Plates

in:

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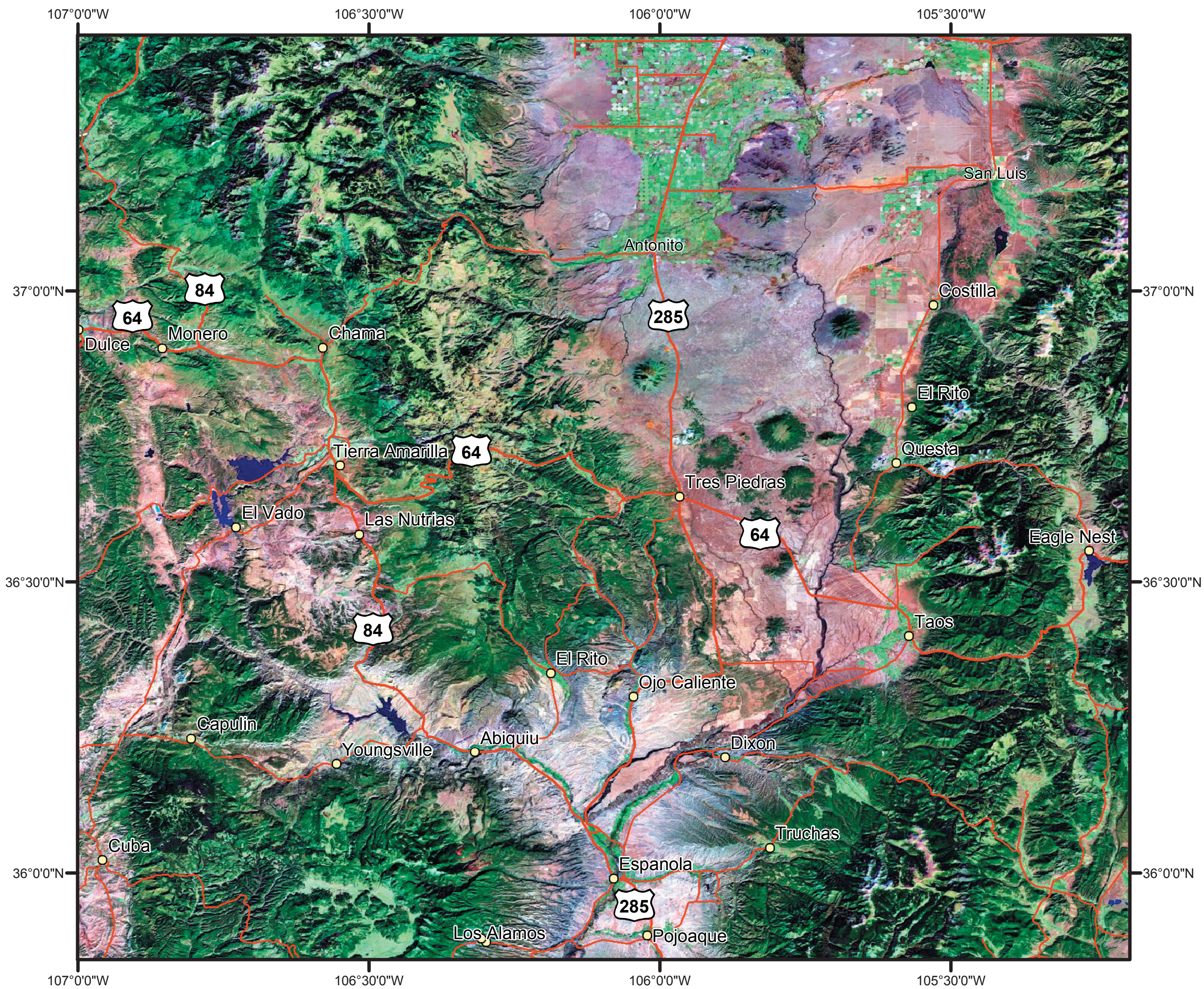


PLATE 1. LANDSAT 7 ETM+ image of the Chama Basin and southern San Luis Basin from two scenes acquired 14-Oct-1999. Image processing by Sawyer et al. (2004). Band 7-4-2 (RGB) panchromatically sharpened with 15-meter Band 8 data.

PLATE 2: GENERALIZED GEOLOGIC MAP – NORTH-CENTRAL NEW MEXICO

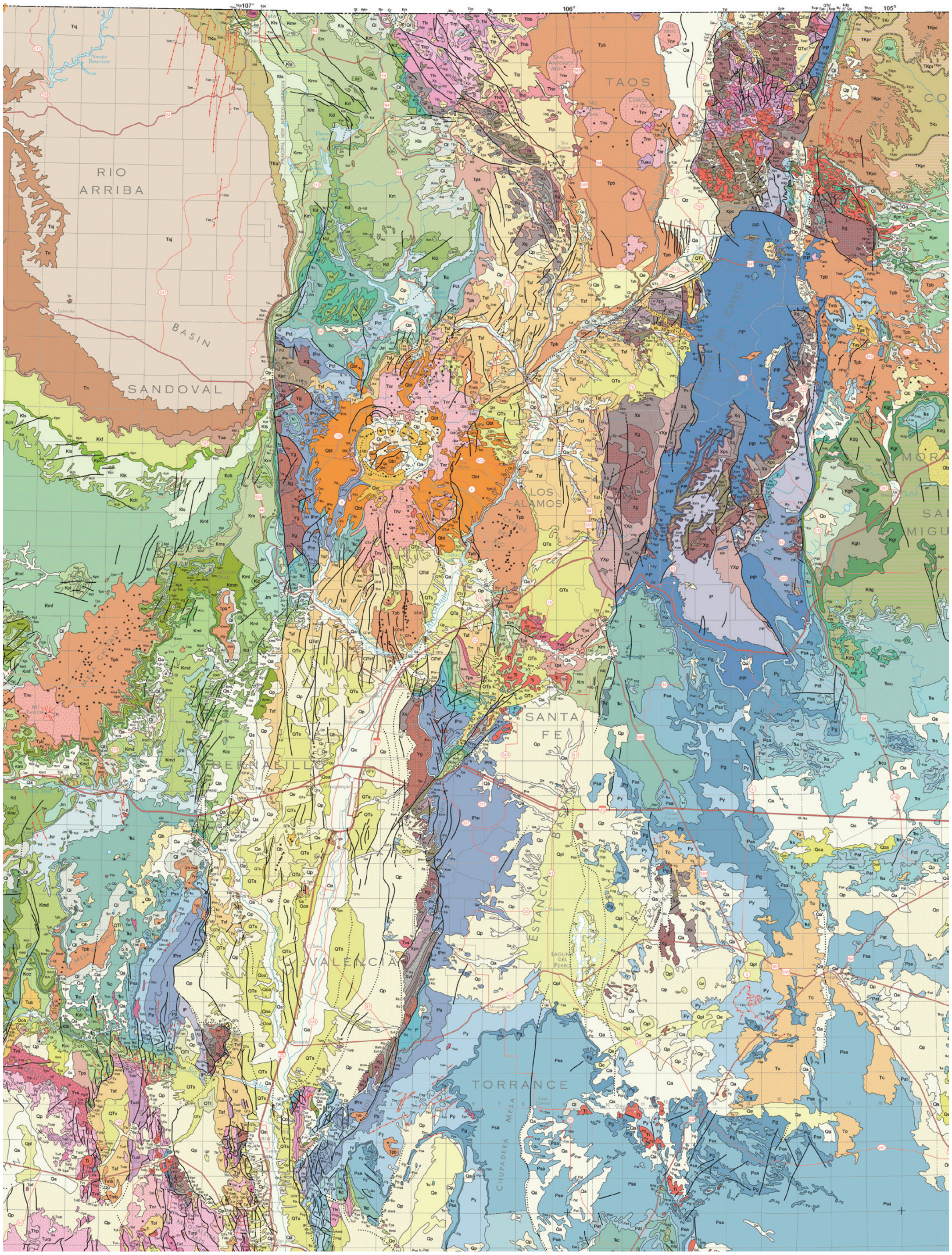


PLATE 2. Geologic map and block diagrams of north-central New Mexico. The geologic map is based largely on 1:500,000 geologic maps of New Mexico and Colorado (NMBGMR, 2004; Tweto, 1979).

