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Front Matter

(Usually includes Dedication, President's Message, & Conference Organizer's Message.)

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Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual Fall Field Conference that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

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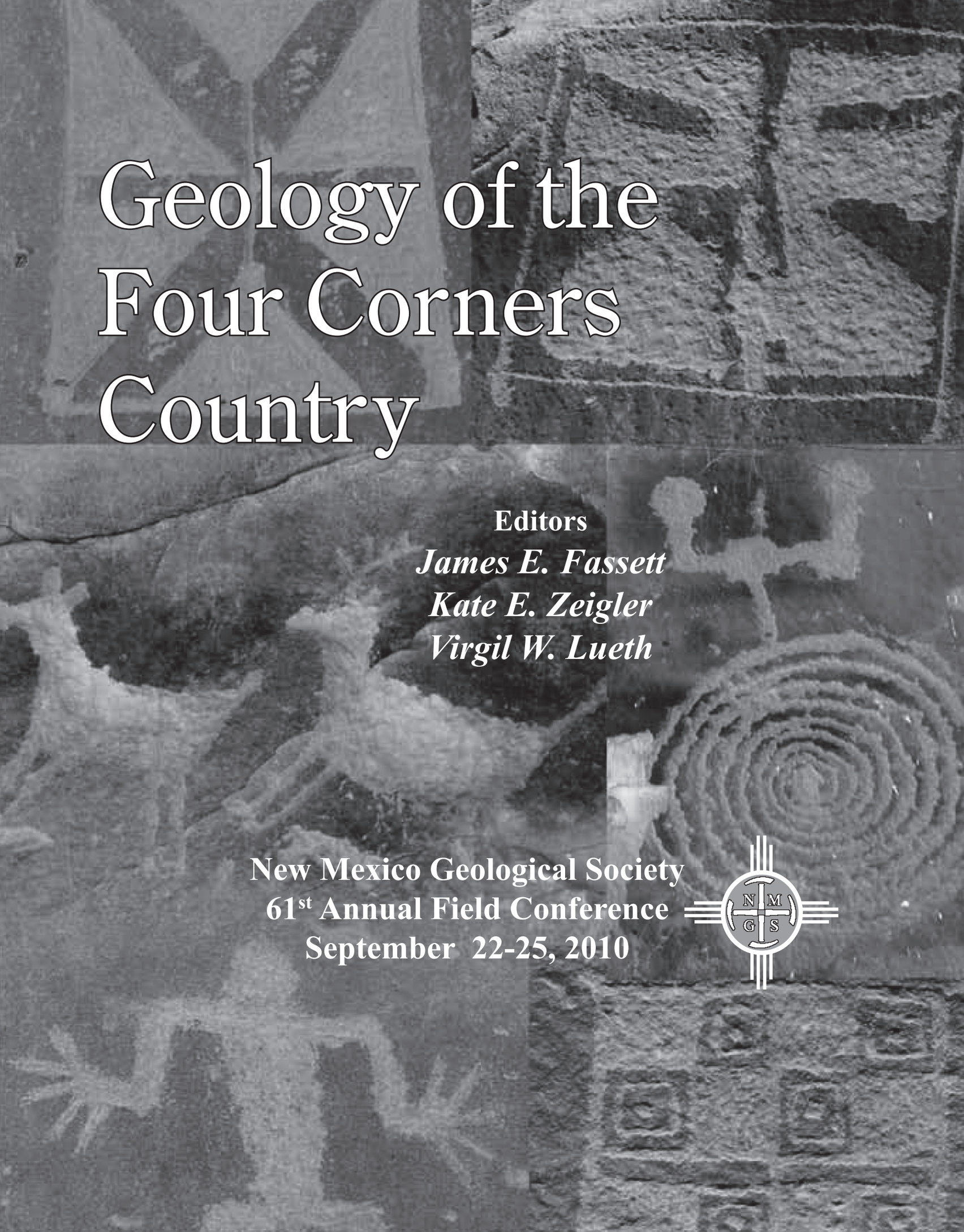
NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs*, *mini-papers*, and other selected content are available only in print for recent guidebooks.

