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 5, 1991. Following are abstracts from two sessions given at that meeting. Abstracts from other sessions will appear in future issues of *New Mexico Geology.*

Stratigraphy, sedimentology, and geochemistry session

Jurassic Todilto Limestone—facies, diagenesis and mineralogy, Grants district, McKinley and Cibola Counties, New Mexico, by *Augustus K. Armstrong*, U.S. Geological Survey, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

The Todilto limestone unit of the Wanakah Formation is 1–30 ft (0.3–9.1 m) thick in the Grants district and records changes in depositional environments from a restricted embayment, with an ephemeral connection to the Curtis–Summerville sea, to a completely enclosed and shrinking body of gypsiferous water. The salina was 300 miles (483 km) east–west, 250 miles (402 km) north–south, and fringed by an extensive limestone–gypsum sabkha. Arenaceous lime mudstones to arenaceous-ooid-ostracode-microbial mat wackestones record a shoaling upward sequence deposited in an arid, subtidal to supratidal, sabkha environment in alternating brackish to hypersaline marine waters. Dolomite is absent in the study area. Petrographic studies show that the calcite lime mudstones were subjected to extensive neomorphism and were derived primarily from an aragonite mud precursor. The aragonite to calcite diagenetic history is evident in the poorly preserved ooids. The salina waters did not support a normal marine invertebrate fauna or flora. Fragments of the marine calcareous algae Dasyclads, belonging to the Tribe Salpingoporelleae, indicate short periods of near normal sea water resulting from marine transgression into the Todilto embayment. Ostracodes are abundant in the sabkha facies and lived in ephemeral gypsiferous ponds. The salinity of the marine waters was influenced by addition of seasonal water from streams and rainfall and by periods of drought and intermittent connections to the Curtis–Summerville sea. The overlying gypsum unit, 0–110 ft (0–33.5 m) thick, found east of the study area, was deposited in the center of the basin during the final salina phase. Lacustrine alkaline evaporites, such as trona and shortite, are unknown in the Todilto Limestone. Megapolygon mounds and tepee box folds, up to 10 ft (3 m) high and 45 ft (14 m) wide and of early diagenetic origin, are found in the supratidal facies associated with calcite pseudomorphs of gypsum. The tepee sutures and cracks on the sabkha crust may have acted as sites of saline ground-water outflow. The tops of the tepees are not eroded but are overlapped and buried by thick-bedded microbial mats of ostracode-supratidal lime mudstone and caliche. Commercial orebodies of uranium are found in the Todilto Limestone Member in the tepee box folds. Isotopic ages of 155–150 Ma from uraninite indicate that the uranium mineralization is syngenetic with the carbonate deposits.

Depositional and stratigraphic setting of a Lower Permian limestone in the southern Mimbres Basin, southwestern New Mexico, by *Brenda J. Buck* and *Russell E. Clemons*, New Mexico State University, Las Cruces, NM 88003

A small limestone outcrop 5 km northwest of the Tres Hermanas Mountains in southwestern New Mexico was studied as part of a project to correlate the stratigraphic and depositional settings of Wolfcampian limestone in the Florida Mountain region. Samples were collected from the 23-m section at 1.7-m intervals; additional samples were taken at lithologic changes. Thin sections of 24 samples were analyzed and classified according to Dunham (1962) and assigned facies belts according to Wilson (1975). Dominant bioclasts include tubular foraminifera, gastropods, ostracods, and algae (stromatolite, phylloid, red, and dasyclad). Minor bioclasts include echinoderms, bryozoans, brachiopods, and fusulinids. Unfortunately, the fusulinids are sparse and mostly neomorphosed. Most bioclasts are encrusted by tubular foraminifera or less abundantly, coated by algae. The section is composed primarily of packstones, but a few wackestones, grainstones, and stromatolite boundstones are also present. Depositional environments varied from shallow, restricted circulation on a marine platform (FB 8) to a shallow, open-marine lagoonal facies (FB 7). The base of this section is composed of stromatolite boundstones and abundant tubular foraminifera, which represent a shallow, restricted environment. These grade upward into a restricted lagoonal environment dominated by gastropods, tubular foraminifera, and ostracods. The top of the section shows the greatest diversity of fauna, containing echinoderms, bryozoans, and brachiopods as well as tubular foraminifera, ostracods, gastropods, and phylloid and dasyclad algae. The fauna, particularly the fusulinids and the abundance of tubular foraminifera, indicate this section is probably Wolfcampian and equivalent to the Hueco and/or Colina Formations.

Type section of the Paleocene Nacimiento Formation, San Juan Basin, northwestern New Mexico, by *Thomas E. Williamson*, Department of Geology, University of New Mexico, Albuquerque, NM 87131 and *Spencer G. Lucas*, New Mexico Museum of Natural History, P.O. Box 7010, Albuquerque, NM 87194

