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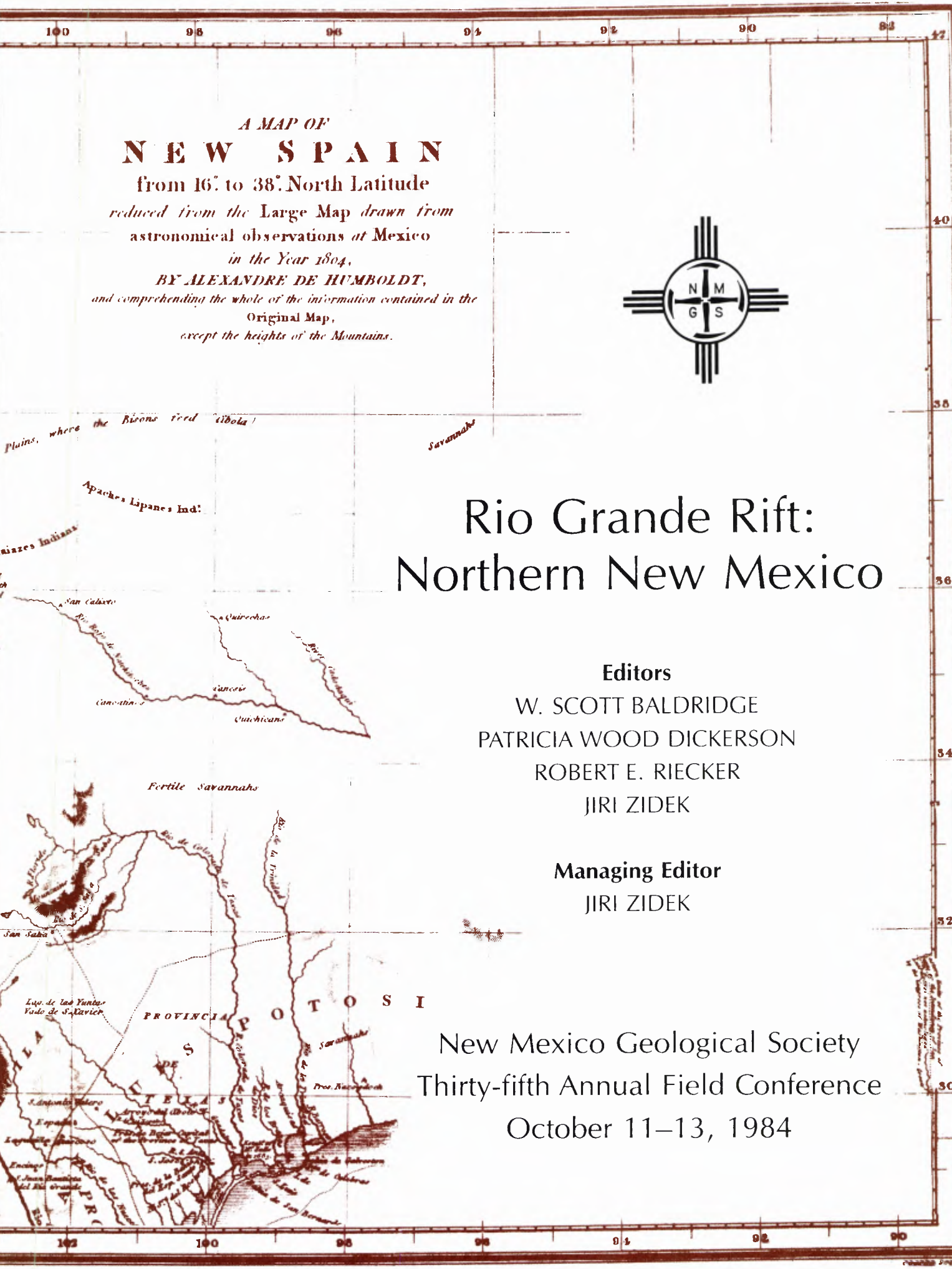
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Longitude West
from Greenwich
This Lake, the limits of which are very imperfectly known from the Journals of Father Escalante, is perhaps the Teguayo Lake, from the borders of which, according to some Historians, the Aztequez removed to the River Gila.
LAKE TIMPANOGOS
Yamparicas Indians
Sierra Verde
Savannahs which extend to the East of Sierra Verde
Raguapui Ind.
Valle Salado
The Western limits of this Salt Lake are unknown
Tabeguachis Indians
Yutas
S.Rustico
Valle S. Jose
Country seen by Father Antonio
Rio del Sacramento
Apaches Llaneros
Ind. Guacaros
Here is a chain of Mountains extending to 110° West Lon. from Paris. It is crossed by a river called by the Missionaries Rio de San Felipe, the borders of which are inhabited by the Nochi Indians.
Moqui Ind.
Jumbuicrariri Indians
Cosninas Indians
Oraybe
Mosanais
Jongoapi
Gualpi
All this Country, from the Mission of Zuñi to the Cobaji Indians has been visited by Father Pedro Font in 1775.
Yamaya Ind.
Yabipias Indians
with long beards
APACHERIA
Chemeguaba Indians
Rio Colorado
Jalchedum Ind.
Tejua Ind.
Jenigueih Indians
Cocomaricopas Ind.
Jumas Indians
Rio Gila
Apaches Gileños Indians
Cajuenches Ind.
Cucapa Indians
Popagos Indians
PROVINCIA
Apaches Chiricaguis
Seris Indians
GULF OF CALIFORNIA
SONORA
Tarahumara
Arispe
Longitude West
from Paris.
BOLSO