PLATE 3 - AEROMAGNETIC MAP OF NORTH-CENTRAL NEW MEXICO

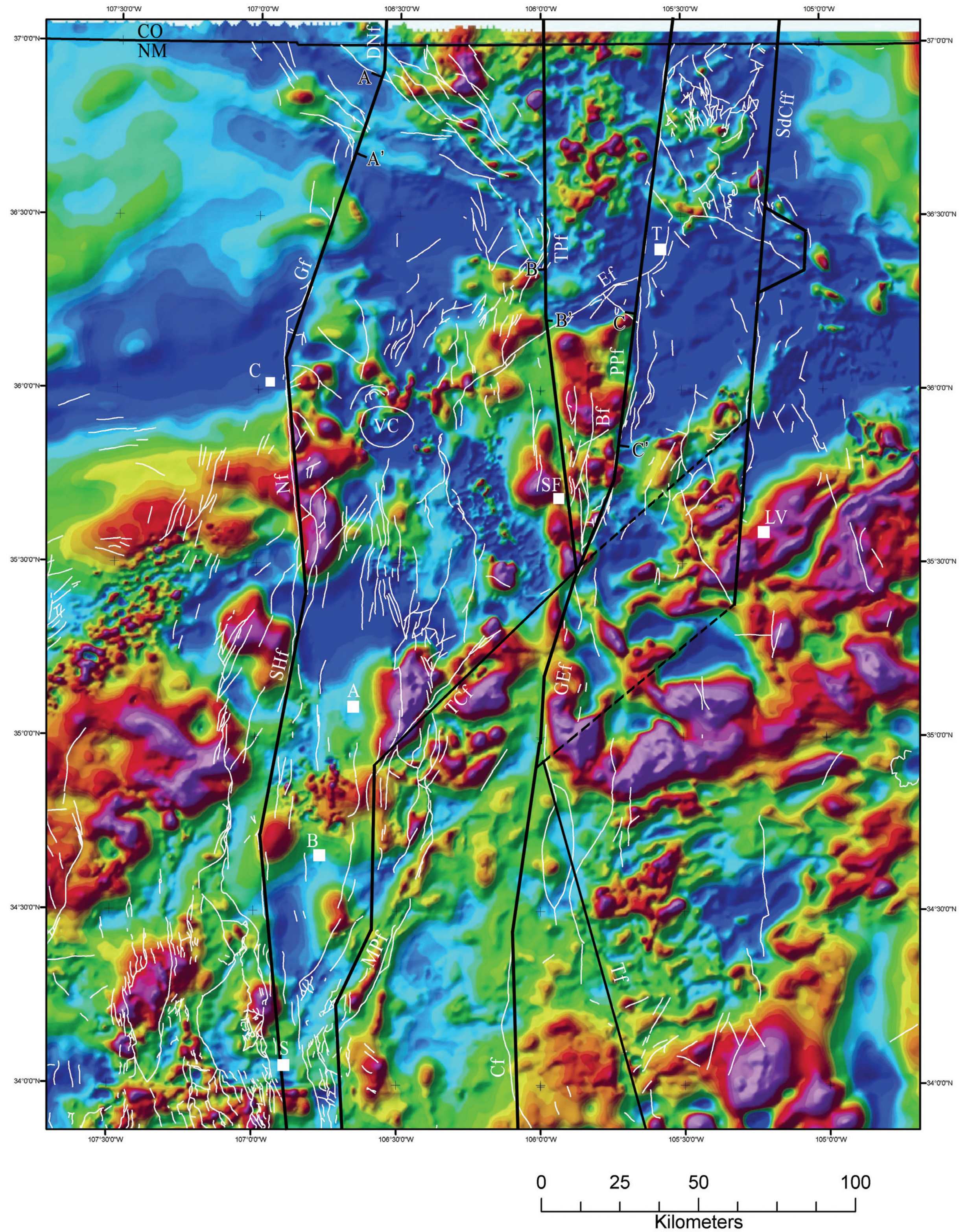
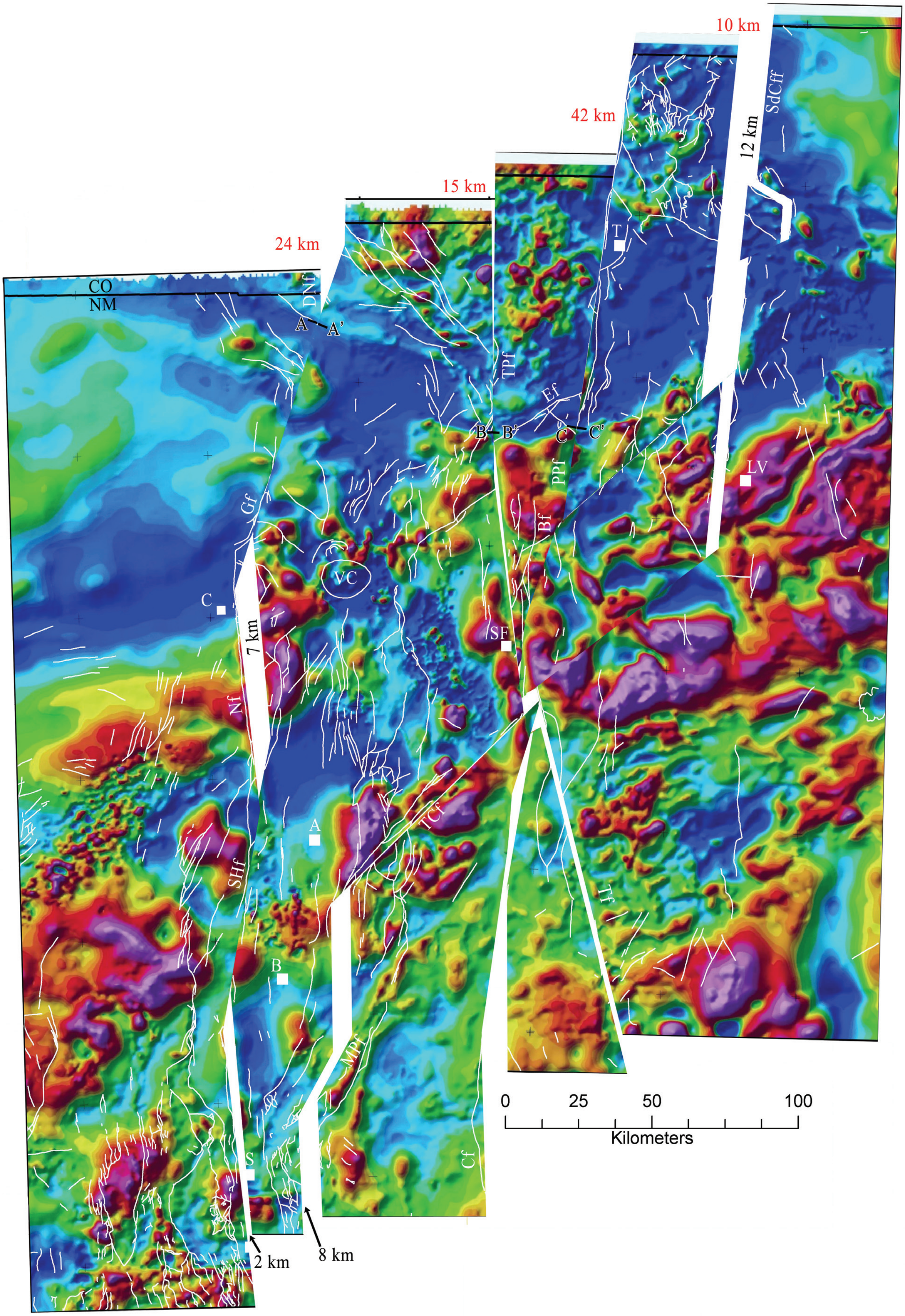


PLATE 3. Aeromagnetic map of part of north-central New Mexico (from Kucks et al. 2001). Heavy line at top is the Colorado–New Mexico state line. Faults (white lines) are from the New Mexico Bureau of Geology and Mineral Resources (2003). Heavy lines are cut lines used in this reconstruction; note that heavy dashed lines southwest of Las Vegas are cut lines that represent ficticious faults used to approximate the southward plunge-out of the Sangre de Cristo uplift (Plate 2). Reference points are: C, Cuba; A, Albuquerque; SF, Santa Fe; VC, Valles caldera; T, Taos; LV, Las Vegas; S, Socorro; B, Belen. Selected geologic structures are: DNf, Del Norte fault (not exposed); GF, Gallina fault; Nf, Nacimiento fault; SHf, San Hill fault; MPf, Montosa–Palomas–Hubble Springs faults; TCf, Tijeras–Cañoncito fault; Ef, Embudo fault; TPf, Tusas–Picuris fault (not exposed); Bf, Borrego fault; PPf, Picuris–Pecos fault; GEf, Glorieta Mesa–Estancia Basin fault; Cf, Chupadera fault; SdCff, Sangre de Cristo frontal faults. A–A´, B–B´, and C–C´ are match points used to reconstruct dextral separations in Plate 2.