The Nacimiento Formation (TN) in the San Juan Basin of northwestern New Mexico is a mud-dominated, fluvial and lacustrine deposit that conformably overlies the Paleocene Ojo Alamo Sandstone and is unconformably overlain by the late Paleocene?–early Eocene San Jose Formation. The TN attains a maximum thickness of about 700 m. The type section of TN is located on the southern end of Mesa de Cuba about 6.5 km southwest of Cuba, NM. A composite section was measured in secs. 11 and 14, T20N, R2W, Sandoval County. The dominant lithologies are: yellowish-gray (5Y 7/2), light-gray (N7) and brownish-black (5YR 2/1) claystones (about 70%); yellowish-gray (5Y 7/2) and grayish-orange (10YR 7/4), very fine to medium-grained, poorly sorted, arkosic, immature sandstones (about 20%); and minor amounts of siltstone, silcrete, and lignite. Thickness of the TN at its type section is 215 m. The surface section measured at the type area can be correlated with an induction laterolog from the Benson Mineral Group Federal 15–21–2 No. 1 well (SW$^1/_4$SE$^1/_4$ sec. 2, T20N, R2W) about 11 km north. This log could serve as a subsurface reference section for the TN type section. In the log, the base of the TN is at 1,787.7 m and the top is at 2,040.6 m, a thickness of 253 m. Total sand thickness is 37 m or 15%. There is considerable contrast between clay and sand lithologies in log signatures. Correlations of relatively thick (2–14 m), laterally extensive sandstones between the surface and the subsurface suggest at the type area of the TN that long-distance subsurface correlation within this unit is possible. Fossils collected from the TN at the type locality indicate an early Paleocene (Torrejonian) age for the upper 165 m of the section. The age of the base of the TN at the type locality is not known so precisely but presumably is also early Paleocene.

Depositional environments of the Panther Seep (Virgilian?–Wolfcampian)–lower Hueco (Wolfcampian) Formations in the Doña Ana Mountains, New Mexico, by *Lorena L. Goerger* and *Russell E. Clemons*, New Mexico State University, Las Cruces, NM 88003

Upper Pennsylvanian and Lower Permian rocks in the Doña Ana Mountains consist of (in ascending order): the Panther Seep (which may cross the Pennsylvanian–Permian boundary), the Bursum, and the Hueco Formations. Deposition of these rocks was on the inactive western margin of the Orogrande Basin and represents a change from a low-energy, intertidal environment to a more open marine environment. Approximately 120 m of section and 49 thin sections were analyzed for this study. Thin sections corresponding to the Panther Seep and Bursum Formations are predominately mudstone and wackestones with a low diversity of fauna, mainly ostracods with few peloids, intraclasts, ooids, and fragments of echinoderms and mollusks (gastropods?). Some of the mudstone/wackestones contain minor quartz sand, which may indicate a near-shoreline setting. Also present are packstone/grainstones with greater amounts of terrigenous clastics (quartz) and more intraclasts with few if any fauna. Laminated wackestones may indicate algal mat growths in an intertidal to shallow restricted setting. The base of the Hueco Formation is marked by a phylloid algae wackestone bank. It also contains ostracods, bryozoa, and *Tuberitina* with a few *Tetrataxis* and *Tubiphytes*. Most of the thin sections are bioclastic wackestones containing ostracods, sponge spicules, phylloid algae, various types of forams, mollusks, gastropods, minor dasyclad algae, and few intraclasts. Few mudstones and some packstone/grainstones indicate a possibly more open marine setting. This section is interpreted as having been deposited in a low-energy, intertidal to lagoonal setting as evidenced by the abundant mudstone/wackestones with low fauna diversity and the laminated algal mudstones. It was interrupted by periodic currents as seen in the terrigenous clastic influx in the packstone/grainstones of the Panther Seep and Bursum Formations. Faunal diversity in the lower Hueco represents a more open marine setting, which changed to a restricted lagoonal to shoreline setting as evidenced by a pebble/granular conglomerate bed and presence of petrified logs in the field. Overall, small transgression–regression cycles are repre-

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sented by interbedded shale and limestone and lithology variations in the section.

Carbonate depositional environments of the middle Permian (Leonardian) San Andres Formation in the southern Sacramento Mountains, Otero County, New Mexico, by *Christopher F. Whitman* and *Russell E. Clemons*, New Mexico State University, Las Cruces, NM 88003

Ninety-seven meters of the basal, massive- to medium-bedded, Rio Bonito Member of the San Andres Formation were sampled at Orendorf Peak, sec. 29, T19S, R12E, at 3-m intervals. The upper contact is the erosional surface and the lower gradational contact with sandstones and evaporites of the underlying Yeso Formation is poorly defined. Forty-two thin sections were studied to determine microfacies using J. L. Wilson's (1975) scheme. Deposition occurred on a shallow equatorial shelf. A tidal-flat facies dominates the lower third of the section as indicated by rip-up clasts, algal mats, horizontal laminations, and a sparse fauna. A thin sheet (2 m) of quartz arenite, similar to the Glorieta Sandstone, stands out as a resistant bed within the easily weathered intertidal facies. Midway through the section, mudstones and wackestones containing ostracods, pelecypods, gastropods, and foraminifera represent slightly restricted marine conditions on the shelf as Permian seas transgressed. Massive cliff-forming limestone in the upper third of the section is normal-marine packstone and wackestone. Characteristic of the normal-marine facies, abraded fragments of echinoderms, pseudopunctate brachiopods, bryozoans, and trilobites were apparently deposited in swales below wavebase but proximal to a surf zone. Thin dasycladacean algae/gastropod grainstones cap the normal-marine facies, representing shoals that developed on the edge of the prograding carbonate platform. The progression upward from tidal-flat to normal-marine facies may be just one cycle repeated many times through San Andres time.

