Frontiers in Earth Sciences

Fabio Cediel
Robert Peter Shaw
Editors

Geology and Tectonics of Northwestern South America

The Pacific-Caribbean-Andean Junction

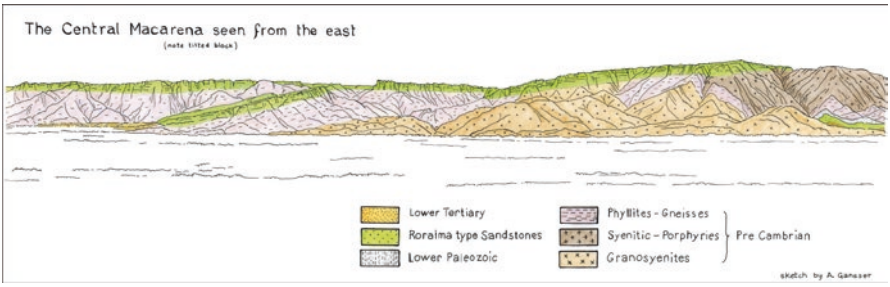
EXTRAS ONLINE

Springer

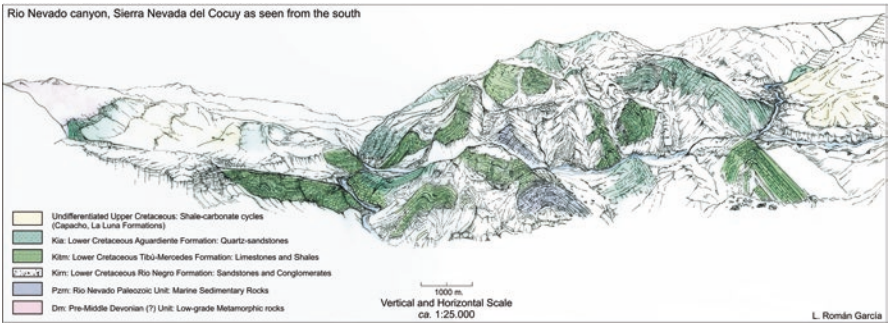
Frontiers in Earth Sciences

More information about this series at http://www.springer.com/series/7066

Central Macarena seen from the east. Based upon early field studies within the Macarena range and the Roraima tepuis, Augusto Gansser documented the puzzling relationships between the Guiana Shield and the Andean belt, in the process formulating the "Roraima Problem" from a geomorphologic-stratigraphic standpoint. Subsequent studies served to highlight the "problem" within the Macarena uplift, where Cambrian sediments are exposed at approx. 1000 m above sea level whilst Silurian sediments within the Orinoco low are buried at approx. 2300 m depth. The coexistence of vertical tectonics (over 2000 m displacement) and extensional strain systems (Phanerozoic graben-rift fills), with thrust-and-fold belts, may point to concealed wrench structures in subsurface, undetected by geophysical methods. An updated synthesis of the Roraima Problem, using new surface and sub-surface cartographic and structural data, is presented within Chap. 1 of this volume. *Redrawn from Gansser A., 1941, Central Macarena, Geological Report Shell No. 100, Appendix 12-16 with enclosures.*



Geological landscape of the Rio Nevado canyon. The juncture between the Santander Massif and the Eastern Cordillera presents some of the most complex structural and stratigraphic relationships to be found anywhere in the Colombian Andes. This scaled geologic sketch of the Rio Nevado canyon was generated during detailed field-based mapping and structural and stratigraphic study, which produced over 20 km of 1:25.000-scale structural cross sections, as revealed in Chap. 9 of this volume. The composition highlights intensely disharmonic folds outcropping along the southern and northern walls of the Rio Nevado canyon, whilst maintaining the relative orientation and geometry of the structures and permitting comparison of the fold styles in both canyon walls. Completed in the style of pioneering Swiss geologist, Arnold Heim, this sketch provides a reliable graphical representation of the complex architecture underlying the Eastern Cordillera. Its production harkens a return to classical methodologies in the understanding and interpretation of natural landscape evolution vs. the indiscriminate use of purely algorithmic methods in the reconstruction of "balanced cross sections". *Adapted from original illustration in ink and water colour on parchment by Laura Román García.*



Fabio Cediel • Robert Peter Shaw
Editors

Geology and Tectonics of Northwestern South America

The Pacific-Caribbean-Andean Junction

Springer

Editors
Fabio Cediel
Consulting Geologist
Department of Geology
University EAFIT
Medellín, Colombia

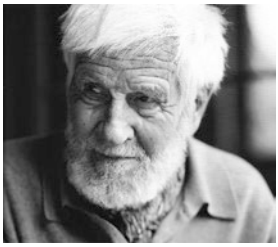
Robert Peter Shaw
Consulting Geologist
Kelowna, BC, Canada

ISSN 1863-4621 ISSN 1863-463X (electronic)
Frontiers in Earth Sciences
ISBN 978-3-319-76131-2 ISBN 978-3-319-76132-9 (eBook)
https://doi.org/10.1007/978-3-319-76132-9

Library of Congress Control Number: 2018940188

Printed on acid-free paper

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland



Augusto Gansser (1910–2012)
Field Geologist, Worldwide Scientific Explorer
Geologic Analysis: Regional Geology and Tectonics
Colombia 1938–1946 "Unique – a dream"

