Paleozoic stratigraphic lexicon and hydrocarbon habitat of Iraq

Aboosh H. Al-Hadidy

ABSTRACT

The crystalline Proterozoic Basement does not crop out in Iraq, but is interpreted from seismic and geophysical potential data to range in depth from about 6–10 km in western Iraq, to 12–15 km in the Zagros Mountains, in eastern Iraq. The Cambrian and Lower Ordovician sedimentary successions of Jordan and Saudi Arabia (including the Middle Cambrian Burj carbonates) are interpreted to extend into Iraq based on seismic data and regional correlations. The entire Paleozoic succession is about 3–4 km thick. The Ordovician-Permian succession in Iraq consists of ten formations that are here described in a lexicon format. For each formation, the type and reference sections in outcrop or/subsurface are reviewed (as defined by the original authors or herein), and further documented by including subsurface data (electrical logs and biostratigraphic studies). The Ordovician-Permian formations (and their members) are here placed chronostratigraphically according to the “Geological Time Scale GTS 2004” (and standard global Ordovician stages) and the Arabian Plate sequence stratigraphic framework.

The ten formations are: (1) the Early?, Middle and Late Ordovician Khabour Formation (with from base-up seven informal members K7 to K1); (2) the Silurian Akkas Formation (with the proposed lower Hoseiba and upper Qaim members); (3 and 4) the Late Devonian Pirispiki Red Beds Formation and enclosed Chalki Volcanics; (5) the Late Devonian (Famennian) and early Carboniferous (early Tournaisian) Kaista Formation; (6) the Carboniferous (Tournaisian) Ora Formation; (7) the Carboniferous (Tournaisian-Visean) Harur Limestone Formation; (8) the Visean-Serpukhovian Raha Formation (proposed here); (9) the late Carboniferous-early Middle Permian Ga’ara Formation; and (10) the late Middle and Late Permian Chia Zairi Formation (in outcrop consisting from base-up of the informal Dariri, Satina Anhydrite and Zinnar members). The Late Devonian-early Carboniferous succession, comprising the Pirispiki, Chalki, Kaista, Ora, Harur and Raha formations, is here proposed to comprise the Khleisia Group.

The Paleozoic succession of Iraq is hydrocarbon-prospective in the western part of the country, and particularly in the Western Desert near Jordan, Saudi Arabia and Syria. The source-rock component of the petroleum system consists of several potential organic-rich shales including the regionally widespread Silurian Akkas “hot shale”. In the Akkas-1 well, two hot shale units have a combined thickness of 61 m (210 ft) and total organic carbon (TOC) values that reach 16.6%. Several reservoirs and seals present exploration targets in the Western Desert of Iraq. In the Akkas field, light (specific gravity of 42° API), sweet oil and gas (no H₂S) were discovered in 1993 in the Akkas and Khabour formations, respectively. The Akkas reservoir occurs in the upper Qaim Member of the Silurian Akkas Formation and consists of sandstones that have a porosity of 6.5% and permeability of 0.2 mD. The Khabour reservoir occurs in the Upper Ordovician K1–K4 members and consists of sandstones with a fracture porosity of up to 7.6% and permeability of 0.13 mD. In North Iraq the carbonates of the Permian Chia Zairi and Triassic Mirga Mir formations correlate to gas reservoirs in the Khuff Formation of Arabia and the Dalan and Kangan formations of Iran, and may therefore be prospective. Southern Iraq, along the Kuwait and Saudi Arabian border, may also be prospective; however, no wells have been drilled into the deep Paleozoic succession in this vast region.
INTRODUCTION

Since the early part of the last century, exploration in Iraq has generally been focused on the relatively shallower Mesozoic and Cenozoic reservoirs located in the eastern and northern parts of the country. Between the late 1950s and early 1990s several exploration and water wells were drilled into the Paleozoic succession in the Western Desert (Figure 1). The Western Desert is a vast region and covers nearly one-third of the country. The Paleozoic succession presents a prospective target for exploration as it contains light and sweet oil as proven by the Akkas field and the Khleisia-1 well in Iraq (Figure 1), and similar Paleozoic fields in neighboring countries. The Ordovician and Silurian reservoirs in the Akkas field have been delineated by six wells and the field is considered commercial. Moreover, the Silurian “hot shale”, which is widely recognized as the main Paleozoic source rock in the Middle East and North Africa, appears to be widely distributed in many parts of Iraq.

In Iraq, the Paleozoic succession is incomplete due to various significant hiatuses, and sampling by deep wells is limited (Figures 2 and 3). Moreover, the known Paleozoic succession is not continuously exposed in any particular outcrop region, nor encountered in a single well or subsurface area of the country (Figures 1 to 3). Accordingly, the Paleozoic succession of Iraq has been reconstructed from outcrops in the northern region of the country, next to Turkey, and the western region next to Jordan (R. Wetzel, 1950 in van Bellen et al., 1959; Gaddo and Parker, 1959; Buday and Týracek, 1980), and from exploration and water wells in the southwestern and western deserts, next to Jordan, Saudi Arabia and Syria (Sadiq, 1985; Tamar-Agha, 1986, 1993; Al-Sakini, 1992; Al-Haba et al., 1991, 1994; Al-Siddiki et al., 1994; Al-Sammarai et al., 1994; Al-Juboury, 1997; Al-Juboury et al., 1997, 1999; Al-Quwaizy, 1997; Al-Hadidy, 1997, 2001, 2003; Aqrawi, 1998a, b; Khalaf and Khoshaba, 1999; Al-Juboury and Al-Hadidy 2005) (Figures 1 to 3). In interior and eastern Iraq, the Paleozoic succession reaches depths of 10–15 km, and becomes much too deep to reach with exploration wells (Buday and Týracek, 1980). The entire Paleozoic succession is about 3–4 km thick (Numan, 1997), and in general, the deep Paleozoic horizons are not adequately imaged by seismic data (Mohammed, 2006).

Therefore, in order to understand the geological evolution and hydrocarbon potential of the Paleozoic succession in Iraq, it is first necessary to identify the rock units that most completely represent this era of nearly 300 million years (Figure 2). These rock units can then be used to build a chronostratigraphic...
Paleozoic stratigraphy, Iraq

Ga’ara Depression

Anah Graben

Low Folded Zone

Western Desert

Southwestern Desert

Mesopotamian Basin

Euphrates River

N

Khabour Formation

Devonian, Carboniferous and Permian

Town

Well

Figure 1: (a) Location of Paleozoic outcrops and wells in Iraq. The structural provinces are after Buday and Jassim (1987) and apply for the Mesozoic and Cenozoic times. The Carboniferous-Permian Ga’ara Formation crops out in western Iraq in the Ga’ara Depression. (b) Paleozoic outcrops in the Ora region in North Iraq include the Khabour Formation, Devonian-early Carboniferous Khleisia Group (Pirispiki Red Beds, Chalki Volcanics, Kaista, Ora and Harur formations) and Permian Chia Zairi Formation (modified from Al-Omari and Sadiq, 1977). (c) Location of Akkas-1 well, which contains the reference section of the Khabour Formation, type section of the Akkas Formation and reference section for the Pirispiki Red Beds, Kaista, Ora and Harur formations. The Silurian Akkas Formation is divided into two members that are named after the towns of Hoseiba and Al-Qaim.
Paleozoic stratigraphy of Iraq

| GEOLOGICAL TIME SCALE GTS 2004 | FORMATIONS AND MEMBERS | TECTONO-STRATIGRAPHY |
|--------------------------------|-------------------------|-----------------------|
| Early Triassic                 |                         |                       |
| Lopingian                      |                         |                       |
| Changhsingian                  |                         |                       |
| Wuchiapingian                  |                         |                       |
| Capitanian                     |                         |                       |
| Wordian                        |                         |                       |
| Roadian                        |                         |                       |
| Guadalupian                    |                         |                       |
| Kungurian                      |                         |                       |
| Artinskian                     |                         |                       |
| Sakmarian                      |                         |                       |
| Asselian                       |                         |                       |
| Cisuralian                     |                         |                       |
| Late                            |                         |                       |
| Gzhelian                       |                         |                       |
| Kasimovian                     |                         |                       |
| Middle                          |                         |                       |
| Moscovian                      |                         |                       |
| Early                           |                         |                       |
| Bashkirian                     |                         |                       |
| Late                            |                         |                       |
| Serpukhovian                   |                         |                       |
| Middle                          |                         |                       |
| Visean                         |                         |                       |
| Early                           |                         |                       |
| Tournaisian                    |                         |                       |
| Middle                          |                         |                       |
| Famenian                       |                         |                       |
| Frasnian                       |                         |                       |
| Middle                          |                         |                       |
| Givetian                       |                         |                       |
| Eifelian                       |                         |                       |
| Early                           |                         |                       |
| Pragian                        |                         |                       |
| Lochkovian                     |                         |                       |
| Pridoli                        |                         |                       |
| Ludlow                         |                         |                       |
| Ludfordian                     |                         |                       |
| Gornian                        |                         |                       |
| Wenlock                        |                         |                       |
| Homerian                       |                         |                       |
| Sheinwoodian                   |                         |                       |
| Llandovery                     |                         |                       |
| Telychian                      |                         |                       |
| Aeronian                       |                         |                       |
| Rhuddanian                     |                         |                       |
| Ordovician                     |                         |                       |
| Late                            |                         |                       |
| Himianial                      |                         |                       |
| Katian                         |                         |                       |
| Sandbian                       |                         |                       |
| Middle                          |                         |                       |
| Darwillian                     |                         |                       |
| “Llanvir”                      |                         |                       |
| Early                           |                         |                       |
| Floian                         |                         |                       |
| Tremadocian                    |                         |                       |
| Late Cambrian                  |                         |                       |
| Hiatus                         |                         |                       |

Figure 2: Stratigraphic column of the Paleozoic succession in Iraq (updated from the Stratigraphic Lexicon of Iraq, van Bellen et al., 1959, and 2005). Also shown is the correlation to the Geological Time Scale GTS 2004 (Gradstein et al., 2004 with amended Ordovician stage names, see Table 1), the Arabian Plate maximum flooding surfaces (MFS; Sharland et al., 2001, 2004, corresponding to lower Paleozoic maximum flooding intervals MFI; Molyneux et al., 2006). The Ordovician Khabour Formation is the oldest known rock unit in Iraq and has seven informal members (K1 to K7). The Silurian Akkas Formation was not known in the 1959 lexicon. It is divided into the informal Hoseiba and Qaim members. The age of the Pirispiki Formation and included Chalki Volcanics was unresolved by R. Wetzel (in van Bellen et al., 1959), and considered by him either as Late Ordovician or Late Devonian; it is here interpreted as Late Devonian as it occurs above the Akkas Formation. The Raha Formation is proposed here. The Ga’ara Formation was tentatively assigned to the Triassic in the 1959 lexicon of Iraq; it is here assigned to the Late Carboniferous and Permian periods. The Khleisia Group is proposed here.
Figure 3: The encountered Paleozoic formations and members of Iraq are shown for the northern and southern outcrops and in wells (gree). The intervals shown in orange are where the total depth of the well did not penetrate the formation or the formation does not crop out.
framework that can be extrapolated to other regions in Iraq where subsurface data does not exist. This paper presents the known Paleozoic formations of Iraq in a lexicon style in stratigraphic order from oldest to youngest. For each formation the type section is reviewed from the Stratigraphic Lexicon of Iraq (van Bellen et al., 1959, reprinted in 2005) or more recent publications, as well as unpublished reports, university theses and new data. For most outcropping formations, the type section is reviewed and updated where appropriate, and a subsurface reference section is added here. In this study, subsurface data are synthesized from cores, electrical logs, petrographic, biostratigraphic and sedimentological studies, and the depositional environments and sequence stratigraphy is presented. The formations are correlated here to the “Geological Time Scale 2004” or GTS 2004 (Gradstein et al., 2004, with amended Ordovician stage names), the Arabian Plate sequence stratigraphy (Sharland et al., 2001, 2004) and to rock units in neighboring countries (Figures 2 and 4). For the Ordovician Period, the standard global stage names are used and the closest corresponding peri-Gonwanan stage names are noted in parenthesis (Table 1). In GTS 1996 (Gradstein and Ogg, 1996) the Middle Ordovician consisted of the Llanvirn and Llandeillo stages, and the Arenig stage was Lower Ordovician. In GTS 2004 (Gradstein et al., 2004), however, S. Molyneux (written communication, 2006) noted that the base of the upper Middle Ordovician Darriwilian Stage is placed at the base of the astrodentatus Graptolite Biozone, which is in the upper Arenig. Therefore in GTS 2004, the Middle Ordovician corresponds to the upper Arenig, Llanvirn and Llandeillo stages. The Llanvirn Stage is therefore shown in quotations to emphasize that it appears to correlate to the Darriwillian and does not represent the lower Middle Ordovician.

PALEOZOIC STRATIGRAPHIC AND HYDROCARBON HABITAT FRAMEWORK

In Iraq, the Proterozoic Basement is not encountered anywhere. According to interpretations of the Bouguer gravity anomaly map (Iraq Petroleum Company - IPC, 1960) and aeromagnetic total field intensity map (CGG, unpublished report, 1974), the crystalline basement lies at a depth of about 6–10 km in west Iraq, 6–8 km in the Rutbah area in west Iraq (Best et al., 1993) and reaches 12–15 km in southeast and east Iraq (Buday and Tynacek 1980; Mohammed, 2006). Above the basement, hydrocarbon-prospective upper Proterozoic and Lower Cambrian sedimentary successions, which are present in some neighboring countries, are not known in Iraqi outcrops nor penetrated in wells. These formations include infra-Cambrian evaporites and carbonates (e.g. Soltanieh Formation and Hormuz Series of Iran, and Huqf Supergroup of Oman), Cambrian clastics (e.g. Salib and Umm Sahm of Jordan, and Siq and Saq sandstones of Saudi Arabia), and shallow-marine carbonates such as the Middle Cambrian Burj Formation of Jordan (Al-Saideen et al., 1998; Konert et al., 2001; Shahin, 2002). The oldest rock unit that is documented in Iraq is represented by the upper part of the Ordovician Khabour Formation (Figures 2 and 3). This formation is gas-bearing in the Akkas field. It correlates to lithologically similar formations in neighboring countries (Figure 4), and in Iraq it was deposited on a broad platform that is informally referred to as the “Akkas Platform” (Al-Hadidy, 2001, 2003). The Akkas Platform extends from north and west Iraq and includes the Ga’ara sub-basin (Figure 1).

The Silurian Period in Iraq is partly represented by the Akkas Formation. A Late Ordovician Hirnantian (late Ashgillian) hiatus near the Silurian/Ordovician boundary is likely to exist and correspond to the glaciation of Gondwana. Another hiatus extends from latest Silurian (Pridoli) to Late Devonian (Figures 2 and 3); it is referred to as “Caledonian” by some authors, but here as the “middle Paleozoic hiatus” instead. The middle Paleozoic hiatus has been associated with the “Caledonian orogeny” although its plate-tectonic origin may more likely be related to local tectonism such as the detachment of the Hun Superterrane in the Silurian and Devonian periods (von Raumer, 1998; Stampfl et al., 2001). The Akkas Formation was deposited as a siliciclastic ramp during a regional transgression in response to a major eustatic sea-level rise associated with the melting of the Gondwana ice cap (e.g. Vaslet, 1990; Mahmoud et al., 1992). The initial phase of the transgression rapidly flooded the Arabian and North African platforms and produced anoxic conditions in intra-platform basins where the organic-rich “hot shales” were deposited. The Silurian “hot shale” in the lower part of the Akkas Formation (and its correlative units in the Middle East and North Africa; e.g. Mahmoud et al., 1992; Lüning et al., 2000, 2003) provides the main source-rock component of the Paleozoic petroleum system. In western Iraq, the hot shales were encountered in several wells (Figure 3). In the Ora region of northern Iraq, however, the Silurian succession is not seen, possibly due to the unconformable relationship between the Khabour and Pirispiki formations (Figure 3).
Table 1
Ordovician Stages

| Ordovician | GTS 1996 | GTS 2004, 2006 |
|------------|----------|----------------|
| Late       | Ashgill  | Hirnantian     |
|            | Caradoc  | Katian         |
|            |          | Sandbian       |
| Middle     | Llandeillo | Darriwilian  |
|            | Llanvir  | ?               |
|            |          | Unnamed         |
| Early      | Arenig   | Floian         |
|            | Tremadocian | Tremadocian  |

In Iraq, the Late Devonian to early Carboniferous (Mississippian Subperiod) Khleisia Group consists of an apparently continuous succession comprising the Pirispiki Red Beds Formation and included Chalki Volcanics, and the Kaista, Ora, Harur and proposed Raha formations (Figure 2). The late Carboniferous (Pennsylvanian Subperiod) to middle Permian (Guadalupian Epoch) is represented by the Ga’ara Formation siliciclastics (Figure 2). The middle Carboniferous hiatus (“Hercynian”) corresponds to the pre-Ga’ara unconformity and is correlated to the pre-Unayzah unconformity of Saudi Arabia (Al-Laboun, 1986, 1987; Al-Husseini, 2004), and pre-Al Khlata unconformity of Oman (Osterloff et al., 2004a, b) (Figure 4). The Ga’ara Sandstone passes upwards to the Middle and Upper Permian carbonates and evaporites of the Chia Zairi Formation (Figure 2); the carbonates of the latter formation represent the final Paleozoic marine transgression that covered most of the eastern part of the Arabian Plate (Figure 4). The Permian clastics and carbonates in neighboring countries contain significant accumulations of oil, non-associated gas and condensate (Figure 4). Together with the Ordovician-Silurian clastics, the Devonian to Permian succession offers several potential reservoirs that could be sourced by the Akkas “hot shale”.

KHABOUR FORMATION: EARLY?, MIDDLE AND LATE ORDOVICIAN

Authors and Nomenclature
R. Wetzel (1950 unpublished report, in van Bellen et al., 1959) first defined the Khabour Formation, which is named after the Khabour River, in the vicinity of which some of the principal outcrops are found. The formation is also known as the Khabour Quartzite-Shale Formation.

Type Section
R. Wetzel (in van Bellen et al., 1959) reported that the type section runs downwards from north to south, along the N-S-trending ridge (43°10’E), which commences about 2 km west of Kaista Village, and which descends to the stream immediately to the north of Chalki Nasara Village (37°15’15”N; 43°9’50”E; Khabour Valley in the Amadia District of North Iraq; Figures 1b and 5). The base of the section is in the deepest bed exposed in the valley, about 1.25 km upstream from Kaista Village. The type section is greater than 800 m (greater than 2,624 ft) thick as the base is not seen.

R. Wetzel (in van Bellen et al., 1959) reported that the type section in outcrop consists of alternations of thin-bedded, fine-grained sandstones, quartzites and silty micaceous shales, olive-green to brown in color (Figure 5). The beds form groups in which hardened, silty, micaceous shales predominate, and others in which the shales are subordinate and the thin-bedded quartzites are dominant. The quartzites are generally cross-bedded, both finely and coarsely, the thicker beds being generally white in color. Bedding planes are usually well-surfaced with smooth films of greenish micaceous shales. Quartzite beds are occasionally truncated by the overlying beds and show fucoid markings, infilled trails and burrows, pitted surfaces and, other bedding-plane structures of unknown origin. Metamorphism is very slight in the thin-bedded shales with quartzites, and almost unnoticeable in the thicker shale beds.
### Regional Paleozoic Correlations

| GEOLOGICAL TIME SCALE: GTS 2004 | SAUDI ARABIA | IRAQ | JORDAN | SYRIA |
|---------------------------------|--------------|------|--------|-------|
| **Early Triassic**              |              |      |        |       |
| Lopingian                       | Khuff Formation | Mirga Mir Formation |        |            |
| Guadalupian                     |               |      |        |       |
| Cisuralian                      |               |      |        |       |
| Permian                          | Unayzah Formation | Ga’ara Formation |        |            |
| Carboniferous                   |               |      |        |       |
| Devonian                        |               |      |        |       |
| Slurian                         |               |      |        |       |
| Ordovician                      |               |      |        |       |
| Late Cambrian                   |               |      |        |       |

Figure 4: The Paleozoic formations and members of Iraq are correlated to Iran, Jordan, Oman, Saudi Arabia, Syria and southeast Turkey. The geological time scale GTS 2004 is after Gradstein et al. (2004) with latest Ordovician stage names (see Table 1 for approximate correlations to previous stage names). The formations in neighboring countries and the proposed correlations are based on Lababidi and Hamdan (1985), Aqrawi (1998a, b), Konert et al. (2001) and Sharland et al. (2001, 2004). For color legend, see Figure 2.
### Paleozoic stratigraphy, Iraq

#### Regional Paleozoic correlations

| TURKEY | SOUTHWEST IRAN | OMAN | SAUDI ARABIA | GEOLOGICAL TIME SCALE: GTS 2004 |
|---------|----------------|------|--------------|---------------------------------|
| Horbol Formation | Kangar Formation | Khuff Formation | Khuff Formation | Early Triassic |
| Dalan Formation | Faraghan Formation | Gharif Formation | Unayza Formation | Permian |
|          |          | Al Khata Formation |          | Carboniferous |
|          |          |          |          | Silurian |
| Kayayolu Formation |          | Berwath Formation |          | Devonian |
| Koprulu Formation |          |          |          | Ordovician |
| Yegini Formation |          |          |          | Late Cambrian |

| Dadas Formation | Gahkum Formation | Sahmah Formation | Qusaiba Member | Qasimbah Formation | Misfar Formation | Jauf Formation | Tawil Formation |
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|                | Sahmah Formation |                  |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
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|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Formation | Jauf Formation | Tawil Formation |
|                |                  |                   |               |                   | Misfar Forma |
Al-Hadidy

Reference Section

The well Akkas-1 (Figures 1 and 6, Tables 2 and 3) was chosen by Al-Hadidy et al. (2001, 2003) as the subsurface reference section for the Khabour Formation, wherein the formation was encountered between 2,327 m and the total depth at 4,238 m (below RTKB) (7,633–13,901 ft) (Al-Haba et al., 1994). The formation is greater than 1,911 m (6,268 ft) thick, as the base of the formation was not penetrated. The Khabour Formation in the subsurface shows variable bed thickness and lithofacies, including cycles of white to gray sandstone, black shale, and siltstone. In the Khleisia-1 well the Khabour Formation was encountered between 2,291 m and total depth at 3,791 m (7,515–12,434 ft below RTKB), and is more than 1,500 m (4,920 ft) thick (Figure 7; Gaddo and Parker, 1959; Al-Haba et al., 1991, 1994).

