Biodiversity, Ecosystems, and Conservation in Northern Mexico

Jean-Luc E. Cartron
Gerardo Ceballos
Richard Stephen Felger,
Editors

OXFORD UNIVERSITY PRESS

BIODIVERSITY, ECOSYSTEMS, AND CONSERVATION IN NORTHERN MEXICO

The editors acknowledge the generous sponsorship of this book by the following institutions:

Arizona-Sonora Desert Museum
Centro de Investigación en Alimentación y Desarrollo (CIAD), A.C.
Centro de Investigaciones Biológicas del Noroeste
Cesar Kleberg Wildlife Research Institute
Cooperativa La Cruz Azul S.C.L.
EDM International, Inc.
JM Kaplan Fund
Museum of Southwestern Biology, University of New Mexico
New Mexico Museum of Natural History
New Mexico State University
T & E, Inc.
Universidad Nacional Autónoma de México
U.S. Fish and Wildlife Service
Wallace Research Foundation

BIODIVERSITY, ECOSYSTEMS, AND CONSERVATION IN NORTHERN MEXICO

Edited by
Jean-Luc E. Cartron
Gerardo Ceballos
Richard Stephen Felger

OXFORD
UNIVERSITY PRESS

2005

OXFORD
UNIVERSITY PRESS

Oxford University Press, Inc., publishes works that further
Oxford University's objective of excellence
in research, scholarship, and education.

Oxford New York
Auckland Cape Town Dar es Salaam Hong Kong Karachi
Kuala Lumpur Madrid Melbourne Mexico City Nairobi
New Delhi Shanghai Taipei Toronto

With offices in
Argentina Austria Brazil Chile Czech Republic France Greece
Guatemala Hungary Italy Japan Poland Portugal Singapore
South Korea Switzerland Thailand Turkey Ukraine Vietnam

Published by Oxford University Press, Inc.
198 Madison Avenue, New York, New York 10016

www.oup.com

Library of Congress Cataloging-in-Publication Data
Biodiversity, ecosystems, and conservation in northern Mexico / [edited by] Jean-Luc E.
Cartron, Gerardo Ceballos, and Richard Stephen Felger.
p. cm.
Includes index.
ISBN-13 978-0-19-515672-0
ISBN 0-19-515672-2
1. Biological diversity—Mexico, North. 2. Ecology—Mexico, North. I. Cartron, Jean-Luc E.
II. Ceballos, Gerardo. III. Felger, Richard Stephen.
QH107.B525 2004
333.95'16'0972—dc22 2004012002

9 8 7 6 5 4 3 2 1

Printed in the United States of America
on acid-free paper

For Dominique, Matthieu, Melanie, and Olivia. Also to the memory of my grandfather Marcel Chichery, geologist, naturalist, and teacher, killed during WWII.
—Jean-Luc Cartron

To Pupa, Pablo, and Regina, the light of my life.
—Gerardo Ceballos

For Silke especially and Grayce and the rest of the world's children.
—Richard Felger

Foreword

To the average informed layperson, the word "megadiversity" probably elicits images of steamy tropical rainforests and perhaps also of coral reefs. If both occur together, like in Indonesia, so much the better because the stereotype is reinforced. It is seldom appreciated, however, that outside the wet tropics there are regions of the world that harbor extremely high numbers of species, high levels of endemism, or fascinating ecosystems. For most Mexicans, and I daresay also for many Americans, news that the arid and desert zones of North America represent one such hot spot of biodiversity would be surprising. Even for professional biologists from other parts of the world, the tremendous biological richness of the deserts of North America may remain unappreciated. I witnessed this while serving in one of the scientific advisory bodies of the United Nations: the perceptions and points of view of the expert on the sub-Saharan deserts were totally at odds with my own view on deserts. Our personal experiences regarding arid lands were based on starkly contrasting systems: mine was based mainly on the Sonoran and Tehuacan Deserts, with their astounding biological richness, and hers mainly on the degraded lands of many Sahelian countries.

Even a country like Mexico, which is fortunate enough to harbor both tropical rainforests and deserts among its biomes, may have more species or a higher percentage of endemics in its arid lands than in its very rich but much less extensive wet tropics. Unfortunately, the pace of destruction that for many years was focused on the tropical forests is now shifting toward the arid lands. The combined pressure of demographics and development, including the extensive introduction of alien species (e.g., buffelgrass, *Pennisetum ciliare* or tamarisk, *Tamarix* spp.), is causing widespread deterioration of precious ecosystems, which until recently were still relatively well preserved over large areas.

Within this dual context of high biological diversity and accelerated pace of anthropogenic impacts, the publication of *Biodiversity, Ecosystems and Conservation in Northern Mexico* is a welcome addition to the armory of ecologists, nongovernmental organizations, and consultants interested in the conservation and sustainable management of our arid lands. The thematic scope of the book is quite ambitious: it includes chapters on terrestrial, marine, and freshwater species; on the geology, biology, human history, and even environmental laws of the region, which includes the whole Baja California peninsula, the state of Sonora, and the Chihuahuan Desert all the way south to San Luis Potosí. The emphasis of the volume is mostly on plants and vertebrates. However, one chapter focuses on scorpions, and two others include coverage of marine and intertidal macroinvertebrates. One chapter addresses ecosystem integrity and functioning in the state of Baja California. In general, even those chapters with a more narrow focus have broad applications and should be of interest to all ecologists regardless of their area of expertise.

An interesting and welcome feature of the book is its balanced national authorship: about three-quarters of the chapters are the product of collaboration between authors on both sides of the U.S.–Mexico border or were written entirely by Mexicans. Not very long ago a book of this kind would have had 90% or more American authors. Increased activity and expertise on the Mexican side, along with a sustained tradition of international collaboration, are transforming the approach to dealing with the manifold problems of our shared ecosystems.

The personnel at the National Commission on Biodiversity of Mexico (CONABIO) was very happy to be able to collaborate in the production of this volume, which adds another title to the growing list of books dealing with the megadiversity of our country. I hope that this book will have the wide distribution it deserves. I also hope that together with other recent works on northern Mexico, once regarded as good only to raise cattle in a permanent fight against harsh environments, the present volume will be used as an important tool to help preserve the beautiful and unique ecosystems of the region.

Jorge Soberón Mainero

Contents

Part I: Historical, Geographic, and Legal Setting

Part II: Patterns of Species Diversity and Ecological Importance of Natural Ecosystems

Part III: Natural Resource Impacts and Conservation at a Population, Species, and Landscape Level

Contributors

EDGAR S. AMADOR-SILVA
Centro de Investigaciones Biológicas del Noroeste, S. C., La Paz, Baja California Sur, Mexico

DANIEL W. ANDERSON
Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, CA, USA

MA. CARMEN BLÁZQUEZ
Centro de Investigaciones Biológicas del Noroeste, La Paz, Baja California Sur, Mexico

RICHARD C. BRUSCA
Arizona-Sonora Desert Museum, Tucson, AZ, USA

ALBERTO BÚRQUEZ
Instituto de Ecología, Universidad Nacional Autónoma de México, Hermosillo, Sonora, Mexico

WILLIAM A. CALDER
Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, AZ, USA

DOMINIQUE CARTRON
Daniel B. Stephens and Associates, Albuquerque, NM, USA

JEAN-LUC E. CARTRON
Department of Biology, University of New Mexico, Albuquerque, NM, USA

GERARDO CEBALLOS
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

MARTHA J. DESMOND
Department of Fishery and Wildlife Sciences, New Mexico State University, Las Cruces, NM, USA

MARK A. DIMMITT
Arizona-Sonora Desert Museum, Tucson, AZ, USA

DIANA DOAN-CRIDER
Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, Kingsville, TX, USA

HUGH DRUMMOND
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

HÉCTOR ESPINOSA PÉREZ
Colección Nacional de Peces, Instituto de Biología, Universidad Nacional Autónoma de México, México D.F., Mexico

Richard S. Felger
Drylands Institute, Tucson, AZ, USA

Ismael Ferrusquía-Villafranca
Instituto de Geología, Universidad Nacional Autónoma de México, México D.F., Mexico

Lloyd T. Findley
Centro de Investigación en Alimentación y Desarrollo, A.C.-Unidad Guaymas, Guaymas, Sonora, Mexico

Ernesto Franco-Vizcaíno
Departamento de Ecología, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Ensenada, Baja California, Mexico

Timothy E. Fulbright
Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, Kingsville, TX, USA

Felipe Galván-Magaña
Centro Interdisciplinario de Ciencias Marinas, La Paz, Baja California Sur, Mexico

Francisco J. García de León
Laboratorio de Biología Integrativa, Instituto Tecnológico de Ciudad Victoria, Tamaulipas, Mexico

Carlos Gómez-Hinostrosa
Instituto de Biología, Universidad Nacional Autónoma de México, México D.F., Mexico

Laura I. González Guzman
Section of Integrative Biology, University of Texas at Austin, Austin, TX, USA

Patricia González-Zamorano
Centro de Investigaciones Biológicas del Noroeste, S. C., La Paz, Baja California Sur, Mexico

L. Lee Grismer
Department of Biology, La Sierra University, Riverside, CA, USA

Mercedes Guerrero-Ruíz
Departamento de Biología Marina, Universidad Autónoma de Baja California Sur, La Paz, Baja California Sur, Mexico

Delladira Gutiérrez Tirado
Laboratorio de Biología Integrativa, Instituto Tecnológico de Ciudad Victoria, Tamaulipas, Mexico

David J. Hafner
New Mexico Museum of Natural History, Albuquerque, NM, USA

Richard E. Harness
EDM International, Inc., Fort Collins, CO, USA

Phillip A. Hastings
Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA, USA

Dean A. Hendrickson
Texas Memorial Museum and Section of Integrative Biology, University of Texas, Austin, TX, USA

Michel E. Hendrickx
Estación Mazatlán, ICML- Universidad Nacional Autónoma de México, Mazatlán, Sinaloa, Mexico

Brent E. Hendrixson
Department of Life, Earth, and Environmental Sciences, West Texas A&M University, Canyon, TX, USA

Héctor M. Hernández
Instituto de Biología, Universidad Nacional Autónoma de México, México D.F., Mexico

David G. Hewitt
Caesar Kleberg Wildlife Research Institute, Texas A&M University-Kingsville, Kingsville, TX, USA

Gina Holguin
Centro de Investigaciones Biológicas del Noroeste, S. C., La Paz, Baja California Sur, Mexico

ARMANDO JARAMILLO-LEGORRETA
Programa Nacional de Mamíferos Marinos, Instituto Nacional de Ecología/ Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Ensenada, Baja California, Mexico

KAREN KREBBS
Arizona-Sonora Desert Museum, Tucson, AZ, USA

ALBERTO LAFÓN TERRAZAS
Facultad Zootecnia, Universidad Autónoma de Chihuahua, Chihuahua, Mexico

JOSÉ LUIS LEÓN DE LA LUZ
Centro de Investigaciones Biológicas del Noroeste, S. C., La Paz, Baja California Sur, Mexico

RURIK LIST
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

JUAN MANUEL LOBATO G.
Centro de Investigaciones Biológicas del Noroeste, S. C., La Paz, Baja California Sur, Mexico

CARLOS MANTEROLA
Unidos para la Conservación, A. C., México D.F., Mexico.

PATRICIA MANZANO-FISCHER
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

LUIS OCTAVIO MARTÍNEZ MORALES
Despacho Székely y Asociados, México D.F., Mexico

CAROLE C. MCIVOR
USGS-Biological Resources Division, c/o Center for Coastal Studies, St. Petersburg, FL, USA

RODRIGO A. MEDELLÍN
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

ERIC MELLINK
Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Ensenada, Baja California, Mexico

RENATO MENDOZA-SALGADO
Centro de Investigaciones Biológicas del Noroeste, S. C., La Paz, Baja California Sur, Mexico

RICHARD A. MINNICH
Department of Earth Sciences, University of California, Riverside, CA, USA

WALLACE J. NICHOLS
Blue Ocean Institute, Davenport, CA, USA

JESÚS PACHECO
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

EDUARDO PALACIOS
Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Ensenada, Baja California, Mexico

CAROL RAISH
U.S. Forest Service, Rocky Mountain Research Station, Albuquerque, NM, USA

FANNY REBÓN GALLARDO
Museo de Zoología, Facultad de Ciencias, Universidad Nacional Autónoma de México, México D.F., Mexico

CHARLOTTE G. REEDER
University of Arizona Herbarium, Tucson, AZ, USA

JOHN R. REEDER
University of Arizona Herbarium, Tucson, AZ, USA

ANA LILIA REINA G.
Arizona-Sonora Desert Museum, Tucson, AZ, USA

BRETT R. RIDDLE
Department of Biological Sciences, University of Nevada Las Vegas, Las Vegas, NV, USA

CRISTINA RODRÍGUEZ
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

RICARDO RODRÍGUEZ-ESTRELLA
Centro de Investigaciones Biológicas del Noroeste, S. C., La Paz, Baja California Sur, Mexico

ROBERT C. ROGERS
Biology Department, University of New Mexico, Albuquerque, NM, USA

LORENZO ROJAS-BRACHO
Programa Nacional de Mamíferos Marinos, Instituto Nacional de Ecología/ Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Ensenada, Baja California, Mexico

MARIO ROYO
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

GEORGINA SANTOS
Instituto de Ecología, Universidad Nacional Autónoma de México, México D.F., Mexico

JEFFREY A. SEMINOFF
Southwest Fisheries Science Center, NOAA-National Marine Fisheries Service, La Jolla, CA, USA

W. DAVID SISSOM
Department of Life, Earth, and Environmental Sciences, West Texas A&M University, Canyon, TX, USA

MARK J. SPALDING
Graduate School of International Relations and Pacific Studies, University of California at San Diego, La Jolla, CA, USA

SCOTT H. STOLESON
U.S. Forest Service, Northeastern Research Station, Irvine, PA, USA

ALBERTO SZÉKELY
Despacho Székely y Asociados, México D.F., Mexico

BRUCE C. THOMPSON
U.S.G.S.-Biological Resources, New Mexico Cooperative Fish and Wildlife Research Unit, Las Cruces, NM, USA

JORGE TORRE COSIO
Comunidad y Biodiversidad, A.C., Guaymas, Sonora, Mexico

JORGE URBÁN R.
Departamento de Biología Marina, Universidad Autónoma de Baja California Sur, La Paz, Baja California Sur, Mexico

MANUEL VALDÉZ
Unidos para la Conservación, A. C., México D.F., Mexico

RAUL VALDEZ
Department of Fishery and Wildlife Sciences, New Mexico State University, Las Cruces, NM, USA

ALBERT M. VAN DER HEIDEN
Centro de Investigación en Alimentación y Desarrollo, A.C.-Unidad Mazatlán, Sinaloa, Mexico

THOMAS R. VAN DEVENDER
Arizona-Sonora Desert Museum, Tucson, AZ, USA

ENRIQUETA VELARDE
Centro de Ecología y Pesquerías, Universidad Veracruzana, Xalapa, Veracruz, Mexico

ROBERT C. WHITMORE
West Virginia University, Division of Forestry, Morgantown, WV, USA

JOHN F. WIENS
Arizona-Sonora Desert Museum, Tucson, AZ, USA

MICHAEL F. WILSON
Drylands Institute, Tucson, AZ, USA

KENDAL E. YOUNG
U.S.G.S.-Biological Resources, New Mexico Cooperative Fish and Wildlife Research Unit, Las Cruces, NM, USA

BIODIVERSITY, ECOSYSTEMS, AND CONSERVATION IN NORTHERN MEXICO

Biodiversity, Ecosystems, and Conservation: Prospects for Northern Mexico

JEAN-LUC E. CARTRON
GERARDO CEBALLOS
RICHARD S. FELGER

Conservation biology is a crisis discipline rooted in the realization that the world's biodiversity is rapidly disappearing. Environmental problems (including loss of species and ecosystems) are mainly the result of explosive human population growth, with an ever-growing demand on natural resources and a steady increase in waste products. Minimizing the negative effects of human activities on the environment requires a conservation-minded culture, an adequate legal framework that is implemented and enforced, properly trained professionals, and funding. Just as important, minimizing environmental damage requires solid scientific information on the biodiversity and functioning of every ecosystem and on conservation threats at a local, regional, and global scale. This knowledge becomes a crucial tool for guiding where and when the protection of nature is most needed and for designing sound management strategies. According to the Latin proverb, *Scientia est potentia* (knowledge is power), and the seventeenth-century philosopher Francis Bacon was one of the first to argue the importance of gathering scientific information on the natural world. Bacon's reasoning was that by learning more about nature we could control or harness it. Today, this same type of knowledge needs to be applied instead to protect ecosystems and species.

This book is first and foremost about conservation in northern Mexico. The information it contains is intended primarily for Mexican government agencies, environmental organizations, and research institutions, but it also has applications at the scale of North America. The stakes are high in Mexico, one of the world's 17 megadiversity countries (Mittermeier et al. 1997). Among all nations, Mexico may support the highest number of reptile species (Flores-Villela and Geréz 1994). It also has one of the highest numbers of vascular plants and amphibians (Dirzo and Gómez 1996; Mittermeier et al. 1997), along with 12% of the world's mammals (Ceballos et al. 2002). As many as 1076 bird species occur in Mexico, a total 30% greater than that for the United States and Canada combined (Ceballos and Marquéz 2000). It is in Mexico that the Neotropic and Nearctic regions merge, producing unique communities of mixed biogeographic affinities. The percentage of endemic species is surprisingly high for a country that is part of a continent (Ceballos and Marquéz 2000).

