Facies in the Unayzah Formation and the Basal Khuff Clastics in subsurface, northern Kuwait

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ABSTRACT

This is the first reporting of the Unayzah Formation from a northern Kuwait deep well where a 304 ft of core was cut in the upper part of the formation. The core consists of about 202 ft of the Unayzah Formation, 74 ft of the Basal Khuff Clastics and 28 ft of the Khuff Formation. Within the Unayzah Formation six major lithofacies were interpreted: (1) high-angle cross-bedded sandstone; (2) fine-grained sandstone; (3) normally graded coarse pebbly sandstone; (4) medium- to fine-grained sandstone and siltstone; (5) red mudstone and siltstone; and (6) black shale. In the Basal Khuff Clastics, four lithofacies were recognised: (1) fine- to medium-grained clean sandstone; (2) muddy bioturbated sandstone and siltstone; (3) dark grey to black carbonaceous shale with sand interbeds; and (4) interbedded sandstone, siltstone and dolomite. These lithofacies can be subdivided into four broad palaeoenvironments; eolian, braided fluvial, flood plain, and coastal plain. The possible eolian facies are represented by high-angle, cross-bedded sandstones of likely dune affinity. Braided fluvial facies consist of pebbly sandstones, which may grade normally to fine-grained sandstone and siltstone. Flood-plain environments are interpreted for the red mudstone, shale, and siltstone, which consist of prominent root casts and other subaerial exposure features. This facies is prominently repeated three times within the cored zone. Coastal plain environments are represented by tidal channels consisting of fine-grained and clean sandstone, crevasse splay and interfluve sediments consisting of bioturbated sandstone, siltstone and shale and by dark grey to black shale of coastal marsh in origin.

The core did not cover the lower contact of the Unayzah Formation. The upper contact of the formation with the Basal Khuff Clastics is placed at the top of the last oxidised red zone. Due to the limited palynofloral information, the age of the cored interval is not definitive but most likely is of Kazanian to Tatarian (Wordian to mid-Wuchiapingian). The Basal Khuff Clastics and the overlying Khuff Formation is equivalent to the OSPZ6 biozone and the Unayzah Formation could be in part equivalent to the OSPZ5 biozone. The sediments belonging to the Basal Khuff Clastics mark the onset of a major transgression that developed into a platform where carbonates of the overlying Khuff Formation were deposited.

INTRODUCTION

The Unayzah Formation and its stratigraphically equivalent sediments are widespread over most of the Greater Arabian Basin. This formation is variable in thickness, generally thinning towards south and southwest on the Arabian Shield and thickening northward in the Widyan Basin in Saudi Arabia where it attains a maximum known thickness of 1,419 ft in the Badanah well (Al-Laboun, 1987; his figure 1). Local variations in thickness are attributed to palaeotopography, being thin on palaeo-highs and relatively thick in palaeo-lows (Al-Laboun, 1987). The formation is named after the town of Unayzah in the al-Qasim region of Saudi Arabia where it is 106 ft thick with an ambiguity in exposure of its basal part. However, in type section of the formation in the Quayba area (26°55’N, 43°34’E), north of Unayzah town, a complete section of the formation is exposed where it is 112 ft thick (Al-Laboun, 1987). In the western areas in Saudi Arabia the formation is either very thin, only 6 ft thick near town of al-Quwey’iyah or completely missing such as in the Tabuk Basin (Al-Laboun, 1987; his figure 2). The Unayzah Formation is stratigraphically equivalent to the Gharif and Al-Khliata formations of the Haushi Group of Oman (Aley and Nash, 1984) and the Faraghan Formation in the Zagros Basin (Szabo and Kheradpir, 1978; Al-Laboun, 1987).
The Unayzah Formation has attained great exploration significance due to its great hydrocarbon-bearing potential (Wender et al., 1998). The formation is a gas and oil producing horizon in Saudi Arabia. It is presently being explored in other Gulf Countries as well. The formation varies in its environments of deposition within the Arabian Plate. Papers describing the depositional environments and palaeontology are published from Oman and Saudi Arabia (Ferguson and Chambers, 1991; Senalp and Al-Duaiji, 1995; Osterloff et al., 2004; Melvin et al., 2005a, b). Nothing has so far has been published about the formation in Kuwait where it occurs at great depths (exceeding 18,000 ft). Partly due to this excessive depth and partly due to more promising prospects in shallower sections, drilling of deeper prospects was rarely undertaken previously. It is only recently that a few deeper wells were drilled to ascertain the potential of the Unayzah and other Palaeozoic reservoirs.

Sidewall cores were recently obtained from the Unayzah section in one of the wells in northern Kuwait. In a nearby well about 304 ft of continuous core was cut covering the lower part of the Khuff Formation, through Basal Khuff Clastics and most of the upper part of the Unayzah Formation (Unayzah “A”). The core was logged, lithofacies were identified, and depositional environments were interpreted. This paper provides a summary of the Unayzah and Basal Khuff Clastics lithofacies and interpreted depositional environments as encountered in the subsurface of northern Kuwait.

