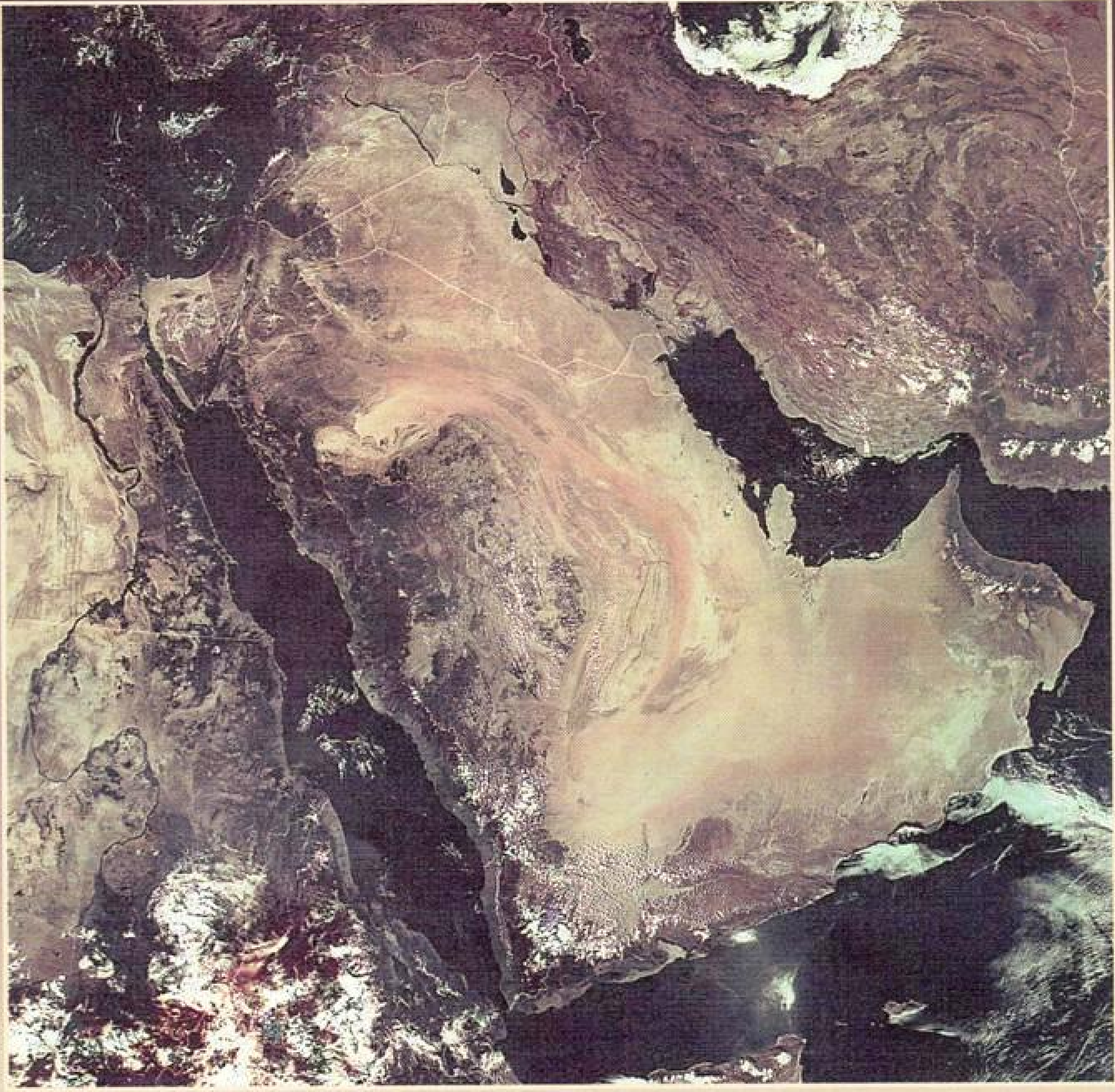
SEPM Special Publication No. 69

Middle East Models of Jurassic/Cretaceous Carbonate Systems



Edited by

A.S. Alsharhan and R.W. Scott

2000

SEPM greatly acknowledges the following for their generous contributions to
Middle East Models of Jurassic/Cretaceous Carbonate Systems

Badley Ashton and Associates, Ltd.

