THE RÍO CHAGRES, PANAMA

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VOLUME 52

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THE RÍO CHAGRES, PANAMA

A Multidisciplinary Profile of a Tropical Watershed

edited by

RUSSELL S. HARMON

Army Research Office,
Research Triangle Park, NC, U.S.A.

Springer

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Cover illustration: Dry season flow in the upper Rio Chagres above the reach known as 'Three Falls', taken at a point (9:17:26N, 79:27:02W) looking downstream towards the first fall, which is about 2m in height. A scale is provided by the person on the right bank of the river with a surveying instrument. A mixed lithology boulder bar extends into the river from the right side of the picture. The bedrock outcrops are altered andesite. The river valley is typically bank full during the wet season. Annual high water marks are indicated by the location of significant bankside vegetation above the current water level. Photograph by Fred Ogden (U. Connecticut).

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Dedication

This book is dedicated to Lance Vander Zyl, Eric Nicoliasen, and Thomas Exenberger - colleagues and friends without whose dedicated support the upper Río Chagres basin fieldwork of 2002, which provided the foundation for much of the research described in this volume, would not have been possible.

Contents

Part II: The Upper Río Chagres Basin

Contributing Authors

Salomón Aguilar
Smithsonian Tropical Research Institute
Center for Tropical Forest Science
P.O. 2072, Balboa, Ancón
Panama City, Panama

Wim G.M. Bastiaanssen
WaterWatch
Generaal Foulkesweg 28
Wageningen 6703 BS
The Netherlands

Eldredge Bermingham
Smithsonian Tropical Research Institute
Center for Tropical Forest Science
P.O. 2072, Balboa, Ancón
Panama City, Panama

Paul R. Bierman
Department of Geology
University of Vermont
Burlington, VT 05405 USA

Stephanie Bohlman
W. M. Keck Remote Sensing Laboratory
University of Washington
Seattle, WA 98195 USA
current affiliation:
Smithsonian Tropical Research Institute
Unit 0948, APO AA-34002-0948 USA
Panama City, Panama

Sandra Brown
Winrock International
Ecosystem Services Unit
1621 N. Kent Street, Suite 1200
Arlington, VA 22207

Magnolia O. Calderón
Engineering Division
Autoridad del Canal de Panama
Panama City, Panama

Lucas E. Calvo Gobbetti
Universidad Tecnológica de Panama
Centro de Inv. Hidraulicas e Hidrotecnicas
Universidad Tecnologica de Panama, Ext. Tocumen
Panama City, Panama

Clara Camargo
Smithsonian Tropical Research Institute
Center for Tropical Forest Science
P.O. 2072, Balboa, Ancón
Panama City, Panama

Richard Condit
Smithsonian Tropical Research Institute
Center for Tropical Forest Science
P.O. 2072, Balboa, Ancón
Panama City, Panama

Virginia H. Dale
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6036, USA

Christopher W. Dick
Smithsonian Tropical Research Institute
Center for Tropical Forest Science
P.O. 2072, Balboa, Ancón
Panama City, Panama

Tufa Dinku
Department of Civil and Environmental Engineering
University of Connecticut
Storrs, CT 06269 USA

Robert C. Faucett
Burke Museum
Box 353010
University of Washington
Seattle, WA 98195-3010 USA

Robert Finkel
Center for Accelerator Mass Spectrometry
Lawrence Livermore National Laboratory
Livermore, CA 94405 USA

Konstantine P. Georgakakos
Hydrologic Research Center
12780 High Bluff Drive, Suite 250
San Diego, CA 92130 USA

Russell S. Harmon
Army Research Office
US Army Research Laboratory
PO Box 12211,
Research Triangle Park, NC 27709-2211 USA

J. Bruce J. Harrison
Department of Earth and Environmental Sciences
New Mexico Institute of Technology
Socorro, NM 87801 USA

Gerald Hartmann
Geoscience Center, Division of Geochemistry
University of Göttingen
37077 Göttingen, Germany

Stanley Heckadon-Moreno
Smithsonian Tropical Research Institute
Box 2072, Balboa
Panama City, Panama

Jan M.H. Hendrickx
Department Earth and Environmental Sciences
New Mexico Institute of Technology
Socorro, NM 87801 USA

Sung-Ho Hong
Department of Earth and Environmental Sciences
New Mexico Institute of Technology
Socorro, NM 87801 USA

Roberto Ibáñez D.
Smithsonian Tropical Research Institute
Center for Tropical Forest Science
P.O. 2072, Balboa, Ancón
Panama City, Panama

David Kinner
INSTAAR, University of Colorado
Boulder CO, USA
and
Water Resources Division
U. S. Geological Survey
3215 Marine Street
Boulder, CO 80302 USA

Ryan Knox
Department of Civil and Environmental Engineering
University of Connecticut
Storrs, CT 06269 USA

Suzanne Lao
Smithsonian Tropical Research Institute
Center for Tropical Forest Science
P.O. 2072, Balboa, Ancón
Panama City, Panama

Jennifer Larsen
Department of Geology
University of Vermont
Burlington, VT 05405 USA

David Lashlee
U.S. Army Yuma Proving Ground
Yuma, AZ 85365 USA

Raúl E. Martínez
Engineering Division
Autoridad del Canal de Panama
Panama City, Panama

