Introduction

Many of the fifteen papers included in this volume summarize years of research on the part of the authors, and we are pleased to offer these major, insightful, works to you in the first electronic bulletin published by the New Mexico Bureau of Geology and Mineral Resources. The overarching theme of the bulletin is presentation of the latest thoughts on the tectonic and volcanic history of the southern Rocky Mountains and Rio Grande rift. The papers cover a broad spectrum of time (Cambrian to Holocene), and a broad geographic area (northernmost Colorado to the boot heel of southern New Mexico). A variety of geologic, geochronologic, and thermochronologic tools are applied in interesting ways to gain new understanding of this region. The papers are generally organized by the geologic age of the topic considered, starting with the oldest events.

McMillan and McLemore compile the geochronology, geochemistry, and field relationships of Cambrian-Ordovician-age alkalic dikes, stocks, and plutons in Colorado and New Mexico, and propose that these igneous rocks were emplaced in an extensional setting. These authors introduce the concept of an early Paleozoic New Mexico aulacogen, similar to the more well-known Cambrian–Ordovician aulacogen in the Wichita Mountains of southern Oklahoma. The precise orientation of this proposed zone of early Paleozoic high topography and extension is uncertain, but if it is oriented north-south, this feature may have influenced subsequent Phanerozoic deformation, including localization of the Cenozoic Rio Grande rift.

Chapin, Wilks, and McIntosh present a carefully screened compilation of over 3,000 K-Ar and $^{40}Ar/^{39}Ar$ ages for volcanic and plutonic rocks to document magmatic trends during Late Cretaceous to Holocene time in New Mexico. These authors show the localization of magmatism in southwestern New Mexico during Laramide deformation, the spread of volcanism from southwestern New Mexico to the four corners of the state between 45 and 21 Ma, waning of volcanism from 21 to 16 Ma, renewed basaltic volcanism at 16 Ma, and localized bimodal volcanism starting at about 10 Ma. The location of possible future volcanic eruptions in the state of New Mexico is also considered.

Two papers in the bulletin examine the Laramide-age structural development of the Front Range of Colorado using radically different methods, but the papers come to the same general conclusion: A model of lateral thrusting of the margins of the Front Range, as opposed to a vertical tectonics model, best fits the observed data. Kelley and Chapin present approximately 200 new apatite fission-track thermochronology data from northern and central Colorado. These data are used to characterize the style of Laramide deformation in the Front Range and Wet Mountains of Colorado, constrain the thermal effects of the Colorado Mineral Belt, and consider the possible effects of the Late Cretaceous Pierre Shale on the temperature structure of the basement of the Front Range prior to Laramide deformation. Erslev et al. provide a comprehensive analysis of minor structures from Mesozoic sedimentary rocks on the margins of the Front Range in Colorado. In contrast to interpretations of geologic and structural data from New Mexico, which suggest tens-of-kilometers of late Laramide-age dextral strike-slip offset, Erslev et al. argue for significant thrust faulting with minor dextral strike-slip motion during Laramide deformation in the Front Range of Colorado. Furthermore, the multistage nature of Laramide deformation (east-northeast-directed compression early, north-northeast-directed compression late), which is well documented in New Mexico, is only weakly preserved in the cross-cutting slickenline relationships in the Front Range.