Rio Grande Rift: Northern New Mexico

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PRESIDENT'S MESSAGE

Welcome to the Thirty-fifth Field Conference of the New Mexico Geological Society, co-sponsored this year by the Los Alamos National Laboratory. Another guidebook has made its way to press. Special thanks are due to Scott Baldridge, Pat Dickerson, Bob Riecker, Jiri Zidek, Kim Manley, and Steve Blodgett for their superhuman efforts in finishing the book, Jim Bones for contributing the frontispiece, and Nancy Young for permitting us to reproduce her art on the guidebook cover.

The Society suffered a near-disaster last year when Jon Callender resigned as managing editor. For those of you who don't know Jon, he talks fast, persuasively, and has very long arms which help him pull manuscripts out of recalcitrant authors. Fortunately, we were able to enlist an equally qualified replacement. Jiri Zidek, our new managing editor, is the founder and past editor of the Journal of Vertebrate Paleontology and the current chief editor–geologist for the New Mexico Bureau of Mines and Mineral Resources. This guidebook could not have been completed without Jiri's dedication. Jiri is quieter than Jon, but should instill the same terror into the hearts of future guidebook authors.

Seeing my name under the President's Message may come as a surprise to some of you. Dave Norman was duly elected to this office by the membership, but, fortunately for him and unfortunately for the Society, was awarded a sabbatical leave for 1984–85. His departure resulted in my promotion to President, and we have been fortunate enough to have Jerry Mueller volunteer to serve as Vice President for the remainder of 1984.

Enjoy yourselves in Taos, it is a fine time of the year in New Mexico's northern mountains. I hope to see you again at the 1985 conference in east-central New Mexico, to be coordinated by Spencer Lucas of the University of New Mexico.

Jeffrey A. Grambling, President

PREFACE

The theme of the 1984 New Mexico Geological Society field conference is the Rio Grande rift. The rift is a fitting subject for this first topical conference of the Society: It has become recognized in the last decade or so, and especially since the 1978 International Symposium in Santa Fe, as a major late Cenozoic extensional feature of the continental lithosphere. As such, the rift has become the focus of an increasing amount of interdisciplinary research directed toward developing a broader understanding of the dynamics and thermal history of the lithosphere.

Since it is impossible for a single field conference to cover the entire rift, this year's guidebook focuses only on its northern New Mexico segment. In northern New Mexico, the rift is tectonically and morphologically well defined; hence, descriptions and discussions of this region are relevant both to the rift and to rifting processes generally.

Although the field conference is topical, we have nonetheless encouraged all papers of relevance to northern New Mexico and southern Colorado, for two reasons. First, we felt it was important to continue the Society tradition of soliciting all work related to the region. And secondly, while the rift is a modern tectonic feature, many of its characteristics and perhaps even its existence are determined by geological events certainly as old as late Paleozoic and perhaps even as old as Precambrian. Hence, work which may not seem rift-related to us at this time may eventually turn out to be relevant.

