindgren, 2004), North America (Russell, 1967) and Africa (Lingham-Soliar, 1994; Bardet *et al*. 2005*a*), and is abundant in the Late Cretaceous deposits of the Middle East (Bardet *et al*. 2000; Bardet & Pereda Suberbiola, 2002; Christiansen & Bonde, 2002).

The occurrence of marine reptiles in the Adaffa Formation reflects the close proximity of the northern Arabian Platform to open marine environments of the southern Neo-Tethys during the latest Cretaceous. Marine incursions into this region are characterized by distinctly Mediterranean faunas (Brown, 1970), and in accordance, the Adaffa Formation marine reptiles show close similarities to those reported from elsewhere in the southern Tethyan region (e.g. Bardet *et al*. 2000). Further exploration of the Adaffa Formation should therefore yield taxa that are common to this biotic zone, and in general reflect the warm equatorial palaeolatitudinal belt that stretched across the Middle East and North Africa during Late Cretaceous times (Bardet *et al*. 2000; Bardet & Pereda Suberbiola, 2002).

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