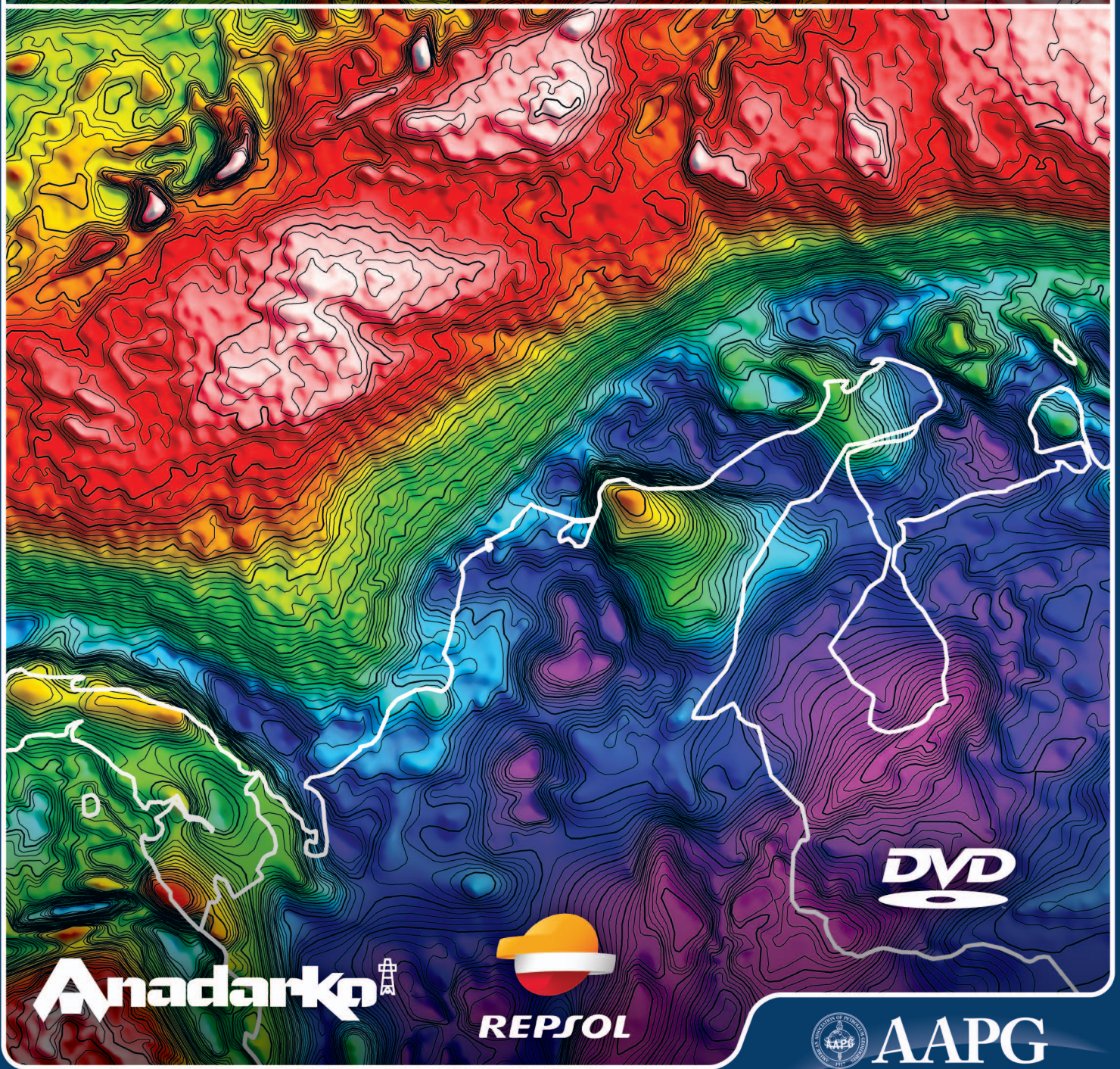
AAPG Memoir 108

Edited by Claudio Bartolini and Paul Mann

Petroleum Geology and Potential of the Colombian Caribbean Margin



AAPG

Petroleum Geology and Potential of the Colombian Caribbean Margin

Memoir 108

Edited by
Claudio Bartolini and Paul Mann

Co-published by
The American Association of Petroleum Geologists
and
Repsol
and
Anadarko

ISBN 13: 978-0-89181-388-0

AAPG Editor: Michael L. Sweet
AAPG Geoscience Director: James B. Blankenship

COVER: The Bouguer gravity anomaly map of the Colombian Caribbean Margin was generated by the Repsol potential fields specialists, using Getech gravity data compilation.

This publication is available from:

The AAPG Bookstore
P.O. Box 979
Tulsa, OK U.S.A. 74101-0979
Phone: 1-918-584-2555 or 1-800-364-AAPG (U.S.A. only)
E-mail: bookstore@aapg.org
www.aapg.org

Geological Society Publishing House
Unit 7, Brassmill Enterprise Centre
Brassmill Lane, Bath BA13JN
United Kingdom
Phone: +44-1225-445046
Fax: +44-1225-442836
E-mail: sales@geolsoc.org.uk
www.geolsoc.org.uk

Affiliated East-West Press Private Ltd.
G-1/16 Ansari Rd., Daryaganj
New Delhi 110-002
India
Phone: +91-11-23279113
Fax: +91-11-2326052\38
E-mail: affiliate@vsnl.com

The American Association of Petroleum Geologists

The American Association of Petroleum Geologists Books Refereeing Procedures

The Association makes every effort to ensure that the scientific and production quality of its books matches that of its journals. Since 1937, all book proposals have been refereed by specialist reviewers as well as by the Association's Books Editorial Board. If the referees identify weaknesses in the proposal, these must be addressed before the proposal is accepted.

Once the book is accepted, the Association Books Editorial Board ensures that the volume editors follow strict guidelines on refereeing and quality control. We insist that individual book papers can only be accepted after satisfactory review by two independent referees. The questions on the review forms are similar to those for the AAPG Bulletin journal. The referees' forms and comments must be available to the Association's Books Editorial Board upon request.

