Abstracts

New Mexico Geological Society

The New Mexico Geological Society annual spring meeting was held at New Mexico Institute of Mining and Technology (Socorro) on April 3, 1987. Following are abstracts from the four sessions given at that meeting. Abstracts from the 1988 meeting will appear in future issues of *New Mexico Geology.*

Sedimentary geology session

INTERIM REPORT ON THE CONODONT BIOSTRATIGRAPHY OF THE KELLY LIMESTONE (MISSISSIPPIAN), CENTRAL NEW MEXICO, by *Stanley T. Krukowski*, Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Kelly Limestone (Mississippian) of central New Mexico is located in several widespread outcrops along the western margins of the Rio Grande Rift. It nonconformably overlies Precambrian igneous and metamorphic rocks and is unconformably overlain by the Sandia Formation (Pennsylvanian). The lower Caloso Member consists of sandstones, shales, lime mudstones and wackestones. The upper Ladron Member disconformably overlies the Caloso and is composed of crinoidal grainstones and packstones. The basal limestones of the Caloso Member have produced conodonts assigned to the species *Patrognathus variabilis*, *Polygnathus inornatus*, and *Pseudopolygnathus fusiformis* indicating a Kinderhookian age. Previously barren strata at the top of the Caloso have yielded undiagnostic conodont faunas; however, one specimen, tentatively identified as *Gnathodus typicus* M1, would suggest a Kinderhookian–earliest Osagean time. The Ladron Member has produced conodonts throughout its thickness. The lowest units contain the conodonts *Gnathodus texanus* and *Polygnathus communis communis* marking the lower *texanus* Zone (upper Osagean). The top of the Ladron is assigned a latest Osagean–Meramecian age because it contains specimens belonging to the genus *Cavusgnathus*. The Caloso Member was determined to be Kinderhookian by early workers based on brachiopod faunas. It was later reassigned a middle Osagean age based on endothyrid foraminifers, *Latiendothyra*, *Medioendothyra*, and *Tuberendothyra*. The Ladron Member was assigned to the late Osagean based on brachiopod and blastoid assemblages, and the first occurrences of the foraminifers *Prisella*, *Pseudotaxis*, and *Tetrataxis*. Results of this study have shown that the Caloso Member is Kinderhookian at its base and possibly earliest Osagean toward the top. The disconformity between the two members corresponds to the Upper *typicus* and *anchoralis–latus* Zones (lower–middle Osagean).

PALEOCURRENT AND FACIES ANALYSIS OF THE ABO FORMATION ALONG A NW–SE SURFACE TRANSECT OF NEW MEXICO, by *John R. MacMillan*, Geoscience Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Paleocurrent analyses in conjunction with width to depth ratios of channel sandstones, relative abundance of different lithologies and their contact relationships, sedimentary structures and fossil content indicate the Abo Formation is composed of various facies (paleoenvironmental deposits) from the Zuni Mountains on the northwest, both sides of the Rio Grande rift to Socorro, NM, and southeastward through Bingham, NM, to the Sacramento Mountains and their transition to Otero Mesa. These facies include alluvial fans, braided stream channels, meandering stream channels (with their flood plains, natural levees and crevasse splays), and sandy tidal flats. The occurrence of the facies varies both stratigraphically within the Abo Formation and laterally due, in part, to syndepositional proximity of remaining highlands, which were probably tectonically formed during the Pennsylvanian Period, and/or marine basins.

SUBSURFACE ANALYSIS OF THE ABO FORMATION IN THE LUCERO REGION, WEST-CENTRAL NEW MEXICO, by *Gregory E. Little*, Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Outcropping of the Abo Formation in the Lucero region of west-central New Mexico is limited to the Zuni Mountains, Joyita Hills, Sierra Lucero–Lucero Mesa areas, and east of Socorro. Analysis of drill cutting and geophysical logs provides a stratigraphic framework between surface exposures. Subsurface data correlate with complete Abo sections near Lucero Mesa and east of Socorro. In the Lucero region, the Abo Formation overlies Precambrian rocks, Pennsylvanian limestones, and rocks assigned to the Bursum Formation and is overlain by the Meseta Blanca Member of the Yeso Formation. Thickness of the Abo Formation varies from 450 ft over the Zuni uplift to 820 ft near Mesa Lucero. The Abo Formation consists of very fine to medium-grained sandstones, siltstones and mudstones with coarser sandstones and conglomerates locally occurring over the Zuni uplift, Joyita Hills, and in exposures east of Socorro. In the western portion of the study area sandstones and siltstones dominate the Abo stratigraphic section by almost 4 to 1 over mudstones. Mudstones become more prevalent to the east with sandstone plus siltstone to mudstone ratios as low as 1:4. High percentages of sandstones and siltstones suggest alluvial-fan and braided-stream environments prevailed in the western portion of the Lucero region. To the east, an abundance of mudstones suggests a meandering fluvial environment of deposition. Initial analysis of well-log curve shapes to determine grain-size trends appears compatible with the above interpretations; however this type of analysis was found to be more difficult than expected.

MARINE SHEET SANDSTONES OF THE UPPER YATES FORMATION, SOUTHERN GUADALUPE MOUNTAINS, NEW MEXICO, by *Magell P. Candelaria*, ARCO Oil & Gas Co., P.O. Box 1610, Midland, TX 79702

Middle Permian strata of the Northwest shelf in the southern Guadalupe Mountains, New Mexico consist of thick shallow marine carbonates interbedded with thinner siliciclastic intervals of uncertain origin. Most previous studies have categorically assigned Capitan-equivalent (Upper Guadalupian) siliciclastic intervals of the Northwest shelf to either of two general depositional environments, shallow marine or eolian, with few sedimentological observations to support the interpretations. A detailed sedimentologic study of the three siliciclastic intervals in the upper 15–30 m of the Yates Formation, supported by reconnaissance observations of the underlying Seven Rivers and overlying Tansill formations, has provided strong evidence for a shallow marine depositional environment for these shelf siliciclastic intervals, contrary to prevailing interpretation. The three siliciclastic units of the upper Yates were examined in detail for sedimentologic and petrographic characteristics within the area extending 5 km from the Capitan shelf edge and for 36 km parallel to the shelf edge. These upper Yates intervals are continuously traceable across the study area and well beyond to the west and into the subsurface to the east. All three units thicken slightly basinward prior to pinching out abruptly between carbonate grainstones of the outer shelf within a few hundred meters of the Capitan massive at the shelf edge. The lowermost unit averages 0.5 m thick and compositionally is a silty peloidal wackestone. The upper two intervals are subarkosic and average 4 and 6 m thick (middle and upper units, respectively). All three intervals are in sharp, planar contact with the underlying carbonate unit. Locally the basal contact is planar erosional with obvious erosion of the substratum in excess of 1 m of relief as evidenced by truncated tepee structures. The upper contact of each siliciclastic interval is gradational to locally sharp. Texturally the siliciclastics range from subangular silt (<64mm) in the silty wackestone to well-rounded, lower, very fine sand (0.09–0.064 mm) in the subarkose units. Rare, isolated, well-rounded, frosted, medium (0.25–0.5 mm) quartz sand grains characteristic of the Yates in the subsurface are present in the subarkose units and are particularly abundant in the area of the pinchout of each subarkose unit. In contrast a feature unique to the silty wackestone is the presence of trace amounts of glauconite. Sorting ranges from well to very well sorted. The heavy-mineral suite is dominated by a well rounded and abraded zircon–tourmaline–rutile assemblage. Biotics are rare within either the silty wackestone facies or the subarkose facies and are found in greatest concentration and diversity in proximity of the Capitan Reef. Biotics range from fusulinids and dasycladacean algae to various molluscan and brachiopod fragments. Evidence of burrowing infauna is extremely rare though local, subtle, fabric mottling is apparent in the subarkose facies. Sedimentologically the two lithofacies are distinct. The silty wackestone is characterized by development of three facies along a shelfward progression. Nearest the Capitan is developed a discontinuous, wavy, crypt-algal, laminated facies. Locally developed within this facies are oscillation ripples containing fusulinids aligned in and parallel to the ripple troughs. Farther shelfward this facies grades into a wavy, laminated, fenestral facies. This facies in turn grades farthest shelfward into a wavy, laminated facies containing ostracods and calcispheres. The subarkose facies exhibit a shelfward diminution of scale, diversity, and abundance of primary sedimentary structures from the reef proximal area. On the basis of sedimentary-structure distribution three facies have been recognized in the shelfward progression: 1) small-scale cross-laminated facies; 2) ripple cross-laminated to plane-parallel facies; and 3) non-laminated to wavy, laminated facies (farthest from the shelf edge). This facies progression is interpreted to be the product of shelfward diminution of hydraulic energy. Moreover, across the area examined, none of these sandstones exhibit evidence of channeling or down-cutting into the subjacent carbonate unit. They exhibit no fining or coarsening upward sequences, no features interpretable as evidence of beach or tidal sedimentation, and no vertical repetitive sedimentation patterns. No stratification types were identified as unequivocal eolian features (i.e. inversely graded translatent laminae, adhesion ripples, high index ripples, deflation surfaces or associated interdune pond facies). All primary sedimentary structures are interpretable as being of subaqueous origin. Furthermore the relative increase in abundance of the medium-sand fraction in the subarkose units near the pinchout is thought due to winnowing in the zone of greater hydraulic energy. Siliciclastic units of the Seven Rivers and Tansill Formations are sedimentologically analogous to these upper Yates intervals. All are herein interpreted as sheet sands deposited in a shallow marine shelf environment. The shelf hydraulic regime was of moderate to low energy, which diminished with increasing distance from the shelf edge. The silty wackestone ☞