Timothy W. Miller
Department of Earth and Environmental Sciences
New Mexico Institute of Technology
Socorro, NM 87801 USA

Helena Mitasova
Department of Marine, Earth, and Atmospheric Sciences
North Carolina State University
Raleigh, NC 27695 USA

Arizmendis S. Montoya
Engineering Division
Autoridad del Canal de Panama
Panama City, Panama

Kyle K. Nichols
Department of Geosciences
Skidmore College
Saratoga Springs, NY 12866 USA

Justin Niedzialek
Department of Civil and Environmental Engineering
University of Connecticut
Storrs, CT 06269 USA

Edwin J.M. Noordman
WaterWatch
Generaal Foulkesweg 28
Wageningen 6703 BS
The Netherlands

Fred L. Ogden
Department of Civil and Environmental Engineering
University of Connecticut
Storrs, CT 06269 USA

Eugene J. Palka
Department of Geography and Environmental Engineering
United States Military Academy
West Point, NY, USA 10996-1695

Rolando Pérez
Smithsonian Tropical Research Institute
Center for Tropical Forest Science
P.O. 2072, Balboa, Ancón
Panama City, Panama

Sievert Rohwer
Burke Museum
Box 353010
University of Washington
Seattle, WA 98195-3010 USA

Pedro Rojas
Autoridad Nacional del Ambiente
Deptartmento Conservación de la Biodiversidad Dirección Nacional de Patrimonio Natural
P.O. Box 0843, Zoná C , Balboa, Ancón.
Panama City, Panama

Augustín Somoza
Departamento Conservación de la Biodiversidad
Autoridad Nacional del Ambiente
P.O. Box 0843, Zoná C , Balboa, Ancón
Panama City, Panama

Klaus Simon
Geoscience Center, Division of Geochemistry
University of Göttingen
37077 Göttingen, Germany

Jason A. Sperfslage
Hydrologic Research Center
12780 High Bluff Drive, Suite 250
San Diego, CA 92130 USA

Gregory Springer
Department of Geological Sciences
Ohio University
Athens, OH, USA 45701

Robert Stallard
Water Resources Division
U. S. Geological Survey
3215 Marine Street
Boulder, CO 80302 USA

Israel Tejada
Autoridad Nacional del Ambiente
Deptartmento Conservación de la Biodiversidad
P.O. Box 0843, Zoná C , Balboa, Ancón
Panama City, Panama

Laura Toma
Department of Computer Science
Duke University
Durham, NC 27707 USA
current affiliation:
Department of Computer Science
Bowdoin College
Brunswick, ME, USA 04011

David Vega
Centro de Inv. Hidraulicas e Hidrotecnicas
Universitá Tecnologica de Panama, Ext. Tocumen
Panama City, Panama

Ellen Wohl
Department of Earth Resources
Colorado State University
Fort Collins, CO 80523 USA

Gerhard Wörner
Geoscience Center, Division of Geochemistry
University of Göttingen
37077 Göttingen, Germany

Preface

This book calls the attention of the scientific community, government organizations and non-government agencies, and the general public, to arguably one of the most important and complex of the world's tropical rainforest regions – the greater Panama Canal Watershed. The Río Chagres basin is the primary source for water to operate the Panama Canal, and also supplies water for electricity generation and potable water for municipal use, but this important national resource is largely unstudied from a scientific standpoint. The broad objective of the book is to characterize and understand the physical and ecological components of an isolated and largely pristine tropical rainforest and describe how the different natural components of a tropical rainforest interact with one another. The majority of the 23 papers contained in the volume are based upon presentations made at an international scientific symposium of the same title held at the Gamboá Rainforest Resort and Conference Center in Gamboá, Panama on 24-26 February 2003. In turn, most of the symposium presentations arose form research undertaken during a multidisciplinary field study conducted in the upper Río Chagres watershed in 2001 by an international group of scientists. Convened under sponsorship of the Autoridad del Canal de Panama, Smithsonian Tropical Research Institute, Universidad Tecnológica de Panama and US Army Yuma Proving Ground Tropic Regions Test Center, this conference brought together some 50 scientists, engineers, and government officials from the international community. The papers in this book follow two perspectives, regional-scale studies of the greater Panama Canal Watershed and more focused papers that consider specific aspects of the upper Río Chagres basin. The book begins with regional geographic overviews of Panama (Ch. 1) and the Panama Canal Watershed (Ch. 2-3). This is followed by two geological papers (Ch. 3-4), the first which describes the geological developmental history of Panama and the second of which presents the geological framework of the upper Río Chagres basin. The next ten papers (Ch. 6-15), forming the central portion of the volume, address the geomorphology, hydrology, and hydrometeorology, and biology of this largely pristine tropical rainforest. The final eight papers (Ch. 16-23) return to the broader perspective, considering similar issues from a regional perspective. A large amount of supplemental material, including a digital elevation model for Panama, species lists from the biological studies, the hydrologic rating curve report for the Rió Piedras, geological field notes and pictures, and other information are available to the interested reader on the web site: http://skagit.meas.ncsu.edu/~helena/riochagres/. A special thanks is due to Brendan Harmon, without whose useful proofreading and editorial assistance the timely preparation of this volume would not have been possible.

