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Geology and coal resources of Alamo Band Navajo Reservation, Socorro County, New Mexico

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The Alamo Band Navajo Reservation, northwest of Socorro, New Mexico (fig. 1), lies within the Datil–Mogollon subprovince on the southeast edge of the Colorado Plateau (Hawley and Love, 1981). This paper presents a summary of a cooperative effort of the U.S. Geological Survey and the New Mexico Bureau of Mines and Mineral Resources to assess the mineral potential of the Alamo Band Navajo Reservation.

Sedimentary and igneous rocks of Mesozoic and Cenozoic age are present on the surface within the reservation boundaries. Virtually all of the rocks exposed on the reservation are structurally complicated by broad-scale folds, multiple-stage faulting, and igneous intrusion. The youngest rocks of Mesozoic age, the Crevasse Canyon Formation of Cretaceous age, are coal bearing.

Core samples collected from coal-exploratory drill holes on the reservation indicate that the coals have a mean apparent rank of high volatile A bituminous. Coal quality tests on eight core samples obtained by drilling yielded average values of 12.7% ash, 0.6% sulfur, and 12,135 BTU/lb, on an as-received basis. Demonstrated resources for the reservation amount to 35.37 million tons of coal.

Previous work

Published geologic reports that include information about the area date back to 1900 when Herrick published a reconnaissance map and accompanying text with measured sections of western Socorro and (then) Valencia Counties. The oil and gas potential of the area was discussed in reports by Wells (1919) and Winchester (1921).

In 1957, Tonking mapped the Puertecito 15-min quadrangle which encompasses nearly all of the Alamo Reservation. He was the first to extend the Crevasse Canyon Formation terminology into the area.

Landis and others (1973) recognized the Twowells Tongue of the Dakota Sandstone in the area. Mayerson (1979) and Jackson (1979) remapped the southeast portion of the reservation using some of the refinements and revisions in stratigraphic nomenclature of Cobban and Hook (1979) and Hook and Cobban (1978, 1979). During the same time period, Massingill (1978) updated the northwestern quarter of Tonking's map to include the Mancos Shale and Tres Hermanos formation. The map presented with this report was compiled largely from the above reports with field checking and aerial photographic update done as required (fig. 2).

Chapin and others (1979) presented a summary of the mineral potential of both the reservation and the Riley area to the east. Briggs and Maxwell (1980) provided a mineral potential summary of the Indian lands to the Bureau of Indian Affairs in 1980 that recommended a study of the coal resource potential of the Alamo Band Navajo Reservation.

Structure

Structural complications including folding and faulting affect all but the youngest rocks in the area. Most of the major faults in the area are associated with the formation of the Rio Grande rift.

Several scales of generally open folds affect both Cretaceous sedimentary and Tertiary volcanic rocks. The folds affecting the Cretaceous rocks are commonly assumed to be related exclusively to Laramide compressional tectonics in central New Mexico. However,

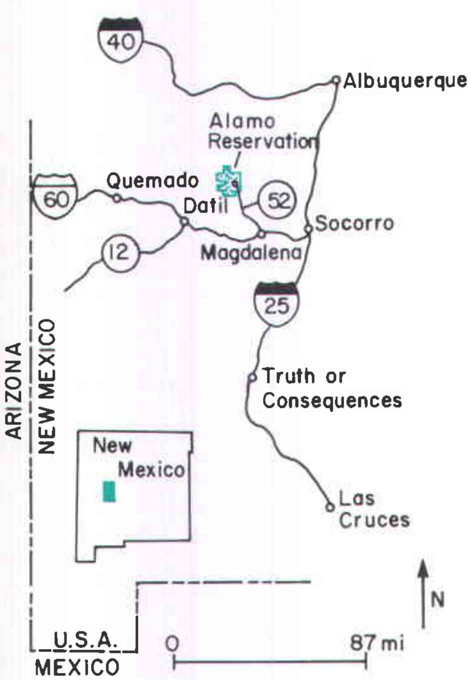

FIGURE 1—LOCATION MAP OF ALAMO BAND NAVAJO RESERVATION.