Depositional controls on sandstone petrology and diagenesis of the Point Lookout Sandstone, San Juan Basin, southwestern Colorado, by *David L. Hicks*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

Sedimentary processes active within a depositional environment to a large degree determine the texture and mineralogy of the deposited sediment and influence the type and degree of subsequent diagenesis. The Upper Cretaceous Point Lookout Sandstone is a regressive coastal sandstone forming the basal member of the Mesaverde Group. Overlying the Point Lookout Sandstone is the continental Menefee Formation and the transgressive marine Cliff House Sandstone (uppermost member of the Mesaverde Group). Recent outcrop studies of the Point Lookout Sandstone in the San Juan Basin have identified three major environments; deltaic, shoreface, and foreshore. Depositional environments impart distinct textural and mineralogical characteristics to deposited sediment, which in turn influence the type and extent of early diagenesis. Petrographic examination yields the following observations: 1) Deltaic deposits, including bar crest to distal deltaic subenvironments exhibit a wide range of textures but may be characterized as poorly to moderately sorted, subangular, and very fine to medium-grained sandstones with a mean composition of $Q_{65}F_{22}L_{13}$. Mineral paragenesis varies with position within the delta. Early cementation of bar-crest deposits by quartz overgrowths prevents later stages of diagenesis. Bar front to distal deltaic deposits exhibit extensive alteration and replacement of quartz and feldspar by calcite with quartz overgrowths less commonly observed. 2) Shoreface deposits are moderately sorted, subangular, and very fine to fine-grained sandstones with a mean composition of $Q_{57}F_{32}L_{11}$. Replacement of quartz and feldspar by calcite, authigenic clay growth, and feldspar alteration are common in shoreface deposits. In both shoreface and bar front to distal deltaic deposits the percentage of primary carbonate grains increases with distance from paleoshorelines. 3) Foreshore deposits are well-rounded, moderately sorted, and medium-grained sandstones with a mean composition of $Q_{77}F_{16}L_7$. As in bar crest deposits quartz overgrowth cementation is common, and primary carbonates are noticeably absent. Porosity throughout the Point Lookout Sandstone is typically very low, averaging 1.5%. Burial history reconstructions of the Point Lookout Sandstone indicate maximum burial (12,000 ft) during the early Miocene. Paragenetic sequence as determined by thin section study indicates the following sequence of events: quartz overgrowth cementation, replacement of quartz and feldspar by calcite, and growth of pore-filling kaolinite. Diagenesis of the Point Lookout Sandstone can be correlated with specific depositional environments and may be understood in terms of the control depositional environment has on clastic mineralogy, textures, and early pore fluid chemistry.

Vertical distribution of sulfur in a coal seam of the Lee Ranch mine, McKinley County, New Mexico—a preliminary report, by *Abraham Araya* and *F. J. Kuellmer*, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Lee Ranch mine is located in the southeastern San Juan Basin approximately 30 miles northeast of Grants, New Mexico. The coals at the Lee Ranch mine are in the Cleary Coal Member of the Menefee Formation. The Cleary consists of a combination of sandstone, siltstone, mudstone, shale, and coal. Coal beds trend northwest parallel to the Cretaceous shoreline and are interpreted to have been deposited in near-shore fresh to brackish paludal swamps and back-barrier lagoons. Coal samples and bounding lithologies, from three drill holes penetrating the BB seam, were analyzed for their sulfur and elemental content. Samples were taken at 5 to 10 cm increments. The macrolithotype composition varies from a clarain-dominated section to durain and vitrain-dominated sections along a northwest–southeast transect (sections 1 to 3). Ash content of the coal and carbonaceous shale samples ranges from about 5% to more than 50%. There is no correlation between the ash and sulfur content. The Fe_2O_3 content of the coal ash and associated sandstone, shales, and partings ranges from about 1% to more than 40%. The Fe_2O_3 content of the few coal samples analyzed is variable and shows about the same range of variability as the associated non-coal samples. Cleat-filling pyrite and calcite are present in samples from sections 1 and 3. The distribution of sulfur varies both horizontally and vertically. The total sulfur content per sample ranges from about 0.3% to almost 4% with an average of 1% or less. Pyritic and organic sulfur are the dominant forms of sulfur with sulfate sulfur occurring in negligible amounts. The pyritic to organic sulfur ratio is less than 1 for samples containing less than 1% total sulfur. Pyritic sulfur becomes the dominant form of sulfur in samples with greater than 1% total sulfur. Two general vertical distribution patterns are observed: 1) higher sulfur content at the top and bottom and lower toward the middle of the seam and 2) higher sulfur content toward the middle of the seam and lower at the top and base. These two distribution patterns and the presence of cleat-filling pyrite suggest that there were at least two stages of sulfur incorporation: 1) sulfur incorporation mainly as organic sulfur at the early stage of peat accumulation and 2) sulfur emplacement resulting from iron sulfide crystallization from vertically moving solutions after burial and coalification of the peat material. The distribution pattern where sulfur content is higher at the top and base of the coal seam represents these two stages of sulfur emplacement with most of the sulfur being fixed as organic sulfur at the early stages of coal formation. The second vertical distribution pattern represents sulfur incorporation at the early stage of peat accumulation. These preliminary results suggest that the ancestral coal-forming peat swamp in this area was not a homogeneous system and that sulfur content and distribution was controlled by the local geochemical and geological conditions. Zones of high sulfur content may represent zones of higher pH (favorable for sulfate reducing bacteria), and ample supply of soluble sulfate and iron-containing minerals.