Gaddo and Parker (1959) noted that some intercalations of dolomite and limestone occur within the Khabour siliciclastic sequences in Khleisia-1 (Figure 9 at depths of 3,300–3,450 m).

Table 2
Key Wells cited in the Paper

| Well       | Latitude        | Longitude      | RTKB | TD (m) RTKB | Spud Date     |
|------------|-----------------|----------------|------|-------------|---------------|
| Akkas-1    | 34°09'18.8" N  | 40°57'49.4" E  | 287  | 4,238       |               |
| Atshan-1   | 36°18'28.6" N  | 42°54'20.1" E  | 1,499.2 | 3,448      | August 24, 1995 |
| Jabal Kand-1| 36°37'44.4" N  | 43°40'04.2" E  | 406 m | 3,848       | January 30, 1983 |
| Key Hole 5/1| 33°33'23" N    | 40°19'25" E    | -    | 1,620       | 1980          |
| Key Hole 5/6| 38°56'13" N    | 32°42'15" E    | -    | 1,240       | 1981          |
| Khleisia-1  | 35°19'21.3" N  | 41°38'18" E    | 293 m | 3,791.4     | May 3, 1959   |
| Mityaha-1  | 35°53'28.1" N  | 42°23'10" E    | 274.85 m | 2,870      | February 25, 1975 |
| Qaim-1     | -               | -              | 208 m | 3,000       | March 1, 2003  |
| West Kifil-1| 32°21'12.4" N  | 43°43'16.7" E  | -    | 5,872       | 1980          |

Table 3
Depths (meter) relative to RTKB

|       | Akkas-1 |  | Khleisia-1 |  | Qaim-1 |  | Key Hole 5/1 |  |
|------|---------|  |------------|  |--------|  |-------------|  |
| RTKB |         |  | Top Ga’ara |  | abs   |  | abs          |  |
| 287  |         |  | Base Ga’ara|  | abs   |  | abs          |  |
| 287  |         |  | Top Raha  |  | 1,100 |  | abs          |  |
| 287  |         |  | Base Raha |  | 1,177 |  | abs          |  |
|       |         |  | Top Harur |  | 1,177 |  | 1,700        |  |
|       |         |  | Base Harur|  | 1,297 |  | 1,865        |  |
|       |         |  | Top Ora   |  | 1,297 |  | 1,865        |  |
|       |         |  | Top Kaista|  | 1,402 |  | 2,012        |  |
|       |         |  | Base Kaista| | 1,447 |  | 2,116        |  |
|       |         |  | Top Pirispiki| | 1,447 |  | 2,116        |  |
|       |         |  | Base Pirispiki| | 1,463 |  | 2,139        |  |
|       |         |  | Top Akkas  |  | 1,463 |  | 2,139        |  |
|       |         |  | Top Qaim  |  | 1,463 |  | 2,139        |  |
|       |         |  | Top Hoseiba| | 2,150 |  | 2,214        |  |
|       |         |  | Top Upper Hot Shale | | 2,205 |  | 2,243        |  |
|       |         |  | Base Upper Hot Shale | | 2,225 |  | 2,280        |  |
|       |         |  | Top Lower Hot Shale | | 2,286 |  | 2,286        |  |
|       |         |  | Base Akkas | | 2,327 |  | 2,291        |  |
|       |         |  | Top Khabour| | 2,327 |  | 2,291        |  |
|       |         |  | Top K1   |  | 2,327 |  | 2,291        |  |
|       |         |  | Top K2   |  | 2,375 |  | 2,325        |  |
|       |         |  | Top K3   |  | 2,525 |  | 2,481        |  |
|       |         |  | Top K4   |  | 2,675 |  | 2,540        |  |
|       |         |  | Top K5   |  | 3,025 |  | 2,843        |  |
|       |         |  | Top K6   |  | 3,225 |  | 3,071        |  |
|       |         |  | Top K7   |  | 3,610 |  | 3,638        |  |
|       |         |  | Total Depth | | 4,238 |  | 3,791        |  |

Reference Section

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**Paleozoic stratigraphy, Iraq**

Most previous studies subdivided the Khabour Formation into four members (e.g. M. Al-Rubaii, in Al-Sammarai et al., 1994; Al-Quwaizy, 1997). In this study the Khabour Formation is divided into seven members (denoted from oldest to youngest as K7 to K1) on the basis of lithofacies, sediment characteristics (such as grain size, color, sedimentary structure, sand/shale ratio) and palynology (Figures 6 to 9).

### Paleontology and Age

R. Wetzel (in van Bellen et al., 1959) reported that *Cruziana* sp. (d’Orbigny 1842) is common throughout the formation. He cited the following fossils: *Fraena* sp. (Roualtin 1850), *Orthoceras* sp., plates of *?eurypterids*, *?fish scales or thin shells indeterminate*, *Palaeoglossa cf. attenuata*. (J. de S. Sowerby),

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**Ordovician Khabour Formation type section**

| Formation                  | Thickness (m) | Lithology                                                                 | Markers and Zones                                                                 | Lithological Description                                                                 |
|---------------------------|---------------|----------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| **UPPER DEVONIAN**        |               |                                                                            | **Gradational boundary, taken at top of thin-bedded quartzite and micaceous shales with *Cruziana*** | Sandstone: yellowish brown, hard, shaly at top.                                        |
| **Pirispiki Red Beds**    | 330 m         |                                                                            | **Feature-forming beds**                                                           | Mudstone: rusty red, sandy, concoidal, friable soft.                                    |
| **Khabour Quartzite - Shale Formation** | 130 m         |                                                                            | **Cruziana sp. Fraena sp. Orthoceras sp.**                                         | Shale: rusty, soft, purple in part. Finely micaceous.                                   |
|                           | 340 m         |                                                                            | **Eurypterids**                                                                    | Siltstone: weathered, pale gray, greenish conchoidal, soft. Grades laterally to green fine sandstone. |
|                           |               |                                                                            | **base not exposed**                                                               | **Sandstone: fine-grained, gray greenish, weathered, ferruginous, hard, 20–40 cm beds.** |
|                           |               |                                                                            | **Sandstone: olive green, papery, micaceous alternating in 5 to 10 cm.**            | **Shale: olive green, fine-grained, quartzitic, very hard, 5 to 50 cm beds, weathered,** |
|                           |               |                                                                            | **Sandstone, generally olive green, fine-grained, ferruginous, and sporadic bands of black shale.** |

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**Fossils noted by R. Wetzel (1950)**

*Cruziana* sp.
*Fraena* sp.
*Orthoceras* sp., from uppermost part only
Plates of *?eurypterids* and *?Lingulopsis*
from uppermost part only.
*?Fish scales or thin shells indeterminate*
*Palaeoglossa cf. attenuata*.

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**Figure 5:** The Khabour Formation in the type section underlies the Pirispiki Red Beds Formation and its base is not exposed (R. Wetzel, 1950). R. Wetzel considered the age of the Khabour Formation as Ordovician (Llandeillo? = Darrilvilian Stage of the Middle Ordovician) and that of the Pirispiki Formation as Ordovician or Late Devonian. In this study the age of the Khabour Formation is interpreted as Early?, Middle and Late Ordovician and the Pirispiki as Late Devonian.

Most previous studies subdivided the Khabour Formation into four members (e.g. M. Al-Rubaii, in Al-Sammarai et al., 1994; Al-Quwaizy, 1997). In this study the Khabour Formation is divided into seven members (denoted from oldest to youngest as K7 to K1) on the basis of lithofacies, sediment characteristics (such as grain size, color, sedimentary structure, sand/shale ratio) and palynology (Figures 6 to 9).

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Figure 6: The Khabour Formation in the reference well Akkas-1 is divided into seven members (K1 to K7). Due to the high temperatures at the bottom of the hole, no electrical logs are available from 3,750 m to total depth (TD = 4,238 m). The ages of the members are shown in terms of GTS 2004 (and standard global Ordovician stages) together with palynozones PZ-5 (Ashgill = Katian-Hirnantian?), PZ-6 (?Caradoc = Sandbian or possibly Darriwilian) and PZ-8 (“Llanvirn” or Darriwilian) of Baban (1996, Figure 8). In Akkas-1, Baban did not identify PZ-7, and the basal interval below 4,150 m was assigned to the Early Ordovician PZ-9 palynozone.
### Paleozoic stratigraphy, Iraq

| System | Series | Stage | Palynozone | Formation | Member/Gp | Depth (m) | Cuttings Lithology | $V_{SH}$ | Spontaneous Potential | Sonic |
|--------|--------|-------|------------|-----------|-----------|-----------|---------------------|----------|-----------------------|--------|
|        |        |       |            |           |           |           | Gamma Ray (API)     |          |                       |        |
|        |        |       |            |           |           |           | 25 50 75 100 125    | 0 0.5 1 | 50 100 150             |        |
|        |        |       |            |           |           |           |                     |          |                       |        |

**Figure 7:** In the Khleisia-1 well the Silurian Akkas Formation is 152 m thick and much thinner than in Akkas-1 where it is 864 m thick (Figure 6). As in Akkas-1, the GR log shows the two hot shales in the Hoseiba Member (API > 100). Also seen in Khleisia-1 are the Pirispiki, Kaista, Ora and Harur, which are included in the Khleisia Group (shown for convenience in the Member/Group column).
Al-Hadidy

?Lingulopsis. The linguloids, Orthoceras sp., and ?eurypterid plates have been collected only from the uppermost part of the formation. R. Wetzel interpreted the age of the upper Khabour Formation as Ordovician (Llandeillo = Darriwilian), this attribution being supported by the determination of Palaeoglossa cf. attenuata (C.J. Stubbe) from high in the type succession. He concluded that the formation is probably Ordovician throughout because a Cambrian age is unproved for any part of the formation, although the lower part could be of this age.

Aqrawi (1998a, b) reported that Seilacher (1963) and Buday and Tyracek (1980) considered the Khabour Formation as Ordovician. He assigned the upper part of the Khabour Formation to the informal “expected” O1 biozone of Late Ordovician (late Caradoc and Ashgill = “late Sandbian-Hirnantian”) age. He noted the following acritarchs: Villosacapsula subglobosum, V. irroratum, V. oklahomense, Eupoikolofusa striata and Villosacapsula setosapellicula; and the chitinozoan Aromoricochitina nigrica. He also noted that the following fossils were reported from the northern outcrops: Billingsella sp., Orthidae, Modiolopsis sp., Orthoceras sp., Endoceras sp., Selenopeltis buchii and Cruziana furcifera.

Based on palynology, the formation has been dated as Middle and Late Ordovician (“Llanvirn” to Ashgill, i.e. “Llanvirn” to Hirnantian) by Al-Sammarai et al. (1994). Khalaf and Khoshaba (1999) based on biostratigraphic studies in outcrop, interpreted the age of the Khabour Formation as late Early Ordovician (Arenig = Floian) to Ashgillian (= Katian-Hirnantian). They reported the following acritarchs: Actinotodissus, Vulcanisphaera, Striatotheca, Peteinosphaeridium velatum and Polygonium cf. gracilis.

In the reference well Akkas-1 the following acritarchs and chitinozoans were recovered from cores and their ages were interpreted by F. Al- Juboury (in Al-Sammarai et al., 1994).

Core 11 (2,337–2,346 m) in the Khabour K1 member of Caradoc-Ashgill (Sandbian-Hirnantian) age yielded: Striatotheca sp., Estiastra sp., Frankea sp., Veryhachium cf. hamii, Desmochitina minor and broken chitinozoa.

Core 12 (2,360–2,369 m) in the Khabour K1 member of Caradoc-Ashgill (Sandbian-Hirnantian) age yielded: Striatotheca sp., Frankea sp. and Striatotheca cf. trigonia.

Core 14 (2,378.8–2387.8 m) in the Khabour K2 member of Caradoc-Ashgill (Sandbian-Hirnantian) age yielded: Veryhachium subglobosum, Eupoikolofusa cf. striata and Orthosphaeridium sp.

Core 16 (2,495–2,493.2 m) in the Khabour K2 member of Caradoc-Ashgill (Sandbian-Hirnantian) age yielded: Villosacapsula setosapellicula, Spinachitina sp., Cyathochitina and cf. Ordovicidium sp.

Core 23 (sample from 4,019.7 m) in the Khabour K7 member yielded Veryhachium subglobosum and Peteinosphaeridium sp. of middle Ordovician “Llanvirn”-Llandeillo (“Llanvirn”-Darriwilian) age.

Core 24 (sample from 4,132 m) in the Khabour K7 member yielded Frankea sp. of middle Ordovician “Llanvirn”-Llandeillo (“Llanvirn”-Darriwilian) age.

Baban (1996) conducted a palynological and organic geochemical analysis of 162 rock samples from the Paleozoic (Ordovician and Silurian) in the Akkas-1 and Khleisia-1 wells. The analysis identified 134 species of acritarchs belonging to 54 genera, 43 species of chitinozoa belonging to 12 genera, and 21 species of spores belonging to 16 genera. Nine palynological assemblages (denoted PZ-1 to PZ-9) were identified in the study and are shown in Figures 8 and 9 for the Akkas-1 and Khleisia-1 wells. Baban (1996) interpreted the age of the Khabour Formation in Akkas-1 to be predominantly “Llanvirn”-Ashgill (“Llanvirn”-Hirnantian) in age (Figures 6 and 8). He interpreted the PZ-9 assemblage as Early Ordovician (Tremadoc-Arenig, = Tremadoc-Floian) and possibly to encompass the basal part of Khabour member K7 in Akkas-1 (Figures 6 and 8), and all of K7 in Khleisia-1 (Figure 9). PZ-8 is interpreted as “Llanvirn” and encompasses the lower part of member K6 and the upper part of K7 in Akkas-1 (Figure 8). In Khleisia-1, PZ-8 is completely within the K6 member (Figure 9). PZ-7 is interpreted as Llandeilian (= Darriwilian) and encompasses member K5 and the lower part of K4 in Khleisia-1 (Figure 9). PZ-7 was not identified in Akkas-1 (Figure 8).
PZ-6 is interpreted as Caradocian (= Sandbian) and occurs within Khabour member K5 in Akkas-1 (Figure 8) and the upper part of member K4 and all of the K3 and K2 members in Khleisia-1 (Figure 9). PZ-5 is interpreted as Ashgillian (Katian-Hirnantian), and corresponds to the Khabour K1 member in Khleisia-1 (Figure 9) and the K3 and lower part of K2 members in Akkas-1 (Figures 6 and 8).

Baban’s (1996) palynozones PZ-5 to PZ-9 do not correlate consistently with the Khabour K1–K7 members between Akkas-1 and Khleisia-1 (Figures 6 to 9). A comparison of the depths of the boundary of the Akkas and Khabour formations (Silurian/Ordovician boundary) shows that the palynological and lithological picks differ by 159 m in Akkas-1 (2,486 m versus 2,327 m) and 126 m in Khleisia-1 (2,417 m versus 2,291 m). In both wells the elevation of the RTKB is about 290 m and so these differences cannot be due to different datums (sea level versus surface). These discrepancies may be an indication of the level of inaccuracy due to cutting samples not being in situ. Also noteworthy is that Core 24 (4,132 m) in the K7 member in Akkas-1 was interpreted as middle Ordovician by F. Al-Juboury (in Al-Sammarai et al., 1994), while Baban (1996) tentatively dated it as ?Tremadocian.

**Underlying Formation**

The base of the Khabour Formation is not exposed in outcrop (Figure 5; R. Wetzel, in van Bellen et al., 1959) nor penetrated in the wells that reached the oldest rocks of Iraq (Figure 3) including Akkas-1 (Figure 6), Khleisia-1 (Figure 7) and Qaim-1. Najar (1999) modeled the depth of the lower Paleozoic sediments and Proterozoic Basement in the western part of Iraq using gravity, magnetic and seismic data (Figure 10). He interpreted the depth of the top Khabour and Proterozoic Basement between Key Hole KH 5/1 and Akkas-1. Also shown in his interpretation is the estimated depth of the middle Cambrian Burj Formation. The interpretation shows that the Ordovician Khabour and older Paleozoic sedimentary section is about 4 km thick in this area, and the Proterozoic Basement is at a depth of about 6.0–7.0 km.

**Overlying Formation and Details of Contact**

R. Wetzel (in van Bellen et al., 1959) reported that in the outcropping type section, the Khabour Formation is overlain by the Pirispiki Red Beds Formation (Figure 5). The contact is apparently gradational and conformable, taken at the top of a succession of thin-bedded quartzites and micaceous shales with *Cruziana*, and below the basal unit of the Pirispiki. The latter unit is 10 m thick (33 ft) and consists of blocky siltstones, brownish in color, which grades laterally into green, fine-grained, soft, onion-weathering sandstones. The Khabour shales are olive-green to brown in color below the contact; the basal Pirispiki is bright green by contrast, passing upwards into dominant red and purple colors. The contact is clear-cut, but the reappearance of thin beds of hard quartzites, indistinguishable from those of the Khabour, within the basal division of the Pirispiki, suggests that there may be no depositional break between the two formations.

In the wells Akkas-1 and Khleisia-1, the Khabour Formation is overlain by the “hot shale” of the Silurian Akkas Formation (Figures 6 and 7). In Iraq there is no clear evidence of glaciogenic or periglacial rock units that represent the Late Ordovician (Hirnantian)-?early Silurian glaciation of Gondwana. The manifestation of this Gondwana glaciation is evident in western Saudi Arabia (Vaslet, 1990) and southwest Jordan (Powell et al., 1994) (Figure 4). The topmost few meters of the Khabour Formation (about 2.0 m in Akkas-1) consist of shallow-marine sandstones that represent the basal part of the Silurian transgression in Iraq (Figures 2-4). These sandstones were probably deposited after a hiatus in Hirnantian times that resulted from the sea-level drop associated with the glaciation of Gondwana.

**Regional Distribution, Depositional Setting and Sequence Stratigraphy**

During the Ordovician Period most of Iraq was covered by a shallow, epeiric sea bordering lowlands whose aerial extent altered in response to transgressions and regressions. R. Wetzel (in van Bellen et al., 1959) interpreted the depositional setting of the Khabour Formation as extensive, shallow-water (or intertidal) mud- and silt-flats. He concluded that the setting was marine in at least the micaceous silty shales wherein the *Orthoceras* sp., etc. are found. He added that intermittent emergence or depositional build-up to dune level is suggested by the nature of the cross-bedding in some of the quartzite units, and by some of the bedding-plane structures.
### Palynology of the Ordovician Khabour Formation and Silurian Akkas Formation in the Akkas-1 well (from Baban, 1996)

| System     | ORDOVICIAN | SILURIAN | DEVO-NIAN |
|------------|------------|----------|-----------|
| Series     | LOWER      | MIDDLE   | UPPER     |
| Stage      | Tremadoc   | Llanvirn | Caradoc   | Ashgill   |
| GTS 2004   | Tremadocian-| Fionian  | Ludlow    | Famennian |
| Palynozone | PZ-9       | PZ-8     | PZ-6      | PZ-5      | PZ-4 | PZ-3 | PZ-2 | PZ-1 |
| Formation  | Khabour    | Akkas    | Pirispiki | Kaista    |
| Depth (m)  | 4,000      | 3,000    | 2,000     | 1,300     |

**Lithology**

- Leiospheres
- Neoveryhachium cariniae
- Veryhachium reductum
- Dileoptus denticulata
- Leiofusa estracha
- Veryhachium lardii
- Veryhachium trispinosum
- Dactylofusa stratifera
- Rhopalopora sp. 1
- Thytopollia maraca
- Deunflia monospinosa
- Ozotobrachion sp.
- Baltisphaeridium aniae
- Hoegklintia cylindrica
- Dileoptus granulatispinosum
- Comaspheeridium sp. 1
- Comaspheeridium williareae
- Estastr stellata
- Hapsidogulla sanamannii
- Hapsidogulla sp. 1
- Elektoroklos aurora
- Deflandrastum sp. 1
- Deflandrastum leonardi
- Dileoptus remotas
- Tasmanites sp. 2
- Tasmanites sp. 3
- Tasmanites roxi
- Leiofusa bermesgae
- Dileoptus cantabrica
- Leptobrachion arbusculiferum
- Tunisphaeridium tentaculiferum
- Leiofusa tumida
- Cymbosphaeridium pilar
- Deflandrastum millepiedi
- Pterospermella granulata
- Domasia limaciformis
- Tasmanites sp. 1
- Triangula sp.
- Baculatriculatus baculatus
- Veryhachium minutum
- Ammonium microcladium
- Multiciphaeridium asombrosum
- Veryhachium formosum
- Mchysthidium sp. A
- Onondagella cylindrica
- Baltisphaeridium multipilum
- Elektoroklos sp.
- Tunisphaeridium caudatum
- Opilatula ramusculeosa
- Leiofusa rhkne
- Veryhachium europeum
- Geron guerliner
- Geron gracilis
- Onondagella deuturni
- Geron cavedon
- Leiofusa irratipellis
- Dactylofusa algens
- Mchysthidium sp. 1
- Dactylofusa monterrosae
- Baltisphaeridium canabricum
- Dileoptus sp. 1
- Multiplicaeridium coralimum

**ACRITARCHS**

- Conochitina micracantha
- Desmochitina minor
- Rhabdochitina pistillifrons
- Ancyrochitina merga
- Conochitina stentor
- Sphaerochitina longicollis
- Ancyrochitina ancyrea
- Conochitina tuba
- Conochitina decipiens
- Desmochitina
- Ancyrochitina fragilis var. brevis
- Ancyrochitina udayanensis
- Ancyrochitina fragilis
- Gotlandochitina acacusensis
- Fungochitina apesinia
- Ancyrochitina laithia
- Solisphaeridium flexipilosum
- Lieliberidium Ilynonse
- Polygonium symbolum
- Orthosphaeridium ternatum
- Polygonium gracile
- Veryhachium balticum
- Orthosphaeridium quadricorne
- Orthosphaeridium quadricorne
- Ordovicidium elegantulum
- Baltisphaeridium filosum
- Baltisphaeridium longispinosum
- Orthosphaeridium bispinosum
- Goniosphaeridium polygonale
- Peteinosphaeridium elegantum
- Salopidium woolhopense
- Diexallophasis pachymura
- Solisphaeridium erizum
- Ammonidium palmitellum
- Duvernaysphaera aranaides
- Diexallophasis caperoradiola
- Baltisphaeridium verrucatum
- Evitcia
- Comasphaeridium sequestratum
- Gorgonisphaeridium

**Spores**

- Hymenozonotriletes genuinus
- Tumulispora malevillensis
- Nikitinsporites canadensis
- Endosporites endorugosus
- Convolutisporites tuberculata
- Stenozonotriletes perforatus
- Spelaeotriletes cabotii
- Umbonatisporites
- Grandispora uncata
- Varrucosisporites nitidus
- Conochitina redoune
- Conochitina lepida
- Conochitina primitiva
- Desmochitina?
- Conochitina? simplex
- Lagenochitina
- Archaeozonotriletes chulus var. chulus

**Figure 8** Palynology of the Ordovician Khabour Formation and Silurian Akkas Formation in the Akkas-1 well.
Figure 8: Palynology of the Ordovician Khabour Formation and Silurian Akkas Formation in the Akkas-1 well (from Baban, 1996).

