AIN SHAMS UNIVERSITY
Faculty of Science
Geology Department

TECTONIC CONTROL ON THE ARAB-D RESERVOIR HYDRODYNAMICS IN THE EAST ARABIAN HYDROCARBON PROVINCE

By

Mohammed Jaber Abdullah Al-Mahmoud
B. Sc. in Geology, King Saud University
M. Sc. in Geology, King Fahd University for Petroleum and Minerals

A Dissertation Submitted to
AIN SHAMS UNIVERSITY, FACULTY OF SCIENCE,
GEOLOGY DEPARTMENT

for the requirements of the degree of
Doctor of Philosophy of Science
(Geology)

GEOLOGY DEPARTMENT
FACULTY OF SCIENCE
AIN SHAMS UNIVERSITY

2009

Approval Sheet

Tectonic Control on the Arab-D Reservoir Hydrodynamics in the East Arabian Hydrocarbon Province

By
Mohammed Jaber Abdullah Al-Mahmoud
B. Sc. in Geology, King Saud University
M. Sc. in Geology, King Fahd University for Petroleum and Minerals

A Dissertation
Submitted for the requirements of the degree of

Doctor of Philosophy
(Geology)

Geology Department
Faculty of Science
Ain Shams University

Advisors **Approved**

Prof. Dr. Adel R. Moustafa
Professor of Structural Geology
Geology Dept., Faculty of Science, Ain Shams Univ. _____

Dr. Mesbah H. Khalil
Geological Consultant, Exploration, Saudi Aramco _____

Prof. Dr. Adel R. Moustafa
_____
Head of Geology Department

ACKNOWLEDGEMENTS

Thanks to Allah for making possible to complete this work as planned.

I am indebted to Prof. Dr. Adel R. Moustafa (Geology Department, Faculty of Science, Ain Shams University), and Dr. Mesbah H. Khalil (Exploration Department, Saudi Aramco) for guiding this dissertation in the direction of my strengths, and managing, with superior effectiveness, the progress of my accomplishments. Their advices during the field and office work and their efforts in making critical reviews of the manuscript are unforgettable.

I thank the Geology Department, Faculty of Science, Ain Shams University for the support of this dissertation.

I am indebted to Saudi Aramco for providing the subsurface data and supporting the field work. Special thanks are due to Mr. Abdulla A. Al-Naim (V.P., Exploration), Mr. Ibrahim M. Assa'adan (General Manager, Drilling), Mr. Ali Y. Al-Hauwaj (Manager, Area Exploration Department), Bassam H. Bahabri (Chief Geologist, New Exploration Opportunities Division), and Mohammed I. Faqira (Chief Geologist, Pore Volume Assessment Division) for their continuous support and encouragement.

Finally I express forever, my love and gratitude to my family for their deep love and devotion, and for their unlimited patience during my work on this dissertation.

ABSTRACT

The present study aims at investigating the role of tectonic activities in and around the east Arabian hydrocarbon province in defining the regional and local hydrodynamics of the Upper Jurassic Arab-D reservoir.

The tectonic activities in eastern Saudi Arabia have resulted in the generation of geologic structures that have affected all reservoirs. Eastward and northeastward regional dipping, faults, and folds are the main structures that can be observed on surface and subsurface geologic maps. The published hydrogeologic maps indicate that such structures have probable effects on the groundwater flow in the Tertiary aquifers; however, such effects were not studied for any reservoir in Saudi Arabia. This observation has inspired the interest in evaluating the effects of these structures within the context of the tectonic phases that generated them on the groundwater flow in the Arab-D reservoir; the main oil-producing zone in Saudi Arabia. To conduct this evaluation, the present study followed a structured methodology based on mapping and characterizing these structures and reservoir hydrodynamics of the Arab-D at regional scale and in selected local areas and interpreting the groundwater flow in the light of the characteristics of the mapped structures. Specifically, the study included review of all published literature on the stratigraphic and structural settings of the Arab-D reservoir within the context of the geologic framework of the Arabian plate, generation of regional maps showing major structures, conducting field work on selected structures, using the available subsurface data to generate maps for local structural models, constructing regional and local hydrodynamic maps, and

interpreting all generated maps in an integrated approach to reveal the relationship between the structures and groundwater flow.

The present study establishes the regional hydrodynamic characteristics of the Arab-D reservoir in eastern Saudi Arabia for the first time. The hydrodynamic maps show that the groundwater in the Arab-D reservoir flows from the west margins of the Arabian basin at central Saudi Arabia and the eastern margins at Zagros Mountains towards the deeper parts of the basin in and near offshore Saudi Arabia.

Two tectonic phases have affected the reservoir hydrodynamics of the Arab-D; the Late Jurassic extensional phase and the Late Cretaceous to present compressional phase.

During the Late Jurassic extensional phase, the Arabian intra-shelf basin, which extends over eastern Saudi Arabia, was created and became the primary controller of the cyclic deposition of the carbonate and anhydrite units of the Arab Formation of which the Arab-D reservoir is the lower member. The non-permeable anhydrite at the top of the Arab-D member became a top seal for the underlying permeable carbonates resulting in the formation of a regional flow unit known as the Arab-D reservoir. The deeper parts of the Arabian intra-shelf basin have continued to exist in eastern Saudi Arabia since it was created. This has caused the groundwater to flow from the flanks of the basin in central Saudi Arabia in a down-dip direction towards eastern Saudi Arabia.

During the Late Cretaceous to present compressional phase, the uplifting of the Zagros and Oman mountains, the regional eastward tilting of

Arabian Plate, the reactivation of the existing north-south faults, and the formation of the Central Arabian graben system have impacted the Arab-D hydrodynamics in several ways. The formation of the Zagros and Oman mountains and eastward tilting of the Arabian Plate created the present-day shape of the hydrogeologic basin in eastern Saudi Arabia. In this basin, the groundwater flows from the structurally and topographically high lands in central Saudi Arabia, Zagros and Oman mountains to the low lands in eastern Saudi Arabia. The reactivation of the north-south faults has generated faults in the Arab-D reservoir. These faults have fault core zones with calcite-filled fractures or fault breccia that act as barriers to groundwater flow surrounded by damage zones with open fractures that act as conduits for groundwater flow. These fault characteristics are responsible for the deflections in groundwater flow directions along the north-south faults such as the Ghawar and Khurais fields, the connectivity between the Arab-D and deeper reservoirs such as in south Haradh and Abqaiq field, and the flow of groundwater in the transfer zones between faults in west Khurais and Ghawar fields. The Central Arabian graben system formed an east-west corridor of intensively fractured rocks which became a fast track for groundwater flow from the Arab-D outcrops in central Saudi Arabia towards deep areas of the hydrogeologic basin in eastern Saudi Arabia.

CONTENTS

LIST OF FIGURES