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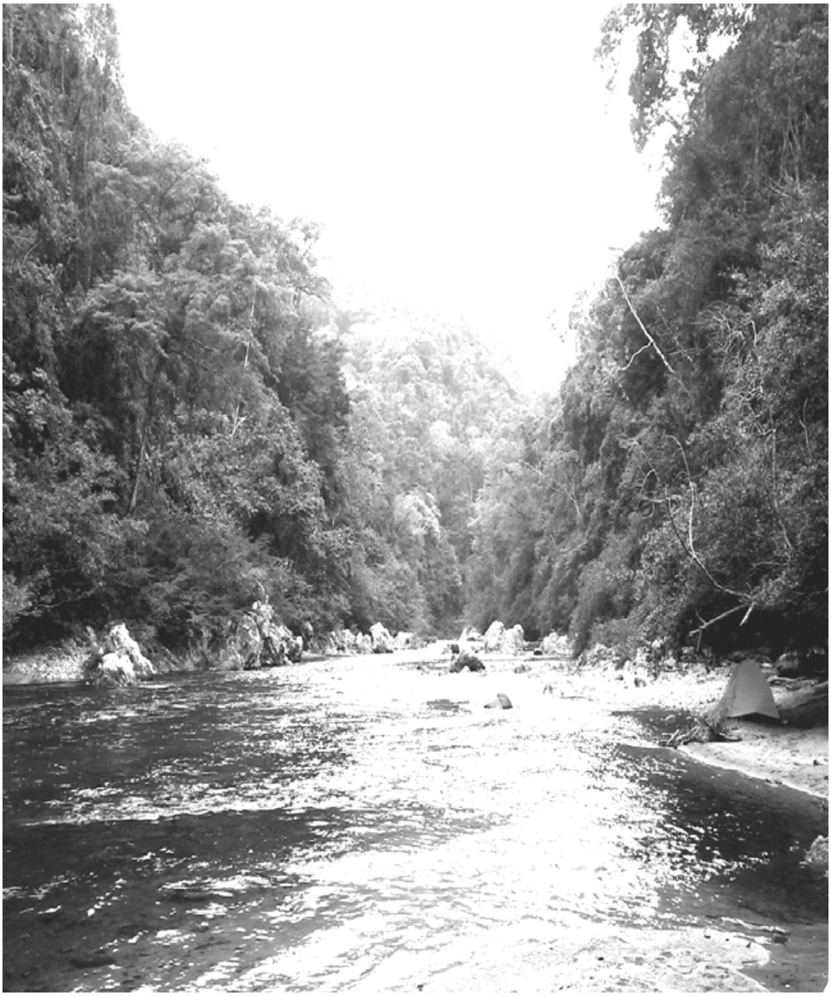

The Upper Río Chagres, Panama

Part I: Setting the Scene

Chapter 1

A GEOGRAPHIC OVERVIEW OF PANAMA:
Pathway to the Continents and Link between the Seas

Eugene J. Palka
United States Military Academy

Abstract: The Republic of Panama occupies about 77,382 km² and, despite its relatively small size, displays a remarkable degree of physical and cultural diversity. Part of the country's physical and biological variety can be attributed to its absolute location within the tropics. Panama's relative location, however, is equally responsible for both the physical and cultural complexity of the country. As the land bridge between the Americas and the major link between the world's two largest oceans, Panama is the crossroads of the western hemisphere. The country's position relative to the continents and oceans constitutes its most important situational advantage. This geographic analysis focuses on the physical geography of Panama, with the goal of providing an overview and larger context for the other papers of this volume. It considers the implications of its relative location and summarizes the physical geography of Panama in general terms drawing from geomorphology, climatology, and biogeography. Although the climate is tropical, Panama experiences significant climate diversity over relatively short distances. Panama also has considerable relief within its comparatively small territorial extent. Elevation differences and associated temperature and precipitation patterns produce distinct vegetative regimes and contribute further to the country's biodiversity. The country's most celebrated resource, however, is its unique location at the intersection of the western hemisphere's continents and oceans.

Key words: Panama; physical geography; geomorphology; climatology; biogeography

1. INTRODUCTION

As an integral part of the land bridge between the continents of North and South America, and as the major connecting link between the world's two largest oceans, the Republic of Panama has proven to be the crossroads of the western hemisphere. The country occupies a territorial extent of about 77,400 km², or an area slightly smaller than the US state of South Carolina (US DOD, 1999). Despite its relatively small size, Panama displays a

R. S. Harmon (ed.), The Río Chagres, Panama, 3-18.

remarkable degree of physical and cultural diversity. Part of the country's physical and biological complexity stems from its position within the tropics, a function of its absolute location. Panama's relative location, however, contributes even further to both the physical and cultural diversity of the country.

This chapter provides a general overview of the country's physical geography in order to provide a larger context for the more comprehensive multidisciplinary analysis of Panama's upper Río Chagres basin, which comprises the majority of this volume. To begin, the country's location is discussed, highlighting the implications of Panama's position relative to the continents and oceans. Then, the physical geography of Panama is examined within the context of three geographic subfields: geomorphology, climatology, and biogeography. The geomorphologic perspective describes the physical relief, principal landforms, and predominant drainage patterns. The climate is addressed in both local terms and within a regional context. Vegetative regimes are discussed in general terms and are connected to physiographic and climatic patterns.