Much of Mexico's biodiversity is in the arid, northern part of the country (loosely defined in this volume) and in waters along this region's extensive coastline. To use examples from this volume, the Baja California peninsula harbors the highest known density of scorpion species in the world (chapter 6). The Huizache area in the state of San Luis Potosí has 75 cactus species, the highest concentration of Cactaceae recorded anywhere to date (chapter 13). With 186 taxa (183 species) documented and 38 (37 species) more expected, the Municipio (County) de Yécora (3300 km^2) in eastern Sonora has one of the highest grass diversities in Mexico (chapter 5). With 44 succulent plant taxa occurring over its 10-km^2 area, Cerro Colorado in Baja California Sur epitomizes the biological wealth of the Sonoran Desert. The largest remaining prairie-dog town complex in North America and its surrounding area in northwestern Chihuahua support about 21% of the mammals of Mexico (chapter 21). The Gulf of California has a macrofauna composed of at least 5969 nominal species and subspecies, including 891 fish taxa, 31 (37%) of the world's cetaceans, and 5 of the 7 sea turtles, with thousands of additional taxa remaining to be described (chapters 9, 14, and 20). As a means of comparison, the Mediterranean Sea covers an area 10 times larger than that of the Gulf of California, yet harbors a total of only 664 fish species (Whitehead et al. 1986; Quignard and Tomasini 2000) and 21 cetaceans (Notarbartolo di Sciara 2002).

As in other parts of the world, northern Mexico's biodiversity is now threatened. Rapid loss of habitat is occurring throughout the region, threatening mangroves (chapter 15), deserts (chapters 11 and 13), grasslands (chapter 21), forests (chapter 3), and oases (chapter 16). Anthropogenic impacts on species include the collapse of northwestern Mexico's sea turtle populations (chapter 20), endangerment of the vaquita in the Gulf of California (chapter 14), rapid decline of the Janos–Casas Grandes prairie dog town complex (chapter 21), and a high incidence of bird electrocutions on concrete power poles in Chihuahua (chapter 17). Exotic species have become the scourge of many ecosystems and wildlife populations, including seabirds (chapters 3 and 23) and freshwater fish (chapter 7).

The present volume begins with four introductory chapters that provide background information and frame many of the issues developed later in the book. In the introductory chapter describing the recently developed legal framework for the conservation of species and ecosystems in Mexico, Szekely et al. (chapter 4) are critical of what they and others view as government inaction. Certainly, lack of implementation or enforcement of Mexico's laws highly contributes to some of the most pressing conservation issues in the northern part of the country (see chapter 20). At the same time, some conservation efforts on the part of individuals and environmental organizations have been truly heroic, and there are success stories to report (chapters 19 and 23).

Among some of the other factors complicating conservation are the social ills of Mexico, which is dogged by poverty and population growth. On the other hand, northern Mexico still has vast expanses of pristine habitat, which cannot be said for many other parts of the world (e.g., Mittermeier et al. 2003). For a long time, some Mexicans have expressed interest in and concern over environmental issues in general and conservation in particular. Since about 1990, a growing number of national and international NGOs (nongovernmental organizations) and government research organizations have become actively involved in conservation issues. Among the most important are World Wildlife Fund Mexico, The Nature Conservancy-Mexico, Pronatura, Instituto de Ecologia A.C., Instituto de Ecologia UNAM, Centro de Investigación Cientifica y de Educación Superior de Ensenada (CICESE), and the state universities of northern states, including Baja California, Baja California Sur, Sonora, Chihuahua, Nuevo León, and Tamaulipas.

The federal government of Mexico relies heavily on the creation of Natural Protected Areas. As of June 2003, it has decreed a total of 33 Biosphere Reserves, 65 National Parks, 4 National Monuments, 2 Areas for the Protection of Natural Resources, 26 Areas for the Protection of Flora and Fauna, and 17 Sanctuaries. As a result, there are many vast federally recognized reserves in the northern part of Mexico (tables I.1 and I.2), though they often lack sufficient infrastructure and funding to be effectively protected. Sierra de San Pedro Mártir in the state of Baja California is a National Park (see chapter 18). The Cuatro Ciénegas basin (see chapter 6) in Coahuila is an example of Area for the Protection of Flora and Fauna. There are also additional reserves created by individual states, and Biosphere Reserves created under UNESCO's Man and the Biosphere (MAB) Program, some of which do not have the status of Biosphere Reserves under Mexican law. For example, El Cielo in Tamaulipas is a MAB Biosphere Reserve, but under Mexican law it is only a State-decreed protected area. Another MAB Biosphere Reserve, Islas del Golfo de California, is protected under federal law but has the status only of Area for the Protection of Flora and Fauna.

With international financial support, the existence of all these reserves in northern Mexico can become a powerful tool for conserving ecosystems in northern Mexico. Some of them could be incorporated into a network of protected areas connecting vast tracts of land on both sides of the U.S.–Mexican border. Felger et al. (2004) proposed an *Escalera Ecológica* in place of the *Escalera Náutica* (an

Table I.1. Biosphere Reserves and National Parks established under federal Mexican law in the northern states of Baja California, Baja California Sur, Chihuahua, Coahuila, Durango, Nuevo León, Sinaloa, Sonora, and Tamaulipas.

Protected Areas	Location	Date of Creation	Size (ha)
Biosphere Reserves			
Alto Golfo de California y Delta del Río Colorado[a]	Baja California and Sonora	June 10, 1993	934,756
El Vizcaíno[a,b]	Baja California Sur	November 30, 1988	2,546,790
Sierra La Laguna	Baja California Sur	June 6, 1994	112,437
Mapimí[a]	Chihuahua, Coahuila, and Durango	November 27, 2000	342,388
La Michilía[a]	Durango	July 18, 1979	9,325
El Pinacate y Gran Desierto de Altar[a]	Sonora	June 10, 1993	714,557
Isla San Pedro Mártir	Sonora	June 13, 2002	30,165
National Parks			
Constitución de 1857	Baja California	April 27, 1962	5,009
Sierra de San Pedro Mártir	Baja California	April 26, 1947	72,911
Bahía de Loreto	Baja California Sur	July 19, 1996	206,581
Cabo Pulmo	Baja California Sur	June 6, 1995	7,111
Cascada de Bassaseachic	Chihuahua	February 2, 1981	5,803
Cumbres de Majalca	Chihuahua	September 1, 1939	4,772
Los Novillos	Coahuila	June 18, 1940	42
Cumbres de Monterrey	Nuevo León	November 17, 2000	177,396
El Sabinal	Nuevo León	August 25, 1938	8

Natural Protected Areas are created upon presidential decrees. Adapted from CONANP (2003).

[a] Also designated as a Biosphere Reserve under UNESCO's Man and the Biosphere Program.

[b] Includes the Laguna Ojo de Liebre complex and Laguna San Ignacio. These lagoons have been designated as Whale Refuges by presidential decrees.

Table I.2. Natural Monuments, Areas for the Protection of Flora and Fauna, and Sanctuaries established under federal Mexican law in the northern states of Baja California, Baja California Sur, Chihuahua, Coahuila, Durango, Nuevo León, Sinaloa, Sonora, and Tamaulipas.

Protected Areas	Location
Natural Monuments	
Cerro de la Silla	Nuevo León
Areas for the Protection of Flora and Fauna	
Valle de los Cirios	Baja California
Cabo San Lucas	Baja California Sur
Islas del Golfo de California	Baja California, Baja California Sur, Sinaloa, Sonora
Cañon de Santa Elena	Chihuahua
Tutuaca	Chihuahua
Campo Verde	Chihuahua
Papigochic	Chihuahua
Cuatro Ciénegas	Coahuila
Maderas del Carmen	Coahuila
Meseta de Cacaxtla	Sinaloa
Sierra de Álamos-Río Cuchujaqui	Sonora
Sanctuaries	
Playa Ceuta	Sinaloa
Playa el Verde Camacho	Sinaloa
Playa de Rancho Nuevo	Tamaulipas

Natural Protected Areas are created upon presidential decrees. There is no Area for the Protection of Natural Resources in northern Mexico. The three listed Sanctuaries are mainly for the protection of sea turtles. Adapted from CONANP (2003).

ambitious project calling for the development of marinas, waterways, and hotels along the Pacific and Gulf of California coasts, discussed in several chapters). The steps include:

- On the U.S. side, the creation of a Sonoran Desert National Park with existing federal lands (Organ Pipe Cactus National Monument, Cabeza Prieta National Wildlife Refuge, and Tinajas Altas) to fulfill conservation promises to Mexico and to parallel Mexico's commitment.
- The establishment of the contiguous Sonoran Desert Peace Parks (Parques Hermanos, *un corredor ecológico fronterizo*). This protected area would consist of the Sonoran Desert National Park, Reserva de Biosfera El Pinacate y El Gran Desierto de Altar, and Reserva de la Biosfera Alto Golfo de California y Delta del Rio Colorado. Teamed with neighboring areas that include the 1.8 million-acre Goldwater Military Range and the 500,000-acre Sonoran Desert National Monument, the Sonoran Desert Peace Parks would encompass 7.5 million acres of contiguous federal lands on both sides of the border.
- Linking the Reserva Alto Golfo contiguously across desert and mountains to conifer forests of the Sierra Juárez.
- The creation of an *Escalera Ecológica* of diverse reserves—for example, Sonoran Desert Peace Parks, plus an additional 7 million acres of Mexican federal lands comprising Reserva de la Biosfera El Vizcaíno, Valle de Cirios, Parque Nacional Sierra de San Pedro Mártir, proposed Parque Nacional Bahía de los Angeles, Parque Nacional Bahía de Loreto, Reserva de la Biosfera Sierra La Laguna, Área de Protección Cajón del Diablo, Área de Protección de Flora y Fauna Islas del Golfo de California, and Área Protegida Isla Guadalupe.

Similar projects have been proposed or are suitable for other areas in northern Mexico: the grasslands along the Chihuahua–New Mexico border (chapter 21); the scrub and temperate forests in the Big Bend (Texas) and Maderas del Carmen (Coahuila) reserves; and the Laguna Atascosa National Wildlife Refuge (Texas) and the proposed Laguna Madre Biosphere Reserve (Tamaulipas).

What is the outlook for northern Mexico? Impacts described in this volume may continue or even accelerate. The *Escalera Náutica* project, which is currently in its early stage of implementation, may well transform the regional landscape and result in wholesale destruction of coastal ecosystems. More formidable threats are looming on the horizon. First, there are the global climate and water issues, 2 paramount challenges of the twenty-first century. Arid northern Mexico is particularly at risk of water shortage, but water-related impacts on wildlife and ecosystems may result equally from human actions aimed at solving the issue. Another conservation threat is the spread of viruses and other pathogens around the globe, resulting from factors such as globalization, climate change, or habitat fragmentation. Currently, the West Nile virus is a source of grave concern, as it has the potential to decimate wild populations of birds throughout North, Central, and South America (Malakoff 2002; Ananthaswamy 2003).

For northern Mexico, as for most regions on earth, the next few decades will decide the ultimate fate of many ecosystems. The pessimistic outlook for the region is that the vast expanses of coastal habitat, grassland, and forest will largely disappear, as meeting the needs of growing human populations for more space and natural resources (chiefly water) completely overrides conservation. The optimistic scenario is that public awareness and education along with funding will continue to grow, natural protected areas can be incorporated into networks such as the ones presented above, and northern Mexico will remain the magnificent and biologically wealthy land it is today. It is our hope that this book will contribute toward realizing this optimistic scenario.

Literature Cited

Ananthaswamy, A. 2003. Death in the sun. New Scientist 26 July 2003. Vol. 179, no. 2405: 12–13.

Ceballos, G. and L. Marquéz. 2000. Las Aves de México en Peligro de Extinción. CONABIO–UNAM–Fondo de Cultura Economica, México D.F.

Ceballos, G., J. Arroyo-Cabrales, and R. A. Medellín. 2002. The mammals of México: composition, distribution, and status. Occasional Papers, Texas Tech University 218: 1–27.

Comisión Nacional de Áreas Naturales Protegidas (CONANP). 2003. Áreas Naturales Protegidas. [Available: www.conanp.gob.mx/]

Dirzo, R., and G. Gomez. 1996. Temporal patterns of taxonomic research on Mexican vascular plants and estimates of the number of known species. Annals of the Missouri Botanical Garden 83: 396–403.

Felger, R., W. J. Nichols, A. Aquirre, F. Arcas, L. Bourillón-Moreno, R. Brusca, J. Compoy, A. Cantú, J.-L. Cartron, G. D. Danemann, H. D'Antoni, P. K. Dayton, S. A. Diehn, L. Gerber, J. L. León de la Luz, C. Mártinez del Rio, R. A. Medellín, F. Molina Freaner, E. Palacious-Castro, and E. Sala. 2004. Escalera Ecológica Initiative: A staircase of reserves through the Gulf of California Corridor. P. 71 *in* Proceedings of the Gulf of California Conference 2004, Tucson.

Flores-Villela, O., and P. Geréz. 1994. Biodiversidad y Conservación en México: Vertebrados, Vegetación y Uso del Suelo. CONABIO and UNAM, Mexico D.F.

Malakoff, D. 2002. Bird advocates fear that West Nile virus could silence the spring. Science 297: 1989.

Mittermeier, R. A., P. Robles Gil, and C. Goettsch Mittermeier. 1997. Megadiversity: Earth's Biologically Wealthiest Nations. CEMEX, México D.F.

Mittermeier, R. A., P. Robles Gil, and C. Goettsch Mittermeier. 2003. The Last Wilderness. CEMEX, México D.F.

Notarbartolo di Sciara G. 2002. Cetacean species occurring in the Mediterranean and Black Seas. *In* G. Notarbartolo di Sciara (ed.), Cetaceans of the Mediterranean and Black Seas: State of Knowledge and Conservation Strategies. A report to the ACCOBAMS Secretariat, Monaco, February 2002, section 3.

Quignard, J. P., and J. A. Tomasini. 2000. Mediterranean fish biodiversity. Biologia Marina Mediterranea 7(3): 1–66.

Whitehead, P. J. P., M.-L. Bauchot, J.-C. Hureau, J. Nielsen, and E. Tortonese (eds.). 1986. Fishes of the North-Eastern Atlantic and the Mediterranean, 3 vols. UNESCO, Paris.

I

HISTORICAL, GEOGRAPHICAL, AND LEGAL SETTING

1

Northern Mexico's Landscape, Part I: The Physical Setting and Constraints on Modeling Biotic Evolution

ISMAEL FERRUSQUÍA-VILLAFRANCA
LAURA I. GONZÁLEZ GUZMÁN
JEAN-LUC E. CARTRON

A proper understanding of the biodiversity of any area should include adequate knowledge of the regional geologic and biotic evolution. In northern Mexico (and many other regions as well), the history of biotic evolution is poorly known. As a result, the studies that model this evolution are largely speculative, yielding not only different but sometimes contradictory findings. The Cenozoic terrestrial vertebrate record is small, but it is sufficient to give us a tantalizing view of the fauna that inhabited this region. In contrast, the Cenozoic angiosperm/gymnosperm record is practically nonexistent; thus, knowledge of the floristic evolution of northern Mexico is filled with inferences or extrapolations from (a) fossil floras from outside the region, (b) this region's Recent floristic composition and/or biogeographic relationships, or (c) a combination of both approaches. The same applies to the terrestrial invertebrate record. Under these circumstances, it is necessary to have means (factual constraints, for instance) to help generate or choose the most parsimonious model.

The solution to this problem would be hopeless were it not for the fact that in any given region, geologic history is intimately linked to the evolution of the biota. Geologic forces continuously mold and change the land upon which the biota develops through time. In this chapter, we describe and discuss the geographic/geologic framework of northern Mexico, sketching how its present-day landscape developed and how the geologic processes/events and the geographic features involved most likely influenced the Cenozoic biota, thus setting constraints on modeling its development. Three examples show what is meant.

(1) The latitudinal position of northern Mexico largely determines the amount of solar energy the region receives and the manner in which this energy is distributed throughout the year. Therefore, to understand the regional history of biotic development, it is essential to establish whether the position of northern Mexico has changed in the geologic past. If it has changed, what was the magnitude of the latitudinal and/or longitudinal displacement, and when did it occur? The answer will greatly influence the model used for describing biotic development.

(2) Were northern Mexico's major geographic features, such as its cordilleras, generated concurrently or at different times? Regardless of the answer, the origin and development of geographic features must have produced discontinuities in the distribution of the then-existing biota, promoting some degree of differentiation. Are the regional biotas now present in northern Mexico the result of such process or processes? When did this all happen? These biotic questions could be addressed in part through an analysis of the geologic (lithic, structural, and fossil) record, which again will set constraints on models attempting to

delineate the region's biotic development or evolution.

(3) It is known that geographic diversity (largely physiographic) enhances habitat diversity, which in turn greatly influences species richness (i.e., biodiversity). Northern Mexico's present-day landscape is physiographically quite diverse and sustains a highly diverse biota. Therefore, knowledge of when and how this region's high geographic diversity came about will also help us understand how and when its biota originated and became diversified.

Each of these issues is addressed in the following sections of this chapter.

As defined in this chapter, northern Mexico corresponds to the territory located from the Trans-Mexican Volcanic Belt north to the Mexico–U.S. border (fig. 1.1). It covers approximately 1,245,900 km^2, or nearly two-thirds of the country's total area, and includes 19 states. It lies between 20°30'–32°30' N and 96°30'–117°15' W. Oceans bound northern Mexico both to the east and west, and it also includes a narrow northwest-southeast trending sea, the Gulf of California. Northern Mexico's littoral is approximately 6,400 km long (four-fifths of it is along the Pacific Ocean–Gulf of California). Two of Mexico's largest cordilleras lie in this territory, which shows a wide array of landforms, climates, and biomes. Figures 1.2–1.6 depict the region's major geographic factors greatly influencing species distribution.