Mineralogical trends in the detrital clay fraction of the Westwater Canyon Member of the Morrison Formation, San Juan Basin, New Mexico, by *Christopher W. Inoue* and *Laura J. Crossey*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

Authigenic clay minerals are useful indicators of the water/rock interactions in a clastic unit. Mixed-layer illite/smectite (I/S) clays are especially promising diagenetic indicators because of their sensitivity to solution chemistry and temperature and their common occurrence in sandstones and shales. The Westwater Canyon Member is a fluvially deposited, medium- to coarse-grained Jurassic sandstone that has hosted a variety of pore fluids, resulting in the formation of authigenic clay minerals. Also present, however, are mixed-layer clays that were deposited with this sandstone in detrital form. An analysis of diagenetic reactions based on the assumption that all of the mixed-layer clay is authigenic could be biased by the detrital clay fraction. We have examined the composition of the fine-grained materials from core samples to determine the mineralogy of detrital clays and to determine trends in the I/S transformation. The detrital clay component in the Westwater Canyon Member occurs as prominent rip-up clasts and fine-grained interbeds in core samples. We have extracted the detrital, fine-grained portion of approximately 30 core samples taken from six cores along a 30-km cross section of the Chaco slope in the southern San Juan Basin, New Mexico, ranging in depth from 560 to 3,264 ft. The I/S (<1 μm size fraction) in rip-up clasts and clay-rich, fine-grained layers are compared laterally and vertically across the region. The authigenic component contains chlorite, kaolinite, and mixed-layer I/S. Clays in fine-grained samples are highly illitic. In contrast to previous work, in which sandstone samples exhibit a distinct pattern of transformation from illite to smectite, our preliminary results reveal no uniform diagenetic trend. Results indicate that the detrital component should be taken into consideration when authigenic clay minerals, such as I/S mixed-layer clays, are used as diagenetic indicators.

Geochemistry of Miocene to early Pleistocene lavas of southwest New Mexico, by *David M. Haag* and *Nancy J. McMillan*, Department of Earth Sciences, New Mexico State University, Las Cruces, NM 88003

Extension in the southern Rio Grande rift began 32–29 Ma ago, followed by the eruption of the Uvas volcanic field (28–27 Ma). Rifting accelerated at approximately 10 Ma after a mid-Miocene volcanic lull. Major- and trace-element and isotopic variations in lavas erupted 19–3 Ma reflect changes in mantle source regions and magma evolution processes associated with rift development. The oldest post-Uvas volcanic field lavas found in southern New Mexico are 18.3 Ma old trachyandesites (SiO_2 = 56–57 wt.%, ϵ_{Nd} = −2.2 to −1.7, $^{87}Sr/^{86}Sr$ = 0.706106–0.706191). These lavas are compositionally and isotopically similar to the Uvas volcanic field lavas but have distinctly higher Ba (1,671–1,872 ppm), Sr (1,053–1,090 ppm), Al_2O_3 (17.1–17.7 wt.%), K_2O (2.7–2.9 wt.%) and lower Mg values. By 13 Ma, intermediate volcanic rocks are absent. A tholeiitic basalt, at Hatchita, erupted at 11.8 Ma has a isotopic composition indicative of a lithospheric mantle source (ϵ_{Nd} = +1.3, $^{87}Sr/^{86}Sr$ = 0.704764). This was erupted as a single event with no derivative magmas, indicating that lithospheric mantle could produce small volumes of magma while being cool enough to prevent assimilation. By 10 Ma, volcanism accelerated, producing both tholeiitic and alkali basalts from a depleted mantle (asthenospheric) source (ϵ_{Nd} = +6.5 to +7.4, $^{87}Sr/^{86}Sr$ = 0.702974–0.703963). Variations in major- and trace-element composition are attributed to degree of partial melting, crustal contamination, trace-element composition of asthenospheric mantle, and, for basalts younger than 9.8 Ma, thermal transformation of lithospheric mantle to asthenospheric mantle (Perry et al., 1987).

Structural geology, seismology, and geochemistry session

Structural geology of the Gonzales Precambrian block, east of Socorro, New Mexico—a new look, by *C. T. Smith*, *R. M. Colpitts*, and *W. Gage*, Department of Geosciences, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Various investigators have interpreted exposures of Precambrian rocks east of Socorro as "islands" exposed during Pennsylvanian time, as basement blocks upfaulted during the development of the Rio Grande rift zone, or as "rootless" masses inserted into the section by shearing and thrust faulting. The Gonzales Precambrian block is defined by two of these masses approximately one mile apart in an east–west direction; the western exposure is bounded on the west by a high-angle normal fault placing Precambrian granitic rock against Santa Fe Group rocks and on the east by an east-dipping series of coarse-grained clastics that are assigned to the Pennsylvanian Sandia Formation. The eastern exposure is bounded on the west by a high-angle normal fault placing Pennsylvanian interbedded limestone and clastic layers against Precambrian granitic rock and on the east by vertical to overturned clastic beds that are also assigned to the Pennsylvanian Sandia Formation. Similar relations occur with several other Precambrian masses south of the Gonzales block. In an attempt to resolve the interpretations mentioned above, detailed mapping (Plane Table 100′ = 1″) of the eastern Gonzales exposure has been completed. Any solution must answer several questions: 1) Are the Precambrian–Pennsylvanian contacts depositional or tectonic? 2) Do the vertical and overturned Pennsylvanian strata east of the eastern exposure result from a basement-core overturned fold? 3) Why do the northern and southern margins of the Precambrian exposures lack clear structural definition? 4) What is the relation between the several Precambrian masses and the overturned folds exposed in the Pennsylvanian and Permian rocks farther to the east? Study of the western Precambrian exposure shows the Precambrian–Pennsylvanian contact is depositional and the overlying east-dipping Sandia beds expose a nearly complete section broken by several high-angle normal(?) faults. Measurement of this section shows that approximately one-half to two-thirds of the Sandia section is missing at the eastern Precambrian exposure. Mapping of the eastern mass shows several Precambrian–Pennsylvanian contacts, all of which are tectonic and exhibit shearing. The folding may be a faulted fault-bend fold or a fault-propagation fold similar to others known to the south and east. Finally, a later thrust fault has overridden the fold and part of the Precambrian mass; a small klippe of coarse-grained sandstone correlated with the lower part of the Sandia Formation is all that remains of the thrust sheet. Low-angle faulting, formerly thought confined to Permian strata, involves more stratigraphic section, exhibits ramp-flat geometry, and is more widespread than previously believed.