2. THE GEOGRAPHIC PERSPECTIVE

Geography is an extremely broad academic discipline that offers a unique spatial perspective for examining a wide-range of problems, at various geospatial scales, at different points in time, and across disciplinary boundaries. Where geography overlaps with other disciplines, distinct geographic subfields emerge. While each of these subfields can be studied individually, they are also routinely applied in a collective fashion to particular places or regions.

To provide a larger context for the multidisciplinary study of the upper Río Chagres basin, this chapter draws from three distinct geographic subfields - geomorphology, climatology, and biogeography - and generalizes information about Panama using the regional method. As an approach to doing geography, the regional method is best described as a synthesis of the pertinent subfields applied to a specific place. Thus, by definition, most regional geography is both interdisciplinary and multidisciplinary. In this case, a regional geography of Panama introduces some of the distinguishing characteristics of the country and provides a point of departure for the more detailed analyses that comprise the remainder of this volume.

3. LOCATION

One of the keys to understanding the historical development, complexity, and importance of Panama, is derived from an examination of its location. The geographic center of the country lies at approximately 9 °N latitude and 80 °W longitude (Fig. 1). The N-S extent of Panama's borders run approximately from 7-10 °N latitude, and the country extends east to west from 77-83 °W longitude. This E-W extent of about 840 km is equivalent to the approximate distance from Washington, D.C. to Boston in the United States. The country's N-S distance varies between 60-180 km. The most important aspect of Panama's location, which is located entirely within the -5:00 hr GMT time zone, stems from its position on the Isthmus of Panama and its position within the tropics.

Panama is a Central American Republic that is bordered by Costa Rica in the west and Columbia in the east. The country is uniquely located at the crossroads of the western hemisphere. Although Panama has been a sovereign state since gaining its independence from Columbia just over a century ago in 1903, its geographic contiguity with the latter and its position astride the land bridge between continents of North America and South American has left an enduring imprint on its landscape and people.

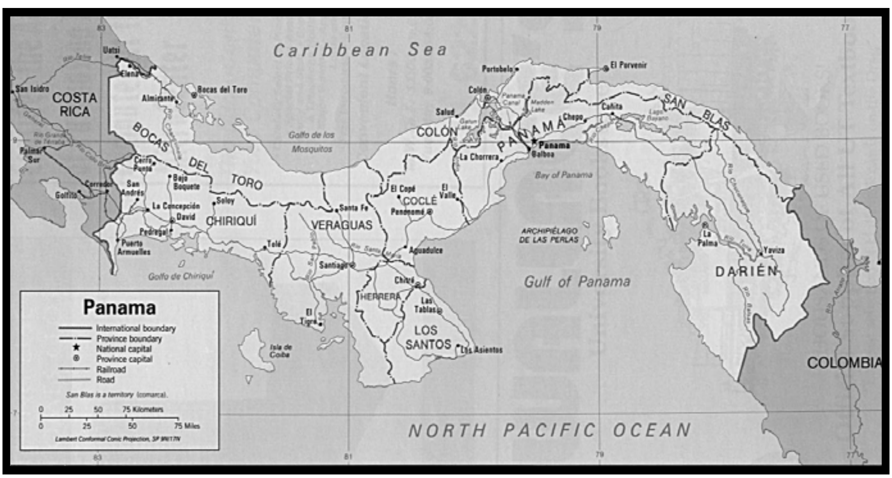

Figure 1. The Republic of Panama (after CIA, 1995).

Panama's location relative to other distinct cultures in the region is apparent in the many different ethnic groups and languages found within its current political borders, where traces of human presence date back more than 11,000 years (Labrut, 19). Located on the narrowest part of the Isthmus of Panama, the territory of the present-day Republic of Panama long has experienced the flow and interaction of flora, fauna, and people between the continents. Since the completion of the Panama Canal in 1913, the country also has served as the conduit between the Atlantic and Pacific Oceans, contributing further to its biodiversity and re-establishing a connection that previously existed up to about 3 million years ago when the current land bridge formed (Coates and Obando, 1996).

4. GEOMORPHOLOGY

Geomorphology involves the study of landforms and the underlying processes that shape them. It entails understanding the physical relief, or the 'lay of the land', and how it evolved. Coates (1997) provides a comprehensive discussion of the formation of Central American land bridge. He specifically notes that the 'Darién Bridge' of eastern Panama surfaced above sea level only 3 million years ago (Coates, 1997). In the western half of the country, the spine that forms the continental divide is the combined expression of earlier episodes of magmatism and tectonic uplift during which mountains were formed by sub-volcanic intrusions (Weil *et al.,* 1972).

The other more routine geomorphic processes that have continued to shape Panama's surface since the quiescence of magmatic activity include weathering and erosion. The former breaks down surface materials, either by physical or chemical means; the latter refers to the movement of weathered surface material by blowing wind, running water, or wave action. The result of these processes is a dynamic physical landscape that is continually reshaped by the forces of nature and one that is reflective of both the dominant geomorphic forces at work and the pervasive influence of climate and weather.

The territory of present-day Panama has been created over the past 140 million years by the interaction of five major tectonic plates: the South American, Caribbean, North American, Cocos, and Nazca plates (see Harmon, 2005, this volume). The Pacific margin of the country is active tectonically, as compared with the Caribbean (*i.e.,* Atlantic) side, which is passive and characterized by a wide continental shelf. This disparity in tectonic activity establishes the conditions for two distinct coastal zones.