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Geology of the Four Corners Country

Editors

James E. Fassett

Kate E. Zeigler

Virgil W. Lueth

New Mexico Geological Society

61st Annual Field Conference

September 22-25, 2010

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The New Mexico Geological Society is a tax-exempt corporation registered in the State of New Mexico that promotes interest in geology and associated sciences, fosters scientific research and publications, encourages cooperation among its members, and stimulates interest in New Mexico geology. These goals are met through annual fall field conferences held in different locations in New Mexico or adjoining states and annual spring meetings, generally held in Socorro, New Mexico, where oral and poster presentations on different aspects of New Mexico geology are given.

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Front Cover Photograph: Variegated beds in the Brushy Basin Member of the Upper Jurassic Morrison Formation near Montezuma Creek, Utah. The colors are from authigenic minerals derived from the alteration of silicic volcanic ash in a saline, alkaline "lake" or wetland. The prominent light-tan cliff above the Brushy Basin Member is the basal unit of the Lower Cretaceous Burro Canyon Formation. In the distance are Sleeping Ute Mountain on the right and the La Plata Mountains on the left, both in Colorado. Looking east from near the top of the Montezuma Creek measured section at Stop 6 on the first day of the 2010 Field Conference. Photo by Fred Peterson, 2010.

Inside Front Cover: Digital elevation and route map by Mark Mansell and Virgil Lueth

Filler and Captions: James E. Fassett

Title Page: Photomontage of petroglyphs at Pictured Cliffs taken by David Grenoble

Inside Back Cover: Stratigraphic correlation chart by C.M. Molenaar (1989).

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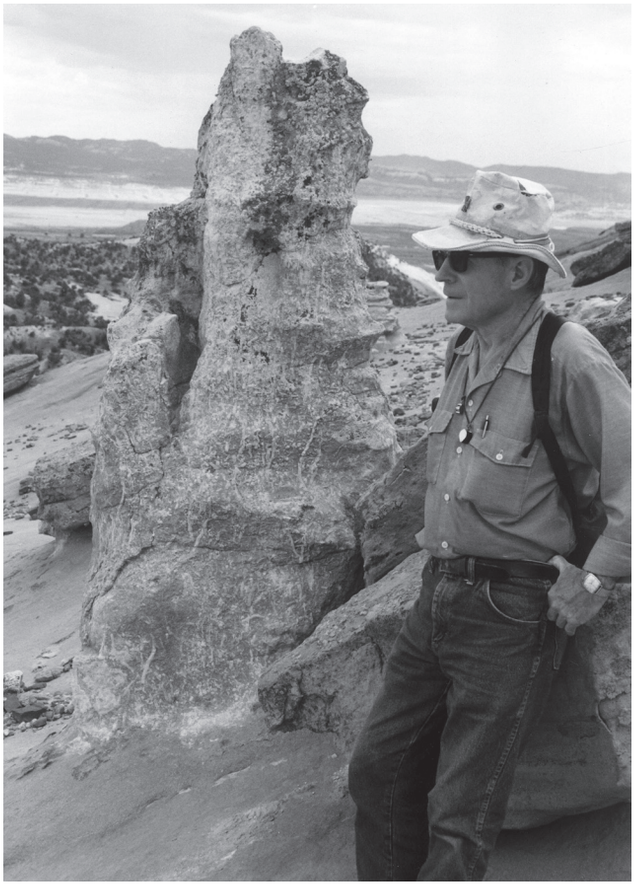
DEDICATION
GEORGE N. PIPIRINGOS AND ROBERT B. O'SULLIVAN

George N. Pipiringos and Robert B. O'Sullivan have made important contributions that have improved, considerably, our understanding of the stratigraphy and regional relations of Triassic and Jurassic sedimentary rocks in the Western Interior of the United States. One of the most significant challenges to understanding the broad relationships of these rocks, especially the Jurassic System, is to bridge the gap between rocks of these ages on the Colorado Plateau and those farther north in the Wyoming-Idaho-Montana region. Many geologists have worked in one or the other of these regions but Pipiringos and O'Sullivan are among the few that have managed to understand these rocks across both regions.