Basement structures and influence on Phanerozoic deformation—structural data from the Joyita Hills, Socorro County, New Mexico, by *William C. Beck*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801

Exposures of Proterozoic rocks within the core of the Joyita Hills display a multitude of planar fabrics, including gneissic to mylonitic foliations, amphibolite dikes, pegmatites, and aplite dikes. Gneissic to mylonitic foliations are high angle to vertical and form three common trends: north, northwest, and east–northeast. North-striking and east–northeast-striking foliations are most common. Brittle reactivation of Proterozoic foliations is either known to have occurred or can be concluded logically to have occurred during each major Phanerozoic orogenic event. Ancestral Rocky Mountain deformation resulted in two normal-fault trends. Through direct field observation, north-striking brittle faults are known to be directly superimposed along north-striking mylonites. Northwest-striking brittle faults are also thought to represent reactivation of northwest-striking foliations, in that both brittle faults and foliations are comparably oriented. Orientations of Laramide wrench faults also show similar attitudes with respect to the ductile basement fabrics. North-striking (synthetic) and east–northeast-striking (antithetic) strike-slip faults define a north-trending, dextral wrench fault system. Although less well defined, northwest-striking strike-slip faults have also been observed and are thought to represent the antithetic shear orientation associated with right-lateral (synthetic) displacement along the northeast-trending Montosa fault zone. Proterozoic mylonite zones and foliations also are thought to have been influential during the Tertiary development of the Rio Grande rift. A well-developed set of conjugate normal faults and mafic dikes strike to the northwest. A less well developed set of conjugate normal faults and mafic dikes strike to the east–northeast. North-striking foliations have been observed along the trace of the East Joyita fault and apparently influenced both the location and orientation of this major, down-to-the-east normal fault (~3 km stratigraphic throw).

A stable-isotope study of soil water, Sevilleta Refuge, New Mexico, by *Russell J. Vanlandingham* and *Andrew R. Campbell*, Geoscience Department, New Mexico Tech, Socorro, NM 87801

In May 1989 drill-core samples were collected from two sites for a stable-isotope study of meteoric recharge through the unsaturated zone. The first site (LTER1) is west of the Rio Grande north of San Acacia in relative highlands. The second site (LTER2) is located east of the Rio Grande south of Turitutu (Black Butte) in relative lowlands. Both sites are within the Sevilleta Natural Wildlife Refuge (SNWR). Both cores had soils ranging from almost pure sand with very low water content (less than 1%) to almost 75% clays with water content about 20%. The isotope profiles for shallow rapid-recharge areas in the SNWR have been relatively well defined (Knowlton, 1990). Our study focused on deeper cores, which hopefully contain older ground water. A typical vadose-zone isotope profile shows an enrichment in the delta-D and delta-^{18}O values at the evaporation front, below which the profile approaches a steady state value. Both of our data sets show the expected behavior at the top of the profile. At the surface the composition of the water approaches that of meteoric water. At about 50–100 cm the heavy-isotope enrichment peak can be seen and then the values swing back to lighter isotope values (about −5 permil). At greater depth LTER1 also shows a shift in the steady state value whereas LTER2 does not. The shift in LTER1 occurs at about 400–500 cm. The shift is about −3 permil in oxygen and about −10 permil in hydrogen. Based on chloride mass balance, LTER1 contains older water at depth than LTER2 does. Presumably, the observed shift is related to different climatic conditions in the past.

Juxtaposition of contrasting Proterozoic tectonometamorphic units in the northern Taos Range, New Mexico, by *Jane N. Pedrick* and *Jeffrey A. Grambling*, Department of Geology, University of New Mexico, Albuquerque, NM 87131

Three different tectonometamorphic units are juxtaposed across ductile shear zones in the northern Taos Range. Published U–Pb zircon ages differ systematically across the shear zones, suggesting that these structural boundaries may represent major terrane boundaries. The first unit is dominated by high-grade gneiss and is exposed north of Questa. Quantitative thermobarometry on pelitic gneiss (Grt–Bt–Pl–Q–Sil–Kfs) yields pressures and temperatures of 9–11 kb and 700–800°C. Mafic gneisses are retrograded mostly to hornblende and plagioclase although pyroxene-bearing rocks are present locally. The second unit is a muscovitic quartzite and is exposed both north and south of Questa. Aluminous layers with Ky–An–Sil