Given the fact that the physical geographic features (e.g., relief, landforms) reflect their geologic makeup, structure, and history, it follows that in a large territory it is possible to discriminate zones that have geomorphic and geologic/tectonic features distinctive enough to differentiate them from neighboring ones. Such zones are the morphotectonic provinces. Once distinguishing criteria have been defined, the recognition of the provinces is objective. Morphotectonic provinces allow an orderly description of vast territories. The description of northern Mexico presented below follows the morphotectonic province division presented elsewhere (Ferrusquía-Villafranca 1993) and represents the only such classification, where the provinces are precisely defined and characterized. Cli-

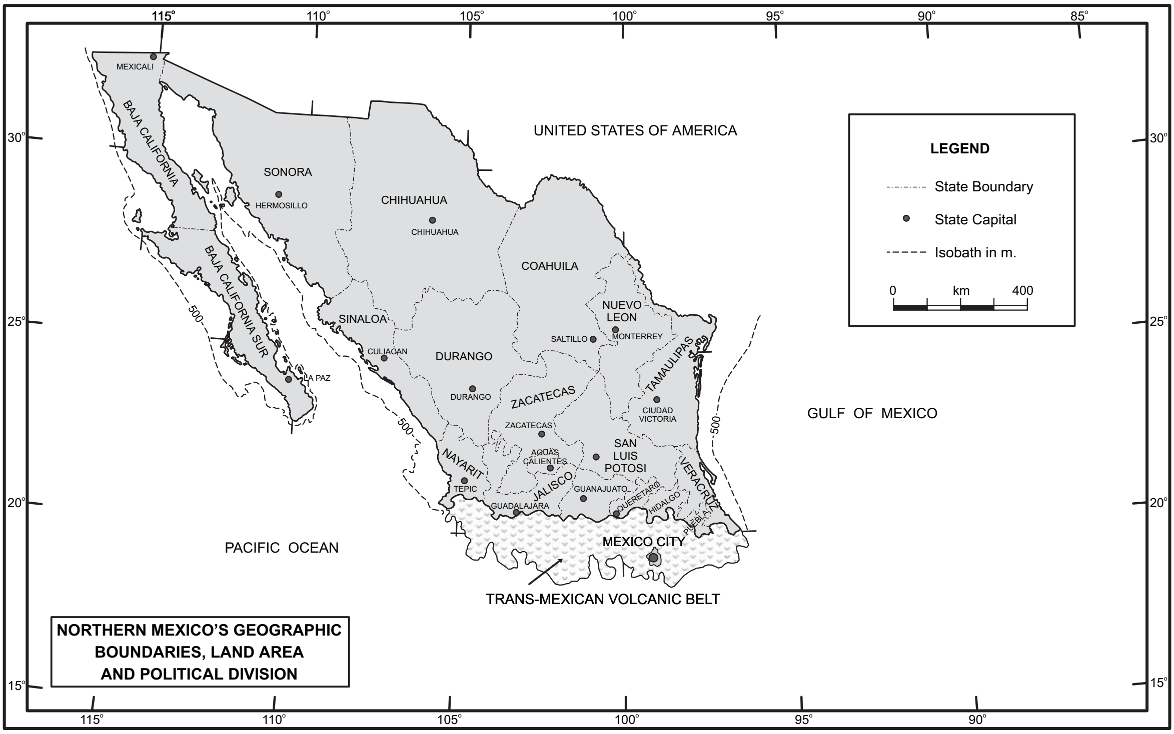


Figure 1.1. Geographic boundaries, land area, and political division of northern Mexico.

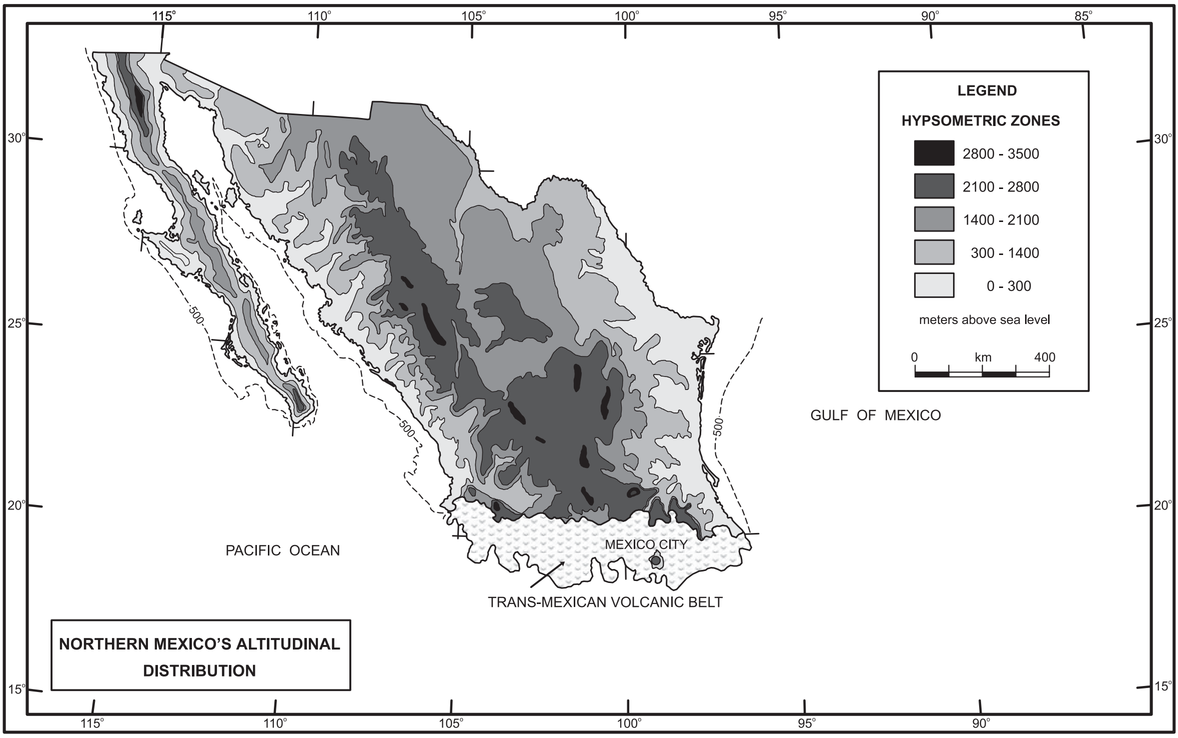


Figure 1.2. Northern Mexico's altitudinal distribution map (modified from Perez-Villegas 1990).

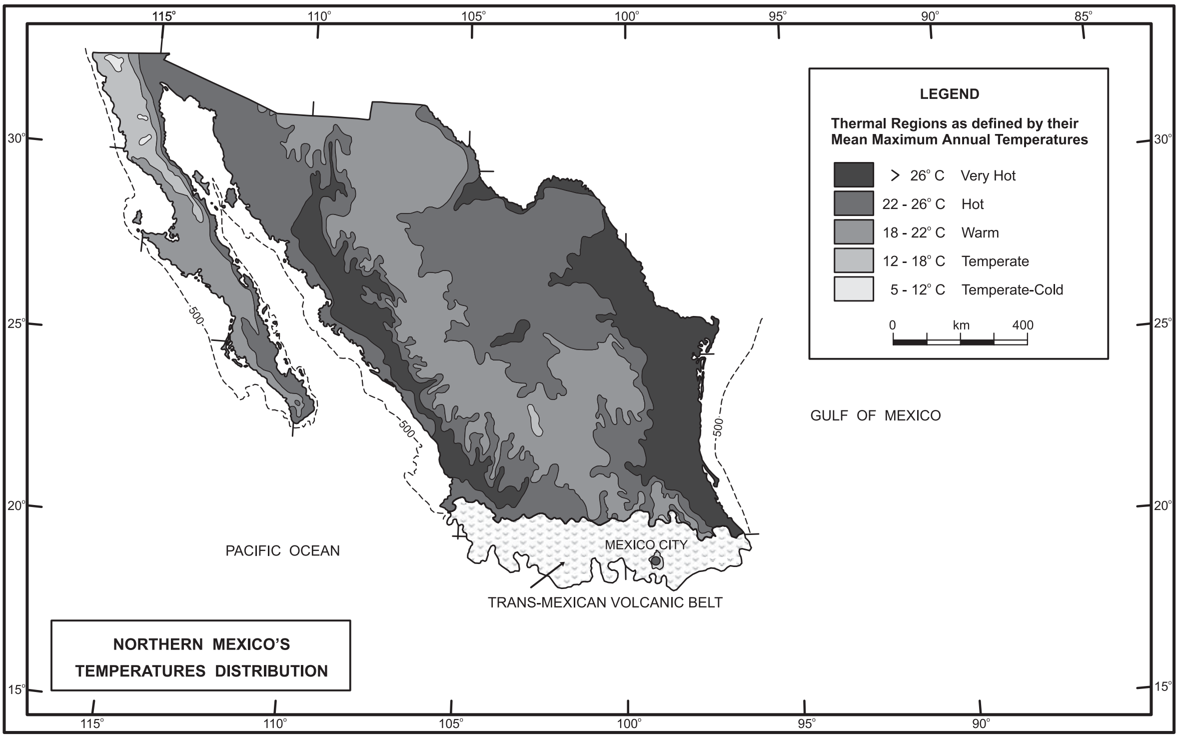


Figure 1.3. Northern Mexico's temperature distribution map (modified from Vidal-Zepeda 1990a).

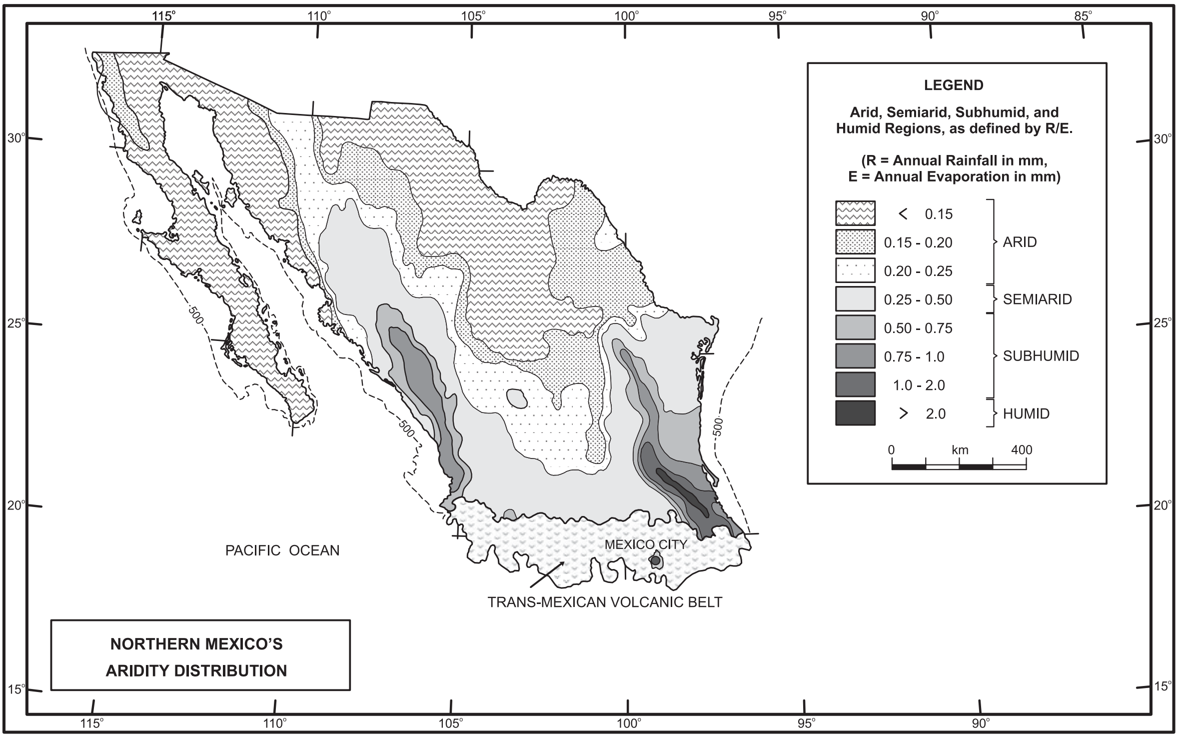


Figure 1.4. Northern Mexico's aridity distribution map (modified from Hernandez 1990).

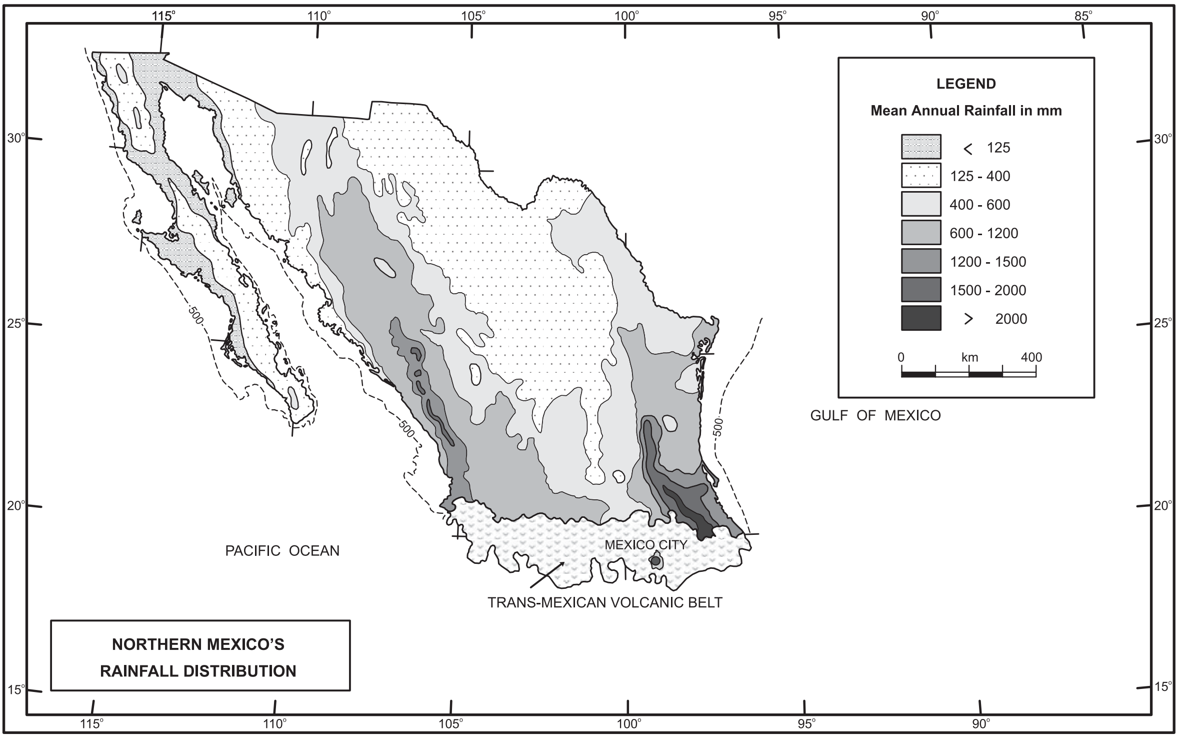


Figure 1.5. Northern Mexico's rainfall distribution map (adapted from Vidal-Zepeda 1990b).

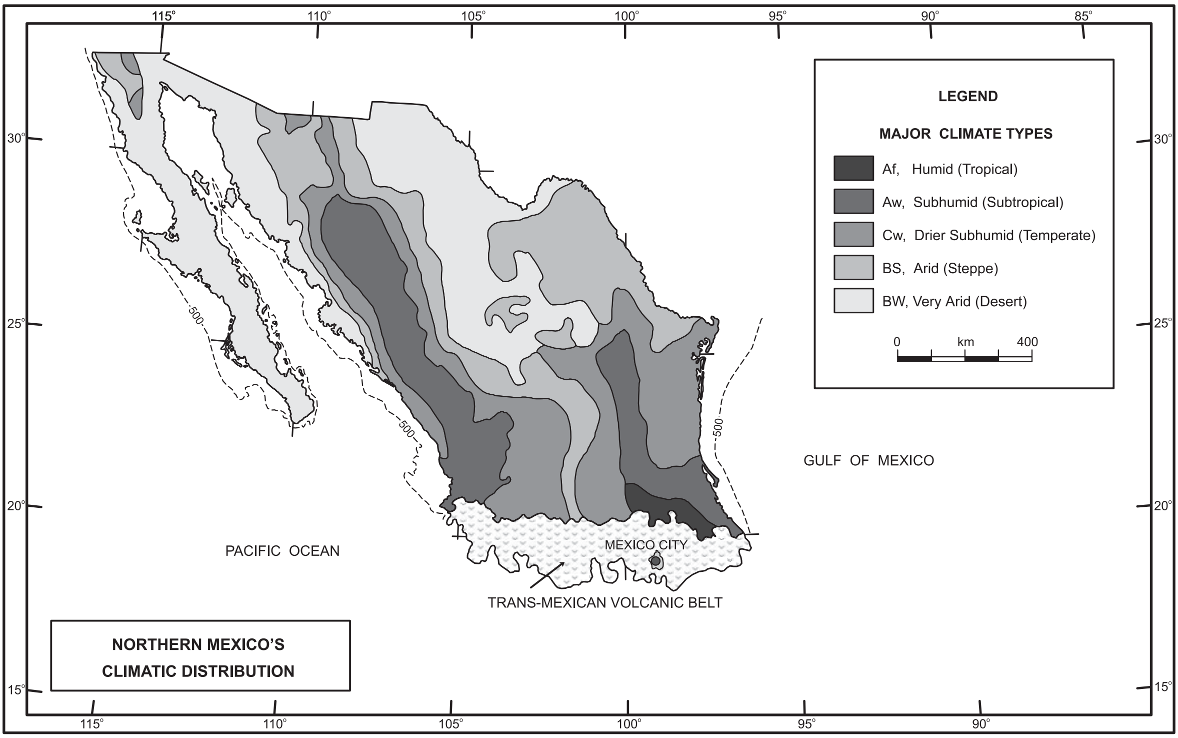


Figure 1.6. Northern Mexico's climatic regions map (adapted from García 1990).

mate description is based on García's (1990) and Köppen-Trewartha's (Trewartha 1968; adapted by García 1988) classifications.

Physical Setting: Northern Mexico's Morphotectonic Provinces

Northern Mexico has 7 morphotectonic provinces: (1) Baja California Peninsula, (2) Northwestern Plains and Sierras, (3) Sierra Madre Occidental, (4) Chihuahua-Coahuila Plateaus and Ranges, (5) Sierra Madre Oriental, (6) Gulf Coastal Plain, and (7) Central Plateau. Their boundaries are defined in figure 1.7, and their main geographic features and climates, designated by three-letter abbreviations, are given in table 1.1. The geology of the morphotectonic provinces can be visualized with the aid of figure 1.8, a generalized geologic map of northern Mexico. To complement the information presented, some selected references to comprehensive or recent works dealing with specific or controversial views are provided following the geologic description of each province.