Critical to understanding the stratigraphy and sedimentology of Triassic and Jurassic rocks throughout the Western Interior of the U.S. is the recognition of regional unconformities. At the time that Pipiringos and O'Sullivan pursued their work, sedimentologists and stratigraphers were focusing their efforts largely on measured sections and interpreting depositional environments within these detailed vertical sections. Valuable though these efforts were, which linked the interpretation of sedimentary rocks to modern depositional environments, the concept of regional unconformities, emphasized by Sloss in his classic work in 1963, had lost favor or at least received considerably less emphasis. The fascination at the time was with depositional environments and modern analogues. Pipiringos and O'Sullivan, however, persevered in their efforts to trace seemingly subtle, but regionally significant, unconformities across the Western Interior. Typically, the unconformities had to be traced through packages of rock that were similar in origin—eolian sandstone-on-eolian sandstone, or red beds on red beds, for example. Another all too frequent problem is that the unconformities are manifested as planar surfaces separating parallel beds above and below in many localities. What might have been dismissed as a diastem or bedding surface by other workers would take on greater significance when



George N. Pipiringos at LaBarge Creek in the Green River Basin, Wyoming. Photo by Norman Denson, 1989.



Robert B. O'Sullivan near Navajo Church about 7 miles east of Gallup, New Mexico. Note the exhumed termite nest in the Recapture Member of the Morrison Formation next to him. Photo by Jacques Robertson, 1998.

careful correlation over long distances revealed their time-stratigraphic relevance. It was this careful tracing of unconformity surfaces over large distances, which required long days in the field, that characterized the work of Pipiringos and O'Sullivan. Their work culminated in 1978 with publication of U.S. Geological Survey Professional Paper 1035-A in which they demonstrated the regional extent and character of major unconformable surfaces within Triassic and Jurassic rocks of the Western Interior of the United States.

It wasn't until the work of Vail et al. (1977), where the importance of regional unconformities became clear at the broader scale of seismic sections, that regional unconformities took on renewed interest. In fact, recognition of the regional unconformities that bounded sedimentary packages was a critical aspect of sequence stratigraphy. At this point, the significance of the work of Pipiringos and O'Sullivan in the Western Interior became apparent. Sequence stratigraphy reinforced the earlier idea, popularized by Sloss (1963), that sedimentary packages are delineated by regional unconformities and that their interpretation requires recognition of these sometimes subtle, but none-the-less critical bounding surfaces.

Both "Pip" (George Pipiringos) and "Sully" (Bob O'Sullivan) may have come by their persistence in chasing down elusive but important details through their earlier lives and personal character. George N. Pipiringos served in the U.S. Army Signal Corps in China during World War II. He then went on to the University of Wyoming where he earned his A.B. and M.A. degrees in geology. He subsequently received a Ph.D. in geology from Johns Hopkins University in Maryland. George had a long, fruitful, and varied career with the U.S. Geological Survey, working on uranium deposits in The Cave Hills area of South Dakota and the Great Divide basin in Wyoming. He also did geologic mapping in Wyoming and northern Colorado, where he published several reports on the stratigraphy of Triassic and Jurassic rocks. Pipiringos enjoyed a rich family life with his wife, Elsie, and their three children, Delia, Sophia, and Pandora. George passed away in 2000, but his contributions to the science, and his family's memories of a loving husband and father, live on.

Robert B. O'Sullivan served in the U.S. Army Air Force as an aircraft armorer during World War II. After the war, Bob went to Yale University for his B.S. degree and then went on to the University of New Mexico where he received a M.S. degree. Both of his degrees are in geology. O'Sullivan has also had a long and productive career with the U.S. Geological Survey, mostly in geologic mapping and stratigraphic studies. In addition, he contributed his expertise to the study of oil shale in the Piceance basin of Colorado. His geologic mapping was focused on the Colorado Plateau, especially in and around the Four Corners area. He has published numerous stratigraphic sections (21 at last count) of Middle and Upper Jurassic strata of the Colorado Plateau. His contributions also include numerous USGS publications and guidebook articles on Jurassic stratigraphy of the Colorado Plateau. He and George Pipiringos worked closely together to correlate Triassic and Jurassic rocks from Wyoming to Colorado and Utah, an endeavor critical to understanding the broader regional relationships of these strata throughout the Western Interior. Bob also found time to enjoy a rich family life throughout his career. His wife Betsy tells amusing stories of summers spent in rather primitive conditions as part of family life with a field geologist. His three children, James, Brett, and Nancy Jean were probably having too much fun to realize how "deprived" they might have been! Bob and Betsy currently enjoy retirement in Lakewood, Colorado, and Bob actively continues his Jurassic research as an Emeritus Scientist at the U.S. Geological Survey.