One estimate approximates the total length of coastline in Panama to be about 3,000 km (US DOS, 2000). The Caribbean coastline extends for about 815 km and includes several good natural harbors, whereas the Pacific coast stretches for about 1450 km (Weil *et al.,* 1972). The Caribbean coast features extensive coral reefs and includes the 350 or so San Blas Islands that are arrayed along the coastline for more than 170 km (Meditz and Hanratty, 1987). Strung out along the Pacific coast are more than 1,000 islands (Meditz and Hanratty, 1987), including the Las Perlas Archipelago, the Coiba Island in the Gulf of Chiriquí, and the tourist island of Taboga. The country experiences two distinct tidal regimes, with a microtidal range of less than 2 m along the Caribbean coast, and a macrotidal variation between 4-6 m along the Pacific coast (US DOD, 1999).

The dominant inland terrain feature is a discontinuous spine of mountains running through the middle of southern Central America (Fig. 2), that has several regional names - the Cordillera de Talamanca in Costa Rica, the Serranía de Tabasará as it crosses the border into Panama, and then the Sierra de Veraguns as it straddles the former Canal Zone (Weil *et al*., 1972; Miditz and Hanratty, 1987). Most sources generally use the term 'Cordillera Central' to refer to the range that extends from the border with Costa Rica to the Panama Canal. Other mountainous areas include the San Blas Mountains 'which attain elevations >900 m, the Sapo Mountains which attains heights of >1,100 m, and the Darien Mountains which reach 1,876 m. Thus, the combination of volcanism and tectonic uplift, weathering and erosion, and the pervasive influence of climate has established pronounced physiographic features on the landscape: volcanoes, drainage basins, rivers, and a complex coastline.

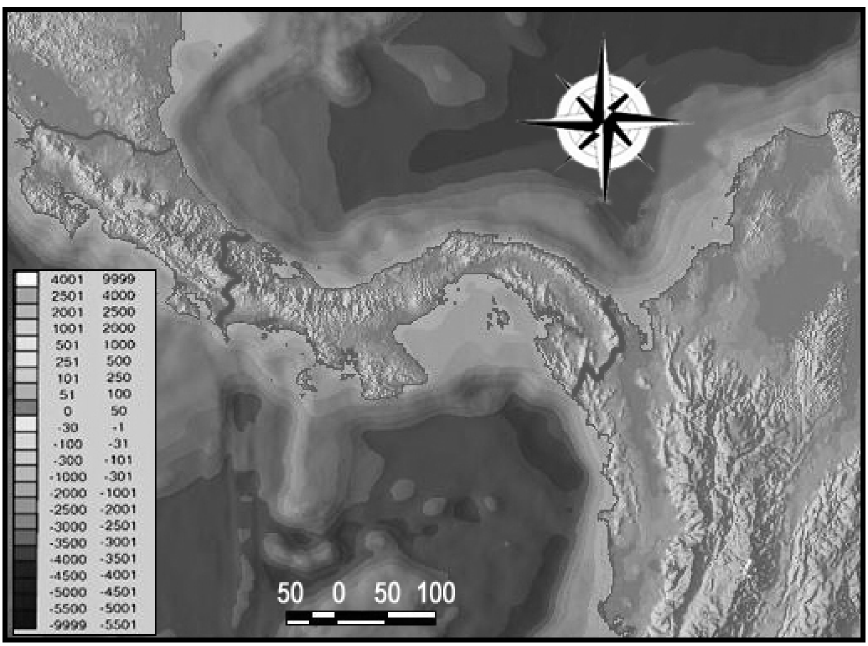

Figure 2. Relief map of southern Central America (USGS, 2001).

Perhaps the most clearly visible physiographic features on Panama's landscape are the mountain ranges and relict volcanoes (Fig. 3). The highest elevations occur in the vicinity of Mount Barú (3,475 m), - (formerly known as Volcán de Chiriquí) - a historically active volcano, which marks the eastern extremity of the Nicaragua volcanic belt in western Panama (Weil *et al.*, 1972). Other smaller volcanic peaks are scattered along the Central Cordillera from the border with Costa Rica eastward to El Valle, near the Panama Canal. Although dormant for several centuries, volcanic ash and lava from Mount Baru have contributed to the formation of fertile, nutrient rich soils (Coates, 1997). The relict volcanoes of the Cordillera Central have also had a profound influence on the drainage patterns in the country.