Highlights

- *Key geological realms in Colombia were the focus of his first enthusiastic geological explorations, including Gorgona Island, Chocó Arc, Sierra Nevada de Santa Marta, La Macarena, and the Guiana Shield: remote regions studied along walking trails, on horseback, in river boats, and light planes, under conditions spanning extreme tropical to glacial.*

- *Gansser was an exceptional draftsman, known by his stylish sketches of landscape, structures, and stratigraphic sections (in the style of Swiss geologist, coworker, and mentor Arnold Heim), giving priority to facts and gathering field data to incorporate in his geologic analysis and regional geological models.*
- *He was a successful explorer of natural resources, particularly oil and gas.*
- *He was a pioneer and leader of the modern geological interpretation of the northern Andes.*
- *Gansser's short exposé on the "Roraima Problem" (1974) demonstrates his capacity for data synthesis, and his continental-scale vision regarding, what even today, remain unanswered questions related to the tectono-sedimentary evolution of the Guiana Shield and its present-day morpho-structural expression.*
- *In 1979, Gansser published several key papers on the origin of the Andean-type "Trans-Himalayan magmatic belt," that was a precursor to the India-Asia collision and uplift of the Himalayas.*

- *In the words of Rasoul Sorkhabi (2012): "Gansser was one of the first geologists to apply plate tectonic theory to the evolution of mountain belts, thanks to his upbringing in Alpine geology where 'mobilist' tectonics characterized by thrust sheets, fold nappes, and compressional forces had been worked out by Swiss geologists, decades before the theory of plate tectonics was universally accepted!"*

Upon his death, Gansser was cremated with his hammer placed along with his body—not merely as a beautiful gesture for the fulfilling life of a great field geologist but also to fulfill a last wish of his:

"Instead of flowers, I would like my geologist's hammer."

Gansser's Principle Publications Related to Northwestern South America

1938 – Der Nevado del Cocuy: Columbianisches Bergerlebnis (self-published). (Note: Gansser immortalized his wife (Toti, his field companion) by naming a

5000 meter peak "Pico Toti," as, while climbing it together, she fell down a slope, but was saved by her rope).
1941 – Geological Report, Shell No. 100. Central Macarena. (Contributors: Renz, O., Hubach, E.) 16 pp. 25 photos 2 Tables 9 Annex. (in-house files).
1945 – Geological Report, Shell Pacific Chocó, (contributors: Poborski, S., Bäclin, R., Swolfs, H., Haanstra, U.) 75 pp. (in-house files).
1950 – Geological and petrographical notes on Gorgona island in relation to northwestern S. America. Schweizerische Mineralogische und Petrographische Mitteilungen. Bulletin Suisse de Mineralogie et Petrographie, v. 30 p. 219–237.
1954 – Observations on the Guiana Shield (S. America). Eclogae Geol. Helvetiae, v. 47 p. 77–112.
1955 – Ein Beitrag zur Geologie und Petrographie der Sierra Nevada de Santa Marta (Kolumbien, Südamarika). Schweiz, Mineralogische und Petrographische Mitteilungen, v. 35 no. 2 p. 209–279.

1960 – Über Schlammvulkane und Salzdome. Mitteilungen aus dem Geologischen Institut der Eidg. Techn. Hochschule und der Universität Zürich, Serie B, Nr. 15. Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich, v. 105 no. 1, p. 1–46.
1962 – Lateinamerika - Land der Sorge und der Zukunft. Sozialwissenschaftliche Studien für das Schweizerische Institut für Auslandforschung 9. Erlenbach-Zürich/ Stuttgart: Rentsch. p. 315.
1963 – Quarzkristalle aus den kolumbianischen Anden (Südamerika). Schweizerische Mineralogische und Petrographische Mitteilungen. Bulletin Suisse de Mineralogie et Petrographie, v. 43 p. 91–103.
1969 – The Alps and the Himalayas, in Himalayan and Alpine Orogeny: New Delhi, Report of the Twenty-Second International Geological Congress, 1964, Part XI, Proceedings of Section 11 p. 387–399.
1973a – Facts and theories on the Andes. Twenty-sixth William Smith Lecture (with generalized geological map of the Andes

1:20,000,000). Journal of the Geological Society of London, v. 129 p. 93–131.
1973b – Orogene Entwicklung in den Anden, im Himalaya und den Alpen, ein Vergleich (Orogenic evolution in the Andes, Himalayas and the Alps; a review) Eclogae Geologicae Helvetiae, v. 66 p. 23–40.
1974a – The ophiolitic melange. A worldwide problem on Tethyan examples. Eclogae Geologicae Helvetiae, v. 63 p. 479–507.
1974b – The Roraima problem (South America). Mitteilungen aus dem Geologischen Institut der Eidg. Technischen Hochschule und der Universität Zürich, Zürich, 177: 80–100.
1981 – Palaeogene komatiites from Gorgona Island, East Pacific: A primary magma for ocean floor basalts? (co-authors: Dietrich, V.J., Sommerauer, J., and Cameron, W.E.) Geochemical Journal v. 15 p. 141–161.
2000 – La Macarena, Massagno, Switzerland (self-published), 111 p.