BP Kuwait

Vrije Universiteit Industrial Associates in Sedimentology Research Grant

ISBN 1-56576-075-1

SEPM (Society for Sedimentary Geology)
1741 E. 71st Street
Tulsa, OK 74136-5108
Printed in the United States of America

CONTENTS

Introduction

Part 1: Sequence Stratigraphy, Chronostratigraphy, and Tectonic Influences

Part 2: Depositional and Diagenetic Models of Carbonate Platforms

Part 3: Hydrocarbon Habitat and Exploration/Development Case Studies

INTRODUCTION: MIDDLE EAST MODELS OF JURASSIC/CRETACEOUS CARBONATE SYSTEMS

ABDULRAHMAN S. ALSHARHAN
Faculty of Science, United Arab Emirates University, P.O. Box 17551, Al Ain, U.A.E.
AND
ROBERT W. SCOTT
Precision Stratigraphy Associates, RR3 Box 103-3, Cleveland, OK 74020, U.S.A.

This volume is the product of the international conference on "Jurassic/Cretaceous Carbonate Platform–Basin Systems, Middle East Models" that was convened in December 1997 jointly by SEPM (Society for Sedimentary Geology) and the United Arab Emirates University in the oasis city of Al Ain, United Arab Emirates (U.A.E.). The concept of this meeting had its roots in the Carbonate Platform Working Group of the Cretaceous Resources, Events and Rhythms Project (CRER), which first convened in 1988 (Ginsburg and Beaudoin, 1990). In order to pursue the CRER goals, the 1997 conference objectives were: (1) to promote and disseminate research on geological and geophysical studies of carbonate platforms in the Tethyan Realm; (2) to provide access to the superb outcrops of the famous Jurassic–Cretaceous platforms and the classic Holocene coastal sabkha of the Arabian Gulf; (3) to promote the interaction between research and exploration/production geoscientists in the region and worldwide; and (4) to demonstrate the interaction of SEPM, academia, and industry personnel as a global community of geoscientists.

The 125 attendees came from four continents; just over 50% were from the Middle East region. Nearly 70% were from the petroleum industry and 30% were from universities or research and consulting groups. Abstracts of the oral and poster presentations were published in the December, 1997, issue of *GeoArabia*, v. 2, no. 4. The conference was summarized by Scott et al. (1998a, b).

The geologic development of the Arabian Platform was closely related to tectonic and sedimentologic processes in the adjacent areas, so that knowledge of the Arabian region informs and constrains hypotheses of the adjacent areas. Today the Arabian Platform is an independent plate locked between the Zagros Mountains suture zone to the northeast in Iran, the Anatolia plate to the north in Turkey, the Red Sea rift to the southwest, and the spreading center in the Gulf of Aden to the southeast (Glennie, 1995). During the Jurassic and Cretaceous Periods, however, the Arabian Platform was attached to the northeastern margin of Africa and straddled the Equator (Smith et al., 1994). In this position it recorded depositional processes upon a low-relief shelf in the tropical zone where mixed clastics and carbonates–evaporites were deposited both laterally and iteratively through time. This geographic position between the Mediterranean–Atlantic oceans to the west, the Indian plate to the south, and the Pacific Ocean to the east allowed this area to experience the migration of diverse biota from several centers of evolution.