Although many of the books result from meetings, the volume editors are expected to commission papers that were not presented at the meeting to ensure that the book provides a balanced coverage of the subject. Being accepted for presentation at the meeting does not guarantee inclusion in the book.

More information about submitting a book proposal and editing a book for The American Association of Petroleum Geologists can be found on its web site: www.aapg.org.

Acknowledgments

AAPG wishes to thank the following for their generous contributions to
Petroleum Geology and Potential of the Colombian Caribbean Margin

AAPG Memoir 108

Contributions are applied toward the production cost of the publication, thus directly reducing the book's purchase price and making the volume available to a larger readership.

The editors want to express their gratitude to the following individuals who supported the book project from the beginning, making possible its development and publication: Joseba Murillas, exploration director Latin America (Repsol U.S.A.), Andrew Mehlhop, exploration manager South America (Anadarko), Stephen D. Johnson, Colombia Country manager (Shell), and Mark Richardson, exploration supervisor South America (ExxonMobil), and for kindly supporting the book sponsorships efforts.

Claudio Bartolini is also grateful to Joseba Murillas and Laszlo Benkovics of Repsol U.S.A. for their absolute support to the book project, including company logistics, time, and encouragement.

It is very important to note that the only reason this book is available to the geoscience community is thanks to the authors' perseverance, focus, and commitment. Their hard work is reflected in the important and innovative papers they contributed. They should all be proud of this first international publication on the Caribbean geology of Colombia.

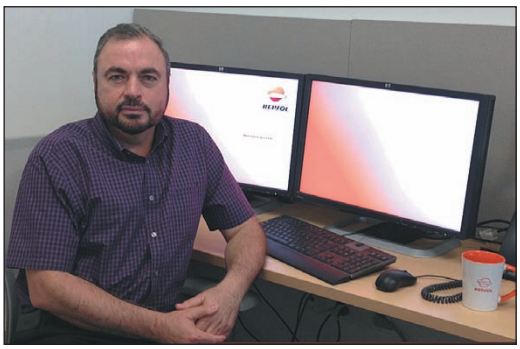
Likewise, the book benefited in great manner by the constructive and assertive technical reviews of a large number of geoscientists who made possible the overall improvement of chapters, adding to the content and technical quality of the volume. These individuals, who are always willing to contribute to the geosciences are: Josh Rosenfeld, Gary Prost, Harold Lang, William Ambrose, Rashel Rosen, Norman Rosen, Gregory Frebourg, Peter Bartok, Carlos Zuluaga, Tiku Ravat,

Michal Ruder, Iain Neill, John Lewis, Jaime Toro, James Kellog, Carlos Dengo, Paul Mann, Carlos Rivero, Joel Curiale, Harry Rowe, Suhas Talukdar, Carlos Macellari, Randy Keller, James Pindell, Van Mount, William Ambrose, Thomas Buerkert, Robert Loucks, Dewi Jones, Charles Kerans, Kevin Burke, Nancy McMillan, Antonio Teixel, Andrey Ortega, Jay Pulliam, Gemma Ercilla, Timothy Lawton, Oscar Lopez Gamundi, Adriana Mantilla, Ran Zhang, Luis Pomar, Andy Horbury, Bonnie Weise, Hermann Duque-Caro, Georgina Guzman, Victor Vega, Mark Gordon, Carlos Alberto Vargas, Joan Flinch, Stephen Leslie, and Mark Norini.

Claudio Bartolini and Paul Mann want to express their gratitude to Kelsy Taylor (AAPG) and Sneha Pant (Lumina) for their excellent editorial work and perfect organization of the book.

About the Editors

Claudio Bartolini



Claudio is a senior exploration advisor at Repsol U.S.A. in the Woodlands, Texas as a member of Repsol's Latin America New Ventures Group. For the last seven years he has coordinated technical collaboration agreements between Repsol and Pemex. He was also the international delegate to the Mexican Association of Petroleum Geologists (AMGP). In 2014, Claudio organized a session dedicated to Mexico's deep water petroleum potential at the Annual AAPG Meeting in Houston. Claudio's career with Repsol began with work on the deep water exploration of the Gulf of Mexico Basin, particularly in Mexico's territorial waters. He has also worked the Chukchi and Beaufort Seas with Repsol's Alaska exploration team, and for two years was part of Repsol's Regional Studies Group in Madrid, Spain working the Llanos Basin of Colombia, and continuing to coordinate with Pemex on projects in the Campeche Shelf of Mexico. Bartolini received his B.S. degree in geology from the University of Sonora, Mexico in 1983 followed by three years of work as an exploration geologist. He returned to academia earning his M.S. in geology from the University of Arizona in 1988 and then joined the Gold Fields Mining Corporation for four years as an exploration geologist in Arizona, California, and Mexico. In 1992, he continued his studies at the University of Texas at El Paso, earning a Ph.D. in geology in 1997 and receiving the College of Science's Outstanding Doctoral Student Award. During this period Claudio was the recipient of a NASA Scholarship, as well as support from the American Geological Institute, the Houston Geological Society, the Peñoles Mining Company, and the El Paso Mineral & Gem Society. His fieldwork was supported by a research grant from Exxon, and he also did an internship with Amoco in Houston, Texas in 1994. While pursuing his doctoral studies, Claudio consulted for several Canadian exploration companies in Mexico and Central America. Upon completing his doctorate, he joined ARCO International Oil and Gas Company's Latin America exploration group, later becoming the principal basin and field researcher for IHS Energy in Houston, Texas. Claudio Bartolini is the senior editor of GSA Special Paper 340, *Mesozoic Sedimentary and Tectonic History of North-Central Mexico,* published in 1999. He also edited AAPG Memoir 74, *The Western Gulf of Mexico Basin: Tectonics, Sedimentary Basins and Petroleum Systems* (2001); AAPG Memoir 79, *The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon Habitats, Basin Formation, and Plate Tectonics* (2003); and AAPG Memoir 90, *Petroleum Systems in the Southern Gulf of Mexico*, published in 2011. For these efforts, he was awarded AAPG's Robert H. Dott Sr. Memorial Award for the Best Geological Special Publication published by the association.