PREVIOUS WORK

The term ‘Unayzah Formation’ was introduced by Al-Laboun (1982) who later formalised it (Al-Laboun, 1986, 1987). The formation was named after the town of ‘Unayzah’ in the Qasim region of central Saudi Arabia. It overlies different formations in different areas with an angular unconformity. This pre-Unayzah unconformity is related to the Hercynian orogeny in the Arabian Plate (Al-Laboun, 1987; Ferguson and Chambers, 1991). Delfour et al. (1982) used the term Unayzah for their lowermost member of the Khuff Formation consisting of fine-grained varied colour clastics rather than as an independent formation. Subsequently El-Khayal and Wagner (1985) formally defined and described the Unayzah Formation from the Unayzah town section of Saudi Arabia. Furthermore, these authors considered the transitional zone between the Unayzah Formation and the overlying Khuff Formation as the basal part of the Khuff Formation. This zone consists of channel-fill sandstone, shale, marl and dolomitic stringers of marginal marine affinity.

Ferguson and Chambers (1991) described the subsurface Unayzah Formation in Hawtah-1 well in central Saudi Arabia. In this area, both its contacts are unconformable with the underlying Silurian Qalibah Formation and the overlying Khuff Formation. They placed the upper boundary of the Unayzah Formation at the base of a “transgressive marine shale” unit and divided it into the informal upper “A” and lowermost “B” members, separated by a coarsening upward siltstone unit. Al-Husseini (2004) gave a summary of the Unayzah Formation and described the character of subunits within the formation. In Saudi Arabia, a basal member is also locally developed and is informally termed Unayzah “C”, which is interpreted as incised channel fills (Al-Husseini, 2004). The Unayzah “C” was encountered in the Hawtah-4 well below the Unayzah B member and above the Qalibah Formation (McGillivray and Hussein, 1992).

The terms “Basal Khuff Clastics” or “pre-Khuff Clastics” (Al-Laboun, 1987) apply to a sequence of sediments sandwiched between the clastic of the Unayzah Formation and the overlying predominantly carbonate Khuff Formation. Near Unayzah town in central Saudi Arabia, this zone is about 60 ft thick and consists of grey shale, marl, sandstone and dolomitic limestone (Senalp and Al-Duaiji, 1995). Senalp and Al-Duaiji (2001) introduced the Ash-Shiqqah Formation for this unit, which forms the upper part of the Unayzah reservoir and stratigraphically extends between the pre-Ash-Shiqqah unconformity and the base Khuff D carbonate. The Ash-Shiqqah Formation was previously called the Ash-Shiqqah Member of the Khuff Formation (Senalp and Al-Duaiji, 1995). This is a transgressive unit below which an unconformity is suggested in the Unayzah, Hawtah and Usaylah regions of Saudi Arabia (Evans et al., 1991; Al-Husseini, 2004).

In northern Kuwait, the Unayzah Formation overlies a thick carbonate succession, most likely the infra-Cambrian Hormuz Group, with a major intervening unconformity. The formation is overlain by the Basal Khuff Clastics, and a thick carbonate sequence correlatable to the main Khuff Formation.
LITHOLOGY IN THE CORE

The Unayzah Formation in northern Kuwait was penetrated in two wells. In one of the wells (Figures 1 and 2) about 304 ft of nearly continuous core (total nine runs) was cut covering the lowermost carbonate part of the Khuff Formation, Basal Khuff Clastics and the Unayzah Formation. The core covered the upper part of unit “A” of the Unayzah Formation but possibly did not reach unit “B”. The basal 202 ft, between 19,029 to 18,827 ft depth, of the core is assigned to the Unayzah Formation. The Basal Khuff Clastics zone is about 74 ft thick, covering between 18,827 to 18,753 ft depth, and the uppermost 28 ft of the cored interval, between 18,753 to 18,725 ft depth, consists of the carbonate zone of the Khuff Formation (Figure 3).

The Unayzah Formation consists of two prominent lithologies; pebbly sandstones and red mudstones and siltstones. The pebbly sandstones generally constitute the main body of fining-upward cycles with a conglomeratic base and fine-grained sandstone, siltstone and shale in the upper part. The red oxidised mudstone and siltstone zone is repeated at least three times within the cored interval and consists of distinct pedogenic features such as root casts, mottling and reduction spots and fissure fills. Locally well-sorted sandstone and black shale lithologies are also developed. The Basal Khuff Clastics zone consists of well-sorted and silica-cemented, generally fine-grained sandstone along with muddy sandstone and siltstone. Locally dark grey to black shale is present and dolomitic beds are developed in the uppermost part. Bioturbation generally increases upwards in the section. The basal carbonate zone of the overlying Khuff Formation (Figures 2 and 3) consists of dolomudstone and dolowackstones, which are locally cross-bedded with argillaceous sandy dolomitic beds near the base. These carbonates of the Khuff Formation are in a faulted contact with the underlying Basal Khuff Clastics zone. This carbonate zone of the Khuff Formation will not be discussed further in this paper.

Figure 1: Location map showing the Unayzah penetration in Kuwait and the Permian outcrop belt in central Saudi Arabia (modified after Stephenson et al., 2004). To the right, the generalised column shows the stratigraphic position of the Unayzah Formation in Kuwait.
Six major lithofacies are recognised within the Unayzah Formation from the core in the northern Kuwait well. These lithofacies are defined on the basis of prominent characteristics such as lithology, colour, internal features including sedimentary structures and bioturbation. Some of the facies are repeated several times within the studied interval. Lithofacies UN-2 and UN-4 are broadly similar in lithology, although internal features are different. Each of these lithofacies is briefly described below. The word facies is used for lithofacies for brevity.