1. Baja California Peninsula Morphotectonic Province

Geographic Aspect

This province is located between 23°00'–32°30' N and 109°30'–117°15' W. It is about 1,200 km long, with an average width of 95 km and an area of 144,000 km^2; the dominant climate is BWh (dry desert group, hot tropical-subtropical type; see table 1.1), cooling northward. Elevation varies between 0 and 2130 m above sea level (masl); most of the mountainous country lies below 1000 masl; the northern half of the province is more mountainous. The peninsula has some 13 rather short, largely seasonal rivers that discharge into the Pacific Ocean. None of these rivers is large (the Río Colorado, the river marking the boundary between the states of Baja California and Sonora, lies east of the Baja California Peninsula Morphotectonic Province, in the Northwestern Plains and Sierras Morphotectonic Province [see fig. 1.7]). There are no lakes.

The Baja California peninsula includes a series of sierras, collectively known as Peninsular Ranges.

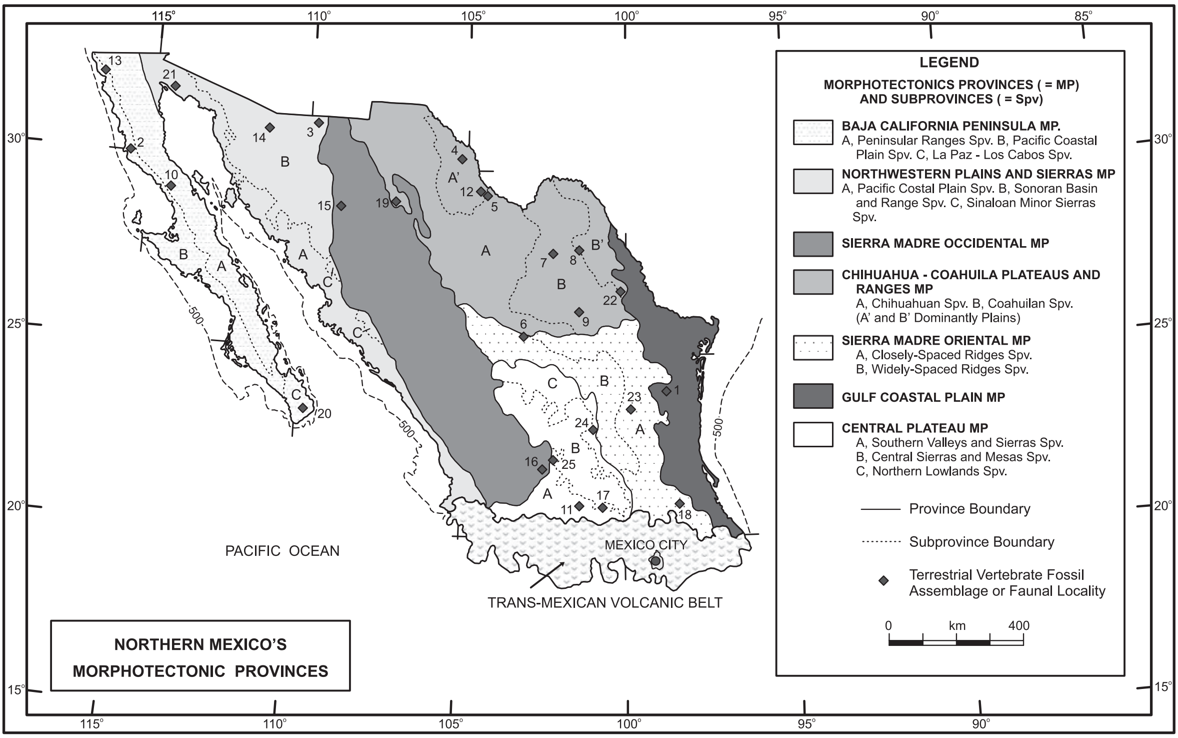


Figure 1.7. Northern Mexico's morphotectonic provinces map (adapted from Ferrusquía-Villafranca 1993, figs. 1.1, 1.2, 1.3, 1.4, 1.5, and 1.8). The chief terrestrial vertebrate fossil localities are also shown (black diamonds). Early Jurassic: **1**, Cañón de Huizachal, Tams. Late Cretaceous: **2**, El Rosario, B. C. N.; **3**, Cuenca de Cabullona, Son; **4**, Sierra Mojada, Chih; **5**, Ojinaga, Chih; **6**, Torreón, Coah; **7**, Hipólito, Coah; **8**, Palau-Múzquiz-Nueva Rosita area, Coah; **9**, Rincón Colorado-Cerro del Pueblo area, Coah. Eocene: Early (Wasatchian): **10** Punta Prieta (Lomas Las Tetitas de Cabra, also known as Occidental Butes), B. C. N. Middle (Bridgerian-Uintan): **11**, Marfil, Gto. Late (Chadronian): **12**, Ojinaga (Rancho Gaitán), Chih. Miocene, Early (Hemingfordian): **13**, La Misión, B. C. N.; **14**, Tubutama, Son; **15**, Yécora, Son; **16**, Zoyatal, Ags. Late (Hemphillian): **17**, San Miguel de Allende area, Gto; **18**, Tehuichila-Zacualtipan area, Hgo; **19**, Yepómera, Chih. Late Pliocene-earliest Pleistocene (Blancan): 17, 19 and **20**, Las Tunas, B. C. S. Pleistocene, Middle (Irvingtonian): **21**, El Golfo, Son. Late (Rancholabrean): **22**, Bustamante Cave, N. L; **23**, San Josecito Cave, N. L./Tams. Border; **24**, El Cedral, S. L. P.; and **25**, Arroyo El Cedazo, Ags.

These span nearly the entire length of the peninsula. In Baja California Sur the ranges are narrower, allowing enough space westward for a broad lowland, the Pacific Coastal Plain (<200 masl), which is widest where it forms the Vizcaíno Desert. The Peninsular Ranges and Pacific Coastal Plain make up the first two subprovinces of the peninsula (fig. 1.7). The Peninsular Ranges end by Bahía de La Paz, giving way southward to the La Paz–Los Cabos (Range and Upland) Subprovince.

Geologic Aspect

The geologic features of the northern and southern halves of the peninsula are quite different, so we describe them separately (fig. 1.8).

Northern Baja California. The Peninsular Ranges include some small portions of Paleozoic crystalline rocks, but largely they consist of Mesozoic (mainly Cretaceous) metamorphic and granitoid plutonic rock bodies. Clastic marine and conti-

Table 1.1. Location and main features of northern Mexico's morphotectonic provinces.

Province[a]	Location	Surface Area (km^2)	Elevational Ranges (m)	Climate[d]	Chief Land Form
1	Northwestern Mexico 109°30'–117°00' W, 23°00'–32°30' N	144,000 (7.3%)[b]	0–2130 (0–1,000)[c]	BWh, BShs, Csa	Sierras and plains
2	Northwestern Mexico 107°00'–116°00' W, 23°00'–32°30' N	236,800 (12%)	0–2200 (200–1000)	BWh, BSh	Sierras and plains
3	Western and northwestern Mexico 102°20'–109°40' W, 20°30'–31°20' N	289,000 (14.7%)	200–3000 (2000–3000)	Cfb, Aw	Sierras and plateaus
4	Northern Mexico 101°31'–110°31' W, 26°00–31°45' N	255,900 (12.5%)	200–2000 (800–1200)	BShw, BWh, BSk	Sierras and plateaus
5	Northeastern and northcentral Mexico	145,500 (7.5%)	200–3000 (1000–2000)		Sierras
	Transverse Sector 100°00'–105°00' W, 24°30'–26°00' N			BWh, BSk	
	Eastern Sector 97°30'–101°20' W, 19°40'–26°00' N			Cfa, Cwa, BSh	
6	Eastern Mexico/Northern Sector 95°30'–100°20' W, 20°00'–26°00' N	87,200 (4.4%)	0–200	Aw', Cw, Cx'w'	Plains
7	Central Mexico 100°00'–104°00' W, 21°00'–24°00' N	85,300 (4.3%)	1000–3300 (2000–3000)	BSh	Plateaus
TOTAL		1,245,900 (62.9%)			

[a] Province names: 1 = Baja California; 2 = Northwestern Plains and Sierras; 3 = Sierra Madre Occidental; 4 = Chihuahuan-Coahuilan Plateaus and Ranges; 5 = Sierra Madre Oriental; 6 = Gulf Coastal Plain; 7 = Central Plateau.

[b] Percent area of Mexico.

[c] Dominant elevational range.

[d] Climate types: BWh = desertlike, mean annual temperature (MAT) > 18°C; BShs Csa = temperate with dry winter; BSh = dry, MAT > 18°C; Cfb = temperate humid with no dry season; BShw = steppelike, winter dry season, MAT > 18°C; BSk = steppelike, MAT > 18°C; Cfa = temperate, no defined dry season; Cwa = temperate with dry winter; Aw = subtropical with dry winter and warm rainy summer; Aw' = tropical with dry winter and rainy summer; Cw = temperate with dry winter; Cx'w' = temperate with little rain throughout the year. The key to the letter symbology is: A = warm humid and subhumid climate group (lack of a well-defined dry season); m = rainy season restricted to the summer; w = dry winter and warm season from April to September; w' = less rainy summer with a short dry season. B = warm to cold and very arid to semiarid climate group; BS = warm to semicold and arid to semiarid climate subgroup; BW = warm to semicold and very arid climate subgroup; h = semiwarm with cool winter; k = temperate with a warm summer; s = rainy winter; C = temperate to semicold and humid to semihumid climate group; a = warm summer; b = cool and long summer; x = rainfall. Source: García 1988.

From Ferrusquía-Villafranca (1993).

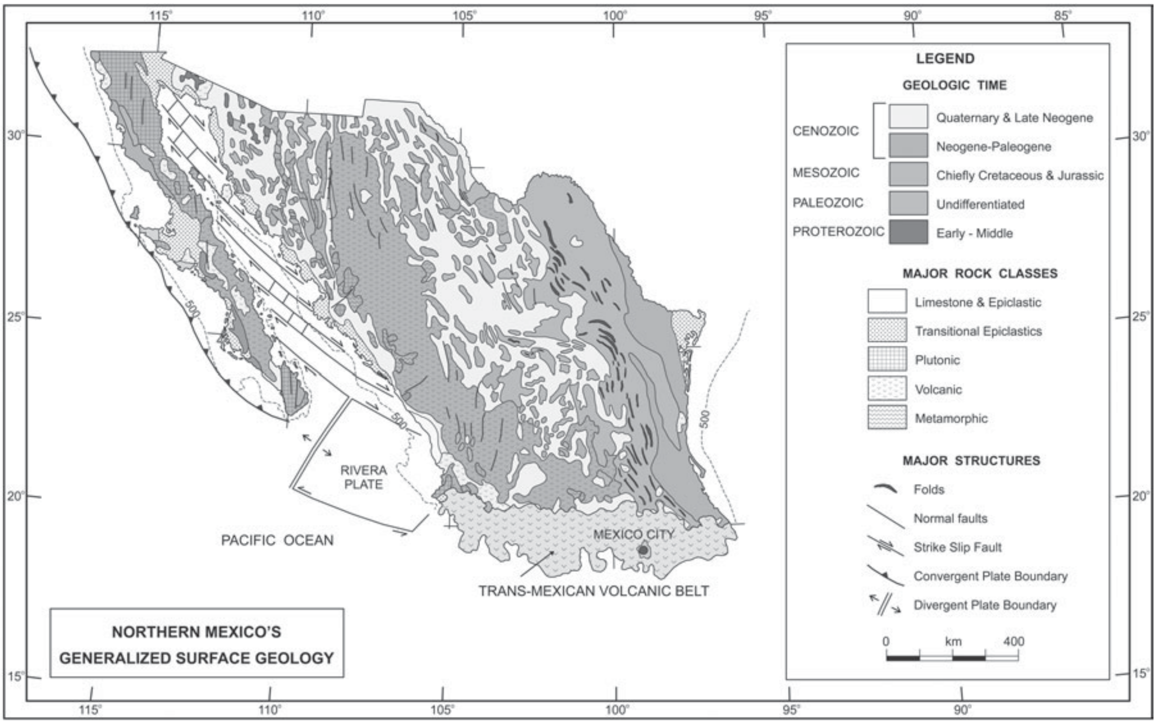


Figure 1.8. Northern Mexico's generalized geologic map (adapted from De Cserna 1990; Ortega-Gutiérrez et al. 1992; Ferrusquía-Villafranca 1993, figs. 1.3, 1.5, 1.7, and 1.9).

nental Cretaceous units occupy part of the narrow Pacific Plain. Dinosaurs and mammals have been found in it (fig. 1.7, location 2; Morris 1967, 1973, 1981; Lillegraven 1972, 1976; Molnar 1974; Clemens 1994; Montellano-Ballesteros 2002). Early Tertiary shallow marine and continental units occur in the south. An Early Eocene (Wasatchian) land mammal fauna, the oldest Cenozoic one from Mexico, was collected from a site near Punta Prieta (fig. 1.7, location 10; Novacek et al. 1991). Late Tertiary volcanics and Plio-Quaternary beach deposits occur in the rest of the plain. Faults deformed the Pre-Quaternary units (fig. 1.8).

Southern Baja California. The largest feature is the Sierra de la Giganta, consisting of Early Neogene volcanics (mafic lava flows and silicic pyroclastic sheets), and fluvio-lacustrine epiclastics and volcaniclastics ("Comondu Formation"). West of La Giganta, the Pacific Plain widens and largely consists of Late Tertiary-Quaternary, fine-grained, shallow marine to beach deposits. Older clastic units occur to the east. Some have yielded Late Oligocene and Miocene marine vertebrates and dicotyledon (legume) wood (Weber and Cevallos-Ferriz 1994). Baja California Sur has a Mesozoic core of sedimentary marine rock bodies, ophiolites, and basaltic volcanics, all indicative of an ocean floor origin.

The peninsular southern end is set apart by a major north–south trending fault and largely consists of a Cretaceous granitoid pluton, unconformably covered by Late Cenozoic fine-grained marine and continental clastics (fig. 1.8); a large Late Pliocene terrestrial vertebrate fauna was recovered from these clastics (fig. 1.7, location 20; Miller 1980).

Gulf of California. The Gulf includes islands formed by volcanic, sedimentary, and/or metamorphic bodies similar to those of adjacent lands. The islands represent uplifted or detached blocks of the submerged continental platform. The oceanic (basaltic) floor is present only in the southern half; it is about 4 ma old and is affected by left lateral faults (arranged *en echelon*), ultimately related to the San Andres Fault System and to the opening of the Gulf (fig. 1.8).

Late Oligocene and Early Miocene marine fossils (e.g., mammals, sharks, mollusks) found in the Gulf margin of Baja California Sur (San Telmo-Bahía de La Paz, ~24–26° N; Vanderhoof 1942; Durham 1950; Smith 1991; Cruz-Marín and Barnes 1996; Barnes 2002) reveal the presence of a marine environment, the "Protogulf," long before the oceanization of its floor (ca. 4 ma).

Selected references. The whole peninsula: Beal 1948; Gastil et al. 1981; Frizzell 1984; Hausback 1984. Northern Baja California: Gastil et al. 1975. Southern Baja California and the Gulf Region: Henry 1989; Ortlieb 1991a,b; Fletcher et al. 2003; Ledezma-Vázquez and Johnson 2003; Oskin and Martín-Barajas 2003.

2. Northwestern Plains and Sierras Morphotectonic Province

Geographic Aspect

The Northwestern Plains and Sierras Province lies between 23°00'–32°30' N and 116°00'–117°00' W; its shape is that of an elongated, obtuse triangle (the southern two-thirds is quite narrow). The base of the triangle is an approximately 640-km long segment of the U.S.–Mexico boundary. Westward, the province is bounded by the 1,870-km long Sonora-Sinaloa-Nayarit Pacific margin, and to the east it shares its 1,280-km long boundary with the Sierra Madre Occidental (fig. 1.7).

The area is about 236,800 km^2. Elevation ranges from 0 to 2,200 masl, but the 200–1,000 masl hypsometric zone is dominant. The climate is desertic (BWh group; see table 1.1) in the northwest, and dry (Bsh group) elsewhere. This province has 7 major rivers, all of which drain to the Gulf of California. Dams have been built along some of these rivers, at least 2 of them where natural lakes existed.

Three main geomorphic zones are present and are recognized as distinct subprovinces: (1) The Pacific Costal Plain, defined by the 200 masl contour line; its southern Sonora–Sinaloan littoral is especially diverse, including delta complexes, estuaries, lagoons and sand bars. (2) The Sonoran Basin and Range (an extension of the U.S. namesake province) consists of narrow, closely spaced, north-northwest–south-southeast trending block mountains, separated by corresponding basins. (3) The Sinaloan Minor Sierras form the smallest geomorphic zone, and show no basin-and-range pattern (fig. 1.7).

Geologic Aspect

Numerous north-northwest–south-southeast trending faults divide the larger part of the province into narrow, uplifted blocks (the sierras or ranges) and downthrown blocks (the basins), where late Middle to Late Tertiary clastic deposits have accumulated; in Tubutama, some have yielded Early Miocene camels (see below). The upthrown blocks exhibit different parts of the geologic column (from Precambrian to Mesozoic), depending on their actual individual uplift and erosion (fig. 1.8).

The Pre-Cambrian consists of high-grade metamorphics, intruded by granitic plutons. The Paleozoic is formed by marine carbonate and siliciclastic units. The Late Triassic-Early Jurassic units are largely continental, both volcanic and clastic. The Cretaceous includes volcanic, plutonic, and marine carbonate units.

The Cenozoic includes Early Tertiary granitoid plutons (genetically related to copper deposits), Middle Tertiary silicic, mesa-forming pyroclastics, epiclastics, and Late Tertiary-Quaternary basaltic flows and clastic units. It appears that coeval to this volcanic activity, extensive parallel block-faulting tectonically overprinted all preexisting rock bodies, giving this province its characteristic basin and range structural pattern. Neogene continental deposits were preserved in the basins thus formed; in one such deposit at Tubutama, a Miocene, highly specialized camel, *Stenomylus tubutamensis*, was recovered and described (fig. 1.7, location 14; Ferrusquía-Villafranca 1990a). The Stenomylini had gazellelike proportions, a short face, and highly hypsodont, very elongated molars; they tended to be smaller than contemporary camels, left no descendants, and geographically were restricted to West Texas, southern New Mexico–Arizona, and, of course, northern Sonora (Ferrusquia-Villafranca 1990a; Honey et al. 1998).