### ACRITARCHS

- Multiplicisphaeridium corallinum
- Diexallophasis
- Dateriocradus monterrosae
- Micrhystridium
- Leiofusa irroratipellis
- Onondagella deunffi
- Geron guerillerus
- Leiofusa rhikne
- Oppilatala ramusculosa
- Tunisphaeridium caudatum
- Electoriskos
- Baltisphaeridium multipilosum
- Veryhachium formosum
- Ammonidium microcladum
- Baculatireticulatus baculatus
- Triangulina
- Tasmanites
- Domasia limaciformis
- Pterospermella granulata
- Deflandrastrum millepiedi
- Leptobrachion arbusculiferum
- Dactylofusa cantabrica
- Leiofusa bernesgae
- Tasmanites roxi
- Deflandrastrum
- Elektoriskos aurora
- Comasphaeridium williereae
- Comasphaeridium
- Diexallophasis granulatispinosa
- Baltisphaeridium aniae
- Deunffia monospinosa
- Tylotpolla maraca
- Rhopaliopora
- Dactylofusa stratifera
- Leiofusa estracha
- Veryhachium reductum
- Neoveryhachium carminae
- Leiospheres

### CHITINOZOA

- Conochitina micracantha
- Desmochitina minor
- Rhabdochitina pistillifrons
- Ancyrochitina ancyrea
- Sphaerochitina pistilliformis
- Ancyrochitina laithia
- Fungochitina apesinia
- Conochitina ancyrea
- Sphaerochitina pistilliformis
- Desmochitina sp.
- Ancyrochitina palma
- Gotlandochitina acacusensis
- Ancyrochitina fragilis
- Ancyrochitina udayanensis
- Ancyrochitina fragilis var. brevis
- Desmochitina sp. 3
- Conochitina decipiens
- Conochitina tuba
- Ancyrochitina ancyrea
- Sphaerochitina longicollis
- Conochitina stentor
- Ancyrochitina merga
- Habdochitina pistillifrons
- Desmochitina minor
- Conochitina micracantha

### Palynozone

| System | Ordovician | Silurian | Devonian |
|--------|------------|----------|----------|
| Series | Lower      | Middle   | Upper    |
| Stage  | Tremadocian-Floian | Llanvirn-Darnillian | Caradoc-Sandbian-Katian Himantian | Ashgill |
| GTS 2004 | ? | ? | ? | Ashgill |
| Palynozone | PZ-9 | PZ-8 | PZ-6 | PZ-5 | PZ-4 | PZ-3 | PZ-2 | PZ-1 |
| Formation | Khabour | Akkas | Pirispiki | Kaista |
| Depth (m) | 4,000 | 3,000 | 2,000 | 1,300 |

**Lithology**
- Abundant
- Present
- Common
- Shale
- Sandstone
- Limestone

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Figure 8 (continued).
The seven informal members of the Khabour Formation correspond to depositional cycles and appear to contain two maximum flooding surfaces (MFS) or maximum flooding intervals (MFI): one in the K4 to K7 member and a second in the K2 member (Figure 2).

Khabour K7, the “lower thick shale” member, was encountered in Akkas-1 between 3,610 m and total depth at 4,238 m (11,841–13,901 ft), and is greater than 628 m (2,060 ft) thick (Figure 6). This basal unit consists of homogeneous black shales, commonly fissile with dominant mica content and irregular pyrite blotches. The great thickness, pyrite content and lack of bioturbation may reflect deposition in reducing euxinic conditions. This interpretation of the depositional environment is supported by the study of Baban (1996).

The Khabour K7 member, on the basis of its probable “Llanvirn” age (F. Al-Juboury, in Al-Sammarai et al., 1994), probably contains MFS O30 of Middle Ordovician “Llanvirn” age (Sharland et al., 2001, 2004; Figure 2) or MFI O30 positioned in the basal shales in the Saih Nihayda Formation in Oman (Drost, 1997; Molyneux et al., 2006). If, however, the age of the K7 member is Early Ordovician as suggested by Baban (1996), then MFI O30 would have to be positioned higher-up in the Khabour Formation. On the basis of its shale lithology and great thickness, the K7 member probably correlates to the Hanadir Shale Member of the Qasim Formation in Saudi Arabia (Vaslet et al., 1987; Senalp and Al-Duaiji, 2001), the black graptolite shales near the base of the Swab Formation in Syria (T.V. Yankauskas and S. Talli, unpublished Syrian Petroleum Company report in Lababidi and Hamdan,
The Khabour K6 “intercalated shale and sandstone” member was encountered in Akkas-1 between 3,225 and 3,610 m (10,578–11,841 ft), and is 385 m (1,263 ft) thick (Figure 6). The overlying Khabour K5 “lower thick sandstone” member was encountered in Akkas-1 between 3,025 and 3,225 m (9,922–10,578 ft), and is 200 m (656 ft) thick (Figure 6). The Khabour K6 and K5 members in Akkas-1 probably correlate to the Middle Ordovician (Llandeillo = Darriwilian) Kahfah Member of the Qasim Formation in Saudi Arabia (Vaslet et al., 1987, 1994). The Kahfah Member is divided into lower and upper units, which are separated by a disconformity, and the two units may correlate to the Khabour K6 and K5 members.

Khabour K4, the “middle thick shale” member, was encountered in Akkas-1 between 2,675 and 3,025 m (8,774–9,922 ft), and is 350 m (1,148 ft) thick (Figure 6). This member is Caradoc in age in Khleisia-1 and most probably contains MFS O40 of Late Ordovician late Caradoc (=Sandbian) age (Sharland et al., 2001, 2004; Figure 2) or MFI O40 in the Hasirah Formation in Oman (Droste, 1997; Molyneux et al., 2006). The K4 member is correlated to the Ra’an Shale Member of the Qasim Formation in Saudi Arabia (Vaslet et al., 1987; Senalp and Al-Duaiji, 2001), the lower part of the Afandi Formation of Syria (T.V. Yankauskas and S. Talli, unpublished Syrian Petroleum Company report in Lababidi and Hamdan, 1985; “Affendi” in Konert et al., 2001; “Affendi” in Brew et al., 1999, 2001), and the upper part of the Dubaydib Formation of Jordan (Andrews et al., 1991; Aqrawi, 1998a, b; Konert et al., 2001) (Figure 4).

Khabour K3, the “interbedded shale and sandstone” member, was encountered in Akkas-1 between 2,525 and 2,675 m (8,282–8,774 ft), and is 150 m (492 ft) thick (Figure 6). Khabour K2, the “upper thick shale” member, was encountered in Akkas-1 between 2,375 and 2,525 m (7,790–8,282 ft), and is 150 m (492 ft) thick (Figure 6). Khabour K1, the “upper thick sandstone” member, was encountered in Akkas-1 between 2,375 and 2,327 m (7,790–7,633 ft), and is 48 m (157 ft) thick (Figure 6). The K1 to K3 members may correlate to the Quwarah Member of the Qasim Formation and may, in part, be coeval to the glaciogenic Sarah and post-glacial Uqlah formations of Saudi Arabia (Vaslet et al., 1987; Vaslet, 1990; Janjou et al., 1997a, b; Senalp and Al-Duaiji, 2001) (Figure 4). K1 to K3 may also correlate to the upper part of the Afandi Formation of Syria (T.V. Yankauskas and S. Talli, unpublished Syrian Petroleum Company report in Lababidi and Hamdan, 1985) and the Risha Formation of Jordan (Andrews et al., 1991; Aqrawi, 1998a, b) (Figure 4).

According to R. Wetzel (in van Bellen et al., 1959), the exposed Khabour quartzites and shales are about 2,000 m (6,560 ft) thick in the Ser Ashuti Mountain Area of Turkey. The entire Khabour Formation is correlated to the Zardkuh Formation of southwest Iran (Zagros Mountains), and the Bedinan Formation of southeast Turkey (Konert et al., 2001) (Figure 4).

Economic Significance
In the Akkas field, sweet gas and condensate were discovered in sandstone in the K1 to K4 members of the Khabour Formation (Al-Haba et al., 1991, 1994). Based on seismic data and six wells the Akkas field is interpreted as a basement-controlled, ‘flat-top’ anticline bounded by ‘door’ faults along its flanks (Figure 10). The faults provide the main pathway for hydrocarbon migration from the lower Silurian source rocks to the Ordovician and Silurian reservoirs. The shale of the lower Hoseiba Member of the Silurian Akkas Formation caps the reservoir in the K1 member of the Khabour Formation. Intra-Khabour shales provide the caprocks for the older Khabour reservoirs.

The Khabour Formation represents one of the main Paleozoic reservoir targets, and it occurs by stratigraphic position below the Akkas source rocks. According to Al-Haba et al. (1991, 1994) the Khabour shales are highly-mature, marine, organic-rich rocks with total organic carbon content (TOC) values of 0.9–5% by weight in Khleisia-1 and Akkas-1. They suggested that these could have generated, in part, the hydrocarbon that was encountered in the Akkas field and Khleisia-1.
Based on the analysis of Core 11 (2,337–2,346 m) in the uppermost Khabour K1 member in Akkas-1 (Figure 6), the average porosity is 7.6%, average permeability is 0.13 mD and average density is 2.69 gm/cc. In the Khabour K2 member four cores were analyzed for reservoir properties: Core 13 (2,369–2,378 m), Core 14 (2,378.8–2,387.8 m), Core 15 (2,387.8–2,397 m) and Core 16 (2,492–2,504.3). The core analysis indicated an average porosity of 6.6%, average permeability of 0.08 mD and average density of 2.69 gm/cc (Al-Sammarai et al., 1994).

Figure 9: Palynology of the Ordovician Khabour Formation and Silurian Akkas Formation in the Khleisia-1 well (from Baban, 1996).
AKKAS FORMATION: SILURIAN

Authors and Nomenclature
The Akkas Formation does not crop out in Iraq and is not included in the Stratigraphic Lexicon of Iraq (van Bellen et al., 1959). A section in water well Key Hole KH 5/1 was first determined to be Silurian in age by Al-Juboury and Al-Beerkhedar (1985), and later by Nader (1990, 1993). British Petroleum (BP) (1990) and F. Al-Juboury (1991, in Al-Haba et al., 1991, 1994) also identified Silurian sections in Khleisia-1 (Figure 7) and KH 5/6. British Petroleum (1990) referred to this section as the Dadas

| System          | ORDOVICIAN          | SILURIAN          |
|-----------------|---------------------|-------------------|
| Series          | LOWER              | MIDDLE            | UPPER            |
| Stage           | Tremadocian - Arenig| Llanvirn          | Llandeillo       | Caradoc           | Ashgill           |
| GTS 2004        | Tremadocian - Floian| Llanvirn - Darriwilian | Sandbian - Kātān Hirmātān |
| Palynozone      | PZ-9               | PZ-8              | PZ-7             | PZ-6              | PZ-5              |

| Formation       | Khabour             | Akkas             |
| Member          | K-7                 | K-6               | K-5              | K-4               | K-3               | K-2               | K-1               |
| Depth (m)       | 3,800               | 3,500             | 3,000            | 2,500             |

| Lithology       | Abundant            | Common            | Present          | Shale             | Sandstone         | Siltstone         | Dolomite          |

ACRITARCHS

Margachitina margaritana
Ancyrochitina ancyrea
Conochitina intermedia
Conochitina micrantha
Desmochitina minor
Rhabdochitina magna
Desmochitina ? coca
Cyathochitina cylindrica
Ancyrochitina sp.
Desmochitina spheraica
Desmochitina cingulata
Conochitina comanulafaeformis
Lagenochitina baltica
Desmochitina sp. 2
Cyathochitina ? touggourtensis
Lagenochitina maxima
Rhabdochitina pistillifrons
Conochitina sp.
Desmochitina urna
Armoricolchitina? niliensis

CHITINOZA

Ambitipores avitus
Archaeozonotriletes chulus var. chulus

SPORES

Scolecodont
Graptolite

Figure 9 (continued).
Formation based on its correlation to southeast Turkey (Figure 4). F. Al-Juboury (in Al-Sammarai et al., 1994) studied the formation in Akkas-1 after which the formation was named in Al-Juboury et al. (1997).

Based on the gamma-ray log and organic content, the Akkas Formation is divided into two members. The name for the lower rock unit is proposed as the Hoseiba Member after Hoseiba City (near the Iraq-Syria border and 28.5 km north-northwest of Akkas-1, Figure 1c). The name of the upper unit

Figure 10: Cross-section from well Akkas-1 to Key Hole KH 5/1 (modified from Najar, 1999; see Figure 1 for location). The Ordovician Khabour Formation and lower Paleozoic succession (Lower Cambrian, Middle Cambrian Burj Formation, Upper Cambrian and Lower Ordovician) is estimated to have a thickness of about 4.0 km (c. 13,100 ft) based on seismic, gravity and magnetic data. The depth to the Basement (dashed line at the top of the gray) is based on geophysical potential data (gravity and magnetics) and does not have a seismic reflection. In contrast the Middle Cambrian Burj Formation (blue) is interpreted as a seismic reflection and appears to onlap the Proterozoic Basement in places.
Paleozoic stratigraphy, Iraq

is proposed as the Qaim Member, after Al-Qaim City near Hoseiba City (27 km north-northeast of Akkas-1, Figure 1c).

Aqrawi (1998a, b) assigned the Llandovery and Wenlock series of the Silurian succession in Iraq to the Akkas Formation, but incorrectly named the upper Silurian (late Wenlock and Ludlow) part of the Akkas Formation as the “Suffi formation”. The term “Suffi” was suggested by Radosевич et al. (1981) for a succession in Key Hole KH 5/1, and also used by other authors (e.g. Al-Juboury and Al-Beerkhedar, 1985; Nader, 1990, 1993). The term “Suffi formation” is considered obsolete.

**Type Section**
The Akkas-1 well (Figures 1, 11 to 13, Tables 2 and 3) established the type section of the Silurian section in the subsurface of the Western Desert in Iraq (Al-Juboury et al., 1997), wherein the formation was encountered between 1,463 m (compared to 1,456 m in Aqrawi, 1998a, b) and 2,327 m (4,799–7,633 ft below RTKB) and is 864 m (2.834 ft) thick. In Qaim-1 (Figures 1, Table 3), the Akkas Formation was encountered between 1,665 and 2,507 m below the RTKB (5,461–8,223 ft), and it is 842 m (2,762 ft) thick. In contrast, in Khleisia-1 the formation is only 152 m (499 ft) thick (2,139–2,291 m; 7,016–7,515 ft; Figures 1 and 7, Table 3).

The Akkas Formation consists of black fissile shale with sandstone and siltstone intercalations. In Akkas-1, the lower Hoseiba Member is encountered between 2,150 and 2,327 m (7,052–7,633 ft) and is 177 m (581 ft) thick (Figures 11 and 12). In Qaim-1, the Hoseiba Member is encountered between 2,185–2,507 m (7,167–8,223 ft) and is 322 m (1,056 ft) thick. The Hoseiba Member consists of black, gray to dark gray shale, fissile, micaceous, noncalcareous, pyritic, silty, with graptolites and brachiopods. It contains two organic-rich, black “hot shale” beds that are fissile, with high-gamma uranium radiation (Figures 11–13). The upper hot shale, in Akkas-1, is 20 m (66 ft) thick, and the lower is 41 m (134 ft) thick (Figures 11–13).

In Akkas-1, the upper Qaim Member is encountered between 1,463 and 2,150 m (4,799–7,052 ft) and is 687 m (2,253 ft) thick (Figure 11 and 12). In Qaim-1 it is encountered between 1,665–2,185 m (5,461–7,167 ft) and is 520 m (1,706 ft) thick. The Qaim Member consists of alternating sandstone, siltstone and shale. The shale is slightly fissile, gray, dark gray, greenish gray, brownish gray and black in color. The sandstones are generally light gray in color, fine-grained, subangular to subrounded, moderately sorted, calcareous, compacted and bituminous in part. The siltstones are light gray, micaceous, bioturbated in part, and with graptolite trace fossils (i.e. drag marks).

**Paleontology and Age**
The Silurian succession in Iraq was divided into the Akkas Formation (Llandovery and Wenlock) and obsolete “Suffi Formation” (late Wenlock and Ludlow) by Aqrawi (1998a, b). Aqrawi (1998a, b) reported the following acritarchs from the Llandovery-Wenlock informal “S2” biozone of the Akkas Formation: *Deunffia furcata*, *Domasia bispinosa*, *Oppilatala eoplanktonica*, *Quadraditum fantasticum*, *Dactylofusa maranhensis* and *Dateriocradus monterrosae*; and the chitinozoa: *Fungochitina fungiformis* and *Conochitina armillata*. He reported the following spores from the Ludlow informal “S1” biozone of the Akkas Formation: *Ambitisporites avitus*, *Archaeozonotriletes chulus* and *Emphanisporites rotatus*; the acritarchs: *Neoveryhachium carminae*, *Cymbosphaeridium pilar*, *Leiosphaeridia laevigata*, *Deflandrastrum millepedi*, *Dielaxallophasis denticulata*, *Visbyphaera dilatispinosa* and *Leiofusa estrecha*; and the chitinozoa: *Ancyrochitina ancyrea*, *Plectochitina carminae*, *P*. *saharica*, *Sphaerochitina sphaerocephala*, *Angochitina valentini* and *A. echinata*.

In the Akkas-1 well, F. Al-Juboury and A. Khoshaba (in Al-Sammarai et al., 1994) reported the following fossils and ages (Figure 11).

**Core 6** (1,466–1474.1 m) in the Qaim Member of Silurian, Ludlow-age yielded *Ambitisporites avitus*, *Synorisporites*, *Visbyphaera*, *Ancyrochitina ancyrea*, *Leiofusa granulacutis*, *Onondagella* sp., *Geron guerillerus* and *Plectochitina*.

**Core 7** (1,743.7–1,752 m) in the Qaim Member is interpreted as Silurian Wenlock-Ludlow in age.
Figure 11: The well Akkas-1 was chosen as the type section for the Silurian Akkas Formation by Al-Juboury et al. (1997), and is here divided into the Hoseiba and Qaim members (localities in Figure 1c). The Akkas Formation does not crop out in Iraq. In the subsurface it overlies the Khabour Formation and is overlain by the Upper Devonian Pirispiki Formation of the Khleisia Group (Figure 15). Baban (1996) identified palynozones PZ-4 (Llandovery), PZ-3 (Wenlock) and PZ-2 (Ludlow) in Akkas-1 (see Figure 8).
Core 8 (1,894–1,903 m) in the Qaim Member of Silurian, Llandovery-Ludlow age yielded Onondagella deunffii, Geron guerillerus, Plectochitina sp., Geron gracilis and Tasmanites spp.

Core 9 (2,017–2,026 m) in the Qaim Member of Silurian, Llandovery-Ludlow age yielded Onondagella deunffii, Leiosphaeridia laevigata, Archaeozonotriletes sp., Tasmanites sp., Geron amabilis and Tylotopella sp.