Paul Mann

Paul Mann is currently the Robert E. Sheriff Endowed Professor of Geology at the Department of Earth and Atmospheric Sciences of the University of Houston. In 1978, he received his B.A. degree in geology from Oberlin College and was elected to Phi Beta Kappa. From 1978 to 1983, he was a Ph.D. student at the State University of New York (SUNY) at Albany where he conducted outcrop-based mapping in Jamaica, Dominican Republic, and Haiti supervised by Professor Kevin Burke. He received the SUNY Presidential Award for Outstanding Dissertation upon graduation in 1983.

From 1983 to 2011, he was successively a research associate, research scientist, and senior research scientist and lecturer at the University of Texas Institute for Geophysics (part of the UT Jackson School of Geosciences since 2003).

For the period of 1984–2003 his work at UTIG was funded by the US National Science Foundation and Petroleum Research Fund of the American Chemical Society. Work during this period included outcrop mapping of subaerial, active plate boundary areas (Jamaica, Hispaniola, Puerto Rico, Cuba, Honduras, Nicaragua, Costa Rica, Panama, Venezuela, Trinidad, and Papua New Guinea) and marine geophysical surveys of active, submarine plate boundaries (Cayman Trough, Solomon Islands and Ontong Java Plateau, Macquarie Ridge, Puerto Rico trench, offshore Venezuela and Trinidad, Nicaragua).

During this period he was a Fellow of the Organization of American States to the Dominican Republic (1984), an Erskine Fellow in New Zealand (1997), a Fellow of the French Academy of Science at the University of Nice (1999–2000), and a Leiv Eiriksson Fellow in Norway (2009).

From 2001 to 2011 he co-led two successive, oil industry consortia at the University of Texas and one consortium from 2011 to present at the University of Houston. During his career, he has been primary research supervisor to four undergraduate honors students, 28 masters students, nine PhD students and five postdoctoral researchers at the University of Texas and University of Houston.

He has edited or co-edited 11 volumes including five GSA Special Papers on circum-Caribbean geology and tectonics (1991–2007), one Elsevier monograph on the Caribbean sedimentary basins (1999), one special issue of *Tectonophysics* on tectonics of the Solomon Islands (2004), one special issue of the *AAPG Bulletin* (2006) on the Maracaibo supergiant basin of Venezuela, a volume dedicated to deformation at strike-slip bends (2007), one special issue of *Marine and Petroleum Geology* (2011), and one special issue of *Geochemistry, Geophysics and Geosystems* (G3) on tectonics and ultrahigh pressure metamorphism and tectonics in Papua New Guinea (in press). In 2010, he was part of the rapid science response team to the 2010 Haiti earthquake and contributed to three articles in a special issue on the earthquake in *Nature Geosciences* (2010).

In 2005, he became a fellow of GSA. From 2006 to 2010, he received the UT Joseph C. Walter Excellence Award, the UT Outstanding Research Award, and the UTIG Directors Circle of Excellence Award. He is a current associate editor of *Marine and Petroleum Geology* and has been a past associate editor of *Geology* and *GSA Bulletin*.

His current industry consortium at the University of Houston, CBTH, focusses on basinal studies, tectonics, and petroleum exploration in a geographic region that includes the Gulf of Mexico, Caribbean, northern South America, and equatorial West Africa and currently supports 34 allied researchers, postdoctoral researchers, grads and undergrads working on various research projects in the CBTH study area along with the development of a regional GIS database. Since 2005, UT and University of Houston grad and undergrad students supported by the CBTH project have received 38 research awards.

He is married to Maria C. Lebron, the assistant director of the Texas Commission on Environmental Quality. They have two daughters: one who graduated from Colby College in 2014 and is employed by the Federal Emergency Management Agency (FEMA) in Washington, DC, and one who is a senior in high school.

About the Sponsors

REPSOL

Repsol, one of the world's leading integrated oil and gas companies, spans the entire energy value chain. Repsol has exploration and production operations in more than 30 countries with 25,000 employees worldwide. Their corporate headquarters are located in Madrid, and their U.S.A. headquarters are in Houston. With a proven track record of exploratory success, Repsol is well positioned for growth in some of the world's most vibrant, high yielding production areas. In the last five years, Repsol has made more than 40 international discoveries, including the world's eighth largest field. Repsol operates five refineries in Spain which are among the most efficient in Europe. As pioneers in renewable energy R&D, they are committed to advancing technical innovation as a key to building a more efficient, secure and sustainable energy model. Repsol has an extensive exploration and production portfolio in Latin America, and is actively exploring the Colombian Caribbean Margin.

ANADARKO

Anadarko is among the world's largest independent oil and natural gas exploration and production companies, with 2.79 billion barrels-equivalent of proved reserves at year-end 2013. Anadarko Petroleum Corporation's mission is to deliver a competitive and sustainable rate of return to shareholders by exploring for, acquiring and developing oil and natural gas resources vital to the world's health and welfare. Their deep and balanced portfolio of assets encompasses premier positions in major U.S. onshore shale and resource plays, and oil-focused opportunities in deepwater basins worldwide. With more than 5700 employees worldwide, Anadarko manages exploration/production activity in 15 countries. Anadarko has more than 27 years of deepwater rig time under contract and is currently leading the industry with 70% five-year deepwater exploration/appraisal success rate. In Colombia, Anadarko, in partnership with Ecopetrol, is in the earliest phase of its exploration for oil and natural gas resources offshore in the Caribbean Sea.

SHELL

Shell is a global group of energy and petrochemical companies. Our headquarters are in The Hague, the Netherlands, and our chief executive officer is Ben van Beurden. The parent company of the Shell group is Royal Dutch Shell plc, which is incorporated in England and Wales.

Our strategy to generate profitable growth remains to drive forward with our investment program, to deliver sustainable growth and provide competitive returns to shareholders, while helping to meet global energy demand in a responsible way.