During much of the Mesozoic Era shallow shelf deposystems were the norm upon the Arabian Platform, and slope deposition rimmed the passive margin located to the present-day northeast (Murris, 1980). Sometime between the Turonian and Campanian obduction of oceanic crust began along the modern eastern margin (Glennie, 1995). By the latest Campanian–earliest Maastrichtian, slabs of ophiolitic oceanic crust were emplaced upon the eastern margin of the Arabian platform, forming the base of the Oman Mountains. During the Maastrichtian a foreland basin developed along this margin and carbonates buried the ophiolites. Shallow marine deposition resumed during Paleogene time, and during the Oligocene the Oman Mountains were uplifted. Possibly as recently as ten million years ago subduction closed the post-Triassic seaway, Neo-Tethys 2, between the Sirjan–Sanandaj Zone and Central Iran/Lut microcontinent (Glennie, 1995). This brought together along the Zagros Crush zone the Zagros Mountains, which were the leading margin of the Arabian platform, and the Sirjan–Sanandaj microcontinent, thus welding together Arabia and Asia. The Arabian Gulf was flooded during the Pliocene following this collision.

The Arabian platform is significant also because it contains approximately two-thirds of the world's recoverable oil reserves and about one-third of the recoverable gas reserves (Beydoun, 1998). Most of these resources are produced from seven nations: Saudi Arabia, Iraq, Kuwait, Iran, Qatar, the United Arab Emirates (U.A.E.), and Oman. Several factors have converged in this region that resulted in the concentration of hydrocarbons (Alsharhan and Nairn, 1997; Beydoun, 1998). (1) Giant volumes of high-quality source rocks are illustrated by the Upper Jurassic Diyab Formation in the paper by Al-Suwaidi et al. (this volume). (2) The geographic continuity of the northeast Arabian shelf margin for a distance of over 2500 km and its great width up to 2000 km created conditions favorable to widespread deposition of source rocks and reservoirs. (3) The history of sedimentation was uninterrupted for much of the Mesozoic during the passive-margin stage of the Arabian platform; several papers in this volume describe sedimentation from Late Jurassic to end of the Cretaceous. (4) Source rocks are juxtaposed with reservoir rocks, such as the Upper Jurassic Arab Formation and the Aptian Shuaiba Formation described by several papers in this volume. (5) Tertiary salt movement and Neogene tectonics during development of the Zagros foreland basin formed folds and produced fractures and stylolites that enhanced permeability. Fractured and stylolitic reservoirs are described in this volume by Alsharhan and Sadd and by Saotome et al. (6) Finally, the paleolatitudinal position of the Arabian platform changed from the Cambrian to the present, thereby influencing the several factors essential to development of diverse petroleum systems (Beydoun, 1998).

The conference was a dynamic exchange of ideas as well as of data, which has been the mode of meetings of the CRER Carbonate Platform Working Group. The present set of papers is the third publication resulting from these meetings. The two previous publications were edited by Simo, Scott, and Masse (1993) and Philip and Skelton (1995). The papers for this book were selected from the conference oral and poster presentations to document new data and present interpretations on the sequence stratigraphy, diagenesis, depositional models, chronostratigraphy, and reservoir characterization of Jurassic and

Middle East Models of Jurassic/Cretaceous Carbonate Systems
SEPM Special Publication No. 69, Copyright © 2000
SEPM (Society for Sedimentary Geology), ISBN 1-56576-075-1, p. 3–6.

Cretaceous carbonates of the Middle East. A number of key themes were emphasized during the meeting and also continue through this volume.

Sequence stratigraphers are cautious of circular reasoning. Uncritical "correlations" with a global cycle chart may result in unwarranted age assignments, as well as lending false credibility to the theory of eustatic control. Practitioners in this volume recommend the separation of sequence stratigraphic correlations from the global cycle chart, and the compilation of local sequence stratigraphy into a local cycle chart before attempting global correlations. The role of seismic data in sequence stratigraphy is clearly critical, although it must be tied to core, outcrop, and/or log data. Evaluation of "surfaces", such as paleosols caused by subaerial exposure, or hardgrounds resulting from marine drowning, or stylolites by diagenesis is also essential to sequence stratigraphic analysis.