Al-Juboury et al. (1997) and Al-Juboury and Al-Beerkhdar (1997) interpreted the age of the Akkas Formation as Silurian (Llandovery-Ludlow) and reported the following acritarchs, chitinozoa and spores:

**Acritarchs:** Cymbosphaeridium pilar Cramer 1964, Baltisphaeridium guelthaense Jardiné, Combaz, Magloire, Peniguel and Vachey 1974, Diezallophaisis denticulatum Stockmans and Willière 1963, Diezallophaisis denticulatum gotlandicum Cramer 1970, Geron amabilis Cramer 1969, Geron gracilis Cramer 1969, Geron guerillerus Cramer 1969, Neovervycshium cariniae Cramer and Diez 1972, Deflandraslrum millepiedi Combaz 1962, Deflandraslrum anthisiae Combaz 1962, Deflandraslrum colonnae Combaz 1962, Onondagella deunffii Cramer 1966, Onondagella cylindrica Jardiné, Combaz, Magloire, Peniguel and Vachey 1974, Onondagella sarpetensis Cramer 1966, Dictyotidium biscutatum Kirjanov 1978, Dictyotidium dictyotum Eisenack 1938, Leiosfusa filifera Downie 1959, Multiplicisphaeridium saharicum Lister 1970, Pterospermella martini Cramer 1967, Ovnia desertica Cramer and Diez 1977, Eupoikilofusa striatfera Cramer 1970 Multiplicisphaeridium arbusculiferum (Downie) Lister 1970, Multiplicisphaeridium cariniosum Cramer 1961, Multiplicisphaeridium ramulosolus (Deflandre) Lister 1970, Visbigysphaera gotlandicum Eisenack 1954, Tunisphaeridium tentaculiferum Martin 1966, Tunisphaeridium caudatum Deunff & Evitt 1968, Tunisphaeridium parvum Deunff & Evitt 1968, Dactylofusa maranhensis Brito & Santos 1965, Dactylofusa saudiariae Cramer and Diez 1972, Cymatisphaera wenlockia Downie 1959, Leiosfusa rhikne Loeblich 1970, Leiosfusa granulacutis Loeblich 1970, Leiosfusa bernesgae Cramer 1964, Lophospheraeidium listeri Kirjanov 1978, Leiosfusa tumida Downie 1995, Deunffia furcata Downie 1960, Domasia bispinosa Downie 1960, Domasia symmetrica Cramer 1970, Domasia limaciformis Stockmans & Willière 1963, Tylotopolla caelamenticus Loeblich 1970, Tylotopolla wenlockia Dorning 1981, Tylotopolla digitifera Loeblich 1970, Comasphaeridium willierea Cramer 1970, Comasphaeridium sequestratus Loeblich 1970, Comasphaeridium simplex Thhusu 1973, Elektoriskos pogonius Loeblich 1970, Lophospheraeidium citrinum Downie 1963, Cymatisphaeridium bikitum Lister 1970, Carminella maplewoodensis Cramer 1968, Oppilatala frondis (Cramer & Diez) Dorning 1981, Diezallophaisis pachymurum (Hill) Dorning 1981, Leiosphaeridia laevigata Stockmans & Willière 1963, Multiplicisphaeridium neaghgae Cramer 1970, and Leiosphaeridia major (Staplin) Downie & Sarjeant 1964.

**Chitinozoa:** Ancyrochitina ancyrea Eisenack 1962, Ancyrochitina nodosa Taugourdeau & de Jekhowsky 1960, Ancyrochitina desmea Eisenack 1968, Plectochitina cariniae Cramer 1964, Linochitina cingulata Taugourdeau & de Jekhowsky 1960, and Conochitina tuba Eisenack 1968.

**Spores:** Ambitisporites avitus Hoffmeister 1959, Ambitisporites dilatus (Hoffmeister) Richardson & Lister 1969, Emphanisporites neglectus Vigran 1964, Emphanisporites rotatus McGregor 1961, Synorisporites verrucatus Richardson & Lister 1969 and Archaeozonotriletes chulus (Cramer) Richardson & Lister 1969.

Baban (1996, Figures 8 and 9) identified three palynozones in the Akkas Formation denoted as PZ-4, PZ-3 and PZ-2 that correspond to the Llandovery, Wenlock and Ludlow series in Akkas-1, respectively. In the Khleisia-1 well, Baban (1996) identified only PZ-2 (Ludlow) directly above PZ-5 (Ashgill = Katian-Hirnantian), implying that the Llandovery and Wenlock series (PZ-3 and PZ-4) are absent. This biostratigraphic interpretation is inconsistent with the presence of the Llandovery hot shale at the base of the Akkas Formation in Khleisia-1 (Figure 7).

**Underlying Formation and Details of Contact**

In Akkas-1, the Akkas Formation overlies the Ordovician Khabour Formation. The contact is taken at the change from quartzitic sandstone below to radioactive shale above. See “Khabour Quartzite-Shale Formation: Overlying Formation and Details of Contact”.

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Figure 12a: Potassium, thorium and uranium logs are shown between 1,295 m and 2,500 m in the well Akkas-1 (from Majidee, 1999). The high content of radioactive elements is particularly evident in the two hot shales in the lower Hoseiba Member of the Silurian Akkas Formation.
Overlying Formation and Details of Contact

In Akkas-1, the Akkas Formation underlies the Devonian Pirispiki Red Beds Formation. The Pirispiki Formation is considered to be Late Devonian in age implying that a hiatus occurred during the Early and Middle Devonian.

Regional Distribution, Depositional Setting and Sequence Stratigraphy

The lower Hoseiba Member of the Akkas Formation was deposited under deep-water euxinic conditions during the early Silurian after melting of the Gondwana polar glaciers. The overlying Qaim Member was deposited on an intra-cratonic siliciclastic platform with shallow-marine to deep-ramp settings. The Akkas Formation is widely distributed in southern and western Iraq. The thickness of the formation reaches a maximum of about 1,000 m (3,280 ft) in the depocenter in the Akkas basin. In Key Hole KH 5/1 and Key Hole KH 5/6 the base was not encountered and the penetrated section is 270 m (888 ft) and 570 m (1,870 ft) thick, respectively (Aqrawi, 1998a, b). The thickness of the Akkas Formation decreases towards northern Iraq and is only 342 m (1,222 ft) thick in Khleisia-1 (Figure 7) and missing in the Ora region (northern thrust zone) (Figure 1b).

Towards Syria, the Akkas Formation is correlated to the Tanf Formation (T.V. Yankauskas and S. Talli, unpublished Syrian Petroleum Company report in Lababidi and Hamdan, 1985), where it attains a thickness of 1,100 m (3,608 ft); or to the Abba Formation (Konert et al., 2001) (Figure 4). The Akkas Formation is correlated to the Gahkum Formation of southwest Iran (Zagros Mountains), the Dadas Formation of southeast Turkey, and the Khisha and overlying Mudawarra formations in the Risha basin of Jordan (Andrews et al., 1991; Aqrawi, 1998a, b; Konert et al., 2001). The Akkas

Figure 12b: Temperature, temperature gradient and radioactive heat generation for the interval 1,295–2,500 m in the well Akkas-1 (from Majidee, 1999). F. Majidee used a quantitative technique to calculate the anomalous temperature gradient and heat generation across the hot shale interval 2,205–2,327 m. He attributed the higher temperature gradient (6.1°C/100 m) to two factors: (1) the high uranium content in the hot shale (up to 24 ppm) increases the rate of radiogenic heat generation to about 5.0 microWatt per cubic meter; and (2) the dominance of shale in the Akkas Formation reduces the conductivity and increases the thermal gradient. In contrast the higher conductivity of the mixed clastics and carbonates in the overlying Khleisia Group results in a lower thermal gradient (2.37°C/100 m).
Formation correlates to the Qalibah Formation of Saudi Arabia, where it can exceed 1,000 m (3,280 ft) (Abu-Ali et al., 1991; Mahmoud et al., 1992; Aoudeh and Al-Hajri, 1995) (Figure 4).

Sharland et al. (their figure 2.7 on p. 36, 2001, Figure 2) correlated the lower hot shale of the Qaim Member to MFS S10 of middle Aeronian age (Llandovery Epoch, Silurian Period). The Silurian hot shale, however, is elsewhere in the Middle East and North Africa considered to be Rhuddanian (early Llandovery) and therefore older than the age of MFS S10. The Akkas Formation is correlated to the Sahmah Formation in Oman (Droste, 1997; Molyneux et al., 2006).

Economic Significance
In Akkas-1, the two hot shale beds with a combined thickness of 61 m are separated by a 61-m-thick shale with normal gamma-radiation values (Figures 11 to 13, modified after Al-Haba et al., 1991, 1994; Aqrawi, 1998a, b; Majidee, 1999). The shales are black, fissile, calcareous, bituminous, pyrite-spotted throughout, and organic-rich with TOC values in the range 1.0–16.6% in Akkas-1, and 1.0–10.0% in Khleisia-1. The HC potential is 49 kilograms hydrocarbon/ton (Al-Haba et al., 1991, 1994; F. Al-Juboury, in Al-Sammarai et al., 1994; Al-Juboury et al., 1997; Salleh and Mokhtar, 1995). The gamma-ray values of the hot shales increase from the background 90–100º API to 145–160º API. The high gamma-ray peak is related to high content of authogenic uranium.

Akkas-1 discovered high gravity oil (42ºAPI) in a fractured sandstone-siltstone reservoir in the Qaim Member in 1993 (Figures 1). Based on the analysis of Core 6 (1,466–1474.1 m), Core 7 (1,743.7–1,752 m), Core 8 (1,894–1,903 m) and Core 9 (2,017–2,026 m) in the Qaim Member, the average porosity is 6.5%, average permeability is 0.2 mD and average density is 2.75 gm/cc (Al-Sammarai et al., 1994). The Qaim reservoir is sealed by intra-Qaim shales.

Based on seismic data, Al-Haba et al. (1991, 1994) concluded that faults and fractures along the eastern flank of the field, provided the main pathways for hydrocarbon migration from the lower Silurian source rocks to the Ordovician and Silurian reservoirs.

PIRISPIKI RED BEDS FORMATION, KHLEISIA GROUP: LATE DEVONIAN

Authors and Nomenclature
R. Wetzel (1950 unpublished report, in van Bellen et al., 1959) first defined the formation. It is named after the Mountain of Pirispiki, which constitutes the southern flank of the Ora Anticline, west of Ora Village (Amadia District, North Iraq; Figure 1b). The Pirispiki Formation, with its included Chalki Volcanics is similar to the “Old Red Sandstone” with volcanics and intrusives, of the Elburz (Alborz), Iran.

Type Section
R. Wetzel (in van Bellen et al., 1959) reported that the type section lies beneath the northern scarp at the base and at the eastern end of Pirispiki. The lower part of the section runs southwards, from the base at 650 m (2,132 ft) 255°E of Ora Police Post (37°16’56”N; 43°21’55”E). This part of the section is terminated by a small fault. The uppermost 11.5 m (37.7 ft) are exposed further west, with base at 1,000 m (3,280 ft) 250°E of the Police Post, the top of the section corresponding to the top of a coarse quartzite bed. The section is 83 m (272.2 ft) thick.

R. Wetzel (in van Bellen et al., 1959) reported that the Pirispiki Formation consists of white, massive, cross-bedded quartzites, with thick aggregates of reddish marls and sandstones, and with lenticular intercalations of conglomerates containing detritus of green igneous rocks. From the top, the formation consists of four divisions (Figure 14):

1. 33 m (108 ft): red, marly sandstones and conchoidal, silty mudstones, some dolomitic, with sporadic thin penecontemporaneous conglomerates containing pebbles of red sandstone, quartzite and green igneous rocks.
2. 24 m (79 ft): white, cross-bedded quartzite, with pitted top-surface, alternating downwards with red and purple, soft sandstones and shales.
Figure 13: The basal part of the Hoseiba Member of the Akkas Formation includes two hot shale beds (after Al-Haba et al., 1991, 1994; Al-Hadithi 1994; Aqrawi, 1998a, b; Majidee, 1999). The average total organic carbon content (TOC) is about 6% in the Akkas hot shales and ranges from 0.96% to 16.2%. According to R. Majidee (1999) the Akkas hot shale in Akkas-1 is in the oil-generation window and has a thermal maturation index (TTI) that ranges from 75 to 93.
(3) 16 m (52.5 ft): yellowish brown, well-bedded sandstone, with bands of rusty red shales.

(4) 10 m (33 ft): blocky siltstones, conchoidal, soft, brownish, weathering pale gray-greenish; grading locally to green, fine-grained, soft sandstone with onion-weathering habit. Occasional ribs of hard, ferruginous, quartzitic sandstones, resembling the underlying Khabour Quartzite.

Reference Section
The well Akkas-1 (Figures 1 and 15, Tables 2 and 3) was chosen by Al-Hadidy (2001) as the subsurface reference section for the Pirispiki Formation. In Akkas-1 the formation was encountered between 1,447–1,463 m (4,746–4,799 ft) and is 16 m (52.5 ft) thick. In the reference well the Pirispiki Formation consists of two units: (1) lower gray sandstone of gray quartz arenite with siltstone; and (2) the upper red silty mudstone with hematite in iron-oxide phase. In the West Iraq wells, no volcanic rocks were encountered. In the well Khleisia-1, the Pirispiki Formation was encountered between 2,116–2,139 m (6,940.5–7,016 ft) and is 23 m (75.5 ft) thick (Figure 7).

Paleontology and Age
In the type section in outcrop (R. Wetzel, in van Bellen et al., 1959) and subsurface (Al-Hadidy, 2001) no fossils were recovered. R. Wetzel provided the following discussion in regards to the age of the Pirispiki Red Beds. At the Ora type locality, the Pirispiki beds were first mapped as a dominantly red clastic unit, in sharp but gradational contact with the underlying Khabour quartzites and grading up...
Figure 15: The Akkas-1 well is chosen as the reference section for the Late Devonian and early Carboniferous Pirispiki, Kaista, Ora and Harur formations. The age of the interval 1,295–1,394 m is interpreted as Tournaisian based on the PC and CM palynozones (Figure 20, Al-Lami, 1998). The interval 1,120.5–1,197 m was interpreted as Visean-Serpukhovian by Kaddo (1997, Figure 26). In this study the Tournaisian CM Biozone is considered to include the Harur Formation as shown in Khleisia-1 by Al-Hasson (1999, Figure 17).
into the Late Devonian Kaista Limestone. This relationship prompted early dating of the Pirispiki as Devonian. Since the underlying Khabour quartzites were later referred to the Ordovician, on fossil evidence, an obscure break was accepted between the Pirispiki and Kaista formations despite absence of any observed field evidence of discontinuity. Although conformity is accepted between the two formations, the abrupt color change at the boundary, and the sudden disappearance of stress micas, which abound in parts of the Khabour, suggest that the conformity may be illusory. If so, the Pirispiki could be of any age from Early Ordovician to latest Devonian.

Al-Hadidy (2001), based on the identification of the Pirispiki Formation above the Silurian Akkas Formation in wells in the Western Desert, interpreted the formation as Late Devonian in age and to form part of Khleisia Group (Figures 3, 7 and 15).

Underlying Formation and Details of Contact
The Pirispiki Formation overlies the Khabour Formation in outcrop (Figure 14) and the Akkas Formation in subsurface (Figures 3, 7 and 15). See “Khabour Formation, Overlying Formation and Details of Contact”, and “Akkas Formation, Overlying Formation and Details of Contact”.

Overlying Formation and Details of Contact
In the type section in outcrop (R. Wetzel, in van Bellen et al., 1959) and subsurface (Al-Hadidy, 2001) the Pirispiki Formation is overlain by the Kaista Formation (Figures 3, 7, 14 and 15). R. Wetzel (in van Bellen et al., 1959) described the contact as seemingly gradational and conformable and taken at the base of a bed of cross-bedded, dark gray to olive brown quartzites, 10-m-thick (32.8 ft), and above an interval of 21 m (68.9 ft) of brown purplish, soft marls, which include thin bands of white quartzite near the top. The break lies 30 m (98.4 ft) above the bottom of a thin conglomerate, which occupies at Ora a stratigraphical position corresponding approximately to that occupied by the lower part of the Chalki Volcanics in the Kaista section.

Regional Distribution, Depositional Setting and Sequence Stratigraphy
The Pirispiki Formation is encountered in the reference well Akkas-1 (Figure 15), Key Hole KH 5/1, Khleisia-1 (Figure 7) and Qaim-1 with thickness ranging from 20–40 m (66–133 ft) (Al-Hadidy, 2001). R. Wetzel (in van Bellen et al., 1959) reported that the Pirispiki Formation crops out in Harur and Kaista (near Chalki, Khabour Valley), and in other outcrops continuous along the strike with that of the measured section at Kaista, as well as Geli Sinat and Shish areas, northwest of Shiranish. He interpreted the depositional setting of the Pirispiki red beds as mixed marine and terrestrial and to have been deposited during a period of igneous activity. The upper red mudstone of the Pirispiki Formation was deposited in flood plains cut by fluvial channels.

CHALKI VOLCANICS, KHLEISIA GROUP: LATE DEVONIAN

Authors and Nomenclature
R. Wetzel (1952 unpublished report, in van Bellen et al., 1959) defined the Chalki Volcanics (which has no synonyms) and named it after the Chalki Village (Figure 1b). The Chalki Volcanics have not been encountered in any wells in Iraq and are only known in outcrops in North Iraq where the type section is defined. The discussion below is summarized from R. Wetzel with the section “Age” stated in a manner that emphasizes that the age of the Chalki Volcanics and Pirispiki Red Beds remained unresolved in the 1950s.

Type Section
R. Wetzel (in van Bellen et al., 1959) reported that the type section is located near Kaista (Khabour Valley, Amadia District, North Iraq). The Chalki Volcanics occur as basalt intercalations, 2–5 m (6.6–16.4 ft) in thickness, within the Pirispiki red beds (Figure 16). The type section lies along the spur, which runs downwards from the western peak of Chia Zinnar (7,090 ft, 2,161.6 m) in a northeast to southwest direction, about 2 km northwest of Kaista Village. The top of the Pirispiki Formation lies about 2 km west-northwest of Kaista Village, at about 37°16’36"N; 43°10’3"E, and the base occurs on the ridge, about 2.7 km north of the village of Chalki Nasara. The basalt beds and associated ash-containing shales, etc., occupy most of the uppermost 20 m (65.6 ft) of the section. The type section is 16 m (52.5 ft) thick in aggregate.
**Kaista Formation and Chalki Volcanics type section**

| Age               | Formation              | Thickness (67 m) | Lithology                                                                 | Markers and Zones                                                                 |
|-------------------|------------------------|------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Upper Devonian    | Ora Shale              |                  | Shale: black with thin limestone dark blue, organic detrital, coarse       | Lithological Description: Shale: black with thin limestone dark blue, organic     |
|                   |                        |                  | occasionally sandy streaks.                                               | detrital, coarse occasionally sandy streaks.                                      |
| Upper Devonian    |                        |                  | Limestone: dark blue to dark brown, organic detrital, lower part silty and| Lithological Description: Limestone: dark blue to dark brown, organic detrital,     |
| (Famennian)       | Kaista                 | 5-10             | silty and micaceous.                                                        | lower part silty and micaceous.                                                   |
| ? Caledonian      |                        | 15-20            | Sandstone: yellowish gray, micaceous, medium to fine.                      | Lithological Description: Sandstone: yellowish gray, micaceous, medium to fine.   |
|                   |                        | 20-30            | Limestone: dark blue, crystalline, fine-grained and shale greenish silty.   | Lithological Description: Limestone: dark blue, crystalline, fine-grained and     |
|                   |                        | 30-40            | Limestone: dark blue, thin bedded with sandy, shaly and micaceous          | shale greenish silty.                                                             |
|                   |                        | 40-50            | Limestone: dark blue, to gray purplish and ferruginous speckled, organic.  | Lithological Description: Limestone: dark blue, to gray purplish and ferruginous   |
|                   |                        | 50-60            | Siltstone: silty shale and siltstone olive green.                          | speckled, organic.                                                                |
|                   |                        |                  | Limestone: green at top reddish at base, siltly with bands of sandstone.   | Lithological Description: Limestone: green at top reddish at base, siltly with     |
|                   |                        |                  | Sandstone and siltstone: greenish, to purple, marly or shaly.              | bands of sandstone.                                                              |
|                   |                        |                  | Limestone: purplish gray, sandy, 5 to 10 cm bedded with green               | Lithological Description: Limestone: purplish gray, sandy, 5 to 10 cm bedded with  |
|                   |                        |                  | micaceous shale.                                                           | green micaceous shale.                                                            |
|                   |                        |                  | Shale: alternating gray purplish and green silty with sporadic bands of    | Lithological Description: Shale: alternating gray purplish and green silty with   |
|                   |                        |                  | quartzitic sandstone white.                                                | sporadic bands of quartzitic sandstone white.                                     |
|                   |                        |                  | Shale and siltstone.                                                       | Lithological Description: Shale and siltstone.                                    |
|                   |                        |                  | Sandstone: quartzitic, fine, greenish and whitish.                         | Lithological Description: Sandstone: quartzitic, fine, greenish and whitish.      |
|                   |                        |                  | Sandstone: whitish and greenish quartzitic medium cross-bedded.            | Lithological Description: Sandstone: whitish and greenish quartzitic medium       |
|                   |                        |                  | Shale: black, micaceous, occasionally green, compact with sporadic bed    | cross-bedded.                                                                    |
|                   |                        |                  | of sandstone green.                                                        | Lithological Description: Shale: black, micaceous, occasionally green, compact     |
|                   |                        |                  | Quartzite: yellowish white, 20 cm bedded.                                  | with sporadic bed of sandstone green.                                             |
|                   |                        |                  | Siltstone: green, micaceous with thin quartzite bands.                     | Lithological Description: Quartzite: yellowish white, 20 cm bedded.               |
|                   |                        |                  | Siltstone: green, shaly, micaceous, with sporadic beds of quartzite.       | Lithological Description: Siltstone: green, micaceous with thin quartzite bands.  |
|                   |                        |                  | Shale: black, micaceous sandy, occasionally green flaky, locally purplish   | Lithological Description: Siltstone: green, shaly, micaceous, with sporadic beds   |
|                   |                        |                  | at base, sporadic quartzite in the middle.                                | of quartzite.                                                                    |
|                   |                        |                  | “Green igneous rock” hard, locally weathering in boulders, decomposed      | “Green igneous rock” hard, locally weathering in boulders, decomposed at base.     |
|                   |                        |                  | at base.                                                                  | Lithological Description: “Green igneous rock” hard, locally weathering in       |
|                   |                        |                  | Siltstone: (Ash stone) bright red, soft.                                   | boulders, decomposed at base.                                                     |
|                   |                        |                  | Tuffite coarse decomposed, dark greenish and purplish, with white           | Lithological Description: Tuffite coarse decomposed, dark greenish and purplish   |
|                   |                        |                  | specks, soft.                                                             | with white specks, soft.                                                          |
|                   |                        |                  | “Green igneous” amygdaloidal, coarse, hard, criss-crossed by abundant      | “Green igneous” amygdaloidal, coarse, hard, criss-crossed by abundant               |
|                   |                        |                  | fibrous veins; small, dark green glassy lapillls.                          | fibrous veins; small, dark green glassy lapillls.                                 |
|                   |                        |                  | Tuffite as above.                                                         | Lithological Description: Tuffite as above.                                       |
|                   |                        |                  | Green igneous as above.                                                    | Lithological Description: Green igneous as above.                                 |
|                   |                        |                  | Shale: (Ash stone) red purplish, with bright green specks, abundant         | Lithological Description: Shale: (Ash stone) red purplish, with bright green      |
|                   |                        |                  | calcite veins.                                                            | Lithological Description: Shale: red purplish, with bright green specks,          |
|                   |                        |                  | Mudstone: silty brick red, soft, sandy in parts occasionally brecciated     | abundant calcite veins.                                                           |
|                   |                        |                  | and conglomeratic.                                                        | Lithological Description: Mudstone: silty brick red, soft, sandy in parts         |