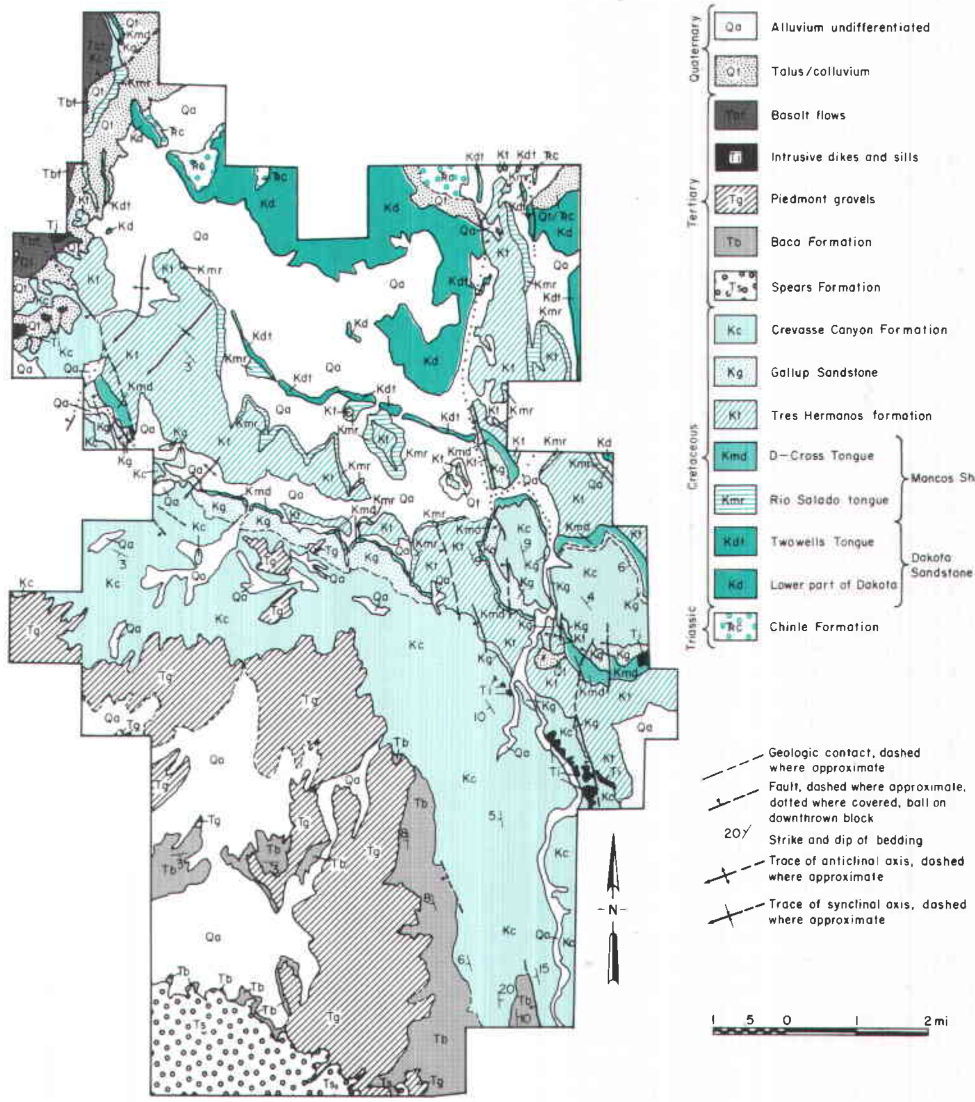

FIGURE 2—GENERALIZED GEOLOGIC MAP OF ALAMO BAND NAVAJO RESERVATION.

some of these folds warp both Cretaceous rocks and Tertiary rocks and obviously formed after Laramide time. The folds that affect the Cretaceous rocks can therefore be either Laramide or much younger in age. Broad-scale anticlines and synclines are prominent features in the study area. The axes of these structures typically trend north to northwest and plunge to the south.

Numerous small-displacement normal faults occur in the east-central portion of the reservation. All these faults trend north to northwest and dip to the west. Chapin and others (1979) suggest that these faults developed during the early stages of development of the Rio Grande rift. Faults with different trends than those associated with the Rio Grande rift also are present in the area. These faults trend to the northeast and some have large displacements.