**Facies UN-1: Well-sorted High-angle Cross-bedded Sandstone**

**Description:** This facies, which is 9–10 ft thick, is only developed in the lower part of the core. It consists of 2 to 4 ft thick fining-upward cycles with coarse- to medium-grained, well-sorted sandstone. The greenish and darker clay laminae increase within the sandstone towards the top of the facies. Internally the sandstone is cross-bedded with more than 30° dip angles. Locally low-angle to planar...
Dolomite
Medium-grained sandstone
Conglomerate/pebbly sandstone
Coarse-grained sandstone
Fine-grained sandstone
Very fine-sandstone to siltstone
Muddy sandstone to siltstone
Muddy carbonaceous siltstone
Black Shale
Grey Shale
Red mudstone/silty mudstone
Red siltstone

Figure 3: Composite log of about 304 ft of core covering basal Khuff Formation, Basal Khuff Clastics and upper part of the Unayzah Formation from the well in northern Kuwait.

lamination is present in the sandstone in the upper part of the cycles. Small-scale faults, at least some of which are syndepositional, are also present in this facies (Figures 4 and 5).

Interpreted Depositional Setting: The presence of features like good sorting and high textural maturity in this facies suggest continuous winnowing in a high-energy environment. The presence of syndepositional faults suggests occasional nonconforming subsidence and/or unstable nature of the underlying substrate. The high-angle cross beds, although not a definitive indicator (Hunter, 1981), may develop along margins of eolian dunes by avalanching of non-cohesive sand down the slip faces. The slip along steep dune slopes of partly cohesive sand may be responsible for the development of other deformational features such as synsedimentary faults. This interpretation therefore favours the eolian origin for this facies. However, the fining-upward nature of individual sandbodies is commonly developed in fluvial environments. The good sorting and possible presence of mud drapes may suggest its deposition in coastal plain environments. Because of all these varied possibilities and without conclusive evidence, the depositional interpretation for this facies is not definite.
Facies UN-2: Medium to Dark Grey Fine-grained Sandstone

Description: The facies is only developed in the lower part of the cored interval below facies UN-1. It overlies the red siltstone/mudstone facies and is about 5 ft thick (Figures 4 and 5). It consists of vaguely developed small fining-upward cycles with medium to dark grey muddy sandstone/siltstone at base, which fines upwards into dark grey carbonaceous siltstone to shale at top. Small syndepositional faults are abundant and some layers are boudinaged making small ball and pillow type structures. The facies is sharply overlain by medium to coarse-grained sandstone of facies UN-1 (Figure 5).

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NORTHERN KUWAIT WELL

<table>
<thead>
<tr>
<th>Formation</th>
<th>Depth (feet)</th>
<th>Gamma-Ray</th>
<th>Lithology</th>
<th>Facies</th>
<th>Lithological Description</th>
<th>Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>UN-5</td>
<td>18,965</td>
<td>0 gamma</td>
<td>Siltstone/very fine-grained sandstone, grey, parallel laminated, grades up into red siltstone/mudstone.</td>
<td>UN 5</td>
<td>Flood plain, Crevasse splay</td>
<td></td>
</tr>
<tr>
<td>UN 4</td>
<td>18,975</td>
<td>300</td>
<td>Siltstone, maroon, grades up into red mudstone.</td>
<td>UN 4</td>
<td>Upper part of bar</td>
<td></td>
</tr>
<tr>
<td>UN 3</td>
<td>18,985</td>
<td>200</td>
<td>Shale-siltstone couplets, rippled fine-grained sandstone.</td>
<td>UN 3</td>
<td>Fluvial</td>
<td></td>
</tr>
<tr>
<td>UN 1</td>
<td>18,995</td>
<td>100</td>
<td>Sandstone; brownish, pebbly/conglomeratic at base to fine-grained at top, planar cross-bedded, locally plane laminated.</td>
<td>UN 1</td>
<td>Fluvial, braided</td>
<td></td>
</tr>
<tr>
<td>UN 2</td>
<td>19,005</td>
<td>50</td>
<td>Sandstone; light brownish grey, conglomeratic at base, coarse-grained, plane laminated.</td>
<td>UN 2</td>
<td>?Eolian</td>
<td></td>
</tr>
<tr>
<td>UN-5</td>
<td>19,015</td>
<td>20</td>
<td>Sandstone; light brown, medium- to coarse-grained, well sorted, high-angle planar cross-beds, small faults.</td>
<td>UN-5</td>
<td>Flood plain, Crevasse splay</td>
<td></td>
</tr>
<tr>
<td>UN-1</td>
<td>19,025</td>
<td>10</td>
<td>Sandstone/siltstone, grey, very fine-grained, rippled, passes up into maroon siltstone/mudstone.</td>
<td>UN-1</td>
<td>Flood plain, Crevasse splay</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Core log with facies, lithological description and depositional environments.
Figure 5: Core photograph from the basal part of the core showing facies UN-5, UN-2 and UN-1 from base to top. Sleeve length is 3 ft.
(a) Close-up of facies UN-5 showing red mudstone and root trace (R).
(b) Close-up showing carbonaceous siltstone and shale of facies UN-2 and the high-angle cross-bedded sandstone of facies UN-1.
(c) High-angle cross-beds and small faults in facies UN-1.
Interpreted Depositional Setting: The facies is interpreted as fluvial in origin and deposited on the margin of a fluvial channel or fluvial overbank or as back swamp deposits (facies Fsc of Miall, 1978). The presence of tectonic features within this facies suggests the instability of the underlying part of the strata. The development of normal and reverse faults and boudinage and ball and pillow structures could be the result of minor slumping, which was likely produced by rapid sedimentation and loading. Some of these structures can develop in eolian settings as well but the facies is too argillaceous to be assigned an eolian origin.