Biographies

Augusto Gansser (2000) La moglie di un geólogo, 2nd edn Massagno, Switzerland, 236 p.
Ursula Eichenberger (Text), Ursula Markus (Hrsg.) (2008) Augusto Gansser. Aus dem Leben eines Welt-Erkunders (From the life of a world explorer) Zürich: AS Verlag, ISBN 978–3–909,111-58-9.
Rasoul Sorkhabi (2012) Memorial to Augusto Gansser (1910–2012) Geological Society of America Memorials, v. 41 p. 15–21.

Note: The Ganssers had four daughters (Ursula, born in Colombia, 1941; Manuela, 1949; Francesca, 1956; and Rosanna, 1959) and two sons (Mario, born in Colombia, 1943; Luca, also born in Colombia, 1945). In 2000, Gansser's dear wife and companion, Linda Biaggi-Gansser (Toti), died. She had kept diaries and notes of their lifelong journey, which formed the basis for the self-published biographical work "La moglie di un geologo: Augusto Gansser."

Acknowledgments

Beginning in the late 1800s, individual scientific curiosity and a persistent search for answers to questions born of field observation led a select group of geoscientists to study the mountainous regions of northern South America. Names like Sievers, Stübel, Karsten, Hettner, Sheibe, Grosse, Gansser, T. Ospina, Renz, Hubach, G. Botero, and Bürgl, considered by us *the Pioneering Generation*, are synonymous with geological reconnaissance, investigation, comparative geology, and geological analysis in *terra incognita*, as in were, in the new world uncovered by A. von Humboldt and J.B. Boussingault.

Early globalization of the world resource economy, in our case for precious metals and fossil fuels, acted as a catalyst to the appearance of, and important contributions from, the *Escuela de Minas* (Medellín, 1887) and the Department of Geology and Geophysics at the *Unversidad Nacional*, Bogotá (1958). Prominent Northern Andean explorers and geoscientists, as well as their North American and European counterparts (*the Industrial Generation*), supported by new technologies and refined methodologies, have permitted a state-of-the-art and up-to-the-moment understanding of the region, as presented herein in *Geology and Tectonics of Northwestern South America*.

The above-noted geological generations, comprised of individuals and considered as a whole, have contributed to the scientific advances reported herein and to the educational and socioeconomic well-being of the Northern Andean region, and we salute them with our profound and enthusiastic academic gratitude.

The Universidad EAFIT (Department of Geology, Medellín) provided fertile ground and an essential place of gathering, investigation, information exchange, discussion, and debate, during incubation, growth, production, and editing of this volume. The open-mindedness, professionalism, dedication, and all-around support provided by this institution are gratefully acknowledged.

Contents

Part VIII Holocene-Anthropocene

Contributors

Mauricio A. Bermúdez Escuela de Ingeniería Geológica, Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Colombia

Matthias Bernet ISTerre, Université Grenoble Alps, Grenoble, France

Institut des Sciences de la Terre, Université Grenoble Alpes, Grenoble, France

Stephanie Brichau Geosciences Environment Toulouse, Université Paul Sabatier, Toulouse, France

Andrés L. Cárdenas-Rozo Earth Sciences Department, EAFIT University, Medellín, Colombia

Fabio Cediel Consulting Geologist, Department of Geology University EAFIT, Medellín, Colombia

Fabio Colmenares Geosearch Ltd., Bogotá, Colombia

Iván D. Correa Area de Ciencias del Mar, Universidad EAFIT, Medellín, Colombia

José F. Duque-Trujillo Earth Sciences Department, EAFIT University, Medellín, Colombia

David A. Foster Department of Geological Sciences, University of Florida, Gainesville, FL, USA

Barry P. Kohn School of Earth Sciences, University of Melbourne, Melbourne, VIC, Australia

Salomon B. Kroonenberg Delft University of Technology, Delft, Netherlands

Hildebrando Leal-Mejía Mineral Deposit Research Unit (MDRU), The University of British Columbia (UBC), Vancouver, BC, Canada

Departament de Mineralogia, Petrologia i Geologia Aplicada, Facultat de Ciències de la Terra, Universitat de Barcelona, Barcelona, Catalonia, Spain

Julian A. Lopez Departamento de Geociencias, Universidad Nacional de Colombia, Bogotá, Colombia

M. I. Marín-Cerón Departamento de Ciencias de la Tierra, Universidad EAFIT, Medellín, Colombia

Joan Carles Melgarejo i Draper Departament de Mineralogia, Petrologia i Geologia Aplicada, Facultat de Ciències de la Terra, Universitat de Barcelona, Barcelona, Catalonia, Spain

J. Mesa-García Departamento de Ciencias de la Tierra, Universidad EAFIT, Medellín, Colombia

Geology Department, University of Michigan, Ann Arbor, MI, USA

Kyoungwon Min Department of Geological Sciences, University of Florida, Gainesville, FL, USA

Santiago Noriega Universidad Nacional de Colombia, Facultad de Minas, Departamento de Geociencias y Medio Ambiente, Medellín, Colombia

Teresa Orozco-Esquivel Centro de Geociencias, Universidad Nacional Autónoma de México, Querétaro, Qro., Mexico

Cristina I. Pereira Area de Ciencias del Mar, Universidad EAFIT, Medellín, Colombia

Juan C. Ramirez Geosearch Ltd., Bogotá, Colombia

Stewart D. Redwood Consulting Economic Geologist, Panama City, Panama

Juan D. Restrepo Departamento de Ciencias de la Tierra, Universidad EAFIT, Medellín, Colombia