Figure 16: The Chalki and Kaista formations in the type section (after R. Wetzel, 1950). R. Wetzel showed the age of the Pirispiki Red Beds and Chalki Volcanics as ?Ordovician with a “Caledonian break” above the Chalki Volcanics. These two rock units are considered Late Devonian in this paper. R. Wetzel interpreted the age of the Kaista Formation as entirely Late Devonian. In this study on the basis of palynology, the upper part of the Kaista Formation is dated as earliest Carboniferous (Figure 17, Al-Hasson, 1999).
R. Wetzel (in van Bellen et al., 1959) described the volcanic rocks as dull green and gray green, red and white-speckled, altered olivine basalts, in beds 2–5 m (6.6–16.4 ft) thick (flows or intrusions), alternating with intercalations of bright red, ash-containing, soft siltstones and shales. The igneous material has been determined petrologically by K.C. Dunham (unpublished reports). The bulk of the material consists of olivine basalts or fine-grained dolerites, with haematite-magnetite rimmed pseudomorphs, in chlorite, replacing the olivine; there are albizzited plagioclase laths and considerable amounts of chlorite and ankeritic carbonates in the groundmass; locally the basalts are crossed by numerous veins of white ankerite with fibrous chalcedony.

Age

R. Wetzel (in van Bellen et al., 1959) attributed an Ordovician age to the Chalki Volcanics because this age was accepted for the enclosing Pirispiki red beds, which are in conformable contact with the underlying Khabour Formation. He cautioned, however, that it is possible that the ages of both the Chalki Volcanics and Pirispiki red beds may require revision, perhaps to Devonian. This is because of the apparent conformable contact between the Chalki Volcanics and the overlying Kaista Formation (Figure 16). Al-Hadidy (2001), based on the identification of the Pirispiki Red Beds above the Silurian Akkas Formation, interpreted the age of the Chalki Volcanics as Late Devonian.

Underlying and Overlying Formations and Details of Contacts

The Chalki Volcanics occur within the Pirispiki Formation, which is discussed above.

Regional Correlations

R. Wetzel (in van Bellen et al., 1959) reported that the Chalki Volcanics are thinner and less significant in Iraq than in southeastern Turkey, where it is possible that much of the Pirispiki may be represented laterally by igneous rocks. The preponderance of dolerite/basalt pebbles in the present-day shingles, which are brought down the Geli Khana from the southern slopes of the Ser Ashuti (north of Ora in southeastern Turkey), indicates that the Chalki Volcanics must be widely exposed within the upper catchment of the Geli River (though observations from within Iraq indicate that dykes and ?sills of these same volcanics also occur within the thick mass of Khabour Formation on the slopes of Ser Ashuti).

Sharland et al. (2001) interpreted the Chalki Volcanics to represent back-arc rift volcanics associated with the initiation of subduction along the Tethyan margin of the Arabian Plate. They interpreted the initiation of subduction to have caused the so-called “Hercynian orogeny” in the Late Devonian. The age of the “Hercynian orogeny” in the Arabian Plate has been reported to range from pre-Late Devonian to middle Carboniferous (see Al-Husseini, 2004).

KAISTA FORMATION, KHLEISIA GROUP:
LATE DEVONIAN AND EARLY CARBONIFEROUS

Authors and Nomenclature

R. Wetzel and D.M. Morton (1952, unpublished report, in van Bellen et al., 1959) defined the Kaista Formation, which is named after the Kaista Village (Khabour Valley, Amadia District, North Iraq, Figure 1b). The formation has no synonyms. In this paper the name Khleisia Group is proposed to include the Pirispiki red beds, Chalki Volcanics, Kaista, Ora, Harur and Raha formations.

Type Section

R. Wetzel (in van Bellen et al., 1959) reported that the upper part of the Kaista Formation (32 m, 105 ft thick) was measured and sampled on the steep slope, 1.5 km north-northeast of Kaista Village, at the foot of the massive limestone cliff, which forms the southern face of the Chia Zinnari. The base of this part of the section is at approximately 37°16’42”N; 43°11’30”E. The lower part of the formation (35 m, 115 ft) was sampled along the spur of the Chia Zinnari, which runs downwards from northeast to southwest, the base of the section being about 2 km west-northwest of Kaista Village, at about 37°16’36”N; 43°10’03”E. The type section is 67 m (219.8 ft) thick.
Paleozoic stratigraphy, Iraq

R. Wetzel (in van Bellen et al., 1959, Figure 16) described the lower Kaista division (35 m, 115 ft thick) as green, occasionally purplish siltstone and silty shale with sporadic bands of quartzites, generally cross-bedded, white or greenish. The upper division (30 m, 98.4 ft thick) consists of thin-bedded, dark blue, argillaceous limestones, weathering to a characteristic ochreous color, grading downwards by alternations to a succession of silty shales and sandstones. Sandy streaks occur commonly in the limestone. The lower part of this division includes bands of fine-grained breccias, with small angular fragments of derived quartzites and limestones in a calcitic matrix.

Reference Section
The Akkas-1 well (Figures 1 and 15, Tables 2 and 3) is chosen as the subsurface reference section for the Kaista Formation, wherein it was encountered between 1,402 and 1,447 m (4,599–4,746 ft) and is 45 m (148 ft) thick. In Akkas-1 the main lithofacies consists of sandstone (quartz arenite), micaceous, siltstone intercalation between the upper and lower sandstone, as well as thin pyrite lamina and yellow sulfur at depth. In the Khleisia-1 well it was encountered between 2,012–2,116 m (6,599–6,940.5 ft) and is 104 m (341.1 ft) thick (Figure 7).

Paleontology and Age
R. Wetzel (in van Bellen et al., 1959) reported that carbonaceous plant remains occur in a silty marl near the base of the upper division, and *Spirifer verneuili* Murchison, other brachiopods and crinoid debris at the top of this division. The basal 35 m (115 ft) of the formation yielded no fossils. R. Wetzel interpreted the age of the Kaista Formation as Late Devonian, Famennian (Figure 16).

Aqrawi (1998a, b) reported the following spores from the Devonian informal “DC1” biozone of the Kaista, Ora and Harur formations: *Amicosporites splendidus*, *Synorisporites lybicus*, *Dictyotriletes emsiensis*, *Dyadospora murasdensa*, *Ambitisporites* spp. and *Retusotriletes* spp. He reported the following acritarchs: *Cymbosphaeridium pilar*, *Diexallophasis denticulata*, *Leiofusa* spp. and *Geron* sp.

Khalaf and Khoshaba (1999) determined the age of the Khleisia Group as Famennian-Tournaisian in outcrop. They identified the following fossils: *Vallatisporites pusillites*, *Retispora lepidophyta*, *Verrucosisporites*, *Auroraspora* and *Retusotriletes*.

In the well Khleisia-1, Al-Hasson (1999) studied the palynology of the interval 1,680–2,174 m (5,510–7,131 ft), which includes the Kaista, Ora and Harur formations (Figures 7 and 17). She identified 187 species of spores belonging to 54 genera (including 20 new species), as well as 29 species of acritarchs belonging to 14 genera (including 2 new species). Based on this study the interval was interpreted in terms of six European miospore biozones (Figure 17); from oldest to youngest: (1) Late Devonian LL Biozone; (2) Late Devonian LE Biozone; (3) Late Devonian LN Biozone; (4) early Carboniferous VI Biozone; (5) early Carboniferous PC Biozone; and (6) early Carboniferous CM Biozone.

The Late Devonian (early Strunian) LL Biozone in Khlesia-1 is characterized by *Retispora lepidophyta* and *Knoxisporites literatus* and includes *Vallatisporites pusillites*, *V. ciliaris*, *Grandispora chinata*, *Geminospora lemurata*, *Corbulispora cancellata*, *Dictyotriletes fimbriatus*, *D. submarginitus*, *Cyclogranisporites commodus*, *Spelaeotriletes pretiosus*, *Spinozonotriletes impensus*, *Auroraspora macra*, *Discernisporites sullivani*, *Velamisporites irrigatus*, *V. perinatus*, *Verrucosisporites dejerseyi*, *V. papulosus*, *V. scoticus*, as well as *Punctatisprites irrasus*, *P. glaber*, *P. glabrimarginatus* and *P. minutus*.

The Late Devonian (middle Strunian) LE Biozone is characterized by the first appearance of *Hymenozonotriletes explanatus* and includes *Gorgonispora cressa*, *Dictyotriletes trivialis*, *Cordylosporites spathulatus*, *Reticulatisporites glumaceous*, *Plicatispora scolecophora*, *Auroraspora solisorta* and *Discernisporites micromanifestus*.

The Late Devonian (late Strunian to late early Tournaisian) LN Biozone is characterized by the first appearance of *Hymanozonotriletes explanatus* and includes *Gorgonispora cressa*, *Dictyotriletes trivialis*, *Cordylosporites spathulatus*, *Reticulatisporites glumaceous*, *Plicatispora scolecophora*, *Auroraspora solisorta* and *Discernisporites micromanifestus*.

The Late Devonian (late Strunian to late early Tournaisian) LN Biozone is defined by the first appearance of *Densosporites spitsbergensis*, *Verrucosisporites scurrus*, *Reticulatisporites pellatus*, *Retusotriletes cf. triangulatus*, *Cordylosporites marciae*, *Convolutispora caliginosa*, *Spelaotriletes crenulatus*, *S. crustatus*, *Rubispora polyptycha*. 
Al-Hadidy

Khleisia-1, Late Devonian-early Carboniferous Palynology

| Series          | LATE DEVONIAN | EARLY CARBONIFEROUS |
|-----------------|---------------|----------------------|
| Stage           | Famenian      | Tournaisian          |
| Formations      |               | Kaista               |
| Biozones        |               | Ora Shale            |
| Depth (m)       |               | Harur Limestone      |
| Sample          |               |                      |

| Lithology       |               |
|-----------------|---------------|
| Spelaeotriletes balticatus |          |
| Discemisporetes sullivani |          |
| Verrucosporoites nitidus |          |
| Auroraspora macra |          |
| Aratrisporites saharaensis |          |
| Radizonates mirabilis |          |
| Anaplanisporetes baccatus |          |
| Cobutispores deccatus |          |
| Colatisporites denticulatus |          |
| Punctatisporites debilis |          |
| Punctatisporites irrasus |          |
| Punctatisporites glaber |          |
| Densosporites claytonii |          |
| Vallatisporites verrucosus |          |
| Verrucosporoites minutus |          |
| Spelaeotriletes pretiosus |          |
| Cyclogranisporites commodus |          |
| Crassispora brycera |          |
| Vallatisporites ciliaris |          |
| Spinozonotriiletes uncatus |          |
| Velamisporites urpatus |          |
| Velamisporites perinatus |          |
| Punctatisporites glabrimarginatus |          |
| Verrucosporoites gibbonerous |          |
| Grandispora echinata |          |
| Corbulispora cancellata |          |
| Dicthyotriiletes fimbriatus |          |
| Dicthyotriiletes submarginatus |          |
| Umbonatisporites distinctus |          |
| Verrucosporoites scoticus |          |
| Spinnozonotriiletes impensus |          |
| Tumulispora rautuberckula |          |
| Lophozonotriiletes triangulatus |          |
| Vallatisporites pusillites |          |
| Verrucosporoites papulopus |          |
| Cyrtospora cristi |          |
| Verrucosporoites dejersyei |          |
| Spelaeotriletes giganteus |          |
| Umbonatisporites abstrusus |          |
| Retispora lepidophyta |          |
| Gomnispora lemurata |          |
| Knoxispora lituralis |          |
| Gorgonispora crassa |          |
| Retussotriiletes uncatus |          |
| Auroraspora solsota |          |
| Kraussisporites mitratus |          |
| Rugospora minuta |          |
| Discemisporetes micromanifestus |          |
| Dicthyotriiletes trivalis |          |
| Retussotriiletes crassus |          |
| Cordylosporoites spaltulatus |          |
| Retusotriiletes perismanus |          |
| Hyemnozonotriiletes explanatus |          |
| Plactispora scoleophora |          |
| Crassispora crassa |          |
| Gomnispora spongia |          |
| Vallatisporites valtatus |          |
| Convoluspora caliginosa |          |
| Raistrickia corynogus |          |
| Retusotriiletes peltatus |          |
| Densosporites spitsbergensis |          |
| Retusotriiletes cf. triangulatus |          |
| Verrucosporoites scurru |          |
| Auroraspora corporga |          |
| Cordylosporoites mariae |          |
| Neoartrickia loganii |          |
| Spelaeotriletes crus |          |
| Baculatsporites fisticulus |          |
| Knoxsporoites tris triangularis |          |
| Rugospora polytylcha |          |
| Spelaeotriletes cremulatus |          |
| Verrucosporoites acutus |          |
| Schopfites delicatus |          |
| Raistrickia clavata |          |
| Schopfites claviger |          |

Figure 17: Upper Devonian and lower Carboniferous (Mississippian) Tournaisian spores identified in well Khleisia-1 for samples taken from interval 1,680 to 2,174 m (after Al-Hasson, 1999).
The Carboniferous (late early to middle Tournaisian) VI Biozone represents the base of the Carboniferous System and is marked by the extinction of *Retispora lepidophyta*. Other extinct species include *Gorgonispora crassus, Geminospora lemurata, Cordylosporites marciae* and *Knoxisporites literatus*. The Carboniferous/Devonian boundary is marked also by the first appearance of *Schopfites delicatissimi* and *Cymbosporites acutus*, as well as *Punctatissporites irrasus* and *Retusotriletes incohatus*.

The early Carboniferous (late middle to late Tournaisian) PC Biozone is defined by the first appearance of *Raistrickia clavata*, and includes *Spelaeotriletes balteatus, Vallatisporites vallatus, V. verrucosus, Reticulatisporites glumaceous, Cordylosporites spathulatus, Plicatispora scolecophora, Verrucosiporites? 10.* In the upper part of the biozone the following species are absent *Spelaeotriletes giganteus, Umbonatisporites abstrusus, Auroraspora corporiga, and Knoxisporites triangulatus.*

The early Carboniferous (late Tournaisian) CM Biozone is represented at its base by the first appearance of *Schopfites claviger* and disappearence of *Cyrtospora cristifer, Hymenzonotriletes explanatus, Reticulatisporites glumaceous, Cordylosporites spathulatus, Plicatispora scolecophora, Verrucosiporites? 10.*

Figure 18: Thickness of the Upper Devonian and lower Carboniferous (Mississippian) Kaista Formation in northwest Iraq (after Al-Hadidy, 2001). The formation consists of sandstones and shales with minor carbonates (Figures 7, 16 and 17). The unit is absent in eastern Jordan and reaches a thickness of more than 100 meters (328 ft) in North Iraq.
spathulatus, Verrucosiporites dejerseyi, V. papulosus and Neoraistrickia loganii. Near the top of the zone the following species are absent Tumulispora rarituberculata, Lophozonotriletes triangulatus, Vallatisporites pusillites, Verrucosiporites scurrus, Spinozonotriletes triangulatus, Vallatisporites pusillites, Spinozonotriletes impensus and Retusotriletes crassus.

Other important age-indicative species in the CM Biozone are: Anaplanisporites baccatus, Apiculiretusispora multiseta, Aratrisporites saharaensis, Auroraspora macra, A. solisorta, Baculatisporites fisticulus, Colatisporites decorus, C. denticulatus, Crassispora trychera, C. cf. drucei. C. holospongii, C. kosankei, Cyclogransipora spp., Puncitatisporites spp., Retusotriletes spp., Densosporites spp., Cymbosporites magnificus, Krauselesisporites ornatus, Radiizonates mirabilis, Spelaeotriletes balteatus, S. crastatus, S. microspinus, Vallatisporites ciliaris, V. galearis and V. microspinus.

No spores of the lower Carboniferous Visean Stage were recognized in the studied interval and particularly notable is the absence of Lycospora pusilla.

The Kaista Formation is predominantly characterized by the LN and lower part of the VI palyzones and is attributed a latest Devonian and early Carboniferous age (Figure 17). The boundary between the Devonian (Famennian) and Carboniferous (Tournaisian) is positioned at about 2,030 m in the Kaista Formation (2,102–2,116 m) (Al-Juboury et al., 1997; Al-Hasson, 1999).

**Underlying Formation and Details of Contact**
The Kaista Formation overlies the Pirispiki Formation in outcrop and subsurface (R. Wetzel in van Bellen et al., 1959; Al-Hadidy, 2001). See “Pirispiki Formation, Overlying Formation and Details of Contact”.

**Overlying Formation and Details of Contact**
The Kaista Formation is overlain by the Ora Shale Formation (R. Wetzel in van Bellen et al., 1959; Al-Hadidy, 2001). The contact is conformable and gradational, taken at the change from lowest black, micaceous, calcareous shales (above) to thin-bedded, dark blue, ochreous-weathering argillaceous limestones weathering to ochreous color (below).

**Regional Distribution, Depositional Setting and Sequence Stratigraphy**
The formation is recorded in the reference well Akkas-1 (Figure 15), Key Hole KH 5/1, Khleisia-1 (Figure 7) and Qaim-1 with a thickness ranging from 45–104 m (66–133 ft) (Figures 3 and 18; Al-Hadidy, 2001). R. Wetzel (in van Bellen et al., 1959) reported that the Kaista Formation crops out in Ora, Harur, and other (unsampled) sections, which occur along the outcrop, and which includes the measured type section at Kaista; Geli Sinat and Shish areas, northwest of Shiranish. The Kaista Formation consists of a sequence of sediments representing the transition from continental-fluvial deposition of the older Pirispiki red beds to shallow-marine sedimentation of the younger Ora Formation. See “Harur Formation” for discussion of correlations to neighboring countries.

**ORA FORMATION, KHLEISIA GROUP: MISSISSIPPIAN (EARLY CARBONIFEROUS) TOURAISIAN**

**Author and Nomenclature**
R. Wetzel (1952, unpublished report) defined the Ora Formation, which is named after the Ora region and has no synonyms.

**Type Section**
R. Wetzel (in van Bellen et al., 1959) reported that the type section is located at the Ora fold (Amadia District, North Iraq, Figure 1b). The exposures of the formation are much faulted and obscured by scree. The lower 96 m (315 ft) was measured and sampled in a section running southwards, with the base located 1,000 m (3,280 ft) N250°E from Ora Police Post (which is at approximately 37°16'56"N; 43°21'55"E). The upper 130 m (426.4 ft) is obscured by scree on this section line, and the type section is deflected 300 m (984 ft) west, along the strike, and then runs southward for 180 m (590.4 ft), up to the base of the first prominent limestone cliff. The thickness of the section is 226 m (741.3 ft).
Reference Section
The Akkas-1 well (Figures 1 and 15, Tables 2 and 3) is here chosen as the subsurface reference section for the Ora Formation, wherein the formation was encountered between 1,297–1,402 m (4,254–4,599 ft) and it is 105 m (344.4 ft) thick. In the Khleisia-1 well it was encountered between 1,865–2,012 m (6,117–6,599 ft) and is 147 m (482 ft) thick (Figure 7). In Akkas-1, the formation is composed mainly of black fissile shale with intercalation of sandstone, siltstone and crinoidal dolomite streaks with pyrite and glauconite.

Paleontology and Age
R. Wetzel (in van Bellen et al., 1959) reported that *Avonia praelongus* Sowerby and *Spirifer julii* Dehee are recorded from near the top of the formation, and *Spirifer verneuili* Murchison and other brachiopods occur near the base. He suggested the age of the Ora Formation as Late Devonian or at the transition of the late Devonian and ?early Tournaisian (earliest Carboniferous).