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or St–Cld–Ky–An indicate P–T conditions near the aluminum silicate triple point (ca. 4 kb, 500°C). The third unit is exposed south of Questa and includes mafic and felsic metavolcanic rocks with rare pelitic and ultramafic schist. Mineral assemblages (Hb–Chl–Pl; Sil–St–Grt–Bt–Chl–Ms–Pl–Q) indicate P–T conditions in the lower amphibolite facies. The contact between the first and second units north of Questa is a subhorizontal, top-to-the-southeast mylonitic shear zone, interpreted to represent a ductile extensional fault (D_1). P–T paths from the underlying gneissic rocks show decompression. Contacts between the second and third units south of Questa define another subhorizontal ductile shear zone (D_1?; vergence not yet determined) across which metamorphic grade does not change. The second unit overlies the third unit along this shear zone. Both subhorizontal shear zones have been folded twice: first about easterly to northeasterly axial planes overturned to the south (D_2) and second about steep, northerly axial planes (D_3). The ductile shear zone separating the first and third units is quite different. Although this boundary is partly obscured by Tertiary volcanism near Questa, preliminary work has linked it with tectonized Precambrian rocks with lineations that plunge gently. Foliation is steep and trends WNW; asymmetric quartz ribbons indicate right-lateral motion. Movement on this WNW strike-slip shear zone is tentatively ascribed to D_4.

Laramide stratigraphy and structural geology of the northern Little Hatchet Mountains, southwestern New Mexico, by *Scott A. Hodgson, George T. Basabilvazo,* and *Timothy F. Lawton,* Department of Earth Sciences, New Mexico State University, Las Cruces, NM 88003

Detailed mapping (1:12,000) and stratigraphic studies have shown that two distinct clastic synorogenic "Laramide" units—the Ringbone Formation and the Skunk Ranch Formation (tentatively named)—and the intermediate volcanic Hidalgo Formation were deposited and subsequently deformed within a complex tectonic/structural regime that existed in southwestern New Mexico during latest Cretaceous–Eocene time. The late Campanian–Maastrichtian Ringbone Formation (Lucas et al., 1990; Basabilvazo, 1990) unconformably overlies Lower Cretaceous rocks and consists of at least 1,600 meters of clastic detritus in the axis of the Ringbone basin. Three members were mapped within the Ringbone: 1) a lower conglomerate unit deposited by a braided fluvial system, 2) a middle feldspathic sandstone–shale unit representing fluvial, lacustrine, and deltaic environments, and 3) an upper conglomerate-sublitharenite sandstone unit that records cyclic alluvial-fan deposition. A laterally continuous olistostrome deposit consisting predominantly of Lower Cretaceous Hell-to-Finish clasts was noted within lacustrine deposits of the middle member. The Skunk Ranch Formation has been tentatively assigned a Paleocene to Eocene age based on fresh-water ostrocode fossils (Lawton et al., 1990) although a latest Cretaceous age is possible. The Skunk Ranch is exposed only in the southern part of the study area where it lies variously on the Lower Cretaceous U-Bar and Mojado Formations and the Ringbone Formation. Similarly to the Ringbone, the Skunk Ranch was mapped as three members: 1) a lower conglomerate–red shale member; 2) a middle sandstone–shale–limestone member of fluvial-lacustrine origin; and 3) an upper cobble conglomerate that probably represents deposition by a braided fluvial system. A 60-m-thick purplish porphyritic basaltic andesite flow was also mapped in the upper part of the middle member. Total exposed thickness is approximately 500 meters. The Hidalgo Formation represents a stratovolcano complex and consists of at least 1,700 m of volcanic breccias and subordinate andesite flows but contains an increasing abundance of sedimentary beds in the upper part. The top of the unit is cut off by a thrust. The Hidalgo Formation has yielded zircon fission-track ages of 69.6 ± 3.2 to 57.9 ± 2.7 Ma (Marvin et al., 1978; Lasky, 1947). The Hidalgo Formation interfingers with the upper member of the Ringbone in the northern part of the field area. We interpret the basaltic andesite flow within the Skunk Ranch to the south to be a "last gasp" Hidalgo volcanic event after a hiatus or a younger but similar flow not directly associated with the Hidalgo stratovolcano. Therefore, we adopt the following stratigraphic sequence in ascending order: Ringbone Formation (late Campanian–Maastrichtian); Hidalgo Formation (Maastrichtian–Paleocene); and Skunk Ranch Formation (Paleocene–Eocene). The Laramide stratigraphy and deformation suggests a two-stage Laramide event in the Little Hatchet Mountains. Stage one began during Late Cretaceous time with relatively simple basement-cored block uplift(s?) along high-angle, northwest-trending reverse faults. The olistostrome deposits with Lower Cretaceous clasts in the middle member of the Ringbone Formation indicate topographically high (structurally high) Lower Cretaceous strata to the south or southeast that would coincide with uplift along the Granite Pass fault at the southern end of the Little Hatchets and/or uplift along the subsidiary Copper Dick fault in the northern part of the range. However, the Granite Pass/Copper Dick uplift was probably not a prominent feature until deposition of the upper member of the Ringbone began. Deposition of the Ringbone Formation occurred in a geographically restricted complementary basin adjacent to the uplifts. Stage two began during the Paleocene with the inception of wrenching along the high-angle fault at Granite Pass. The Skunk Ranch Formation was deposited in an associated wrench basin. A wrench-related flower structure then developed, producing east-northeast-yielding telescoped thrusts that folded and cut all three Laramide units. Skunk Ranch deposition was probably coeval with this latter stage of deformation as suggested by abundant soft-sediment deformation within middle member lacustrine strata.