Sergio A. Restrepo-Moreno Universidad Nacional de Colombia, Facultad de Minas, Departamento de Geociencias y Medio Ambiente, Medellín, Colombia

Department of Geological Sciences, University of Florida, Gainesville, FL, USA

Pedro A. Restrepo-Pace Oilsearch Limited, Sydney, NSW, Australia

Laura Román-García Geosearch Ltd., Bogotá, Colombia

Carlos Javier Sánchez Earth Sciences Department, EAFIT University, Medellín, Colombia

Johan M. Sánchez Geosearch Ltd., Bogotá, Colombia

Luis Fernando Sarmiento-Rojas Independent Consultant, Bogotá, Colombia

Robert P. Shaw Departament de Mineralogia, Petrologia i Geologia Aplicada, Facultat de Ciències de la Terra, Universitat de Barcelona, Barcelona, Catalonia, Spain

César Vinasco Departamento De Geociencias Y Medio Ambiente, Universidad Nacional De Colombia, Facultad De Minas, Medellin, Colombia

Carlos A. Zuluaga Departamento de Geociencias, Universidad Nacional de Colombia, Bogotá, Colombia

Abbreviations

BABB	Back-Arc Basin Basalt
BA-Suarez	Buenos Aires-Suarez
CA-VA	Cajamarca-Valdivia Terrane
CAT	Caribbean Terrane Assemblage
CCOP	Cretaceous Caribbean-Colombian Oceanic Plateau
CCSP	Central Continental Sub-Plate
CHO	Chocó Arc
CLIP	Caribbean Large Igneous Province
CTR	Central Tectonic Realm
ca.	circa, approximately
cm	centimeter
DEM	Digital Elevation Model
dm	decimeter
E	East
EC	Eastern Cordillera (of Colombia)
e.g.	exempli gratia, for example
etc.	et cetera
Fig., Figs.	Figure, Figures
Fm., Fms.	Formation, Formations
GER	General Element Ratio
GS(R)	Guiana Shield (Realm)
Ga.	Giga-annum, billion years
Gp.	Group
g/t	grams per tonne
HFSE	High Field Strength Elements
ICP(ES)	Inductively Coupled Plasma (Emission Spectroscopy)
INGEOMINAS	Instituto de Investigaciones en Geociencias, Minería y Química
i.e.	id est., that is
kbar	kilobar(s)
kg/yr.	kilograms per year
LILE	Large Ion Lithophile Elements

LOI	Loss On Ignition
K-(feld)spar	potassium feldspar
Ka	kilo-annum, thousand years
km	kilometer
m	meter
mm	millimeter
mg/kg	milligrams per kilogram
Ma	mega-annum, million years
m.y.	million years
M	million
MALI	Modified Alkali Lime Index
MMT	Million Metric Tonnes
MORB, N-, E-	Mid Ocean Ridge Basalt, Normal, Enriched
MSP	Maracaibo Sub-Plate Realm
MVT	Mississippi Valley-Type
N	North
NAB	Northern Andean Block
PAT	Pacific Terrane Assemblage
PER	Pearce Element Ratio
PGEs	Platinum Group Elements
PLOCO	Provincia Litosférica Oceánica Cretácica del Occidente de Colombia
ppm	part per million
REE(L, H)	Rare Earth Element(s) (Light, Heavy)
RSZ	Romeral Shear Zone
RTG	Ridge Tholeiitic Granitoid
S	South
SEDEX	Sedimentary Exhalative
T	tonnes
UPME	Unidad de Planeacón Minero Energético
UTM	Universal Transverse Mercator
VAG	Volcanic Arc Granites
VMS	Volcanogenic Massive Sulphide
vs.	versus
W	West
WTR	Western Tectonic Realm
wt%	weight percent

Prologue

….back to basics, back to the source!
….it has been said:

The scientists who study the earth [universe] as a whole, are often in error but never in doubt. Nowadays they're less often in error, but their doubts have grown as big as all outdoors (Ferris 2005)

The northwest corner of continental South America, as well as its Pacific and Caribbean companions, has travelled a long and varied route over the last 540 million years (Phanerozoic), in order to reach its present (temporary) resting point. The scientific curiosity of most researchers today, however, concentrates upon the more recent stages of the journey (let's say, the last 100 m.y. or so, from Late Cretaceous to present). The debate over tectonic models for emplacement of the Caribbean plate remains open. Notwithstanding, an understanding of the geological history of continental South America, and its Phanerozoic interplay with distinct oceanic plates and continental masses, is a critical factor in the formulation of any geological model for today's Caribbean.

By the time of the scientific revolution, the NW corner of South America and its bordering Pacific Ocean and Caribbean Sea were covered by incipient geological maps, although the region remained an as yet untested geophysical laboratory. The search for "ores" (not yet considered geological exploration) and wildcat drilling for oil had revealed promising economic prospects and raised interesting academic questions about the geological history of the region. In Europe and North America, as the debate regarding the validity of plate tectonic theory reached its zenith, the scarce hard geological data available for NW South America were forced to fit the nascent paradigms of the new tectonic era.

