Springer Geology

Jai Krishna

The Indian Mesozoic Chronicle

Sequence Stratigraphic Approach

Springer

Springer Geology

More information about this series at http://www.springer.com/series/10172

Jai Krishna

The Indian Mesozoic Chronicle

Sequence Stratigraphic Approach

Springer

Jai Krishna
Former Professor and Head
Centre of Advanced Study in Geology
Institute of Science
Banaras Hindu University
Varanasi, Uttar Pradesh
India

ISSN 2197-9545 ISSN 2197-9553 (electronic)
Springer Geology
ISBN 978-981-10-2476-4 ISBN 978-981-10-2477-1 (eBook)
DOI 10.1007/978-981-10-2477-1

Library of Congress Control Number: 2016952005

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #22-06/08 Gateway East, Singapore 189721, Singapore

To the memory of my loving revered parents, Shyama and Parashuram, whose human values, upbringing, and guidance transformed me to what I am today at the youthful age of 71, and whatever little substance, endurance, and positivity I could realize in academics and personal life.

Foreword

No other era in the geological history of the earth was more significant and exciting than the Mesozoic. The Permian end witnessed the most pronounced extinction of life, when approximately 90–95 % of marine life and 70 % of terrestrial life perished. Thus in a way, life once again evolved almost from scratch during the Triassic, the oldest period of the Mesozoic. There was proliferation and rapid evolution of conodont animals and of ammonoids, appearance of dinosaurs and coral reefs. Initially, the Triassic sea is believed to have been shallow; it rapidly deepened in Early Triassic, followed by shallowing, particularly after the Carnian.

During the Jurassic, the conodont animals disappeared though preponderance of ammonoids continued. The first bird *Archaeopteryx* appeared, *Pterosaurs* ruled the sky, and other dinosaurs dominated the land, rise in sea level caused transgression in several parts of the peninsula, the sea level kept on fluctuating. There was lush growth of forests.

The Cretaceous marked breakup of the Gondwana land, rise in the sea level and incursion of sea in the peninsular and the Lesser Himalayan parts, major volcanic activity, and another event of extinction of life which included majestic dinosaurs. India, like a Noah's Ark, with its southern fauna and flora, embarked on its long northward journey.

Paleontologic, sedimentologic, paleogeographic, volcanic, basinal, and tectonic aspects of the Indian Mesozoic succession have been studied by various researchers in fairly great detail, but mostly in isolation. What has lacked is identification of mega-sequences and their further differentiation, integration of fauna within the ambit of sequence stratigraphy and erection of regional sequence stratigraphic framework by utilizing the ammonoids in précising the surfaces and correlating these with the regional surfaces and events. An assimilation of updated various geologic elements and their unbiased synthesis to seek whether the evolutionary changes, tectonics, sea level fluctuations, and evolving sedimentologic framework were independent or closely linked and formed part of one story. In other words, erecting the sequence and event stratigraphy based on detailed lithology and paleontology to reconstruct a holistic view of the geological history of the Indian

Mesozoic. This exercise could be attempted only by someone who has an intimate knowledge of various aspects of the Mesozoic history, not only of India but also of the world, particularly the Gondwana Land.

There could be no person better than Prof. Jai Krishna to attempt this kind of synthesis. He has spent more than five decades meticulously studying the Jurassic sequences in India along with his dedicated team. He often educated me with his views regarding the regional evolution of basins inter-alia tectonics and evolution of life. Most impressive was his effort to correlate poorly fossiliferous/ unfossiliferous sequences on the basis of regional sequence stratigraphic context. I am glad that after relinquishing the sponsored teaching and research, Prof. Jai Krishna decided to synthesize various aspects of the Indian Mesozoic inclusive of comparison with other basins between Arabia and Australia. The book "The Indian Mesozoic Chronicle: Sequence Stratigraphic Approach" would be encyclopedic in nature and useful to the students, teachers, researchers, and petroleum geoscientists in the educational institutions and industries.

O.N. Bhargava

Preface

Time to time in the past two decades, my research collaborators in India and abroad, also others passionately involved in the progress of Indian geology, even students in India, particularly at BHU, desired of me a book on my comprehension of the Indian Mesozoic sequences. Near my formal retirement in 2010 came 'The Making of India', an immensely inspiring magnum opus on Indian Geology, written by my revered guru (teacher) Prof. K.S. Valdiya. This also kindled the fire in me to go for an exciting post-retirement innings. Once formally free from teaching and sponsored research in 2014, I began scribbling my comprehension of the Kachchh Mesozoic. As I continued mostly in early morning sessions in Varanasi, Gurgaon, and Bangalore, the canvas of the project went on assuming yet larger dimensions than originally contemplated to engulf the entire Gondwanian Tethyan Margin from Arabia to Australia.

The whole array of integrated progress in the Indian Mesozoic geology, realized since my initiation in the Indian Mesozoic in the mid-1960s, is interwoven with the innovative threadwork of sequence stratigraphy. The key to the study is development of ammonoid-based high-resolution zonal scales in the Indian Triassic and Jurassic comparable to the best of the world, while the Cretaceous is considerably reinforced with the composite records of ammonoids, foraminifers, dinocysts, and nannoplanktons.

Emphasis is placed primarily to high-quality lithostratigraphic differentiation along with meticulous recording of the sections, bed by bed ammonoid collection in the field, and the resultant ammonoid stratigraphic range charts based upon comprehensive taxonomic studies in the laboratory. The cardinal requisite of good stratigraphic refinement has been the differentiation of a large number of stratigraphically precise ammonoid bearing levels, in several fold larger number of beds in the sedimentary column, to ensure the development of near-optimum number of zones/subzones/horizons as the best measure of quality refinement. The ammonoid-based $\sim$25 zone succession in the $\sim$25 my long Bathonian–Tithonian scale of Kachchh is uniquely developed in a single superfamily—Perisphinctacaea, that too near exclusively in the Kachchh basin.

The author's attraction to sequence stratigraphy stemmed primarily from it being an effective powerful tool to unify the highly kaleidoscopic array of apparently disjunct geological facets strewn over large regions of the like of Indian subcontinent. His understanding of sequence stratigraphy has been an integrated refined chronostratigraphically controlled realistic comprehension of rock relationships of genetically related cyclic strata, units, events, and geological phenomena based on sedimentology, paleontology, eustatics, tectonism, magmatism, and many other such interrelated subdisciplines.