In upstream we focus on exploring for new oil and gas reserves and developing major projects where our technology and know-how adds value to the resource holders.

In downstream our emphasis remains on sustained cash generation from our existing assets and selective investments in growth markets.

EXXONMOBIL

ExxonMobil is the world's largest publicly traded international oil and gas company. We hold an industry-leading inventory of global oil and gas resources. We are the world's largest refiner and marketer of petroleum products, and our chemical company ranks among the world's largest. We apply science and innovation to find better, safer and cleaner ways to deliver the energy the world needs.

Our upstream business encompasses high-quality exploration opportunities across all resource types and geographies, an industry-leading resource base, a portfolio of world-class projects, and a diverse set of producing assets. We have an active exploration or production presence in 39 countries.

Our balanced downstream portfolio includes refining facilities in 17 countries. We are the world's largest integrated refiner and manufacturer of lube basestocks and a leading marketer of petroleum products and finished lubricants. Our high-quality products, combined with a strong global refining and distribution network, position us as a premier supplier around the world.

ExxonMobil Chemical is one of the largest chemical companies in the world, with a unique portfolio of commodity and specialty businesses that deliver superior returns across the business cycle. We manufacture high-quality chemical products in 15 countries. With a major presence in the Asia-Pacific, we are well positioned to competitively supply the rapid chemical demand growth in this region.

ExxonMobil has had a continuous business presence in Colombia for nearly 100 years and has over 400 employees through the country. We have operations in the fuels, lubricants, and chemicals markets as well as exploration activity. We support the community through a number of programs focusing on math and science education, the environment, and women's economic opportunities.

We are proud to play a leading role in providing the energy the world needs to support economic growth, technological advancement, and the well-being of communities around the globe.

Claudio Bartolini kindly dedicates this book to his wife Gilda Yolid, for her unconditional friendship and life-long support during the bad and good times.

Dedication

Fernando Etayo-Serna is presently the head and biostratigrapher of Proyecto Hidrosogamoso (Middle Magdalena Valley) at INGEOMINAS, Bogota, Colombia. He was a professor of paleontology, stratigraphy, and field geology at the Department of Geology, National University of Colombia, Bogota for 26 years, from 1975 to 2001. He has been highly recognized for the formation of many generations of Colombian geoscientists, and he has supervised many research projects and theses. In addition, over the years, he has conducted numerous biostratigraphic and stratigraphic projects in the sedimentary basins of Colombia, which constitute the most impressive contribution to the understanding of the formation and evolution of sedimentary basins. Since 1962, Etayo-Serna has published national and international eminent papers on the Mesozoic geology, which are the pillars of the present day knowledge on biostratigraphy and stratigraphy in the country. During his professional life, Etayo-Serna has received the following honors and awards; the Louderbach Memorial Award in Stratigraphy by the University of California, Berkeley, Department of Paleontology in 1975; the O.C. Wheeler Plate and Honorary Life Member by the Asociación Colombiana de Geólogos y Geofísicos del Petróleo in 1996; the Juan Herkrath Muller Medal for excellence by the National University of Colombia in 1997; the Outstanding Teaching Award by the National University of Colombia (years 1991, 1992,1993,1995,1996,1997, 2000); the Honorable Mention for excellence of conference presentation by the Asociación Colombiana de Geólogos y Geofísicos del Petróleo in 2000; Professor Emeritus in 2000 by the National University of Colombia, and the 2009 Honor "Fundadores: Luis Guillermo Durán – Padre Jesús Emilio Ramírez" by the Sociedad Colombiana de Geología. He earned a bachelor's of geology and geophysics from the National University of Colombia in 1963, and a Ph.D. in paleontology from the University of California, Berkeley in 1975. His photograph was taken at the Type Locality of La Paja Formation, on August 28, 2014.

Selected Publications

Etayo Serna, F., 2011, Viaje a pie por los pisos del Cretácico de Colombia: XIV Congreso Latinoamericano de Geología, Medellín, Colombia.

Etayo-Serna, F., G. Carrillo-Castillo, 1996, Bioestratigrafía del Cretácico mediante macrofósiles en la Sección El Ocal, Valle Superior del Magdalena, Colombia, Geología Colombiana, n. 20, p. 81–92.

Etayo-Serna, F. 1994, Estudios Geológicos del Valle Superior del Magdalena, Universidad Nacional de Colombia, Bogotá, XIX: 1–3.

Etayo-Serna, F. et al., 1985, Mapa de terrenos geológicos de Colombia, Publicaciones Geológicas Especiales del INGEOMINAS, 14(1): 1–135. Bogotá.

Etayo-Serna, F., 1979, Zonation of the Cretaceous of Central Colombia by ammonites, Publicaciones Geologicas Especiales, Ingeominas (2): 1–188.

Kevin Burke was born in London, England in 1929 and studied at the University College London graduating with a B.Sc. in 1951 and a Ph.D. in 1953. His first job was teaching at the University College of the Gold Coast (presently University of Legon, Ghana) where he worked with W.J McCallien on what is now known to be a 550 Ma suture zone and with Werner Bruckner on Quaternary surficial deposits. Returning to Britain he spent five years in the British Geological Survey (1956 to 1961) developing methods of exploration for Uranium, Helium, and Beryllium in the Survey's Atomic Energy Division and testing techniques and instruments in Zimbabwe, Malawi, Tanzania, Uganda, Sierra Leone, Ghana, England, Ireland and, on assignment to the International Atomic Energy Agency, in the Republic of Korea. In 1961, he founded a geology department in what is now the University of the West Indies in Kingston Jamaica where he worked on sedimentary geology and structure both on and offshore. From 1965 to 1972, as a professor in the University of Ibadan, Nigeria he worked on Precambrian structure, the Cretaceous Benue Rift System, the Niger delta, and the Quaternary deposits of southwestern Nigeria as well as developing a lasting interest in the tectonic evolution and geomorphology of the African Continent. That interest led to his working, mainly on hotspots, with J. Tuzo Wilson and Bill Kidd, in Erindale College of the University of Toronto, Canada from 1972 to 1973. From 1973 to 1983 he worked as a professor at the State University of New York in Albany with John Dewey, Bill Kidd, and Celal Sengor on how the newly recognized processes of plate tectonics had worked globally and throughout Earth's history. While in Albany he identified, with John Dewey, the Wilson Cycle