The proverbial "complexity" of NW South America has become the repeated, almost clichéd, introduction to any paper written on the geology and tectonic history of the region. Curiously, the main geological features (presumably) are often expressed in terms of the "Andean cordilleras," their intramontane valleys and flatlands (*llanos*), that is, in terms of the most basic physiographic elements of physical geography. Contrary to these physiographic underpinnings, we herein propose the

use of stratigraphic-controlled morphostructural features, as a first approach to understanding the large-scale geotectonic framework of NW South America.

The NW corner of South America, including the western Guiana Shield, Northern Andean Block (or North Andes), and neighboring Pacific and Caribbean plates, provides an excellent natural laboratory, of "manageable" scale, suited to the testing of modern tectonic, magmatic, geophysical, and metallogenic models, currently used by many as unquestionable paradigms. To undertake such an exercise we apply and interpret factual data, provided by generations of field-based geological and geophysical surveys, combined with biostratigraphic, geochronological, lithochemical, isotopic, and petrographic research, and not least of all, detailed basin analysis. All of this information is publically available—albeit, not (yet) as a fully comprehensive, integrated, computerized data bank—as critical historic information has yet to be passed from paper to digital format. Notwithstanding, carefully and patiently compiled empirical observations permit the dedicated scientist to present well-founded interpretations, syntheses, and conclusions pertaining to the detailed geological history of the region.

The geological laboratory of NW South America is endowed with the following:

- Proterozoic metamorphic, igneous, and sedimentary rock units, remnants of intracratonic orogens, not yet fully documented let alone understood.
- Paleontological and geochronological data which attest to the presence of lithostratigraphic units belonging to each recorded erathem of the Phanerozoic.
- Morphostructural patterns which reveal the interference and/or superposition of peneconteporaneous or successive tectonic events.
- A history of tectonic interaction between oceanic and continental plates, recorded in diverse marine and terrestrial environments from throughout the Phanerozoic.
- Sedimentary basins filled with tectonostratigraphic sequences that register uplift, basin development, and regional orogenic evolution.
- Widespread magmatic suites, exposed at essentially all levels, generated along extensional, collisional, transcurrent, and consuming plate margins, which record tectonic, petrogenetic, and isotopic interactions within/between oceanic and continental crust and the upper mantle throughout much of the Phanerozoic.
- A highly varied metallogenic record, temporally and spatially reflective of the tectonomagmatic development of the region.
- A complete range of climatic zones and thermal layers, originating at sea-level and extending up to almost 6000 m elevation.

Via this volume, northern Andean tectonostratigraphic and magmatic history may be contrasted with classical cordilleran-type orogenic and magmatic models, such as those used in the Central Andes and elsewhere. Numerous differences are illustrated that render the application of typical "Cordilleran-type" or "Andean-type" models for northern Andean development unacceptable. Throughout this volume, the importance and contribution of underlying Proterozoic through mid-Mesozoic geological and structural elements, in the evolution of Mesozoic through Cenozoic northern Andean orogenic phase tectonics (structural style, uplift

mechanisms, basin development, magmatism, etc.), are revealed. These features are exemplified by highly oblique subduction-collision systematics associated with accretion of allochthonous oceanic terranes along the Pacific margin; the detachment, migration, and "plis de fond" style of deformation developed in the Maracaibo tectonic float; and unique inversion systematics culminating in the transpressive pop-up of the Eastern Cordillera, all of which have no clear geological analog in classical Cordilleran-type orogens. A critical revision of subduction models and the generation of related (or unrelated) granitoid arcs in the Northern Andes lead the reader to comparative regional geological analysis beyond the Andes.

Almost 30 years ego, Peter Molnar presented a crucial paper entitled "Continental Tectonics in the Aftermath of Plate Tectonics." He observed: "The success of plate tectonics required an acceptance of continental drift, and thus a reinterpretation of the large-scale geological history of most of the earth. But the basic tenet of plate tectonics, rigid-body movements of large plates of lithosphere, fails to apply to continental interiors, where buoyant continental crust can detach from the underlying mantle to form mountain ranges and broad zones of diffuse tectonic activity."

Today, in the light of Molnar's prognosis, we attempt to understand key geological features, observed in the Guiana Shield and within the basement beneath Cenozoic northern Andean basins, documented via surface geological mapping and detailed geophysical studies. Beyond the multiple deformation processes engraved upon the Guiana Shield, as it partially underlies cratonized Paleozoic and Mesozoic basins, we recognize large scale grabens and rifts, as well as Proterozoic basement involved in basin deformations and the tectonic migration of continental "subplates," or tectonic rafts incorporated in exotic terranes.

The Pacific–Caribbean–Andean Junction presents a multidisciplinary approach to understanding the geological history and tectonic assembly of NW South America, with a focus upon onshore and circum-continental Colombia as the geological keystone of the region. The individual thematic contributions integrated herein are presented by an experienced team of independent, predominantly autochthonous geoscientists from academia and industry, supported by international experts, all with a long-standing, hands-on relationship to the northern Andean geological mosaic. Although the individual works and resulting volume are not free of controversial conclusions, the combined thesis permits geological and tectonic synthesis at a detailed scale, which will in turn permit re-evaluation of historic impasses and the reformulation of critical questions that may lead to higher levels of understanding through new avenues of research.