Dextral oblique-slip deformation along the Montosa fault zone at Abo Pass, Valencia and Socorro Counties, New Mexico, by *Steven N. Hayden,* Department of Geology, University of New Mexico, Albuquerque, NM 87131

The Montosa fault (MF) zone bounds the Los Pinos and southern Manzano mountain ranges on their eastern margins. The MF, formerly mapped as a Laramide thrust fault, displays dextral-oblique motion by an anastomosing zone of conjugate Riedel shears and by slickensides that rake the fault plane from 26°S to 75°S. The MF zone follows foliation in the Proterozoic Sais Quartzite, which dips 55°–75° toward N70°W, for several miles from Cerro Montosa in the Los Pinos Mountains to the Abo Pass area of Socorro and Valencia Counties. It is then deflected to the east around a chevron fold in the Sais Quartzite and the southern margin of the Proterozoic quartz monzonitic Priest pluton. This deflection causes a right-stepping, releasing (transtensional) bend. This releasing bend is characterized by a 1-km-long by 1/3-km-wide depression flanked by normal faults and an extensional syncline. The west-flowing Abo Arroyo turns NNE for 1/2 km through this bend east of the Sais quarry of the Santa Fe Railroad before resuming its westward drainage. North of Abo Arroyo, the dip of the MF varies from 50°E (dextral normal-slip) to 70°W (dextral reverse-slip) and resumes the NNE trend. The variable-slip geometry of this fault zone indicates that a complex dextral transpressional tectonic regime was responsible for the late Laramide uplift of the Manzano and Los Pinos mountain ranges. Previously published fission-track dates suggest that uplift occurred from Paleocene time in the Los Pinos Mountains to late Eocene time in the Manzano Mountains.

Gas analysis of fluid inclusions—application toward precious-metal exploration, Steeple Rock district, Grant County, New Mexico, by *Randy K. Ruff* and *David I. Norman,* New Mexico Institute of Mining and Technology, Department of Geological Sciences, Socorro, NM 87801

Boiling of hydrothermal fluids is a mechanism commonly associated with deposition of epithermal ore minerals. Boiling strips the fluids of relatively insoluble gases such as H_2, He, CH_4, N_2, H_2S, and CO_2 with this gas plume migrating toward the surface to form a gas halo around centers of hydrothermal activity. Gas halos are known to exist around geothermal zones and presumably around extinct geothermal systems that generated many hydrothermal ore deposits. Studies at Creede, Colorado, Copper Flat, New Mexico, and Pueblo Viego, Dominican Republic record the presence of gas halos around ore deposits. Variations of the relative abundances of some of these gases such as CO_2, and H_2S should reflect on the location of centers for hydrothermal mineralization. In addition, gas plumes may be the only geochemical evidence in rock well above an ore deposit where hydrothermal fluids did not penetrate the surface or were diluted by ground waters. Thus, recognition of gas halos may prove useful in exploration for hydrothermal deposits. The Steeple Rock district provides an opportunity to look for gas halos in an epithermal environment on both a district-wide and local scale. Presently active exploration and good exposures of relatively undisturbed surface mineralization make the district an ideal setting to test the hypothesis. Mineralization is mostly in the form of fault-controlled veins hosted by Oligocene andesite and dacite flows. Vein types range from delicate crustiform banding of different quartz varieties and calcite to extensive brecciation with a massive matrix. In addition, areas of intense silicification and adjacent argillic alteration are present in the central part of the district. Past and current production in the district is predominantly from underground mines exploiting scattered Au–Ag–base-metal deposits. Surface samples of veins and silicified rock from throughout the Steeple Rock district have been collected with emphasis on obtaining a representative sample of all quartz/calcite generations present at each sample site. The samples are crushed and split down to about 30 grams. The sample is then crushed under high-vacuum to release the fluid inclusion volatiles which are then analyzed by a quadrupole mass spectrometer. The gases, H_2, He, Ch_4, H_2S, and

CO_2, are measured and preliminary results reveal anomalous CO_2 and H_2S gas contents. The latter are known to be associated with ore deposits. Results will be presented on a two-dimensional surface map showing gas-ratio anomalies.

Hypocenter and velocity model estimation near Socorro, New Mexico using direct and reflected arrival times, by *Hans E. Hartse* and *Allan R. Sanford*, Geophysical Research Center and Geoscience Dept., New Mexico Tech, Socorro, NM 87801; and *John S. Knapp*, Physical Science Dept., Missouri Southern State College, Joplin, MO 64801

Local microearthquake seismograms recorded near Socorro, New Mexico often show, in addition to direct P and S arrivals, clear, strong S_zS, P_zP , and S_zP phases representing S-to-S, P-to-P, and mode-converted S-to-P reflections from a sill-shaped magma body near 19 km depth. The reflections have been used previously to confirm that the reflector is magma, map the areal extent of the magma body, study shear velocity (V_s) distribution in the crust, and study the internal structure of the magma body. To better constrain locations of local earthquakes recorded with the Socorro seismic network we developed a computer program that simultaneously inverts direct and reflected arrival times to solve jointly for hypocenters and a crustal velocity model. Using this program we inverted arrival-time data from 75 local earthquakes that had between 6 and 11 recording stations per event, an average of 20 picks per event, and an epicentral distribution of 2400 km^2 surrounding Socorro. At least three and as many as 10 reflections per event were included in the inversion. The complete data set consists of 564 P, 485 S, 169 S_zS, 77 P_zP, and 160 S_zP arrival times. Before inverting, timing errors of between 0.075 and 0.450 s were assigned each arrival, depending on pick quality. For the results reported below, parameter errors are for one standard deviation, and all diagonals of the resolution matrix exceed 0.94. We found compressional velocity (V_p) for the upper 10 km of crust (5.94 ± 0.02 km s^{-1}), V_p for the ductile mid-crust (5.80 ± 0.06 km s^{-1}), average depth to the reflector (18.77 ± 0.19 km), and Poisson's ratio for the upper (0.256 ± 0.002) and lower (0.229 ± 0.006) layers. Thus, V_p probably decreases slightly in the ductile crust while V_s increases slightly (3.40 to 3.44 km s^{-1}) with depth. An even areal distribution of positive and negative reflected-phase residuals indicates no regional trend for magma body dip. Small differences between station corrections calculated with all the data and corrections calculated with only direct arrivals also indicate little regional dip or unevenness on the reflecting surface. Focal depth estimates were much better constrained when reflections were included in the locations. For the 75 events depth error averaged 0.59 ± 0.12 km while depth error averaged 1.90 ± 0.95 km when only direct arrivals were used to locate the events. Origin times were also better constrained, but reflections did not influence epicenter determination. This improvement in hypocenter estimation will allow us to better determine the dimensions of the seismogenic zone and to better understand the behavior of the earthquake swarms common to central New Mexico.