In the southern part of the province, the basin and range pattern does not exist. The Paleozoic, Createaceous, and Early Tertiary units are largely crystalline (high-grade metamorphics, granitoid plutons, and rhyolitic to basaltic volcanics). Middle Tertiary pyroclastics occur near the Sierra Madre Occidental (fig. 1.8).

The Quaternary in the Pacific Coastal Plain consists of tabular, marine-continental bodies developed by prograding delta complex systems, whose sediments were redistributed by waves, tides, and along-shoreline currents. A large Middle Pleistocene terrestrial vertebrate fauna is known from the northwestern end of this subprovince (fig. 1.7, location 21; Shaw 1981; Arroyo-Cabrales et al. 2002).

Selected references. Cook and Bally 1975; Roldan-Quintana 1984; Henry and Aranda-Gómez 1992; Bortolini et al. 1995; McDowell et al. 1997; Roldan-Quintana et al. 2003.

3. Sierra Madre Occidental Morphotectonic Province

Geographic Aspect

The Sierra Madre Occidental Province lies between 20°30'–31°20' N and 102°20'–109°40' W; it includes parts of Sonora, Chihuahua, Durango, Sinaloa, Zacatecas, Nayarit, and Jalisco. It is Mexico's largest morphotectonic province (~289,000 km^2), and it has a rectangular shape (length 1300 km, average width 190 km). Elevation varies from 200 to 3000 masl, dominating in the 2000–3000 masl hypsometric zone. Elevation exerts a greater influence on the climate than does the 10° latitudinal spread. The Cfb temperate humid climate (see table 1.1) dominates at the higher elevations, while lower terrain is characterized by its humid subtropical, winter-dry climate (Cwa). Near the coast, the climate type is tropical wet-and-dry (Aw).

The Sierra Madre's western slope, being more humid, has more rivers (11) than the eastern slope (5). Along the western slope, those rivers in the northern half of the Sierra Madre Occidental discharge into the Gulf of California, while the other rivers drain into the Pacific Ocean. The rivers of the eastern slope drain into the Rio Grande (Río Bravo) or in "La Laguna," and in one endorheic basin located in northwest Durango–southeast Coahuila. Lago Santiaguillo, about 70 km north of Durango City, is the only lake in this province.

Geomorphologically, the province consists of closely spaced volcanic sierras and plateaus that coalesce to form larger ranges. River systems draining largely into the Gulf of California separate the individual sierras and plateaus (fig. 1.7).

Geologic Aspect

The volcanic bodies that make up the Sierra Madre Occidental Province are arranged in 2 complexes. The Lower Complex chiefly consists of andesitic lavas and pyroclastic sheets (some are rhyolitic) dating 100–45 ma; it is broadly arcuate and intensely faulted; its basement is largely unknown, but some Cretaceous carbonates have already been detected. The Upper Complex unconformably overlies the Lower Complex and consists of an extensive silicic ignimbrite succession up to 1000 m thick that spans the province. The ignimbrites issued largely through calderas (200–400), some very large (diameter 40 km), dating 54–34 ma (dominating the younger ones). The Upper Volcanic Complex is largely horizontal (fig. 1.8).

Locally, Late Cenozoic sedimentary clastic bodies occupy structural or topographic depressions; a Middle Miocene leporid and some large Quaternary mammals have been recovered from these clastic bodies (fig. 1.7, location 15; Ferrusquía-Villafranca 1990a, unpubl. data). In the northwestern part of the province, near Yépomera, Chihuahua, a large latest Miocene-earliest Pliocene mammal fauna has been known for a long time (fig. 1.7, location 19; Lance 1950; Ferrusquía-Villafranca 1978; Lindsay and Jacobs 1981; Lindsay 1984). In the southeast, Miocene mammals are also known from Aguascalientes (fig. 1.7, location 16; Dalquest and Mooser 1974; Ferrusquía-Villafranca 1990a, 2003).

Selected references. McDowell and Clabaugh 1979; Roldan-Quintana 1984; Moore et al. 1994; Nieto-Samaniego et al. 1999; Aranda-Gómez et al. 2003; Roldan-Quintana et al. 2003.

4. Chihuahua-Coahuila Plateaus and Ranges Morphotectonic Province

Geographic Aspect

The Chihuahua–Coahuila Province lies between 26°00'–31°45' N and 101°31'–110°31' W; it is bounded to the west and south by the Sierras Madre Occidental and Oriental, respectively, and to the north by the Rio Grande; to the east, it grades into the Gulf Coastal Plain (the 200 masl contour line is the limit). The area is about 255,900 km^2. Elevation ranges from 200 masl to a little higher than 2000 masl. The western half is higher (>1200 m); in the eastern half, eastern Coahuila gradually slopes down to the Coastal Plain. The climate is very arid in the west (Bw group; see table 1.1), grading to less arid to the northeast (steppelike; Bs group).

The Rio Grande and its tributary the Río Conchos are the only major rivers in this province. Smaller rivers discharge into endorheic basins; some basins have lakes, such as Laguna Guzman, Laguna

Santa María, and Laguna Patos in northern Chihuahua, and Lago Toronto and Lago Palomas in northwestern Durango. Coahuila has only 1 lake (along the Río Salado, in the northeast, close to the Coahuila–Nuevo León border), which has been dammed and named Venustiano Carranza Dam.

Geomorphologically, the province includes low, northwest–southeast trending block-folded ranges and block-mesas, separated by flat-lying basins and plateaus. In the northwest, the ranges are fairly narrow and largely consist of Cretaceous limestone and Neogene volcanics; in the north, large mesas are present; everywhere else mesas and wider ranges dominate, formed also by Cretaceous limestone, while volcanics are scarce. Lowlands occur in the southwest (Bolson de Mapimi) and south (La Laguna area); the latter area separates this province from the Sierra Madre Oriental (fig. 1.7; small-scale maps do not allow us to plot these last features).

Geologic Aspect

The Late Precambrian and Paleozoic units have a very small total outcrop area (Villa Aldama-Placer de Guadalupe in northern Chihuahua, and Delicias in southwestern Coahuila). Jurassic units also are little exposed, chiefly occurring in the Placer de Guadalupe area, so that the Mesozoic sequence is mainly composed of Cretaceous units. The Cretaceous units largely consist of marine carbonates and clastics; this character and the stratigraphic succession are similar to those of the Sierra Madre Oriental. The major difference between the 2 provinces pertains to structural style. The folds of the Chihuahua-Coahuila Plateaus and Ranges are somewhat broader, axially trending northwest–southeast, and form 2 discontinuous or distinct sets. The northwestern set of folds is parallel to the Rio Grande in the north of Chihuahua and seems to correspond to a pull-apart basin, the Chihuahua Trough (Haenggi 2002). The other set of folds originates in the Big Bend area of Texas, ending north of Monterrey, but the folds do not coalesce with those of the Sierra Madre Oriental. Elsewhere in Coahuila, the Cretaceous units form block-faulted, somewhat tilted, mesas (fig. 1.8). Late Cretaceous dinosaurs have been recovered from scattered localities both in Chihuahua and Coahuila (fig. 1.7, locations 4–9; Rodríguez de la Rosa and Cevallos-Ferriz 1998; Ferrusquía-Villafranca, unpubl. data).

The Cenozoic is continental, unconformably overlies Cretaceous units, and in Chihuahua includes silicic volcanics of Oligocene-Miocene age that form northwest–southeast trending sierras, frequently bounded by faults. Small silicic plutons and mafic lava flows complete the igneous rock succession in Chihuahua. In Coahuila, this succession is less well represented. The intermontane basins and lowlands are frequently grabens, where volcaniclastic and epiclastic fluviolacustrine Late Paleogene or Neogene deposits occur (fig. 1.8). Near Ojinaga, Chihuahua, a Late Eocene mammal fauna was collected from one such deposit, the Prietos Formation (fig. 1.7, location 12; Ferrusquía-Villafranca 1969; Ferrusquía-Villafranca and Wood 1969; Ferrusquía-Villafranca et al. 1997). Thin, flat-lying Quaternary deposits floor the basins and lowlands.

Selected references. Imlay 1936, 1938, 1943, 1944; Bridges 1965; Bridges and DeFord 1965; Navarro and Tovar 1974; Cook and Bally 1975; Charleston 1981; Eguiluz 1984; Brown and Dyer 1987; Haenggi 2001, 2002.

5. Sierra Madre Oriental Morphotectonic Province

Geographic Aspect

The Sierra Madre Oriental Province is divided into the Closely-Spaced Ridges and Widely-Spaced Ridges Subprovinces (fig. 1.7), which largely differ in structural features (see below). Another more informal but quite practical geographic subdivision, into Eastern and Transverse Sectors, is first used to describe this province. The name and position of these sectors are descriptive enough, so that they were not discriminated in figure 1.7.

The Eastern Sector lies between 19°40'– 26°00' N and 97°30'–101°20' W; its area is about 77,000 km^2; it is 550 km long and 140 km wide (average) and extends from the Trans-Mexican Volcanic Belt in the south to the Monterrey area, Nuevo León, in the north. The Transverse Sector is the western extension of the Eastern Sector, reaching as far as the Sierra Madre Occidental. This sector then chiefly lies east–west (i. e., transverse to the Eastern Sector [hence the name]), between 24°30'–26°00' N and 100°00'–105°00' W; its area is about 68,000 km^2, and it is 400 km long and 120 km wide (average).

Elevation varies from 200 to slightly higher than 3000 masl, but with an uneven distribution; the 1000–2000 masl hypsometric zone is dominant. The Eastern Sector's climate varies from Cfa temperate humid to Cwa temperate dry (see table 1.1), whereas the Transverse Sector's climate is dominantly BWh desertic.

The humid eastern slope of the Sierra Madre's Eastern Sector is the one that has rivers. All 10 of them drain to the Gulf of Mexico; most have carved deep gorges and canyons. The Ríos Santa María and Moctezuma, tributaries of the Río Pánuco, are the only rivers that have cut through the entire width of this sector. There are no lakes in the Sierra Madre Oriental. Karstification is extensive.

Geomorphologically, this province consists of folded ridges and intermontane, elongated valleys, and plateaus. It is the spacing and other features of the ridges that allow the distinction between the 2 subprovinces.

Geologic Aspect

The province consists largely of Early Jurassic continental and shallow marine (siliciclastics and evaporates) units and Cretaceous marine carbonate units that change upward to fine clastic, shallow marine to transitional units. The exposed area is much less for the Jurassic than for the Cretaceous. This latter system is dominated in extent and thickness by the Lower Cretaceous (Ortega-Gutiérrez et al. 1992); it represents the transgression apex of the epicontinental sea that covered much of northern Mexico at that time (fig. 1.8).

Late Cretaceous dinosaurs have been collected from several localities in the Eastern Sector (fig. 1.7, location 6; Ferrusquía-Villafranca, unpubl. data), and in southern Coahuila, near this sector; in 1 locality, scarce angiosperm remains were also found (fig. 1.7, location 9; Rodriguez de la Rosa and Cevallos-Ferriz 1998). The only Jurassic (Early) vertebrate fauna of this province comes from the Huizachal Canyon in Tamaulipas (fig. 1.7, location 1; Clark et al. 1994, 1998; Fastovsky et al. 1995; Reynoso-Rosales 1996; Montellano-Ballesteros 2002).

The Mesozoic units are folded into anticlinoria and synclinoria, whose spacing diminishes from west to east; around Monterrey, Nuevo León, they bend westward, changing their axial orientation from north-northwest–south-southeast to nearly east–west. These structures are also cut by faults. The resulting fold-ranges are separated by long and narrow intermontane depressions, where Late Paleogene-Neogene terrigenous fluviocustrine clastic units have been formed (fig. 1.8). This extensive regional uplift and structural deformation is part of the Laramide Orogeny, which occurred during the Middle and Late Eocene (~50–40 Ma).

Quaternary karstification of the limestone fold-ranges in this province and in the neighboring Chihuahua-Coahuila Plateaus and Ranges has produced numerous and complex cave systems, where Pleistocene vertebrates were trapped, thus generating fossil assemblages (fig. 1.7, locations 22 and 23). The best known such assemblage comes from the San Josecito Cave along the Nuevo León/Tamaulipas border (Stock 1943; Ferrusquía-Villafranca 1978; Arroyo-Cabrales et al. 2002; McDonald 2002).

Selected references. Imlay 1936, 1938, 1943, 1944; De Cserna 1956, 1960, 1989; Carrillo-Bravo 1961; McBride et al. 1974; Cook and Bally 1975; Sutter 1980, 1984, 1987; Padilla-Sanchez 1985.

6. Gulf Coastal Plain Morphotectonic Province

Geographic Aspect

The Gulf Coastal Plain Province consists of the lowlands bordering the Gulf of Mexico exclusive of the Yucatán Platform. The Teziutlan Massif (regarded by some as part of the Trans-Mexican Volcanic Belt) and associated volcanic hills nearly divide the province into 2 sectors, Northern and Eastern, leaving a narrow strip or corridor that communicates between them. The Northern Sector falls within northern Mexico's boundaries and is described here (fig. 1.7). This sector lies between 20°00'–26°00' N and 96°30'–100°20' W; it covers an area of about 87,200 km^2 and is 100 km wide (average), becoming wider northward. Elevation varies from 0–200 masl. The climate is Aw' tropical in the southern third, becoming temperate and drier (Cw to Cx'w) to the north.

The Gulf Coastal Plain is traversed by the rivers that drain the Sierra Madre Oriental. Lakes are present only at and near the mouth of the Río Pánuco; they include Laguna de la Culebra, Laguna de la Tortuga, and Laguna de Altamira in southern Tamaulipas, and Laguna del Pueblo Viejo in northern Veracruz.

The Gulf Coastal Plain littoral is affected by prograding fluvial sedimentation related to the development of offshore islands, lagoons, and estuaries. The flats are the dominant geomorph and include floodplains, alluvial fans, marine terraces, and beach lands (both sandy and muddy).

Geologic Aspect

This province is well known due to its oil reaches. Numerous units have been defined, and their outcrops show a regional pattern of bandlike zones successively younger toward the gulf. The units consist of marine limestones and fine-grained clastics that make up tabular bodies gently dipping eastward. The Tertiary sequence spans the whole period and unconformably rests on Cretaceous carbonates. The different-age bodies are wider in the northern part, where they were deposited in a large paleobay, the Rio Grande Embayment (fig. 1.8). A large Miocene palynoflora is known from the Coastal Plain in southern Veracruz (Paraje Solo Formation; Graham 1978, 1993).

Subsurface information discloses the presence of some large sedimentary thickenings, which correspond to paleobasins, where subsidence occurred at a greater rate than in the rest of the province. The Quaternary sedimentary bodies are typically transitional, deposited in shore and fluvial environments. Quaternary and Tertiary sedimentary bodies are broader in the north.

The province's Cenozoic geologic record depicts the gulfward marine regression of the epicontinental sea that once covered northern Mexico, concomitantly increasing its territory.

Selected references. Murray 1961; Viniegra-Osorio 1965; Barker and Blow 1975; Cook and Bally 1975; Wilson 1987; Galloway and Blow 1989; Galloway et al. 1991; Coleman et al. 1991.

7. The Central Plateau Morphotectonic Province

Geographic Aspect

The Central Plateau Province is bounded by the Sierras Madres Occidental and Oriental and by the Trans-Mexican Volcanic Belt. It lies between 21°00'–24°00' N and 100°00'–104°00' W. It is parallelogram-shaped, 450 km long and 280 km wide (average); the area is about 85,300 km^2. Elevation ranges from 1000 to 3300 masl, but the 2000–3000 masl hypsometric zone (Sierra de Guanajuato-Zacatecas) is dominant. The climate is arid hot to semiarid temperate (BSh group; see table 1.1). There are no major rivers in this province, and only a single lake, Laguna de Yuriria in southern Guanajuato.

Geomorphologically, the Central Plateau consists of 3 zones or subprovinces (fig. 1.7): The Southern Valleys and Sierras, which largely corresponds to the Río Lerma-Santiago basin; the Central Sierras and Mesas, which corresponds to the Sierra de Guanajuato-Zacatecas; and the Northern Lowlands, formed by rolling lands and isolated hills.

Geologic Aspect

The Central Plateau Province is especially complex (fig. 1.8). The Pre-Cenozoic rock bodies largely consist of Late Paleozoic metamorphic units that crop out in Zacatecas; Late Triassic marine carbonate and siliciclastic units exposed both in Zacatecas and in San Luis Potosí; and Middle and Late Jurassic marine and Cretaceous marine and low-grade metamorphic bodies chiefly exposed in Zacatecas, San Luis Potosí, and Guanajuato (largely the Central Sierras and Mesas Subprovince).

The Cenozoic unconformably rests on the older rock bodies; it includes sedimentary clastic, volcanic (both lavic and pyroclastic), and plutonic units. The sedimentary units are of Paleogene and Late Neogene age, such as the Guanajuato Conglomerate (Middle Eocene) and the San Miguel de Allende Formation (latest Miocene), which have both yielded mammal faunas. Early Neogene units are scarce, but one such unit in Aguascalientes yielded a mammal fauna.

Volcanics overlie the Paleogene clastics; they are lava flows and pyroclastic sheets of andesitic to rhyolitic composition that form mesas and occasional peaks. Their age is 35 ma (similar to that of the Sierra Madre Occidental's Upper Volcanic Complex). Small- to medium-size plutons of granitic to dioritic or even gabbroic composition intrude into the Tertiary sequence; their emplacement is related to the genesis of this province's mineral deposits. Locally, other younger (Neogene) volcanic flows or fine clastics cover the mesas or floor the adjacent lowlands. Thin, flat-lying Quaternary deposits crop out in the lowlands.

