GEOLOGY AND COAL RESOURCES OF THE ALAMO BAND NAVAJO RESERVATION, SOCORRO COUNTY, NEW MEXICO

by

JoAnne Cima Osburn

New Mexico Bureau of Mines and Mineral Resources

Open-File Report 160

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U.S. Geological Survey and New Mexico Bureau
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Administrative Report to the U. S. Bureau of Indian Affairs
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CONCLUSIONS

The Alamo Band Navajo Reservation is located in the Datil Mogollon Subprovince on the southeastern edge of the Colorado Plateau. 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. The lowest 400 feet of the 1000 foot-thick Crevasse Canyon Formation contain coals derived from plant material accumulated in lagoons or coastal swamps while the coals occurring stratigraphically higher in the Crevasse Canyon Formation were derived from plant materials accumulated in fresh-water swamps further inland from the seacoast.

Eight 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 these same core samples yielded average values of 12.7 percent ash, 0.6 percent sulfur, and 12,135 BTU/lb. on an as-received basis.

Coal resources on the reservation were calculated using reliability, thickness and depth categories. Only measured and indicated resources were calculated because of the discontinuous nature of the coal beds and the structural complexities of the area. Demonstrated resources for the reservation amount to 35.37 million tons of coal. A total of 65% of the resources occur under less than 150 feet of overburden. About 83% of all coal resources on the reservation have stripping ratios of overburden to coal thickness in excess of 20:1.

The coal resources of the Alamo Band Navajo Reservation are very limited and do not constitute a major resource. Small resource figures coupled with the remote location of the reservation demands that any exploitation of this resource be done on a local scale.

INTRODUCTION

Purpose and Scope

The information compiled and synthesized in this report was gathered as part of a program of mineral resource studies on Indian reservations conducted by the U. S. Geological Survey for the Bureau of Indian Affairs. The present investigation was conducted by the New Mexico Bureau of Mines and Mineral Resources as a result of a cooperative agreement between that organization, the Alamo Band Navajo Indians, and the U. S. Geological Survey. This report specifically evaluates the coal resource potential of the Alamo Band Navajo Reservation.

This report consists of a detailed (1:24,000 scale) geological map (Plate 1) compiled from three theses and four other maps made by members of the Bureau staff, an accompanying geologic report with emphasis on coal resource potential of the area, geologic cross-sections (Plate 2), and logs of drillholes completed for both stratigraphic and resource evaluation (Appendix 1). Most maps used in this study did not have specific coal outcrop data plotted. Some stratigraphic names had to be changed to reflect recent work, primarily by Hook and Cobban (1978, 1979; and Hook, Molenaar, and Cobban, in prep.). These problems, plus differences in mapping style, were resolved by using aerial photograph interpretation and field checking. Many of the original maps used in the compilation are also available as New Mexico Bureau of Mines and Mineral Resources Open-file maps. The drilling program on the Alamo Reservation was part of a larger project on the geology of the central Datil Mountains that included about forty percent of the reservation lands.