Facies UN-3: Upward-fining Coarse Pebbly Sandstone

Description: This facies set is better developed in the lower and middle cored part of the formation and generally consists of pebbly sandstone or conglomerate at base, which fines upward into finer-grained sandstone (Figure 6). Generally the base of the facies is sharp to irregular and pebbles are 1–2 cm in diameter or less with rare exceptions. Pebbles are generally poorly sorted with angular to subangular shape and are of quartz, red and grey shale and resembles facies Gm (Miall, 1978, 1992). Internally, the facies is structureless, plane-laminated, or cross-bedded. This basal zone generally passes upward into sandstone, which is pinkish brown, pebbly and coarse- to medium-grained. The sandstone is gritty with medium sorting. Internally, it is generally planar cross-bedded, however, some cross beds are trough in nature, similar to facies St and Sp of Miall (1992). Occasionally plane laminations are observed.

Interpreted Depositional Setting: The basal part of the facies is interpreted as channel lag deposits (Walker and Cant, 1984) formed during the initiation of new stream channel or during the increased seasonal flow conditions. The incised older deposits provided some of the sediments. As the initial intensity of the stream decreased, the coarser sediments were deposited. Relatively poor to medium sorting suggests the sediment flow entrapment duration was possibly short and long-distance transportation did not occur. The facies fines upward into medium-grained sandstone, which was deposited by streams during the relatively steady flow period under generally lower flow regime conditions. Occasionally upper flow regime conditions prevailed, which resulted in the formation of plane laminations.

Facies UN-4: Fine-grained Sandstone and Siltstone

Description: This facies occurs in two different facies associations: (1) towards the top of fining upward sequences, facies Fl and Fsc of Miall (1992), starting from conglomerate to coarse sandstone to fine-grained sandstone, and (2) as a base of a small fining-upward cycle (Figures 4, 7 and 8), which partly resembles facies Ss of Miall (1992). It consists of fine-grained sandstone, which gradually changes upwards to carbonaceous siltstone and shale interbeds. The sandstone may be cross-bedded and siltstone ripple laminated to plane laminated. In the former case, the lower contact of the facies is gradational and in the latter case the lower contact is abrupt and locally erosional.

Interpreted Depositional Setting: The facies belonging to the upper part of the upward-fining sequence were deposited in fluvial environments as the upper part of the within-channel bar sequence (Cant and Walker, 1976), or the channel-fill under lower flow regime conditions. The waning flows produced either planar cross beds and ripple lamination due to traction and plane lamination resulting from further reduction in the flow competency as the upper flat bed (Harms et al., 1975). In the second case, where the facies form the base of the sequence, it was developed during overbank flooding or as crevasse splay deposits fining distally from the stream. Some of these sediments may have been deposited as back swamp deposits (Miall, 1992).

Facies UN-5: Red Mudstone and Siltstone

Description: This is very distinct facies owing to its brick red colour. It consists of red silty mudstone, mudstone and locally developed thin light cream and grey mudstone. These lighter colour zones are interbedded with red sediments and appear to mark top of cycles. Locally lighter colour spots are developed. In one case a 5–7 cm thick zone consisted of greenish silty matrix with 2–4 cm diameter
Unayzah Formation and Basal Khuff Clastics, northern Kuwait

Figure 6: Core photograph showing channelised conglomerate and pebbly cross-bedded sandstone of facies UN-3. Sleeve length is 3 ft.
(a) Close-up showing irregular channel base and eroded clasts.
(b) Close-up showing pebbly cross-bedded sandstone/conglomerate.

reduction spots resembling floating pebbles. Locally thin fining-upward cycles are developed. The base of these may consist of siltstone, which fines upward to red silty mudstone and mudstones. Generally mm-thick red and darker parallel lamination is developed; however, occasionally very small-scale ripple lamination is also developed. Rootlet casts, leaching and other pedogenic features are common (Figures 7, 9 and 13).

Interpreted Depositional Setting: This facies is typical of flood-plain deposits where fine-grained facies are developed as palaeosols. The red colouration attests to the well-drained and oxygenated soil conditions (Driese and Ober, 2005). The principal source of iron needed for the red bed formation comes from the diagenetic alteration of iron oxyhydroxides associated with clay fraction (Bensing et al., 2005) and sand- to silt-sized ferromagnesian grains (Walker, 1976). The pedogenic features, fissure fills and rootlet casts also suggest its deposition in subaerially exposed terrestrial environments. The fine parallel lamination and ripple lamination are interpreted as deposition under lower flow regime conditions (Harms et al., 1975) close to the end and demise of the moving floodwaters. The interbedded dense greenish mud likely suggests deposition in lacustrine/pond environments where very fine mud was deposited as a last phase of a floodwater deposition from standing water.
**Facies UN-6: Black Shale**

**Description:** This facies is 12 ft thick (between 18,887–18,875 ft depth) and consists of black highly carbonaceous shale with thin fine-grained sandstone and siltstone interbeds (Figures 10 and 11). The sandstone and siltstone become relatively thicker at the margins of the facies and have vaguely developed ripple lamination. Leaf imprints are observed in the black shale. This facies is similar to facies C of Miall (1992). The black shale zone passes gradationally upward into a 6 ft thick zone consisting of medium- to fine-grained sandstone, which is clean and well-sorted and internally consists of bidirectional cross beds and wavy and flaser beds near its top.