Al-Lami (1998) conducted a palynological study of the interval 1,295–1,394 m (4,247.6–4,572 ft) in Akkas-1 (Figure 20), which is nearly coincident with the entire Ora Formation (Figure 15). He interpreted the age of the Ora Shale as Carboniferous, Tournaisian. In the well Khleisia-1, Al-Hasson (1999) studied the palynology of the interval 1,680–2,174 m (5,510–7,131 ft), which includes the Ora Formation (Figures 7 and 17). The formation is characterized by the upper part of the VI and lower part of the PC palyzones and is attributed an earliest Carboniferous (Tournaisian) age.

See also reports by Aqrawi (1998a, b) and Al-Hasson (1999) in “Kaista Formation, Paleontology and Age”.

Overlying Formation and Details of Contact
The Ora Formation overlies the Kaista Formation in the outcrop type section, reference well Akkas-1 and Khleisia-1 (Figures 7, 15 and 19). See “Kaista Formation, Overlying Formation and Details of Contact”.

Regional Distribution, Depositional Setting and Sequence Stratigraphy
The Ora Formation is recorded in wells Akkas-1 (Figure 15), Key Hole KH 5/1, Khleisia-1 (Figure 7) and Qaim-1 with a thickness ranging from 100–300 m (328–984 ft; (Figures 3 and 21 after Al-Hadidy, 1999; Gaddo and Parker, 1959; Al-Haba et al., 1991, 1994). R. Wetzel (in van Bellen et al., 1959) reported that the Ora Formation crops out in Kaista and Harur, near Chalki, Khabour Valley, and other outcrops intermediate between and continuous with these exposures; Geli Sinat and Shish areas, northwest of Shiranish.

The Ora Formation represents the progradation of a siliciclastic ramp upon a shallow to open-marine platform during a regional transgression. Buday and Tyracek (1980) concluded that the formation was deposited on a shallow-marine shelf and that it is widespread in northern Iraq but may not be present in the southern part of the country. Sharland et al. (2001, 2004) positioned MFS D30 of late Devonian, late Famenian age in the Ora Formation. However, because the Ora is dated as early Carboniferous, MFS D30 is probably more likely to occur in the Late Devonian Kaista Formation. See “Harur Formation” for discussion of correlations to neighboring countries.
**Ora Shale Formation type section**

| Age | Formation | Thickness (226 m) | Lithology | Markers and Zones | Lithological Description |
|-----|-----------|-------------------|-----------|-------------------|--------------------------|
| LOWER CARBONIFEROUS (Lower Tournaisian) | Harur Limestone Fm | Gradational boundary taken at the transition from dominant limestone above to dominant shale below |
| ? | LOWER TOURNAISIAN OR UPPER DEVONIAN - LOWER TOURNAISIAN TRANSITION | Top of Zi zone |
| ? | | Highly fossiliferous |
| ? | | Abundant productus |
| ? | | Feature forming ledge |
| ? | | Full of brachiopods, crinoids, etc. |
| ? | | Very fossiliferous, abundant crinoids |
| UPPER DEVONIAN | FAMENNIAN | Lowest black micaceous shale highly fossiliferous; top of thin-bedded dark blue arg. limestone weathers into ochreous color |

Limestone: dark blue, crystalline partly ferruginous.  
Shale: black, limy, soft with rip-up clasts of limestone dark blue crystalline.  
Marl: yellowish brown, yellow in parts, conchoidal soft.  
Limestone: dark blue, hard, ferruginous weathered thin bedded with shale black.  
Shale: dark blue to black, silty, flaky, soft with occasional streaks of ferruginous limestone.  
Shale: dark blue, flaky, soft with streaks of ferruginous marl 1 to 1.5 m apart, and thin bands of limestone dark blue, 1 cm thick, silty.  
Limestone: dark blue, crystalline weathered ferruginous, with marly limestone and shale.  
Shale as above with rip-up clasts of limestone as above.  
Shale as above, with rips of limestone as above, organical detrital, occasional sandy.  
Limestone: dark blue, shaly, brittle, weathers whitish.  
Shale: dark blue, flaky, soft with ferruginous marly bands containing productus, spirifer, etc.  
Shale: olive green, limy, somewhat harder and silty.  
Shale: dark blue, flaky, soft laminated and ferruginous in parts.  
Shale: limy and somewhat silty, harder than above and weathering olive greenish or ferruginous.  
Shale: dark blue as above with band of marl dark blue, calcareous ferruginous and sporadic limestone, marly to shaly, dark blue weathered olive brown.  
Limestone: as above, thin-bedded to laminated with bands of black shale.  
Shale: black, flaky, soft, with dispersed silt grade quartz.  
Limestone: finely granular fossiliferous.  
Shale: limy and silty soft to medium hard, weathering olive green arenaceous in parts.  
Shale: black finely laminated, alternating with 5 cm thick limestone.  
Quartzite: coarse whitish and brownish stained hard, weathers pinkish brown.  
Limestone: dark blue, argillaceous.

Figure 19: The Ora Shale Formation in the type section (after R. Wetzel, 1950) overlies the Kaista Formation and underlies the Harur Formation. R. Wetzel considered the age of the Kaista Formation as either Late Devonian or early Carboniferous (Mississippian). More recent palynology studies in wells indicate that the formation is entirely Carboniferous (Tournaisian) (see Figure 17, Al-Hasson, 1999; and Figure 20, Al-Lami, 1998).
Paleozoic stratigraphy, Iraq

Economic Significance
According to Al-Haba et al. (1991, 1994), the average TOC of the Ora shales is about 1.5% in Akkas-1 and 3.5% in Khleisia-1. The organic matter is composed of woody fragments, lignins, chitins, pollen and spores, which are mostly of continental origin. As a result, these potential source rocks are gas-prone.

HARUR FORMATION, KHLEISIA GROUP: MISSISSIPPIAN (EARLY CARBONIFEROUS) TOURNAISIAN

Authors and Nomenclature
R. Wetzel and D.M. Morton (1952, unpublished report) defined the formation, which is named after the Village of Harur, 11.5 km west-southwest of Ora (Figure 1b). The formation has no synonyms.

Type Section
R. Wetzel (in van Bellen et al., 1959) reported that the type section lies on the southern flank of the Ora fold (Amadia District, North Iraq), in the cliff-face, with base about 1,500 m (4,920 ft) N250°E of Ora Police Post (which is at approximately 37°16′56″N; 43°21′55″E). The thickness of the type section is 62 m (203.4 ft). R. Wetzel described the formation as thin-bedded, black, organic detrital limestone, with intercalations of black calcareous micaceous shales in the lower and upper parts (Figure 22).
Reference Section

The Akkas-1 well (Figures 1 and 15, Table 2 and 3) is chosen as the subsurface reference section for the Harur Formation, wherein the formation was encountered between 1,177 and 1,297 m (3,861–4,254 ft) and it is 120 m (394 ft) thick. In the Khleisia-1 well it was encountered between 1,700–1,865 m (5,576–6,117 ft) and is 165 m (541 ft) thick (Figure 7).

The Harur Formation consists of dolomite facies in the lower and upper parts and is separated by shale in the middle part. The dolomite microfacies is a coarse crystalline crinoid-echinoderm-algal dolostone.

Paleontology and Age

R. Wetzel (in van Bellen et al., 1959) reported that abundant coral and brachiopod faunas are found in the formation, including Caninia cornucopiae (Michelin) emend. Carruthers, Fasciculophyllum (Zaphrentis) cf. omaliusi (Edwards and Haime), Michelinia megastoma Phillips, Vaughania cleistoporoides Conrad, etc.; also crinoids, bryozoa, foraminifera occur. According to Wetzel, the age of the Harur Formation is early Tournaisian (earliest Carboniferous).
Paleozoic stratigraphy, Iraq

According to Al-Hasson (1999) the age of the Harur Formation is late Tournaisian (early Carboniferous) based on the identification of Spelaeotriletes balteatus, Discernisporites sullivanii, Verrucosisporites nitidus, and Schopfites claviger indicating the (CM Biozone). See also reports by Aqrawi (1998a, b) and Al-Hasson (1999) in “Kaista Formation, Paleontology and Age”.

Underlying Formation and Details of Contact
The Harur Formation overlies the Ora Shale Formation in outcrop and subsurface (Figures 7, 15, 19 and 22). See “Ora Formation, Overlying Formation and Details of Contact”.

Overlying Formation and Details of Contact
R. Wetzel (in van Bellen et al., 1959) reported that in the type section, the Harur Formation is overlain by the Permian Chia Zairi Limestone Formation (Figure 22). The contact is a major unconformity that is also found at Harur and at Kaista, and it shows no discernible angular discordance. At Ora, the top of the Harur Limestone is marked by ferruginous crusts, sporadic haematitization and sporadic sandstones. At Kaista, the basal Chia Zairi follows upon a pitted, ferruginous-coated limestone surface, with a surficial coating of ferruginous minerals at the top of the Harur. In spite of the magnitude of the non-sequence, no angular discordance is observable in any studied section.

In the wells Akkas-1 (Figure 15) and Key Hole KH 5/1 (Figure 24) the Harur Formation is overlain by the Raha Formation (Figure 3). The contact is conformable and placed between the Harur carbonates below and the Raha clastics above.
The Harur Formation is encountered in well Akkas-1 (Figure 15), Jabal Kand-1, Key Hole KH 5/1 (Figure 24), Khleisia-1 (Figure 7) and Qaim-1, with a thickness that ranges from 85 to 165 m (279–541 ft; Figures 3 and 23; Al-Hadidy, 2001). R. Wetzel (in van Bellen et al., 1959) reported that the Harur Limestone is known in outcrops in Kaista and Harur near Chalki, Khabour Valley, and in the Geli Sinat and Shish areas northwest of Shiranish, Amadia district, northern Iraq.

Buday and Tyracek (1980) interpreted the depositional setting for this formation as a neritic, marine environment characterized by reefs and fore-reef facies. The deposition of the Harur carbonates is continuous with that of the underlying Ora clastics. The top surface of the Harur Formation represents an exposure stage over the Iraq platform.

The Khleisia Group forms a Late Devonian-early Carboniferous depositional sequence that is altogether missing in many regions of the Middle East (Figure 4). For example, in Iran, Jordan and Oman the Late Devonian is represented by a hiatus. Towards Saudi Arabia, the Khleisia Group sequence passes to the Jubah and overlying Berwath formations. Towards southeast Turkey, the group passes to marine clastics and carbonates of the Hazro and overlying Kayayolu formations (Konert et al., 2001). The

Figure 23: Thickness of the lower Carboniferous (Tournaisian) Harur Formation in northwest Iraq (after Al-Hadidy, 2001). The formation consists of shallow-marine carbonates and clastics (Figures 7, 15 and 22). It is missing in Jordan and its thickness is about 120–160 m (394–525 ft) in western Iraq.

Regional Distribution, Depositional Setting and Sequence Stratigraphy
The Harur Formation is encountered in well Akkas-1 (Figure 15), Jabal Kand-1, Key Hole KH 5/1 (Figure 24), Khleisia-1 (Figure 7) and Qaim-1, with a thickness that ranges from 85 to 165 m (279–541 ft; Figures 3 and 23; Al-Hadidy, 2001). R. Wetzel (in van Bellen et al., 1959) reported that the Harur Limestone is known in outcrops in Kaista and Harur near Chalki, Khabour Valley, and in the Geli Sinat and Shish areas northwest of Shiranish, Amadia district, northern Iraq.

Buday and Tyracek (1980) interpreted the depositional setting for this formation as a neritic, marine environment characterized by reefs and fore-reef facies. The deposition of the Harur carbonates is continuous with that of the underlying Ora clastics. The top surface of the Harur Formation represents an exposure stage over the Iraq platform.

The Khleisia Group forms a Late Devonian-early Carboniferous depositional sequence that is altogether missing in many regions of the Middle East (Figure 4). For example, in Iran, Jordan and Oman the Late Devonian is represented by a hiatus. Towards Saudi Arabia, the Khleisia Group sequence passes to the Jubah and overlying Berwath formations. Towards southeast Turkey, the group passes to marine clastics and carbonates of the Hazro and overlying Kayayolu formations (Konert et al., 2001). The
Hazro Formation is considered to be Late Permian by some authors (e.g. Wagner, 1962; Fontaine et al., 1980; Archangelsky and Wagner, 1983). The Harur Formation is correlated to the lower part of Markada Formation in Syria (T.V. Yankauskas and S. Talli, unpublished Syrian Petroleum Company report in Lababidi and Hamdan, 1985).

**Nijili Formation: Obsolete**

H.V. Dunnington (1954, unpublished report, in van Bellen et al., 1959) defined the Nijili formation, which is named after the Ghadir an Nijili, a stream-debouchure breaking the southern rim of the Ga’ara Depression about 6.25 km N195°E from the type section (Figure 1).

Dunnington reported that the type section of the formation is located in the Ga’ara Depression, in a stream course on the southern face of a gravel ridge about seven kilometers east-northeast from Bir Mulsu, at approximately 33°32’10”N, 40°11’50”E. In the type section it is greater than 16 m (52.5 ft) thick as the base is not exposed. The lithology of the formation is flaky, saliferous marls and shales, dominantly yellow and green in color, with some purplish bands, and with two thin beds of sandstone near to the base. Indeterminate plant remains are found at the contact between the Nijili formation and overlying Ga’ara Sandstone.

H.V. Dunnington (in van Bellen et al., 1959) reported that the Nijili formation is concordantly overlain by the Ga’ara Sandstone. The contact is taken at the base of continuous sandstone and at the top of the argillaceous beds. The transition is abrupt and haematitization is evident at the sandstone/marl contact. This led Dunnington to suspect that a hiatus and emergence separated the deposition between the two formations.

Antonets et al. (1963) and Tamar-Agha (1986) studied the Nijili and Ga’ara formations and found that the two formations represent laterally and vertically interfingering and interbedding lithofacies. They therefore included the two units in the Ga’ara Formation as have subsequent studies.

**Raha Formation, Khleisia Group: Mississippian (Early Carboniferous) Visean-Serpukhovian**

**Authors and Nomenclature**
The Raha Formation is proposed here and named after the El-Raha water well near the center of the Ga’ara Depression, half a kilometer from the southern rim. In the well Key Hole KH 5/1 the obsolete “Suffi formation” is a synonym (Radosevic et al., 1981, in Tamar-Agha, 1993; Nader, 1993; Nader et al., 1993a, 1994). The name “Suffi” was incorrectly assigned to the upper part of the Silurian Akkas Formation by Aqrawi (1998a, b) and later adopted in Sharland et al. (2001, 2004).

**Type Section**
The Raha Formation does not crop out in Iraq and it is defined in the Key Hole KH 5/1 wherein it is encountered between 670 and 854 m (2,198–2,801 ft), and is 184 m (604 ft) thick (Figures 1 and 24). The formation consists of marine shales that represent a sharp facies change and environmental setting from the overlying continental clastics of the Ga’ara Formation. In Akkas-1 it is encountered between 1,100 and 1,177 m (3,608–3,861 ft) and is 77 m (253 ft) thick.

**Paleontology and Age**
In the Key Hole KH 5/1, Nader et al. (1993a, 1994) studied the palynology of the interval from the surface to 1,100 m. They interpreted the Ga’ara Formation between 0 and 728 m based on late Carboniferous (Stephanian) samples from the interval 538–662 m. Al-Moula (2002) interpreted the age of the samples from between 812–1,157 m as early Carboniferous Tournaisian (PC and CM biozones, Figure 25) and those from 735–772 m as Visean. He interpreted the Ga’ara Formation between the surface and 670 m and the “Suffi formation” (i.e. Raha Formation) between 670 and 854 m.

Kaddo (1997) studied the palynology of the upper part of the Akkas-1 well based on nine samples from the interval 1,120.5–1,197 m (Figure 15 and 26). All the samples were rich in miospores.
except for the sample from 1,178 m. He identified 129 species belonging to 54 genera (including 16 new species). He identified the late Tournaisian-early Namurian (= Serpukhovian) miospore *Aratrisporites saharaensis* that only appeared in Iran and North Africa, primarily in the late Visean-early Namurian (= Serpukhovian). Other miospores of late Visean-early Namurian (Serpukhovian) that are more widely known included: *Kraeuselisporites ornatus*, *Colatisporites denticulatus*, *C. decorus*, *Rotaspora knoxi*, *Prolycospora rugulosa*, *Spelaeotrilites* spp., *Vallatisporites* spp., *Savitrisporites nux*, *Waltzispora polita*, *W. planiangulata*, *Raistrickia accincta* and *R. nigra*. He placed the boundary between the Visean and Namurian at 1,143.6 m.

**Underlying Formation and Details of Contact**

The Harur Formation underlies the Raha Formation in Key Hole KH 5/1 (Figure 24) and Akkas-1 (Figure 15). The contact is taken at the change from marine shale of the Raha to dolomite of the Harur Formation. There does not appear to be any significant stratigraphic discontinuity at the contact.

**Overlying Formation and Details of Contact**

The Raha Formation is overlain by the Ga’ara Formation in Key Hole KH 5/1 (Figure 24). The boundary appears to represent a major hiatus in the middle Carboniferous and a change from a marine setting in the early Carboniferous (Visean-Serpukhovian) to a continental setting in late Carboniferous (Stephanian = late Moscovian-Gzhelian).
Regional Distribution, Depositional Setting and Sequence Stratigraphy

The Raha Formation represents the youngest formation to be deposited in Iraq below the middle Carboniferous pre-Ga’ara unconformity. The pre-Ga’ara unconformity is correlated to the pre-Unayzah unconformity of Saudi Arabia (so-called “Hercynian unconformity”). As a result the Raha Formation is the first candidate for erosion that is associated with the pre-Ga’ara unconformity. The formation was probably deposited over many parts of Iraq and subsequently eroded during the middle Carboniferous.

The Raha Formation on the basis of its Visean-Serpukhovian age and lithology is correlated to the Berwath Formation of Saudi Arabia (see Al-Husseini, 2004).

Economic Significance

In Akkas-1, in the Ga’ara Formation a cored interval (Core 5: 1,135.32–1,144 m) was analyzed for reservoir parameters. The interval has an average porosity of 20% and average permeability of 58 mD.

GA’ARA SANDSTONE FORMATION: PENNSYLVANIAN (LATE CARBONIFEROUS) TO GUADALUPIAN (MIDDLE PERMIAN)

Authors and Nomenclature

The Ga’ara Sandstone Formation was studied by mineral and petroleum companies in both outcrop and boreholes in the Western Desert. The name, age and stratigraphic position of the formation has been a source of confusion. H.H. Boesch (1938, unpublished report, in van Bellen et al., 1959) first named the formation. Synonyms include the obsolete “Gres de Ga’ara” (Mitchell, 1956, in van Bellen et al., 1959) and the obsolete “Nijili formation” (H.V. Dunnington, 1954, in van Bellen et al., 1959). The Ga’ara and Nijili formations were incorrectly considered as Triassic in age, on the basis of tentative stratigraphic position by Dunnington (1954, in van Bellen et al., 1959). Antonets et al. (1963) and Tamar-Agha (1986) studied the Nijili and Ga’ara formations and combined the two units into the Ga’ara Formation, as have subsequent studies. Tamar-Agha (1993) divided the accessible part of the Ga’ara Formation into the Rumliya and overlying Ataif units.

Type Section

H.V. Dunnington (in van Bellen et al., 1959) reported that the type section is located at Tel Aafaif, Ga’ara Depression, southwest Iraq (33°31’N, 42°28’E) where about 50 m (164 ft) is exposed, but the base is not seen (Figures 1 and 27). At the type locality of the underlying and obsolete Nijili formation, the total thickness of Ga’ara Sandstone is calculated to be about 85 m (279 ft) (by subtraction of the site-elevation from the projected base of the Mulussa Limestone). The lithology is coarse-grained, current-bedded, variegated sandstones, creamy red to white in fresh exposure, weathering through rusty red-brown to violet, black, etc., with some beds of white sandstones, locally quartzitic (Figure 27). Subordinate bands of purple and red sandy marls occur in the formation, and in the uppermost part of the formation, gray and greenish sandy or silty marls occur.