The classic image of stratigraphic dating is that of the lone biostratigrapher working at a microscope; however, this image has been replaced by the "chronostratigraphic team", which integrates multiple technologies and data sets. The challenge now is how to define time lines with greater precision. High-resolution correlations must utilize chemostratigraphy, paleoecology, and cyclostratigraphy together with biostratigraphy to test whether sequence surfaces indeed are time lines. Biostratigraphy must be used to calibrate chemostratigraphy and cyclostratigraphy, because the sedimentary cycles are not uniquely identified. Biostratigraphic analyses may be facilitated in the near future by automated computerized intelligent systems that achieve preliminary microfossil identifications.

The papers in this volume highlight the need for a regional correlation project of Middle Eastern Jurassic and Cretaceous carbonates. Such a project has the potential to contribute to the measurement of tectonic subsidence rates and the scales and durations of hiatuses, factors that must be known for any kind of modeling. For example, the amplitude of relative sea-level cycles is pertinent to reservoir modeling.

Understanding diagenesis is also critical to estimating hydrocarbon reserves and recovery. Even when our predictions of the location of porous grainstones, organic-rich facies, and effective regional seals and traps are accurate, diagenesis can still make or break a prospect. Seals may be breached, source rocks may not be mature or may have matured before traps were developed, and primary porosity may have been destroyed by cementation or compaction. Alternatively, primary porosity may be enhanced by dissolution, dolomitization, or fracturing, and porosity zones may be isolated by cementation. Many diagenetic trends are controlled by depositional facies or structural trends. Once we understand the diagenetic effects, the relationships between controls of primary facies and structure and the geophysical or log responses can be understood, then predictions will be more effective. Exploration and production teams and research teams must be brought together to generate new ideas and improve their practical application to the carbonate reservoirs and to enhance recovery in various Middle East fields.

The papers were selected for this volume in order to illustrate some of these generalizations and are organized under three themes: sequence stratigraphy, chronostratigraphy, and tectonic influences; depositional and diagenetic models of carbonate platforms; and hydrocarbon habitat and exploration/development case studies. A synopsis of each paper follows and serves to highlight the contributions of each.

Section 1 shows that sequence stratigraphic and chronostratigraphic models can be tested by Middle East carbonate examples. It begins with a review of the tectonic evolution of the Middle East (Glennie, this volume), which shows that the eastern margin of the Arabian platform was passive from Late Permian until earliest Cretaceous time, when the Late Permian spreading center, Neo-Tethys 1, evolved into a subduction zone and a second spreading center, Neo-Tethys 2 formed, separating central Iran from the Arabian platform. Mid-Cretaceous plate tectonic movement of the Arabian platform established regional tectonic features that affected structural development and sedimentation in the region.

The 800-meter-thick shallow-water Middle Jurassic section in the Musandam Peninsula, U.A.E., and Oman can be directly correlated into the subsurface of the U.A.E. de Matos and Walkden (this volume) use the ammonites and foraminifers to identify the standard stage boundaries in the region, and they clarify the lithostratigraphy. Walkden and de Matos (this volume) show that subaerial exposure contacts separate the Lower Jurassic section of the Musandam Peninsula into meter-scale cyclothems that reflect sea-level changes at the scale of Milankovitch climatic frequencies. The facies are clues to the depositional processes, and the diagenetic changes significantly affect reservoir character.

The uppermost Jurassic of the Arabian platform is well exposed in central Lebanon, where the sequence stratigraphic succession serves to document long-term depositional cycles. Toland (this volume) defines two unconformity-bounded sequences in the Tithonian section and suggests a correlation with part of the Arab Formation in the subsurface of the U.A.E. and Saudi Arabia. The top of the second sequence is a prominent paleo-karst contact overlain by Cretaceous clastics.