Fred Peterson
United States Geological Survey

PRESIDENT'S MESSAGE

It's early autumn of another year. The days are getting shorter, tree leaves are beginning to change color, and there is a touch of chill in the evening air. For much of the geological community in New Mexico, and many others interested in the geology of our state, pulses quicken and anticipation heightens as an event as regular as the seasons approaches. The annual NMGS Fall Field Conference is upon us! Welcome to all who are attending this 61st conference, the most recent in a lineage that began before most of us were born.

The 2010 Fall Field Conference, organized by Jim Fassett and Kate Zeigler, explores the geology of the Four Corners Region, that part of the Colorado Plateau where the states of New Mexico, Colorado, Utah, and Arizona meet, and a region of spectacular geology and scenery. The focus of this conference is Mesozoic stratigraphy and geochronology, and the energy and other geologic resources of the region, but participants will be introduced to other aspects of the geology as well.

This is not the first NMGS field conference to focus on the Four Corners/San Juan Basin region; in fact, the Society's annual field conferences were "born in the Basin", so to speak, as this was the venue for its first two conferences, in 1950 and 1951. Since then conferences 28 (1977), 40 (1989), 43 (1992), and 48 (1997) have explored portions of this region, and several other conferences have ventured in from neighboring areas. So why do we keep returning?

The Colorado Plateau is a large area, and its geologic record and history is diverse and complex; single conferences can only reveal portions of the entire geologic panorama preserved there. Many aspects of the geology of the San Juan Basin are world renowned, such as the classic Late Cretaceous transgressive-regressive sequence, thick Triassic and Jurassic nonmarine sedimentary deposits, the varied and important Late Cretaceous-Paleocene-Eocene vertebrate faunas, and unusual and impressive volcanic features, to mention a few. Ongoing research continuously generates new information, interpretation, and perspectives, which each new field conference introduces to its participants. And of course the geological resources of the Basin – principally natural gas, oil, and coal – are considerable and have been utilized for the better part of a century. The drive to better understand the sources, distribution, and quantity of these resources has stimulated much geological research and generated new uses of these resources. Coal-bed methane, for example, was just beginning to be developed 20 years ago; now it contributes a significant percentage of New Mexico's total natural gas production. Thus, our knowledge of the geology of any particular part of the state, but especially the Four Corners region, continues to advance, and each new field conference presents much that is new.

These annual field conferences and the accompanying guidebooks would not be possible without the incredible efforts of many volunteers – the organizers, guidebook editors, authors of road logs and papers, numerous individuals helping with the logistics, the state's geoscience departments and their faculty and students, and others who expend their time and effort to make each Fall Field Conference possible. Organizing all of the components of a field conference is more complicated than many realize, and yet every year, with a different cast of main characters, somehow the conference proceeds on schedule, and usually so smoothly that participants need only to sit back and enjoy the show. Even the weather almost always cooperates (something the Executive Committee will take credit for!).

This year, as always, we thank some special people for their efforts in making this conference a reality and for assisting your society throughout the year. The Society's longstanding collaborative relationship with the New Mexico Bureau of Geology & Mineral Resources is of great importance, and we appreciate the constant support of its Director, Peter Scholle. The Bureau handles sales of NMGS publications, and Bureau personnel process conference registrations and set up sales tables at NMGS and other events (Kitty Pokorny, Connie Apache), maintain the NMGS web site (Adam Read), and contribute much time and effort as cochair of the Publications committee (Shari Kelley).

Virgil Lueth, our managing editor, molded all of the varied contributions to the guidebook into the volume you have before you and saw it through to publication by the time of this conference. Shari Kelley, Dan Koning, and Kate Zeigler organized and ran the Society's successful annual Spring Meeting this past April in Socorro, at which about 50 talks and posters were presented.

One of the Society's most important functions is to support undergraduate and graduate geoscience students throughout New Mexico. This is done through many scholarships, research grants, waiving of the NMGS membership fee, and discounts on its publications. This year, NMGS will award approximately $50,000 in scholarships and research grants; some 25 students are attending this field conference on NMGS scholarships. These funds are derived from generous donations made over the years by present and past members and by the wise investments of these funds by the NMGS Foundation. In this context we also thank long-time NMGS member Bob Myers, who heads the Society's Scholarship Committee.

While writing this my thoughts turned to the first NMGS Field Conference I attended (25th, at Ghost Ranch, in 1974) as a newly-arrived young UNM faculty member. Little did I imagine then that I would be attending nearly all of the next 36 conferences and would have the honor and privilege of serving as NMGS president! While paging through the 1974 guidebook I came upon the name of Jim Fassett, as a road log author and as secretary of the society (he would be president in 1976). Clearly Jim, in coorganizing this 2010 conference, exemplifies the long-term interest in and dedication to NMGS that many of its members have shared over the years, and which is such an important part of the success (and longevity) of our society.