The red Guanajuato Conglomerate has yielded at Marfil the only known Middle Eocene terrestrial vertebrate fauna from Mexico (also the southernmost known fauna from North America), with rodents related to the ancestral stock of the South American Caviomorpha (fig. 1.7, location 11; Edwards 1955; Fries et al. 1955; Black and Stephens 1973; Ferrusquía-Villafranca 1987, 1989; Ferrusquía-Villafranca et al. 2002). The Early Miocene Zoyatal Tuff of Aguascalientes yielded the namesake mammal fauna, which includes perissodactyls and artiodactyls that belong to extant families, except the extinct Merycoidodontidae (fig. 1.7, location 16; Dalquest and Mooser 1974; Ferrusquía-Villafranca 1990a, 2003; the site lies near the Central Plateau–Sierra Madre Occidental boundary, within the latter province).

Eastern Guanajuato has yielded a large and highly diverse mammal assemblage of latest Miocene–Early Pleistocene age (fig. 1.7, location 17; Carranza-Castañeda and Ferrusquía-Villafranca 1978, 1979; Dalquest and Mooser 1980; Carranza-Castañeda et al. 1981, 1994; Miller and Carranza-Castañeda 1984, 2002; Carranza-Castañeda and Miller 2002). This assemblage includes the second earliest record of South American immigrants in North America (*Glossotherium*, fission-track dated as 4.1 ± 0.3 ma and 3.9 ± 0.3 ma old; Kowallis et al. 1998). These ages indicate an earlier date for the beginning of the Great American Faunal Interchange (GAFI) than usually thought. However, the presence of large North American mammals in the Amazonian Peru, dated about 9 ma, indicates even a far earlier date for this event (Campbell et al. 2000; Ferrusquía-Villafranca 2003).

Aguascalientes and San Luis Potosí also carry large Pleistocene vertebrate assemblages (fig. 1.7, locations 24 and 25; Mooser and Dalquest 1975; Ferrusquía-Villafranca 1978; Arroyo-Cabrales et al. 2002; McDonald 2002).

The sedimentary Mesozoic units are deformed into folds of varied extent, amplitude, and axis orientation. They are also affected by faulting, which appears to have 2 dominant directions, north-northwest–south-southeast and east–west. There are several grabens largely in the southern part, whose structural orientation coincides with the fault directions; their genesis must have occurred during the same faulting episode.

Selected references. Echegoyen et al. 1970; Cook and Bally 1975; Labarthe-Hernández et al. 1982; Martínez-Reyes 1992; Barboza-Gudiño et al. 1999; Ferrari et al. 1999; Cerca-Martínez et al. 2000; Aranda-Gómez et al. 2003.

Constraints on Modeling: Correlation of Historical, Geologic, Geographic, and Biotic Processes, Events, and Features

This correlation is presented as a series of integrative considerations and remarks aimed at establishing the relevance of geologic processes and geographic features in influencing the development of northern Mexico's biota throughout the Cenozoic (see figs 1.1–1.9). The timing and duration of the processes, events, and features discussed below are plotted in appendix 1.1; their supporting evidence has already been given above and will be supplemented as needed. We provide the most parsimonious interpretations. Inferences are as objective as possible and kept at a minimum.

(1) Tectonically, northern Mexico's territory has been part of the North American Plate at least since the Cretaceous, and its latitudinal position has remained stable since that time (Ross and Scotese 1988; De Cserna 1989; Sedlock et al. 1993). Significant tectonic rearrangement during the Cenozoic has occurred only on the adjacent Pacific Ocean floor, involving subduction (of the Farallon Plate) and detachment of the Baja California peninsula by deep transform faults, thereby originating the Gulf of California (Ortlieb 1991a,b; Ferrari 1995; Henry and Aranda-Gómez 2000; Fletcher et al. 2003).

(2) This extensional deformation seems to be genetically related to the magmatism that originated the Sierra Madre Occidental volcanic field and to the associated plutonic and volcanic bodies, which chiefly occurred in the Late Paleogene (ca. 35–30 ma). The deformation is related as well to the basin and range faulting of western Sonora and the adjacent southwestern United States, which took place in the Late Neogene (McDowell and Clabaugh 1979; Roldan-Quintana 1984; Henry 1989; Henry and Aranda-Gómez 1992, 2000; McDowell and Mauger 1994).

(3) The Sierra Madre Oriental and much of the Chihuahua-Coahuila Plateaus and Ranges have a different and more complicated origin that largely involves folding (generated by compression), faulting (of various kinds), and regional uplift; preexisting structures partly controlled the behavior of tectonic forces. This complex process is known as the Laramide Orogeny; its major episodes took place during the Middle and Late Eocene (De Cserna 1956, 1960, 1989; Sutter 1980, 1984, 1987; Haenggi 2002).

(4) As a result of the regional uplift, the epicontinental sea that covered much of northern Mexico during a good part of the Mesozoic at last retrograded (gulfward) in the Cenozoic, leaving a record of its gradual regression in the Gulf Coast Plain (and elsewhere in Coahuila), and forming a low and narrow land-corridor located between the Gulf of Mexico and the increasingly higher Sierra Madre Oriental ranges (Murray 1961; Galloway et al. 1991).

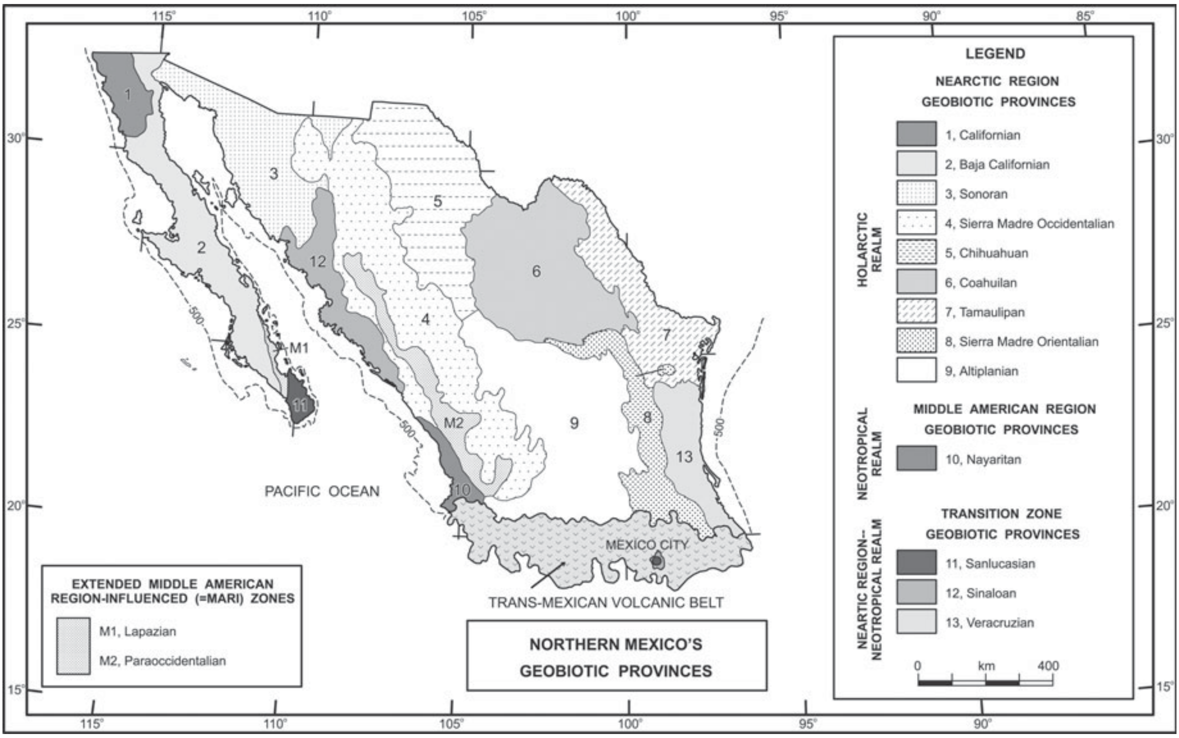


Figure 1.9. Geobiotic provinces of northern Mexico. Adapted from Ferrusquía-Villafranca (1990b). Although largely congruent with biotic province systems, the geobiotic province delineation scheme is conceptually distinct. It is based on multiple parameters including morphotectonic and paleontologic information. Each geobiotic province was presumably subjected to a distinct paleoenvironment during much of its history during the Cenozoic. The separation between Neotropic and Holarctic Realms is set at the Trans-Mexican Volcanic Belt.

(5) Additional tectonic and magmatic activity has caused the emplacement of Middle and Late Tertiary volcanic and plutonic bodies in Chihuahua and in the Central Plateau, as well as the faulting that generated the horsts (upthrown blocks) and grabens (downthrown blocks) of these regions. The horsts and grabens frequently correspond to the topographic highs (uplands, mesas, etc.) and lows (basins, flats, lowlands, etc.) seen there. Some horsts consist of Pre-Cenozoic rocks that became exposed during subsequent erosion in the Late Cenozoic (Bridges and DeFord 1965; De Cserna 1989; Haenggi 2001, 2002).

(6) The Trans-Mexican Volcanic Belt (TMVB) started to develop during the Late Oligocene–Early Miocene with the emplacement of silicic to andesitic lava flows and pyroclastic sheets in the western half that mainly formed high plateaus and a few peaks. The magmatic activity migrated eastward, producing in the Late Neogene–Quaternary large stacks of andesitic to basaltic flows and pyroclastics that formed plateaus, sierras, and spectacular peaks (Demant 1984; Nieto-Obregon et al. 1985; Pasquare et al. 1986, 1987a,b; Ferrari et al. 1995, 1999; García-Palomo et al. 2002).

It should be noted that in the Gulf Coastal Plain, the Late Neogene–Quaternary volcanics were nonconformably emplaced upon the emerged Paleogene–Early Neogene sedimentary units. Such emplacement locally reduced the plain to a narrow land strip or corridor, thereby generating the present-day subdivision of this province into its Northern and Eastern Sectors.

During Late Neogene–Quaternary time, fluviolacustrine units were laid down in the lowlands throughout the TMVB; many sites have yielded large mammal faunas from such units (Ferrusquia-Villafranca 1978; Miller and Carranza-Castañeda 1984, 1996, 2002; Arroyo Cabrales et al. 2002).

(7) As a result of this complex geologic makeup and evolution, northern Mexico eventually acquired

a very diverse geographic layout. The region covers about 1,245,900 km^2 of rugged territory and spans 12° of latitude (from 20°30' to 32°30' N). It includes a large variety of geomorphs such as flats (of diverse size and altitudinal position: from near sea level to ~2000 masl), mountains (isolated or forming sierras or cordilleras), plateaus, valleys, and basins (fig. 1.2; Raisz 1964; Espinasa-Pereña 1990; Lugo-Hubp 1990). The climate is also diverse, changing from very arid, hot desert in the west and north to tropical, very humid with no defined dry season in the southeast (figs. 1.3–1.6; García 1990). It is befitting, then, that this geographically diverse territory be populated by a very diverse biota.

(8) The detailed Cenozoic paleogeographic evolution of northern Mexico, and particularly of its terrestrial landscape, is not well known (Morán-Zénteno 1984; De Cserna 1989). Worldwide, there were important climatic changes during the Cenozoic. However, the region's latitudinal position has changed little since the Late Cretaceous–Paleocene (Ross and Scotese 1988). Thus, climatic factors strongly influenced by latitudinal position (i.e., general insolation, light and temperature spatial distribution, and major wind patterns) remained largely (elevation did vary; see below) similar to those of the Recent during the Cenozoic. The increasing complexity of the landscape developed during the Cenozoic must have greatly influenced the climate (and related processes such as soil development) because, among other factors, high cordilleras force the wind to discharge rain on the oceanside slopes. On the landward side, the wind is depleted of its moisture, and as a result, there is less rain throughout the year. Given that the Sierras Madres and the Chihuahua-Coahuila Plateaus and Ranges were present in northern Mexico at least by the Late Paleogene–Early Neogene (ca. 30–25 ma), it is reasonable to postulate that the present-day major climatic regions of northern Mexico have existed since then and that increasing aridity in the north developed over time in a spatially uniform manner. The persistence of such different climatic regions in this vast territory for an interval nearly half as long as the Cenozoic must have had a profound effect on soil development and, of course, on the resident biota.

It should be noted that northern Mexico's present-day climate is influenced and partly determined by factors or phenomena occurring elsewhere, such as the El Niño/Southern Oscillation, polar air-mass invasions, and hurricanes, which in turn are controlled by physical or astronomical causes of worldwide reach. This must have been so in the past, too. Thus, among other factors influencing the climate of northern Mexico, the actual temperatures, humidity, and rainfall distribution and dynamics must have reflected the influence of worldwide climatic trends and changes that took place in the Cenozoic (see chapter 2 for a discussion of this topic).

The influence of elevation likely played an increasingly important role as northern Mexico's tall physiographic features developed. Southward range extensions of northern biotas with high-elevation affinities (or "acrobionts") would have been promoted when and where mountain ranges developed. Conversely, mountain ranges could have blocked the northward range extension of tropical, low-elevation species and communities.

(9) The continental glacier advance and retreat episodes that occurred in North America during the Middle and Late Pleistocene must have caused successive contractions and expansions of the climatic belts, thus producing major changes (fluctuations?) in the fluviolacustrine sedimentary regime, as well as important north–south and/or south–north shifts or displacements of the then-existing ecological associations (communities, ecosystems, and biomes) and species distributions. These changes probably increased in intensity northward.

However, the detailed comprehensive study and mapping of such climatic, sedimentary-stratigraphic, and biotic records of shifts for northern Mexico as a whole during the Pleistocene remains to be made. Even in the best-known areas, such as the Mexican Basin or the Valley of Puebla, nothing like an integrative geologic/paleontologic/paleoclimatic study has been published. There are, however, several works that deal with particular aspects of the record, such as those by Axelrod (1979), Van Devender (1990), and Arroyo-Cabrales (1994), to name just a few.

(10) Biogeographically, the role of the major geographic/geologic features of the region remains to be precisely assessed. The available geologic/geographic information, parsimoniously interpreted, allows one to recognize the following sequence of biogeographic events:

- The Sierra Madre Oriental and much of the Chihuahua-Coahuila Plateaus and Ranges were the first Cenozoic cordilleras to develop in northern Mexico. Their presence generated geographic diversity, which in turn led to habitat diversity. It also created barriers that restrained dispersal of the species making up the biota then inhabiting northern Mexico. In short, these cordilleras promoted regional biotic differentiation as early as early Late Eocene time, as they had fully developed by that time. The role of these cordilleras as upland platforms that allowed southward range extension of acrobiont communities, such as pine forest or pine-oak forest, merits consideration in its own right.

- At present, the Sierra Madre Oriental Eastern Sector ends by the parallel 20° N, where it meets the TMVB. However, the striking similarity in makeup and structure of the Sierra Madre Oriental Eastern Sector and the eastern cordillera just south of the TMVB (a fold-belt in southeastern Veracruz, northern Oaxaca, and adjacent Puebla; Ortega-Gutiérrez et al. 1992) strongly suggests physical continuity between them (De Cserna 1960, 1989; Murray 1961; Sedlock et al. 1993). If in fact there was such a continuity, it follows that during the Late Eocene–Early Neogene, both cordilleras would have formed a much longer fold-mountain belt, or "Mega-Eastern Sector," later severed (buried) by the TMVB. Should this be so, by Late Eocene–Early Neogene time the Mega- Eastern Sector functioned as a highland corridor that penetrated into Middle America (at least down to 17°30' N), allowing significant dispersal of acrobiont communities much earlier than in western Mexico. This effect was enhanced by the presence of the Sierra de Zongolica, a block mountain range formed by uplifted Mesozoic metamorphic basement rocks, which lies just west of the eastern cordillera mentioned above (Ortega-Gutiérrez et al. 1992). The eastern development of the TMVB during the Late Neogene–Quaternary maintained this upland platform.
- The gradually widening Gulf Coastal Plain (an event related to the Sierra Madre Oriental development and to the regional uplift) probably afforded during the Paleogene–Early Neogene a land corridor that allowed biotic exchange between the northern (which became Nearctic) and southern (which became Neotropical) regions. This corridor became restricted to a narrow land strip by Late Neogene–Quaternary time, as the TMVB became a more effective barrier, due to the emplacement of volcanics in its eastern part reaching close to the Gulf coast.
- The Sierra Madre Occidental could have acted as a biotic provincial barrier within the Nearctic Region no earlier than Late Oligocene time, when it was fully developed. From this upland platform, acrobiont communities, such as pine forest and pine–oak forest, could have expanded their range southward, as highlands in the Sierra Madre del Sur and in the TMVB were or became available.

  On the ocean side, the Sierra Madre Occidental promoted the development of moist-tropical conditions, which contributed to generate a corridor that allowed northward dispersal of tropical (to transitional) communities, enabling them to become established farther north than the normal tropical latitude.
- The TMVB could have functioned as an effective Nearctic/Neotropical–Middle American regional barrier no earlier than the Middle to early Late Miocene, at which time it was essentially complete. At an earlier time, the territory corresponding to the TMVB probably functioned as a broad transitional zone between the northern (which became Nearctic) and southern (which became Neotropical) biotas.
- The Baja California peninsula's biota seems to have had little exchange with mainland northern Mexico for a long time. The Gulf of California and its predecessor, the "Protogulf," as well as the developing Sierra Madre Occidental, probably played a significant role, becoming barriers that effectively forestalled biotic exchange for many lineages (see chapter 11).

Conclusions

There is practically no specific factual information on the Cenozoic biotic development of northern Mexico. However, some of this information gap can be filled using knowledge of the region's geologic/geographic history, which allows us to trace the major features of such development. The geologic/geographic history also introduces constraints on models aimed at describing the development of this vast territory's biota.

Northern Mexico's present-day geographic position largely determines the amount of solar energy it receives and the way this energy is distributed throughout the year. Because northern Mexico's position has changed little since at least the Late Cretaceous, spatial patterns for atmospheric factors directly related to solar energy input (e. g., temperature, humidity, rainfall, and wind circulation) could have become increasingly locked in place with the development of this territory's present-day major geomorphic features during the Cenozoic. However, the climate varied a great deal during this era (contrasting significantly with that of the Cretaceous), responding to worldwide changes and trends, which themselves were fine-tuned by evolving particular features of the landscape.