The eventful Mesozoic has been the game changer of the earth's Phanerozoic history, especially in the Indian context. Indian Mesozoic studies have been done mostly in isolation at basinal level, only occasionally extending to specific sectors. Compilations lack the very element of life and dynamism. The Cretaceous in Spiti is seldom related to Cauvery, or to that of Kachchh, or Triassic of Kashmir to that in Myanmar. It is this holistic subcontinental approach that has been endeavoured through the application of sequence surface timelines across the subcontinent and even beyond on the Gondwanian Tethyan margin.

The Indian Late Precambrian–Neogene record is organized into five mega-sequences. The fourth among them—also the most important one—spans through the intra-Permian–intra-Paleocene interval from the origin to the closure of the Neotethys. It is further differentiated into three first-order sequences, 35 second-order sequences, and then several second-order sequences into third-, fourth-, and fifth-order ones. The first-order sequences are developed in Spiti Himalaya (intra-Permian to Pliensbachian), in Kachchh (Toarcian to Barremian), and compositely in Cauvery, Spiti, and Kachchh (Aptian–Paleocene), and subsequently extended on either side of India from Arabia to Australia.

The mega-sequence began with outpouring of the Panjal and coeval volcanics. The first-order sequences are found punctuated by major Gondwana dismemberment extensional tectonics and magmatism at the ~183 ma intra-Jurassic Karoo and coeval volcanism with principal manifestation in the west sector, intra-Cretaceous ~126 ma Rajmahal and coeval volcanism with cardinal expression in the east sector as the intervening first-order SBs. The first-order MFSs, respectively, signal the initiation of oceanization in the northwest spreading away of the Aargo block in northeast at the ~159 ma intra-Oxfordian MFS, and farther up the initiation of spreading between India and Madagascar at the ~92 ma intra-Turonian MFS. The mega-sequence formally closed soon after the termination of Deccan magmatic event, yet notional closure of the Neotethys stretched farther into Paleogene collision of India and Asia.

The validation of the developed first/second-order sequence framework in east and west of India on the Gondwanian Tethyan Margin is realized through comparison with Arabia, East Africa, Madagascar, Pakistan, High Himalaya, Indonesia, Papua New Guinea, Timor, West Irian, and NW Australia. The first- and second-order sequence surfaces are consequences of intra-basinal to inter-regional tectonics and geographically restricted to broad tectono-stratigraphically homogeneous regions of the Gondwanian Tethyan Margin in the present study. The resultant sequence surfaces are often found discordant to those of other such regions, for example, to the Eurasian Tethyan Margin framework. On the contrary, the third- and finer order sequences shorter than ~1.5–2.0 my are governed by earth's orbital dynamics, and thus found globally isochronous.

Comparison of the Indian sequence framework also includes important hydrocarbon-producing regions and basins across the Indian divergent margins both in east and west; and based there upon, a highly positive scenario of the Indian Mesozoic hydrocarbon perspective of source/reservoir rocks is outlined in sequence stratigraphic backdrop as an edifice for elaborate evaluation in near future.

The Indian Mesozoic geological developments irrespective of location in east, north, south, or west sectors, whether in intra-cratonic or peri-cratonic rift basins, frontier or foreland basins, marine or non-marine, guide-fossil bearing or devoid, in carbonate or clastic facies, exposed, onshore, or offshore, deep or shallow, in Indian ocean or South Tibetan collision arena are considered genetically related resultants of the same regional tectonics, allowing correlation of units and chronicle of regional events through the all-pervading sequence surface timelines. So time corresponded the magnetic anomalies, origin, climax, and termination of igneous activities, eustatics, climatic and anoxic events, breakup, dispersal, and collision episodes, rifting, transform sliding, and spreading phases in an alternative innovative sequence stratigraphic context. The single all unifying sequence surface ages are found echoed through highly precise SHRIMP zircon, U/Pb, and Ar40/Ar39 radiometric ages, mega/micro faunal/floral records, and magnetic anomalies through the span of the mega-sequence almost equally strong from all the sectors and varied geological settings of the region as unanticipated strong support to interdisciplinary manifestations of a single spreading framework encircling and engulfing the Indian plate.

In the precision chronicle of the multifaceted happenings at sub-zonal resolution and multiples in east, west, north, and south, the plethora of litho-stratigraphic unit names has been largely done away with and rather made redundant. The large intra-Jurassic stratigraphic gap in Kachchh with increase in duration from margin to basin, has been précised in different sections, and its long held interpretation radically revised from subaerial to submarine all over the GTM from Arabia to Australia. Other major gaps of the Indian geological record are also differentiated as subaerial or submarine. All the formations and members throughout the basin have been precisely age ranged. Ammonoid heterochronic evolution, geography, expansion, and migration events back and forth Indian subcontinent during the Jurassic are also outlined in first- and second-order sequence stratigraphic context.

Ammonoids as guide fossils provide a singular advantage to its researchers. Even a single incomplete fragmented specimen when found, much like the aircraft black-box, starts unfolding the geological history like a time machine on the outcrop itself as if the specimen itself is in a narrative conversation with the discoverer. It is these conversations with ammonoids on the outcrops, and discourses on the ammonoid bearing and coeval Indian Mesozoic sequences in the classrooms, seminars, and conferences, that I, in the form of this book, present unto the learned Mesozoic geoscience and allied scholars, researchers, teachers, and professionals across the world.

Varanasi, India Jai Krishna

Acknowledgements

In the backdrop of not so creativity-conducive Indian post-retirement scenario, the book quite unwillingly has been singly written, yet it incorporates and heavily dwells on the published and unpublished data of joint works with the former research scholars and other collaborators.

At the outset, I salute with immense gratitude all my teachers at the Department of Geology, University of Lucknow, where I learnt the alphabets of geology, in particular late Prof. S.N. Singh who sowed in me the first seeds of paleontology and stratigraphy. Professor Singh not only supervised my Ph.D. thesis but also provided me exemplary lessons to meet the challenges of the worldly sphere. I express my indebtedness to the Banaras Hindu University, my colleagues and students there, amidst whom I could progress in the academic arena. I offer my reverence to the land of Kachchh where I carried on my professional field studies, also my thankfulness to Mr. P.H. Bhatti and family of Bhuj for their diverse help over the decades during my numerous stays there.