Location and Accessibility

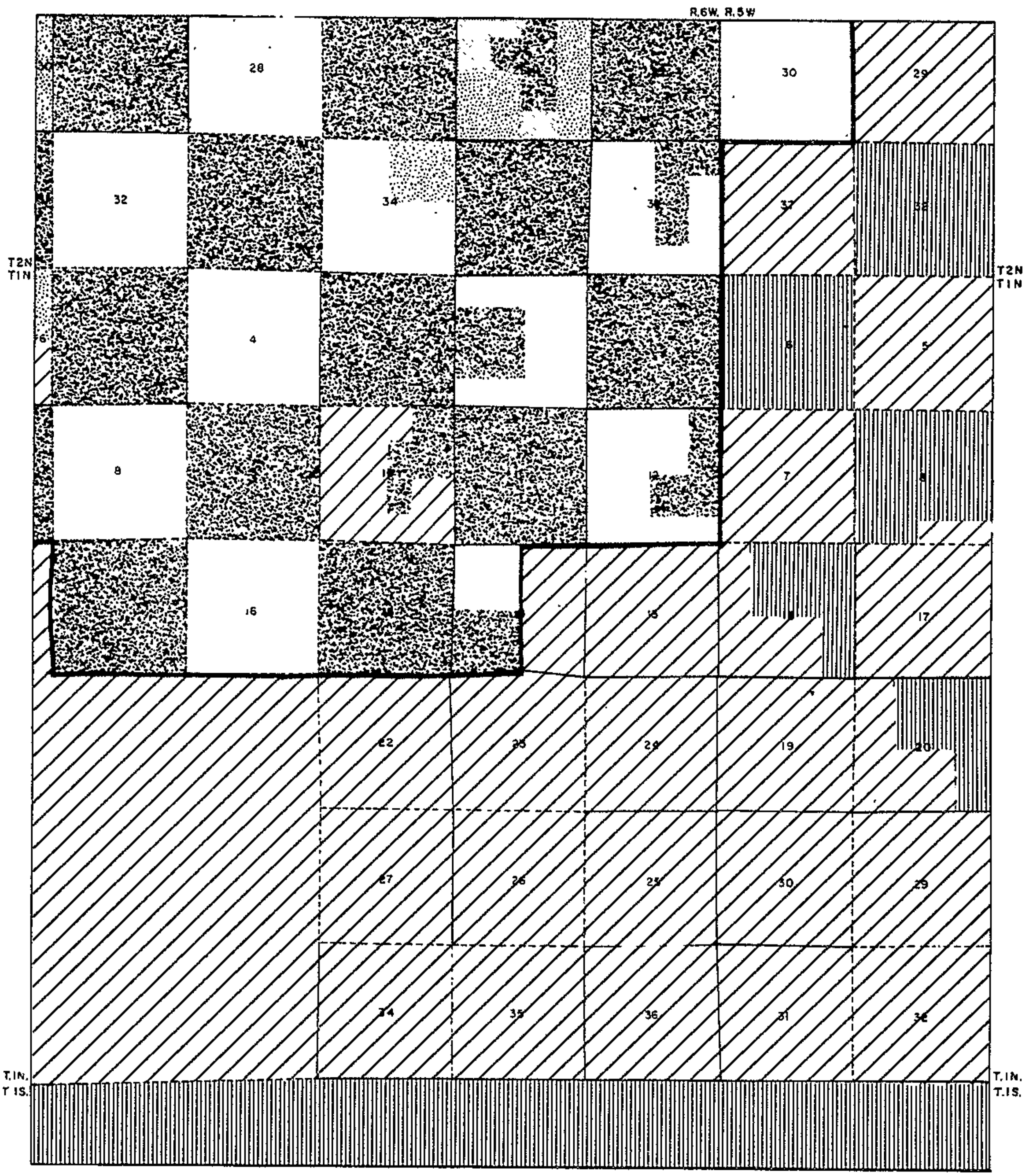
The Alamo Indian Reservation comprises about 86 square miles located about 20 miles northwest of Magdalena in northwestern Socorro County. The reservation can be reached by car on U.S. 52. A paved continuation of this road runs along the western boundary of the reservation to the Navajo Community Center where it continues north but is unpaved. Numerous dirt roads and tracks provide access to nearly all portions of the reservation.

Land Ownership

Ownership maps (figs. 1-6) of both surface and mineral rights on the reservation were compiled using county, BLM, Forest Service, and Indian records. These sources often present conflicting data. The surface ownership on the Alamo Band Navajo Reservation is divided into three different categories of Indian lands and lands held by non-Indians. The mineral ownership can be divided into Indian, Federal, railroad and private lands. The Indian records were considered most accurate unless a combination of the other sources presented strong evidence to the contrary. Some of the conflicts were unresolvable; surface rights conflicts are presented in Table 1.