Stratigraphy

TRIASSIC SYSTEM—Triassic redbeds that make up the Chinle Formation are the oldest rocks exposed in the study area. The unit underlies broad valleys near the northern boundary of the reservation. The Chinle is easily recognized in outcrop and on aerial photographs by its characteristic red color and by the resistant Dakota Sandstone that lies unconformably above it.

The Chinle Formation consists of red, purple, and gray mudstones, siltstones, and claystones with lesser amounts of conglomeratic lenses in crossbedded sandstones. A maximum thickness of 120 ft is preserved on the reservation, but Massingill (1979) reports up to 500 ft of Chinle to the east near Riley.

Floodplain sedimentation is indicated by the predominance of fine-grained sediments. The lentils of conglomerate and the presence of discontinuous, crossbedded sandstones suggest deposition by anastomosing channels flowing across the floodplain.

CRETACEOUS SYSTEM—Five Cretaceous formations are recognized which are from oldest to youngest: the Dakota Sandstone, the Mancos Shale, the Tres Hermanos formation, the Gallup Sandstone, and the Crevasse Canyon Formation. These units, with the exception of the Tres Hermanos formation, have been described in other basins in the state including the San Juan Basin, the Zuni Basin, and the Acoma Basin.

Dakota Sandstone—The Dakota Sandstone lies unconformably on the Chinle Formation. In the study area two units, the lower part of the Dakota Sandstone and the younger Twowells Tongue, are mapped. The Twowells Tongue apparently pinches out approximately 2 mi south of the Rio Salado.

The Dakota Sandstone exposed in the area is a generally upward-fining sequence of resistant, well-sorted quartzose sandstone containing conglomeratic lenses at the base and intercalated shales at the top. The base of the Dakota Sandstone is typically erosional and is made up of a weathered gravel of well-rounded quartzite and chert pebbles and siltstone chips derived from the upper part of the Chinle Formation (Mayerson, 1979). The contact between the Dakota and the overlying part of the Mancos Shale is gradational; I have placed the upper Dakota contact at the point where very thin shales are intercalated with a slightly fining-upward sand sequence.

The Twowells Tongue of the Dakota Sandstone was first recognized in the area by Landis and others (1973) and lies stratigraphically between the two lowest tongues of the Mancos Shale. The Twowells is an upward-fining sequence of quartzose sandstone very similar to the basal Dakota in character.

Mancos Shale—Two Mancos tongues are mapped in the northern part of the reservation, the Rio Salado tongue above the Twowells Tongue of the Dakota Sandstone and the D-Cross Tongue between the Tres Hermanos formation and the Gallup Sandstone. A stratigraphically lower Mancos unit is present below the Twowells Tongue of the Dakota in the area but does not crop out above the alluvium.

The Rio Salado tongue of the Mancos Shale consists of the shales that lie between the Twowells Tongue of the Dakota Sandstone and the Tres Hermanos formation (Hook and others, 1983, in press). The Rio Salado is typically a medium-gray to brownish-gray silty mudstone with thin, light brownish-gray, nodular limestones throughout. Approximately 10 ft above the basal contact with the Twowells, the Rio Salado tongue contains *Sciponoceras gracile,* a standard zone ammonite of the Western Interior Cretaceous (Cobban and Scott, 1972). An oyster, *Pyconodonte newberryi* (Stanton), also occurs in the *Sciponoceras gracile* Zone and serves as a very good stratigraphic marker because it is confined to the light-colored calcareous shales and limestones in the basal part of the Rio Salado tongue (Hook and Cobban, 1978). Several partial specimens of *Mammities depressus* have been found in concretions near the top of the Rio Salado tongue on the Alamo Reservation.

The D-Cross Tongue is a slope-forming unit present throughout the study area between the Tres Hermanos formation and the Gallup Sandstone. The unit can be conveniently divided into lower and upper parts. The lower part is a medium-gray, bioturbated, slightly calcareous to noncalcareous silty shale containing many fossil-bearing concretions. Fossils identified in the lower part of the D-Cross include: *Prionocyclus novimexicanus, Scaphites ferronensis, Coilopoceras inflatum,* and *Scaphites whitfieldi.* The upper portion of the D-Cross Shale is generally more silty and less calcareous than the lower portion of the unit. Several light-colored sandstone beds less than 1 ft thick occur in the upper part of the D-Cross. Fossils identified from the upper part of the D-Cross include: *Lopha sannionis, Prionocyclus novimexicanus,* and *Baculites yokoyamai* (Hook and Cobban, 1979). The D-Cross Tongue reaches a maximum thickness of 140 ft in the east-central part of the reservation. The contact of the D-Cross Tongue with the underlying Tres Hermanos formation is gradational over approximately 15 ft. Similarly, the upper contact of the D-Cross with the overlying Gallup Sandstone is also gradational. The base of the Gallup Sandstone is mapped at the base of the first sandstone interval thicker than 1 ft.