I thank in particular Profs. Gerd Westermann, James Howard, Raymond Enay, Elie Cariou, Jacques Thierry, Eric Bueffteau, Guillermo Melendez, Indrabir Singh, and Surendra Kumar, Dr. Syed Jafar, Dr. K.P. Jain, Dr. Rahul Garg, Dr. M. Venkateshwarlu, and many others with whom I coauthored publications. I profusely thank my former research students, Dr. Deobrat Pathak, Dr. Bindhyachal Pandey, Dr. Jairam Ojha, and Dr. Nageshwar Dubey who immensely helped me in field and laboratory in our long yet continuing association. Innumerable colleagues in India and abroad are also thanked with whom I have had fruitful interaction during my umpteen sojourns across India, and outside.

During my travels, particularly, in those young impressionable years, I found myself singularly fortunate to have met and interacted with stalwarts of the world geological arena who may have made impressions and germinated seeds on my then young mind, and to whom, of the like of Profs. C. Roy, D.N. Wadia, W.D. West, M.R. Sahni, B.P. Radhakrishna, Rajnath, G.W. Chiplonkar, F.J. Pettijohn, G. Middleton, Tuzo Wilson, A. Gansser, Dennis Shaw, John Talent, T. Matsumato,

C. Egeler, Henry Tintant, B. Ziegler, A. Seilacher, and many others, I very pridefully remember at this juncture.

I am grateful to all the reviewers who in spite of their engaging schedules painstakingly perused the MS and provided valuable comments that helped me improve upon the content, organization, and the MS at large.

Besides being appreciative of the help from several colleagues for consulting them on specific points, or making available valuable reprints, I am pleased to record here with gratitude the exemplary support and multifarious help constantly over the past 3 years from two senior fellow geoscientists, Dr. O.N. Bhargava and Prof. N.C. Ghose. They earnestly desired to see the venture fructify, and I fail to find words in expressing my indebtedness to them.

I appreciate with thankfulness the role played by Mr. Aninda Bose, the first Springer executive that I had the privilege to meet. Only his coolness and endurance let me surge through the time-taking review process. I also appreciate the help received from a few other Springer personnel at different stages of the publication of the book.

I myself, not a computer suave to the desired level, always necessitated assistance of a computer graphic specialist. This work and my many other publications would not have been complete but for the constant support of my Corel graphic specialist Abhishek Jaiswal who has over the last 10 years drawn all the figures/tables of this book and of other publications.

All the Jaikrishnas now numbering ten inclusive of my grandsons and granddaughters have constantly encouraged me in spite of my cutting on the time normally spent with them. Words fail me in acknowledging my wife Neera's exemplary coolness, patience, endurance, positive energy, and servicefulness, and what not that singularly kept me marching forward, particularly in intervals of slow progress in this venture. Timely help by Neeharika, Mohini, and Vladimir in cross-checking the references is gratefully appreciated.

Jai Krishna

Contents

1 Introduction and Paleogeographic Context, Previous Work, High-Resolution Scale, Magnetochronologic Perspective, Radiometric Scenario, Igneous Activities, Anoxic Events and Eustatic Fluctuations 1
1.1 Introduction and Paleogeographic Context 1
1.2 Rationale of the Study 5
1.3 Previous Work 8
1.4 Development of a Scale 15
1.5 Magnetostratigraphic Perspective 15
1.6 Radiometric Scenario 21
1.7 Igneous Activities 21
1.8 Oceanic Anoxic Events. 22
1.9 Eustatic Fluctuations. 22
References. 23

2 Mesozoic Stratigraphic Framework in India with Focus on the Jurassic Geological Record in the Kachchh Basin. 27
2.1 Origin of the Kachchh Basin 27
2.1.1 Reactivation of the Precambrian Weak Zones 28
2.1.2 Infra-rift Sagging. 29
2.1.3 Intra-Triassic Rift Initiation 29
2.1.4 Early Non-marine Phase Prior to the Neotethyan Transgression 29
2.2 Salient Features in Brief Prior to the Mesozoic 30
2.2.1 Intra-Devonian Origin of the Paleotethys 30
2.2.2 Major, Widespread Gaps in India and Neighbourhood Prior as also During the Late Permian–Early Paleogene Mega-Sequence 30
2.2.3 Widespread Basal Permian Extensional Tectonics, and Glaciation, Followed up Further by Major Transgressive Event. 32

2.2.4 Intra-Permian Origin of the Neotethys 32
2.2.5 Wide Spread Early/Late Permian Change in Inland Non-marine Gondwana Basins at the Start of the Mega-Sequence 33
2.2.6 Early/Late Permian Change in Marine Basins 34
2.3 Triassic 36
2.3.1 Triassic System—International and National Status 36
2.3.2 Development of Triassic in India 36
2.3.3 Triassic Succession in Spiti 36
2.3.4 Intra-Triassic Interstage Boundaries 37
2.3.5 Paleogeographic Framework at the Start of the Triassic Contextual to Kachchh 49
2.3.6 Suspected Presence of the Late Triassic in the Non-marine Nirona Formation as Encountered in Nirona and Banni Wells of Kachchh 50
2.3.7 Broad Stratigraphic Correlation of the Non-marine Nirona Formation to Non-marine Gondwana Units as also to Spiti Marine Units 50
2.3.8 Marine Triassic in Neighbourhood 50
2.4 Biostratigraphic Zonation in the Triassic 51
2.4.1 Ammonoid Zones in the Spiti Triassic 51
2.4.2 Conodont Zones in the Triassic of Spiti 51
2.4.3 Palynozones in the Non-marine Triassic 51
2.5 Salient Mid-Triassic Features 52
2.5.1 Biotic and Abiotic Changes Across the Mid-Triassic Anisian/Ladinian Boundary in Spiti 52
2.5.2 Mid-Triassic Unconformity and Associated Changes in Inland Gondwana Non-marine Basins as also in East and West Sector Coastal Basins 52
2.5.3 Intra-Triassic Localized Rifting/Igneous Event in India 53
2.5.4 Triassic Palyno-Record in the West Sector 53
2.6 Jurassic 53
2.6.1 Jurassic System—International and National Status 53
2.6.2 Development in the Indian Subcontinent 54
2.6.3 Outline of the Ammonoid Biogrographic Framework 54
2.6.4 Marine Jurassic in Jaisalmer 57
2.6.5 Marine Jurassic in High Himalaya with Focus in Spiti 57
2.6.6 Brief Summary of the Marine Jurassic in the Neighbouring Pakistan 58
2.7 Jurassic in Kachchh 66
2.7.1 Initiation of the Marine Transgression in Kachchh 66
2.7.2 Improbability of the Transgression in Early Pliensbachian During the Terminal Phase of Eustatic Fall 66