The majority of the surface rights on the Alamo Band Navajo Reservation belong to the Alamo Band Navajo of the Puertecito Navajo and the United States government as provided by a warranty deed entered in the Socorro County records on June 7, 1948. Alamo Band land comprises 54% of the study area. Indian Allotment sections belonging to specific members of the Alamo Band comprise 25% of the reservation land. Private ownership by non-Indians accounts for 14% of the reservation. The remaining 7% of the land surface is owned by the entire Navajo Tribe.

Surface Ownership of Indian Spring Canyon Quadrangle



Legend

Private
Navajo Tribe
Public domain
Alamo Band
Indian Allotment
National Forest
Conflicting ownership data
Boundary, Indian lands

Figure 1

Surface Ownership of Puertecito Quadrangle

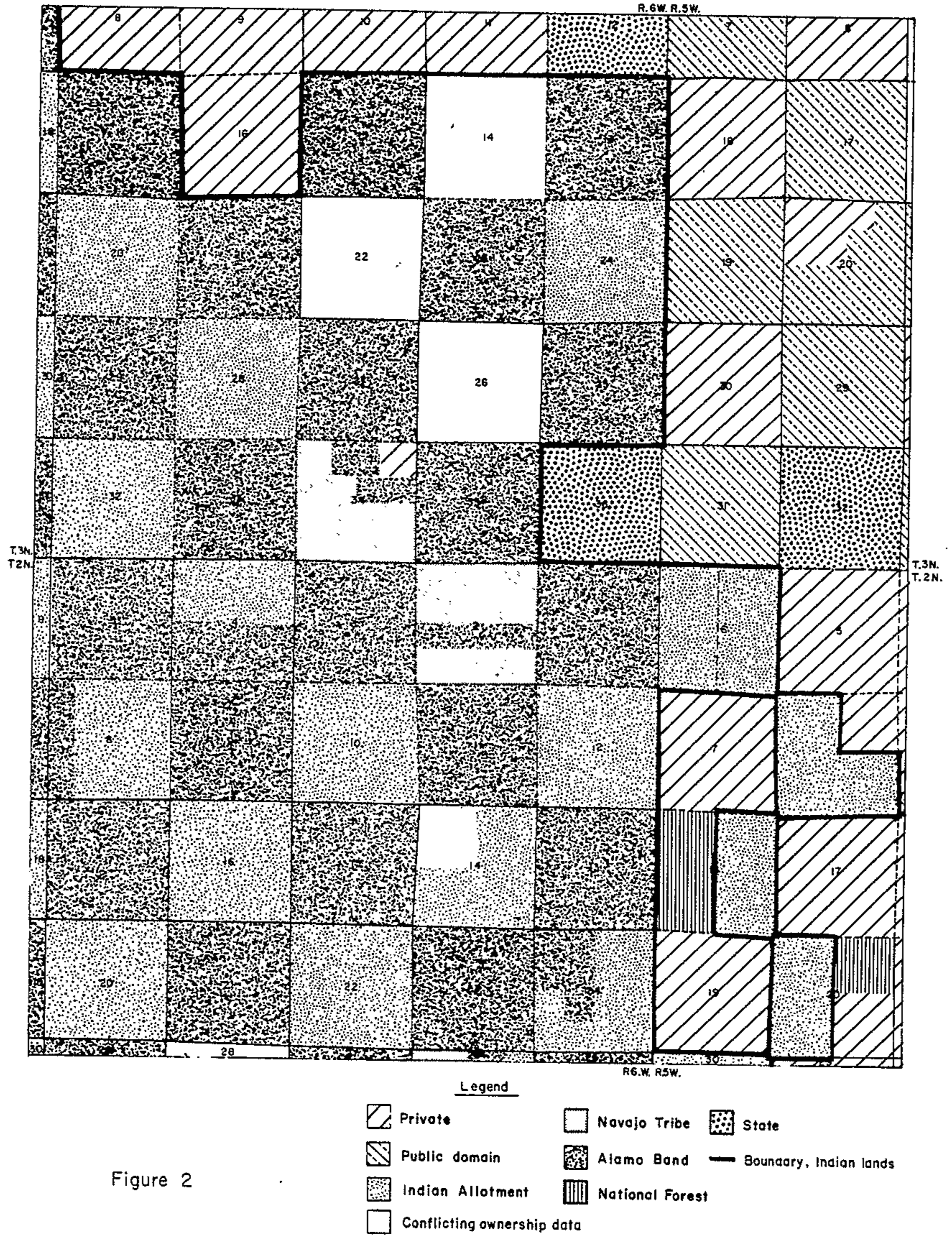


Figure 2

Surface Ownership of Table Mountain Quadrangle

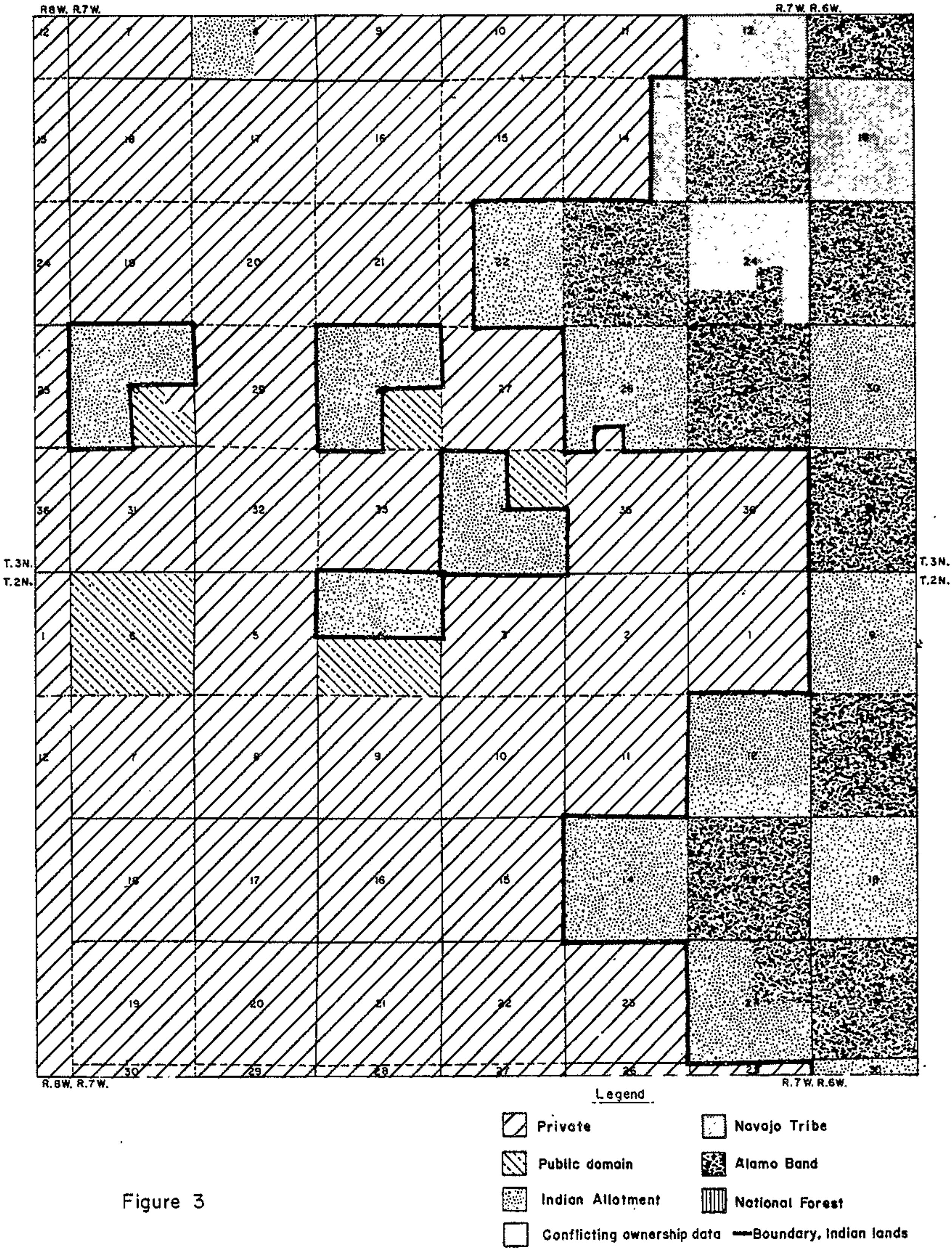


Figure 3

Mineral Ownersnip of Indian Spring Canyon Quadrangle

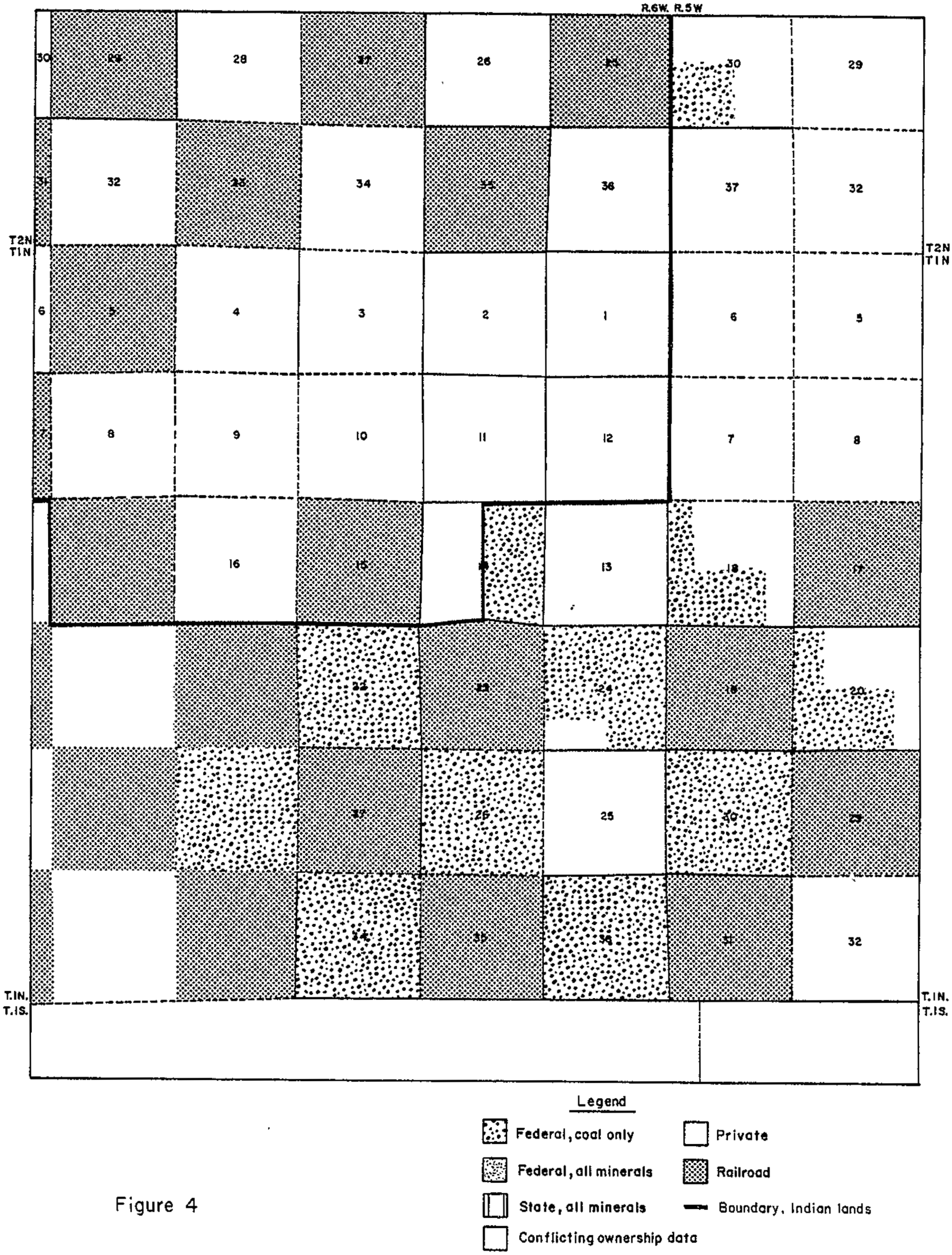


Figure 4

Mineral Ownership of Puertecito Quadrangle

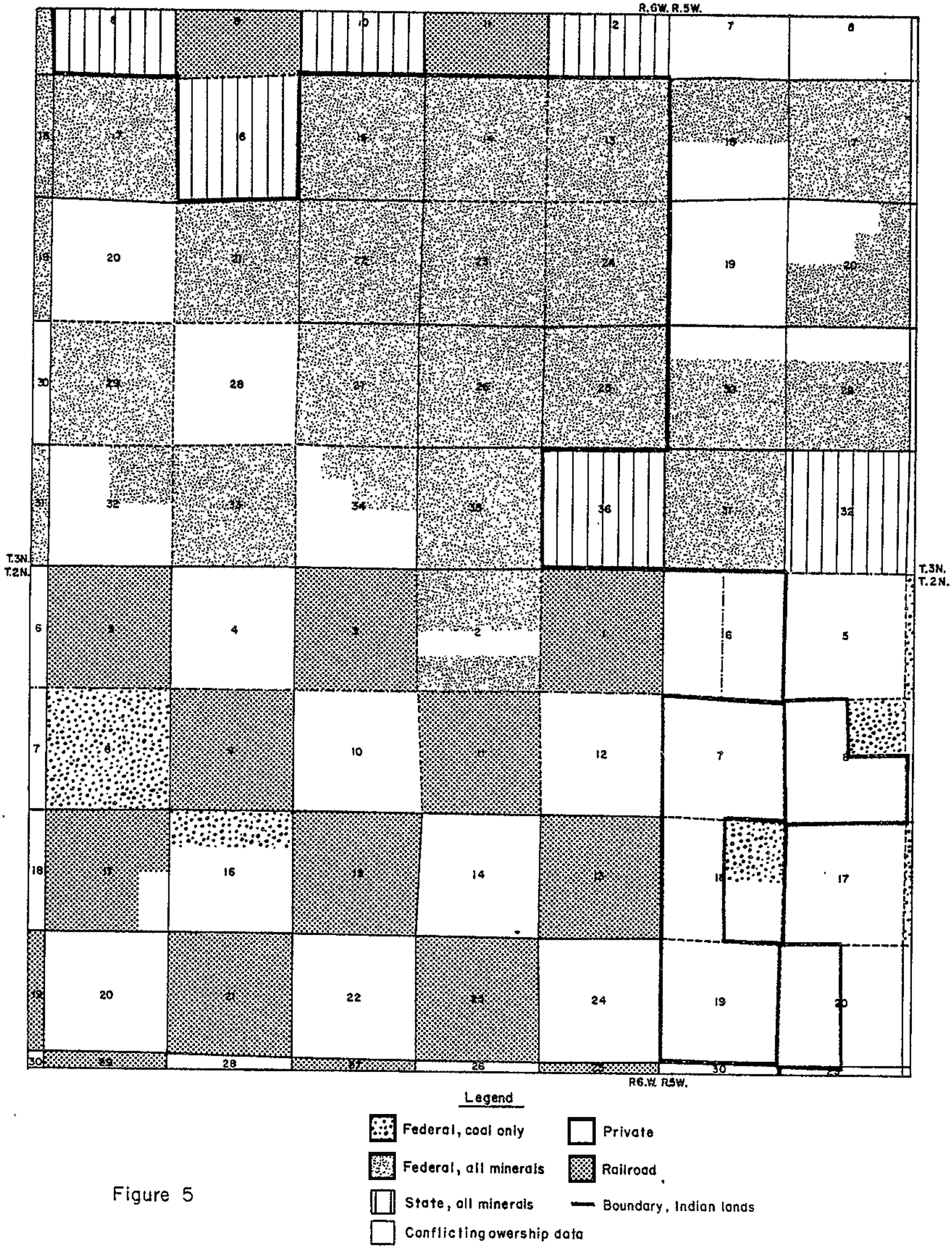


Figure 5

Mineral Ownership of Table Mountain Quadrangle

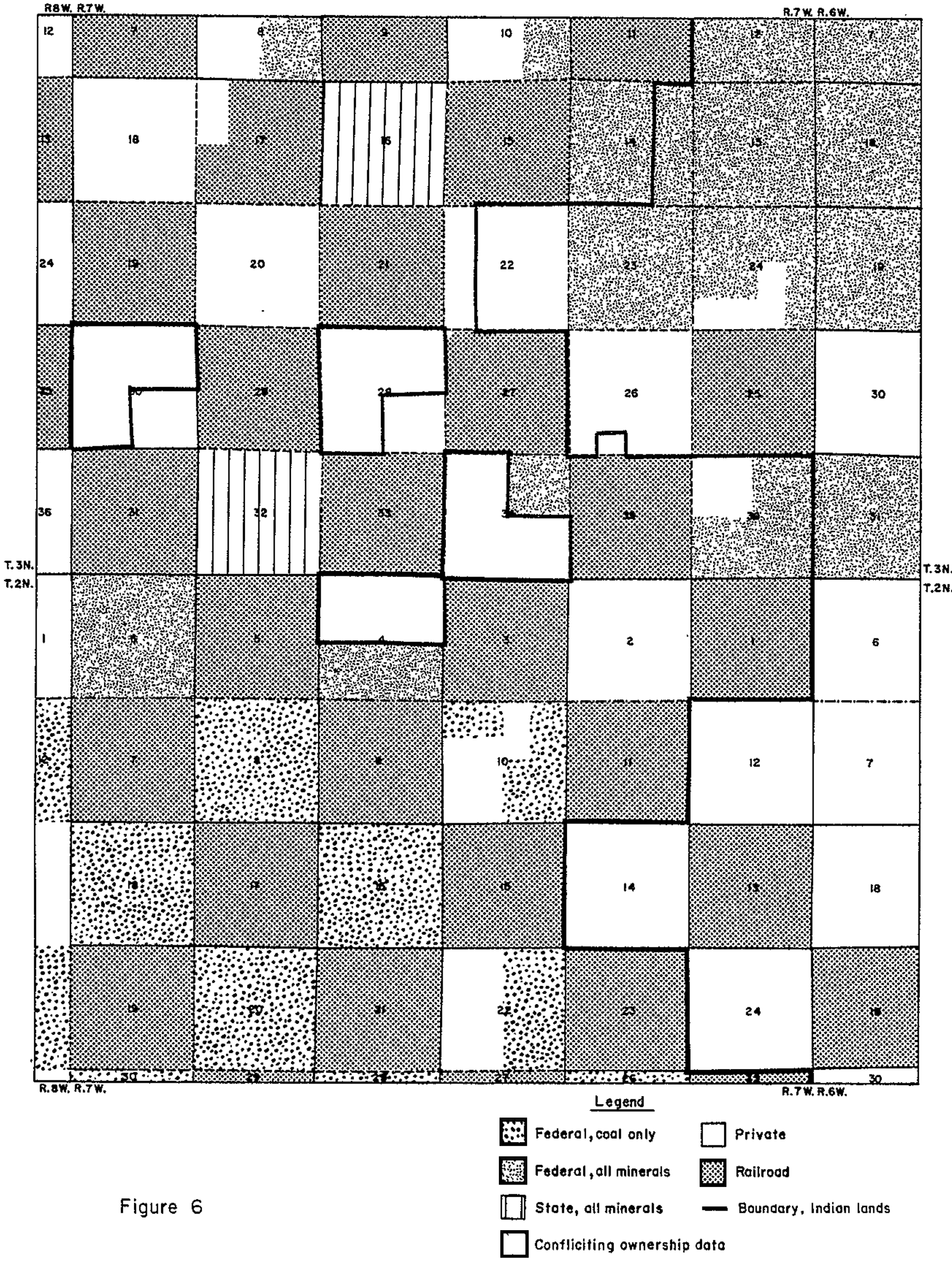


Figure 6

TABLE 1

Conflicting surface ownership data on the Alamo Band Navajo Reservation

	Sources of surface ownership information			
Location	County Records 1981 tax records, deeds	BLM Records MTP's, color quads	Indian Records 1979 Bovay Eng. Map	U.S. Forest Service Oral com. J. Logan, 1981