PLATE 4: DISTRIBUTION OF CONTRACTION AND EXTENSION FOR PHANEROZIC TECTONIC EVENTS IN NORTHERN NEW MEXICO



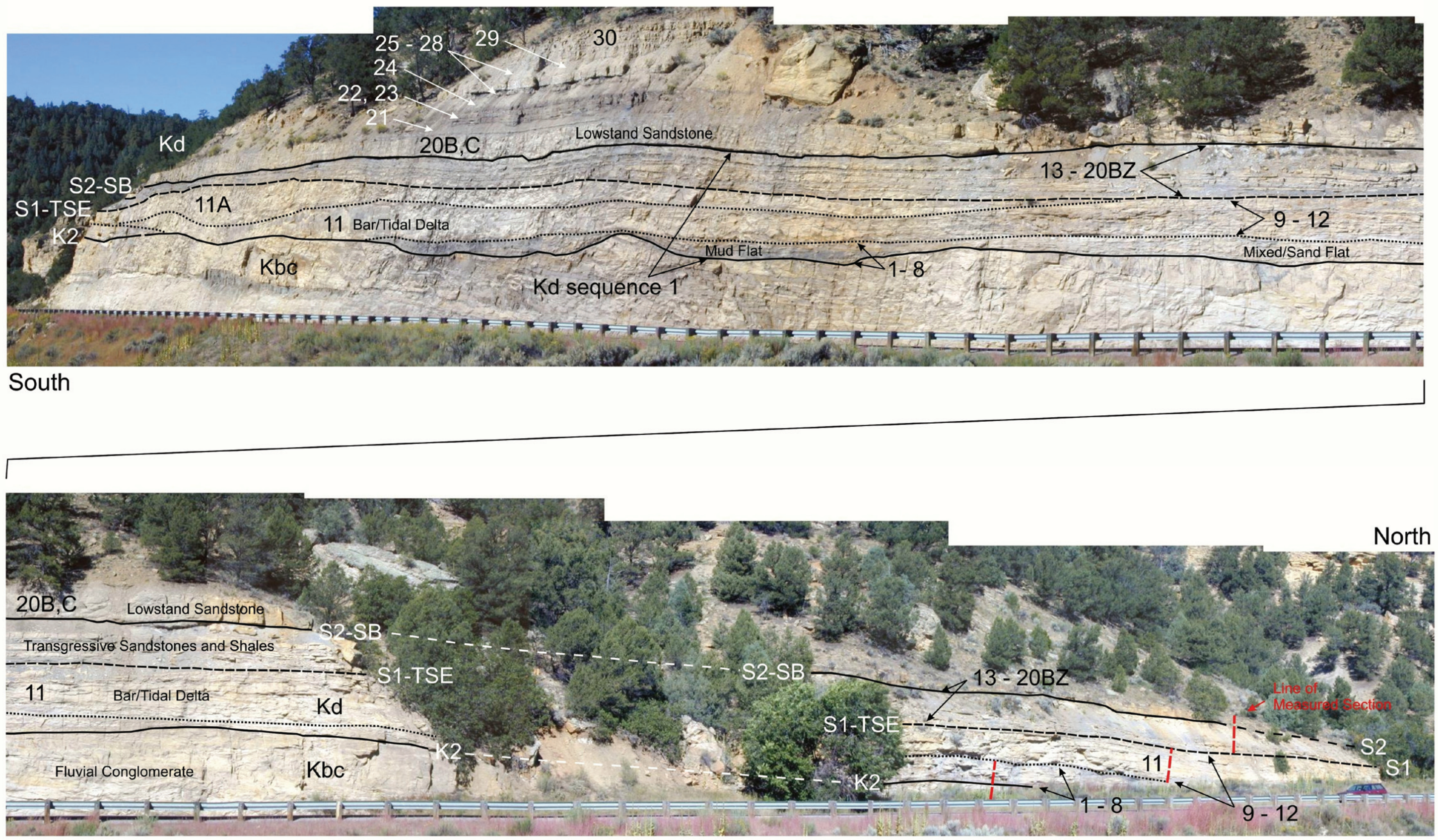


PLATE 5. Annotated panoramic view of the lower part of the Dakota outcrop at Highway 84 showing significant boundaries. Numbers are lithologic units discussed in Varney (this volume) and in much more detail in Varney (2000). View is split with the south half on the top and the north half on the bottom.

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PLATE 4. Maps showing distribution of contraction and extension for Phanerozoic tectonic events in the southwestern U.S. and resolved shear stress on north-striking faults in northern New Mexico. For simplicity, only the Picuris–Pecos fault is depicted. See text in Cather et al. (this volume) for discussion. Symbols are explained in Plate 3. (a) Cambrian extension during opening of the southern Oklahoma aulacogen. 1. Extension direction in southern Oklahoma aulacogen (Keller and Baldridge, 1995). 2. Extension direction in the hypothetical westward continuation of the aulacogen in the Apishipa uplift area of southeastern Colorado (Larson et al., 1985). (b) Late Mississippian, Pennsylvanian, and early Permian Ancestral Rocky Mountain orogeny. 1. Directions of major crustal shortening and probable sinistral deformation in the Wichita uplift area (Brewer et al., 1983; Budnik, 1986). 2. Direction of major crustal shortening in the Uncompahgre uplift (Frahme and Vaughn, 1983). 3. Shortening direction for northwest-trending en echelon folds adjacent to the Pleasant Valley fault (Wallace et al., 2000). 4. Shortening direction for en echelon folds adjacent to the Fresnal fault (Otte, 1959). 5. Approximate shortening direction for en echelon basins and uplifts in the southern Sangre de Cristo Mountains (Baltz and Myers, 1999, fig. 71). 6. Dextral deformation in the Central Basin Platform area (Yang and Dorobek, 1995). 7. Approximate extension direction for striated late Pennsylvanian fault, Joyita Hills (Beck and Chapin, 1994; note that this extension direction is at odds with the other kinematic indicators in this figure). (c) Late Cretaceous–Eocene Laramide orogeny. 1. Contraction direction from dominant trend of folds in the central Colorado Plateau (Kelley, 1955; Woodward, 1984). 2. Contraction direction from dominant trends of basins and uplifts, central Wyoming (Brown, 1993, figs. 3, 4). 3. Generalized shortening direction from minor-fault data, Front Range (Erslev et al., 2004). 4. Shortening direction for en echelon folds in eastern San Juan Basin (Baltz, 1967). 5. Generalized shortening direction from minor-fault data in central Colorado (Wawrzyniec et al., 2002). 6. Generalized shortening direction in southwestern New Mexico (Seager, 2004). (d) Miocene extension in the Rio Grande rift. 1. Generalized extension direction from several late Oligocene–early Miocene dikes west of Socorro (Aldrich et al., 1986). 2. Extension direction from early Miocene dikes in the Questa caldera area (Aldrich et al., 1986). 3. Extension direction in Browns Park (1984, 1986). 4. Extension direction in Split Rock Basin, Granite Mountains area (Love, 1970; Chapin and Cather, 1994).

PLATE 6: DAKOTA FORMATION OUTCROPS

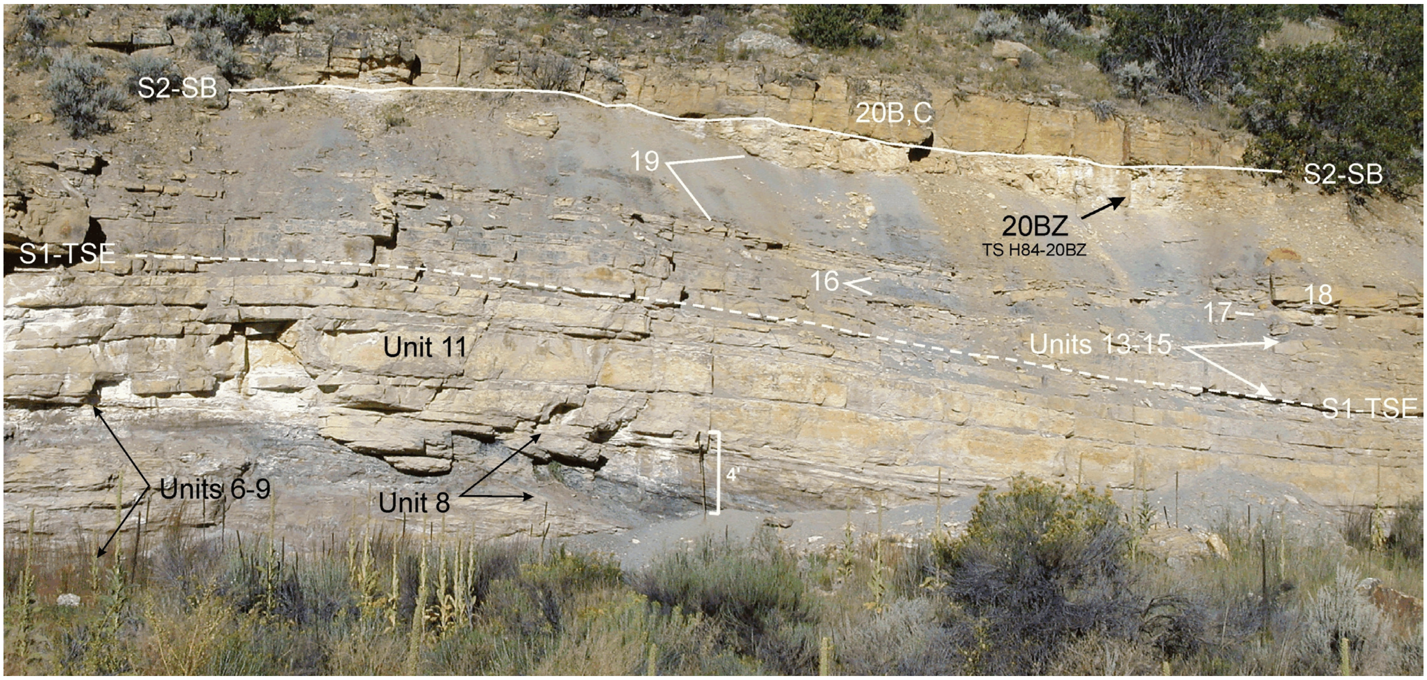


PLATE 6A. Units 6 through 20C at the north end of the base of the Highway 84 outcrop (see figure 6 in Varney, this volume). Note position of unit 11, part of a suspected barrier bar sandstone beneath TSE surface S1. Unit 8 is a tidal channel that thins to 0 southward (see figure 5 in Varney, this volume). X-ray diffraction analysis of a sample from Unit 20BZ shows a high concentration of kaolinite. The notation TS H84-20BZ refers to a thin section described in Varney (2000). Hiking staff for scale is about 4 feet high.