Mechanics of single-layer drape folding—some simple models with practical applications, by *William C. Haneberg*, New Mexico Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro, NM 87801

Theoretical displacement, finite strain, and stress fields, along with calculated fold geometry, were compared in order to better understand the development of single-layer drape folds with bonded and frictionless lower boundaries. The upper boundary of the layer was a free surface, and vertical displacement along the lower boundary was specified by a Fourier series incorporating a step of variable height and width. Analytical solutions—obtained using a commercial computer package for symbolic mathematical manipulation—show that the mechanics of single-layer drape folding are controlled by dimensionless layer thickness, step width, step height, and, to a lesser degree, lower boundary conditions. Layer compressibility, to which the model was largely insensitive, was described by the dimensionless ratio of Lamé constants. For layers with compressibility similar to that of soil or rock, variations in step geometry were accommodated near the lower boundary and the resulting folds were virtually identical. Likewise, principal finite strain plots show little discernible difference except in isolated areas. Principal stress trajectory and displacement fields for layers with bonded and frictionless lower boundaries, however, are strikingly different. Complicating factors such as far-field extension or compression, layering, and nonlinear material properties were not investigated. However, for cases in which the present models are applicable, it would appear that field studies of large-scale fold geometry alone can yield little information about the mechanics of drape folding. Finite strain analyses, if carefully conducted and focused on critical portions of folds, may have some utility. The nature and orientation of minor structures, controlled by principal stress magnitude and orientation, is apparently much more sensitive to different lower-boundary conditions. For example, a layer with a bonded lower contact should be characterized by extensional fractures oblique to bedding, whereas a layer with a frictionless lower contact should be characterized by extensional fractures parallel or perpendicular to bedding, depending on location. Andersonian fault orientation may or may not be a useful tool, depending on details of step geometry. In areas of active deformation, for example associated with ground-water withdrawal and land subsidence, it should also be possible to infer lower-boundary conditions by observing near-surface displacement fields.

(Continued in next issue)

NMBMMR Mineral Museum Notes

The New Mexico Bureau of Mines and Mineral Resources Mineral Museum has recently received several important additions to its collections, including the private collections of William T. Worthington and Mahlon T. Everhart.

The Everhart collection is of particular interest in that it includes outstanding New Mexico specimens from the Asa B. Fitch collection. Fitch was a prominent mining man in the Magdalena district at the turn of the century. His collection is rich in such treasures as azurite, aurichalcite and calcite pseudomorphs after calcite, and smithsonite from the Graphic and Kelly mines, and such rarities as cuprite and delafossite crystals from the Silver Monument mine in Sierra County, copper and cuprite crystals from the 85 mine near Lordsburg in Grant County, and linarite crystals from Cumberland, England. The Worthington collection is rich in such New Mexico treasures as mineral suites from the Continental mine in Grant County and the Orogrande district in Otero County. Select specimens from both collections are on display in the museum.

Another outstanding recent acquisition is a 15.5-cm-long twinned cerussite crystal from the Stephenson–Bennett mine in Doña Ana County. This historically important specimen came courtesy of the Harvard Mineralogical Museum and is currently on display.

Finally, four superb cinnabar crystal specimens from Hunan and Kweichow, China were donated to the Museum by Tom P. Chen in memory of his long-time friend, Alvin J. (Lefty) Thompson (1903–1990). Chen studied under Thompson and received an MS in extractive metallurgy from NMIMT in 1960. Thompson taught at New Mexico Tech from 1947 to to 1957 and served as Director of NMBMMR from 1957 to 1968. The specimens donated in his honor are fine examples of excellent crystals from the world's premier cinnabar locality and are currently on display in the Mineral Museum.

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Review

Panning for gold and gemstones in New Mexico, by *David and Clois Walker*, 1991: 6704 Bolton Circle, Fort Smith, Arkansas 72903, 24 pp. $5.20

This booklet presents selected roadside sites suitable for hobbyist panning activities. Compiled from the Jay Ellis Ransom guide books, 24 sites in 16 counties are presented with an eye to easy accessibility for family vacationers and rockhounds. Each site is located on a well-drawn sketch map derived from the Official Highway Map of New Mexico, and the authors recommend that this latter map be used in conjunction with the text. A chart is provided detailing the minerals that might be found at each site, but no guarantees for successful panning are advanced.

The booklet should prove popular with the casual rockhound or vacationer who would like to try gold panning on an amateur level but cannot afford the time or resources to embark on a major expedition.

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