CHAPTER 1

INTRODUCTION

This study defines the high-resolution sequence stratigraphy and characterization of the Triassic Khuff carbonates in the subsurface of Haradh Area in southern Ghawar Field, in eastern Saudi Arabia (Fig. 1.1). This report is presented to King Fahd University of Petroleum and Minerals as a thesis in partial fulfillment of the requirements for a master’s degree in geology.

Carbonates of the Khuff Formation (Permo-Triassic age) in the Middle East contain some of the largest natural gas accumulations in the world, estimated at about 15-20% of the world’s non-associated gas reserves (Al-Husseini, 2004), and are the target of gas exploration and development in the Arabian Gulf region (Fig. 1.2). The first Khuff gas discovery in the Middle East was in 1948, where a significant volume of non-associated gas discovered was in Bahrain. In 1957, the Khuff gas reservoir was discovered in Saudi Arabia, in the Dammam Field. Moreover, in Qatar, a major discovery was made in 1971 in the North Field, with estimated recoverable reserves of 900 TCF, making it the world’s largest gas field (Alsharhan, 2006).

There has been an increase in development of, and drilling through, the Khuff Reservoirs in Eastern Saudi Arabia to meet the production demands for non-associated gas according to the recent direction the national energy strategy of Saudi Arabia. One of the big challenges before this huge undertaking is that the quality of the Khuff
Figure 1.1: Map of the Arabian Peninsula showing the Ghawar Field in the Eastern Province of Saudi Arabia (subsurface study area outlined) and the Khuff outcrop belt against the eastern limits of the Arabian Shield.
Figure 1.2: Map of the Arabian Peninsula showing the fields within the Khuff Province (enclosed by blue line) (After Al-Husseini, 2004).
reservoirs is notoriously heterogeneous both laterally and vertically. Therefore, careful studies are necessary to map out, model, and predict quality and distribution of these reservoirs throughout Ghawar, where most of the current activity is concentrated.

This is a research study to develop a sequence stratigraphic framework, and characterization of the upper Khuff reservoirs (A and B) of Triassic age (Al-Dukhayyil et al., 2006), in the Haradh Area in southern Ghawar Field. This study intends to geologically characterize the most completely cored wells in Haradh Area covering the Khuff A and B reservoirs (Fig. 1.3) to develop the sequence stratigraphic framework for the Triassic Khuff in Haradh Area.

1.1. OBJECTIVES

The justification for such a study of the Khuff A and B reservoirs is the needed to develop a depositional model that can ultimately map out, in time and space, and predict reservoir quality. To do so, it is must to understand the controls on deposition and accumulation of sediments and on the preservation of such sediments into rock that has become host to a series of major gas reservoirs in the region. To fulfill the requirements of this goal, this study has set forth the following objectives:

1. Synthesis the current state of knowledge and understanding from published literature on the temporal relationships of the Triassic Khuff Formation and the Triassic intra-Khuff members in outcrop and in the subsurface, and how they relate to each other, guided by biostratigraphy, mapping, and genetic relationships. The contribution of this study to this objective is sedimentological and sequence
Figure 1.3: Khuff Members in Ghawar Field and their equivalent in outcrop of central Saudi Arabia (based on Vaslet et al., 2005; Hughes, 2005; Al-Dukhayyil and Al-Tawil, 2006). Note that the informal “Buraydah” Member and its subsurface equivalent are introduced in the present study.
stratigraphic analysis in select sections in outcrop and in the subsurface to supplement
and improve data presented in the most recent publications on the Khuff Formation.

2. The subsurface stratigraphy for the Triassic Khuff A and B has always been based on
a combination of reservoir and lithologic aspects. A fundamental objective of this
study is to define a high resolution sequence stratigraphic framework for the Triassic
Khuff in the subsurface using a traverse in Haradh (southern most Ghawar Field) that
is representative of the most complete Triassic Khuff Stratigraphy. Definition of the
high-resolution cyclicity and sequence stratigraphy will provide a correlation
framework beyond the resolution of the best available biostratigraphy. The need for
this high-resolution sequence stratigraphy is even more necessary in the mostly
micropaleontologically barren Triassic Khuff (the focus of this study) because of: 1.
its hostile arid/hypersaline paleoecology (evident by extensive evaporate and oolite
deposits) and 2. its deposition immediately subsequent to the biggest marine mass-
extinction in the Phanerozoic history of the Earth.

3. The high resolution cycle and sequence stratigraphic framework is based upon the
recognition of internal architecture, hierarchy of depositional cycles and their
stacking patterns within the Triassic Khuff immediately after the end-Permian.

4. Decipher the predominant paleoclimate of the Arabian Peninsula at the earliest
Triassic.

5. Define facies and depositional environment models of the Triassic Khuff succession
partitioned by, and representative of, each genetic unit within the high resolution
sequence stratigraphic framework.
6. While detailed geochemical and diagenetic studies are beyond the scope of this study, it is proposed that the detailed high-resolution sequence stratigraphic and facies frameworks can provide initial understanding of the cross-cutting relationships that may on have influenced early stage controls on diagenetic processes.

7. Define and map porosity-bearing facies, while classifying their pore-types, within the well-defined sequence stratigraphic and facies model framework. This facilitates the high resolution identification and mapping of reservoir facies in the subsurface, as well as improving the understanding of controls on development, temporal and spatial distribution, and prediction of lithofacies away from control points of reservoir quality. This study provides a working model for exploring or/and development and production of un-associated gas-bearing rocks in the Triassic Khuff of the subsurface of Saudi Arabia.