Both the Lower Aptian Shuaiba Formation carbonate in the U.A.E. and a Lower Aptian clastic unit in Alaska consist of ten shoaling-up cycles (Kendall et al., this volume). Their onlapping shelf geometries are similar to geometries of the Bahamian Neogene sections, which record high-frequency eustasy. By dynamic forward modeling of sedimentary fill of the Shuaiba Basin, U.A.E., these authors show that the seismic sequence geometry can be used as input to a published sea-level curve. The modeling tests the timing and magnitude of the processes.

Using the quantitative stratigraphic technique of graphic correlation, Scott et al. (this volume) test the synchroneity of depositional cycles in Oman relative to those defined elsewhere in the Tethyan Realm. Nine cycles are recognized in each of the Albian Nahr Umr and Cenomanian Natih Formations, Oman. These may indeed be eustatic, because most cycles in the Oman section are the same age as cycles elsewhere. Sediment accumulation rates increased progressively from the Albian to the Cenomanian from 1 to 5 cm/1000 years.

Skelton and Masse (this volume) describe Lower Cretaceous rudists of the region and for the first time relate them to Tethyan assemblages. They present the data in a way that enables all stratigraphers to identify and utilize rudists for correlation and environmental analyses of cores and outcrops.

Section 2 includes eight papers about depositional and diagenetic models. The Middle East Mesozoic section exhibits a wide variety of depositional and diagenetic models of carbonate platforms. Middle Jurassic oncoids in the northern Sinai, Egypt, were formed as Mg-calcite in a shallow shelf environment (Holail, this volume). Diverse geochemical data, including depletion of oxygen isotopes, suggest subaerial exposure and meteoric diagenesis.

Berriasian–Hauterivian carbonates are exposed in central Saudi Arabia (Shebl and Alsharhan, this volume). Microfacies of the Sulaiy, Yamama, and Buwaib formations represent open-platform and shelf-lagoon conditions. Regional unconformities separate Valanginian, Hauterivian, and Barremian strata. These disconformities separate mudstone and wackestone below from coarse siliciclastic rocks above.

Microfacies of the Maastrichtian Simsima Formation in northwestern Oman represent the final Cretaceous carbonate platform stage with rudists, corals, algae, and larger foraminifers (Alsharhan et al., this volume). The Simsima Formation is divided into two longer-term depositional cycles that have numerous subaerial exposure contacts at bedding planes within it. Multiple diagenetic processes modified the porosity greatly.

The spectacular Upper Cretaceous rudist biostromes in Oman represent widespread platform paleocommunities that Schumann (this volume) traces across outcrops separated by many kilometers. The rudist communities are monospecific associations of constratal *Vaccinites* that developed in restricted conditions during regional transgressions and did not form reefs because of abiotic factors. Colonial corals with clinger radiolitids are common below and above the *Vaccinities* beds and formed biostromes in a slightly deeper environment than the *Vaccinites* beds.

The Middle to Upper Jurassic shallow marine carbonates in Yemen experienced diverse stages of diagenesis (synsedimentary, shallow burial, deep burial, and uplift diagenesis) that resulted in its reservoir potential (Al-Thour, this volume). Dolomite formed during the latter three stages and dedolomitization operated during weathering oxidation. The Aptian Shuaiba Formation consists of two major reservoirs in the Ghaba North Field, Oman (Al-Awar and Humphrey, this volume). The lower reservoir zone consists of facies deposited in a marine environment with restricted circulation, whereas the upper zone represents open shallow marine conditions. Together they constitute a longer-term, shoaling-up cycle with a regional unconformity at the top. These heterogeneous reservoirs produce from secondary macroporosity, fracture porosity, and intercrystalline microporosity. Meteoric dissolution as indicated by stable isotopes was facilitated by repeated subaerial exposure. Three stylolite types affect the performance of Lower Cretaceous carbonate reservoirs in the U.A.E. (Alsharhan and Sadd, this volume). Stylolites are more abundant toward the flanks of producing fields, and most are subparallel to bedding, indicating burial compaction.