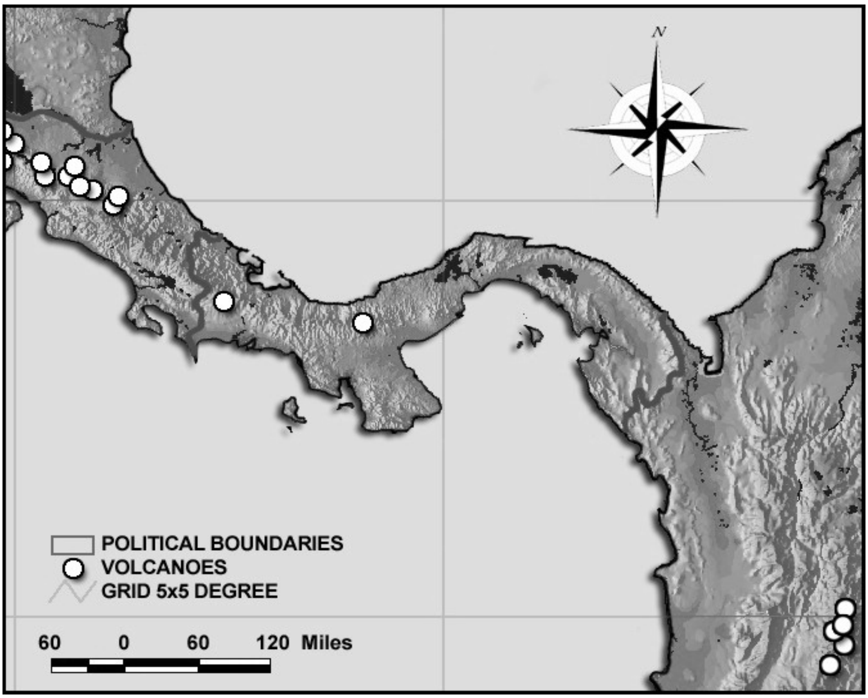

Figure 3. Volcanic activity across eastern Central America (USGS, 2001). White circles denote historically active volcanoes.

4.1 Volcanoes

Perhaps the most clearly visible physiographic features on Panama's landscape are the mountain ranges and relict volcanoes (Fig. 3). The highest elevations occur in the vicinity of Mount Barú (3,475 m), - formerly known

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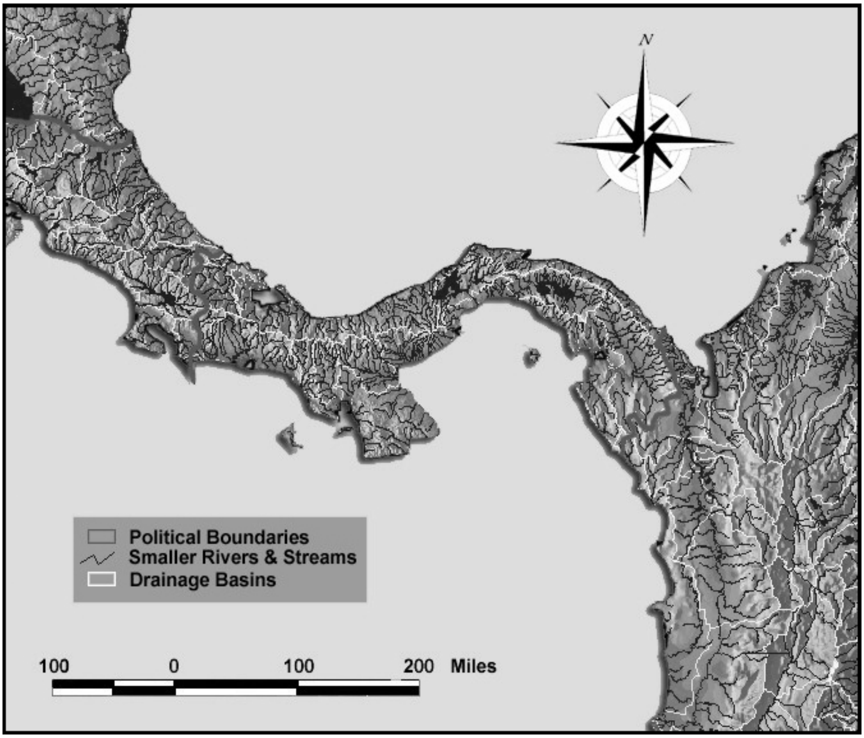

Figure 4. River drainages of Panama (USGS, 2001).

4.2 River Characteristics

Given the rugged nature of its relief and its tropical location, one would expect Panama to be well endowed with fresh water resources. The country has about 500 rivers by most accounts, about 350 of which discharge into the Pacific and the remaining 40% of which drain into the Atlantic (Fig. 4). Those rivers that flow into the Pacific are generally longer, of shallower gradient, and have longer, more developed basins. The steep, conical character of many of Panama's mountains results in radial drainage patterns, within which streams extend outward in all directions from the mountain summit. The more prominent patterns, however, are the parallel streams that are associated with elongated, parallel mountain ranges of steep relief in close proximity to the coast. For example, the Río Chagres exhibits a parallel pattern (see Kinner *et al*., 2005, Chapter 5).

By several criteria, the Río Chagres is Panama's most important river (ANAM, 2000) and, uniquely, the only river in the world to flow into two oceans. Originally dammed in its lower section in 1914 to form Gatun Lake, a second dam was constructed in the lower portions of the upper basin in 1935 to form Lago Alajuela. Currently the Río Chagres provides about 40% of the water necessary to operate the Panama Canal and provides the drinking water for residents of Panama City and Colón, which amounts to nearly 50% of the country's population of 3 million (ANAM, 2000). Fortunately, the Chagres National Park was established in 1985 by Panama's Autoridad Nacional del Medioambiente (ANAM) to protect the hydrologic basin of this extremely significant river (ANAM, 2000).