So, enjoy this conference, and plan to attend future ones as well, including Tusas Mountains (2011), Sierra County (2012), and I- 40 Albuquerque to Flagstaff (2013).

Barry Kues, President

CONFERENCE ORGANIZERS' MESSAGE

Welcome to the 61st New Mexico Geological Society Fall Field Conference in the Four Corners Country. This year's field conference will revisit the terrain examined on the society's 48th Field Conference in 1997. The trip leaders for this field conference have many decades of experience studying the fascinating geology in this beautiful part of the world. In the course of our travels, we will go eastward from the scenic Canyon Country of southeastern Utah and northeastern Arizona into Colorado skirting the southern flanks of the La Plata and San Juan Mountains and following the northern rim of the San Juan Basin and we will then turn south into New Mexico's haunting mesas and badlands. These travels will take us from terrain in which mostly Jurassic rocks are well exposed in Utah and Arizona and into Upper Cretaceous and Paleogene strata that form the broken topography of southwestern Colorado and northwestern New Mexico.

The Four Corners Country contains world-class energy resources from the giant Aneth oil field in the Paradox Basin of southeastern Utah to the enormous gas resources of the San Juan Basin in New Mexico and Colorado including the world's largest coal-bed methane field (see back cover). In addition, two mine-mouth power plants are currently being fed by large Fruitland Formation coal deposits that outcrop on the western edge of the San Juan Basin in New Mexico.

The stratigraphy and origin of the Jurassic strata in southwestern Utah and northeastern Arizona have puzzled and intrigued geologists for decades, but relatively recent detailed studies of these strata have provided more definitive data to unravel the mysteries of these rocks. The strange and wonderful depositional environment of the "Lake" T'oo'dichi deposits in the Brushy Basin Member of the Morrison Formation will be observed and discussed in detail. The stratigraphy of the Upper Cretaceous rocks of the San Juan Basin has been more straight-forward, however, the position of the interface between these rocks and overlying Paleocene strata has been, and continues to be, hotly debated; especially because of the presence of abundant dinosaur fossils in lowermost Paleocene strata.

In short, the Four Corners Country offers something for everyone and we look forward to sharing our love of this fascinating part of the world with our field-conference companions. We would especially like to thank U. S. Geological Survey geologists Fred Peterson and Christine Turner for the time and energy they expended in the preparation of the Day 1 road log for this field conference. This road log is not just the product of searching the literature and noting mileages between cattle guards for its compilation but rather is the result of many weeks on the outcrop reexamining complex stratigraphic relationships to come up with better answers to the puzzles the rocks in this area have presented over the years.

We also thank the authors of the papers in this guidebook for their contributions in making this publication another NMGS classic compendium that will be used as a guide to the geology of this area for years to come. And once again, our Managing Editor Virgil Lueth has come through with flying colors in preparing an attractive and well laid-out publication; Virgil has been a joy to work with.

Jim Fassett and Kate Zeigler

x

FIELD CONFERENCE SCHEDULE

Wednesday, September 22, 2010—registration and ice-breaker

6:00-9:00 pm Registration and icebreaker party at the Conference Center, Holiday Inn Express, Cortez, CO

Thursday, September 23, 2010—First Day: Cortez, CO to Bluff, UT, and return.

6:00-7:00 am Breakfast (not provided)

7:30 am Buses depart from Holiday Inn parking lot, Cortez

12:00 noon Lunch provided

6:30 pm Banquet at Conference Center, Holiday Inn Express, Cortez

Friday, September 24, 2010—Second day: Cortez, CO to Farmington, NM.

6:00-7:00 am Breakfast (not provided)

7:30 am Private-vehicle caravan departs from Holiday Inn parking lot, Cortez

12:00 noon Lunch provided

5:00 pm Arrive in Farmington

6:00 pm Barbecue dinner at Bruce Black's Kokopelli cave in Farmington

Saturday, September 25, 2010—Third Day: Farmington to Barrel Spring locality

6:00-7:00 am Breakfast (not provided)

8:00 am Auto caravan departs from large lot east of Courtyard Marriott in Farmington

1:00 pm Conference ends at Barrel Spring stop – Hasta Luego!