The Rio Grande rift, largely because of its control on drainage, has strongly influenced Indian and Spanish settlement and trade patterns. In recognition of this intimate relationship between the geology and the culture and history of northern New Mexico, this year's guidebook includes an integrated group of papers on the archaeology of northern New Mexico. Three of these papers, by Peckham, Schroeder, and Cordell, were originally presented as part of a lecture series at the College of Santa Fe entitled *Man on the Rio Grande: 10,000 Years of Human History,* organized by John Ware and Myra Ellen Jenkins.

We wish to thank K. Manley for putting together this year's road logs and coordinating the field trips; J. M. Casey, J. A. Grambling, P. W. Lipman, S. J. May, and J. C. Reed, Jr. for their contributions to the road logs; S. Blodgett for aid with road logs, technical editing, and logistics; J. Ware for coordination and assistance in editing of the archaeological papers; G. Ponder for editorial assistance with the initial manuscripts; D. Witt of the Harwood Foundation of the University of New Mexico and R. Richardson of the Colorado Railroad Museum, Golden, Colorado, for historical photographs; A. Bowman for contemporary photographs; D. Carlton and T. Ellis for locating the map on title page; J. Tubb, A. Garcia, and J. Paskiewicz for assistance with illustrations; B. Hahn, P. O'Rourke, B. Reecer, and N. Warnes for word-processing support; L. Woodwell for help with logistical arrangements; and the many reviewers of manuscripts for their time and effort. We are especially grateful to N. Young for the cover print and J. Bones for the frontispiece and end plate. Finally, we acknowledge the support of the Los Alamos National Laboratory and the New Mexico Bureau of Mines and Mineral Resources.

W. Scott Baldridge, Los Alamos National Laboratory
Patricia Wood Dickerson, CONOCO Inc., Midland, Texas
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Jiri Zidek, New Mexico Bureau of Mines & Mineral Resources

RIO GRANDE RIFT: PROBLEMS AND PERSPECTIVES

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INTRODUCTION

Our intent in this paper is to present new ideas concerning the Rio Grande rift which we hope are at least provocative, if not correct, and to emphasize important unanswered questions which will be fruitful areas for continued research. Our approach is to evaluate, relate, and interpret existing data derived from a number of disciplines, rather than primarily to present new data. We hope thereby to achieve a synthesis of sorts—a new and broad perspective on the Rio Grande rift. This perspective should help guide future observations by directing attention toward the more fundamental questions regarding rifting processes. In this paper we use the Basaltic Volcanism Study Project (1981, p. 838) definition of rifts as elongate depressions overlying places where the entire thickness of the lithosphere has ruptured in extension.

Among the topics and ideas that we address are: (1) the regional extent of the Rio Grande rift, (2) the structure of the crust and upper mantle, (3) whether the evidence for an "axial dike" (i.e., a composite mafic intrusion) in the lower crust is compelling, (4) the nature of faulting and extension in the crust, and (5) the structural and magmatic development of the rift. These issues provide important constraints on the nature of thermal and tectonic processes involved in formation of the Rio Grande rift.

The Rio Grande rift is a region where the lithosphere is being permanently altered through thinning and (probably less importantly) intrusion of mafic magmas. The rift is the culmination of a long and complex geologic history. Initiation of rifting probably resulted from plate-boundary interactions along the west coast of North America (e.g., Lucas and Ingersoll, 1981). However, the presence of a major thermal event associated with the immediately preceding subduction regime may have been a necessary condition for rifting.

DESCRIPTION AND REGIONAL EXTENT

The Rio Grande rift extends as a well-defined series of asymmetrical grabens from Leadville, Colorado, to Presidio, Texas, and Chihuahua, Mexico, a distance of more than 1,000 km (Fig. 1). North of Socorro the rift is a distinctive morpho-tectonic feature. The main rift grabens have undergone vertical structural offsets of as much as 6 km (e.g., near Bernalillo). South of Socorro the rift is not physiographically distinctive, yet can be distinguished from the adjacent Basin and Range province by a variety of geologic and geophysical signatures (Seager and Morgan, 1979).