The broad landscape and climatic uniformity of northern Mexico during the Early Paleogene became episodically complicated through the Tertiary. By Middle–Late Eocene time, extensive tectonic activity generated the Sierra Madre Oriental, the fold-ranges and high plateaus of Chihuahua and Coahuila, the gulfward regression of the epicontinental sea that covered much of northern Mexico, and the development of the Coastal Plain of the Gulf of Mexico. By Early Oligocene time, extensive magmatic activity in the west generated the Sierra Madre Occidental. Such activity is related to extensional deformation ultimately responsible for the detachment of the Baja California peninsula and for producing the basin and range structural pattern, so characteristic of southwestern North America. These last 2 processes occurred during the Late Neogene.

By Middle Miocene time, extensive magmatic activity across central Mexico generated the Trans-Mexican Volcanic Belt, thus completing the major geographic features included in or bounding northern Mexico's landscape. The species that lived in northern Mexico during the Late Paleogene–Early Neogene adapted to varying local/regional conditions, and in due time became differentiated into several regional biotas. The whole spectrum of environmental factors must have played a role in this differentiation process, but to trace it precisely requires information that is not available at present. Nevertheless, it remains clear that in broad terms, the current biotic differentiation of northern Mexico could not be older than Middle Miocene time (ca. 15 ma).

The Pleistocene glaciations that affected the Northern Hemisphere must have exerted an important effect on climate and on biotic distribution in northern Mexico; however, a detailed, region-wide study of the influence of glaciations remains to be conducted.

Acknowledgments

I. F.-V. thanks Gerardo Ceballos Gonzalez, Instituto de Ecología, University of Mexico, for his kind invitation to participate in this important project. I. F.-V. also expresses his gratitude to Zoltan De Cserna (Instituto de Geología, University of Mexico), Jose Luis Macías (Instituto de Geofísica, University of Mexico), and Richard Felger (director, Drylands Institute) for their careful review of the manuscript; their comments and questions helped much to improve this chapter. Discussions with colleagues both from the University of Mexico and from other institutions provided important information or ideas, among them Shelton P. Applegate and Oscar Carranza-Castañeda (paleontologic issues) and Jaime Roldan-Quintana and Jose Luis Macías (geologic issues). The maps were drafted by Jose Ruiz, and the manuscript prepared by Karla and Ismael Ferrusquía Jr.; we thank them for their kind help. The Cooperativa La Cruz Azul S.C.L., México, D.F. graciously covered the additional cost of producing figure 1.8 in color.

Appendix 1.1: Proposed Holistic Geobiologic Integration on Northern Mexico's Biotic Development

The approximate timing and duration of the major Cenozoic geologic/geographic factors that shaped this vast territory are shown on the following page and correlated with key climatic, paleontologic, and biotic events and features; their relationships are briefly worked out.

In the heading, the chronostratigraphic terms are separated by a slash from the corresponding geochronologic term. The geologic time (AB. or Geol.) is expressed in megaanni (ma, millions of years). The chronostratigraphic/geochronologic framework is adapted from Remane et al 2001. A continuous, numbered vertical line in the chart's body represents the known recorded duration or time span of a given process, event, or feature; a discontinuous line represents its inferred or probable duration. The small inset square in the lower right corner of the chart is developed in the large inset in the lower left corner.

General Abbreviations

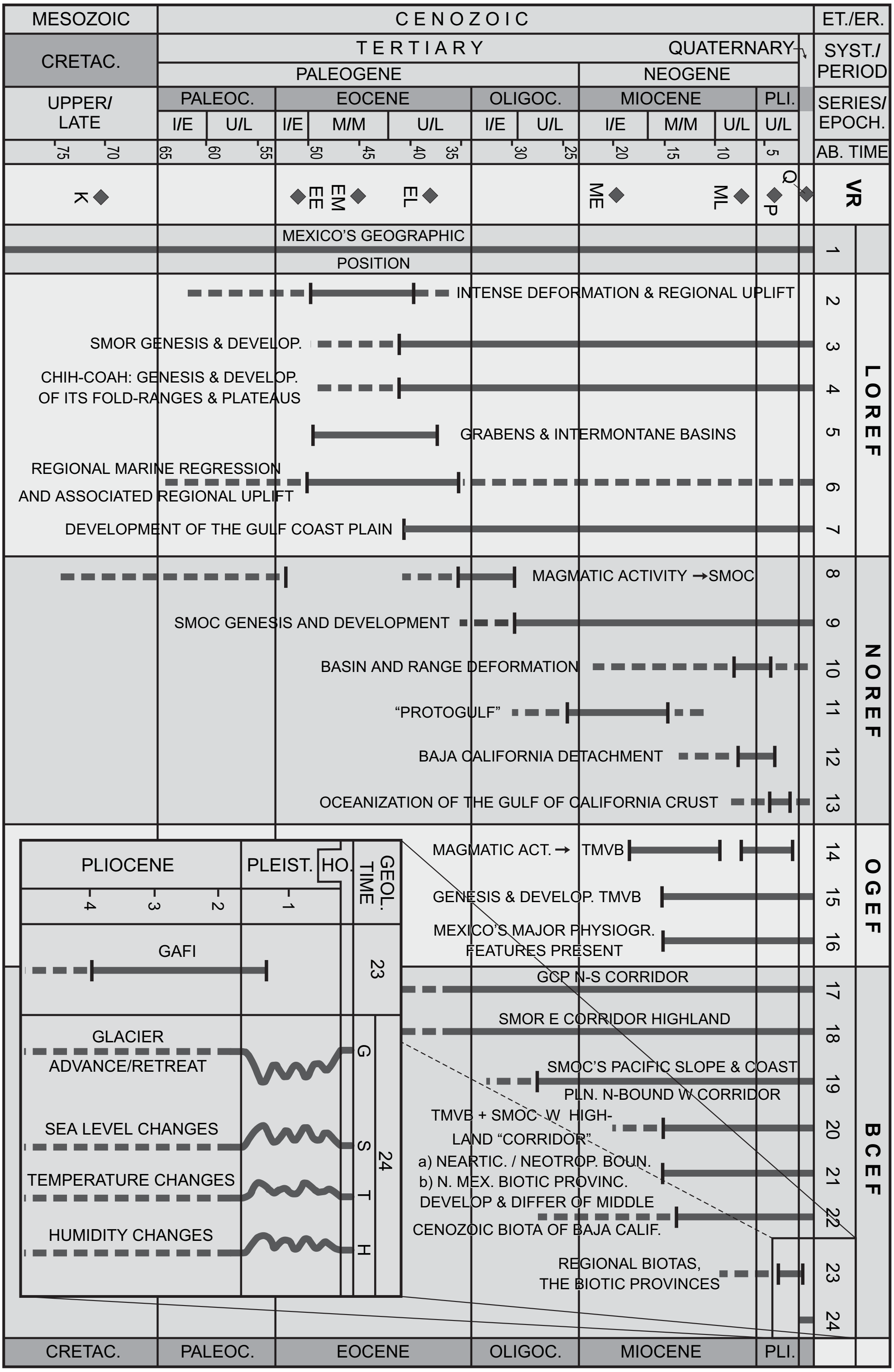
BCEF, biotic and climatic processes, events, or features; Cretac., Cretaceous; E, Early; ER, era; ET, erathema; G, regional advance/retreat of the continental icecap (glacier); H, humidity; HO, Holocene (= Recent); I, inferior; lower; L, Late. LOREF, Laramide Orogeny related processes, events, and features. M, Middle. NOREF, Middle and Late Cenozoic processes, events, and features generated by extensional deformation and magmatism, ultimately related to plate tectonic dynamics of southwestern North America (northwest Mexico included) and the adjacent Pacific crust (= the Nevada Orogeny). OGEF, other geologic events and features; Oligoc., Oligocene; Paleoc., Paleocene; Pleist., Pleistocene; Pli., Pliocene; S, mean sea level; Syst., system; T, temperature; U, upper.

Number Symbology and Remarks

1. The Geographic position of the Mexican territory has remained more or less constant since the Late Cretaceous.

LOREF: 2. Major folding, faulting, magmatic activity, and regional uplift (essence of the Laramide Orogeny). **3.** Genesis and development of the Sierra Madre Oriental (SMOR). Recorded existence of this cordillera as a major physiographic feature of northern Mexico. **4.** Genesis and development of the fold-ranges and high plateaus of the Chihuahua-Coahuila Morphotectonic Province. **5.** Genesis of structural lowlands (grabens) and intermontane basins in 2 and 3. The co-occurrence of events 2, 3, and 4 promoted the extensive development of rugged-relief territory in northern Mexico, increasing significantly its physiographic diversity. **6.** Regional marine regression. **7.** Development of the Coastal Plain of the Gulf of Mexico.

NOREF: 8. Magmatic activity (chiefly volcanic) generated the Sierra Madre Occidental (SMOC). **9.**


MESOZOIC
CENOZOIC
ET./ER.
CRETAC.
TERTIARY
QUATERNARY
SYST./ PERIOD
PALEOGENE
NEOGENE
UPPER/ LATE
PALEOC.
EOCENE
OLIGOC.
MIOCENE
PLI.
SERIES/ EPOCH.
I/E
U/L
I/E
M/M
U/L
I/E
U/L
I/E
M/M
U/L
U/L
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
AB. TIME
K
EE
EM
EL
ME
ML
P
Q
VR
MEXICO'S GEOGRAPHIC POSITION
1
INTENSE DEFORMATION & REGIONAL UPLIFT
2
SMOR GENESIS & DEVELOP.
3
CHIH-COAH: GENESIS & DEVELOP. OF ITS FOLD-RANGES & PLATEAUS
4
GRABENS & INTERMONTANE BASINS
5
REGIONAL MARINE REGRESSION AND ASSOCIATED REGIONAL UPLIFT
6
DEVELOPMENT OF THE GULF COAST PLAIN
7
LOREF
MAGMATIC ACTIVITY →SMOC
8
SMOC GENESIS AND DEVELOPMENT
9
BASIN AND RANGE DEFORMATION
10
"PROTOGULF"
11
BAJA CALIFORNIA DETACHMENT
12
OCEANIZATION OF THE GULF OF CALIFORNIA CRUST
13
NOREF
MAGMATIC ACT. → TMVB
14
GENESIS & DEVELOP. TMVB
15
MEXICO'S MAJOR PHYSIOGR. FEATURES PRESENT
16
OGEF
GCP N-S CORRIDOR
17
SMOR E CORRIDOR HIGHLAND
18
SMOC'S PACIFIC SLOPE & COAST PLN. N-BOUND W CORRIDOR
19
TMVB + SMOC W HIGH-LAND "CORRIDOR"
20
a) NEARTIC. / NEOTROP. BOUN.
b) N. MEX. BIOTIC PROVINC.
21
DEVELOP & DIFFER OF MIDDLE CENOZOIC BIOTA OF BAJA CALIF.
22
REGIONAL BIOTAS, THE BIOTIC PROVINCES
23
24
BCEF
PLIOCENE
PLEIST.
HO.
GEOL. TIME
4
3
2
1
GAFI
23
GLACIER ADVANCE/RETREAT
SEA LEVEL CHANGES
TEMPERATURE CHANGES
HUMIDITY CHANGES
G
S
T
H
24
CRETAC.
PALEOC.
EOCENE
OLIGOC.
MIOCENE
PLI.

Genesis and development of SMOC. Recorded existence of this cordillera as a major physiographic feature of northern Mexico. **10.** Genesis and development of the Basin and Range structural deformation best recorded in the Northwestern Plains and Sierras Morphotectonic Province. **11.** Presence of the Protogulf, a narrow lowland transgressed by a shallow sea. **12.** Baja California detachment from mainland Mexico. **13.** Oceanization of the Gulf of California crust (completed only in the southern half).

OGEF: 14. Magmatic and tectonic activity across central Mexico generated the Trans-Mexican Volcanic Belt (TMVB). **15.** Genesis and development of the TMVB. Recorded existence of this cordillera as a major physiographic feature of Mexico. **16.** All the major physiographic features included in or bounding northern Mexico are now present. The regional landscape acquires at last a modern look, similar to that seen today.

BCEF: 17. The Coastal Plain of the Gulf of Mexico functioned as a north–south trending corridor for temperate and tropical biotic elements. **18.** The SMOR functioned as a highland corridor that allowed southward dispersal of acrobiont communities. The Zongolica Range enhanced this effect. **19.** The SMOC's Pacific slope and associated coastal plain functioned as a western corridor that fostered northward dispersal of tropical biotic elements. **20.** The TMVB's western part and the adjacent SMOC functioned as a western highland corridor that allowed southward dispersal of acrobiont communities.

21. Establishment of: (a) The Nearctic Realm/Neotropical Realm boundary; (b) the biotic provincialization of continental northern Mexico. (a) Before the presence of the TMVB, the temperate and tropical communities that inhabited Mexico had a broad zone of contact and interaction. The geologically rapid development of the TMVB put an end to this broad zone of contact. (b) The different morphotectonic provinces of continental northern Mexico, which resulted from this region's complex geologic history, were all in existence at least by Middle Miocene time. The biota that inhabited northern Mexico during the Cenozoic must have followed suit, becoming differentiated into regional biotas best adapted to local conditions. This process most likely was completed also by Middle Miocene time, producing distinctive regional biotas. The differentiation of regional biotas occurred in geobiotic provinces, each of them characterized by a distinct paleoenvironment (fig. 1.9; see also Ferrusquía-Villafranca 1990b).

22. Development and differentiation of the Middle Cenozoic biota of the Baja California peninsula into regional or zonal biotas distinctive enough to be recognized as different biotic provinces. The striking differences between the biota of Baja California and that of continental northern Mexico duly attest the prolonged near-isolation of the former. **23.** The Great American Biotic Interchange (GAFI) was made possible by the Central American land connection. GAFI may have started earlier than 4 ma, and it had a greater impact in southern than in northern Mexico.

24. The Quaternary Glaciation events. Four major continental ice cap advance/retreat episodes occurred in the Pleistocene (curve 24G). They had a profound effect on sea level, making it fall (curve 24S) or rise. The climate was deeply affected, so that for places at a given latitude, the weather became colder and drier during glacier advances (curves 24 T and H), and warmer and more humid during the retreats. Climatic zones were displaced, contracted, or expanded. Biogeographic distributions of floras, faunas, and/or biotic elements were severely affected.

Notes on the Terrestrial Vertebrate Record

The presentation that follows is arranged from older to younger (see figure 1.7 for the geographic position of the localities). The Late Cretaceous Assemblage is based on records from sites in Baja California, Sonora, Chihuahua, and Coahuila. Dinosaurs occur in all sites, mammals only in Baja California Norte. The Early Eocene (Wasatchian) fauna is from Punta Prieta, Baja California Norte. It mainly consists of archaic mammals. The Middle Eocene (Bridgerian) fauna is from Marfil, Guanajuato. It includes rodents related to the ancestral stock of the South American Caviomorpha. The Late Eocene (Chadronian) fauna is from Ojinaga, Chihuahua. It largely consists of rodents and large herbivores; most belong to extinct families worldwide. The Early Miocene (Heminfordian) faunas are from Baja California Norte, Sonora, and Aguascalientes. They chiefly include herbivores that belong to extant modern families. The Late Miocene (Hemphillian) faunas are from Chihuahua, Guanajuato, and Hidalgo. They are diverse and include both herbivores and carnivores that belong to modern families, now largely extinct in North America (including northern Mexico). The Late Pliocene

(Blancan) faunas are from Baja California Sur, Chihuahua, and Guanajuato. Some include early records of South American immigrants (xenarthrans and caviomorph rodents). The Middle and Late Pleistocene (Irvingtonian and Rancholabrean) faunas are from many sites in northern Mexico. Large assemblages are known from Nuevo León, San Luis Potosí, Aguascalientes, and Guanajuato. The record is biased toward large, now extinct mammals such as proboscidians, artiodactyls, and perissodactyls. Some related taxa remain extant elsewhere (Asia, Africa, and South America).

Literature Cited

Aranda-Gómez, J. J., M. M. Godchaux, G. J. Aguirre-Díaz, B. Bonnichsen, and J. Martínez-Reyes. 2003. Three superimposed volcanic arcs in the southern Cordillera: A record of tectono-magmatic activity from the Early Cretaceous to the Miocene, Guanajuato, Mexico. Pp. 123–168 *in* Geologic Transects across Cordilleran Mexico, Guidebook of the Fieldtrips for the 99th Annual Meeting of the Geological Society of America, Cordilleran Section, Puerto Vallarta, Jalisco, Mexico. Publicación Especial 1. Instituto de Geología, Universidad Nacional Autónoma de México, México D.F.

Arroyo-Cabrales, J. 1994. Taphonomy and paleoecology of the San Josecito Cave, Nuevo León, Mexico. Ph.D. dissertation, Texas Tech University, Lubbock.

Arroyo-Cabrales, J., O. J. Polaco, and E. Johnson. 2002. La mastofauna del Cuaternario Tardío en México. Pp. 103–123 *in* M. Montellano-Ballesteros and J. Arroyo-Cabrales (coords.), Avances en los Estudios Paleomastozoológicos en México. Seria Arqueología del Instituto Nacional Antropología e Historia (INAH), México D.F.

Axelrod, D. I. 1979. Age and origin of Sonoran Desert vegetation. California Academy of Sciences Occasional Paper 132.

Barboza-Gudiño, J. R., M. Tristán-González, and J. R. Torres-Hernández. 1999. Tectonic setting of pre-Oxfordian units from central and northeastern Mexico: a review. Geological Society of America, Special Paper 340: 197–210.

Barker, R. W., and W.H. Blow. 1975. Biostratigraphy of some Tertiary formations in the Tampico-Misantla Embayment, Mexico. Journal of Foraminiferal Research 6: 39–58.

Barnes, L. G. 2002. Evolutionary history of the fossil marine mammals of Mexico. Pp. 125–225 *in* M. Montellano-Ballesteros and J. Arroyo-Cabrales (coords.), Avances en los Estudios Paleomastozoológicos en México. Seria Arqueología del Instituto Nacional Antropología e Historia (INAH), México D.F.

Beal, C. H. 1948. Reconnaissance of the geology and oil possibilities of Baja California, Mexico. Geological Society of America Memoir 31.

Black, C. C., and J. J. Stephens, III. 1973. Rodents from the Paleogene of Guanajuato, Mexico. Texas Tech University Museum, Occasional Paper 14.