4.3 The Panama Canal Watershed

The watersheds of the Panama Canal region (of which the Río Chagres basin is an integral part) comprise nearly 552,761 hectares, extending on both sides of the waterway into the provinces of Coclé, Panama, and Colón (ACP, 2001). Of the water withdrawn from these watersheds, 58% is used to operate the canal locks, 36% for generating electricity, and 6% for drinking water (ACP, 2001). The boundaries of the greater Panama Canal Watershed are defined by law within Panama's constitution because the watershed and its dense tropical rainforest constitute a critical natural resource for the country. The continuing health of the watershed and its rainforest are dependent upon favorable climate and compatible human activities.

5. CLIMATOLOGY

Climatology is the subfield of geography that examines the long-term conditions of the atmosphere and the interactions between the atmosphere and the earth's surface. Climate profoundly influences a host of environmental processes such as the growth of vegetation, soil formation, watershed hydrology, and geomorphic denudation. Climate also influences human activities ranging from agricultural to building practices. The term climate is often referred to as the 'average weather' of a location, but this can be overly simplistic and misleading. Depending on the spatial scale considered or the timeframe used, a variety of different climatic patterns emerge in the analysis of any region, regardless of its size. As the spatial scope narrows and as the timeframe shortens, a host of factors internal to the climate system begin to play an increasingly important role in developing a clear analysis of 'average' atmospheric conditions. Factors such as topography, vegetation, regional pressure variability, and El Niño phases may play an important part in determining the climate for a particular season or year. This is especially true for Panama. Thus, geographers typically examine climate from both a regional and local perspective.

5.1 Regional Climate Patterns

Panama has a tropical climate that stems in part from its location between 7-10° N latitude. Using the Köppen climate classification system, Panama's climate is generally characterized as an ***A*** type (tropical climate with all monthly mean temperatures over 18 °C. More specifically, the country exhibits a regional pattern that includes an ***Af*** climate (sufficient precipitation all months) along the Atlantic coast, and an ***Aw*** climate (dry season during the winter) along the Pacific coast and on the south side of the continental divide.

Despite uniformly high temperatures and precipitation year round, temperatures on the Atlantic side of the isthmus are slightly higher, in general, than on the Pacific, and precipitation is of higher intensity on the Atlantic side. Average annual temperatures range from 23-27 °C in coastal areas throughout the country and average a milder 19 °C in the interior highlands (Microsoft, 2001). The rainfall pattern is more pronounced with an average of 2,970 mm on the Atlantic side and about 1,650 mm on the Pacific side of the continental divide (Microsoft, 2001).

5.2 Climate Controls and Localized Patterns

Climate controls influence a variety of variables such as temperature, temperature range, precipitation, and wind; and are the cause of the N-S and coastal-upland variations in Panama's climate. Controls such as insolation, pressure, ocean currents, maritime influence, altitude, and topographic barriers, all play a role in determining the climate of Panama, due to the country's mountainous terrain, equatorial proximity, coastal position between the Pacific Ocean and the Caribbean Sea, and its location relative to the inter-tropical convergence zone (ITCZ).

The amount of incoming solar radiation, or insolation, that Panama receives is primarily a function of its latitude. Located between 7-10 °N latitude, Panama is only a short distance north of the equator. As a result, the country receives high amounts of insolation throughout the year, and maximum amounts during the summer, when the northern hemisphere is tilted towards the sun and periods of daylight are slightly longer. This results in year-round high temperatures with minimal seasonal and daily variation, especially at sea level locations.

The country's location on the Isthmus of Panama also contributes to the small annual and daily temperature range. The coastal orientation of the country subjects it to the moderating effects of the ocean and sea. This type of situation influences the temperature range between summer and winter, and even from day to night, regardless of latitudinal location. However, temperatures around the country can vary widely due to variations in elevation and rugged nature of the topography. Altitude has a dramatic effect on temperature. Air temperatures decrease with increasing elevation as a function of the dry environmental lapse rate, which averages about -10 °C per 1,000 meters increase in elevation. With much of Panama dominated by the continental divide, altitude must be considered carefully. Several peaks have elevations that exceed 3,500 m, so these mountains can experience temperatures that may vary by 10-15 °C over relatively short horizontal distances. Such temperature variability makes it very difficult to characterize broad regions as having uniform climate types. Moreover, elevation and orientation to prevailing winds can combine to produce microclimatic niches (Rees, 1997).

The influence of topographic barriers has a dramatic effect on precipitation regimes throughout the country. Orographic precipitation on the windward side of mountain ranges is common as moist air is forced upwards and cooled adiabatically. By contrast, air on the leeward side of mountain ranges descends and warms adiabatically resulting in a rain shadow effect where the air is warmer and much drier. The Atlantic coast of Panama experiences a sustained onshore flow of wind accompanied by orographic precipitation, except during the winter months. Thus, the Caribbean side has higher precipitation totals throughout the year, with only a short dry season during winter.

The Inter-Tropical Convergence Zone (ITCZ) has a significant impact on Panama's climate as the low-pressure system migrates seasonally across the country. Atmospheric pressure controls the amount and seasonality of precipitation. Parts of the country receive increased rainfall based on the presence of the ITCZ from May to December, and significantly less rain from January to April as the ITCZ migrates south.