F. Cediel and R. P. Shaw

Part I
Regional Overview

Chapter 1
Phanerozoic Orogens of Northwestern South America: Cordilleran-Type Orogens. Taphrogenic Tectonics. The Maracaibo Orogenic Float. The Chocó-Panamá Indenter

Fabio Cediel

Abbreviations

CAT	Caribbean terranes
CA-VA	Cajamarca-Valdivia terrane
CCOP	Caribbean-Colombian oceanic plateau
CCR	Colombian Caribbean Realm
CHO	Chocó-Panamá Arc
CTR	Central Tectonic Realm
DAP	Dagua-Piñón
GDFS	Garrapatas-Dabeiba Fault System
GSR	Guiana Shield Realm
GU-FA	Guajira-Falcón terranes
IRLPM	Igneous-related low-pressure metamorphism
ME	Sierra de Mérida ("Venezuelan Andes")
MOF	Maracaibo orogenic float
NAB	North Andean belt
NW SA	Northwestern South America
OPTFS	Oca-El Pilar Transform Fault System
PAT	Pacific Terranes
RO	Romeral Mélange
SNStM	Sierra Nevada de Santa Marta
WETSA	W-E Tectono-Sedimentary Anomaly
WTR	Western Tectonic Realm

F. Cediel (✉)
Consulting Geologist, Department of Geology University EAFIT, Medellín, Colombia

F. Cediel, R. P. Shaw (eds.), *Geology and Tectonics of Northwestern South America*,
Frontiers in Earth Sciences, https://doi.org/10.1007/978-3-319-76132-9_1

1.1 Introduction

Regional geology of northwestern South America and the link between local and global continental-oceanic geology.

Regional geological syntheses contain, by nature, a certain degree of geological "guess estimation." Such works cannot conceal or ignore the significant lack of fundamental geological information for extensive areas of northwestern South America. In fact, they tend to emphasize this aspect. Notwithstanding, a certain degree of geological speculation, based upon empirical observation at the regional level, is necessary from time to time. Such inference can provide a kind of inventory with which to qualify the state of geological knowledge for specific areas and for a region as a whole. It is hoped that such presentations would encourage new concepts, debates, and syntheses applicable to a better understanding of the geological history of the region as a whole.

No attempt has been made in this synthesis to reconcile differing or contradictory geological, geophysical, or geochemical interpretations, and the alert reader will detect apparent inconsistencies in differing interpretations of the geological record. These discrepancies are derived from the fact that, in some cases, the quality or density of the available data, or differing data sources, affects the nature and validity of the resulting conclusions.

1.2 Tectonic Realms (Figs. 1.1 and 1.2)

Via definition of the various litho-tectonic and morpho-structural domains, I derive a synthesis in terms of tectonic plates, subplates, terranes, composite terranes, and sedimentary basins. This analysis contrasts with the general custom observed in Northern Andean literature, of using major physiographic features such as cordilleras, serranías, valleys, or depressions as geologic reference points (e.g., "Western Cordillera," "Central Cordillera," etc.), thereby incurring the false notion that, for example, a certain cordillera or depression today corresponds to a single litho-tectonic unit or represents a single geological or tectonic time period or event.

1.2.1 Guiana Shield Realm (GSR)

This litho-tectonic realm is comprised of the autochthonous mass of the Precambrian Guiana Shield. The western edge of the GSR extends throughout the subsurface of the Llanos, Guarico, and Barinas-Apure basins of northeastern Colombia and northwestern Venezuela. To the south, the GSR extends beneath the eastern foreland front of Colombia's Eastern Cordillera, through to the Garzón Massif, and under the Putumayo basin. In Ecuador, the GSR underlies the Putumayo-Napo basin, the

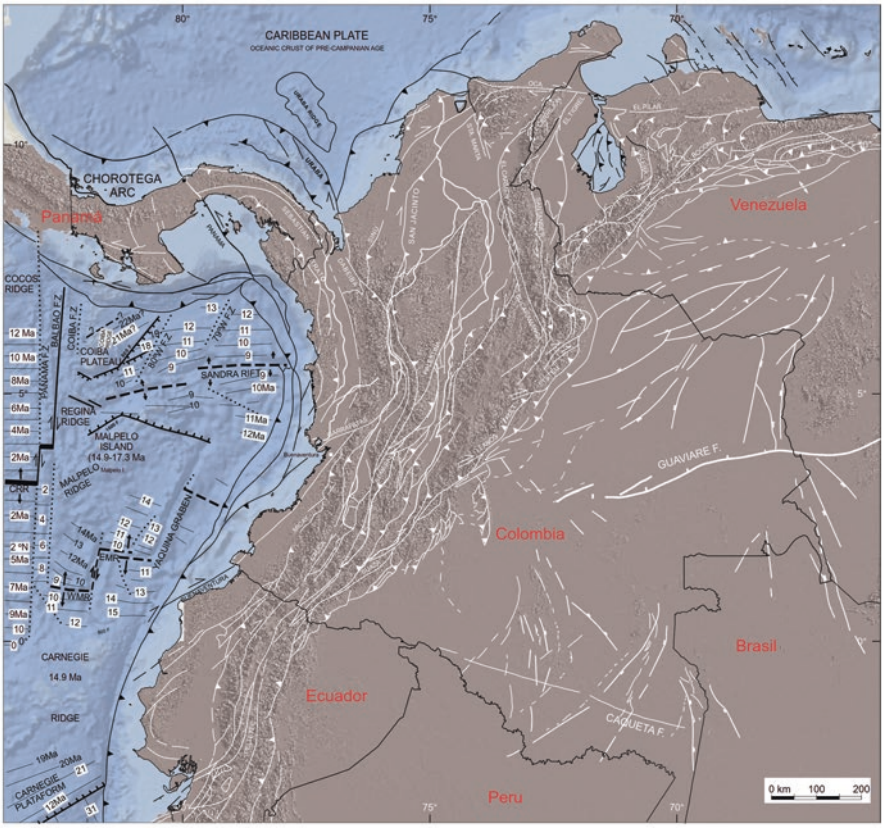


Fig. 1.1 Structural sketch map of NW South America

eastern margin of the Cordillera Real, and extends eastwards into the Amazon basin of both Colombia and Ecuador.