Robinson (1981) suggests a shallow, nearshore, transitional zone between shoreface sands and clean offshore muds for the environment of deposition of the D-Cross Shale. Evidence that points to this conclusion includes the silty nature of the shales and the abundance of fossils in the unit.

Tres Hermanos formation—The Tres Hermanos formation is composed of a basal coastal sandstone sequence, a middle paludal to continental sequence, and an upper, coastal sandstone sequence. The lower part of the Tres Hermanos consists of approximately 70 ft of yellowish-gray, thin- to medium-bedded sandstone. This interval commonly has a number of sedimentary structures including crossbedding, bioturbation, ripples, and abundant fossils in concretions.

The middle part of the Tres Hermanos formation is a sequence of paludal shales and thin, calcareous sandstones. Petrified wood and large pelecypods are common in this interval. Sandstones in the middle part of the Tres Hermanos are typically crossbedded and have scoured, sharp bases. Thin, lenticular coals, less than 1.2 ft thick, are present in the upper portion of the interval. The predominantly fine-grained sediments and minor sandstones suggest sedimentation on a marshy coastal plain.

The upper part of the Tres Hermanos formation consists of 40–90 ft of fine to very fine grained sandstone in the study area. This sandstone generally coarsens upward, is bioturbated and burrowed, and in some places has medium-grained, fossiliferous sandstone lenses. Like the lower part of the formation, the upper part represents deposition of a coastal barrier and shoreface sequence.

Mesaverde Group—The Gallup Sandstone of the Mesaverde Group in the study area is a cliffy, 30–70-ft-thick sandstone that lies conformably above the D-Cross Tongue of the Mancos Shale. The contact of the Gallup Sandstone with the underlying D-Cross shale is gradational and the base of the Gallup is mapped at the base of the first resistant sandstone. The Gallup contact with the overlying Crevasse Canyon Formation is sharp and represents the boundary between the upper shoreface/foreshore sands of the Gallup and the finer grained lagoonal sediments of the lower part of the Crevasse Canyon Formation.

The Gallup Sandstone is a generally coarsening-upward sequence of very fine to medium-grained sandstone. The lower part of the Gallup contains abundant horizontal laminations, planar crossbeds, and burrow mottling. This lower part of the unit represents a transitional zone between the offshore muds of the D-Cross shale and the lower shoreface sands found in the lower part of the Gallup. The guide fossil *Lopha sannionis* occurs in the Gallup in dark-colored, thin, medium-grained sandstone layers. Higher in the Gallup, the sandstones become bioturbated and then intensely burrowed in the portion deposited in lower shoreface environments. In contrast, the upper part of the Gallup is characterized by stacked planar crossbeds that are only moderately burrowed.

The Crevasse Canyon Formation of the Mesaverde Group consists of a sequence of generally fine-grained rocks and associated coals. Surface and subsurface data obtained in this and other studies in the area show that the Crevasse Canyon Formation in the Datil Mountains can be roughly divided into three parts. These parts are from bottom to top: a lower coastal swamp sequence, a medial coastal plain sequence, and an upper freshwater swamp sequence with strong fluvial influence. The lower part of the formation, conformable with the Gallup Sandstone, is a coastal swamp or lagoonal sequence and is typically composed of interbedded mudstones, siltstones, and occasional, slightly calcareous, thin sandstones. The thickest coal zone that occurs in the area begins approximately 60 ft above the Gallup Sandstone. This coal zone probably is the stratigraphic equivalent of the Dilco Coal Member of Molenaar (1973) that is present in the Zuni Basin.

The middle part of the Crevasse Canyon Formation is composed of a series of interbedded siltstones and very fine-grained sandstones with thin dolomite and limestone layers. Coal is rare in this interval. The lenticular pods of siltstone and sandstone suggest deposition on a flat, coastal plain by an anastomosing stream system.