T. 1 N., R. 6 W.				
Sec. 2, E½, N½NW¼ and S½SW¼;	Alamo Band Navajo Land	Indian land	Navajo land	Private land
Secs. 4 and 8;	"	"	"	"
Sec. 10, W½, S½SE¼, NE¼SE¼, and W½NW¼NE¼;	"	"	"	"
Sec. 12, W½, W½NE¼, and S½SE¼;	"	"	"	"
Sec. 16;	"	"	"	"
Sec. 18, NW¼;	"	"	"	"
Sec. 14, NW¼.	National Forest	Indian land	Indian Allotment	Private land
T. 2 N., R. 5 W.				
Sec. 30.	Private land	Indian land	Indian Allotment	Private land
T. 2 N., R. 6 W.				
Sec. 14, NW¼;	Navajo lands	Indian land	Indian Allotment	Private land
Sec. 28, NE¼	"	"	"	"
Sec. 32;	"	"	"	"
Sec. 34, W½, SE¼;	"	"	"	"
Sec. 28, W½, SE¼;	"	"	"	Indian land
Sec. 36, W½, S½SE¼, NE¼SE¼, SE¼NE¼.	"	"	Navajo land	Private land
T. 3 N., R. 6 W.				
Sec. 14;	Santa Fe Railroad	Indian lands	Navajo lands	--
Sec. 22;	"	"	"	--
Sec. 26.	"	"	"	--
T. 3 N., R. 6 W.				
Sec. 36, E½, SW¼	Private land	Indian land	Navajo Tribe	
Sec. 36, NW¼.	"	"	Indian Allotment	

Mineral ownership on the reservation is divided among private (42%), Federal (30%), and railroad (28%) owners. The private ownership category undoubtedly includes some mineral rights owned by the Alamo Indians, both as a group and individually, but to resolve the individual owners would require extensive patent, deed, and title searches that are beyond the scope of this project. For the purposes of this report, Indian minerals ownership is considered private ownership. The Alamo Band is currently investigating ownership problems on the