Detailed geologic mapping, geophysics, and expanded geochronology and thermochronology datasets are providing important new insights into the tectonic history of five major fault zones in New Mexico, including the Embudo–Picuris–Pecos–Sangre de Cristo (Bauer and Kelson), Nacimiento (Pollack et al.), Tijeras (Abbott et al.), Montosa (Behr et al.), and Hot Springs (Harrison and Cather) fault systems. Bauer and Kelson place important age constraints on the Picuris Formation (from 34.64 ± 0.16 to 18.59 ± 0.70 Ma) in the southeastern San Luis Basin south of Taos, New Mexico. Deformation of the Picuris Formation is used to document < 18 Ma dextral slip on one strand of the Picuris-Pecos fault system, motion that occurred well after Rio Grande rift extension began at approximately 27 Ma. The 8-km wide, north-trending Picuris–Pecos fault system appears to be linked to the north-trending Los Cordovas fault zone in the basin and may have formed the early structural boundary of the San Luis Basin. Subsequently, the northeast-trending, sinistral Embudo fault zone truncated the Picuris–Pecos fault zone and merged with the north-trending Sangre de Cristo fault zone to form the modern structural margin of the southwestern San Luis Basin. Pollock et al. use detailed mapping, balanced geologic cross-sections, and gravity data to develop a new tectonic model for low-angle faulting on the west side of the Sierra Nacimiento. A wedge of Proterozoic basement was thrust below the sedimentary section to the west. Dextral slip on the fault between the wedge and the main mountain front is constrained by the distribution of the Proterozoic San Joaquin granite to be 3–15 km. Strike-slip motion occurred before thrusting, and thus could be Proterozoic, Ancestral Rockies or early Laramide in age. Abbott et al. show that the Tijeras–Cañoncito fault system on the east side of the Sandia Mountains was initially activated as a dextral strike-slip, north-side-down normal fault during Laramide deformation, based on interpretation of kinematic indicators on minor fault planes. The fault system was subsequently reactivated during Rio Grande rift extension as a left-lateral strike-slip, down-to-the-north normal fault, based on interpretations of slickenline data, $^{40}Ar/^{39}Ar$ ages of intrusions displaced by the fault system, and apatite fission track (AFT) thermochronology. The strands along the northeast part of the fault system displaced 34 Ma intrusive bodies and have not moved significantly since ca. 32 Ma, but strands of the fault system to the southwest, near the village of Golden, New Mexico, remained active until Holocene time. Behr et al. use slickenline data and AFT thermochronology to demonstrate that Montosa fault was dominantly a dextral reverse to dextral strike-slip fault during Laramide deformation. This fault zone was reactivated during Rio Grande rift extension and shows sinistral strike-slip and dip-slip normal motion. AFT data indicate that differential offset across this fault was minimal after 14–25 Ma. Finally, Harrison and Cather document about 26 km of dextral offset across the 15 km wide Hot Springs fault zone in the Fra Cristobal and northern Caballo Mountains in south-central New Mexico based on offset of a Devonian pinchout, Laramide structures, and geophysical anomalies. As much as 35–65 km of dextral offset may be recorded by deflections of Lower Paleozoic pinchouts on either side of the Palomas Basin. At least 3.1 km of dextral offset on the Chloride fault in the Black Range is constrained to have occurred after Eocene Rubio Peak deposition and before emplacement of a 34.93 ± 0.04 Ma ash flow tuff.

These new detailed studies of individual important fault systems in New Mexico indicate a complex history of Laramide-age thrust and reverse faulting, as well as dextral strike-slip offset. Estimates of the amount of dextral offset in these new studies range from as little as 3 km to as much as 65 km. The timing of strike-slip offset can be difficult to constrain, but data from the Tijeras fault in the Sandia Mountains and from the Chloride Fault in the Black Range indicate that offset occurred before the emplacement of 32–35 Ma volcanic and intrusive rocks. The data from the Taos region suggest localized dextral faulting as young as < 18 Ma. The Laramide structures were reactivated as sinistral normal faults in many places during Rio Grande rift extension.