Over much of its length the rift is part of a broad region of "rift-like" late Cenozoic extensional deformation, i.e., a region characterized by large crustal blocks separated by steeply dipping normal faults. In central New Mexico, west of Albuquerque and Socorro, this region is more than 200 km in width, extending southwestward across the physiographic Colorado Plateau to Springerville, Arizona, and perhaps farther (Baldridge and others, 1983). A broadly linear, northeast-trending array of late Cenozoic volcanic fields, commonly referred to as the Jemez lineament, separates this extended terrain (transition zone) along the southeastern margin of the plateau from the less deformed "core" to the northwest. The Jemez lineament must correspond to a major boundary or zone of weakness in the lithosphere. However, it is not an expression of a fault or fracture zone and does not correspond to any single, simple structure in the upper crust (Baldridge and others, 1983). Farther south, the extended region encompasses the entire Mogollon–Datil volcanic field. In southern New Mexico and northern Chihuahua, the rift is not physiographically distinguishable from the Basin and Range province extending across southern Arizona and southern New Mexico.

Although the style (i.e., extensional deformation) and timing of structural deformation of the entire extended region are similar to that of the main rift grabens, the magnitude of deformation is much less. Vertical offset on normal faults of the Colorado Plateau transition zone probably does not exceed a few hundred meters. In the Mogollon–Datil region of southwestern New Mexico, narrow, deep grabens exist near Datil, Reserve, and Silver City, but these are separated from the larger, main grabens of the rift by a region 100 km or so wide, in which extensional deformation formed only shallow grabens.

This recognition of a broad, "rift-like" region is fully in accord with definitions of the rift based on geophysical and topographic criteria (e.g., Cordell, 1978; Ander, 1981). Whether the term "Rio Grande rift" is applied to the entire region (e.g., Cordell, 1978), or is restricted to the deeper, physiographically distinguishable main grabens, as we prefer, is largely a semantic argument. The important point is that the continuity of structural style and timing across this broad region clearly indicates a continuity in underlying process. That is, formation of the Rio Grande rift and Colorado Plateau transition zone and breakup of the Mogollon–Datil volcanic field all resulted from, and were part of, the very widespread Basin and Range deformational event.

LITHOSPHERIC STRUCTURE

The fact that deformation associated with the Rio Grande rift affected such a large region suggests that it resulted from an event that perturbed the entire lithosphere. The structure of the lithosphere beneath the rift is anomalous in many respects (Fig. 2):

(1) A moderate amount of crustal thinning has taken place beneath the axis of the rift. At 35°N latitude, depth to Moho is 33 km beneath the Albuquerque–Belen Basin compared to about 45 km under the Arizona–New Mexico border and to 50 km under the Great Plains (Olsen and others, 1979). North–south interface dips are small (0–2°) so that uplifted Moho beneath the rift exists from the southern border of New Mexico northward to Colorado. Discontinuous reflection segments on COCORP lines within the rift basin have two-way travel times that correspond well to a depth of 33 km (Brown and others, 1979).

(2) The sub-Moho compressional velocity (P_n velocity) beneath the rift axis is 7.6–7.7 km/s, significantly lower than velocity of "normal" mantle (8.0–8.2 km/s) beneath the Great Plains. Gravity modeling suggests that a low-density layer, which we presume correlates with this low P_n material, persists westward from the rift beneath the Colorado Plateau at least as far as northeastern Arizona, where P_n has been directly measured at 7.8 km/s along the reversed Chinle–Hanksville line. Black and Braile (1982) argue that such low P_n values are primarily due to high temperatures in the mantle. Velocities of 7.6–7.9 km/s therefore strongly suggest that the asthenosphere is in direct contact with the base of the crust beneath the rift and southeastern Colorado Plateau, without any intervening normal mantle.

The very broad (long-wavelength) gravity low extending across the entire state (about 500 km) at the latitude of Albuquerque (Fig. 2) is related in part to the shape of the low-velocity zone in the upper mantle (the asthenosphere). Other east–west gravity profiles between latitudes 32° and 38° also show this asthenospheric diapir, which thus forms a ridge-like Moho upwarp approximately parallel to the surface trace of the rift (Cordell, 1978; Ramberg and others, 1978). Both heat-flow and electrical-conductivity measurements support this gravity picture of an asthenospheric upwarp. The axis of the asthenospheric low does not coincide with the axis of the rift, but instead is displaced about 200 km westward.