facies represents deposition in a shallow subtidal to supratidal (?) environment. The subarkose facies represents deposition in strictly a shallow subtidal environment of perhaps only a few meters depth. Input of mature likely multicycle siliciclastics to the aqueous shelf environment may well have been via eolian and/or fluvial processes. However transport and uniform distribution across the shelf was by a variety of shallow marine processes operating on various periodicities. These fine-grained siliciclastics were winnowed within the outershelf hydraulic environment and subsequently transported in suspension across the Capitan massive to be deposited in the deep waters of the Delaware Basin.

ORIGIN OF SANDSTONE–CARBONATE ALTERNATIONS OF THE UPPER YATES FORMATION, NORTHWEST SHELF, DELAWARE BASIN, NEW MEXICO, by *Magell P. Candelaria*, ARCO Oil & Gas Co., P.O. Box 1610, Midland, TX 79702

The interbedded sandstone and carbonate strata of the Permian upper Yates and lower Tansill Formations on the Northwest shelf of the Delaware Basin, New Mexico were studied to determine their sedimentologic and temporal relationships. The evidence suggests local minor tectonic, as opposed to eustatic, control of carbonate sedimentation and of the sandstone–carbonate alterations. Along the most basinward 5 km of the Northwest shelf the Yates–Tansill study interval consists of three sandstone–carbonate alternations with a composite thickness of up to 40 m. The carbonates vary from skeletal grainstones to nonskeletal wackestones and range up to 12 m thickness each. The sandstones are very well sorted, very fine grained siliciclastic units from 0.5–8 m thickness and range from silty peloidal wackestones to subarkose arenites. The Yates–Tansill interval grades laterally basinward into the Capitan reef facies at the shelf edge. Within each of the carbonate intervals a number of peritidal facies have been recognized that collectively exhibit upward-shoaling characteristics. The upward-shoaling sequence is typically 1–2 m thick each and is hemicyclic. Several of these sequences may exist in vertical succession in each carbonate unit examined. Commonly a hemicyclic sequence is capped by a ragged erosion surface that is overlain by another similar hemicycle. The stacking of these truncated upward-shoaling sequences is interpreted to be the product of peritidal sedimentation to depositional fill level in response to episodic relative shelf subsidence of comparable magnitude. The upper few centimeters of many hemicycles evidence peritidal diagenesis interpretable in some cases as evidence of emergence. In two instances the diagenesis is analogous to incipient pedogenesis implying extended subaerial exposure. In contrast, the contemporaneous shelf carbonate facies farther basinward and farther shelfward do not exhibit upward-shoaling sedimentation, erosion, or comparable diagenesis. The area of upward-shoaling peritidal facies is interpreted to represent a paleotopographic high or crest of the geomorphic shelf marginal mound. The relationship of the marginal mound to sandstone deposition has long been enigmatic. The interbedded sandstones are seemingly structureless sheet sands that are continuous across the study area including the area of shelf crest facies in the subjacent carbonate interval. Within a few hundred meters of the shelf edge each sandstone interfingers with and abruptly pinches out into the reef-proximal shelf facies. In general, all three sandstone intervals are in sharp but conformable contact with the underlying carbonate units except across the area of shelf-crest facies where the basal contact is clearly erosional and the carbonate substratum locally exhibits evidence of incipient pedogenesis. In marked contrast, the upper contact of each sandstone with the overlying carbonate unit is typically of a more gradational nature. The sandstones exhibit no evidence of down-cutting, or coarsening- or fining-upward sequences. Primary sedimentary structures are rarely visible; where present they are small scale (< 20 cm) and discontinuous. Their apparent absence is due to high textural maturity (very fine grain size < 0.1 mm, and high degree of sorting) and/or thorough reworking by infauna. The overall distribution of sedimentary structures indicates subaqueous deposition within an hydraulic regime of shelfward diminishing energy. Contrary to most previous interpretations, no evidence of eolian stratification was found to support an eolian depositional environment for the shelf sands. Shelf sandstone transport processes remain enigmatic but are dominantly basinward directed and likely of marine origin. Siliciclastic input to the marine shelf environment is believed to have been slow but continuous along the strandline. The effectiveness of marine transport of siliciclastics across the shelf was governed largely by minor episodic relative shelf subsidence, which periodically increased or maintained water depth favorable for subaqueous transport of shelf siliciclastics. Apparent unrestricted marine transport of quartz sands across the most basinward 5 km of the shelf requires the absence or lack of influence of any hydrographic barrier such as a marginal mound during sandstone depositional episodes. This condition was repeatedly met by a combination of erosional truncation of the shelf crest facies of the marginal mound and subsequent increased shelf water depths due to relative subsidence of a few meters, at which time siliciclastics were transported basinward by a variety of marine shelf processes. The gradation of sandstone upward into upward-shoaling, hemicyclic, peritidal carbonates along the crest of the shelf marginal mound is interpreted to be a dual lithology depositional couplet. This couplet is unique to the area of the shelf crest and consists of a lower sandstone member grading upward to upward-shoaling peritidal carbonates, which became episodically emergent locally. In this "all wet" shelf interpretation, the sandstones represent the subtidal sedimentation and the carbonates represent the intertidal–supratidal sedimentation. The interpretation of minor (1–2 m) episodic relative shelf subsidence controlling the alternation of shelf carbonate and sandstone deposition is an alternative to the long-professed dogma of dominantly eustatic control of Northwest shelf depositional sequences. This interpretation is preferable to previous interpretations in that it is documentable on the scale of an outcrop, it is consistent with the observed sedimentologic and stratigraphic relationships of the Yates–Tansill sequence, and it may be applicable to comparable stratigraphic sequences elsewhere in the Permian Basin.

TODILTO AS A FORMATION, NOT A MEMBER OF THE WANAKAH FORMATION, MIDDLE JURASSIC OF NORTHERN NEW MEXICO, by *Spencer G. Lucas*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

Gregory (1971) named the Todilto Limestone for outcrops in Todilto Park, New Mexico, and Darton (1928) and others subsequently extended its distribution across northern New Mexico. Two informal members of the Todilto have long been recognized: 1) a basal limestone member that is as much as 13 m of laminated, kerogenic micrite; and 2) an upper gypsum member that is as much as 55 m of laminar to massive gypsum–anhydrite. Burbank (1930) named the Wanakah Member of the Morrison Formation near Ouray, Colorado for 20 m of shale, limestone and sandstone underlain by 18 m of gypsum and limestone that he termed the "Pony Express beds." It has long been clear that Burbank's Pony Express beds = the Todilto Limestone of Gregory and that the remainder of Burbank's Wanakah Member = the unit long (but incorrectly) called Summerville Formation in northwestern New Mexico. The simplest nomenclatural solution thus is to abandon the term Pony Express, and restrict the name Wanakah to the upper, dominantly clastic portion of Burbank's original Wanakah Member. This means that the Todilto Formation (with two unnamed members) in northwestern New Mexico and southwestern Colorado is overlain by the Wanakah Formation. An alternative solution recently advocated by the U.S. Geological Survey is to reduce Todilto to member rank as the basal member of Wanakah Formation and term the upper, dominantly clastic portion of the Wanakah the Beclabito Member. This solution is less favorable because it: 1) unnecessarily introduces a new stratigraphic name (Beclabito); 2) reduces the two members of the Todilto to bed status even though they are mappable at 1:24,000 scale; and 3) runs contrary to long-standing and extensive published usage, which has recognized the Todilto and Wanakah as separate formations.