The upper part of the Crevasse Canyon Formation crops out near Abbe Springs Canyon on the reservation and is composed of fine-grained sandstones, mudstones, and minor coals. These coals are not as thick, continuous, or numerous as the coals present in the lower part of the formation. The coals in the upper part of the Crevasse Canyon probably were deposited in broad, freshwater swamps adjacent to fluvial channels on the upper coastal plain. Coal pollen studies show angiosperm pollen and no marine nor brackish water indicators, thus suggesting a lack of marine influence on the upper part of the Crevasse Canyon (Chapin and others, 1979).

TERTIARY SYSTEM—Tertiary rocks and their relationships to each other on the Alamo Reservation document a wide range of geologic processes and events including fluvial sedimentation, widespread volcanism, injection of dikes and sills, and widespread erosion. The oldest Tertiary rocks on the reservation are the Baca Formation (Eocene). Volcanism to the south of the area during Oligocene time was the source of the volcaniclastic apron comprising the Spears Formation that is present in the southwest corner of the reservation. Intrusive igneous dikes of Miocene age were emplaced along faults and fractures associated with the opening of the Rio Grande rift. Deposits of Pliocene age include extrusive basalt flows as well as piedmont deposits derived from erosion of earlier Tertiary deposits.

Baca Formation—The Baca Formation in the study area comprises a redbed sequence of sandstones, siltstones, shales, and conglomerates. The lower contact of the Baca with the underlying Crevasse Canyon Formation is unconformable whereas the upper contact of the Baca with the overlying Spears Formation is conformable (Cather, 1982). Cather (1980, 1982) recognized three informal map units in the area: a lower red unit, a middle sandstone unit, and an upper red unit. These units represent distal braided alluvial-plain, fine-grained lacustrine-delta, and lacustrine-basinal environments, respectively (Cather, 1980).

The Baca Formation has received considerable attention as a potential source of uranium. A substantial amount of drilling has been done just southeast of the reservation but has yet to indicate significant amounts of uranium mineralization. Cather (1980) suggests that uranium mineralization in this area is confined to the lacustrine delta facies of the Baca.

Spears Formation—The Spears Formation crops out in the southwest corner of the reservation as gently south-dipping hogbacks. Within this area, the Spears Formation is composed mainly of volcaniclastic sedimentary rocks with minor quantities of interbedded lava flows and pyroclastic units. The most common lithologies present on the reservation are feldspathic sandstones, conglomerates, and debris-flow deposits.

The Spears Formation conformably overlies the older Baca Formation and is overlain unconformably by either the Hells Mesa or La Jencia tuffs outside the reservation. The lower contact of the Spears Formation is usually gradational and is placed at the stratigraphically lowest horizon where recognizable volcanic detritus is found.

Mafic intrusions—Mafic intrusive dikes are common features on the eastern side of the reservation. These rocks were emplaced along extensional fault zones related to the development of the Rio Grande rift (Chapin and others, 1974). The dikes are typically less than 8 ft in width (too small to be shown on map) and range from a few feet to thousands of feet in length.

Intrusive sills in the area are confined to a northwest-trending band along Jaralosa Creek. These sills are nearly flat lying and are generally less than 20 ft thick.

Basalt flows—Flows of basaltic composition cap Tres Hermanos Mesa in the northwest part of the reservation. These flows typically have ropy flow structures, are porphyritic, and have oxidized, red, vesicular tops and brecciated bottoms. Flows to the north outside the reservation that are probably coeval with these flows have been dated at 3–6 m.y. B.P. (Bachman and Menhert, 1979). The volcanic neck that forms La Cruz Peak in the center of the reservation is probably the same age as the basalt flows in the area.

Gravels—Tertiary gravels cover much of the southwest part of the reservation. These deposits are made up of clasts of Oligocene volcanic rocks in a silty sand matrix. The gravels are mostly piedmont deposits formed by coalescing alluvial fans derived from the Gallinas Mountains. The gravels range from Early to Late Tertiary in age and were deposited on a deeply eroded surface of the Crevasse Canyon dipping to the north.