Bortolini, C., P. E. Damon, M. Shafiqullah, and M. M. Morales. 1995. Geochronologic contributions to the Tertiary sedimentary-volcanic sequences ("Baucarit Formation") in Sonora, Mexico. Geofísica Internacional 34: 67–77.

Bridges, L. W. 1965. Geología del área de Plomosas, Chihuahua. Universidad Nacional Autónoma de México, Instituto de Geología Boletín 74.

Bridges, L. W., and R. K. DeFord. 1965. Precarboniferous Paleozoic rocks in Central Chihuahua, Mexico. American Association of Petroleum Geologists, Bulletin 45: 98–104.

Brown, M. L., and R. Dyer. 1987. Mesozoic geology of northwestern Chihuahua, Mexico. *In* Mesozoic Rocks of Southern Arizona and Adjacent Areas. Arizona Geological Society Digest 18: 381–394.

Campbell, K. C., M. Frailey, L. Romero-Pittman, S. B. Ingement, and D. R. Prothero. 2000. Late Miocene dynamics of the Great American Faunal Interchange: waifs are out. Journal of Vertebrate Paleontology 20 (suppl. 3): 33A.

Carranza-Castañeda, O., and I. Ferrusquía-Villafranca. 1978. Nuevas investigaciones sobre la fauna del Rancho El Ocote, Plioceno medio de Guanajuato, México. Informe Preliminar. Universidad Nacional Autónoma de México Revista 3: 29–38.

Carranza-Castañeda, O., and I. Ferrusquía-Villafranca. 1979. El género *Neohipparion* (Mammalia-Perissodactyla) de la fauna local Rancho El Ocote, Plioceno Medio, de Guanajuato, México. Universidad Nacional Autónoma de México, Instituto de Geología Revista 3: 29–38.

Carranza-Castañeda, O., I. Ferrusquía-Villafranca, and W. E. Miller. 1981. Roedores caviomorfos pliocenicos de la región Central de México. II Congreso Latinoamericano de Paleontología, Porto Alegre, Brasil Annals II: 721–729.

Carranza-Castañeda, O., and W. E. Miller. 2002. Inmigrantes sudamericanos en las faunas del

Terciario Tardío del Centro de México. Pp. 69–81 *in* M. Montellano-Ballesteros and J. Arroyo-Cabrales (coords.), Avances en los Estudios Paleomastozoológicos en México. Seria Arqueología del Instituto Nacional Antropología e Historia (INAH), México D.F.

Carranza-Castañeda, O., M. S. Petersen, and W. E. Miller. 1994. Preliminary investigation of the geology of the northern San Miguel Allende area, northeastern Guanajuato, Mexico. Brigham Young University Geology Studies 40: 1–9.

Carrillo-Bravo, J. 1961. Geología del Anticlinorio Huizachal-Peregrina al Noroeste de Ciudad Victoria, Tamaulipas, Asociación Mexicana de Geólogos Petroleros Boletín 13: 1–198.

Cerca-Martínez, M., G. J. Aguirre-Díaz, and M. López-Martínez. 2000. The geologic evolution of southern Sierra de Guanajuato, Mexico: a documented example of the transition from the Sierra Madre Occidental to the Mexican Volcanic Belt. International Geology Review 12: 131–151.

Charleston, S. 1981. A summary of the structural geology and tectonics of the State of Coahuila, Mexico. Pp. 28–36 *in* S. Charleston, C. I. Smith, and J. B. Brown (eds.), Lower Cretaceous Stratigraphy and Structure, Northern Mexico. Fieldtrip Guide. West Texas Geological Society Publication 81–74.

Clark, J., M. Montellano, J. Hopson, R. Hernández, and D. Fastovsky. 1994. An Early or Middle Jurassic tetrapod assemblage from the La Boca Formation, northeastern Mexico. Pp. 295–302 *in* N. Fraser and H. D. Sues (eds.), In the Shadow of the Dinosaurs: Early Mesozoic Tetrapods. Cambridge University Press, New York.

Clark, J., M. Montellano, J. Hopson, R. Hernández, and V. H. Reynoso. 1998. The Jurassic vertebrates of Huizachal Canyon, Tamaulipas. Pp. 1–17 *in* Avances en Investigación-Paleontológica de Vertebrados. Instituto de Investigaciones en Ciencias de la Tierra, Publicación Especial 1. Universidad Autónoma del Estado de Hidalgo Pachuca, Hidalgo, Mexico.

Clemens, W. A. 1994. *Gallolestes pachymandibularis* (Theria, incertae sedis; Mammalia) from Late Cretaceous deposits in Baja California Norte, Mexico. PaleoBios 33: 1–10.

Coleman, J. M., H. H. Robert, and W. R. Bryant. 1991. Late Quaternary Sedimentation. Pp. 325–352 *in* A. Salvador (ed.), The Geology of North America, vol. J, The Gulf of Mexico Basin. Geological Society of America, Boulder, Colorado.

Cook, T. D., and A. W. Bally (eds.). 1975. Stratigraphic Atlas of North and Central America. Princeton University Press, Princeton, New Jersey.

Cruz-Marín, A., and L. G. Barnes. 1996. A new agorophiid from San Juan de la Costa, Baja California Sur; The oldest fossil Odontocete from Mexico. Sixth North American Paleontological Convention, Abstracts of Papers. Paleontological Society Special Publication 8: 91.

Dalquest, W. W., and O. Mooser. 1974. Miocene vertebrates of Aguascalientes, Central Mexico. University of Texas-Austin, Texas Memorial Museum Pearce-Sellards Series 21.

Dalquest, W. W., and O. Mooser 1980. Late Hemphillian mammals of the Ocote local fauna, Guanajuato, Mexico. University of Texas-Austin, Texas Memorial Museum Pearce-Sellards Series 32.

De Cserna, Z. 1956. Tectónica de la Sierra Madre Oriental de México entre Torreón y Monterrey. Twentieth International Geological Congress, México D.F.

De Cserna, Z. 1960. Orogenesis in time and space in Mexico. Geologische Rundschau 50: 595–605.

De Cserna, Z. 1989. An outline of the Geology of Mexico. Pp. 233–264 *in* A. W. Bally and A. R. Palmer (eds.), The Geology of North America, vol. A, The Geology of North America, an Overview. Geological Society of America, Boulder, Colorado.

De Cserna, Z. 1990. Tectónica, Map IV.2.1; scale 1: 4,000,000. Atlas Nacional de México. Instituto de Geografía, Universidad Autónoma de México, México D.F.

Demant, A., 1984. Interpretación geodinámica del vulcanismo del Eje Neovolcánico Transmexicano. Universidad Nacional Autónoma de México, Instituto de Geología Revista 5: 217–222.

Durham, J. W. 1950. Megascopic paleontology and marine stratigraphy, Part 2 of the "E. W. Scripps" cruise to the Gulf of California. Geological Society of America Memoir 43.

Echegoyen, S. J., S. M. Romero, and S. Velásquez S. 1970. Geología y yacimientos minerales de la parte central del Distrito Minero de Guanajuato. Consejo de Recursos Naturales No Renovables Boletín 75: 1–36.

Edwards, J. D. 1955. Studies of some Early Tertiary red conglomerates of Central Mexico, U. S. Geological Service Professional Paper 264: 153–185.

Eguiluz, A. S. 1984. Tectónica cenozoica del norte de Mexico. Asociasión Mexicana de Geólogos Petroleros Boletín 36: 43–62.

Espinasa-Pereña, R. 1990. Geomorfología I, Map IV.3.4; scale 1: 4,000,000. Atlas Nacional de

México. Instituto de Geografía, Universidad Autónoma de México, México D.F.

Fastovsky, D. E., J. M. Clark, N. Strater, M Montellano, R. Hernández, and J. A. Hopson. 1995. Depositional environments of a Middle Jurassic terrestrial vertebrate assemblage, Huizachal Canyon, Mexico. Journal of Vertebrate Paleontology 15: 561–575.

Ferrari, L. 1995. Miocene shearing along the northern boundary of the Jalisco block and the opening of the southern Gulf of California. Geology 23: 751–754.

Ferrari, L., H. V. Garduño, G. Pasquare, and A. Tibaldi. 1995. Volcanic and tectonic evolution of Central Mexico: Oligocene to present. Geofísica Internacional 33: 91–105.

Ferrari, L., M. López-Martínez, G. J. Aguirre-Díaz, and G. Carrasco-Núñez. 1999. Space-time patterns of Cenozoic arc volcanism in Central Mexico, from the Sierra Madre Occidental to the Mexican Volcanic Belt. Geology 27: 303–306.

Ferrusquía-Villafranca, I. 1969. Rancho Gaitán local fauna, Early Chadronian, northeastern Chihuahua. Boletín de la Sociedad Geológica Mexicana 30: 99–138.

Ferrusquía-Villafranca, I. 1978. Distribution of Cenozoic vertebrate faunas in Middle America and problems in migration between North and South America. Pp. 193–329 *in* I. Ferrusquía-Villafranca (ed.), Conexiones Terrestres entre Norte y Sudamérica. Universidad Nacional Autónoma de México Boletín 101.

Ferrusquía-Villafranca, I. 1987. Reubicación geocronológica del Conglomerado Guanajuato basado en nuevos mamíferos. Pp. 21–22 *in* Simposio sobre la Geología de la Región de la Sierra de Guanajuato. Programa Resumenes y Guía de Excursiones, Instituto de Geología, Universidad Nacional Autónoma de México, México D.F.

Ferrusquía-Villafranca, I. 1989. A new rodent genus from Central Mexico and its bearing on the origin of the Caviomorpha. Pp. 91–117 *in* C. C. Black and M. R. Dawson (eds.), Papers on Fossil Rodents in Honor of Albert Elmer Wood. Natural History Museum of Los Angeles County, Science Series 33: 91–117.

Ferrusquía-Villafranca, I. 1990a. Biostratigraphy of the Mexican Continental Miocene. Universidad Nacional Autónoma de México, Paleontología Mexicana 56: 1–149.

Ferrusquía-Villafranca, I. 1990b. Regionalización Biogeográfica, Map IV.4.10; scale 1: 4,000,000. Atlas Nacional de México. Instituto de Geografía, Universidad Nacional Autónoma de México, México D.F.

Ferrusquía-Villafranca, I. 1993. Geology of Mexico: A Synopsis. Pp. 3–107 *in* T. P. Ramamoorthy, R. Bye, A. Lot, and J. Fa (eds.), Biological Diversity of Mexico, Origins and Distribution. Oxford University Press, New York.

Ferrusquía-Villafranca, I. 2003. Mexico´s Middle Miocene mammalian assemblages: an overview. American Museum of Natural History Bulletin 245: 321–347.

Ferrusquía-Villafranca, I., C. Galindo-Hernández, and H. Barrios-Rivera. 1997. Los mamíferos oligocénicos de México: revisión y adición a la fauna local Rancho Gaitán, Formación Prietos, Chadroniano de Chihuahua Nororiental. Pp. 97–134 *in* J. Arroyo-Cabrales and O. J. Polaco (coords.), Homenaje al Profesor Ticul Alvarez. Colecciones Cientificas, Instituto Nacional de Antropología e Historia, México D.F.

Ferrusquía-Villafranca, I., E. Jiménez-Hidalgo, J. A. Ortiz-Mendieta, and V. M. Bravo-Cuevas. 2002. El registro paleogénico de mamíferos de México y su significación geológico-paleontológica. Pp. 25–45 *in* M. Montellano-Ballesteros and J. Arroyo-Cabrales (coords.), Avances en los Estudios Paleomastozoológicos en México. Seria Arqueología del Instituto Nacional Antropología e Historia (INAH), México D.F.

Ferrusquía-Villafranca, I., and A. E. Wood. 1969. New fossil rodents from the Early Oligocene Rancho Gaitán local fauna, northeastern Chihuahua, Mexico. University of Texas-Austin, Texas Memorial Museum Pearce-Sellards Series 16.

Fletcher, J. M., J. A. Pérez-Venzor, G. González-Barba, and J. J. Aranda-Gómez. 2003. Ridge-trench interactions and the ongoing capture of the Baja California microplate: New insights from the southern Gulf Extensional Province. Pp. 13–31 *in* Geologic Transects across Cordilleran Mexico, Guidebook of the Fieldtrips for the 99th Annual Meeting of the Geological Society of America, Cordilleran Section, Puerto Vallarta, Jalisco, Mexico. Publicación Especial 1. Instituto de Geología, Universidad Nacional Autónoma de México, México D.F.

Fries, C., Jr., W. C. Hibbard, and D. H. Dunkle. 1955. Early Cenozoic vertebrates in the red conglomerate at Guanajuato, Mexico. Smithsonian Miscellaneous Collections 123.

Frizzell, V. A., Jr., ed. 1984. Geology of the Baja California Peninsula. Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles.

Galloway, W. E., and W. H. Blow. 1989. Genetic stratigraphic sequence in basin analysis II. Application to North-west Gulf of Mexico Cenozoic Basin. American Association of Petroleum Geologists Bulletin 73: 143–154.

Galloway, W. E., D. G. Bebout, W. L. Fisher, J. B. Dunlap, R. Cabrera-Castro, J. E. Lugo-Rivera, and T. M. Scott. 1991. Cenozoic. Pp. 325–352 *in* A. Salvador (ed.), The Geology of North America, vol. J, The Gulf of Mexico Basin. Geological Society of America, Boulder, Colorado.

García, E. 1988. Modificaciones al Sistema de Clasificación Climática de Copen (Para Adaptarlo a las Condiciones de la República Mexicana). Instituto de Geografía, Universidad Nacional Autónoma de México, México D.F.

García, E. 1990. Climas, Map. IV.4.10, scale 1:4,000,000. Atlas Nacional de México, vol. II. Instituto de Geografía, Universidad Nacional Autónoma de México, México D.F.

García-Palomo, A., J. L. Macías, G. Tolson, G. Valdez, and J. C. Mora. 2002. Volcanic stratigraphy and geological evolution of the Apan region, east-central sector of the Trans-Mexican Volcanic Belt. Geofísica Internacional 41: 133–150.

Gastil, G., G. Morgan, and D. Krummenacher. 1981. The tectonic history of Peninsular California. Pp. 285–305 *in* W. G. Ernst (ed.), The Geotectonic Development of California, vol. 1. Prentice-Hall, Englewood Ciffs, New Jersey.

Gastil, G., R. P. Phillips, and E. C. Allison. 1975. Reconnaissance geology of the State of Baja California Norte. Geological Society of America Memoir 140.

Graham, A. 1978. Distribution and migration of Cenozic floras in Mesoamérica. Pp. 166–192 *in* I. Ferrusquía-Villafranca (ed.), Conexiones Terrestres entre Norte y Sudamerica. Universidad Nacional Autónoma de México, Instituto de Geología Boletín 101: 166–192.

Graham, A. 1993. Historical factors and biological diversity. Pp. 109–127 *in* T. P. Ramamoorthy, R. Bye, A. Lot, and J. Fa (eds.), Biological Diversity of Mexico, Origins and Distribution. Oxford University Press, New York.

Haenggi, W. T. 2001. Tectonic history of the Chihuahua Trough, Mexico and adjacent USA, Part I: The pre-Mesozoic setting. Boletín de la Sociedad Geológica Mexicana 54: 28–66.

Haenggi, W. T. 2002. Tectonic history of the Chihuahua Trough, Mexico and adjacent USA, Part II: Mesozoic and Cenozoic. Boletín de la Sociedad Geológica Mexicana 55: 38–94.

Hausback, B. P. 1984. Cenozoic volcanic and tectonic evolution of Baja California Sur, Mexico. Pp. 219–236 *in* V. A. Frizzell (ed.), Geology of the Baja Peninsula. Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles.

Henry, C. D. 1989. Late Cenozoic Basin and Range structure in western Mexico adjacent to the Gulf of California. Geological Society of America Bulletin 101: 1147–1156.

Henry, C. D., and J. J. Aranda-Gómez. 1992. The real Southern Basin and Range mid-to Late Cenozoic extension in Mexico. Geology 20: 701–704.

Henry, C. D., and J. J. Aranda-Gómez. 2000. Plate interactions control Middle-Late Miocene, Proto-Gulf and Basin and Range extension in the southern Basin and Range. Tectonophysics 318: 1–26.

Hernandez, M. E. 1990. Medidas de Aridez, Map IV.4.9D, scale 1: 8,000,000. Atlas Nacional de México. Instituto de Geografía, Universidad Autónoma de México, México D.F.

Honey, J. G., J. A. Harrison, D. R. Prothero, and M. S. Stevens. 1998. Camelidae. Pp. 439–462 *in* C. M. Janis, K. M. Scott, and L. L. Jacobs (eds.), Evolution of Tertiary Mammals of North America, vol. 1: Terrestrial Carnivores, Ungulates and Ungulate-like Mammals. Cambridge University Press, New York.

Imlay, R. W. 1936. Evolution of the Coahuila Peninsula, Mexico. Part. IV, Geology of the Western part of the Sierra de Parras. Geological Society of America Bulletin 47: 1091–1152.

Imlay, R. W. 1938. Studies of the Mexican Geosyncline. Geological Society of America Bulletin 49: 1651–1694.

Imlay, R. W. 1943. Evidence for Upper Jurassic landmass in Eastern Mexico. American Association of Petroleum Geologists Bulletin 27: 524–549.

Imlay, R. W. 1944. Correlations of the Cretaceous formations of the Greater Antilles. Central America and Mexico. Geological Society of America Bulletin 55: 1005–1045.

Kowallis, B. J., C. C. Swisher, O. Carranza-Castañeda, W. E. Miller, and G. D. Tingey. 1998. Preliminary radiometric dates in selected Late Tertiary vertebrate faunas from Mexico. Universidad Autónoma del Estado de Hidalgo Pachuca, Hidalgo, México. Instituto de Investigaciones en Ciencias de la Tierra, Publicación Especial 1, Paleontología de Vetebrados: 103–108.

Labarthe-Hernández, G., M. Tristán-González, and J. J. Aranda-Gómez. 1982. Revisión estratigráfica del Cenozoico de la parte central del Estado de San Luis Potosí.