Reference Section

In the composite reference section in the Ga’ara Depression region, about 100 m (328 ft) of the Ga’ara Formation is exposed in outcrop and 670 m (2,198 ft) was penetrated in well Key Hole KH 5/1 (Figures 1 and 24) (Yugoslav Team, 1981; Sadiq, 1985; Tamar-Agha, 1986, 1993; Tamar-Agha et al., 1992, 1997; Al-Rubaii et al., 1991, in Al-Haba et al., 1991; Nader et al., 1993a, 1994; Al-Hadidy et al., 2002). According to Tamar-Agha et al. (1992) the section in Key Hole KH 5/1 between the near-surface and 565 m (1,853 ft) consists from base-up:

Unit 1: 137 m (449 ft) sandstone-mudrock fining upwards sequences;
Unit 2: 70 m (230 ft) mudrock-sandstone coarsening upwards sequences;
Unit 3: 118 m (387 ft) monotonous mudrock sequences;
Unit 4: 68 m (223 ft) mudrock-sandstone coarsening upwards sequences;
Unit 5: 272 m (892 ft) sandstone-mudrock fining upwards sequences.
### Palynology of interval 735 to 1,157 m in Key Hole 5/1 well

| Species | System | CARBONIFEROUS - MISSISSIPPIAN |
|---------|--------|--------------------------------|
|         | Stage  | Toumaisian (Tn3) | Visean |
|         | Formation | Ora | Harur | Raha |
| Sample/Depth (m) | 1,157 | 1,154 | 1,142 | 890 | 855 | 838 | 812 | 772 | 754.6 | 735 |
| Spore Biozones | PC | CM | Visean |

| Species | System | CARBONIFEROUS - MISSISSIPPIAN |
|---------|--------|--------------------------------|
|         | Stage  | Toumaisian (Tn3) | Visean |
|         | Formation | Ora | Harur | Raha |
| Sample/Depth (m) | 1,157 | 1,154 | 1,142 | 890 | 855 | 838 | 812 | 772 | 754.6 | 735 |
| Spore Biozones | PC | CM | Visean |

- **Umbonatisporites distinctus**<br>- **Umbonatisporites sp. 1**<br>- **Prolycospora rugulosa**<br>- **Araltrispores saharaensis**<br>- **Rugospora polyptycha**<br>- **Vermucisporites congestus**<br>- **Vermucisporites magnificus**<br>- **Vermucisporites papulosus**<br>- **Acanthotrilettes intonsus**<br>- **Convolutispora varicosa**<br>- **Dictyotrilettes submarginatus**<br>- **Dictyotrilettes muriatus**<br>- **Reticulatisporites pellatus**<br>- **Neoraistickia cymosa**<br>- **Neoraistickia logani**<br>- **Lophozonotilettes triangulatus**<br>- **Crassispores holospongia**<br>- **Retusotrilettes iraqensis**<br>- **Retusotrilettes cf. iraqensis**<br>- **Lophozonotilettes dentatus**<br>- **Tetanispores granulatus**<br>- **Densospores claytonii**<br>- **Densospores variabilis**<br>- **Cyclogranisporites commodus**<br>- **Cyclogranisporites minutus**<br>- **Microreticulatisporites sulcatus**<br>- **Grandispores composita**<br>- **Cribrostomites ronidus**<br>- **Vellamispores irugatus**

- **Spelaeotrilettes sp.2**<br>- **Retusotrilettes sp.2**<br>- **Retusotrilettes sp.1**<br>- **Spinozonotilettes cf. uncatus**<br>- **Raistrickia clavata**<br>- **Schopfites claviger**<br>- **Anaplanisporites baccatus**<br>- **Anaplanisporites sp.1**<br>- **Densospores pseudannulatus**<br>- **Cristalispores menendezii**<br>- **Convolutispora floridana**<br>- **Retusotrilettes crassus**<br>- **Retusotrilettes incohatus**<br>- **Calamospora microrugosa**<br>- **Calamospora nigrata**<br>- **Calamospora cf. pedata**<br>- **Auroraspora solisorta**<br>- **Leiotrilettes subintortus**<br>- **Retusotrilettes leptocentrumi**<br>- **Apiculiretusispora granulata**<br>- **Auroraspora macra**<br>- **Indotriradites dolianiti**<br>- **Indotriradites tedanitus**<br>- **Leiotrilettes tumidus**<br>- **Retusotrilettes leptocentrumi**<br>- **Apiculiretusispora cf. denticulata**<br>- **Retusotrilettes leptocentrumi**<br>- **Apiculiretusispora granulata**<br>- **Procoronaspora serrata**
| Species                        | Formation |
|-------------------------------|-----------|
| Velamisporites magnus         | Raha      |
| Velamisporites rugosus        | Raha      |
| Labiadienites sp. 1           | Raha      |
| Camptotritiletes bucculentus  | Raha      |
| Retusotritiletes avonensis    | Raha      |
| Crassipora kosankei           | Raha      |
| Crassipora trychea            | Raha      |
| Cristallasporites echinatus   | Raha      |
| Densosporites spitsbergenensis| Raha      |
| Spelaeotriletes microspinus   | Raha      |
| Convolutispora caliginosa     | Raha      |
| Spelaeotriletes baltatus      | Raha      |
| Spelaeotriletes crastatus     | Raha      |
| Discernisporites micromanifestus | Raha  |
| Colatisporites decorus        | Raha      |
| Colatisporites denticulatus   | Raha      |
| Vallatisporites microspinus   | Raha      |
| Vallatisporites verrucosus    | Raha      |
| Vallatisporites galeans       | Raha      |
| Vallatisporites ciliaatis     | Raha      |
| Vallatisporites cf. ciliaaris | Raha      |
| Densosporites variomarginatus | Raha      |
| Radizonates arcuratus         | Raha      |
| Raistriickia pinguis          | Raha      |
| Spinozonotritiletes uncatus   | Raha      |
| Punctatisporites glabrimarginatus | Raha  |
| Punctatisporites irarus       | Raha      |
| Punctatisporites planus       | Raha      |
| Densosporites rarispinosus    | Raha      |
| Apiculiretusispora sp. 1      | Raha      |
| Endosporites s.p. 1           | Raha      |
| Spelaeotriletes s.p. 1        | Raha      |

| Species                        | Formation |
|-------------------------------|-----------|
| Klaeuselisporites echinatus   | CM        |
| Foveosporites appositus       | CM        |
| Cirratrichadites rarus        | CM        |
| Punctatisporites cf. resolitus| CM        |
| Adelisporites multiplicatus   | CM        |
| Adelisporites sp. 1           | CM        |
| Lophotriletes copiosus        | CM        |
| Lophotriletes tuberculatus    | CM        |
| Lophotriletes cf. granooenatus| CM        |
| Lophotriletes cf. tribulosus  | CM        |
| Lophotriletes sp. 1           | CM        |
| Waltzispora prica            | CM        |
| Spelaeotritiletes arenaceus   | CM        |
| Spelaeotritiletes triangulus | CM        |
| Auroraspora corporiga        | CM        |
| Pinatispora quasibrata        | CM        |
| Cyclogranisporites sp. 1      | CM        |
| Neoraistrickia sp. 1          | CM        |
| Granulatisporites microgranifer | CM      |
| Granulatisporites cf. microgranifer | CM  |
| Granulatisporites granulatus  | CM        |
| Vallatisporites variomarginus | CM        |
| Klaeuselisporites ornatus     | CM        |
| Knoxeporites hederatus        | CM        |
| Neoraistrickia inconstans     | CM        |
| Neoraistrickia cf. inconstans | CM       |
| Waltzispora cf. polita       | CM        |
| Schopfites cf. delicatus      | CM        |
| Cingulizonates cf. capistratus| CM        |
| Schopfipollenites ellipsides  | CM        |
| Discernisportes sullivani    | CM        |

Figure 25: Lower Carboniferous (Mississippian) Tournaisian-Visean spores identified in well Key Hole KH 5/1 for samples from the interval 735–1,157 m (after Al-Moula, 2002). The newly proposed Raha Formation occurs between 670 and 854 m (Figure 24). Kaddo (1997), assigned two samples (812 m and 838 m) to the CM Biozone (Tournaisian) that are here attributed to the Visean-Serpukhovian Raha Formation. On the basis of its clastic lithology (and position above the Harur carbonates) the interval 670–854 m is retained as the lower part of the Raha Formation. The interpretation of the CM Biozone in the cuttings samples from 818 m and 838 m is considered as questionable.
### Akkas-1, Visean-Serpukhovian Palynology

| Series / System | LOWER CARBONIFEROUS - MISSISSIPPIAN |
|----------------|-------------------------------------|
| Stage          | Visean | Namurian |
| GTS 2004       | Harur  | Raha     |
| Formation      | Visean | Serpukhovian |
| Depth (m)      |         |          |
| Sample         | 1,197   | 1,178    |

#### Lithology

| Sample | 1,180 | 1,170 | 1,160 | 1,150 | 1,140 | 1,130 | 1,120 |
|--------|-------|-------|-------|-------|-------|-------|-------|
|        |       |       |       |       |       |       |       |

**Figure 26:** Lower Carboniferous Visean-Serpukhovian miospores identified in well Akkas-1 for the interval 1,120.5–1,197 m (after Kaddo, 1997). This interval contains the upper part of the Harur Formation shown as limestones (blue) and dolomites (green), and the newly proposed Visean-Serpukhovian Raha Formation. Y. Kaddo emphasized the identification of the late Tournaisian-early Namurian (= Serpukhovian in GTS 2004) miospore Aratrisporites saharaensis that is known only in the Middle East and North Africa, primarily in the late Visean-Serpukhovian. He placed the boundary between the Visean and Serpukhovian stages at 1,143.6 m.
Paleontology and Age
H.V. Dunnington (in van Bellen et al., 1959) reported that no fossils were recovered and the age was incorrectly presumed to be probably Triassic. Čtyroky (1973) described plant megafossils that he considered to be of Middle to Late Permian age and belonging to the Cathaysian floral province. The age of the Ga‘ara is late Carboniferous and Permian according to Al-Amiri et al. (1971), Al-Haba et al. (1991, 1994), Al-Sammarai et al. (1994), and Nader et al. (1993a, 1994).

In the well Key Hole KH 5/1, Nader et al. (1993a, 1994) reported the following spores from the Permian informal “CP1” biozone of the Ga‘ara Formation: Deltidospora priddyi, Calamospora mutabilis, Calamospora pallida, Lophotriletes commissuralis, Raistrickia aculeata, Crassispis plicata, Cirratiradites rarus, Spelaeotriletes arenaceus, Spelaeotriletes triangulus, Kraeuselisporites ornatus, Vallatisporites vallatus, Latensina trileta, Pityosporites westphalensis, Quasillinites diversiformis, and Protohaploxypinus swardi.

Underlying Formation and Details of Contact
In the type section the Ga‘ara Formation overlies the obsolete Nijili formation (Figure 27); the latter being reinterpreted as the lower part of the Ga‘ara Formation (Antonets et al., 1963; Tamar-Agha, 1986). In this study, in the reference section in Key Hole KH 5/1, the Ga‘ara Formation lies on the Visean-Serpukhovian Raha Formation (Figure 24).

Overlying Formation and Details of Contact
H.V. Dunnington (in van Bellen et al., 1959) reported that in the type outcrop section, the Ga‘ara Formation is overlain by the Upper Triassic Mulussa Formation (Figures 1 and 27); the contact is gradational, concordant and taken at the top of greenish marls directly underlying the lowest limestone bed of the Mulussa Formation, and a few feet above the highest sandstone bed of the Ga‘ara Formation.

In the wells Atshan-1, Jabal Kand-1 and West Kifil-1 (Figures 28), a clastic section that may be attributed to the Ga‘ara Formation is overlain by the Chia Zairi Formation (F. Al-Juboury, 1991 in Al-Haba et al., 1991; Nader et al., 1993b, 1994). The age of the clastic section in Atshan-1 is Late Permian according to Nader et al. (1997) and accordingly this unit may be coeval to the Chia Zairi Formation elsewhere in Iraq.

Regional Distribution, Depositional Setting and Sequence Stratigraphy
H.V. Dunnington (in van Bellen et al., 1959) reported that the Ga‘ara Formation is found throughout the Ga‘ara Depression, of which the formation forms the floor, and in the lowest exposures of the high cliffs encircling the southern limits of the depression. The Ga‘ara Sandstone has not yet been found in subsurface sections in North Iraq (Figure 3), and it is absent from the exposed sections of North Iraq.

In well Key Hole KH 5/1 (Figure 24), A. Al-Juboury (written communication, 2006) and the present author recognized four successive lithofacies and interpreted their corresponding environments as described below (from base-up).

Lithofacies I sequence (565-670 m) consists mostly of coarsening upwards shale, sandstone and siltstone sequences. The sandstones are mostly quartz arenite in which the quartz grains are generally monocrystalline, medium-sized, subangular to subrounded, and well sorted. The depositional setting is interpreted as deltaic.

Lithofacies II sequence (360–565 m) consists mostly of alternations of fining upwards pebbly sandstone, sandstone and siltstone sequences. The sandstones are generally cross-bedded and consist of quartz arenites with few micas. The environment is interpreted as a meandering-fluvial system.

Lithofacies III sequence (360–240 m) consists of mudstones with no sedimentary structure except a few varved structures that is interpreted as a lake system. This interval corresponds to unit 3 of Tamar-Agha et al. (1992), which consists of 118 m (387 ft) of monotonous mudrock sequences.
Al-Hadidy

Lithofacies IV sequence (240 m to surface) consists of fining-upward sequences separated by erosional surfaces. The sequences consist of fine- to coarse-grained sandstone with fine pebbly sandstone, and chert fragments. The sandstones are generally quartz arenite, subangular to subrounded and well sorted with few plant remains. The setting is interpreted as a braided fluvial system.

The Ga’ara Formation forms a wedge, which thins away from Key Hole KH 5/1 towards northeast and North Iraq towards Atshan-1 and Jabal Kand-1 where it is about 50–80 m thick (Al-Hadidy, 2001). In these latter two wells, however, the Ga’ara Formation consists of gray to black shale, sandstone with thin dolomitic limestone beds. In Atshan-1 this succession was dated as Late Permian (Nader et al., 1997) and may therefore correlate to the basal part of the transgression associated with the Chia Zairi Formation. It may therefore be much younger than the Ga’ara Formation in the Ga’ara Depression region and Key Hole KH 5/1.

No glaciogenic or peri-glacial facies have been recognized in Iraq as in the more southerly regions of the Arabian Peninsula. The Ga’ara Formation is correlated with the Unayzah Formation in Saudi Arabia, Faraghan Formation in Iran (Al-Laboun, 1986, 1987) and Al Khlata and Gharif formations in Oman (Osterloff et al., 2004a, b). In Syria it is correlated to the Doubiyat Formation (Konert et al., 2001) and in eastern Syria to the lower part of Amanus Formation. The formation is missing in eastern Jordan (Risha Basin) and southeast Turkey (Figure 4; Konert et al., 2001).

Economic Significance
Geochemical analysis of the shaly beds of the Ga’ara Formation in Jabal Kand-1, Atshan-1 and West Kifil-1 indicate the occurrence of continental organic matter with an average TOC of about 1% (Al-Haba et al., 1991, 1994). In Saudi Arabia, the correlative Unayzah Formation is a regional reservoir (McGillivray and Husseini, 1992; Al-Husseini, 2004).

CHIA ZAIRI FORMATION: MIDDLE AND LATE PERMIAN

Authors and Nomenclature
R. Wetzel (1950, unpublished report, in van Bellen et al., 1959) defined the Chia Zairi Formation, which has no synonyms. Hudson (1958) divided the formation into the lower Zinnar formation,
middle Satina Evaporite member and upper Dariri formation. These three units are here considered as informal members of the Chia Zairi Formation. The Satina Evaporite member derives its name from Jabal Satina, northeast of Ora.

**Type Section**

R. Wetzel (in van Bellen et al., 1959) reported that the type section is located on the north flank of the Ora fold (along Geli Khana) and over the mountain to Ora in a north-south line (Figure 1b). The top of the section lies 2.9 km north of Ora Police Post (about 37°18’07”N, 43°21’36”E), and the base at 1.3 km northwest of the Police Post (about 37°17’15”N, 43°21’08”E). The type section is 811 m (2,660 ft) thick. The base of the type section of the Satina Anhydrite member lies about 1.6 km due north of the Ora Police Post (37°16’38”N, 43°21’37”E).

The lower Zinnar member is 432 m (1,417 ft) thick and consists of alternating thin-bedded, dark blue, organic-detrital limestone and fine-grained, argillaceous, often nodular, dark blue limestones, with groups of harder, massive, cliff-forming, silicified limestones (Figure 29). A coral bed occurs in the middle, and intercalations of black micaceous shale and marl occur in the lowest 25 m (82 ft). The Zinnar member has a thickness of 387 m (1,269.4 ft) at Harur.

The middle Satina Evaporite member is 61 m (200 ft) thick and consists of vacuolar dolomites with solution and recrystallization breccias, and recrystallized dolomitic marls with blockwork (Figure 29). Some thin bands of microfossiliferous limestone occur at the base. In the Harur area, where it is 77 m (252.6 ft) thick, some thin sandstones occur near the base of this member.

The upper Dariri member is 318 m (1,043 ft) thick and consists of thin-bedded, dark blue limestones, dominantly of organic-detrital type, with groups of harder, more massive, silicified, scarp-forming limestones (Figure 29). Bands with chert nodules occur at several horizons. The upper 25 m (82 ft) are partly oolitic and streaked with false-bedded wisps of sandstone. Stylolithic bedding planes occur all through the succession. The Darari member is 296 m (971 ft) thick at Harur.

**Reference Section**

The Jabal Kand-1 well (Figures 1, 28 and 30) is chosen as the subsurface reference section for the Chia Zairi Formation, wherein it was encountered between 5,127 and 5,700 m (16,816–18,696 ft) and is 573 m (1,879.4 ft) thick. The formation is divided into upper (CH1: 5,127–5,440 m) middle (CH2: 5,440–5,560 m) and lower (CH3: 5,560–5,700 m) units.

The CH1 and CH3 units are generally composed of skeletal lime grainstone-packstone; the skeletal components are composed of fusulinids, bryozoans, brachiopods, and echinoderms. Coarse crystalline dolomite, shale, and silstone intercalations with streaks of sandstone and dolomite also occur as mixed facies in these two units. The middle CH2 unit consists of mixed carbonates and siliciclastics. The three subsurface CH units may correspond to the three outcrop members.

**Paleontology and Age**

R. Wetzel (in van Bellen et al., 1959) reported that the lower Zinnar member contains corals, including *Michelinia aff. syangensis* Reed, *Michelinia* spp., *Polythealis* sp., etc.; crinoids, brachiopods (*Reticularia indica* Waagen), goniatites; foraminifers and algae: *Cribrogenerina* sp., *Geinitzina* sp., *Archaeodiscus* sp., *Polydiedoxina* sp., textularids, trochamminids, lagenids, etc.; *Fenestella* sp., *Fistulipora* sp.; *Anthracoporella* sp., *Polydiexodina* sp., textularids, *Eogoniolina johnsoni* Endo. R. Wetzel (in van Bellen et al., 1959) reported that the Satina Evaporite member yielded indeterminate microfauna, and algae (*Epimastopora* sp., *Gymnocodium bellerophontis* (Rothpletz), *Macroporella* sp., *Mizzia velebitana* Schubert, *Permocalculus compressus* (Pia), *P. fragilis* (Pia), *P. solidus* (Pia), *P. tenuellus* (Pia), etc.; *Eogoniolina johnsoni* Endo). R. Wetzel (in van Bellen et al., 1959) reported that the Satina Evaporite member yielded indeterminate microfauna, and algae (*Epimastopora minima* Elliott 1955) near the base. The upper Dariri member contains colonial corals, crinoids, brachiopods (*Marginifera* spp.), bivalves (*Halobia* sp.), goniatites, fusulinids (*Archaeodiscus* spp.), *Problematica* sp. and calcareous algae (*Gymnocodium bellerophontis* Rothpletz), *Mizzia velebitana* Schubert, *Permocalculus compressus* (Pia), *P. digitatus* Elliott, *P. forcepinus* (Johnson), *P. fragilis* (Pia), *P. plumosus* Elliot, *P. tenuellus* (Pia).
The age of the Chia Zairi Formation was interpreted by Hudson (1958) and Elliott (1955, 1958) as Middle to Late Permian based on coral, algae, and benthonic foraminifera. Singh (1964) recovered a palynoflora from the Chia Zairi Formation in the Atshan well, 12 miles west of Mosul and suggested a Late Permian age. In the Jabal Kand-1, Atshan-1 and Mityaha-1 wells the same age assignment was determined (Youhanna and Shathaya, 1988; Omar, 1990). Youhanna and Shathaya (1988) indicated the palynoflora from the Chia Zairi Formation in the Atshan well, 12 miles west of Mosul and suggested Middle to Late Permian based on coral, algae, and benthonic foraminifera. The age of the Chia Zairi Formation was interpreted by Hudson (1958) and Elliott (1955, 1958) as Middle to Late Permian based on coral, algae, and benthonic foraminifera. Singh (1964) recovered a palynoflora from the Chia Zairi Formation in the Atshan well, 12 miles west of Mosul and suggested a Late Permian age. In the Jabal Kand-1, Atshan-1 and Mityaha-1 wells the same age assignment was determined (Youhanna and Shathaya, 1988; Omar, 1990). Youhanna and Shathaya (1988) indicated the palynoflora from the Chia Zairi Formation in the Atshan well, 12 miles west of Mosul and suggested Middle to Late Permian based on coral, algae, and benthonic foraminifera.
Figure 28: Correlation of the Chia Zairi Formation from North Iraq in the reference well Jabal Kand-1 (Figure 30) to West Kifil-1 in Central Iraq, and Diwan-1 in South Iraq. In Jabal Kand-1 the formation is 573 m thick compared to the type section (Figure 29) where it attains a thickness of 811 m. In western Iraq the clastic unit below the base of the Chia Zairi carbonates may be Late Permian in age (e.g. Atshan-1, Nader et al., 1997) and accordingly this unit may be coeval to the Chia Zairi Formation elsewhere in Iraq. Moreover, the clastic unit above the Chia Zairi carbonates in Mityaha-1 was dated by Nader et al. (1993b) as Late Permian and reflects the proximal position of these wells (Figure 31).

Nader et al. (1993a, b) reported the following spores from the upper informal “P1” biozone of the Chia Zairi Formation: Iraqispora labrata, Fotonicispores novicus, Vestigiospores densus, Striatobacillites richteri, Platyacisporites papillionis, Fimbriaesporites fimbriatus, Osmundaciatites, Camptotriletes, Distriatites insolitus, Falcisporites zapfei, Florinites milloti (this is probably ?Florinites balmei of Stephenson et al. (2003), hence the assemblage may correspond to their OSPZ6 palynozone), Deltoidospora levis, Punctatispores incomptus, Calamospora hartungiana, Granulatispores microgranifer, Cyclogranisporites micacaeus, Leschikisporis cestus, Echinatispores gaaraensis (new species defined by Nader et al., 1993a,b), Microbaccispora tentula, Cirrattriradites saturni, Densoisporites solidus, and Punctatospores minutus.