Ten repetitive hardground surfaces in the mainly Albian Nahr Umr Formation developed by meteoric exposure and subsequent marine overprinting (Immenhauser et al., this volume). They are reliable correlation markers in Oman, and they are recognized by the integration of stratigraphic, petrographic, and geochemical evidence.

In Section 3, Middle East hydrocarbon habitat and reservoir case studies provide models for other carbonate basins. Lateral variations in thickness and lithology of Upper Jurassic rocks resulted from sea-level changes, local structure, and spreading of the Neo-Tethys (Ayoub and Ennadi, this volume). About 75% of the present structural configuration in onshore U.A.E. is the result of Late Cretaceous compression produced by overthrusting in Oman. Gas was generated in the Upper Jurassic Hanifa Formation during subsequent subsidence in the U.A.E.

The Upper Jurassic Diyab Formation in the U.A.E. has a basinal lime mudstone facies that sourced reservoirs in the Arab Formation and in the Thamama Group (Al-Suwaidi et al., this volume). The facies of the Diyab change westward, landward in Abu Dhabi to oolitic packstone and grainstone. The authors present new geochemical data to define oil types and propose timing and migration routes from several source rocks in Abu Dhabi. Generation began in the Late Cretaceous.

Davies et al. (this volume) use sequence stratigraphic geometries and stacking patterns to develop reservoir models of the Berriasian–Valanginian Minagish Formation in the Umm Gudair Field, Kuwait. Ten lithofacies suggest deposition on a homoclinal carbonate ramp. Reservoir facies with micritic microporosity are present in most systems tracts. Parasequences are separated by flooding contacts, and stratal stacking influenced the development of intraformational flow barriers and reservoir compartmentalization.

Pore geometry of the Barremian upper Kharaib reservoir in offshore U.A.E. is a result of original depositional fabric and subsequent diagenesis (Saotome et al., this volume). Producing facies are rudist–peloidal grainstone/packstone, algal–peloidal grainstone/packstone, and bioclastic wackestone/mudstone deposited on a carbonate shelf in a shoaling-up succession. Unique pore-throat distributions resulted from depositional textures and dolomitization. Facies and pore-throat distributions were the basis for a detailed reservoir simulation.

The Shuaiba Formation in the U.A.E. is a major reservoir and also records Early Aptian depositional processes. Alsharhan et al. (this volume) demonstrate by means of well logs, petrography, and geochemical analyses that porosity was mainly controlled by diagenesis during early shallowing and later deeper burial. The basinal facies of the Bab Member of the Shuaiba Formation is demonstrated to be a mature source rock that has generated hydrocarbons in the basin. Stable-isotope values of the cement are more depleted than those of the matrix.

Cretaceous sequence stratigraphy in the Mesopotamian basin of southern Iraq was controlled by the culmination of the Neo-Tethys rifting, the movement of the Arabian Platform into the tropical and subtropical climatic zones, and the contemporaneous growth of salt structures (Sadooni and Aqrawi, this volume). Reservoirs were formed within clastic deposits that are intercalated with carbonate platform deposits.

The final paper, by Alsharhan and Scott (this volume), presents a summary of the basins in the eastern Arabian platform and describes many of the reservoir types. The U.A.E. is bounded by structurally positive features on the northwest and on the east. Since the Permian two passive-platform-margin basins developed. Sedimentation in these basins has consisted of epeiric shelf carbonates and minor evaporites and clastics, reflecting long-term and short-term depositional cycles resulting from the interplay of tectonics and eustasy. Oil and gas reserves are in reservoirs of shallow-water Jurassic and Cretaceous carbonates. The source rocks are deep-water shale and argillaceous limestone sealed by evaporites, dense limestone, and shale.