QUATERNARY SYSTEM—Quaternary deposits on the reservation include floodplain deposits, blow sands, and piedmont-slope deposits in which the clasts range in size from silt to gravel. Most of the Quaternary deposits in the area have been grouped together as undifferentiated alluvium. The youngest deposits on the reservation are made up of clay through pebble-sized clasts currently being deposited in ephemeral stream channels. Talus and colluvium occupy extensive surface area on the sides of hills and mesas. These deposits can be split into talus that is composed of basalt clasts, such as those in the extreme northwest corner of the reservation, and the talus/colluvium deposits that are primarily composed of Cretaceous sandstones that have slid downslope on the thick, intervening mudstones of the Mancos Shale.

COAL GEOLOGY—The average as-received heating value for the eight samples of coal collected during this investigation from six drillholes is 12,135 BTU/lb. The average moist, mineral-matter-free heating value is 14,050 BTU/lb, which indicates an apparent coal rank of high volatile A bituminous according to the rank classification of the American Society of Testing and Materials Standard D388–77 (1980).

Proximate, ultimate, BTU, and forms of sulfur analyses were performed by Hazen Research in Golden, Colorado. Eight samples from six drillcores were selected for analyses.

The sulfur content for the coals on the Alamo Reservation averages 0.6%. The samples were analyzed with respect to forms of sulfur; an average of 83% of the sulfur present was organic sulfur with the remaining sulfur being pyritic. No sulfur was present as sulfate.

Coal resources—A total of ten stratigraphic test holes averaging 280 ft deep were drilled on or near the reservation. Samples of drill cuttings were taken at 5-ft intervals, and all holes were geophysically logged. The lenticularity and discontinuous nature of the coal beds was shown during the core drilling; three seams greater than 2.5 ft thick were not present 20 ft away from the rotary hole. In place of the coal beds in these cores were very fine to fine-grained, crossbedded sandstones, with abundant coal fragments in the lower parts of the sandstones. The presence of these sandstone bodies suggests that the coals were cut by migrating fluvial channels.

Coal resources were tabulated by thickness categories as established in U.S. Geological Survey Bulletin 1450–B (1976; table 1). To calculate the coal resources defined by a given data point, the thickness, depth to coal, and areal extent were considered. Both measured and indicated categories for subeconomic resources were calculated as defined by Bulletin 1450–B (1976, p. B6). More detailed information on the coals of the Alamo Reservation can be found in Osburn (1982).

Potential for mining—Coals present on the Alamo Reservation, though of excellent quality, are thin, lenticular, and discontinuous. The lower coal zone of the Crevasse Canyon

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TABLE 1—ESTIMATED RESOURCES OF BITUMINOUS COAL ON ALAMO RESERVATION; in millions of short tons; all values rounded; 1,800 short tons/acre-ft used in calculations; dashes mean coal is absent in category shown; maximum depth, 350 ft; only townships with coal reported.

Location T.	R.	Measured thickness of coal bed in ft 1.2–2.3	2.3–3.5	>3.5	Indicated thickness of coal bed in ft 1.2–2.3	2.3–3.5	>3.5	Totals
1 N.	6 W.	0.95	—	—	—	—	—	0.95
2 N.	6 W.	4.00	5.00	0.52	15.06	2.55	—	27.13
2 N.	7 W.	1.74	—	—	5.55	—	—	7.29
Totals		6.69	5.00	0.52	20.61	2.55	0.00	35.37

Formation contains the thickest coals in the area. In addition, the rocks associated with the coals are fine grained and soft and could be easily mined.

The transportation costs of the coal remain the largest problem. No major roads or railroads are located in the area and no population center exists nearby to use small amounts of coal. Therefore, the most feasible utilization of the coal on the Alamo Reservation would be for domestic heating purposes on the reservation. This would utilize the resource and help prolong wood resources in the area. Chapin and others (1979) suggested that the coal could be used for fuel in a sand and gravel or cement operation. This remains a viable possibility.

In conclusion, coal resources of the Alamo Indian Reservation are very limited and do not constitute a major resource. Small resource figures coupled with the remote location of the reservation demand that any exploitation of this resource be done on a local scale.