2.7.3 Oldest Jurassic Ammonoid Evidence. 68
2.7.4 Oldest Jurassic Nannoplankton Evidence. 68
2.7.5 Regional Evidence of the Early Toarcian Marine Transgression 68
2.7.6 Jurassic Stratigraphic Record of Kachchh and Neighbourhood 69
2.7.7 Lithostratigraphic Framework in the Jurassic of the Kachchh Basin 69
2.7.8 Adoption of the Member Units of Biswas and Others. 72
2.7.9 Fundamentals of Stratigraphic Refinement and Ammonoid Zonation 76
2.7.10 Lithostratigraphic Differentiation and Guide Fossil Collection in the Field Followed by Systematic, Bio- and Chrono-Stratigraphy in the Laboratory 76
2.8 Ammonoid Stratigraphic Refinement in Kachchh—Principal Results at a Glance. 79
2.8.1 Hettangian–Pliensbachian Record (Non-marine) 80
2.8.2 Toarcian–Aalenian Record (Largely Marine, yet Ammonoid Devoid). 80
2.8.3 Bajocian 81
2.8.4 Bathonian 84
2.8.5 Callovian. 90
2.8.6 Oxfordian 100
2.8.7 Kimmeridgian 110
2.8.8 Tithonian. 120
2.8.9 Intra-Jurassic Interstage Boundaries. 128
2.9 Cretaceous 130
2.9.1 International Status 130
2.9.2 Development in India 130
2.9.3 On the Local/Regional Stages in the Indian Cretaceous. 130
2.9.4 Integrated Indian Cretaceous Ammonoid Zonal Succession. 131
2.9.5 Exposed Cretaceous record in Kachchh and Jaisalmer . . . 132
2.9.6 Subsurface and Offshore Record 134
2.9.7 Early Vis-à-Vis Late Cretaceous in Kachchh. 134
2.9.8 Interstage Cretaceous Boundaries 134
References. 138

3 Outcrop-Based Sequence Stratigraphic Studies on GTM with Focus on the Kachchh Mesozoic 145
3.1 Sequence Stratigraphic Studies 145
3.1.1 Brief History of Sequence Stratigraphic Studies 145
3.1.2 Sequence Stratigraphic Studies on GTM 146
3.1.3 Update on Sequence Stratigraphic Studies by the Author 147

3.2 Elements of the Depositional Sequences 147
3.2.1 Sequence Stratigraphic Surfaces, and Types of Unconformities at Sequence Boundaries 151
3.2.2 Shoreline Migration Processes 151
3.2.3 Terminology and Definitions 151
3.2.4 Parasequences as Building Blocks of the Sequences 153
3.2.5 Parasequence Stacking Patterns 153
3.2.6 Subaerial and Submarine Stratigraphic Gaps 153
3.2.7 Bathymetric Changes in Shallow Marine Near Coast Systems 154
3.2.8 Sequence Surfaces Versus Spatiotemporal Distribution of Ammonoids 156
3.2.9 Asymmetric Sequences in Context of Thickness 156
3.2.10 Bathymetric Changes and Ammonoid Heterochronic Evolution 157
3.2.11 Sediment Accumulation Rates, Facies and Their Depositional Environemnts 158
3.2.12 Biotic and Abiotic Parameters 159
3.2.13 Refined Chronostratigraphy—An Essential Requisite for Sequence Stratigraphic Studies 160
3.2.14 Sequence Stratigraphy as Here Understood 161
3.2.15 Rationale of Sequence Stratigraphic Studies 161
3.2.16 Uniformity of Sequences in Broadly Homogeneous Tectonostratigraphic Regions 162
3.2.17 Temporally Changing Geographical Extent of the Broadly Uniform Tectonostratigraphic Regions 162
3.2.18 Sequence Stratigraphic Studies in the Indian Geological Record 162
3.2.19 Applicative Attributes of the Sequence Stratigraphic Studies 163
3.2.20 Isochronous Surfaces of the T/R Sequences 163
3.3 The Mega Mesozoic Sequence and Its Three First-Order Sequences 164
3.3.1 T-I. Basal Triassic to Intra-induan Frequens Zone (Limestone + Shale Member) Second-Order Sequence 168
3.3.2 T-II. Basal Olenekian Rohilla Zone to Intra-olenekian Flemingites-Euflemingites Zone Second-Order Sequence 168
3.3.3 T-III. Late Olenekian Meekoceras Zone–Early Ladinian Fassinian Curionii Zone Second-Order Sequence 168
3.3.4 T-IV. Intra-Ladinian Langobardian Gredlerensis Zone–late Early Ladinian Maclerni Zone) Second-Order Sequence 168

3.3.5 T-V. late Early Ladinian Sutherlandi Zone–Early Carnian Aon Zone (up to the Level BL 20) Second-Order Sequence. 168
3.3.6 T-VI. Mid to late Early Carnian Second-Order Sequence 169
3.3.7 T-VII. Latest Early to Late Carnian Second-Order Sequence 169
3.3.8 T-VIII. Early Norian Second-Order Sequence 169
3.3.9 T-IX. Middle to Late Norian Second-Order Sequence. . . . 170
3.3.10 T-X. Rhaetian Second-Order Sequence 170
3.4 Sequence Stratigraphy in the Kachchh Jurassic 171
3.4.1 Advantage of Relative Subtemperate High Latitude Location of Kachchh for Greater Part of the First-Order Toarcian–Barremian (~ 56.40 my Long) Sequence. 172
3.4.2 Domination of the Kachchh Ammonoid Fauna by a Single Subfamily in Each Second-Order Sequence 173
3.4.3 Auxiliary/Minor/Secondary Extraneous Elements Crucial for GTM/ETM Correlation 173
3.4.4 Strategic Significance of the Kachchh Mesozoic 173
3.4.5 Ammonoid Heterochrony also Used in Relative Chronometry 174
3.4.6 Geological Dynamics Through Outcrop Based Sequence Stratigraphic Studies in the Indian Mesozoic. 174
3.4.7 Geographically Restricted GTM Ammonoid Subfamilies as Representative of Second-Order Sequences. 174
3.4.8 Second-Order and Bigger Sequences Controlled by Regional Tectonics. 175
3.4.9 Third-Order and Smaller Sequences Governed by Earth's Orbital Dynamics and so Global 175
3.4.10 Origin of the Kachchh Basin and Principal Sequence Surfaces Between the Precambrian and the Time of Origin of the Kachchh Basin. 175
3.4.11 SB of the Mega Order Sequence. 176
3.5 First- to Third-Order Sequence Stratigraphy in the Kachchh Jurassic. 177
3.5.1 J-I. Hettangian Second-Order ~ 2.0 my Long Sequence with Middle Hettangian Liasicus Zone MFS. 179
3.5.2 J-II. Hettangian–Sinemurian Boundary to Rauricostatum Zone ~ 8.5 my Second-Order Sequence with Oxynotum Zone MFS. 180
3.5.3 J-III. Latest Sinemurian to End Pliensbachian ~ 8 my Long Second-Order Sequence with Ibex Zone MFS. 181