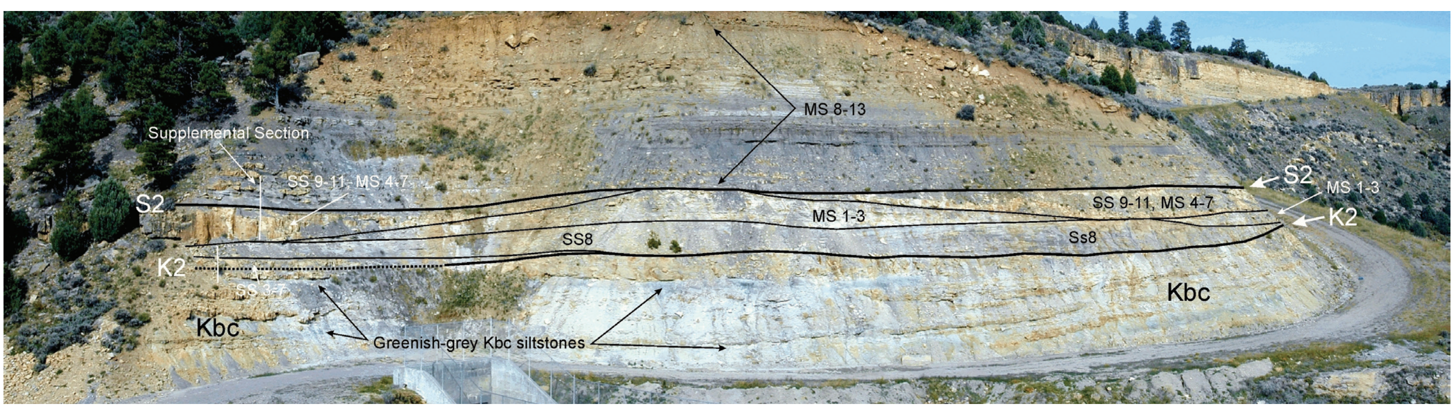


PLATE 6B. View to the east of the west end of the Dakota outcrop at Heron Dam. The position of the supplemental section is shown on the left. The main section was measured behind the nose on the right and up to the top of the prominent sandstone on the skyline in the background. The Burro Canyon Formation (Kbc) forms the base of this outcrop. Note the presence of characteristic greenish gray shales in the Kbc. In this illustration, "MS" designates rock units in the main measured section and "SS" designates rock units in the supplemental section. Unit numbers tie to the discussions in the text. The Dakota rests on the K2 unconformity and here it comprises proximal tidal flat gravelly shales, SS8,mixed sandstone shale tidal flat sediments, MS 1-3, and a tidal channel, SS 9-11, MS 4-7. The S2 surface is both a lowstand surface of erosion and a transgressive surface of erosion. Clay mineral analyses here and at the Highway 84 outcrop show that S2 is highly kaolinitic and most likely the same surface at both locations.

PLATE 7: PETROLEUM GEOLOGY OF THE DAKOTA INTERVAL CROSS-SECTION AND BURRO CANYON TYPE LOG

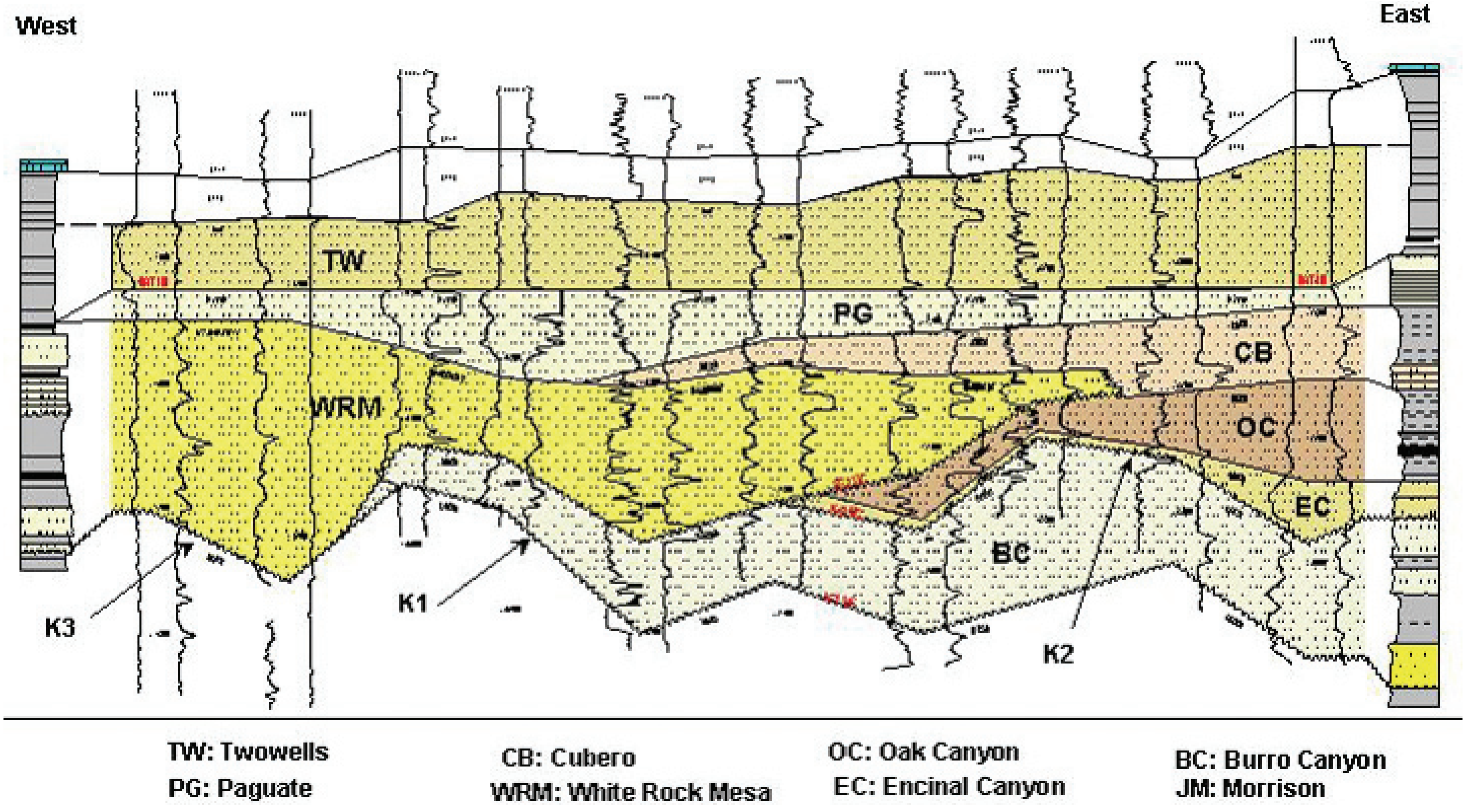


PLATE 7A. Dakota producing interval stratigraphic cross-section from the Four Corners in the west to the Chama Basin (Heron Dam) in the east (216 km. or 134 mi.), with outcrop sections on each end and well logs in between. Note westward erosional truncation of all lower Dakota and Burro Canyon as well as K-2 and K1 unconformities by K3 unconformity. Also note westward onlap of upper shoreface parasequence of Cubero on White Rock Mesa fluvial wedge. This cross-section is a summary of approximately 100 wells between outcrops.

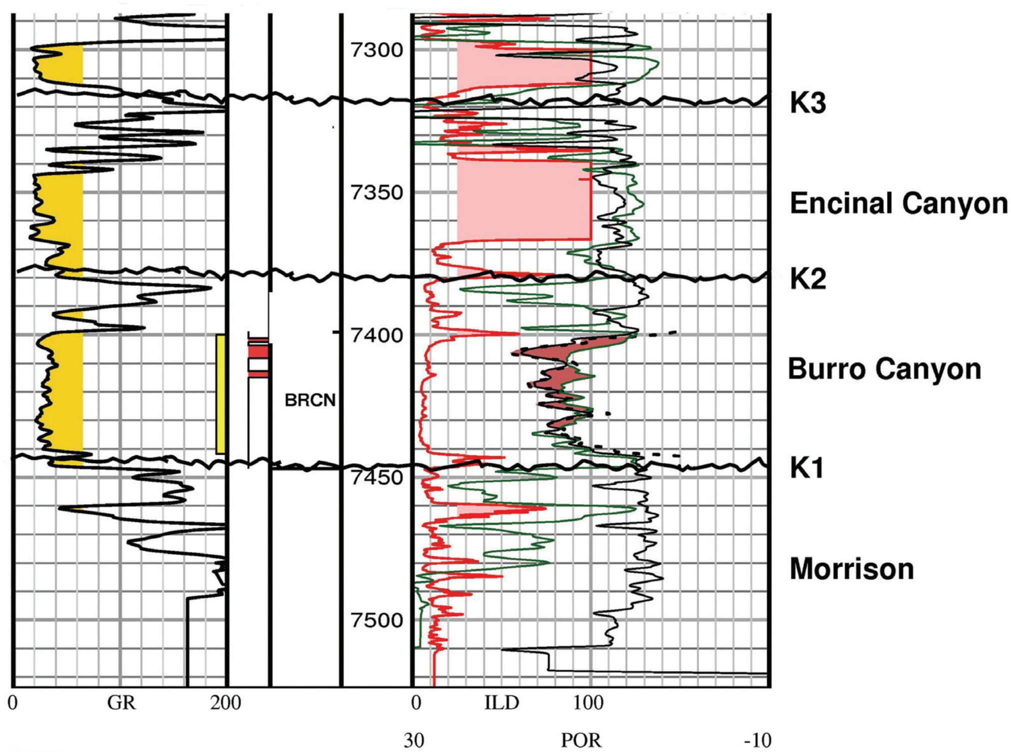


PLATE 7B. Burro Canyon type log showing low-resistivity, high-porosity reservoir with gas effect. Green mudstones and the K2 unconformity cap this reservoir.