STRATIGRAPHY OF THE MORRISON FORMATION (LATE JURASSIC) IN THE LAMY AREA, SANTA FE COUNTY, NEW MEXICO, AND CORRELATION BETWEEN THE MORRISON ON THE COLORADO PLATEAU AND IN EAST-CENTRAL NEW MEXICO, by *Adrian P. Hunt*, and *Kenneth K. Kietke*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

The Morrison Formation in the Lamy area (T15N, R10E) consists of 183 m of variegated mudstones, sandstones, siltstones and conglomerate. Based on lithologic characteristics and stratigraphic position, the Recapture, Westwater Canyon, Brushy Basin and Jackpile Sandstone members can be recognized. The Recapture overlies gypsum or limestone of the Todilto Formation and consists of 81.3 m of pale reddish-brown mudstones and fine-grained sandstones. Overlying the Recapture are 48 m of medium-grained sandstones and minor mudstones of pale greenish-yellow color. This sandstone sequence, which also includes rare conglomerates, is assigned to the Westwater Canyon Member. The Brushy Basin consists of 37 m of variegated grayish-red, purple, and pale olive mudstones. Overlying the Brushy Basin is 10 m of white coarse-grained kaolinitic sandstone assigned to the Jackpile Sandstone Member. Above the Jackpile is a 2–cm-thick ferrugenous zone, which weathers moderate brown in color, overlain by 7 m of medium-grained white sandstone. This upper sandstone sequence may be correlated with the Encinal Canyon Member of the Dakota Formation. The stratigraphic section at Lamy represents the easternmost outcrops of the Morrison that can be correlated with the sequence on the Colorado Plateau. Forty miles east at Romeroville Gap (T15N, R16E) the members of the Morrison that are present at Lamy cannot be recognized. However, in most of east-central New Mexico, the Morrison section is homotaxial with that on the Colorado Plateau. The evidence from Lamy and Romeroville indicates that the homotaxial relationship is not the result of depositional continuity of facies across central New Mexico.

NEW OBSERVATIONS CONCERNING THE JURASSIC–CRETACEOUS BOUNDARY IN EAST-CENTRAL NEW MEXICO, by *John M. Holbrook* and *Robyn Wright*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

The "basal white sandstone" of the Cretaceous (Albian) Mesa Rica Sandstone in the Tucumcari Basin is now recognized as a series of localized fluvial deposits properly belonging to the underlying Jurassic Morrison Formation. Previous misinterpretation of this relationship has resulted in incorrect placement of the J–K boundary throughout northern exposures in the Tucumcari Basin. Locally, the kaolinitic and feldspathic "basal white sandstone" can be directly correlated to Morrison sandstones and shales that underlie the Albian Tucumcari Shale. In a landward direction, as the Tucumcari pinches out and the Mesa Rica becomes fluvial, distinction of Jurassic and Cretaceous sandstones is more problematic. The story of the J–K boundary is further complicated by the presence of a previously unrecognized, genetically distinct sandstone that occurs locally between the Morrison ("basal white sandstone") and either the Tucumcari or Mesa Rica Formation. This clean, locally bioturbated, quartz arenite was deposited in fluvial and marginal marine (estuarine) environments that backfilled topographic lows on the post-Morrison surface during base-level rise associated with the encroaching Tucumcari sea. As yet unnamed, we tentatively place this unit as a basal member of the Tucumcari Shale. A possible stratigraphic equivalent in northeastern New Mexico and southeastern Colorado is the basal sandstone member of the Glencairn Shale.

SANDSTONE MEMBER OF LOWER CRETACEOUS U–BAR FORMATION IN EAST POTRILLO MOUNTAINS, SOUTH-CENTRAL NEW MEXICO, by *Donna Courington*, Earth Sciences Department, New Mexico State University, Las Cruces, NM 88003

The sandstone member of the Lower Cretaceous U-Bar Formation in the East Potrillo Mountains, south-central New Mexico, ranges from 25 to 66 m thick, and consists of four intervals of coarse sandstone and conglomerate interbedded with very fine grained sandstone and siltstone. Four lithofacies have been identified: 1) pebble conglomerate, 2) crossbedded to hummocky stratified coarse sandstone, 3) horizontally laminated sandstone, and 4) bioturbated fine sandstone and siltstone. Each coarse interval consists of up to three stacked sequences of, in ascending order, pebble conglomerate, crossbedded to hummocky stratified sandstone, and horizontally laminated sandstone. The grain size of each coarse interval increases upward. The fine sandstone and siltstone lithofacies is predominantly bioturbated although locally horizontal laminations and vertical burrows are found. Coarsening-upward sequences are present near the top of this lithofacies where it underlies the coarse intervals. The sandstone member is interpreted as a stacked sequence of offshore sand ridges deposited in a shallow marine environment. The coarse intervals were deposited on the up-current side of the ridges; the fine-grained sandstone and siltstone on the down-current side. The presence of hummocky stratification indicates the importance of storms in the evolution of the sand ridges, but bipolar paleocurrent data suggest an additional tidal influence.

DEPOSITIONAL ENVIRONMENTS, SEDIMENT DISPERSAL, AND PROVENANCE OF THE UPPER CRETACEOUS COLORADO FORMATION, SOUTHWESTERN NEW MEXICO, by *Edward L. Kaczmarek*, Earth Sciences Department, New Mexico State University, Las Cruces, NM 88003

The Colorado Formation (Upper Cretaceous) in southwestern New Mexico consists of approximately 200 m of interbedded shale and sandstone and is exposed at several locations in Grant and Luna Counties. Three informal members have been designated in each of eight stratigraphic sections. The lower member is composed of bioturbated, fossiliferous siltstone, shale, and very fine grained sandstone and was deposited in a shallow marine or prodelta environment. The middle member consists of massive or laminated sandstone, shale, and laminated and planar tabular-crossbedded sandstone that were deposited in a delta front environment. The upper member is composed of carbonaceous shale and lenticular, trough-crossbedded sandstone. Sedimentary structures and lithologies indicate a nonmarine depositional environment, perhaps within a lower delta plain. The Colorado Formation was deposited in the southwesternmost part of the Western Interior Seaway. Paleocurrent data from delta plain sandstones indicate a northeastward paleoslope. Detrital modes of 22 sandstones imply derivation from sedimentary and volcanic source rocks that were probably part of the arc and back-arc orogenic belt in southern Arizona and northern Mexico.

SANDSTONE PETROLOGY AND PROVENANCE OF THE SANTA FE GROUP (OLIGO–PLEISTOCENE) IN THE SOUTHWESTERN ALBUQUERQUE BASIN, CENTRAL NEW MEXICO, by *Richard P. Lozinsky*, Department of Geoscience, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Santa Fe Group of late Oligocene to middle Pleistocene age is the major syn-rift deposit of the Rio Grande rift. Santa Fe Group deposits from the Gabaldon badlands, Bobo Butte area, and from the Humble Santa Fe Pacific #1 and Shell Santa Fe Pacific #2 oil test wells were analyzed to determine sandstone detrital modes and provenance. Most samples are poorly sorted lithic arenites that were deposited in an alluvial-fan/playa complex. Point counts of 34 stained thin sections show an average composition of 40% quartz, 44% feldspar, and 16% lithics. Plagioclase and monocrystalline quartz are the dominant detrital grains. Lithic grains average 92% volcanic, 8% sedimentary, and $<1\%$ metamorphic in origin. Conglomerate in the Gabaldon badlands and Bobo Butte area contains 50–88% Oligocene ash-flow tuff. Conglomerate in the Bobo Butte area also contains about 25% Cretaceous mudstone and sandstone. These data indicate that the source area for the Santa Fe Group deposits contained ash-flow tuff and Cretaceous sedimentary rocks. Imbricated clasts show a flow direction eastward away from the Lucero uplift. This suggests that the Lucero uplift was the source area for these deposits. No ash-flow tuffs or Cretaceous sedimentary rocks are now present in the Lucero uplift. Thus, sometime in the past, the Lucero uplift must have contained at least one ash-flow tuff sheet and some Cretaceous sedimentary rocks that have subsequently been removed by erosion.