(3) The compressional velocity in the lower crust beneath the rift (6.4–6.5 km/s) is substantially less than lower-crust velocities (6.7–6.8 km/s) under the flanks both to the east and west. Lower-crust velocities on the order of 6.5 km/s are rather uncommon in continental North America, existing mainly in the Great Basin section of the Basin and Range province and in the Rio Grande rift (Prodehl, 1979; L. Braile and others, written comm. 1984). We interpret such subnormal lower-crust velocities to be mainly due to high crustal temperatures and to suggest that no major compositional difference exists between the lower

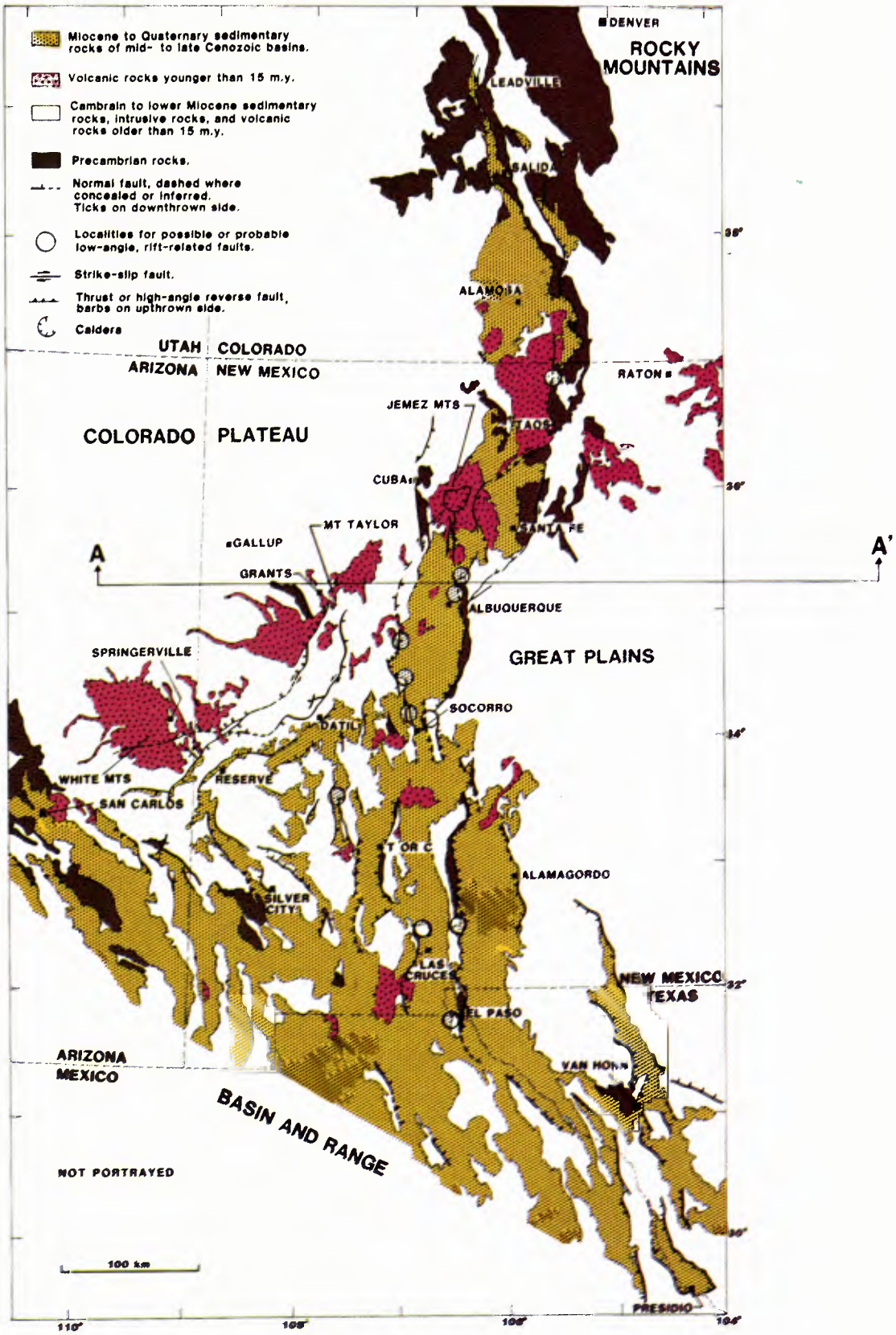


FIGURE 1. Generalized tectonic map of the Rio Grande rift. After Woodward and others (1978), Tweto (1978), NMGS Map (1982), and Baldridge and others (1983). A–A′ shows location of cross section in Figure 2.