PLATE 8: PETROLEUM GEOLOGY OF THE DAKOTA INTERVAL
PAGUATE INTERVAL

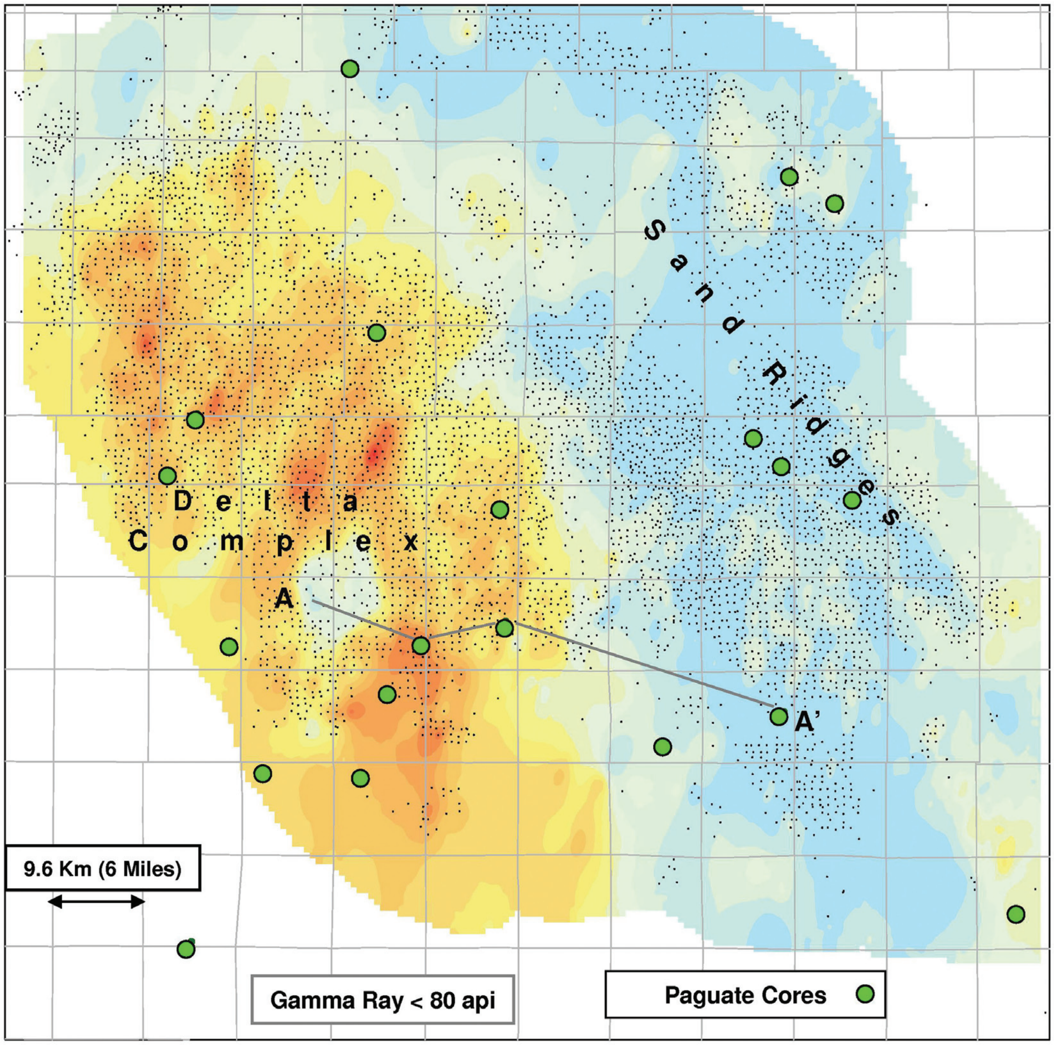


PLATE 8A. Paguate interval net sandstone isopach map showing northeast-prograding delta complex flanked by northwest-trending shoreface sand ridges built by longshore drift. Note distributary channels that form meander belts up to 3 miles (4.8 km) wide. Darker areas are distributary thicks and lighter gray areas are thin swales between sand ridges.

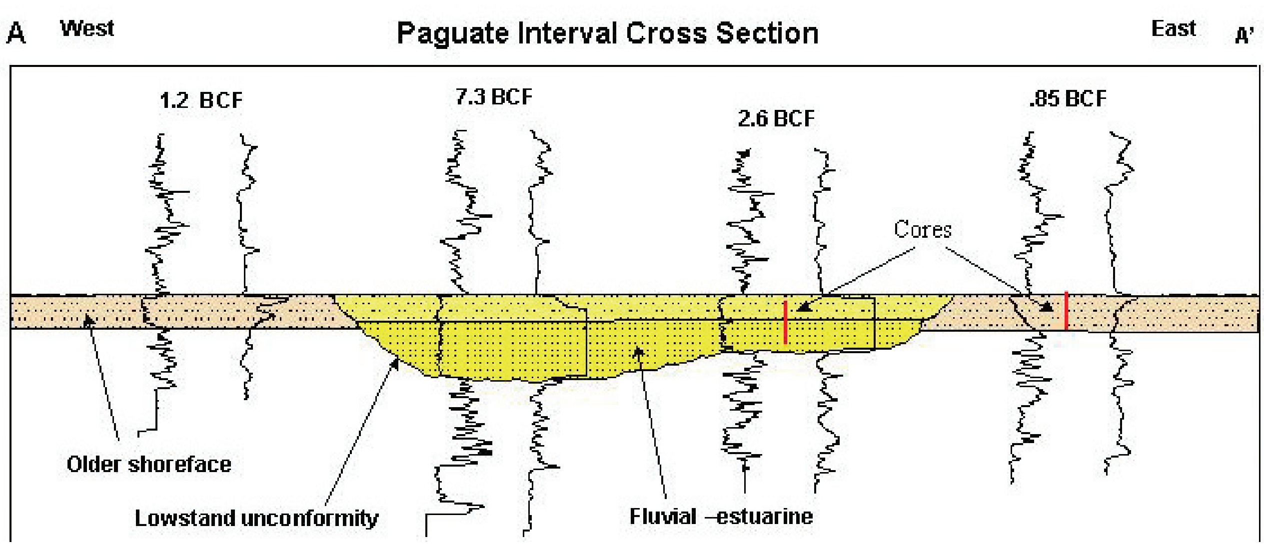


PLATE 8B. Paguate stratigraphic cross-section A-A' perpendicular to delta complex in Plate 8A. Lowstand distributary channel-fill facies filled eroded older shoreface deposits. Note contrasting log characters of blocky distributary and coarsening-upward shoreface, as well as location of two key cores. Also note higher gas recoveries from distributary sandstones.