Volcanics and general session

GROUND-WATER LEVELS AND DIRECTION OF GROUND-WATER FLOW IN THE CENTRAL PART OF BERNALILLO COUNTY, NEW MEXICO, SUMMER 1983, by *G. E. Kues*, Water Resources Division, U.S. Geological Survey, Albuquerque, NM 87102

In 1980, toxic chemicals were detected in water samples from wells in and near Albuquerque's San Jose well field. At the request of Environmental Improvement Division of the New Mexico Health and Environment Department, the U.S. Geological Survey conducted a study to determine ground-water levels and flow direction. Water levels were measured in 44 wells in a 64–mi^2 area along the Rio Grande and adjacent areas during a period of near-maximum municipal pumpage. Based on the altitude of screened interval, wells were grouped into shallow (screened interval above an altitude of 4,800 ft) or deep (screened interval below an altitude of 4,800 ft) zones. Ground water in the shallow zone generally moves from north to south parallel to flow in the Rio Grande. Ground water in the deep zone generally moves from the northwest to the east and southeast. A poorly developed cone of depression within the deep zone was present in the northeast. Water levels in wells were as much as 18 ft higher in the shallow zone than in the deep zone in the vicinity of the San Jose well field, indicating a downward gradient.

LAND SUBSIDENCE IN THE SOUTHERN HUECO BOLSON, *J. Ni* and *A. H. Smyth*, Department of Physics, Geophysics Program, New Mexico State University, Las Cruces, NM 88003

Ground water, leveling and geological data are used to study present and future land subsidence in the southern Hueco Bolson. As the result of ground water withdrawal since 1904, more than 46 m of water-level (piezometric surface) decline has occurred in the study area. Consequently, land subsidence has occurred within the Hueco Bolson and has been observed in leveling profiles. Before 1956, the rate of land subsidence was about 1.7 mm/yr. This rate has increased to 7.4 mm/yr in recent years, in correspondence with an increased pumping rate. However, the ratio of land subsidence to water-level decline has remained constant. This value, about 5×10^{-3}, determined empirically from leveling and water well data, is low and is consistent with those values determined for regions in which the vertical effective stress has not yet exceeded the preconsolidation stress. Computer modeling of land subsidence gives similar ratios of land subsidence to water-level decline. Land subsidence outside the area of leveling surveys can be predicted by our model. Based on historical water withdrawal rates, preconsolidation stress (equivalent to a hydraulic head of about 60 m) could be exceeded by the year 1998 when the rate of land subsidence could rise above the present rate.

FOSSIL VERTEBRATES FROM THE MENEFEE FORMATION (CRETACEOUS), SANDOVAL COUNTY, NEW MEXICO, by *L. K. Martini*, *A. P. Hunt*, and *S. G. Lucas*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

Abundant, but fragmentary, fossils of vertebrates are present in the Cleary Coal Member of the Menefee Formation in the E½ sec. 19, T14N, R1E, Sandoval County. These fossils occur together with petrified wood and shipworm burrows in channel sandstone. The vertebrate fossils represent a fish, turtles, dinosaurs (ankylosaurs and hadrosaurids), and a pterosaur and are part of the University of New Mexico (UNM) collection. They are: 1) a single, large vertebral centrum (UNM MV–2270) of an amiid; 2) carapace fragments of baenid (UNM MF–2261) and trionychid (UNM MV–2262, 2267 and 2268) turtles; 3) scute fragments of an ankylosaur (UNM MV–2260); 4) the proximal end of a left femur (UNM MV–2259) and edentulous jaw fragments (UNM MV–2263, 2264) of hadrosaurids; and 5) the proximal end of the right metacarpal IV (UNM MV–2269) of a large pterosaur, comparable in size to *Pteranodon*. Stratigraphic relationships of the Cleary Coal Member to better dated stratigraphic units indicate that the Cleary ranges in age from late Santonian to early Campanian. The vertebrates reported here are the first ☞

identified from the Menefee Formation and one of the few vertebrate faunas of late Santonian–early Campanian age known from North America. The pterosaur from the Cleary Coal Member is the first pterosaur fossil discovered in New Mexico.

PORPHYROBLAST MICROSTRUCTURES AS INDICATORS OF EARLY STRAIN EVENTS IN METAMORPHIC ROCKS—WITH EXAMPLES FROM PRECAMBRIAN ROCKS OF THE PICURIS RANGE, NORTHERN NEW MEXICO, by *P. W. Bauer*, Geoscience Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

In multiply deformed, medium- to high-grade metamorphic rocks, tectonite fabrics (foliations and lineations) are commonly overprinted or obliterated by later generations of structures. However, in many rocks these earlier fabrics tend to be preserved as inclusion trails within and adjacent to porphyroblasts such as garnet, staurolite, andalusite, kyanite, and plagioclase. Petrographic analysis of such microstructures in and around porphyroblasts and megacrysts in metamorphic rocks provides a method of reconstructing the occurrence and relative timing of fabric-forming deformational events. Evidence for these early fabrics may be indistinguishable at larger scales of observation. In many rocks these porphyroblasts reveal consistent relationships between mineral growth and deformation. Early Proterozoic metasedimentary rocks in the Picuris Range of northern New Mexico contain a variety of well-preserved porphyroblasts containing inclusion trails. Although unambiguous interpretations of the more complex microstructures in these minerals are rare, they do indicate a metamorphic/kinematic history that is more complicated than is apparent from outcrop-scale and map-scale structures. They also suggest that mineral growth and deformation are somehow interdependent and that relatively short periods of time separated the major strain events. In the Picuris Range, porphyroblast microstructures make it possible to integrate anomalous large-scale structural and stratigraphic relationships into a coherent picture of a progressive strain history.

GEOCHEMISTRY OF THE HEMBRILLO CANYON SUCCESSION, SIERRA AND DOÑA ANA COUNTIES, NEW MEXICO, by *D. E. Alford*, Geoscience Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Proterozoic supracrustal rocks in the central San Andres Mountains, New Mexico are dominated by a large volume of metasediments with lesser amounts of mafic metaigneous rocks and minor amounts of felsic volcanic rocks. These rocks are collectively referred to as the Hembrillo Canyon succession. Metasediments are an important part of the succession. Felsic metavolcanic rocks are of local importance in the Hembrillo Canyon area only. The mafic igneous rocks of the area are common throughout the succession and have incompatible element distributions characteristic of basalts erupted in modern volcanic arcs. Incompatible element distributions in felsic metavolcanic rocks are similar to rhyolites from continental margin arcs and associated back-arc basins. Mafic rocks exhibit tholeiitic trends and have undergone olivine plus or minus clinopyroxene fractionation. Depletion of Ta and Nb relative to REE and Th indicate a significant subduction-zone component in the source. Felsic volcanics have relatively high contents of heavy REE and high field strength elements, a feature characteristic of felsic volcanics from continental rifts and back-arc basins in or near continental crust. The metasedimentary rocks of the area are composed of quartzites, feldspathic quartzites, arkosites, schists, and phyllites with minor conglomerates. Metamorphism has obscured some of the original textures of these rocks, but it appears that most metasediments are quartzites, quartz-rich arkoses, or quartz-intermediate subgraywackes. The metasediments contain low concentrations of Fe, Mg, Ti, and Co, a feature characteristic of clastic sediments deposited on or near continental crust. Chemical and petrographic studies of the sediments indicate a dominantly felsic plutonic–volcanic provenance with minor mafic and andesitic input. Sedimentary structures (e.g. crossbedding and imbricated pellets) indicate two source directions: one dominant source to the north contributing major amounts of felsic igneous detritus, a second, less important source contributing much finer grained andesitic material from a southerly direction. These same sedimentary structures suggest that the rocks were deposited in a series of submarine fans by turbidity currents in a proximal environment. Coarse-grained arkoses, conglomerates, and quartzites may represent channel-fill deposits associated with the fans. Overall, data suggest that the Hembrillo Canyon succession was deposited in a continental margin back-arc basin. Continental and arc detritus was rapidly fed into a tectonically active basin. Interbedded with the sediments are intrusive volcanic rocks and felsic tuffs. The mafic rocks in the area are derived from a mantle source with a significant subduction-zone component.