of Ocean opening and closing as the key to understanding the continental history of the Earth. Research in Albany included working with students Jack Grippi, Paul Mann, Cal Cooper, and Jim Pindell in Jamaica and the Dominican Republic. In 1983, he became director of the Lunar and Planetary Institute (LPI) in Clear Lake Houston and simultaneously a professor at the University of Houston (UH). He gave up working at the LPI in 1988 but continues to be a professor at the UH. Since arriving in Houston his work with colleagues has addressed geological problems in the Gulf of Mexico, Caribbean, and Latin America and extended to impact structures and the geological evolution of Africa, Eurasia, and the Atlantic Ocean. A revived youthful interest in carbonatites and collaboration with Lew Ashwal has led to the discovery that carbonatites in continental areas are products of the melting of older carbonatites in the mantle lithosphere. An interest in large igneous provinces (LIPs) and their spatial and temporal distribution led him to work with Trond Torsvik (the Norwegian paleomagnetist) and the discovery of the relationship of hotspots, kimberlites, and LIPs to Plume Generation zones on the Core–Mantle boundary (CMB) as well as to establishing the long-term stability of two huge equatorial, antipodal, dense objects (TUZO and JASON) on the CMB that appear to have analogues on Mars. Burke presently divides his time between UH, during the northern winter, and MIT, where he is a long-term visitor, for the rest of the year.

Hermann Duque-Caro (Deceased) has more than 30 years of experience as a geoscientist, and he is presently a consultant for the oil industry in Colombia, where he has founded *Duque-Caro & Cia. Ltd.* He has published more than 50 articles in national and international journals, has participated as a speaker in numerous geologic congresses and meetings, and is a member of numerous scientific associations. Duque-Caro is also known for the development of research projects, and at present time, he is conducting the following projects: stratigraphic and biostratigraphic comparison of the DSDP and ODP, sites, Colombia Basin with the Colombia Caribbean Margin stratigraphy in search for tectonic, sedimentary, and paleoclimatic implications; improvement of the Cretaceous and Cenozoic stratigraphic resolution by integrating conventional (biostratigraphy and palynostratigraphy) and non-conventional (chemostratigraphy and authigenic minerals) tools; and biostratigraphy and paleoceanography of the Paleogene and Neogene deposits in NW Colombia. Over the past 30 years, Duque-Caro has accomplished the following. 1) Geologic, stratigraphic, and biostratigraphic consulting (1992–2014) for oil companies in the Cretaceous and Cenozoic basins of Colombia 2) 30 years of continuous work (1961–1992) at Ingeominas, Colombia (field work and laboratory), both research and consulting, on the stratigraphy, biostratigraphy and regional geology of the Pacific and the Caribbean in the coastal regions of Colombia and NW South America 3) Participation as a land based scientist in the Ocean Drilling Program, ODP- Leg 165, Sites 999 y 1000, Colombia Basin, December 1995 to February 1996, Texas A&M University 4) Eight years of experience at Ingeominas (1984–1992) in scanning electronic microscopy and microprobe (EDX) quantitative and semi-quantitative analyses, applied to solid materials and 5) One year of research on the Paleogene and Neogene foraminiferal biostratigraphy of the marine Cenozoic deposits of Colombia: USGS at the U.S Nat. Museum, Washington, D.C., 1967–1968. He has held honorary positions as a regional editor for the Journal of South American Earth Sciences, London, 1988-present, and he was a member of the Editorial Board of the Journal of Petroleum Geology, London, 1988–2000. Duque-Caro was awarded the Wheeler Plate in 1983 by the Asociación Colombiana de Geólogos y Geofísicos del Petróleo. He earned a bachelor's in geology and geophysics from the Universidad Nacional de Colombia in 1959, then took graduated courses in micropaleontology and stratigraphy at Columbia University and laboratory practice at Lamont Doherty, Palisades (1961–1962) and finally earned a Ph.D. degree in micropaleontology and stratigraphy from Princeton University in 1991.

At his doctoral dissertation presentation, Duque-Caro was asked by Sheldon Judson, chairman of the Geology Department at Princeton University: What kind of geologist are you? Duque-Caro now believes that he should have answered with Hutton's philosophy: *I am a passionate follower of Hutton's thought, 1788: "In examining things present, we have data from which to reason with regard to what has been; and, from what has actually been, we have data for concluding with regard to that which is to happen here after."..... "But how shall we describe a process which nobody has seen performed, and of which no written history gives any account? This is only to be investigated, first, in examining the nature of those solid bodies, the history of which we want to know; and 2ndly, in examining the natural operations of the globe, in order to see if there now actually exist such operations".....*

Selected Publications

Duque-Caro, H., 2006, Comentario a: Quantitative biostratigraphic model for the Tertiary of the Lower Magdalena Basin, Colombian Caribbean: Ciencia, Tecnología y Futuro, Instituto Colombiano del Petróleo. Bucaramanga, v. 3, n. 2 p. 183–196.

Duque-Caro, H., G. Guzman-Ospitia, and R. Hernadez, 1996, Mapa Geológico de Colombia, Plancha 38 - Carmen de Bolivar, Escala 1:100.000, Memoria explicativa: Ingeominas, Bogotá, 83 p.

Duque-Caro, H., 1990, The Choco Block in the northwestern corner of South America: Structural, tectonostratigraphic and paleogeographic implications: Journal of South American Earth Sciences, v. 3, n. 1, p. 71–84.

Duque-Caro, H., 1990a, Neogene stratigraphy, paleoceanography and paleobiogeography in northwest South America and the evolution of the Panama seaway: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 77, p. 203–234.