PLATE 9: PETROLEUM GEOLOGY OF THE DAKOTA INTERVAL
TWOWELLS INTERVAL AND DAKOTA PETROPHYSICAL TYPE LOG

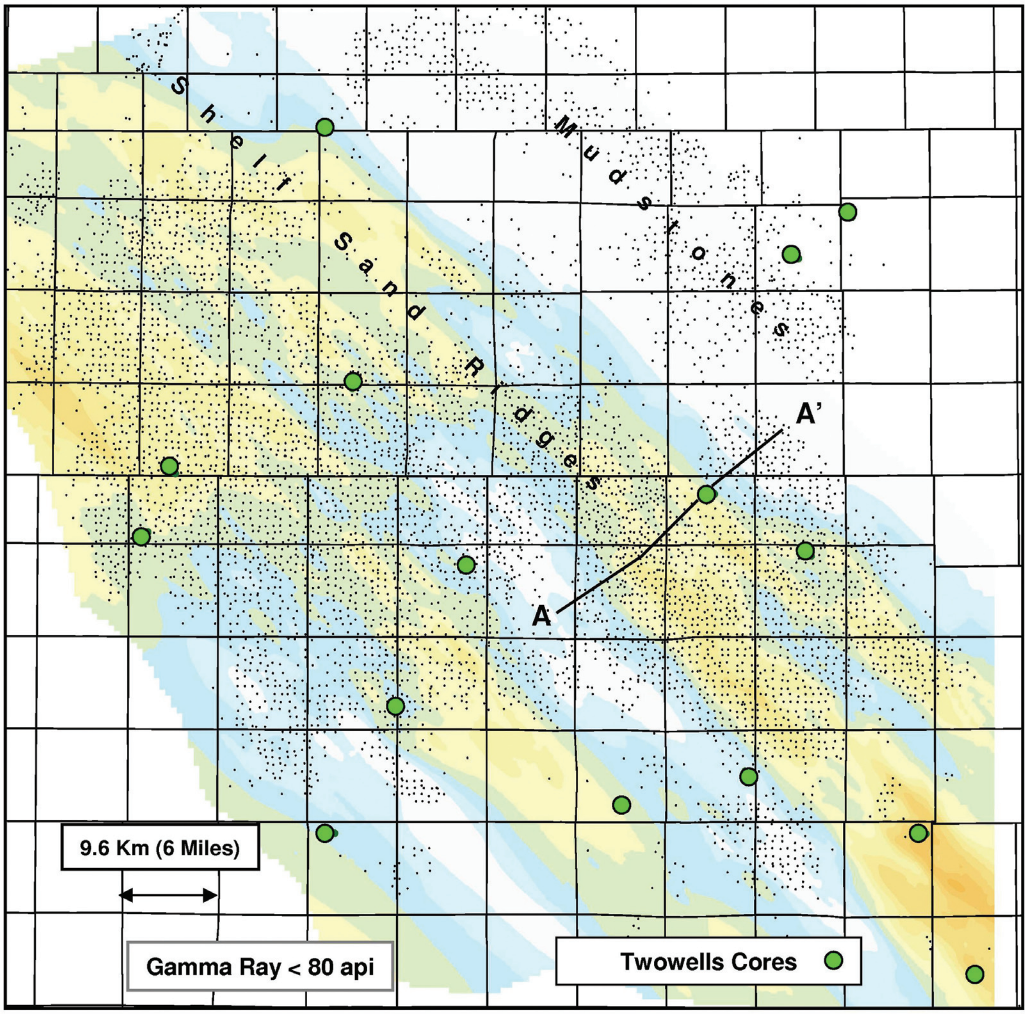


PLATE 9A,. Twowells interval net sandstone isopach map showing prominent northwest-trending, shelf-sandstone ridges. Yellow areas are shelf-ridge sandstone thicks and blue areas are thin, shaly swales between ridges. The white area to the northeast labeled mudstones marks the terminus of Twowells sandstones in the San Juan Basin; Twowells parasequences are composed of mudstones in this area and to the northeast. Crossbedding in sandstone outcrops of similar Twowells ridges indicate a southeasterly to southerly paleocurrent flow (Owen et al., 1978).

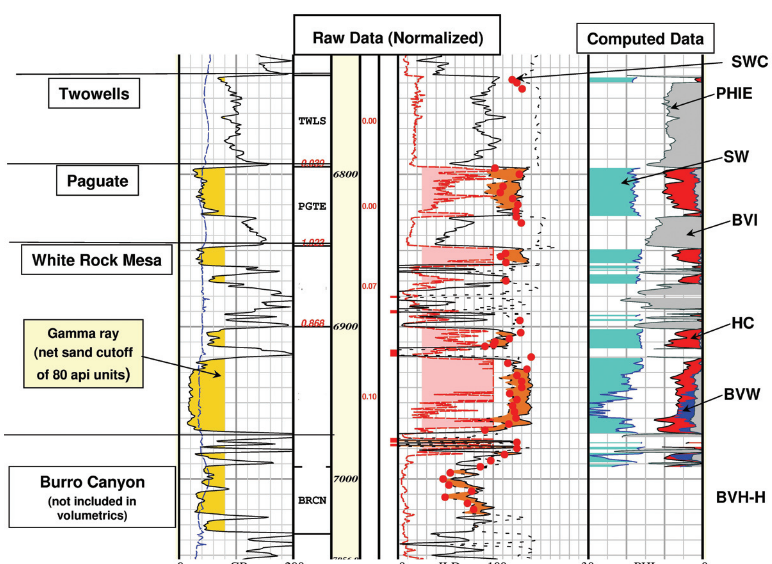


PLATE 9B. Petrophysical type log with raw data on left and computed volumetric parameters on right. SWC = sidewall cores; PHIE = effective porosity; SW = water saturation; BVI = immovable water; HC = hydrocarbons; BVW = moveable water; BVH-H = bulk volume hydrocarbon feet.

PLATE 10: PETROLEUM GEOLOGY OF THE DAKOTA INTERVAL
VOLUMENTRIC GAS IN PLACE

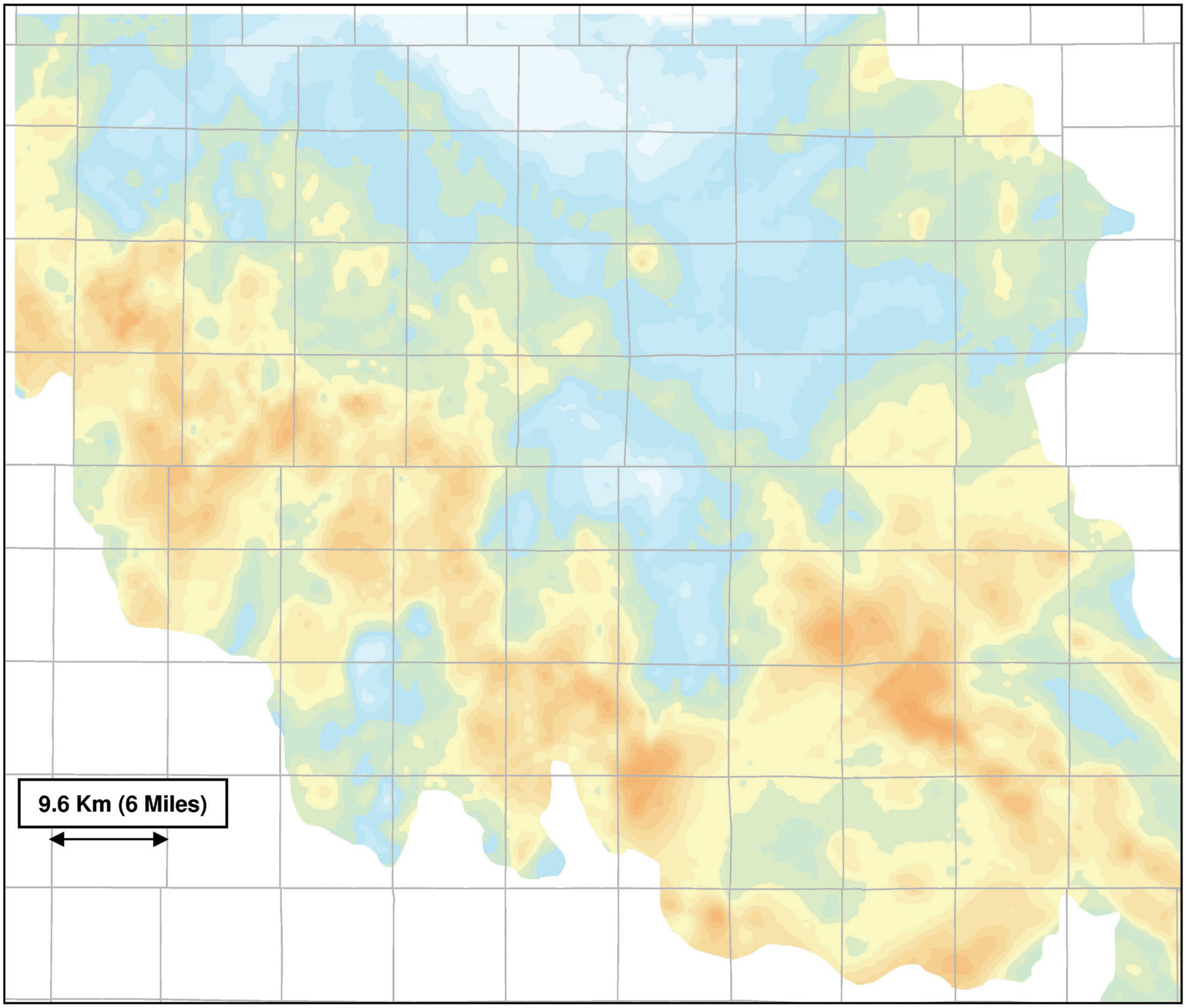


PLATE 10. Basin Dakota Field volumetric gas-in-place map. Warmer colors represent higher amounts of gas in place.