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Geographic names

U.S. Board on Geographic Names

Carnuel—populated place, in Tijeras Canyon 4.8 km (3 mi) east of Albuquerque; name is reportedly derived from the Cañon de Carnuel Grant, given to landless persons by the Spanish judge of Albuquerque in 1819; Bernalillo County; sec. 25, T. 10 N., R. 4 E., NMPM; 35°03′50″ N., 106°27′24″ W.; *not:* Carnue.

Carthage—locality, 6.4 km (4 mi) east-northeast of Old Carthage and 19.3 km (12 mi) east-southeast of San Antonio; location of former post office for mining community now known as Old Carthage; Socorro County; sec. 8, T. 5 S., R. 3 E., NMPM; 33°53′00″ N., 106°39′32″ W.

Deerhead Canyon—canyon, 3.2 km (2 mi) long, heads at 32°56′32″ N., 105°45′05″ W., trends west-southwest to Haynes Canyon 5.3 km (3.3 mi) southeast of High Rolls and 16.9 km (10.5 mi) east-northeast of Alamogordo; Otero County, New Mexico; sec. 1, T. 16 S., R. 12 E., New Mexico Principal Meridian; 32°56′07″ N., 105°46′43″ W., *not:* Haynes Canyon.

Haynes Canyon—canyon, 6.4 km (4 mi) long, heads at 32°55′52″ N., 105°45′55″ W., trends northwest to Fresnal Canyon 0.81 km (0.5 mi) east of High Rolls and 12.9 km (8 mi) northeast of Alamogordo; Otero County, New Mexico; secs. 1,2,3,4, and 12, T. 16 S., R. 12 E., New Mexico Principal Meridian; 32°57′03″ N., 105°49′ 30″ W.

Mockingbird Mountains—mountains, highest elevation 2,271 m (7,450 ft), 12.9 km (8 mi) long, forms the north end of the San Andres Mountains, south of Mockingbird Gap between Tularosa Valley on the east and Jornada del Muerto on the west, 64 km (40 mi) northwest of Tularosa; Socorro County, New Mexico; T. 9, 10 S., R. 4,5 E., New Mexico Principal Meridian; 33°34′ N., 106°27′ 30″ W. (north end), 33°27′30″ N., 106°27′30″ W. (south end).

Nogal Arroyo—watercourse, 8 km (5 mi) long, heads at the mouth of Nogal Creek at 33°37′34″ N., 105°45′08″ W., trends northwest to head of Nogal Draw 5.6 km (3.5 mi) northeast of Carrizozo; nogal is Spanish word for "walnut tree"; Lincoln County, sec. 29, T. 7 S., R. 11 E., NMPM; 33°40′20″ N., 105°49′26″ W.

Nogal Canyon—canyon, 23.3 km (9 mi) long, heads in the Sierra Blanca at 33°30′30″ N., 105°48′15″ W., trends northeast along the course of Nogal Creek to open out 1.6 km (1 mi) north of Nogal; Lincoln County; sec. 32, T. 8 S., R. 13 E., NMPM; 33°34′25″ N., 106°42′28″ W.

Nogal Creek—stream, 23.3 km (14.5 mi) long, heads in the Sierra Blanca at 33°30′30″ N., 105°48′15″ W., flows northeast 14.5 km (9 mi) through Nogal Canyon, then northwest to the head of Nogal Arroyo 11.3 km (7 mi) east-southeast of Carrizozo; Lincoln County; sec. 21, T. 8 S., R. 11 E., NMPM; 33°37′34″ N., 105°45′08″ W.

Nogal Creek—stream, 23.3 km (14.5 mi) long, heads in the Sierra Blanca at 33°30′30″ N., 105°48′15″ W., flows northeast 14.5 km (9 mi) through Nogal Canyon, then northwest to the head of Nogal Arroyo 11.3 km (7 mi) east-southeast of Carrizozo; Lincoln County; sec. 12, T. 8 S., R. 11 E., NMPM; 33°37′34″ N., 105°45′08″ W.

Old Carthage—locality, 6.4 km (4 mi) west-southwest of Carthage and 13.7 km (8.5 mi) southeast of San Antonio; location of former mining community and Carthage coal mines which existed from 1880 and 1885; Socorro County; sec. 15, T. 5 S., R. 2 E., NMPM; 33°52′36″ N., 106°43′37″ W.; *not:* Carthage.

—Dave Love,
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