PETROLOGY AND GEOCHEMISTRY OF LAVAS FROM THE NORTHWEST CERROS DEL RIO, by *K. E. Duncker* and *J. A. Wolff*, Department of Geology, University of Texas at Arlington, Arlington, TX 76019, *P. T. Leat*, Imperial College, London, and *P. R. Kyle*, Geoscience Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Preliminary analysis of geochemical and petrographic data from 40 Cerros del Rio lavas suggests the following: 1) spatial distribution of lava types may support the existence of a tholeiitic shield volcano to the northwest of the Cerros field; 2) quartz phenocrysts found in the lavas are most probably xenocrystic in nature, rather than high-pressure phases; and 3) crustal contamination occurred during the evolution of Cerros del Rio magma. Cerros del Rio samples were collected on the east side of the Rio Grande from Ortiz mountain and Sagebrush flats, and on the west side of the river from various locations including Frijoles and Alamo Canyons. The dominant lava types found on the east side are classified as hawaiites and andesites with interfingering tholeiites. On the west side of the river, dominant lava types are classified as tholeiites and andesites with minor amounts of interfingering hawaiites. The range of chemical variation among all the lavas sampled is large and may confirm the suggestion that a shield volcano, which tapped a different source than that of the Cerros, is buried under Bandelier Tuff to the northwest. Petrographically, the occurrence of disequilibrium textures in plagioclase megacrysts, in addition to the occurrence of quartz xenocrysts in all rock types, is consistent with contamination by a felsic component. Also, in some andesites, olivine is rimmed by opx reaction halos suggesting that the magma was subjected to mixing with a relatively silica-enriched component. Some quartz found in the lavas has a strained metamorphic texture and small, oriented microlites of rutile indicating that the ultimate source for the quartz was a metamorphic rock. The existence of Nb and Ta troughs in chondrite-normalized incompatible-element diagrams for the Cerros del Rio lavas is consistent with contamination by crustal material. Incompatible-element ratios (Th/Ta and La/Yb) increase with increasing Fe/(Fe+Mg) suggesting the importance of AFC processes in the differentiation of these lavas.

QUATERNARY RHYOLITE MAGMATISM IN THE JEMEZ MOUNTAINS, by *J. A. Wolff, S. D. Balsley, D. C. Kuentz*, and *S. Self*, Department of Geology, University of Texas at Arlington, Arlington, TX 76019, and *P. R. Kyle*, Geoscience Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Petrographic and geochemical characteristics of rhyolites erupted from the Jemez Mountains during the past 3 Ma do not support the notion of a single long-lived silicic magma chamber beneath the Valles caldera. Pre-caldera andesites and dacites have trace-element abundances indicating substantial involvement of upper crust in petrogenesis. In contrast, the Bandelier group of rhyolites (pre-Bandelier ignimbrites, Bandelier Tuffs, and Cerro Toledo rhyolites) may be either lower crustal melts or extreme fractionates of mantle-derived basalts. While the lower Bandelier Tuff appears to represent a single variably fractionated batch of high-silica rhyolite magma similar in many respects to the Bishop Tuff of California, the upper Bandelier displays chaotic internal chemical variations indicating a complex origin. It may be derived in part from remelted lower Bandelier cumulates. However, the post-upper Bandelier eruptives (Valles Rhyolite) mark a return toward the earlier upper-crustal-dominated compositions. The most recent unit, the El Cajete Series rhyolite (El Cajete pumice, Battleship Rock ignimbrite, the Banco Bonito lava) is in internal petrographic disequilibrium; most of the "phenocrysts" are interpreted as derived from a pre-existing igneous body. The El Cajete Series magma was erupted in the act of being generated by crustal melting. The Quaternary history of Jemez Mountains magmatism is thus a succession of independently generated silicic magma bodies, some of which were erupted during or very soon (10–100 ka) after generation.

EVOLUTION OF THE POST-BANDELIER TUFF MAGMA SYSTEM, VALLES CALDERA, NEW MEXICO, by *T. L. Spell* and *P. R. Kyle*, Geoscience Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Valles caldera is located near the center of the Jemez Mountains volcanic field in north-central New Mexico. The caldera was formed at 1.12 ± 0.03 Ma upon eruption of the Tshirege Member of the Bandelier Tuff (upper Bandelier Tuff) and subsequent emptying of the upper part of a zoned rhyolitic magma chamber. These events were followed by resurgence, the formation of a central structural dome, and eruption within the caldera of rhyolitic pyroclastic rocks, lava flows, and domes of the Valles Rhyolite Formation. The Valle Grande Member, a group of high-silica rhyolite domes, composite domes, and flows erupted on or near ring fracture vents encircle the caldera and volumetrically dominate the Valles Rhyolite Formation. These rocks have K/Ar ages ranging from 1.18 ± 0.03 to 0.45 ± 0.02 Ma and show progressive changes in both petrography and chemistry with time. Phenocryst assemblages include Qtz + San + Plag + Bio + Mag–Ilm + Zir ± Hbl ± All ± Ap ± Cpx. In general, phenocryst percentages range from <2 to ~ 35 while plagioclase and ferromagnesian minerals increase in abundance when going from older to younger domes. Changes in chemistry include enrichments of Na, Si, As, Rb, Y, Nb, Mo, Sb, Cs, HREE's, Ta, Pb, Th, and U, and depletions of Mg, Al, P, K, Ca, Ti, Mn, Fe, Sr, Zr, Ba, LREE's, Eu, and Hf with time. Models proposed to account for these changes include progressive partial melting of a lower crustal source, roof rock contamination, silicate-liquid immiscibility, thermal (Soret) fractionation, and crystal-liquid fractionation involving side-wall crystallization. The latter is the favored model here. Mechanisms proposed to account for reversals in differentiation trends at < 0.73 Ma and ~ 0.51 Ma are eruption of sufficient volumes of magma to disrupt compositional zonation of magma chamber replenishment.

CORRELATION OF IGNIMBRITES USING PALEOMAGNETISM AND $^{40}Ar/^{39}Ar$ DATING, by *W. C. McIntosh*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Paleomagnetic studies and $^{40}Ar/^{39}Ar$ dating are powerful, reliable techniques for correlation of Oligocene ignimbrites (ash-flow tuffs) in the Mogollon–Datil volcanic field. Accurate correlation of these regional ignimbrites has previously been hampered by lithologic variations within units, by the imprecision of conventional K/Ar dating, and by the discontinuous pattern of outcrops produced by Basin and Range faulting. High-precision $^{40}Ar/^{39}Ar$ ages of sanidine separates from 21 Mogollon–Datil ignimbrites range in age from 35.6 to 24.2 Ma and define four brief eruptive intervals (35.6 to 33.5 Ma, 32.0 to 31.6 Ma, 29.0 to 27.4 Ma, and 24.2 Ma). These ages are sufficiently precise (relative error ± 0.15 Ma) to uniquely distinguish between units erupted at least 0.3 m.y. apart. The outflow sheets of Mogollon–Datil ignimbrites typically exhibit uniform thermoremanent magnetism (TRM) directions, many of which are sufficiently distinctive to unambiguously identify the unit. Thin, unwelded distal fringes of some regional ignimbrites have been identified paleomagnetically, revealing previously unknown overlapping relationships between units from the Mogollon and Socorro eruptive centers. Magnetic polarity zone boundaries provide valuable time–stratigraphic marker horizons, some of which can be traced throughout much of the volcanic field. Uncertainty of structural correction has been the largest obstacle to paleomagnetic correlation of Mogollon–Datil ignimbrite outflow sheets because TRM vectors can be rotated by tectonic movements. Alternatively, where units are identified by independent means, the TRM directions can provide a sensitive, reliable measure of local tectonic rotations in highly extended terrains. The intracauldron facies of Mogollon-Datil ignimbrites commonly show nonuniform magnetizations and cannot be easily correlated with outflow facies using paleomagnetism.

PROBLEMS OF BLOODGOOD CANYON TUFF (OLIGOCENE, MOGOLLON–DATIL VOLCANIC FIELD, SOUTHWESTERN NEW MEXICO): A REVIEW, by *W. E. Elston*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

Bloodgood Canyon Tuff is a quintessential *moonstone tuff*, i.e., quenched hypersolvus ignimbrite of quartz and iridescent sanidine cryptoperthite (moonstone). With associated lavas (e.g. rhyolites of Diablo Range and Jerky Mountains), it plots at the ternary minimum of the Ab–Or–SiO_2–H_2O system and is interpreted as the evolved end member of high-SiO_2 magmas of the Oligocene "ignimbrite flare-up." Certain two-feldspar tuffs and lavas (e.g. Apache Spring Tuff and Fanney Rhyolite of Bursum cauldron, Mogollon Mountains) are interpreted as less-evolved members of the same system. Differing interpretations of field relations result in conflicting petrologic schemes: a) All principal moonstone tuffs correlate with Bloodgood Canyon Tuff. Although extensive and voluminous, it is merely the evolved basal zone of Apache Spring Tuff and is overflow from the Bursum cauldron. Less-evolved Fanney Rhyolite is younger, hence there was a reversal in magmatic evolution. b) Moonstone tuffs erupted from several centers (e.g. Gila Cliff Dwellings cauldron) and occur in several stratigraphic levels (e.g. Bloodgood Canyon and Railroad Canyon Tuffs separated by Jerky Mountain Rhyolite). All are younger than the Bursum cauldron assemblages; magmatic evolution was undirectional. Apache Spring, Bloodgood Canyon, and Railroad Canyon Tuffs have not been seen in unequivocal superposition. Current attempts to solve problems by mapping, geochemistry, radiometric dating, and magnetostratigraphy have revealed additional complications but point toward eventual solutions.