Duque-Caro, H., W. Page, and J. Cuellar, 1983, General geology, geomorphology and neotectonics of Northwestern Colombia, Tenth Caribbean Geological Conference, Cartagena, Agosto 1983 Field Trip C: Ingeominas, Bogotá, v. Guidebook, 53 p.

Duque-Caro, H., 1979, Major structural elements and evolution of northwestern Colombia: AAPG, Memoir 29, p. 329–351.

James N. Kellogg has studied the geology and tectonics of the southwest Caribbean and northern Andes for over 30 years. He is a professor in the Department of Earth and Ocean Sciences and director of the Andean Geophysical Laboratory at the University of South Carolina, and editor-in-chief of the Journal of South American Earth Sciences. Kellogg pursued geophysical and structural studies of the northern Andes, funded by the Venezuelan Ministry of Energy and Mines, for his M.A. (1978) and Ph.D. (1981) in geology and geophysics at Princeton University. After graduate school he joined the Hawaii Institute of Geophysics, serving several years as chair of the Marine Geophysics Division, continuing studies in the Andes as well as seamounts in the western Pacific. In 1987, he joined the faculty of the University of South Carolina as professor of applied geophysics. His principal research interests include seismic, geodetic, gravity, and tectonic studies of active margins and the Andean orogenic belt. Kellogg served as chair of the Department of Geological Sciences and was principal investigator for the GEGEO (Guinea Equatorial GEOscience) Program, the Central and South America (CASA) GPS Geodesy Project, and the Colombia, Peru, and Bolivia Geophysical Projects. The CASA Project was the first GPS project at a convergent plate boundary and the first with a global civilian tracking network. But the greatest success of the CASA experiment was meeting Beatriz Rincon from Bogota, his future wife. Kellogg is very proud of his many accomplished students in petroleum exploration, and academic and government research, including a vice president of a major Colombian oil company, several department chairs, the head of the Colombian GPS network, and a new fellow of the American Geophysical Union. His research has been published in over 60 peer-reviewed articles. He has taught short courses in seismic interpretation, advanced structural geology, petroleum geology, and potential field methods in Houston, Columbia, Bogota, Bucaramanga, Medellin, Lima, Rabat, Kuwait, and Abu Dhabi. He is a member of the South Carolina Academy of Science, a Distinguished Fulbright Lecturer, and a member of the American Geophysical Union, Society of Exploration Geophysicists, AAPG, and GSA.

Fabio Cediel currently lives in Medellín where he collaborates with EAFIT University and is coordinating the production of a new multi-author contribution to be entitled *Geology of Colombia*. He most recently served as senior editor and co-author for the 15 volume set *Petroleum Geology of Colombia* to be published by EAFIT University and the Agencia Nacional de Hidrocarburos, (ANH). Important works in which he has served as principle author include *Facies Distribution and Tectonic Setting through the Phanerozoic of Colombia* (INGEOMINAS, 1994), *Seismic Atlas of Colombia: Seismic Expression of Structural Styles in the Basins of Colombia* (GEOTEC, 1998), *Geological Map of Colombia* (GEOTEC, 2000), and *Tectonic Assembly of the Northern Andean Block* (AAPG Memoir 79, 2003). He is presently a member of the Colombian National Academy of Sciences and the Colombian Association of Petroleum Geologists and Geophysicists. Cediel has served as president to the Colombian Geological Society (1968), delegate to the International Oceanographic Committee, Paris (1969), editor of Geological Field Trips, Colombia (1959–1978), president of the Professional Geologists Council of Colombia (CPG, 1984–1986), and scientific advisor to INGEOMINAS (2002–2003) and ECOPETROL (2004). From 1968 through 1979, he served as assistant and associate professor at the Universidad Nacional de Colombia (Bogotá). In 1969, as co-founder of the geological consultancy GEOTEC, he published the first edition of the GEOTEC Geological Map of Colombia, and initiated a longstanding technical relationship with numerous companies in the petroleum and mineral resources sectors. Returning to Colombia, Cediel implemented regional studies of Paleozoic and Mesozoic stratigraphy, pioneering the application of paleo-geographic and tectonic analysis in the understanding of the geological evolution of the Colombian Andes. He was awarded a DAAD (German Academic Exchange Service) scholarship, and between 1960 and 1967 completed investigations at the Universität Stuttgart, Institut für Geologie (Germany) where he was awarded his Dipl.-Geol. and *Doctor rerum natura* (Dr. rer. nat.) for studies completed on Jurassic stratigraphy in

the Murcia Province, Spain and the Eastern Cordillera, Colombia. Cediel studied engineering and chemistry at Fort Belvoir, Virginia, the University of Maryland (USA), the Ecole Polytechnique (Paris, France) and the Technische Hochschule Karlsruhe, (Karlsruhe, Germany) from 1953 to 1957.

Selected Publications

Cediel, F., 2012, Petroleum geology of Colombia: University EAFIT, (Agencia Nacional de Hidrocarburos, ANH), v. 1–15.

Cediel, F., R. P. Shaw, and C. Caceres, 2003, Tectonic assembly of the Northern Andean Block, *in* C. Bartolini, R. T. Buffler, and J. Blickwede, eds., The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics: AAPG Memoir 79, p. 815–848.

Cediel, F., C. Caceres, 2000, Geological map of Colombia, third digital edition, scale 1:1.000.000. Annex 1 - Extensive legend chart, Annex 2 - Tectono-stratigraphic chart, GEOTEC, Bogotá, Colombia.

Cediel, F., D. Barrero, and C. Caceres, 1998, Seismic atlas of Colombia: Seismic expression of structural styles in the basins of Colombia, GEOTEC, v. 1–6 (8.414 Km. seismic line digital & paper print), Robertson Research, Llandudno, U.K.

Cediel, F., F. Etayo, and C. Caceres, 1994, Facies distribution and tectonic setting through the Phanerozoic of Colombia: A regional synthesis combining outcrop and sub-surface data, presented in 17 consecutive rock-time slices (scale 1:2.000.000). GEOTEC, Bogotá, Colombia, INGEOMINAS, Bogotá, Colombia.