**Interpreted Depositional Setting:** The facies is interpreted as deposited in swamp/marsh type vegetated setting. Such environments may develop in the intra-channel area, vegetated flood plain area or as marsh in the interfluve area within the delta-plain setting. The associated sandstone beds at both the lower and upper margin of this facies are relatively clean and well-sorted and indicate
reversing flow (Figure 11). This is interpreted as showing the tidal influence in the ambient sediments, which were deposited in coastal-plain environments. For this facies, therefore, marsh, swamp or lagoonal settings in interfluve area within coastal plain environments is favoured.

FACIES IN THE BASAL KHUFF CLASTICS (BKC)

The Basal Khuff Clastics section is about 74 ft in thickness and overlies the Unayzah Formation. It consists of clean sandstones, muddy sandstone with burrowing features, and carbonaceous shale. These are initial sediments deposited in coastal plain environments as a result of a rise in base level. The facies identified within the Basal Khuff Clastics in northern Kuwait are described below.

Facies BKC-1: Fine- to Medium-grained Clean, Mature Sandstone

This facies is developed in the lower and middle part of the Basal Khuff Clastics and is easily distinguishable from the Unayzah sediments in view of its finer grain size, good sorting, textural and mineralogical maturity and the presence of bioturbation (Figures 12, 14 and 15). This facies can be subdivided into two subfacies that are briefly described below.

Subfacies BKC-1.1: Fine-grained Quartz Arenite

Description: This facies consists of brownish grey fine-grained well-sorted silica-cemented sandstone and occurs twice. Individual beds are generally less than a foot thick with irregular bed tops covered with mm-cm-thick coal layer. Overall a fining upward trend is apparent and the top zone becomes almost siltstone. Internally the beds are plane-laminated in the lower reaches and the upper beds are cross-bedded. Rare opposite directed cross-bedding is also observed. Due to mineralogical and textural maturity and excellent sorting, grading within the individual beds is difficult to determine although some individual beds appear to be normally graded. The basal portions of the beds are more homogenous while very thin hardly visible carbonaceous lamina appear towards the tops. Locally the sandstone has a dotted specked appearance.

Interpreted Depositional Setting: Excellent sorting and maturity of the sandstone in this facies suggests continuous winnowing in a high-energy setting. Normal grading within the beds and sharp bedding planes are interpreted as likely the preservation of sediments of a relatively high-energy event such as during a flood or storm. Lull in sedimentation is reflected in deposition of carbonaceous/
coaly stringers at bed tops. The specks are interpreted as small burrows that could have been altered due to diagenesis. Tidal influence is evident in these sediments due to the presence of bidirectional cross beds. The facies is associated closely with the estuarine/delta plain type interfluve facies. It is therefore interpreted that the facies was deposited in tidal channels (Horne and Ferm, 1978) in the lower coastal plain environments.

Subfacies BKC-1.2: Medium to Fine-grained Sandstone

Description: The subfacies is 5 ft thick and sharply overlies the facies BKC-3 described below. The facies is represented by a fining-upward sequence consisting of medium- to coarse-grained sandstone at its base, which becomes fine-grained upwards at top. The sandstone consists of small black spotted rounded specks. Internally it is planar-bedded in the basal zone and planar cross-bedded in the upper zone.

Interpreted Depositional Setting: The setting is interpreted as a fluvial distributary channel system (Dalrymple, 1992) in the transitional terrestrial-marine environment. The specks most likely are diagenetically altered burrows. The relatively coarser grain size and planar lamination in the basal part suggests the upper flow regime conditions during the initiation of the channel, which changed to a lower flow regime upwards producing planar cross beds and a progressive decrease in grain size.

Figure 9: Core photograph showing thick occurrence of distinctive red colour facies UN-5. Sleeve length is 3 ft.
(a) Close-up of a thin greyish zone formed in a localised pond within the flood plain.
(b) Close up of a root trace (R).
Figure 10: Core log with facies and environments. Facies UN-6 is the first strong indication of marine incursion at 18,887 ft depth.

**Facies BKC-2: Muddy Bioturbated Sandstone and Siltstone**

**Description:** This facies consist of grey fine-grained sandstone and siltstone and includes small fining-upward sequences. This facies is repeated a few times in the core. The lithology is muddier than facies BKC-1 with an increase in carbonaceous material, bioturbation, vertical and horizontal burrows, specking, and in the presence of rootlet casts. Locally low-angle cross-bedding and ripple cross lamination are developed. The facies is closely associated and interbedded with facies BKC-1. Typically the facies has a lower gradational contact and upper sharp and abrupt contact with facies BKC-1 (Figure 14).

**Interpreted Depositional Setting:** This facies is interpreted as deposited in interfluve environments within an estuarine/delta plain setting (Reinson, 1992). Repeated fining-upward trends represent crevasse splay deposits and/or overbank flood deposits. The coarser bottom part of the sequences
reflects deposition close to the main channel and the finer upper parts were deposited farther away into the interfluve area. Rootlet casts demonstrate exposure and development of vegetation in the interfluve zones. This interpretation is further supported by the presence of burrows and increase in carbonaceous material, which is expected to be common in these environments. The muddy nature of the sandstone and siltstone suggests relatively low-energy conditions of deposition and fits well in the above interpretation.