3.5.4 J-IV. Second-Order Early Toarcian–End Aalenian Second-Order Sequence of ~12.5 my Duration with MFS in the Nitiscens Zone 183
3.5.5 J-V. Basal Bajocian–Mid-Late Bajocian ~1.7 my Long Second-Order Sequence with MFS in Early Bajocian Propinquans Zone 195
3.5.6 J-VI. Late Bajocian Garantiana Zone–Mid. Middle Bathonian Morrisi Zone ~1.5 my Long Second-Order Sequence with Early Bathonian Macrescens Subzone MFS 200
3.5.7 J-VII. Second-Order Late Middle Bathonian Mantataranus Zone / Bremeri Zone–O-I Horizon of Late Middle Callovian Obtusicosta Zone Obtusicosta Subzone Sequence of ~2.40 my Duration with MFS Above the Diadematus Subzone of Chrysoolithicus Zone 207
3.5.8 J-VIII. Late Middle Callovian O-II Horizon Obtusicosta Subzone Obtusicosta Zone–early Early Oxfordian Second-Order Sequence of ~2.1 my duration with MFS in A-II Horizon Depressum Subzone Athleta Zone of early Late Callovian Age 225
3.5.9 J-IX. Second-Order Obliqueplicatum Zone–Subevolutus Sequence with MFS Above the Late Middle Oxfordian Schilli Subzone of Orientalis Zone of ~4.8 my Duration 231
3.5.10 J-X. Second-Order early Early Kimmeridgian Kachchhensis Zone–Mid. Early Kimmeridgian Giganticus Subzone Sequence of ~2.0 my Duration with MFS Above the Kachchhensis Zone 239
3.5.11 J-XI. Second-Order late Early Kimmeridgian Alterneplicatus Zone–late Late Kimmeridgian Katrolensis Zone of ~4.0 my Duration Sequence with MFS Above the Bathyplocus Zone 241
3.5.12 J-XII. Second-Order early Early Tithonian Pottingeri Zone–Virgatosphinctoides Zone Sequence of ~2.8 my Duration with MFS in Rajnathi Subzone of Virgatosphinctoides Zone 243
3.5.13 J-XIII. Second-Order Natricoides Zone–Densiplicatus Zone Sequence of ~3.6 my Duration with MFS Above the Natricoides Zone 245
3.5.14 J-XIV. Terminal Part of Densiplicatus Zone Third-Order TST Of ~400 ky with MFS/MFI in Bed 19 A-B 247

3.6 Cretaceous 248
3.6.1 C-I. Early to Middle Berriasian Second-Order Sequence 250
3.6.2 C-II. Late Berriasian Second-Order Sequence 251
3.6.3 C-III. Valanginian Second-Order Sequence (beds 5–9 of the Ghuneri Member) in the Ghuneri–Amarsar Section 251
3.6.4 C-IV Hauterivian Second-Order Sequence (Beds 10–12 of the Ghuneri Member) in the Ghuneri–Amarsar Section 251
3.6.5 C-V Barremian Second-Order Sequence (Beds 13–14 of the Ghuneri Member) in the Ghuneri–Amarsar Section 252
3.6.6 C-VI. Early Aptian Deshayesites Zone–late Aptian Furcata Zone Second-Order Sequence of the Early part of the Ukra Member (Beds 15 and 16) 253
3.6.7 C-VII. Early to Middle Albian Second-Order Sequence (Bed 17 of the Ukra Member and Bed 18 of the Upper Member) 256
3.6.8 C-VIII. Late Albian–Middle Cenomanian Second-Order Sequence of Beds 19–22 of the Upper Member of Umia Formation 256
3.6.9 C-IX Late Cenomanian–Late Turonian Second-Order Sequence of the Upper Part of the Karai Formation/ Sattapadi Shale in the Wells and the Overlying Bhuvanagiri Formation 256
3.6.10 C-X. Coniacian–Santonian Second-Order Sequence with Intra-Coniacian MFS 256
3.6.11 C-XI. Late Campanian Second-Order Sequence with MFS Above the ?Early Campanian Delawarensis Zone 256
3.6.12 C-XII. Maestrichtian duration Second-Order Sequence with MFS Above the Early Maestrichtian Tridens Zone 257
3.7 Salient Features of the Indian Cretaceous Record. 257
3.7.1 Intra- and Terminal Cretaceous Events Contextual to India 257
3.7.2 Application of Sequence Stratigraphy 257
3.7.3 Recent Independent Sequence Formulations in Different Indian Basins Vis-a-Vis Regional to Global Correlatibility of the Sequence Surfaces 258
3.7.4 Regional Uniformity of the Sequences 258
3.7.5 Differences of Ages Among Recent Sequence Formulations 259

3.7.6 Sequence Framework in the Indian Cretaceous 259
3.7.7 Foraminifer Evidence of yet Otherwise Unsubstantiated Presence of Late Cretaceous Stages in Kachchh 259
3.7.8 Speculation on Second-Order Late Albian–Early Cenomanian Sequence. 259
3.7.9 Intra-Cretaceous First-Order SB with or Without Gap. . . . 260
3.7.10 Significant Difference in Ages of the Said Gaps 260
3.7.11 Creation of Indian Stages in Jurassic and Cretaceous—An Uncalled for Exercise. 260
3.7.12 Summary. 261
3.8 Scales of Cyclicity in the Kachchh Jurassic Geological Record . . . 265
3.8.1 Rationale of the Preliminary Exercise 265
3.8.2 Asymmetric and Highly Uneven Duration of the Sequences and Stages 265
3.8.3 Relatively Shorter Duration of the First-Order TSTs to Corresponding RSTs 266
3.8.4 Sequences, Periodicity and Durations 269
References. 271