The Guiana Shield formed the backstop for the progressive accretionary continental growth of northwestern South America from the Middle to Upper Proterozoic through to the Holocene. Outcrops of 1300–900 Ma granulite document continental collision, penetrative deformation, and high-grade metamorphism during a broadly Grenvillian-aged orogenic event.

1.2.2 The Central Tectonic Realm (CTR)

The CTR is a composite and temporally and compositionally heterogeneous lithotectonic realm. The Precambrian and Paleozoic constituents of the CTR are allochthonous to parautochthonous with respect to the Guiana Shield autochthon, while

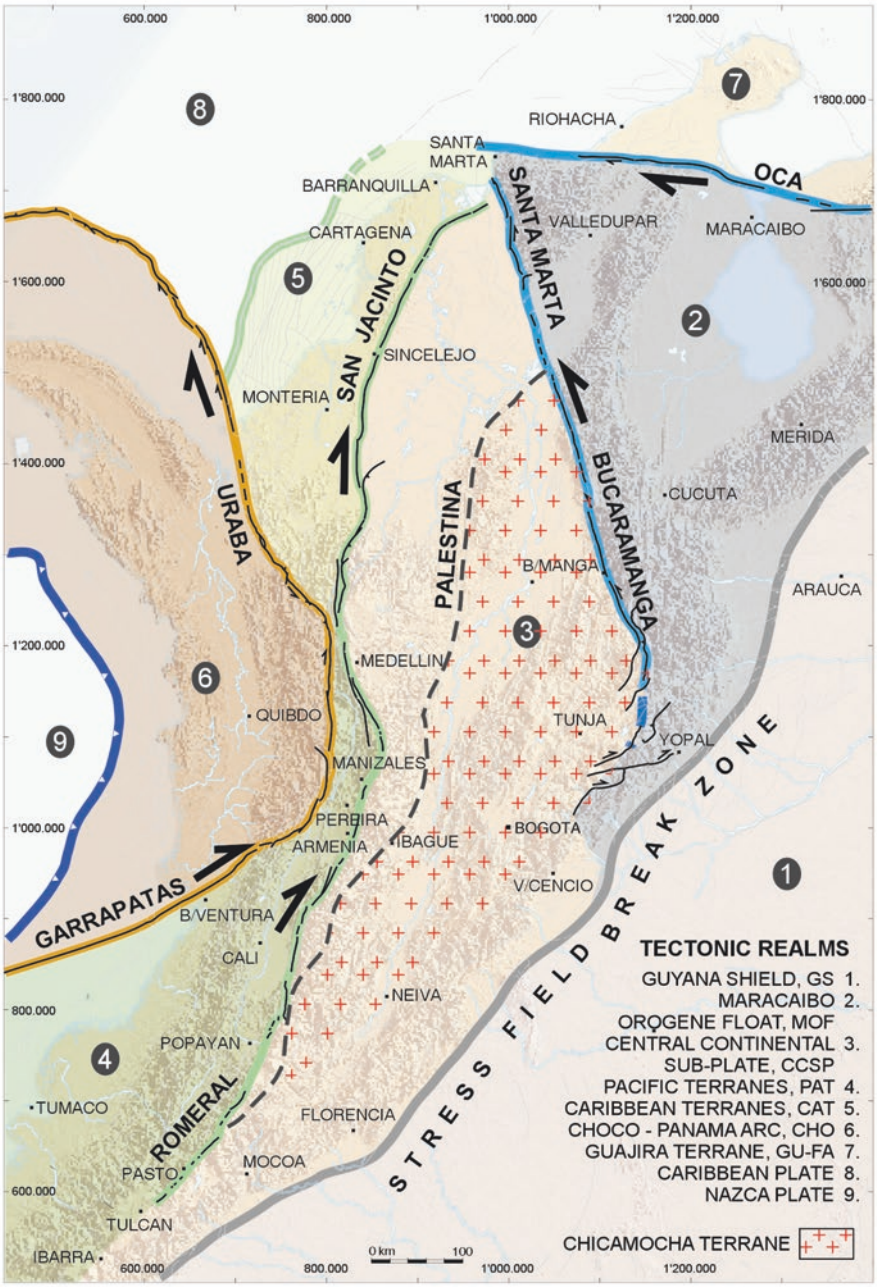


Fig. 1.2 Main tectonic realms of NW South America

the Mesozoic to recent components are considered to be parautochthonous to autochthonous with respect to the CTR.