**Facies BKC-3: Dark Grey to Black Carbonaceous Shale with Sand Interbeds**

**Description:** This facies is only 2 ft thick and consists of dark grey to black carbonaceous shale with thin intercalations of very fine-grained lighter colour sandstone/siltstone beds (Figure 15). These lighter colour beds reduce in thickness and frequency towards the middle of facies. The sandstone/siltstone have vaguely developed ripple lamination and marginal beds are weakly burrowed. This facies is sharply overlain by facies BKC-1.2 (Figure 16).
### Lithological Description

<table>
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<tr>
<th>Depth (feet)</th>
<th>Gamma-Ray</th>
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<th>Facies</th>
<th>Lithological Description</th>
<th>Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>18,785</td>
<td>0 - 300</td>
<td>Sandstone; brownish grain, fine-grained, clean, quartz arenite, fining upward, mm-cm, coaly layers between beds, cross-bedded, dominantly uni-directional, locally bi-directional</td>
<td>BKC 1</td>
<td>Coastal plain tide influenced channel</td>
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<td>18,795</td>
<td></td>
<td>Siltstone; dark grey, muddy, rootlet, vertical burrow. Sandstone; fine-grained, coarser at base, spotted (specked), burrows, locally bioturbinated, rootlets. Fining up sequences.</td>
<td>BKC 2</td>
<td>Coastal plain interfluves</td>
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<td>18,805</td>
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<td>Sandstone passes up into siltstone, pinkish, quartz arenite, rootlets, normally graded.</td>
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<td>Coastal plain channel</td>
<td></td>
</tr>
<tr>
<td>18,815</td>
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<td>Siltstone; dark grey, muddy, rootlet, vertical burrow.</td>
<td>BKC 2</td>
<td>Coastal plain interfluves</td>
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<td>18,825</td>
<td></td>
<td>Siltstone/mudstone; red passes up into greenish dense siliceous clay. Sandstone; light brown, medium-coarse-grained passes up into greenish clay, rootcast, bioturbinated.</td>
<td>Contact</td>
<td>Crevass splay deposits</td>
<td></td>
</tr>
<tr>
<td>18,835</td>
<td></td>
<td>Siltstone/mudstone; red with occasional light colour dense clay zones.</td>
<td>UN 5</td>
<td>Flood plain, Paleosol</td>
<td></td>
</tr>
<tr>
<td>18,845</td>
<td></td>
<td>Sandstone; pinkish brown, fine-grained, quartz arenite, clean, locally dm scale shale partings, normally graded beds, planar laminated to planar cross-bedded, dispersed burrows.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Interpreted Depositional Setting:

The black carbonaceous shale is the main characteristic of this facies and is interpreted to reflect deposition in a vegetated and reduced environment. The facies is closely associated with other coastal plain facies such as tide-influenced channels. The setting is interpreted as a marsh in interfluve area within the coastal plain (coastal marsh of Reinson, 1992). An increase from sand to black shale towards the middle of the facies reflects deposition changing progressively from margins of marsh to its centre.

**Facies BKC-4: Interbedded Sandstone, Siltstone and Dolomite**

**Description:** This facies makes the uppermost about 13 ft of the Basal Khuff Clastics. The lower contact of the facies is recognised at 18,766 ft with a prominent change to darker colour and an increase in bioturbation (Figures 17 and 18). The upper contact with the carbonate succession of...
the Khuff Formation is faulted with about a half-foot zone consisting of dark shale and siltstone clasts floating in the ambient anhydrite cement (Figure 18). The facies consists of fine-grained grey to dark grey and black carbonaceous sandstone and siltstone with shale and dolomite interbeds (Figure 17c). The bioturbation is prominent in this zone especially in the sandstone and siltstone beds. Among the burrows, Paleophycus and Planolites are recognisable and other possible burrows are of Diplocraterion, Conichnus, Chondrites and Macaronichnus. Disseminated pyrite is common in the shaly zones.

**Interpreted Depositional Setting:** The interbedded varying lithology and other characteristics such as burrows and burrowing represent lower coastal plain marginal-marine environments. This interpretation is also supported by the stratigraphic position of this facies, which overlies the coastal tidal channel complex associated facies (BKC-1-3) and underlies the shallow-marine carbonates of the Khuff Formation. The facies marks the initiation of the second phase of the pronounced transgression during which coastal areas were flooded and a broad Khuff Formation carbonate platform started to develop.
SUMMARY AND AGE CONSIDERATIONS

The pre-Unayzah unconformity represents a hiatus of different duration within the Arabian Plate (e.g. see Angiolini et al., 2004). In northern Kuwait, the Unayzah Formation unconformably overlies an undated carbonate sequence. Sidewall cores from this carbonate sequence did not yield any biota and thus it is possibly part of the infra-Cambrian Hormuz Group. If true, it would suggest a substantial pre-Unayzah gap in deposition.

The Unayzah Formation was deposited under varied conditions and reservoir characteristics are largely facies dependent. A major part of the formation, which is represented in the core, was deposited in terrestrial environments. The facies are interpreted to represent a distal alluvial fan system with multi-story channel-fill sediments. From the facies pattern, which evolve from coarse pebbly sandstone and conglomerate at base to fine-grained sandstone at top, it is evident that streams were braided in nature. Only in one case does a relatively better development of fine-grained siltstone/shale facies at the top of the sequence suggest the likely presence of a point-bar sequence and thus a meander loop.
development. However, overall the facies style and pattern in the cored Unayzah Formation suggest proximal to source setting in northern Kuwait. The sediments are poorly sorted. Although the apparent matrix porosity is fair to good, clay (illite) plugging of the pores renders the permeability poor. Thin fine-grained zones at the top of individual sequences are expected to be laterally discontinuous and therefore ineffective vertical barriers for fluid migration. Consequently, the coarse facies without appreciable interbedded fine-grained zones may be considered one continuous zone for reservoir evaluation purposes.