4 Integration of the Micro/Macro Faunal/Floral Data into Ammonoid Stratigraphic Framework in the Indian Mesozoics 277
4.1 Indian Lithobiostratigraphic Refinement, Correlation and Integration 278
4.1.1 The Indian Sedimentary Basins with Geological Record of the Mega-Sequence. 278
4.1.2 On the Utilization of the Ammonoid Data. 278
4.1.3 The Indian Mesozoic Lithostratigraphy Scenario. 278
4.1.4 Biostratigraphic Range Charts 279
4.1.5 Integration of the Non-ammonoid Zonal Schemes to Ammonoid Schemes. 279
4.1.6 Enlargement of the Stage Level Stratigraphic Record in the Mega-Sequence. 280
4.1.7 Relative Degree of Stratigraphic Refinement Among the Three Mesozoic Systems in India 280
4.1.8 On the Benthic/Planktic Foram-Based Basinal/Regional Indian Stages. 281
4.2 Microfossil-Based Zonations in the Indian Mesozoic 282
4.2.1 Integration of the Diverse Indian Biostratigraphic Record Vis-à-Vis Sequence Surfaces. 283
4.2.2 Naming of Bio/Chronostratigraphic Zones Exclusively Through Their Basal Boundaries. 284
4.3 On the Earlier Assigned Guide Fossil-Based Ages and Correlations in the Indian Mesozoic Successions 284
4.3.1 Bivalves 284
4.3.2 Conodonts. 286

4.3.3 Foraminifers 287
4.3.4 Pollen–Spores and Dinocysts. 292
4.3.5 Nannoplanktons. 295
4.4 Sequence Stratigraphic and Microfossil Zonal Integration in the West Indian Basins. 301
4.4.1 Full Second-Order TST Substantiated Only Through the Ammonoid Record in Jaisalmer 302
4.4.2 Interpretation of the Saurashtra and Narmada Cretaceous Successions in Sequence Stratigraphic Context 302
4.4.3 Stratigraphic Framework in the Narmada Basin 303
4.4.4 West Indian Basins of Jaisalmer, Barmer, Cambay, Kachchh, Saurashtra, Narmada, Mumbai Offshore, and Kerala–Konkan 305
4.4.5 Lumping of Several Morphologically Close Species of the Bagh Succession Under *Placenticeras mintoi* 307
4.4.6 Post-Nimar Intra-Turonian Guide Fossil Records and Not Intra-Nimar 308
4.4.7 Late Cenomanian–Early Turonian Condensed to Starved Interval at Site 258 Leg 26 of the Indian Ocean 308
4.4.8 Evidence of Volcanism in the West Sector of the Indian Ocean 308
4.4.9 Demarcation of Important Cretaceous Sequence Surfaces in Kachchh and Elsewhere 309
4.5 Sequence Stratigraphy-Based Interpretations in the Bengal and Other East Sector Basins 309
4.5.1 The Important But Enigmatic Non-Marine Dubrajpur Formation in Bengal Basin Wells. 309
4.5.2 Discrepancies About the Definition, Age and Geographical Expanse of the Dubrajpur Formation 311
4.5.3 Volcanism in the Bengal Basin 311
4.5.4 Volcanic Intervals in the Bengal Basin Boreholes. 312
4.5.5 Bengal Basin Palynozones. 312
4.5.6 Age Revision to the Bengal Basin Units and Palynozones Through Sequence Surfaces 313
4.5.7 Suggestive Ages to the Six Volcanic Intervals in the Bengal Basin Borehole DPD 6 313
4.5.8 On the Palynology-Based Sequence Stratigraphic Surfaces in the Indian East Coast Wells 315
4.6 Ranges of the Palynozones Through Sequence Surfaces (Fig. 2.42) 317
4.6.1 Pollen–Spore-Based Palynozones 317
4.6.2 Dinocysts. 317
4.7 Application of Sequence Surfaces in Precision Dating of the Cretaceous Units in the East Sector 319
4.7.1 Cauvery Basin. 319

4.7.2 K-G Basin 321
4.7.3 Other Indian East Coast Mahanadi, Purnea, Bengal, Assam and Andaman Basins 321
4.7.4 The Intra-Albian and Intra-Turonian MFSs in the Indian Basins 322
4.7.5 Demarcation of the First-Order Intra-Cretaceous MFS . . . 324
4.7.6 Correlations Among Cauvery, Spiti, and Kachchh Successions 324
4.7.7 Second-Order Surfaces in Between the Mid-Middle Albian MFS and the Above Interpreted First-Order MFS in Spiti and Kachchh 326
4.8 Salient Other Aspects of the Indian Mesozoic 327
4.8.1 Evaluation of the Lithobiostratigraphic Data of Jaisalmer and Barmer Basins 327
4.8.2 Comparative Evaluation of the Jurassic Member Units of Kachchh and Jaisalmer 328
4.8.3 Need of Formal Indian Working Groups for Each International Stage 330
4.8.4 Sequence Stratigraphy-Based Revised Ages to Formations and Members of the Kachchh Jurassic 330
4.8.5 On the Intra-Oxfordian Uplift and Emergence of Mainland 341
4.9 Intrabasinal Correlations with Temporal and Spatial Extent of the Kachchh Mesozoic Formations and Members 343
4.9.1 Patcham Formation 344
4.9.2 Chari Formation 351
4.9.3 Katrol Formation 354
4.9.4 Umia Formation 355
4.9.5 Cretaceous 356
4.9.6 Mundhra Formation 357
4.9.7 Kori and Naliya Units 357
4.9.8 Recent Progress in the Age Assignments of the Oldest and Youngest Sediments in Different Parts of the Kachchh Basin 357
References 360

5 Applicability of the Sequence Framework in IEAP and GTM, with Brief Comments on the Hydrocarbon Prospects in the Indian Basins 367
5.1 Comparison with the Earlier Indian Frameworks 368
5.1.1 Initiation of Sequence Differentiation in India 368
5.1.2 Ammonoid-Based Sequence Stratigraphic Studies in the Indian Mesozoics 368
5.1.3 Sequences Without Précised SBs and MFSs 369
5.1.4 ONGC Sequence Framework 370
5.1.5 On the Efforts in the Kachchh Basin 372