COMPOSITIONAL FACIES OF THE BLOODGOOD CANYON TUFF, MOGOLLON–DATIL VOLCANIC FIELD, SOUTHWESTERN NEW MEXICO, by *S. J. Seaman*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

Up to 300 m of Bloodgood Canyon Tuff fills the Gila Cliff Dwellings basin. An extensive sheet (to 30 m thick) surrounds the basin in isolated outcrops. Current research is designed to test whether the Gila Cliff Dwellings complex represents a caldera and whether the Bloodgood Canyon Tuff originated within the Gila Cliff Dwellings complex or within the neighboring Bursum cauldron. Correlation between the Bloodgood Canyon Tuff and the mineralogically similar Railroad Canyon Tuff, which occurs north of the Gila Cliff Dwellings basin, is unresolved. Analyses from three traverses through the Bloodgood Canyon Tuff within the basin and numerous analyses from Bloodgood Canyon Tuff and Railroad Canyon Tuff outside of the basin indicate that: 1) essentially no trace-element or major-element zonation exists from the base to the top of the Bloodgood Canyon Tuff within the basin; 2) Bloodgood Canyon Tuff and Railroad Canyon Tuff outside of the Bursum–Gila Cliff Dwellings complex are generally enriched in Zr, Y, Sr, and Ba relative to Bloodgood Canyon Tuff within the basin; 3) preliminary microprobe results indicate that sanidine crystals in distal Bloodgood Canyon Tuff are enriched in Ba relative to those in basin-filling Bloodgood Canyon Tuff. These results suggest that there may have been at least two distinct eruptions of Bloodgood Canyon Tuff, and possibly three if the Railroad Canyon Tuff is a distinct unit. In addition, the predominant geographic separation of "enriched" tuff outside the basin and "depleted" tuff within the basin is difficult to explain with an origin of the tuff in an eruptive center other than the Gila Cliff Dwellings complex.

Tectonics and geophysical session

TECTONICS AND DEPOSITIONAL ENVIRONMENTS IN THE EARLY PENNSYLVANIAN OF SOUTH-CENTRAL NEW MEXICO, by *J. F. Kalesky*, Earth Sciences Department, New Mexico State University, Las Cruces, NM 88003

The Pennsylvanian Magdalena Group unconformably overlies Precambrian to Mississippian strata throughout south-central New Mexico. Regional southward tilting, warping, and erosion resulted in progressively older pre-Pennsylvanian subcrop relations from south to north. Normal marine shelf sedimentation was represented by upward-shoaling cycles containing mixed siliciclastics and carbonates. Channels cut into Ordovician strata in the southern Caballo Mountain area suggest that this area was a relatively deep valley or trough during Late Mississippian–Early Pennsylvanian erosion. Marine transgression from the south backfilled the pre-existing stream valleys with sequences of quartz arenite, bioclastic grainstone, pelloidal-algal wackestone and shales. Topographically higher areas were blanketed with thin discontinuous beds of bioclastic grainstone, laminated packstone, and shales. Semi-restricted tidal to nearshore environments are reflected in local sections by finely laminated hematitic dolomites, nodular shales, ripple-laminated silty lime mudstones–wackestones, pelloidal and oncolitic grainstones, sandy limestone conglomerates, and black carbonaceous shales supporting petrified wood float. Depositional onlap farther to the north resulted in younger and more terrigenous sequence. The cyclic nature of these deposits reflects a proximity to the shoreline and suggests a rapidly shifting base level, possibly controlled by Early Pennsylvanian glacial eustasy and/or tectonic loading. The time–stratigraphic position of the valley-fill depositional unit may be broadly correlated to other Late Mississippian–Early Pennsylvanian valley-fill sequences recognized in the Delaware Basin and Grand Canyon.

LARAMIDE AND TERTIARY STRUCTURES OF THE SALADO MOUNTAINS, SIERRA COUNTY, NEW MEXICO, by *A. B. Mayer*, Department of Earth Sciences, New Mexico State University, Las Cruces, NM 88003

The Salado Mountains make up the southern half of an east-tilted late Tertiary fault block located 12 mi west of Truth or Consequences, New Mexico. The oldest rocks exposed are Precambrian metadiorite, muscovite schist, and granite, which are overlain by approximately 2,000 ft of Paleozoic sedimentary rocks. During Laramide time, the southern half of this area was uplifted as a basement-cored block along an east-trending high-angle fault. Drag folding along the trend of this zone may suggest a component of left-lateral strike-slip movement. This uplift resulted in the gentle doming of the area and the formation of east-trending extensional structures to the north of the fault margin. An intermediate-composition dike dated at 43.7 ± 1.7 m.y. intrudes the fault zone providing an upper time limit for Laramide deformation in this area. Intermediate-composition flows and laharic breccia, and silicic crystal-lithic and lithic ash-flow tuffs buried these structures during mid-Tertiary time. Late Tertiary extensional block faulting raised the Salado Mountains at least 1,500 ft along a north–northwest-trending, west-dipping fault zone and rotated them approximately 21° to the east. The trend of faults, as well as major tensional fractures, indicate a δ_3 direction of N70E–S70W. This bounding fault cuts Laramide strucstures. Uplift and erosion of the late Tertiary block has exposed a stock of intermediate composition north of the Salado Mountains in the Garcia peaks. Smaller scale north-trending extensional faults occur on the east side of these mountains.

FLEXURAL ISOSTASY AND THE UPLIFT OF THE SANDIA MOUNTAINS, NEW MEXICO, by *T. Wallace* and *C. Chase*, Department of Geosciences, University of Arizona, Tucson, AZ 85721

The Sandia Mountains are an eastward-tilted fault block of Precambrian rocks situated along the eastern margin of the Rio Grande rift in central New Mexico. They are considered a "classical" example of tilt-block mountain building but represent an enigma typical of mountain ranges formed in extensional environments. Most of the uplift of the Sandias has taken place in the last 15 m.y., coincident with the opening of the Rio Grande rift. The present elevation and uplift rate are both much higher than that for surrounding terrain. The Sandias are too small to be the result of an upper-mantle driving force, nor has there been significant emplacement of Cenozoic magmatic rocks to build a recent crustal root. We propose that the uplift of the Sandia Mountains can be explained by flexural isostasy. We propose a three part geo- ☞

logic history for the Sandias: a) Precambrian magmatism resulted in a locally compensated proto-Sandia mountain range. The batholith cooled at a rate higher than the erosional rate, and eventually the underlying lithosphere flexurally suppressed the excess mountain root. b) Late Paleozoic and Mesozoic sediments on the top of the Sandias indicate that the Sandias were a low-relief, regional topographic high until at least mid-Cenozoic times. The low relief is consistent with a flexural thickness of 15 km (or greater). c) The lithospheric thickness of 15 km was intact until approximately 15 m.y.a. The onset of extension along the Rio Grande rift resulted in thinning and finally breaking the lithosphere along the Sandia and Rincon faults allowing the expression of the Precambrian root. The Sandias could have a root as thick as 7 km, but because the mountain range is spatially small, it does not have a significant Bouguer gravity signature.

CAÑONCITO DE LA UVA AREA, SOCORRO COUNTY, NEW MEXICO, by *K. B. Brown*, Geosciences Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Cañoncito de la Uva, in central Socorro County on the edge of the Rio Grande rift, has Paleozoic rocks and later structural features. Pennsylvanian Burrego, Story, Del Cuerto, and Moya Formations represent marine deposition. Regression and influx of clastic sediments began with Permian Bursum deposition and reached a climax as the fluviatile Abo Formation was deposited. Yeso sandstone, limestone, and gypsum indicate a return of marine conditions. The marine and nonmarine sediments are cut and folded by a suite of features suggestive of a wrench regime. North–northwest-trending folds with eastward vergence, north–northwest-striking high-angle reverse faults, and northeast-striking apparently strike-slip faults indicate a transpressive regime of north-northeast, right-lateral displacement, with east–northeast-directed compression. Other fold axes trend northeastward, and suggest a separate period of transpression with northeast displacement and southeast-directed compression. Thrust faults and overturned strata further north in the Los Pinos support transpressional hypotheses. Small northwest-trending grabens and extension of the Abo Formation along northerly faults show transtension has also affected the area. Absolute dating of these events in the Cañoncito de la Uva area has not been possible because Tertiary volcanics and sediments are not present in the area. Similarity to Laramide-age compression to the north and south suggests this deformation is also of Laramide age.