In the lower part of the formation a prominent high-angle cross-bedded sandstone of possible eolian origin offers the best reservoir characteristics. The sandstone is partially friable and loosely cemented making it a very good porous zone with likely good permeability. Otherwise eolian facies are not recognised from the cored upper part of the formation. Nevertheless, the eolian facies are reported from the Unayzah Formation from Saudi Arabia (Melvin and Heine, 2003; Price et al., 2005).

The Basal Khuff Clastics were deposited in the distant coastal plain type setting as opposed to the dominantly fluvial environments for the Unayzah Formation. The flooding surface is recognised from lithologic transition of underlying red mudstone and siltstone of flood plain affinity to a 6–7 ft thick dark grey carbonaceous very fine-grained muddy sandstone/siltstone, which is weakly to moderately burrowed with possible root casts and is interpreted of coastal-plain affinity. This muddier zone is
### Lithological Description

<table>
<thead>
<tr>
<th>Depth (feet)</th>
<th>Facies</th>
<th>Lithological Description</th>
<th>Environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>18,725</td>
<td></td>
<td>Dolowackestone; medium dark grey, likely horizontally to locally low-angle cross-bed, disseminated pyrite.</td>
<td>Shallow-marine</td>
</tr>
<tr>
<td>18,735</td>
<td></td>
<td>Dolomudstone; dark grey, partially shattered.</td>
<td></td>
</tr>
<tr>
<td>18,745</td>
<td></td>
<td>Dolomudstone; dark grey, partially shattered.</td>
<td>Shallow-marine</td>
</tr>
<tr>
<td>18,765</td>
<td></td>
<td>Sand-shale intercalations, lenticular beds with dolomudstone bed, bioturbated sand at top.</td>
<td>Transgressive coastal-marine</td>
</tr>
<tr>
<td>18,775</td>
<td></td>
<td>Sandstone/siltstone; muddy, medium bioturbated, burrows, flaser-bedded in lower part passes down to dolomite bed and dark shale.</td>
<td>Transgressive sand</td>
</tr>
<tr>
<td>18,785</td>
<td></td>
<td>Sandstone; light grey, fine-grained, grades upwards to siltstone, burrows, rootcasts.</td>
<td>Coastal plain channel</td>
</tr>
<tr>
<td>18,795</td>
<td></td>
<td>Sandstone; medium-coarse-grained, light grey, specked, planar-cross-bedded, sharp basal contact.</td>
<td>Interfluve marsh</td>
</tr>
<tr>
<td>18,805</td>
<td></td>
<td>Shale; black, carbonaceous, with 2–4 cm thick sand/silt layers.</td>
<td>Channel</td>
</tr>
</tbody>
</table>

**Figure 16: Core log with facies and environments, as well as the contact of the Basal Khuff Clastics and the overlying carbonates of the Khuff Formation.**

Sharply and erosively overlain by the clean, silica-cemented quartz arenites. These facies are part of a tidal channel complex in the lower coastal plain where tidal and fluvial channels and interfluve facies were deposited. The grain size, as compared to the Unayzah Formation generally, becomes finer and is both texturally and mineralogically mature. Burrows and bioturbation is significant in the sediments of intra-channel areas. The sediments are dominantly cemented with silica, which has reduced the primary porosity and consequently resulted in poor reservoir potential. However, due to the brittleness of these sediments they are more prone to brittle fracturing and as a result could develop into a possible fracture play. Nevertheless, relatively better porous zones are locally present as patches within the channelised facies, especially where fluvial influence is dominant. In the intra-channel and interfluve facies bioturbation has reduced the porosity and as a result the reservoir quality is poor. These sediments represent initial stages of a major marine transgression.
Figure 17: Core photograph showing part of the Basal Khuff Clastics (BKC) in northern Kuwait.

(a) Small fining-upward cycles with brownish grey sandstone passing up into darker siltstone and shale. Note dark colour specks likely burrows (B) in the sandstone and root cast (R) in the finer lithology of facies BKC-2.

(b) Close-up of the contact between facies BKC-2 and the overlying facies BKC-4 at 18,766 ft depth. Lower part of the facies BKC-4 consists of dark grey, fine-grained burrowed carbonaceous sandstone and siltstone. Possible Conichnus burrow (arrowed).

(c) Interbedded shale, siltstone and dolomite beds of facies BKC-4 in the upper part of the Basal Khuff Clastics.