Panama's climate is more complex than might be anticipated given the small territorial extent of the country. Attempting to characterize Panamanian climate regionally is difficult due to the interactions of several

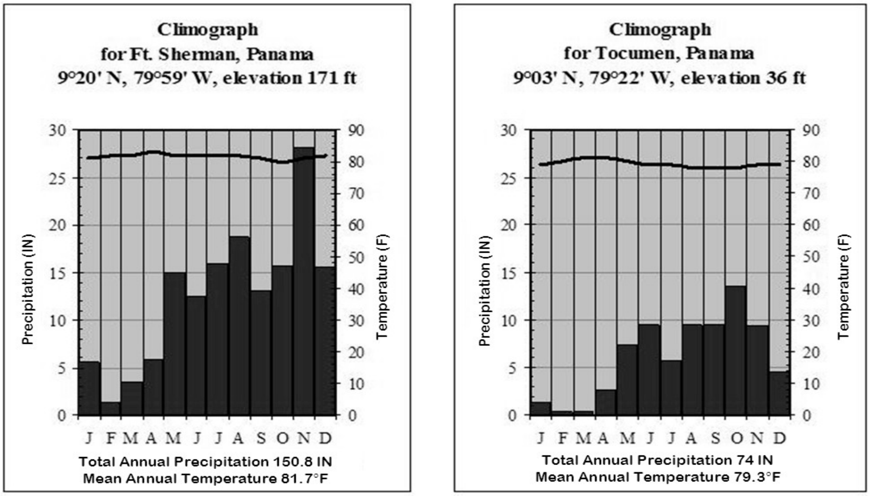

Figure 5. Climographs for two locations in central Panama demonstrating Atlantic versus Pacific variability – (left) for Ft. Sherman near the Atlantic coast and (right) for Tocumen near the Pacific coast (data from USAFCCC, 2003).

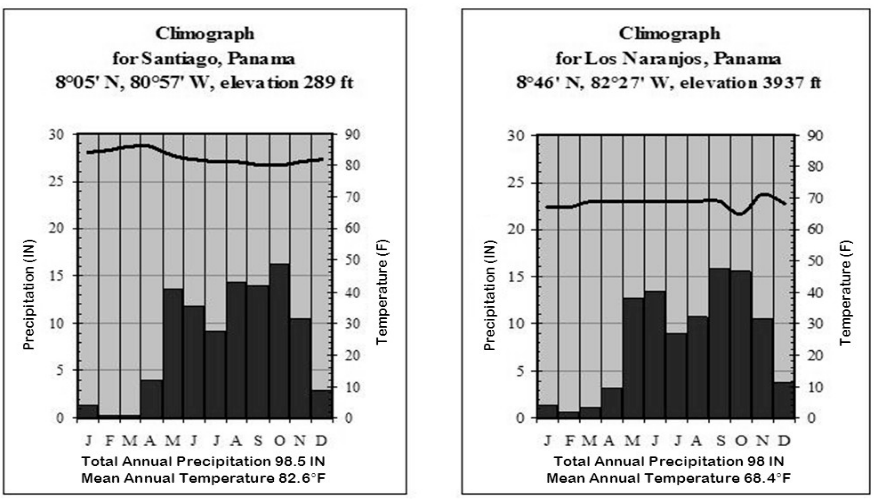

Figure 6. Climographs for two locations in central Panama illustrating interior lowland versus highland variability – (left) for Santiago a lowland site and (right) for Los Naranjos, a highland site (data from USAFCCC, 2003).

climate controls. Altitude and maritime location significantly affect temperature regimes, while pressure systems and topographic barriers influence precipitation patterns. The overall result is a tropical climate with local temperature and precipitation variations based on elevation, orientation, and proximity to the coast. Climographs, graphical representations of monthly mean temperature and monthly precipitation for a specific location, help to portray the impact of climate controls and provide a clearer picture of the climate diversity within the country (Figs. 5 and 6).

6. BIOGEOGRAPHY

Panama's biogeographic complexity stems from its geomorphology and climate. Biogeography is the study of the distribution of plants and animals, where these biotic entities occur, and why they occur at disparate locations. This field of study utilizes information derived from many other disciplines and subfields, such as meteorology, climatology, geomorphology, botany, zoology, ecology, and resource management. The biogeographic scale of study normally is regional to continental and global. However, based on being the focal point of the 'Great American Biotic Interchange' (Simpson, 1940), Panama's biogeography is as complex as any comparable area in the world.

6.1 Vegetation Patterns

Panama's incredible biodiversity is attributable to its tropical location and its position on the Central American land bridge. Webb (1997) provides a comprehensive statement of the 'Great American Biotic Interchange' noting that more than half of the present land mammals of South America came from North and Central America by way of the land bridge (Webb, 1997). Using Holdridge's (1967, 1974) classification scheme, Panama has twelve life zones, defined by climatic and soil conditions and associated forests. The biological diversity is highlighted by an estimated 10,000 species of plants (Labrut, 1993). More conservative surveys include up to 9,000 vascular plants, along with 218 species of mammals, 929 of birds, 226 of reptiles, and 164 of amphibians (Microsoft, 2001).

Natural vegetation zones include forested mountains, hills, lowlands, savannas, coastal mangrove swamps, and tidal flats. Dense tropical forests include multistory canopies that extend some 20-50 m above the ground in uncleared parts of the eastern and northwestern regions of the country (US DOD, 1999). Mangrove swamps are common along the Caribbean coast, with savannas and rolling foothills in other coastal locations. Land cover