AVERAGE CRUSTAL SHEAR-WAVE VELOCITIES FROM THE PLAINS OF SAN AGUSTIN TO CARRIZOZO, NEW MEXICO UTILIZING FUNDAMENTAL-MODE RAYLEIGH WAVES, by *K. K. Hostettler* and *J. W. Schlue*, Geoscience Department and Geophysical Research Center, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The shear-wave (β) velocity structure was obtained for a great-circle path across the Rio Grande rift (San Agustin Plains to Carrizozo, New Mexico) from the linear inversion of phase-velocity data acquired from NTS explosion SERENA. The model was composed of 12 perfectly elastic, homogeneous, isotropic, horizontal layers over an infinite half-space. Initial model parameters, i.e. shear-wave velocities, were based upon refraction studies in the region. Due to the limited bandwidth of the data, velocities below 22 km were not allowed to vary significantly during the inversion. Of the 12 initial velocities, only 3 distinct velocity regions were obtained. The final model consisted of 2 km of sediment with β = 2.48 km/sec overlying a layer 20 km thick with an average β = 3.43 km/sec. The portion of the crust below 22 km was constrained to a shear-wave velocity of 3.80 km/sec over a mantle with β = 4.40 km/sec. The final model was compared to a surface-wave study for the Albuquerque–Belen Basin. The general trends of both final models were very similar. However, the pronounced velocity minimum seen at approximately 18 km in the Albuquerque–Belen Basin was not apparent on the final model for the path between the San Agustin Plains and Carrizozo.

ANALYSIS OF THE SEISMOGENIC ZONE IN THE CENTRAL RIO GRANDE RIFT NEAR SOCORRO, NEW MEXICO, *K. M. King*, *A. R. Sanford*, and *L. H. Jaksha*, Geoscience Department and Geophysical Research Center, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Five hundred thirteen well-located microearthquakes were used in an analysis of focal depths in the central Rio Grande rift near Socorro, New Mexico. The seismogenic zone extends from approximately 4 to 12 km in depth with more than 60 percent of the events occurring between 8 and 12 km. A sharp decrease in the number of focal depths below 12 km is interpreted as the rapid transition from brittle to ductile crust. This essentially normal depth to the seismogenic zone occurs in a region where heat flows as high as 490 mW/m^2 (11.7 HFU) have been observed and where a thin magma body is known to exist at a depth of approximately 20 km. Several distributions of focal depths along a profile within the area are bimodal, possibly indicating a semi-ductile zone from 8 to 10 km lying between layers of more brittle crust above and below. Relatively shallow seismicity, with focal depths occurring predominantly between 4 and 8 km, exists approximately 25 km north of Socorro near the apex of a region of surface uplift. A previous study of a major swarm in this region found some microearthquakes whose first motions were compressive in all but 10 to 25 percent of the focal sphere, implying that these earthquakes may be related to injection of magma, steam, or hot water.

INTERNAL STRUCTURE OF THE SOCORRO MAGMA BODY DEDUCED FROM MICROEARTHQUAKE P-PHASE REFLECTIONS, by *J. P. Ake* and *A. R. Sanford*, Geoscience Department and Geophysical Research Center, New Mexico Institute of Mining and Technology, Socorro, NM 87801

An earlier work comparing the gross characteristics of P- and S-phase reflections indicated that rapid lateral variations occur in the internal structure of the Socorro magma body southwest of Socorro. The present study analyzed the structure of the body at that location by breaking the propagation path effects into two parts: upper-crustal/near-surface effects and mid-crustal/magma-body interaction effects. The upper-crustal and near-surface effects have been approximated by the initial portion of the direct P-phase due to the favorable geometry of source, reflector, and receiver and the small magnitudes of the swarm events used in the analysis. Synthetic seismograms, which included attenuation and interbed multiples, were calculated and compared to the observed P-phase reflections. The modeling results indicate that the magma body is better approximated by a two-layer structure, a thin layer of full-melt underlain by a crystalline mush, than by a single-layer model. The layer thicknesses vary by small, but resolvable amounts over the ~500 m distance covered by the reflection points. To determine an "average" structure for the magma body in this area, the stacked spectrum of the observed P-phase reflections was modeled. The best-fit model consists of a thin (~70 m) layer of non-rigid, low-velocity material underlain by a second, thin (~60 m) layer of slightly higher velocity material. This second layer may be an earlier, partially solidified intrusion or a crystalline mush at the base of a single magma chamber. The resulting magma body is less than 150 m in total thickness. A body this thin, even at mid-crustal depths, would need to be replenished often to remain in a nonrigid state.

ECONOMICS OF COAL PRODUCTION CYCLICITY, WITH SPECIAL REFERENCE TO NEW MEXICO, by *Orin J. Anderson* and *Donald L. Wolberg*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Production statistics compiled during the last 80 years illustrate the fact that annual coal output varies widely within trends that are periodically reversed to lend a cyclical nature to the coal industry in New Mexico. Production trends and the trend reversals have been related to national economic factors and political events, but these events and factors are quite different prior to and following 1960. Prior to 1960, the factors were: the wartime economy, the Great Depression, and the sudden appearance of low-cost convenient natural gas. Baseline coal demand was provided by the steel and smelting industries, the electric utility industry, and the railroads. Since 1960, wartime economies have not been a factor, the railroad—steam locomotive market—has disappeared, the steel industry has been in recession, and electric utilities have grown to completely dominate the coal market. Within that market framework, coal must compete with other fuels used in steam electric generation. Affecting total coal usage and competitiveness are: 1) the declining U.S. industrial base; 2) current low petroleum prices; 3) moderation in rate of growth of electrical consumption in the residential sector; and 4) recent completion of nuclear generating stations. In a more extended time frame, Federal coal leasing policy is also of significance to the coal industry. The declining U.S. industrial base has not impacted the New Mexico coal industry directly although it has had an impact on other mining ventures. Of greater importance to the state's coal industry have been recent events in the uranium-nuclear fuel cycle industry: 1) the disappearance of the uranium mining and milling activities that were large consumers of the state's coal-generated electric power, and 2) the completion of the Palo Verde nuclear generating station near Phoenix. Moreover, these two events outweigh the threats to coal usage posed by low petroleum–natural gas prices because electric utilities in New Mexico and the mountain states have low fuel-switching capabilities.

MINERALIZATION, ALTERATION AND IGNEOUS ACTIVITY IN THE FLORIDA MOUNTAINS, SOUTHWESTERN NEW MEXICO, by *Russell E. Clemons*, Department of Earth Sciences, New Mexico State University, Las Cruces, NM 88003

Manganese, barite, and fluorite have been mined and prospected in the Little Florida Mountains. Mineral deposits in the Big Florida Mountains include manganese, barite, fluorite, zinc, lead, copper, silver, and gold. Mineralized veins in the Little Florida Mountains are in post-23.6-m.y.-old rocks. Veins and oxidized replacement deposits in the Big Florida Mountains are mostly in early Paleozoic carbonate and alkalic plutonic rocks. A few veins are in faulted Eocene rocks. Propylitic alteration is pervasive in Tertiary volcanic breccias, and conspicuous epidote coats fractures of these and older rocks in the Florida Mountains. Argillic alteration has significantly changed the alkalic syenites throughout the central Florida Mountains. Source of Eocene volcaniclastics is unknown, but andesitic sills and dikes intruded into them indicate post-early Eocene igneous activity in the Florida Mountains. Fanglomerates shed from 23.6-m.y.-old rhyolites in the Little Florida Mountains were lithified and faulted preceding mineralization. A dacitic volcanic vent in the southeastern Little Florida Mountains is believed to coincide with this stage of mineralization. Several small intrusions of finely crystalline adamellite in the Big Florida Mountains, although of unknown age, intrude small Laramide thrust sheets. Lithologically identical rocks intrude middle Oligocene volcanic rocks in the Mimbres Basin near Deming. An adamellite batholith probably underlies the Florida Mountains and northeastern part of the Mimbres Basin. The dacite plug in the southeastern Little Florida Mountains represents a surficial venting of this magma during early to middle Miocene time. Penecontemporaneously hypabyssal adamellite intruded the Paleozoic and Cenozoic roof rocks in the Florida Mountain–Deming area. Associated hydrothermal pneumatolytic fluids formed the ore deposits and extensive alteration.