Five papers in the bulletin use new high precision $^{40}Ar/^{39}Ar$ dates to identify previously unrecognized trends in the timing and distribution of latest Eocene to Pliocene volcanism in Colorado and New Mexico. In addition $^{40}Ar/^{39}Ar$ geochronology is applied in a novel way to determine the age of manganese mineralization in the Socorro area. McIntosh and Chapin use $^{40}Ar/^{39}Ar$ geochronology and paleomagnetic data to establish the stratigraphic framework of the regionally extensive Central Colorado volcanic field. Seven large-volume ignimbrites are recognized, four of which are tied to specific caldera centers in the Sawatch Range, whereas the remaining three likely were also sourced in the Sawatch Range. A new caldera, the Marshall Creek caldera, is defined in this study. Three ignimbrites from the San Juan volcanic field onlap tuffs from the Central Colorado volcanic field. Geochemical trends demonstrate an increase in alkalinity of intrusive bodies, and accompanying economic mineralization, from west to east across the field. Three fossiliferous sedimentary deposits that potentially include valuable paleoclimatic information, the Antero Formation (33.8 Ma), Pitch-Pinnacle Formation (33.7–32.9 Ma), and Florissant Formation (34.1 Ma), were also dated. Brister and McIntosh extend the correlation of regional ignimbrites from eruptive centers in the San Juan and Central Colorado volcanic fields into the subsurface of the Alamosa part of the San Luis Basin of Colorado by dating sanidine in well cuttings by $^{40}Ar/^{39}Ar$ analysis. The lower portion of the Oligocene volcanic and volcaniclastic section in the Alamosa Basin contains andesitic lavas from the San Juan field and Gribbles Park Tuff from the Central Colorado field, whereas the upper part of the section has only San Juan ignimbrites. Before this study, the Gribbles Park Tuff had not been recognized south of Bonanza. These authors conclude that the lower Oligocene section is thickest to the west, the regional San Juan ignimbrites covered a subdued topography across the Alamosa Basin, and significant eastward tilting of the Alamosa Basin began after the eruption of the 27.3 Ma Carpenter Ridge Tuff. Chamberlin et al. also use $^{40}Ar/^{39}Ar$ geochronology to establish the timing of complex eruptive events; in this case the post-collapse history of the 31.9 Ma Socorro caldera in central New Mexico. A 1–1.5 Ma gap between caldera collapse and central block uplift and related moat-filling volcanism and sedimentation indicate that the Socorro caldera is not a typical resurgent caldera. The Socorro caldera is the northeasternmost caldera in a series of southwest younging calderas in the Mogollon–Datil volcanic field. 30 Ma basaltic lavas that ponded in the southwestern moat of the Socorro caldera herald the beginnings of a new phase of volcanism that led to the formation of the next younger caldera to the southwest, the Sawmill Canyon caldera. Lueth et al. use $^{40}Ar/^{39}Ar$ geochronology to date a potassium-bearing phase, cryptomelane, in the Luis Lopez manganese district to determine the timing of manganese mineralization with respect to volcanic, tectonic, and metasomatic events affecting the Socorro area. These authors use the minimum ages of mineralization (6.69 ± 0.04–6.33 ± 0.04 Ma), ages of local rhyolitic volcanism (9.5–7.0 Ma), and the timing of potassium metasomatism (14.1–7.4 Ma) to develop a new model for mineralization in this mining district that involves lateral flow of mineralizing fluids from north of the deposit. Olmstead and McIntosh document the 8.2–0.8 Ma eruptive history of the Ocate volcanic field at the transition between the Southern Rocky Mountains and the High Plains in New Mexico by dating basalts using the $^{40}Ar/^{39}Ar$ method. The extensive new data-set records the episodic nature of volcanism in this field and a north to south progression in timing of volcanism across the field. The detailed data also reveal a pulse of down-to-the-west normal faulting between 4.37–5.13 Ma and decreasing erosion rates in the last 6 Ma.

Dunbar and Phillips report ^{36}Cl surface exposure ages for some of the youngest lava flows in the state of New Mexico, the 3.6.0–33.9 ka basalt flows in the Zuni-Bandera volcanic field. The age of 3.9 ± 1.2 ka for the McCartys flow reported in this paper is older that that estimated from archeological evidence, but confirms that the McCartys flow is the youngest basalt flow in New Mexico. Despite the challenges of dating young basalts, several geochronologic tools, including ^{14}C and ^{3}He dating techniques, yield ages that are similar to the ^{36}Cl surface exposure ages for the youngest flows. The ability to date young basalt flows accurately is important in identifying possible volcanic hazards.

We hope that you enjoy this collection of papers. Some of these papers have the potential to become classics in the scientific literature about the Rio Grande rift and the Southern Rocky Mountains.