1.2. LOCATION OF THE STUDY

The studied Triassic Khuff Carbonates (A and B) in the subsurface are located in the Haradh Area, southern Ghawar Field, eastern Saudi Arabia. This research is based on detailed sedimentological study of a total of four wells having the most complete continuous cored interval in Haradh Area covering the Khuff A and B Carbonates. Four wells, here named A, B, C and D, have been selected along a 65 Km long south to north traverse (Fig. 1.4). This author sedimentologically described, documented and interpreted, bed by bed, a total of 402.3 meter (1,320 feet) of core in detail.
Figure 1.4: The approximate location of the studied wells
1.3. PREVIOUS WORK

The first pioneer geologist in Saudi Aramco, Max Steineke in 1937, studied the Khuff Formation outcrop. The Formation was named after Ayn Khuff at its type section (Steineke et al., 1958). In 1945, Bramkamp et al., measured and described in detail the 171.4 meters (562.4 feet) thick Khuff section near Ar Rayn, and designated it as the Khuff reference section (Powers et al., 1966). The base was defined as the unconformable contact between a lower sandy phase of the Khuff and the underlying massive Saq sandstone, of presumed Cambro-Ordovician age. The top was placed at a sharp contact between Khuff carbonate and red and green gypsiferous shale, now assigned to the Triassic Sudair Shale. The Khuff gross lithologies in the outcrop are carbonates mixed with evaporites and some shale (El-Khayal et al., 1980, and Al-Laboun, 1988).


A major field mapping program included the Khuff Formation in outcrop conducted in the 1980’s by Bureau de Recherches Géologiques et Minières (BRGM) in
collaboration with the Saudi Geological Survey [formally the “Saudi Arabian Deputy Ministry for Mineral Resources (DMMR)”], examined the lithostratigraphy, sedimentology and biostratigraphy in central Saudi Arabia.


A comprehensive sedimentological and micropaleontological study of the Khuff B and C Carbonates, with isotope analysis was completed on 18 wells in ‘Ain Dar, Shedgum and ‘Uthmaniyah by Hughes et al. (2003). This work enabled a sequence-based series of paleoenvironmental maps to be compiled. Hughes (1995, 2000, 2003, and 2005) studied the Khuff biostratigraphy, micropaleontology and palaenvironment in both surface and subsurface.

Al-Aswad (1997) proposed the interpretation of the sedimentary environment, the depositional evolution, and sequence stratigraphy of the Khuff Formation in the south-central outcrop, Saudi Arabia.

Al-Dakhil and Kamal (2000) developed a lithostratigraphic-based six-layer scheme for the Khuff C carbonates in central and southern Ghawar field, which were defined to the larger extent on density, neutron, gamma-ray wire line log curves, and secondarily
using thin-section petrography plugs for constraining the lithological picks. This enabled
the first pass assessment of reservoir quality and distribution for each layer.

Al-Eid (2000) divided the Khuff B reservoir in the subsurface of the Hawiyah Area,
in Ghawar Field, into seven layers, defined various diagenetic facies and proposed their
diagenetic pathways; and constructed a geostatistical predictive model of reservoir
quality facies distribution in the Hawiyah Area.

Sharland et al., (2001) compiled a synthesis from published data and provided a
chronostratigraphic and tectonostratigraphic evolution of the Late Precambrian and
Phanerozoic sedimentary succession of the Arabian Plate (AP). The study identified
eleven tectonostratigraphic megasequences separated by major unconformities and sixty
three Maximum Flooding Surfaces (MFS). The Khuff Formation is assigned to the
lower part of the Arabian Plate megasequence AP6 which extends from the mid Permian
Pre-Khuff unconformity to the upper Marrat Formation, of Early Jurassic age.

Vaslet et al. (2005) presented a regional synthesis of previous and new
lithostratigraphic and biostratigraphic data collected from outcrops of the Khuff
Formation, and presented it in a chronostratigraphic and sequence stratigraphic
framework. The study extended stratigraphically from below the Pre-Khuff
Unconformity to the Sudair/Khuff Boundary, geographically along N-S outcrop region of
about 1,200 km; the study also included several sub-crop wells.

Where most of this previous work is lithostratigraphic-based, this study is
sequence-stratigraphic-based. Unlike the previous sequence stratigraphic subsurface
studies in Ghawar, this study covers the entire Triassic Khuff Carbonates continuously
along a four-well traverse in the Haradh Area. The previous sequence stratigraphic
subsurface studies did not address the complete Triassic Khuff stratigraphy, but instead they covered Khuff A and B carbonates separately.

Finally, several carbonate sedimentologists, in Saudi Aramco, studied the stacking patterns and sequence stratigraphic framework of Khuff C, B, and A from core and wire line logs in Ghawar Field, and identified the sequence boundaries marked by the development of various exposure features expressed by paleosol and karst development, however, a greater emphasis was given to the Permian Khuff C. Most of these studies were not published, but this author would like to recognize their contribution. These sedimentologists are: Markenllo (1988), Barnaby (2000), Al-Tawil (2000-2007), Mayer (2001-2002), Al-Eid (2001-2007), and Al-Dukhayyil (2001-2007).