A clear change in lithologic characteristics is observed in the uppermost 13 ft, (18,766–18,752.5 ft depth; Facies BKC-4) of the Basal Khuff Clastics interval (Figures 16 to 18). It is described here for reference and because it marks the major transgression. This zone consists of dark grey to black, slightly greenish, fine-grained, medium bioturbated, pyritic sandstone with likely Conichnus, Chondrites, Paleophycus, Planolites and possible Diplocraterion and Macaronichnus burrows. The sandstone is locally flaser-bedded and fines upward into muddier and silty lithology. Interbedded within the sandstone are dark grey shale and up to a 1-foot-thick light to medium grey dolomudstone beds. About a half-foot thick fault gouge with crushed rock fragments in an anhydritic matrix separates the Basal Khuff Clastics and the overlying dolomudstone and dolowackstone of the Khuff Formation (Figure 18). This upper zone of the Basal Khuff Clastics is comparable to the upper transgressive part of the Ash Shiqqah Formation of Senalp and Al-Duaiji (2001). Part of the Basal Khuff Clastics succession could have been faulted-out by the overlying fault, which separates it from the carbonates of the Khuff Formation.
Palynological analyses of the core from the zone below the Khuff Carbonates covering samples from 18,752.5 to 19,008 ft depth were carried out. This interval is composed of Basal Khuff Clastics and part of the Unayzah Formation. The depth 18,752.5 ft is at the contact of Basal Khuff Clastics and the overlying carbonate succession of the Khuff Formation.

Written communication with Jim Fenton (2005) who analysed the samples from the core is quoted below:

"**Palynofloral characteristics:** predominantly miospores, with rare microplankton at 18,752.5 ft, including a single acritarch of marine origin. Fungal remains dominate at 18,752.5 ft, being represented by superabundant *Reduviiasporonites chalasta*.

**Recovery:** Variable, generally poor with the core from 18,859 ft being particularly impoverished. Relatively impoverished assemblages were also recovered from 18,878.5 and 18,917 ft.
Age criteria: The presence of *Florinites balmei* at the top and base of the study interval indicates equivalence to Zone OSPZ6 of Stephenson et al. (2003), a zone described from the Basal Khuff Clastics in Saudi Arabia. The actual age of the interval is more problematic, but is considered to represent a Tatarian [Capitanian] to approximately end-Permian age range. The age assignment is supported by the co-occurrence of *R. chalasta* and *F. balmei*, which is a characteristic of Tatarian [Capitanian] to end-Permian palynofloras worldwide.

At 18,878.5 and 18,917 ft specimens of *Hamiapollenites ?tractiferinus* and *Potonieisporites* spp. occur. These taxa are usually considered to range no younger than Kazanian [Wordian] in Russia, although...
The OSPZ5 biozone is correlatable with the lower to middle parts of the Upper Gharif Member in Oman (Stephenson et al., 2003; Osterloff et al., 2004). Angiolini et al. (2004) assigned Kazanian (Wordian) age only to the uppermost part of the Upper Gharif Member. They considered the lower and middle part of the overlying main Khuff Formation as Kazanian and Tatarian (Wordian to early Wuchiapingian) age (figure 2 of Angiolini et al., 2004). Similarly, Haq and Al-Qahtani (2005) considered the Basal Khuff Clastics and basal part of the Khuff Formation as Kazanian (Wordian) in age and the middle to upper Khuff Formation as Tatarian (Capitanian-early Wuchiapingian) in age. However, Stephenson et al. (2003, their figure 2) assigned Kazanian (Wordian) age to the upper part of the Unayzah Formation and Tatarian (Capitanian-early Wuchiapingian) age to the Basal Khuff Clastics zone. The *Hamiapollenites ?tractiferinus* and *Potoniesporites* spp. in the cored interval fall within the Unayzah Formation in the present scheme. This zone is therefore correlated with the depositional sequence DS P15 (Osterloff et al., 2004) of megasequence AP5 of the Arabian Plate (Sharland et al., 2001).

Based on core description the facies UN-6 above 18,887 ft, about 60 feet below the upper contact of the Unayzah Formation, indicates the first clear influence of a marine incursion during the deposition of the otherwise dominantly continental Unayzah Formation. In the overlying 23 ft interval (18,869–18,846 ft), fluvial facies with some indications (e.g. burrowing) of distal coastal marine influence occur. This interval is overlain by about a 20-ft-thick zone consisting of red mudstone and siltstone of terrestrial floodplain affinity. It is the uppermost distinctive palaeosol red zone. The upper boundary of the Unayzah Formation is placed at the top of this red zone at 18,827 ft.

Distal and minor marine influence may have also occurred in the Unayzah Formation as deep as 19,000 ft, about 173 ft below the top of the Unayzah Formation, where unrecognised calcareous fragments were recovered. At around 18,995 ft indications of reversing current and localised possible burrowing is present in the overlying interval. This is unique to the Unayzah Formation in northern Kuwait since the upper part of the formation in central Saudi Arabia consists of only terrestrial sediments deposited in alluvial fans, braided streams, playa lakes (Ferguson and Chambers, 1991; Senalp and Duaiji, 1995) and in eolian (Melvin and Heine, 2003) environments.

The Basal Khuff Clastics in Saudi Arabia and its equivalent zone in Oman are considered as the lower part of the OSPZ6 biozone (Stephenson, 2006) and a similar conclusion can be made for the Basal Khuff Clastics in Kuwait (Figure 19).

**CONCLUSIONS AND FUTURE STUDY**

The Unayzah Formation in northern Kuwait was broadly deposited in braid plain environments. Marine influence within the formation is likely due to its deposition in the proximity of upper coastal plain settings. The Basal Khuff Clastics is a transitional sequence leading upwards to the fully marine facies of the Khuff Formation. An attempt to assign an age bracket to the studied section was inconclusive and requires more data to establish accurately. Details of reservoir characteristics, palynological studies, sequence stratigraphy and regional correlation are some of the topics for extending the scope of the study.

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REFERENCES


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