Underlying Formation and Details of Contact
The Chia Zairi Formation overlies the Harur Formation in outcrop type section (Figure 29). See “Harur Formation, Overlying Formation and Details of Contact”. In the subsurface, the Chia Zairi Formation overlies the Ga’ara Formation (Figures 28 and 30). See “Ga’ara Formation, Overlying Formation and Details of Contact”.

Overlying Formation and Details of Contact
R. Wetzel (in van Bellen et al., 1959) reported that in the type section, the Chia Zairi Formation is overlain by the Triassic Migra Mir Formation (Figure 29). The contact is rapidly gradational and conformable, at the
| Age          | Formation                  | Thickness (m) | Lithology                                                                 | Markers and Zones          | Lithological Description                                                                                                                                 |
|-------------|----------------------------|---------------|---------------------------------------------------------------------------|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| PERMIAN     | Chia Zairi Formation type section |               | thin-bedded, massive feature forming                                        | Cliff                       | Limestone: marly, gray brown weathered yellowish gray, laminated splintery with bands of crystalline limestone.                                           |
|             |                            |               | Brachiopod lumachella Marginifera fauna                                    | Cliff                       | Limestone: crystalline dark gray brownish, well bedded, dolomitic medium to fine-grained, weathered yellowish gray with rugged surface, partly oolitic. |
|             |                            |               | Field marker Archaediscus Problematica                                     | Cliff                       | Limestone: marly.                                                                                                                                     |
|             |                            |               | Fault plane                                                                | Cliff                       | Limestone: crystalline as above thin-bedded.                                                                                                              |
|             |                            |               | Cliff base top                                                             | Cliff                       | As above and faintly foetid.                                                                                                                              |
|             |                            |               | Section transferred to Jabal Satin                                         | Cliff                       | Limestone: gray weathering dark gray blue, crystalline, fine-grained, organic detrital in parts, 30–50 cms bedded with bands of chert nodules, black weathered brown 0.5 to 1 m bedded. |
| TRIASSIC    | Migra Mir Formation      |              | Abundant Shells                                                           | Cliff                       | As above, thin and medium thick-bedded                                                                                                                  |
|             | contact gradational       |              | Limestone: pale blue, weathered whitish at top and bottom, fine-grained, dense vermicular dolomitic crusts weathered out in a pale yellow color | Cliff                       | Limestone: dark gray brown to black, crystalline, hard, fine-grained, thin bedded; with silicified crusts; occasionally chert.                        |
|             |                            |              | Limestone: weathered whitish, organic detrital, partly dolomitic, abundant goeds. | Cliff                       | Limestone: dark blue to black, thin-bedded, crystalline densely organically detrital and coarser in parts; occasionally chert nodules.                  |
|             |                            |              | Limestone: dark blue and gray purplish, crystalline, fine to medium-grained hard; 1 m bedding with rugged weathered surface. | Cliff                       | Limestone: dark blue to black, weathered gray blue, crystalline, hard, partly pseudo-oolitic; 0.5 m bedded, crinoidal and shell remnants, occasionally chert. |
|             |                            |              | Limestone: as above, pale to dark blue.                                    | Cliff                       | Limestone: gray bluish to black, partly dolomitic, fine-grained thin-bedded.                                                                          |
|             |                            |              | As above 1 m bedding, crinoids at top, occasional silicified corals.        | Cliff                       | As above 1 m bedding, crinoids at top, occasional silicified corals.                                                                                   |
|             |                            |              | Limestone: marly dolomitic, partly oolitic, weathered white.               | Cliff                       | Limestone: as above, pale gray to yellowish, sugary at top grading downward into marl.                                                              |
|             |                            |              | Limestone: pale gray bluish, crystalline, fine to medium-grained partly cherty. | Cliff                       | Limestone: as above and dolomite, pale gray yellow, highly vacuolar in parts; oolitic at base.                                                     |
|             |                            |              | Limestone: as above pale to dark blue.                                     | Cliff                       | As above pale to dark blue.                                                                                                                             |
|             |                            |              | As above pale gray to yellowish, sugary at top grading downward into marl. | Cliff                       | As above pale gray to yellowish, sugary at top grading downward into marl.                                                                         |
|             |                            |              | Limestone: dolomitic.                                                      | Cliff                       | Limestone: as above pseudo-oolitic, partly marly, partly cherty weathered whitish.                                                                  |
|             |                            |              | As above pseudo-oolitic, partly marly, partly cherty weathered whitish.    | Cliff                       | Marl: pale gray, recrystallized abundant recrystalline breccia with limestone band.                                                                |
|             |                            |              | Marl and recrystallized breccia.                                          | Cliff                       | As above vanicoloured, bands of recrystalline breccia.                                                                                               |
|             |                            |              | Limestone: dark blue to black, crystalline, fine to medium-grained, hard, partly oolitic, partly dolomitic; shelly. | Cliff                       | Shale: black, soft.                                                                                                                                   |
|             |                            |              |                              | Cliff                       | Limestone: grayish blue to black, crystalline to marly, occasionally shaly, thin organic detritus; microfauna; thin top, thick bedded; occasionally chert. |

(Continued on facing page)
| Lithology | Thickness (m) |
|-----------|--------------|
| **PERMIAN** | **Chia Zairi** |
| 440 | Fenestella |
| 460 | Fusulinids |
| 480 | Cliff |
| 500 | Wetzelia zone |
| 520 | Base of cliff Abundant microfossils |
| 540 | Fusulinids ledge |
| 560 | Fusulinids Base of cliff Top of ledge |
| 580 | Base of cliff Feature forming ledge |
| 600 | Ferruginous horizon |
| **LOWER CARBONIFEROUS** | **Harur Formation** |
| 620 | Limestone: black, weathered pale gray bluish crystalline to marly, thin-bedded to laminated, partly shaly, partly papery, generally fine-grained, shaly and with abundant crinoids. |
| 640 | Limestone: dark blue to black, crystalline to slightly marly, occasionally dolomitic thin to 0.5 m bedded; abundantly fossiliferous; occasionally chert. |
| 660 | Limestone: black gray to dark blue, crystalline, fine-grained slightly dolomitic, very hard calcite vained, shell sections in calcite or silified, in a massive cliff with rugged surface. |
| 680 | Limestone: black gray to dark blue, crystalline fine-grained slightly dolomitic, very hard or silicified weathers in a massive cliff with rugged surface. |
| 700 | As above, 5 cm to 1 m bedded. |
| 720 | Limestone: black weathered grayish blue organic detritus, fine-grained, brittle thin-bedded. |
| 740 | Limestone: crystalline as above, thin to 1 m bedded abundantly fossiliferous. |
| 760 | Limestone: black, organic detritus, brittle, flaggy partings, 10 cm bedded. |
| 780 | Limestone: black, crystalline, fine-grained, hard, massive bedded partly pseudo-oolithic; abundant fauna. |
| 800 | Limestone: as above but thin-bedded, marly and nodular near top. |
| 820 | As above, 1 m to massive bedded. |
| 840 | Limestone: black, crystalline, fine-grained, weathered gray, thin to massive bedded; generally highly fossiliferous. |
| 860 | Limestone: dark blue, weathers with a knobly surface, crystalline, fine-grained, thin-bedded; abundantly fossiliferous. |
| 880 | Marl: gray shale: black, flaky, soft limestone as above. |
| 900 | Limestone: marly sandy. |
| 920 | Marl: brown, shaly, soft with thin rip-ups of black limestone. |
| 940 | Marl: dark olive green, sandy towards base, ferruginous to haematitic. |

(Continued from facing page)

Figure 29: The Chia Zairi Formation in the type section overlies the lower Carboniferous Harur Formation and underlies the Triassic Mirga Mir Formation (after R. Wetzel, 1950). In North Iraq outcrops, the upper Carboniferous and Permian Ga’ara Formation and lower Carboniferous (Visean-Serpukhovian) Raha Formation are not known in outcrop.
base of a succession of thin-bedded, soft limestones and marls. The top of the formation is fractured locally, and mineralized with calcite, with azurite and malachite staining. There is a fairly abrupt lithological junction of the Chia Zairi Formation with the overlying, marly, chemical sediments of the Triassic Mirga Mir Formation. The upper beds of the Chia Zairi, however, though retaining the general characteristics of the formation, contain oolitic bands and false-bedded wisps of sandstone, indicating progressive shallowing. The evidences of shallowing are shown best in the Harur section at Darari (approximately 37°16'20"N, 43°15'48"E). The Triassic/Permian boundary has been taken to correspond with the lithological boundary between a succession of soft, thin-bedded, gray and yellowish limestones and marls of the Mirga Mir (above), and the highest, dark blue limestones of the Chia Zairi (below). This horizon maybe time transgressive regionally, but in the field it adequately separates these clearly distinguishable, mappable formations.

In the well Mityaha-1 (Figure 28), Nader et al. (1993b) placed the Triassic/Permian boundary at 2,704 m at the top of a massive sandstone bed on the basis of Late Permian, age-indicative microspores: *Lueckisporites virkkiae*, *Nuskoisporites dulhuntyi* and by the first appearance of other species such as *Alisporites australis*, *Falcisporites stabilis* and *Striatoabietites richteri*. The Triassic-indicative species included *Cordaitina gunyalensis*, *Falcisporites snopkovae* and *Aratrisporites parvispinosus*. In the Atshan-1 well, Nader et al. (1997) studied the interval 3,374.7–3,447.8 m and dated it as Late Permian (Thuringian) on the basis of *Nuskoisporites dulhuntyi*, *Lueckisporites virkkiae* and *Distriatites* spp.

**Regional Distribution, Depositional Setting and Sequence Stratigraphy**

R. Wetzel (in van Bellen et al., 1959) reported that the Chia Zairi Formation is found in outcrop in Jabal Satina, northeast of Ora; Harur, near Chalki (Khabour Valley); Chia-i-Zinnar, 2 km northeast of Kaista, near Chalki; other localities in the vicinity of the Khabour River, north of Chalki; Av-i-Massis and Geli Sinat areas, north and northwest of Shiranish; and Atshan-1. The formation covers the eastern part of Iraq, from Ora in North Iraq (Atshan-1, Jabal Kand-1, and Mityaha-1, Figures 3 and 28) to southern Iraq (West Kifil-1 and Diwan-1) (Figure 31, Al-Hadidy, 2001). It is missing in the Khleisia-1 and Akkas-1 wells due to either erosion or non-deposition.

In the Jabal Kand-1 and Mithaya-1 wells, the upper part of the formation shows greater clastic influence than the type section in northern Iraq (Figure 31). Nader et al. (1993b) interpreted the CH1 member as Tatarian (late Middle Permian, Capitanian, and Late Permian) and the margin of the Tethys Ocean to be located towards northeast Syria (Figure 31, Al-Hadidy, 2001). The widespread distribution of the formation represents deposition on a carbonate platform in an epeiric sea (Murris, 1980; Al-Juboury et al., 1997; Al-Hadidy, 2001).

The lower Zinnar member (probably CH3 unit in subsurface) consists of carbonates that were deposited during the middle Permian transgression over an eroded surface (pre-Ga’ara unconformity) and older rock units. The Zinnar member contains MFS P20 of Sharland et al. (2001, 2004; Figure 2), which they placed in the “Wetzella Limestone” of Hudson (1958). It is correlated (at least in part) with the Khuff D Member of Saudi Arabia (Al-Jallal, 1995), lower Dalan Member of Iran (Szabo and Kheradpir, 1978) and Khuff cycles P17 to P27 of Oman (Osterloff et al., 2004b) (Figure 4).

According to R. Wetzel (in van Bellen, 1959), the middle Satina Anhydrite member (probably CH2 unit in subsurface) contains residual recrystallized breccias and dolomitized marl with blockwork, which suggests that these sediments were originally associated with anhydrite that was later dissolved at outcrop. The Satina evaporites and dolomites represent a temporary closing of the connection with the open sea. The Satina member is correlated (at least in part) with the Khuff D Anhydrite of Saudi Arabia (Al-Jallal, 1995), Nar Member of the Dalan Formation of Iran (Szabo and Kheradpir, 1978) and the Middle Khuff Anhydrite of Oman (Osterloff et al., 2004b) and the United Arab Emirates (Alsharhan, 2006) (Figure 4).

The upper Dariri member (probably CH1 unit in subsurface) reflects a return to open-marine conditions and contains MFS P30 and P40 of Sharland et al. (2001, 2004; Figure 2). The Dariri member is correlated with the Khuff C and (at least in part) lower Khuff B member of Saudi Arabia (Al-Jallal, 1995), upper Dalan Member of Iran (Szabo and Kheridpir, 1978) and Khuff cycles P30 to P40 of Oman (Osterloff et al., 2004b) (Figure 4).
PALEOGEOGRAPHIC EVOLUTION

Figure 30: The well Jabal Kand-1 is chosen as the reference section for the Middle and Late Permian Chia Zairi Formation. In this well the formation is divided into three units with the upper CH1 and lower CH3 being predominantly limestone, while the middle CH2 unit consists of alternating dolomites and clastics. The clastic unit below the Chia Zairi Formation is here shown as the Ga’ara Formation although it may be coeval with the Chia Zairi carbonates elsewhere in the basin.
The Chia Zairi Formation is correlated to the Umm Ima Formation in Jordan, and Gomaibrik Formation in southeast Turkey (Konert et al., 2001) (Figure 4).

Economic Significance
The geochemical analysis of the Chia Zairi Formation in Atshan-1, Jabal Kand-1, West Kifil-1 and Diwan-1 show source rock potential, particularly in the lower shaly part which is about 20 m thick (Al-Haba et al., 1991, 1994). The Chia Zairi Formation extends into Iran, Saudi Arabia and Qatar where the correlative Khuff and Dalan formations contain the main reservoirs for non-associated gas in the Arabian Gulf.

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In Iraq, the potential Paleozoic source rocks include the shales of the Khabour (K7, K4 and K2 members), Akkas and Ora formations. Of these shales, the main Paleozoic source rock, as in other Middle East and North Africa countries, is represented by the two lower “hot shale” beds of the Akkas Formation. The Akkas “hot shale” has a net thickness of 61 m and a TOC of 1.0–16.6% in Akkas-1. The net source rock interval can reach a thickness of up to 70 m. It is the most likely source rock of the Akkas field and Khleisia-1 where the oil is light (42° API gravity) and sweet. The Khabour shales may also be source rocks and, in part, may have sourced the gas found in the uppermost Khabour reservoir in Akkas field and Khleisia-1.

The known Paleozoic reservoir rocks in Iraq include the uppermost Khabour sandstones (K1 to K4 members) and upper Akkas clastics (upper part of the Qaim Member). The Khabour K1 member has an average porosity of 7.6% and average permeability of 0.13 mD. The Khabour K2 member has an average porosity of 6.6% and average permeability of 0.08 mD. Fractures in the Khabour reservoirs in Akkas field occur along two orientations and provide preferential flow directions. The deeper Khabour members have nil to low porosity and permeability, but may have reservoir potential if they

**EXPLORATION AND HYDROCARBON POTENTIAL: A SYNOPSIS**

In Iraq, the potential Paleozoic source rocks include the shales of the Khabour (K7, K4 and K2 members), Akkas and Ora formations. Of these shales, the main Paleozoic source rock, as in other Middle East and North Africa countries, is represented by the two lower “hot shale” beds of the Akkas Formation. The Akkas “hot shale” has a net thickness of 61 m and a TOC of 1.0–16.6% in Akkas-1. The net source rock interval can reach a thickness of up to 70 m. It is the most likely source rock of the Akkas field and Khleisia-1 where the oil is light (42° API gravity) and sweet. The Khabour shales may also be source rocks and, in part, may have sourced the gas found in the uppermost Khabour reservoir in Akkas field and Khleisia-1.

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are fractured. Sandstone beds in the Kaista and Ga’ara formations also have good reservoir potential. Together with the lower Triassic Mirga Mir Formation, the Chia Zairi Formation corresponds to the Khuff Formation of Arabia and the Dalan-Kangan formations of Iran. The Chia Zairi and Mirga Mir formations may be self-sourcing and contain multiple reservoirs.

Taking into consideration the stratigraphic distribution of the Paleozoic formations and their depth variations, the exploration potential of Iraq’s Paleozoic can be divided into three regions (Figure 32). In the northern region, the Permian carbonates of the Chia Zairi Formation are not too deeply buried and may constitute reservoirs. The Permian carbonates could be self-sourced or sourced from older formations such as the Akkas Formation, from further to the south.

In the central region extending along the border with Jordan and Syria, between Khleisia-1 and Akkas-1 (Figure 32), the main exploration targets are low-relief, fault-controlled structural closures that are similar to the Akkas field (Figure 32). The structural style consists of elongated horsts and grabens with potential traps in the tilted fault blocks. These hydrocarbon prospects require evaluation in terms of the age of fault movements, structured trap development, and source rock maturation and migration. In this region, Al-Haba et al. (1991, 1994) calculated that an average thickness of 65 m of hot shale with a TOC of 6% could generate 16 billion barrels of hydrocarbon in just the region between Akkas-1 and Khleisia-1 (about 20,000 sq km).

In the third region, located north of the Iraq-Saudi Arabia border (Figure 32), there are no deep wells in Iraq and only a few borehole penetrations in Saudi Arabia. However, by comparison to northwest Saudi Arabia and Jordan, it is anticipated that the Paleozoic succession will be completely represented in this region. Based on regional seismic data, the depth to the top of the Permian in this area is estimated to be about 3–5 km (Mohammed, 2006).

CONCLUSIONS

The Stratigraphic Lexicon of Iraq (van Bellen et al., 1959) is revised for the Paleozoic succession based on a comprehensive review of numerous studies and data. The Cambrian and Lower Ordovician successions of Jordan and Saudi Arabia are evidently present in Iraq on the basis of seismic data and regional correlations. The oldest known Ordovician Khabour Formation is divided into seven informal members (from base up K7 to K1), and the formation is dated as possibly Early Ordovician and definitely Middle and Late Ordovician. The revised lexicon adds the formally defined Silurian Akkas Formation along with its proposed lower Hoseiba and upper Qaim members. The Pirispiki Red Beds and enclosed Chalki Volcanics are here placed in the Upper Devonian rather than the Upper Ordovician as was the case in van Bellen et al. (1959). The term Khleisia Group is proposed to encompass the Pirispiki Red Beds, Chalki Volcanics, Kaista, Ora and Harur formations, as well as the proposed Raha Formation (previously “Suffi formation” that is here considered obsolete). The ages of the latter four formations are: (1) Kaista: Late Devonian (Famennian) and early Carboniferous (early Touraisian); (2) Ora: Carboniferous (Touraisian); (3) Harur: Carboniferous (Tournaisian-Visean); and (4) Raha: early Carboniferous (Visean-Serpukhovian). The term “Nijili formation” (van Bellen et al., 1959) is considered obsolete and this rock unit is combined with the overlying Ga’ara Formation. The Ga’ara Formation was previously interpreted as Triassic but its age is now interpreted as late Carboniferous-early Middle Permian. The late Middle and Late Permian Chia Zairi Formation consists of, from base-up, the Dariri, Satina Anhydrite and Zinnar members in outcrop, and is divided in the subsurface into the possibly correlatable CH3 to CH1 units.

Major unconformities are interpreted in the Paleozoic succession: (1) above or within the uppermost Ordovician Khabour Formation corresponding to the Gondwana glaciation during the Hirnantian Stage; (2) between the Silurian Akkas Formation and the Upper Devonian-lower Carboniferous Khleisia Group, i.e. the middle Paleozoic unconformity; (3) between the Khleisia Group and upper Carboniferous-Permian Ga’ara Formation, i.e. the middle Carboniferous unconformity; and (4) between the Ga’ara and Middle-Upper Permian Chia Zairi formations. The Raha, Ga’ara and basal Chia Zairi clastics may be difficult to distinguish without biostratigraphic and sedimentological analyses. The Triassic/Permian boundary is retained between the Chia Zairi and Mirga Mir formations, except in the Mityaha-1 well where it is placed above sandstones previously attributed...
The Paleozoic succession contains a complete petroleum system that is prospective in the western part of Iraq. Besides the well-known basal Silurian hot shale of Arabia and North Africa, the Ordovician Khabour and Carboniferous Ora shales may also constitute source rocks. In the Akkas field of western Iraq, the Ordovician and Silurian sandstone reservoirs have porosities ranging from 6.5–7.6% and permeabilities ranging from 0.13–0.2 mD. The late Paleozoic sandstones have higher porosities and could constitute an exploration target. The Permian Chia Zairi and overlying Triassic Mirga Mir formations correlate to the Khuff Formation of the Arabian Gulf, Amanus Formation of Syria, and the Dalan-Kangan formations of Iran. In the Arabian Gulf and Iran, these formations contain the world’s largest reserves of non-associated gas and therefore the Chia Zairi and Mirga Mir may also be prospective in Iraq.

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ABOUT THE AUTHOR

Aboosh H. Al-Hadidy is a Senior Chief Geologist in the Fields Division of the Geological Department for the North Oil Company, Ministry of Oil, Kirkuk, Iraq. He received his BSc degree in Geology and MSc and PhD degrees in Sedimentology and Stratigraphy of the Paleozoic of Iraq, Mosul University, Iraq. He joined the Iraq National Oil Company in 1980 where he started as a well-site geologist. Since 1996 he has been working for Mosul University-INOC – Kirkuk project. His current interests are focused on research on reservoir and geological models in the northern oil fields of Iraq.

dr_aboosh_hadidy@yahoo.com

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