GEOLOGY AND ORE DEPOSITS OF THE SOUTHERN SAN MATEO MOUNTAINS, SOCORRO COUNTY, NEW MEXICO, by *Eugene W. Cox*, Consulting Geologist, Socorro Engineering, P.O. Box F, Socorro, NM 87801, *Michael L. Hermann*, Exploration Geologist, 5001 Northern Trail NW, Albuquerque, NM 87120, and *Cortney E. Hesse*, Exploration Geologist, P.O. Box 571, Socorro, NM 87801

The San Mateo Mountains of south-central Socorro County are located within the Mogollon-Datil volcanic field of southwestern New Mexico. A thick sequence of Tertiary-aged tuffs, lavas, and associated volcaniclastic and sedimentary rocks in the southern San Mateo Mountains is exposed in large tilted fault blocks surrounded by alluvial fans, low-relief pedimented bedrock surfaces, and scattered exposures of pre-Tertiary basement rocks. Repeated volcanotectonic activity in the area has produced complex stratigraphic and structural relationships. Tertiary (Oligocene) rock units of the southern San Mateo Mountains include the Red Rock Ranch Formation (up to 1000 m thick), Rock Spring Formation (up to 1200 m thick), La Jencia Tuff (0–25 m thick), Vicks Peak Tuff (300–1400 m thick), tuff unit of Turkey Springs (60–120 m thick), tuff unit of Milliken Park (0–60 m thick), and interbedded lavas including the Springtime Canyon quartz latite (0–180 m thick). Mafic, intermediate, and felsic intrusive rocks are locally exposed along fault systems in the area. Ore deposits of the southern San Mateo Mountains occur within distinct host rocks. Gold–silver mineralization located in the San Jose mining district is hosted by Vicks Peak Tuff within fracture zones, hydrothermal breccias, and quartz veins. Silver–gold base-metal deposits in the Diggins prospect area occur in mineralized tuffs and lavas of the Rock Spring Formation and crosscutting intrusive rocks. Gold mineralization is associated with late-phase felsic intrusive rocks, fracture systems, and alteration zones that are discernible in classified satellite imagery.

GOLD-BEARING QUARTZ VEINS OF THE CENTRAL PART OF THE GOLD HILL MINING DISTRICT, HIDALGO AND GRANT COUNTIES, NEW MEXICO, by *Robert D. Beard*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

The Gold Hill mining district is located approximately 20 km northeast of Lordsburg, New Mexico. Gold-bearing quartz veins, found throughout the district, are most numerous in the central part. The majority of these veins occur along diabase dikes that strike N40°W to N, and dip 20°–60°. Host rocks are upper amphibolite-grade supracrustals of the Bullard Peak Series (minimum age 1550 m.a.), Burro Mountain granite (1450 m.a.), and diorite and quartz monzonite of unknown age. Diabase dikes are not foliated, but some are intensely fractured parallel to strike. Nearly vertical basaltic and rhyolitic dikes, striking N60°E to E, crosscut the diabase dikes. Quartz veins along basaltic and rhyolitic dikes are nearly barren of mineralization. Veins range up to a meter in width, but most are less than quartz, minor pyrite, and Fe–Mn oxides. Oxidized vein material, found almost exclusively on dumps, has a gossan texture and consists of Fe–Mn oxides and quartz. Values of unoxidized veins range up to 0.37 oz Au/ton and up to 0.90 oz Ag/ton. Nearly all host-rock Au and Ag values are below detection limits (10 ppb and 5 ppm, respectively). Mineralization has been dated as early Cenozoic and may be related to Laramide intrusive activity in the region.

SCANNING ELECTRON MICROSCOPY OF AUTHIGENIC ZEOLITES IN VOLCANICLASTIC SEDIMENTARY ROCKS FROM NEW MEXICO, by *Mark R. Bowie*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Authigenic zeolite mineralization in volcaniclastic sedimentary rocks is widespread where rhyolitic ash was deposited in basins in the western United States. The zeolites are diagenetic alteration products of the reaction between saline, and usually alkaline, fluids with vitric ash or clay minerals. The most common zeolites identified in sedimentary rocks in New Mexico are clinoptilolite, chabazite, erionite, mordenite, and analcime. Clinoptilolite is by far the most abundant zeolite and is present in all known zeolite occurrences in the state. The others are comparatively restricted in distribution. Authigenic zeolites are very microcrystalline, which makes their examination by ordinary light microscopy difficult. The scanning electron microscope is an ideal tool for the study of these minerals; sample preparation is easy and the instrument provides great depth of field. The form, habit, degree of crystallinity, size, and spatial and paragenetic relationships of the constituent minerals can be studied without disrupting the sample. Scanning electron microscopy reveals that clinoptilolite occurs as subhedral to euhedral, coffin-shaped, monoclinic laths and plates up to several micrometers in length, either isolated or in clusters. Chabazite crystals are subhedral to euhedral "cubes" or "rhombs" up to a few micrometers on a side. They are typically intergrown, forming clusters or radial stringers a few micrometers long. Erionite and mordenite, often difficult to differentiate based on morphology alone, occur as thin fibers or needles tens of micrometers in length. Analcime is very distinctive, occurring as cubo-octahedral and trapezohedral crystals commonly 100 micrometers in diameter.

A CATHODOLUMINESCENCE STUDY OF THE LEMITAR CARBONATITES AND ASSOCIATED FENITIZATION, SOCORRO COUNTY, NEW MEXICO, *Virginia T. McLemore*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Cathodoluminescence (CL) is the characteristic visible radiation (color) produced in a mineral subjected to bombardment of electrons. Many features of a sample are observed under CL that are not seen using standard optical petrography. Applications of CL include mineral identification, determining mineral distribution, observing textures and structures, among others. CL studies are especially useful in examining carbonatites and associated fenitization. Carbonatites are unique carbonate-rich rocks of apparent magmatic descent and are characterized by a distinct but variable mineralogy, composition, and associated alteration (fenitization). The Lemitar carbonatites exhibit bright-red CL that is characteristic of carbonatites elsewhere in the world. The bright-red luminescence is due to compositional variations in fine-grained carbonate minerals, predominantly calcite and dolomite. Apatite luminesces blue to green-gray to gray and is typically zoned. Magnetite occasionally exhibits CL zoning not observed using optical microscopy. Examination with the electron microprobe reveals the zoning is caused by complex intergrowths of magnetite, ilmenite, rutile and/or leucoxene, calcite, and quartz. Fenitization is the alkalic metasomatic alteration adjacent to carbonatites and alkalic rocks. In the Lemitar Mountains, unaltered country rocks exhibit less intense luminescence when exposed to CL than carbonatites and fenites. K-feldspars are typically blue to white or gray, or do not luminesce in unaltered rocks, whereas they luminesce brown or red in fenites, probably due to replacement by carbonate and/or activation of ferric iron, rare-earth elements, and manganese. Apatites luminesce yellow to green in unaltered and slightly fenitized rocks and luminesce blue to green-gray to gray in highly fenitized rocks. Slightly fenitized rocks exhibit veins of red-luminescing carbonate along grain boundaries, within fractures, and replacing chlorite, feldspar, and hornblende. Highly fenitized rocks exhibit bright-red luminescent matrix with relict feldspars (replaced by carbonate).

TRIASSIC STRATIGRAPHY, CARTHAGE AREA, SOCORRO COUNTY, NEW MEXICO AND THE SOUTHEASTERNMOST OUTCROPS OF THE MOENKOPI FORMATION, by *Adrian P. Hunt* and *Spencer G. Lucas*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

Triassic strata in the Carthage area (T5S, R2E) are 163 m of redbeds that rest disconformably on Permian strata and are disconformably overlain by a thin sequence of the Upper Jurassic Morrison Formation. Three principal Triassic units can be recognized here: 1) a basal unit that is 15.7 m of dominantly moderate reddish-brown mudstone and sandstone/conglomerate; 2) a middle unit that is 6.0 m of moderate reddish-brown conglomeratic sandstone in which clasts are mostly extraformational chert; and 3) an upper unit of 141 m dominated by moderate reddish-brown and grayish-red mudstone with thin intraformational conglomerates and sandstones in its upper half. The basal unit has been called Santa Rosa Sandstone but is better termed Moenkopi Formation because of its lithologic similarity to Moenkopi outcrops on the Sevilleta Grant northeast of Socorro. Furthermore, typical strata of Santa Rosa in Guadalupe County, New Mexico, are intensively crossbedded quartzarenites and are quite distinct lithologically from the basal Triassic unit near Carthage. The Moenkopi outcrops in the Carthage area are the southeasternmost outcrops of this formation. The middle unit near Carthage arguably is homotaxial with the Shinarump Member of the Chinle Formation on the Colorado Plateau, and the upper unit is equivalent to the lower Petrified Forest Member of the Chinle. These stratigraphic assignments are supported by lithologic resemblances, stratigraphic position, regional stratigraphic relationships, and fossils. Fossils from the upper unit near Carthage pertain to phytosaurs and metoposaurid labyrinthodonts, indicative of a late Triassic age. □