The editors express their appreciation to the SEPM editor of Special Publications, Robert W. Dalrymple, for his guidance and support of this publication. We thank our colleagues for affording us part of their valuable time reviewing manuscripts to make this set of papers more technically sound. They include I. Al-Aasm, I.A. Al Jallal, D. Bosence, R. Bray, D. Budd, M. Cassidy, J.M. Connan, J. de Matos, J.A.D. Dickson, M. Esteban, A.J. Everts, P.C. Franks, E. Gili, K.W. Glennie, B. Granier, R. Handford, P.M. Harris, R. Höffling, J. Hopkins, G. Hughes, R. Hulstrand, A. Immenhauser, R.W. Jones, C.G.St.C. Kendall, C. Kerans, A. Kirkham, R. Koepnick, J. Kuss, L.S. Land, A. Lomando, R. Loucks, J.-P. Masse, S.J. Mazzullo, P. Nederlof, E. Oswald, J. Philip, J.M. Pons, B. Pratt, D. Prezbindowski, A. Saller, D. Schumann, A.J. Simo, P. Skelton, J. Smewing, A. Smith, A. Strasser, V. Vahrenkamp, F. Van Buchem, and G. Walkden.

The editors express their profound thanks to all contributors to this volume for their support, cooperation, promptness, and patience improving the manuscripts. Special thanks are due to SEPM and the United Arab Emirates University for co-sponsoring the conference from which this volume arose. The University has allowed our participation in this undertaking and supported its successful completion in many ways. For processing the manuscripts, we are particularly grateful to the essential administrative assistance of Ms. Bonita Valdez-Cruzada and Ms. Girija Bhaskaran.

We would like to express our gratitude and appreciation to His Highness Sheikh Nahyan Mubarak Al Nahyan, Minister of

Higher Education and Scientific Research and Chancellor of the U.A.E. University, for his guidance and support during the planning and running of the conference and for his encouragement to create this publication.

As editors, it is our privilege to present this volume to all of you. It is a worthy publication for geoscientists working in the Middle East and comparable areas around the world.

Abdulrahman S. Alsharhan, Al Ain, U.A.E.
Robert W. Scott, Cleveland, Oklahoma, U.S.A.

REFERENCES

ALSHARHAN, A.S., AND NAIRN, A.E.M., 1997, Sedimentary basins and petroleum geology of the Middle East: Amsterdam, Elsevier Science, 843 p.

BEYDOUN, Z.R., 1998, Arabian Plate oil and gas: Why so rich and so prolific?: Episodes, v. 21, p. 74–81.

GINSBURG, R.N., AND BEAUDOIN, B., 1990, Cretaceous Resources, Events and Rhythms: Background and Plans for Research: NATO ASI series C, Mathematical and Physical Sciences, v. 304: Dordrecht, The Netherlands, Kluwer Academic Publishers, 352 p.

GLENNIE, K.W., 1995, The Geology of the Oman Mountains: An Outline of Their Origin: Beaconsfield, Bucks, UK, Scientific Press Ltd., 92 p.

MURRIS, R.J., 1980, Middle East: Stratigraphic evolution and oil habitat: American Association of Petroleum Geologists, Bulletin, v. 64, p. 597–618.

PHILIP, J., AND SKELTON, P.W., 1995, Palaeonenvironmental models for the benthic associations of Cretaceous carbonate platforms in the Tethyan Realm: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 119, p. 1–199.

SCOTT, R.W., ALSHARHAN, A.S., AND ENOS, P., 1998a, Jurassic/Cretaceous carbonate platform–basin systems — Middle East models: Episodes, v. 21, p. 39.

SCOTT, R.W., ALSHARHAN, A.S., AND ENOS, P., 1998b, Jurassic/Cretaceous carbonate platform–basin systems — Middle East models: Episodes, v. 21, p. 361–362.

SIMO, J.A., SCOTT, R.W., AND MASSE, J.-P., 1993, Cretaceous Carbonate Platforms: American Association of Petroleum Geologists, Memoir 56, 479 p.

SMITH, A.G., SMITH, D.G., AND FUNNELL, B.M., 1994, Atlas of Mesozoic and Cenozoic Coastlines: Cambridge, UK, Cambridge University Press, 99 p.