Manuel Julivert graduated in sciences from the University of Barcelona, Spain in 1952. He earned a Ph.D. from the University of Oviedo, following the defense of his dissertation entitled: Geology of a part of the Cantabria Mountains, Spain. From 1953 to 1956, he was associate professor at the University of Oviedo. In 1957, he moved to Bucaramanga, Colombia, and held the geology professor position in the College of Engineering at the Industrial University of Santander, Colombia. In 1959, Julivert moved to the department of natural sciences at the National University in Bogota, Colombia, and took the position of professor of structural geology. During his tenure at the National University, he influenced the new generations of geoscientists, and encouraged a large number of students to continue their studies in geology. He made very important contributions to the geology of Colombia, and also set the basis for the future of the career in Colombia. His students still have the remembrances of the scientist who loved to teach geology and do field work in the most inaccessible regions of the country. A group of former students postulated him to be honored in this volume. As his former students still say, Professor Julivert perhaps does not realize he was a role model for a small number of privileged students at the National University in Bogota. In 1964, he joined the University of Oviedo, and after teaching for 12 years, he moved to the Autonomous University of Barcelona in 1976, where he became emeritus professor in geology. In 1988, he was appointed member of the Royal Academy of Sciences and Arts of Barcelona. He has published a large number of articles on structural geology and tectonics in national and international journals, and he has written several books. He has participated in a lot of geology conferences worldwide, and scholars from different countries have taken him all over the world to visit the most fascinating outcrops. Julivert continues organizing field trips to the Sahara Desert, where he has spent the last 20 years of his life.

Selected Publications

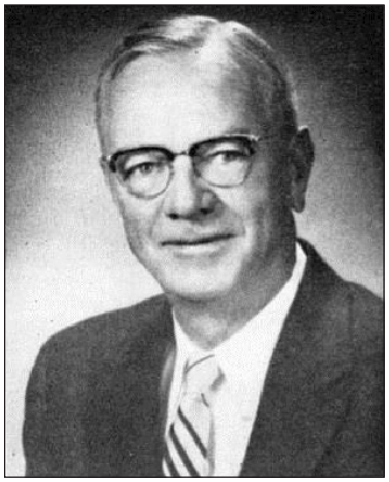
Julivert, M., and S. Garcia-Lopez, 2003, El Sahara: Tierras, Pueblos y Culturas, Universidad de Valencia, ISBN 84-370-5798-1

Julivert, M., 1970, Cover and basement tectonics in the Cordillera Oriental of Colombia, South America, and comparison with some other folded chains, GSA Bulletin, v. 81, n. 12, p. 3623–3646.

Julivert, M., 1968, Colombia, in Commission de Stratigraphie, Amerique Latine, v. 5 of Lexique Stratigraphique Internationale: Paris, Centre Nationale de la Reserche Scientifique, Fasc. 4ª, (Pt. 1), 650 p.

Julivert, M., 1963, Mapa geologico del extremo sur de la Sabana de Bogota: Universidad Industrial de Santander, Departamento de Geologia, Colombia.

Julivert, M., 1959, Geologia de la vertiente oeste del macizo de Santander en el sector de Bucaramanga, Colombia, Publicaciones Cientificas.



Orby Clinton Wheeler (1898–1970) was a pioneer in petroleum geology. He passed away October 19, 1970, in Coral Gables, Florida, of complications following surgery. Wheeler, who later became known as "Jimmie" to many of his friends, was born in Gainesville, Texas, on October 30, 1898, where he attended public schools. In 1916, he entered the University of Texas Law School, but transferred to geology and did exceedingly well. In 1918, his third year in college, he collaborated with Drew Christner in publication of an article on the geology of Terrell County, Texas. Shortly thereafter, in 1919–1920, he worked on the evaporites of Texas, New Mexico, Oklahoma, and Kansas in a search for commercial deposits of potash for the Texas Bureau of Economic Geology and the USGS. The work was performed under two stalwarts, W. E. Wrather and J. A. Udden. During World War I, he joined the armed services, and, after release from service in 1919, began his work in potash. During his time in Texas he attended meetings of the Southwestern Association of Petroleum Geologists (which later became the AAPG); he became a member of the Zeta Chapter of Sigma Gamma Epsilon, an honorary geological fraternity, and a member of the Austin Masonic Lodge. While on his potash work in northwest Texas he wooed a charming school teacher at Cliff-side, Texas, by the name of Katherine Riggs whom he married on August 5, 1920. They both entered the university that fall. In 1921, without waiting for his B.A. degree, he accepted the position of resident geologist on the Demares Concession in Colombia, South America, which was offered to him by Oliver B. Hopkins, then chief geologist for Tropical Oil Company and International Petroleum Company, Ltd.

In 1918, J. C. Trees, G. W. Crawford, and M. L. Benedum drilled a discovery well on the Infantas reversal on the Demares Concession in Colombia. Their company, Tropical Oil Company, was acquired by International Petroleum Corporation in 1920, and active development ensued under the direction of Oliver Hopkins. Jimmie and his wife arrived in Cartagena by boat and then had to travel overland to Barranquilla, where they boarded a stern wheeler for the trip upstream to Barranca Bermeja on the concession. As family quarters were not available on the concession, Mrs. Wheeler had to live for a time at the intermontane city of Medellin. The Demares concession was difficult to explore, with its flat and hilly terrain covered with steaming tropical forest (jungle) and soft Tertiary outcrops. Picas-paths had to be hacked with machetes. Heavy rainfall and biting insects made the job even more difficult. Early in the survey, Jimmie observed that three good fossil zones held the key for stratigraphic zonation and structural mapping of the Tertiary section. He soon discovered that the productive Infantas structure was not a simple anticline as mapped but was overthrust westward toward the stable side of the basin. He also observed that the surface seepages were derived directly from outcrop of the main oil-bearing sandstones. During his mapping of the general Infantas district he discovered a large domal expansion on the west side of the thrust, which on drilling led to the discovery of the La Cira field, the most productive one in Colombia. His work in the middle Magdalena Valley was an accomplishment of the highest scientific value.