The CTR has played host to numerous complex geological events from the Early Paleozoic up to the present. These events include a Middle Ordovician-Silurian Cordilleran-type orogeny followed by a period of prolonged regional extension (taphrogenesis), which began in the Mississippian (?) and continued into the Middle Mesozoic. The Mesozoic-Cenozoic transition to transpressional regimes, collisions, and magmatism during the Northern Andean orogeny defines the present structural and morphological character of the CTR.

The oldest constituent of the CTR is the exotic Chicamocha terrane. This Precambrian allochthon, a possible relict of Oaxaquia, was welded directly to the Guiana Shield during a Grenvillian orogenic event. In Colombia, Chicamocha is represented by fragmented granulite-grade bodies of migmatite and quartz-feldspar gneiss. To the west of Chicamocha, the Cajamarca-Valdivia terrane represents the remnant of an oceanic island arc, accreted during the Early Paleozoic, which presently forms the litho-tectonic basement to much of the physiographic Central Cordillera.

1.2.3 Maracaibo Orogenic Float (MOF)

The MOF hosts numerous composite litho-tectonic provinces and morpho-structural features, including the Sierra Nevada de Santa Marta (SM), the Sierra de Mérida (ME, the "Venezuelan Andes"), the Serranía de Perijá and Santander Massif (SP), and the César-Ranchería and Maracaibo basins. The MOF is characterized as a disrupted segment of the northwesternmost Guiana Shield, overlain in this region by extensive Phanerozoic supracrustal sequences. In the Late Cretaceous, the MOF began to migrate northwestward, along the Santa Marta-Bucaramanga and Oca-El Pilar fault systems, in the process uplifting the Sierra de Mérida, the Santander-Perijá belt, and the Sierra Nevada de Santa Marta. Although technically a part of the Guiana Shield, the MOF is distinguished from the GSR by a unique and regionally constrained style of deformation brought about by the evolving Mesozoic-Cenozoic through recent interaction between the Pacific (Nazca) and Caribbean plates and continental South American. The possible causes, timing, and mechanisms behind this migration remain a matter of debate.

1.2.4 Western Tectonic Realm (WTR)

Despite important local data, complete characterization of individual terranes in the WTR, including the definition of their limits and time(s) of collision/accretion with the continent, remains deficient. Regardless, it has been established that all litho-tectonic units comprising the WTR include fragments of Pacific oceanic plateaus,

aseismic ridges, intra-oceanic island arcs, and/or ophiolite, and all developed within and/or upon oceanic basement, as demonstrated by paleomagnetic data and paleogeographic reconstructions.

The WTR consists of two composite terrane assemblages: (1) the Pacific (PAT) assemblage, including the Romeral (RO), Dagua (DAP), and Gorgona (GOR) terranes, and (2) to the north, the Caribbean terranes (CAT), including San Jacinto (SJ) and Sinú (SN).

1.3 Pacific Terranes (Romeral, Dagua-Piñón, Gorgona)

The Romeral terrane contains mafic-ultramafic complexes, ophiolite sequences, and oceanic sediments of probable Late Jurassic(?) and Early Cretaceous age. Although an allochthonous origin for some of the constituents of the Romeral assemblage may argue (see discussion in Cediel et al. 2003), much of the Romeral terrane appears to represent the reworked remnants of pericratonic, marginal basin mafic magmatism and continental to marine sedimentation, deposited along the rifted proto-Caribbean margin. Multiple phases of tectonic reworking and translation during the Meso-Cenozoic led to burial, high-pressure metamorphism, dismemberment and obduction/accretion of the marginal basin assemblages along the paleocontinent (represented by metamorphic rocks of the CTR), and the present-day configuration of the Romeral tectonic mélange and shear zone.

To the west of the Romeral assemblage, the Dagua terrane is dominated by basalt and diabase with important thicknesses of flyschoid siliciclastic sediments, including siltstone and graywacke with chert and minor limestone. The chemical characteristics of the Dagua basalt/diabase are unlike those of island arc or marginal basin basalts, and appear to represent accreted fragments of aseismic ridges, and/or oceanic plateaus which numerous authors associate with the Caribbean-Colombian oceanic plateau (or CCOP; e.g., Kerr et al. 1997; Sinton et al. 1998). A Middle to Late Cretaceous age for basalts of the Dagua terrane correlates well with numerous Middle and Upper Cretaceous paleontological dates for this unit from both Colombia and Ecuador.

Farther west, the Gorgona terrane is located on the westernmost margin of northwestern South America; however, it is located mostly offshore. It also appears to represent an accreted oceanic plateau; however, paleomagnetic data and tectonic reconstructions (e.g., Kerr and Tarney 2005) suggest it is far traveled and unrelated to the Dagua terrane and the CCOP in general. It contains massive basaltic flows, pillow lavas, komatiitic lava flows, and a peridotite-gabbro complex; it has been assigned a Late Cretaceous age.

With respect to the Gorgona terrane, studies by McGeary and Ben-Abraham (1989) suggest it also represents an aseismic oceanic ridge or fragment of an oceanic plateau. Notwithstanding, paleomagnetic data presented by Estrada (1995) indicates Gorgona doesn't have any clear correlation with the CCOP. For example, the El Horno basalt (86 ± 3 Ma) was located at about 25° south relative to South America in Late Cretaceous time. Estrada (1995) presented reconstructions and possible trajectories that suggest a longitude of origin near 135° west. Similar con-