PLATE 11: PETROLEUM GEOLOGY OF THE DAKOTA INTERVAL VOLUMETRIC GAS IN PLACE WITH GAS PRODUCTION

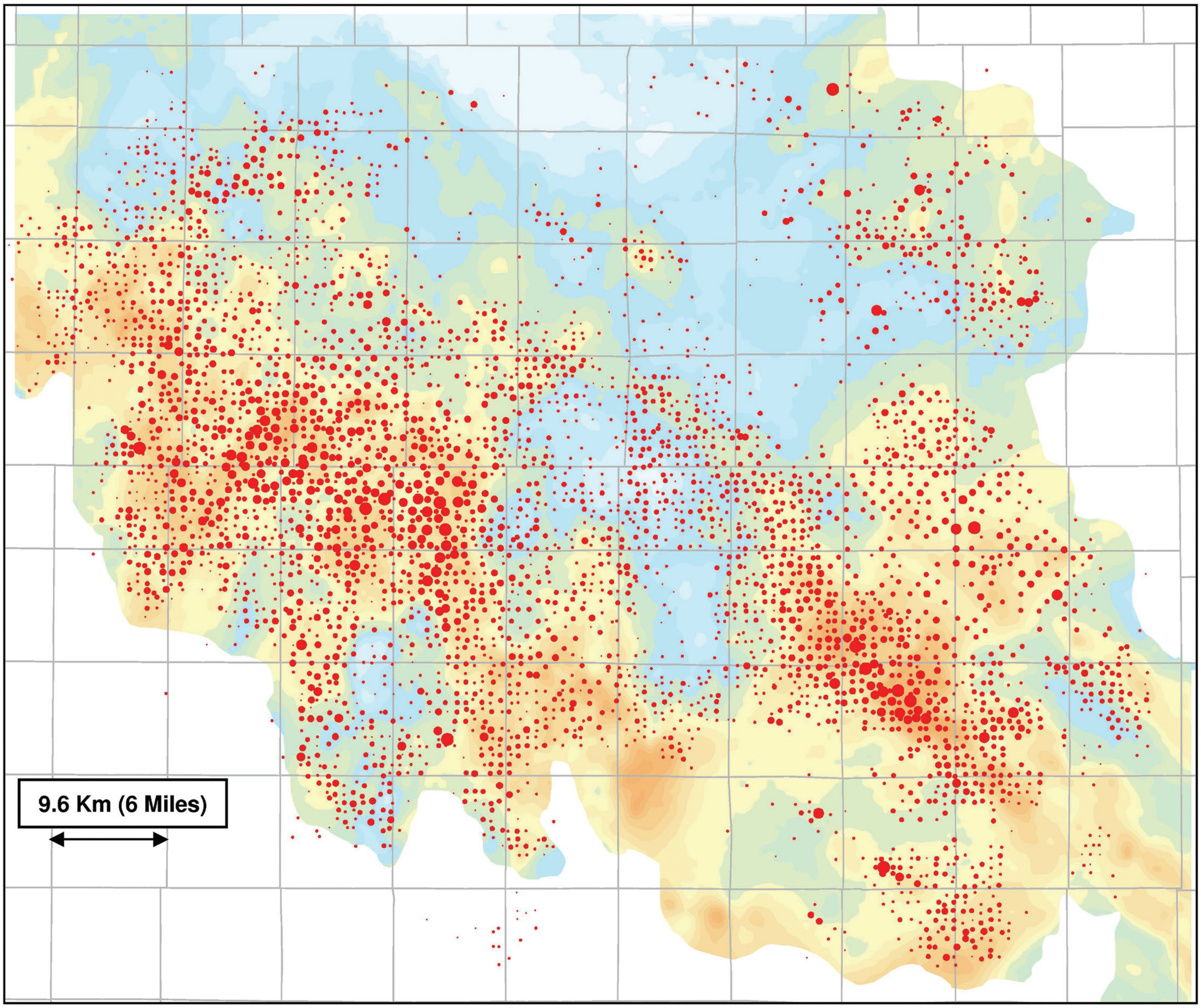
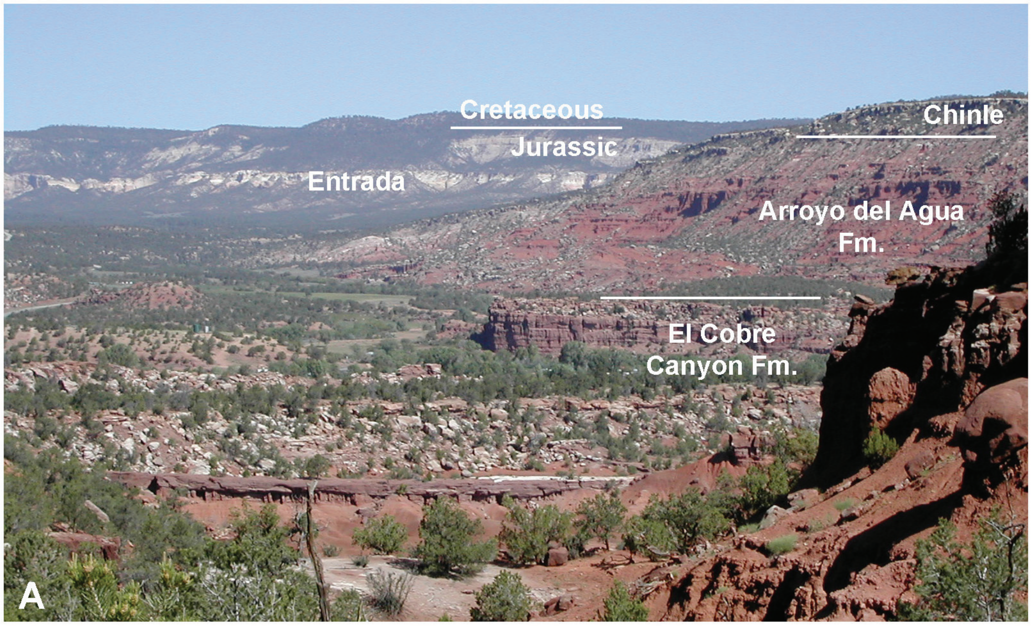


PLATE 11. Basin Dakota Field original gas-in-place map with well production bubble overlay. Warmer colors represent higher amounts of gas in place, and bubble size is relative to gas production.

PLATE 12: PHOTOGRAPHIC STRATIGRAPHY OF THE CHAMA BASIN
PALEOZOIC AND MESOZOIC STRATIGRAPHY



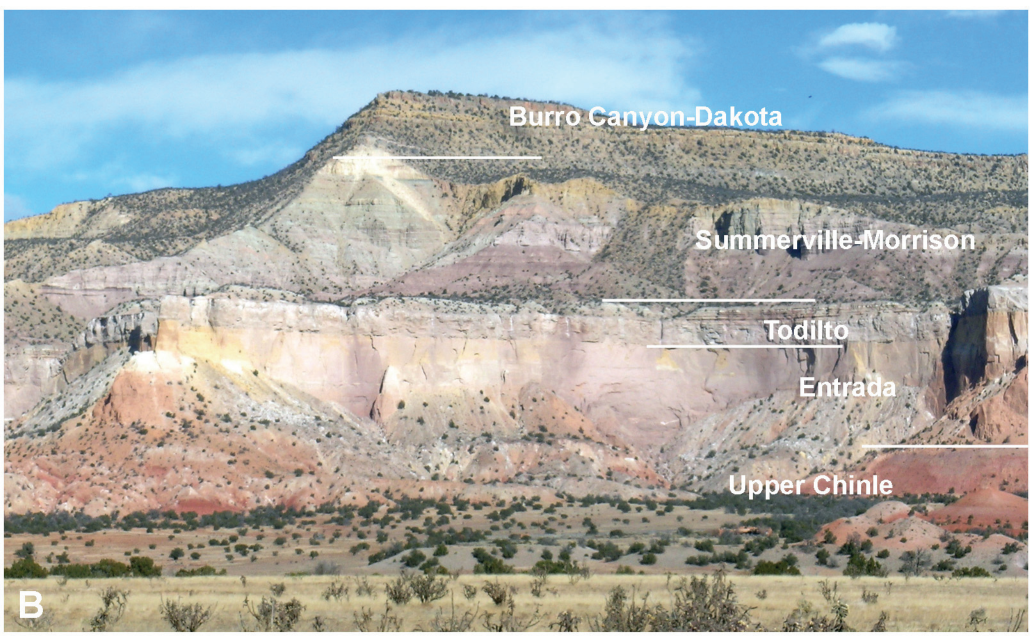
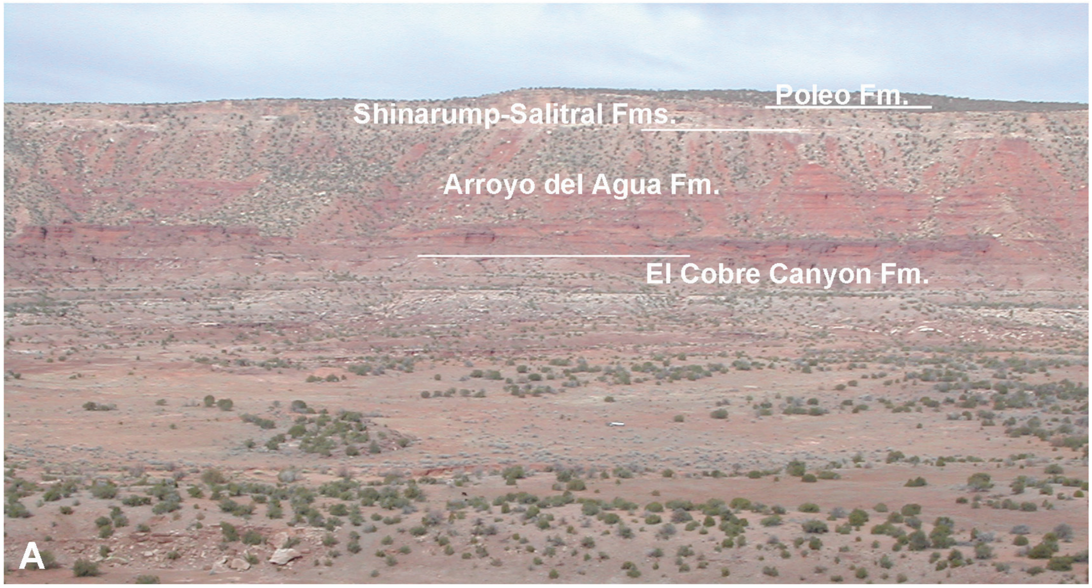


PLATE 12. Paleozoic and Mesozoic stratigraphy in the Chama Basin. A, Paleozoic and Mesozoic strata northwest of Coyote, New Mexico. Mesa Montosa is in the foreground and is composed of the Lower Permian Cutler Group's El Cobre Canyon and Arroyo del Agua formations. The mesa is capped by the Upper Triassic Shinarump, Salitral and Poleo formations of the Chinle Group. In the distance, the Jurassic Entrada Sandstone, Summerville-Bluff-Morrison formations and Cretaceous strata can be seen. B, Mesa Montosa immediately north of Ghost Ranch (not the same as Mesa Montosa near Coyote). Upper Triassic Petrified Forest Formation (Chinle Group) floors the valley and creates low red and purple hills in the foreground. The steep cliffs of the mesa are Jurassic Entrada Sandstone, Todilto and Summerville-Bluff-Morrison formations. Mesa Montosa is capped by the Cretaceous Burro Canyon-Dakota formations.