5.2 Validation of the Present Sequence Framework in India, IEAP and GTM 372
5.2.1 Broad Correspondence of the Indian and Arabian MFSs 373
5.2.2 Basal Intra-Permian SB on IEAP and GTM 373
5.3 Comparison of the Indian Triassic, Jurassic, and Cretaceous Sequence Surfaces 375
5.3.1 Comparison with Wombat Plateau ODP Well Sequence Framework off the NW Australian Margin Sites 759, 760, 761 and 764 East of IEAP 375
5.3.2 Comparison with ETM Second-Order Sequence Framework 378
5.3.3 Intra-Jurassic First-Order early Early Toarcian SB 379
5.3.4 Intra-Jurassic First-Order late Middle Oxfordian Schilli Subzone MFS 379
5.3.5 First-Order Intra-Cretaceous Barremian/Aptian Boundary SB 380
5.3.6 Intra-Cretaceous early Middle Turonian Turoniense Zone MFS 380
5.3.7 Early Bajocian Laeviuscula Zone MFS 381
5.3.8 Early Bathonian Macrescens Subzone MFS 381
5.3.9 Mid/late Middle Bathonian Basal Bremeri Zone SB 382
5.3.10 Mid/late Early Callovian MFS 382
5.3.11 On the Younger Jurassic Sequences in Jaisalmer and Spiti 382
5.4 Validation in Detail of the Indian Jurassic–Cretaceous Sequence Stratigraphic Framework on GTM West of India 384
5.4.1 Comparison with Composite East Africa 384
5.4.2 Comparison with the Morondova Basin of Madagascar 387
5.4.3 Comparison of the Kachchh and Arabian Plate Sequence Stratigraphic Frameworks 403
5.5 Validation of the Kachchh First- and Second-Order Sequence Framework on GTM East of India 413
5.5.1 Comparison with Wombat–Exmouth Plateaus and Dampier Basin Well Sections 413
5.5.2 Iriyan Jaya 417
5.5.3 Timor Gap 424
5.5.4 Timor 425
5.5.5 Sula 425
5.6 Sequence Stratigraphic Comparison of the Gondwanian Tethyan (GTM) and Eurasian Tethyan (ETM) Margins 426
5.6.1 Basal SB of the Mega-Sequence 430
5.6.2 Terminal SB of the Mega-Sequence 430

5.6.3 MFS of the Mega Sequence 431
5.6.4 First-Order Intra-Triassic MFS 431
5.6.5 First-Order Intra-Jurassic MFS 432
5.6.6 First-Order Intra-Jurassic SB 432
5.6.7 First-Order Intra-Cretaceous SB 432
5.6.8 Broad Comparison of the Sequence Fameworks of Kachchh on GTM with ETM Frameworks of Haq et al. (1987), Graciansky et al. (1993, 1998). 433
5.6.9 Long-Term TST on ETM and GTM 433
5.6.10 Second-Order MFSs of Haq et al., Jacquin et al., and Granciansky et al.. 434
5.6.11 Diachrony and Differences in Second-Order MFSs Between ETM and GTM. 434
5.6.12 Diachrony and Differences in Second-Order SBs of ETM and GTM. 435
5.6.13 Intra-Bathonian Second-Order MFS 435
5.6.14 Intra-Bathonian Second-Order SB 435
5.6.15 Intra-Callovian MFS 436
5.6.16 Intra-Callovian SB. 436
5.6.17 Intra-Oxfordian MFS. 436
5.6.18 Intra-Oxfordian SB 436
5.6.19 Intra-Kimmeridgian MFS 437
5.6.20 Intra-Kimmeridgian SB 437
5.6.21 Intra-Tithonian MFS 437
5.6.22 Intra-Tithonian SB. 437
5.6.23 Comparison of Principal Ammonoid Lineages 438
5.6.24 Summary of Comparison of Sequence Frameworks of GTM and ETM. 438
5.6.25 Comparison of Third-Order Sequences 439
5.7 Hydrocarbon Prospects in the Mega-Sequence Geological Record in India in Sequence Stratigraphic Context with Focus on the Kachchh Basin 439
5.7.1 Conceptual Remarks in Sequence Stratigraphic Context 439
5.7.2 Tectono-Stratigraphic Framework 440
5.7.3 Paleogeographic Perspective 442
5.7.4 Differentiation of Marine and Non-marine Regimes Within the Mega-Sequence in India 442
5.7.5 Temporal Organization into Syn-Rift, and Rift/Drift Intervals. 443
5.7.6 Regional Igneous Events Among the Required Heat Sources in the Hydrocarbon Source Sediment Kitchen . . . 443
5.7.7 Availablility of Restricted Depositional Environments. . . . 444
5.7.8 Context of Oceanic Anoxism Through the Mega-Sequence 444

5.7.9 Global and East Arabian / Northwest Australian Context. 446
5.8 Summarized Evaluation of the Indian Hydrocarbon Prospects in the Mega-Sequence 446
5.8.1 On the Successive Second-Order Intervals of the Mega-Sequence. 447
5.8.2 Late Permian–Anisian First-Order TST Interval 448
5.8.3 Ladinian–Pliensbachian First-Order RST Interval 449
5.8.4 Toarcian–late Middle Oxfordian TST Interval. 449
5.8.5 Terminal Middle Oxfordian–Barremian First-Order RST Interval 452
5.8.6 Early Aptian–Mid-Middle Albian TST Interval. 452
5.8.7 Cenomanian. 453
5.8.8 Late Cenomanian–early-Middle Turonian TST Interval 453
5.8.9 Late Turonian–Intra-Paleocene First-Order RST Interval 453
5.9 Concluding Remarks 454
References. 455

6 Crucial Links Among Evolution, Extensional Tectonics, Ammonoid Provincialism and Sequence Surfaces. 461
6.1 Fossil Fuel/Energy Resources Vis-à-Vis Sequence Stratigraphic Surfaces. 462
6.1.1 Permian and Paleogene Coal. 462
6.1.2 Hydrocarbon Source/Reservoir Sediments. 464
6.2 Cephalopod and Ammonoid Evolutionary Events. 464
6.2.1 Global Distribution of Higher Grade Cephalopod/ Ammonoid Taxa Vis-a-Vis Geographically Restricted Regional Spread of Ammonoids 465
6.2.2 Simultaneous Mass Extinctions Across the World and Diachronous Regional Extinctions 465
6.2.3 Five Major/Mass Extinctions. 465
6.2.4 Mass Extinctions and Evolution of Cephalopods, Particularly, Ammonoids. 466
6.2.5 Origin of the Nectic Cephalopods Near the First-Order Intra-Cambrian Sequence Surface 466
6.2.6 Cephalopod Evolution and Extinctions at Sequence Surfaces. 467
6.2.7 Pre-Jurassic Ammonoid Evolution and Sequence Surfaces. 467
6.3 Origin/Extinction of Subfamilies at Second-Order Sequence Surfaces 468
6.3.1 Early Jurassic Psiloceratidae and Others 468
6.3.2 Middle Jurassic Macrocephalitinae and Others 469