In 1927, he was granted a leave of absence from Tropical Oil Company and went back to study geology at Stanford. He was an outstanding student there, doing fieldwork in the Ventura Basin, California. He obtained his B.A. degree and was elected to Phi Beta Kappa. Following graduation in 1929, he returned to his old company as field supervisor in Colombia. In 1930, he was transferred to the home office in Toronto, Ontario, as geologist in charge of Colombian operations. From there his progress continued upward from chief geologist of International Petroleum Company and Imperial Oil, Ltd., to director of exploration coordination and, subsequently, to director and vice-president for Exploration and Production for International Petroleum Company. In 1946, he moved with the home office to Coral Gables, Florida, where he continued as vice-president and director until his retirement on January 1, 1961.

Being a company man during his geologic career, his reports are largely in the files of his former employer. Besides his early publications in 1918, and later, on the Pico Formation of the Ventura Basin, California, he released material on the Tertiary of the middle Magdalena Valley and on the petroleum developments in Colombia during the years 1933–1935 and 1940–1941. During his managerial work, he supervised exploration in Canada, Ecuador, Peru, and Venezuela. In Peru he was in charge of directing the work which, after many years, solved the very complicated fault pattern of the La Brea y Parinas Estate. Here faults of several ages, many of which are horizontal, made every well a wildcat venture.

Table of Contents

Note to the Reader

This publication is a continuation of AAPG's efforts to combine the best of both digital and print publications for its members.

A portion of each chapter is printed. The DVD located in the inside back cover of this book contains all of the full chapters in PDF format. All are in color.

The dual digital and print format allows authors greater scope for both length of papers and number of color figures and provides the reader with much more versatility in using the content. For example, figures can be used directly for making slides or Microsoft PowerPoint presentations and can be enlarged on the screen as needed for easier viewing.

Individual chapters can be easily printed for later reading, and key word searching through the papers is possible. Finally, this format allows AAPG the flexibility to publish a volume that contains material that will appeal to a wider audience with additional interests.

The volume is divided in four parts containing four to nine papers. Each part focuses on a different theme and scale of observation relevant to this vast Caribbean region that includes many, poorly known petroleum frontier areas.

A number of papers are summaries of recently completed M.S. or Ph.D. studies by graduate students at universities in Colombia or the United States. For this reason, the information and fresh ideas in this volume offer many new data and interpretations that will hopefully shape the direction of research in this region for many years to come. We, the older geoscientists generation, salute this rising younger generation of energetic and talented geoscientists.

Preface

Petroleum Geology and Potential of the Colombian Caribbean Margin

The Caribbean area has been the subject of extensive academic and commercially oriented studies that have led to an understanding of the region's geology and economic potential. In addition, it is important to remark the unlimited efforts of Ecopetrol in educating geoscientists along with the National Agency of Hydrocarbons in making data available for academic research. These two entities are also the pillars of the petroleum geology knowledge in Colombia.

Several seminal contributions cover the Caribbean plate's tectonic framework, structural styles, continental margins, sedimentary basin evolution, magma genesis and volcanism, gravity and magnetics, etc. These include: "The Caribbean Research Project" introduced in Hess and Maxwell, 1953 (GSA Bulletin v. 64, p 1–6); "Caribbean gravity field and plate tectonics" by Bowin, 1976 (GSA Special Paper 169); "The Caribbean-South American plate boundary and regional tectonics" by Bonini, Hargraves and Shagam, 1984 (GSA Memoir); "The geologic and tectonic development of the north America-Caribbean plate boundary in Hispaniola" by Mann, Draper, and Lewis, 1991 (GSA Special Paper 262); "The geologic and tectonic development of the Caribbean plate boundary in southern Central America" by Mann, 1995 (GSA Special Paper 295); "Active strike-slip and collisional tectonics of the northern Caribbean plate boundary zone" by Dolan and Mann, 1998 (GSA Special Paper 326); "Caribbean-South American plate interactions, Venezuela" edited by Lallemant and Sisson, 2005 (GSA Special Paper 394); and "The origin and evolution of the Caribbean plate" by James, Lorente and Pindell, 2009, published by the GSL. Obviously, these are only a few of the invaluable contributions made by hundreds of geoscientists who have conducted and documented exploration and research projects throughout the Caribbean region in the last 50 years. Additionally, the volumes generated during the Bolivarian Congress, which is held every two years in Cartagena, Colombia are another domestic effort to contribute to the geosciences.

Numerous research oriented wells were drilled throughout the Caribbean region in order to acquire a deeper knowledge of it's geologic history and the composition and structure of its ocean basins, starting in 1966 with the Deep Sea Drilling Project with the drilling vessel Glomar Challenger, and continued since 1985 by the Ocean Drilling Program by the JOIDES Resolution. Much of the data amassed during these scientific expeditions are available in the *Initial Reports of the Deep Sea Drilling Project*, *Technical Notes, and Technical Reports,* and follow-up publications. The contribution of these drilling programs to revelation of the evolution of the Caribbean plate and its basins cannot be overstated.

This volume aims to integrate recent information obtained during intensive petroleum exploration activities along the Caribbean margins of Colombia and Venezuela. Although the focus of the book is petroleum geology and hydrocarbon potential in this part of the Caribbean, a number of papers cover non-petroleum related geological and geophysical studies, attesting to its multidisciplinary nature. The 27 papers reveal new insights about the area's petroleum play concepts and petroleum systems, plays and exploration, carbonate and siliciclastic stratigraphy, basin evolution, organic geochemistry, plate tectonics, and potential fields (gravity and magnetics).

This new international book about the petroleum geology of the Colombia Caribbean Margin is dedicated with great respect to those geoscientists who have made not only very important contributions to the geology of the Caribbean region and Colombia, but who have also formed and trained several generations of geologists and geophysicists in the United States and Latin America. The book honors: Hermann Duque-Caro, Kevin Burke, Fernando Etayo-Serna, James Kellogg, Fabio Cediel, Manuel Julivert, and Orby Clinton Wheeler.