PLATE 13: PHOTOGRAPHIC STRATIGRAPHY OF THE CHAMA BASIN UPPER PENNSYLVANIAN TO LOWER PERMIAN STRATIGRAPHY



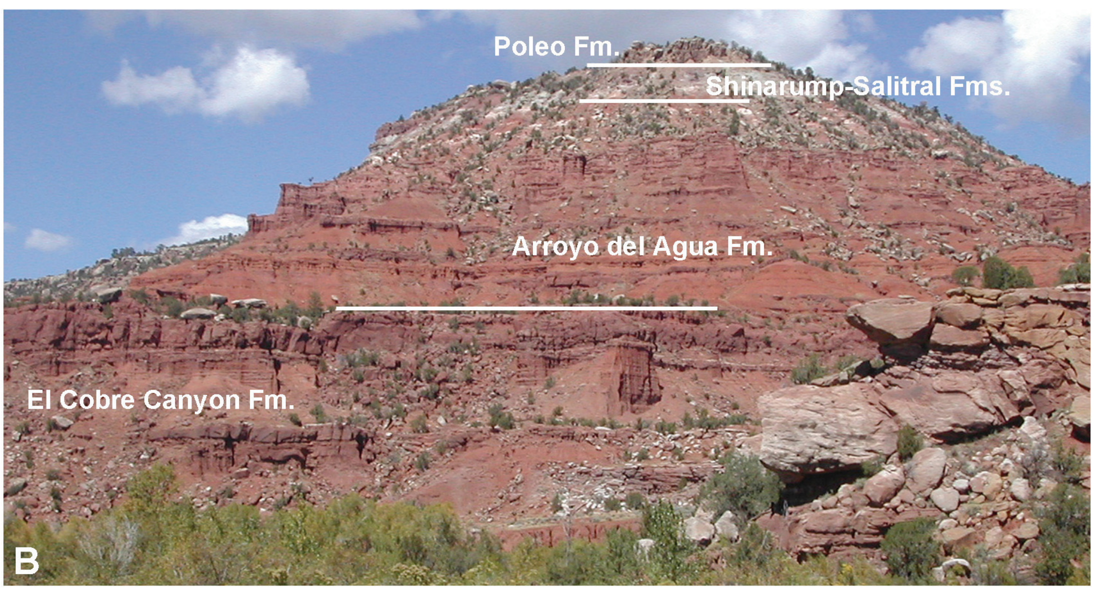


PLATE 13. Upper Pennsylvanian - Lower Permian strata in the Chama Basin. A, Western wall of El Cobre Canyon, northeast of Abiquiu. The El Cobre Canyon Formation of the Lower Permian Cutler Group floors the valley and creates low benches. The walls of the canyon are Arroyo del Agua Formation (Cutler Group), and are capped by the Upper Triassic Shinarump-Poleo formations of the Chinle Group. B, Flank of the side of Mesa Montosa, near Arroyo del Agua, New Mexico, showing the transition between the lower, sandier El Cobre Canyon Formation (Cutler Group) and the upper, siltier Arroyo del Agua Formation. The mesa is capped by the Upper Triassic Shinarump-Poleo formations of the Chinle Group.

PLATE 14: PHOTOGRAPHIC STRATIGRAPHY OF THE CHAMA BASIN TRIASSIC STRATIGRAPHY

PLATE 14. Upper Triassic strata in the Chama Basin. A, Overview of Coyote Amphitheater, the only locale in the Chama Basin where the entire Chinle Group is exposed. The Shinarump Formation is not visible in this photograph, but is found in the walls of the deeply incised Coyote Canyon. The Chinle Group is capped by the Jurassic Entrada Sandstone and the steep slopes above the Entrada Sandstone are the Summerville-Bluff-Morrison formations. B, Aerial photography of Orphan Mesa, southeast of Ghost Ranch. The Upper Triassic Petrified Forest and Rock Point formations comprise the base and slopes of the mesa, with the Jurassic Entrada Sandstone capping it. In the distance, younger Jurassic and Cretaceous strata are visible. C, East wall of Abiquiu Dam, just south of the dam itself. The walls of this earthwork dam are the Upper Triassic Poleo Formation (Chinle Group), with thin deposits of the Salitral and Shinarump formations near the base of the walls. The Poleo Formation is thickest here at Abiquiu Dam. D, Rock Point Formation (Upper Triassic Chinle Group) exposed in a mesa along US 84, south of Ghost Ranch. The mesa is capped by the Jurassic Entrada Sandstone.

PLATE 15: PHOTOGRAPHIC STRATIGRAPHY OF THE CHAMA BASIN
JURASSIC STRATIGRAPHY

PLATE 15. Jurassic stratigraphy in the Chama Basin. A, Far view of the cliffs of Mesa Alta that parallel Highway 96 between Coyote and Gallina, New Mexico. The striking gold cliffs are the Jurassic Entrada Sandstone, with the Todilto and Summerville-Bluff-Morrison formations creating the steep slopes above the Entrada. These mesas are capped by Cretaceous Burro Canyon-Dakota formations. B, Chimney Rock near Ghost Ranch. Red and gold cliffs are the Jurassic Entrada Sandstone, and the caprock is the Todilto Formation. C, Close-up view of the gypsum in the Todilto Formation just north of Ghost Ranch. The Entrada is visible beneath Todilto debris. Notice the Summerville Formation is infilling hummocky topography on the Todilto Formation. D, Upper part of the Jurassic section north of Ghost Ranch. Lower variegated slopes are the Summerville Formation, with the Bluff Sandstone creating cliffs locally. Summerville and Bluff formations are capped by the color banded Morrison Formation (Brushy Basin Member), which is famous in the Four Corners area for it dinosaur fossils.

PLATE 16: PHOTOGRAPHIC STRATIGRAPHY OF THE CHAMA BASIN CRETACEOUS AND CENOZOIC STRATIGRAPHY

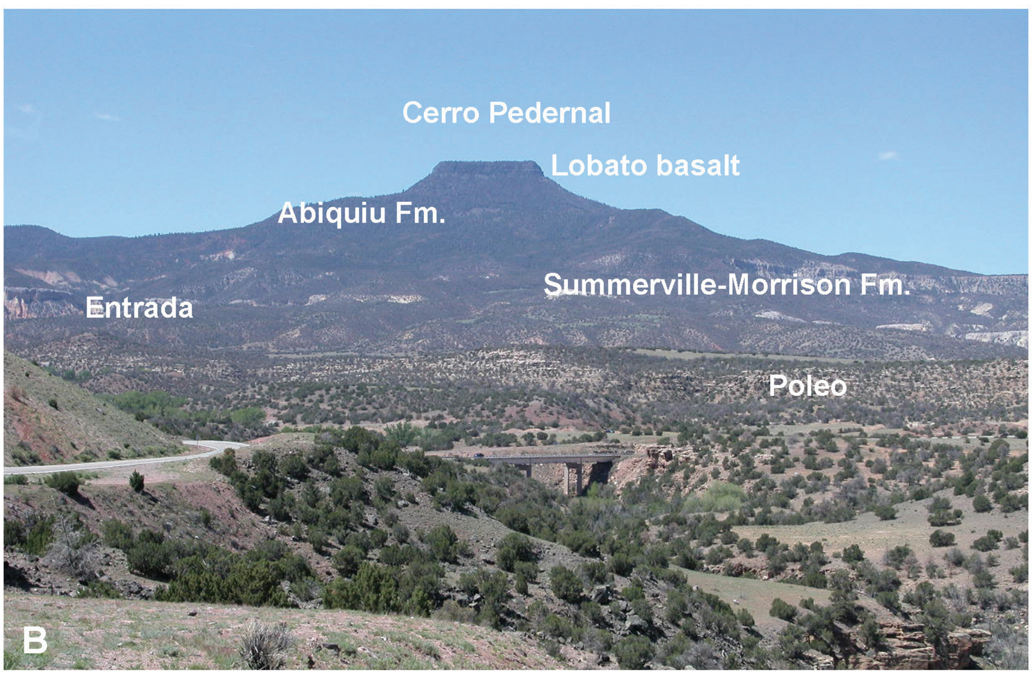


PLATE 16. Cretaceous and Cenozoic stratigraphy in the Chama Basin. A, Cretaceous stratigraphy at the hogback west of Gallina, New Mexico. Lower gold cliffs are the Point Lookout Sandstone, the slopes are formed by the Menefee Formation and the cuesta is capped by the Cliff House Sandstone. B, View of Cerro Pedernal, looking southwest. Low, flat country in the foreground is the Upper Triassic Poleo Formation (Chinle Group). Occasionally visible gold cliffs are the Jurassic Entrada Sandstone, which is overlain by the Summerville-Bluff-Morrison formations. The flanks of Cerro Pedernal are the Oligo-Miocene Abiquiu Formation, and this striking landmark is capped by the Late Miocene Lobato basalt flow.