6.3.3 Late Jurassic Katroliceratinae and Others 472
6.3.4 Appearance/Disappearance of Superfamilies Linked to Bathymetry 472
6.3.5 Globally Concordant Third-Order Sequences. 473
6.3.6 Replacement of Lineages at the First/Second-Order Sequence Surfaces. 473
6.3.7 Subfamilial Origin/Extinctions in the Subboreal Region. 475
6.4 Genetic Link Between the Origin/Extinction of Ammonoid Taxa and Extensional Tectonics 475
6.4.1 Origin/Extinction of Multiple Subfamilies and Superfamilies Triggered by Rift-Tectonism and Volcanism at First/Second-Order Sequence Surfaces. 476
6.4.2 Tilt of the Median High at the Second-Order Intra-Callovian MFS 477
6.4.3 Rift Abortion Related Inversion of Bathymetry, and Change of Paleoslope 478
6.5 Crude Suggestion of Relative Depths Based upon Spatio-Temporal Distribution of Ammonoid Sub/Superfamilies in the Basin 478
6.5.1 Maximum Bathymetry Based on the Suborder Level Distribution 478
6.5.2 Depth Estimates Based on the Distribution of Superfamilies. 479
6.5.3 Estimates Based Even at the Subclass Ammonoidea Level. 479
6.6 Heterochronic Evolutionary Framework of the Dominant IEAP Ammonoid Subfamiles 482
6.6.1 Approach/Methodology to the Heterochronic Evolutionary Framework 482
6.6.2 Macrocephalitinae and Its Chrysoolithicus Lineage 483
6.6.3 Evolutionary Inversion of Macrocephalitinae at the 2nd Order MFS 484
6.6.4 Eucycloceratinae 485
6.6.5 Kinkeliniceratinae 485
6.6.6 Mayaitinae. 486
6.6.7 Katroliceratinae 487
6.6.8 Virgatosphinctinae. 487
6.6.9 Examples of Paedomorphic and Peramorphic Heterochronic Evolution 488
6.6.10 Suggestive Genetic Link Between Heterochronic Evolutionary Changes and Sequence Stratigraphic Framework (Fig. 6.5) 491

6.7 Ammonoid Distribution, Provincialism and Migration to and Fro IEAP 492
6.7.1 Salient Ammonoid Distribution Features During the Toarcian–Barremian 1st Order Sequence Interval with Focus on 2nd Order Sequences 493
6.7.2 Toarcian–Mid-Middle Bathonian 496
6.7.3 Late Middle Bathonian–Early Middle Callovian 496
6.7.4 Late Middle Callovian–Late Early Oxfordian 496
6.7.5 Late Early to Latest Late Oxfordian 496
6.7.6 Basal to Mid-Early Kimmeridgian 497
6.7.7 Late Early to Latest Kimmeridgian 497
6.7.8 Early Early to Mid-Early Tithonian 497
6.7.9 Late Early to late Late Tithonian 497
6.8 Speculative Linkage of Prime Evolutionary Landmarks to Major Regional/Global Geological Events and Their Precision Dating Through Sequence Surfaces 498
6.8.1 Intra-Permian Basal SB of the Mega-Sequence 498
6.8.2 Intra-Triassic First-Order MFS 500
6.8.3 Suggestive Origin of the Planktonic Forams at the First-Order Intra-Jurassic SB 501
6.8.4 The Origin of Birds—The Flying Dinosaurs Near the First-Order Intra-Jurassic MFS 501
6.8.5 Barremian/Aptian Boundary First-Order SB Evolutionary Marks 502
References 502

7 High-Resolution Intrabasinal to Inter-regional Geodynamic Chronicle During the Span of the Intra-Permian–Intra-Paleogene Mega-Sequence in and Around India on the GTM 505
7.1 Backdrop to the Geodynamic Chronicle 506
7.1.1 Transformation from the Origin to the Closure of the Late Permian–Early Paleogene Mega-Sequence 506
7.1.2 Sequence Surfaces as Regional Eventful Additional Timelines to Date Events of One Sector in Some Other Distant Sector 511
7.1.3 Predictable Spatio-Temporal Distribution of Biotic and Abiotic Parameters Across the Sequence Surfaces as also from Proximal Margin to Distal Basin on the Individual Surfaces 517
7.1.4 Chronicle of the Events at the Subzonal Resolution of $\sim$400 ky or its Multiples 518

7.1.5 Unified Integrative Geodynamic History of the Indian Plate, and the Ammonoid Provinces, Corridor Seaways and the Related Oceans Included in the Tell-Tale 523
7.1.6 Constraints and Influence of the Inherent Precambrian Structural Trends in and Around India, and Progressive Refinement of the Size of Greater India 544
7.2 Sequence Stratigraphy Based Geodynamic Chronicle 545
7.2.1 Brief Outline 546
7.2.2 Basal to Intra-Permian Infra-Rift Sagging to Syn-rift Transition Event in the East 547
7.2.3 Early Permian–Middle Triassic Igneous Event ($\sim$289 to $\sim$243 ma) with Climax at the Second-Order Sakmarian/Artinskian MFS of the Intra-Devonian–Early Permian First-Order Sequence 549
7.2.4 Possible Earlier Origin of the Neotethys 550
7.3 The Spitiian First-Order Sequence 552
7.3.1 Early/Late Permian ($\sim$272 ma) Basal Mega SB Geological Event 553
7.3.2 Anoxic Events Vis-à-Vis Sequence Stratigraphic Surfaces 554
7.3.3 Mega-Sequence Surfaces and the Indian Energy Resources (Fig. 7.5) 554
7.3.4 The End-Permian Mass Extinction at the Second-Order SB, and Its Varied Causes 555
7.3.5 Major Organic Evolution Events Suggestively Linked to the First-Order Sequence Surfaces 556
7.3.6 Example of Quantum Evolutionary Steps in Cephalopods/Ammonoids 556
7.3.7 Major Evolutionary Leaps of Higher Grade Taxa in the Animals and Plants 557
7.4 First-Order Intra-Triassic Late Anisian Hollandite Zone–Kellnerites Zone MFS Rifting Event 558
7.4.1 Early Triassic Bathymetric Increase in Spiti Vis-à-Vis Eustatic Changes During the Intra-Olenekian–Intra-Carnian Interval 561
7.4.2 Application of Sequence Stratigraphic Concepts and Sequence Surfaces in Correlation of Marine and Non-marine Units 562
7.4.3 Regional Build-up of Sands in the Ensuing First-Order RST 562
7.5 The Kachchhian First-Order Sequence 563
7.5.1 The Multifaceted Widespread First-Order Intra-Jurassic SB Geological Event 563