reservation. Federal mineral rights are divided into two categories: Federal ownership of all minerals (94%) and Federal retention of only the coal rights (6%). Railroad ownership is noted because the large amount of land under railroad control requires that any minerals exploration in the area must involve permission of the railroad. The Atchinson, Topeka, and Santa Fe Railroad mineral rights stem from an Act of Congress on July 27, 1866 that granted the Atlantic and Pacific Railroad these lands (Myrick, 1970). The railroad has sold most of the surface rights in the Central Datil Mountains but retains most of the mineral rights (Dale Trubey, Santa Fe Mining Co., oral communication, 1981).

Physiography

The Alamo Reservation lies in the Datil Mogollon Subprovince, a transitional zone between the Basin and Range Province and the Colorado Plateau Province (Hawley and Love, 1981). The landscape is dominated by a series of gently-dipping sandstone cuestas and intervening shale valleys formed by differential erosion of the Upper Cretaceous rocks that comprise most of the surface rocks. The northern half of the reservation is made up of broad alluvial surfaces underlain by sediments deposited by the Rio Salado (locally known as Alamocito Creek) and its tributaries. The landscapes in the southwestern part of the reservation are dominated by Tertiary piedmont slope deposits.

Local relief is approximately 1050 feet. The low point is located in the channel of the Rio Salado at about 5900 feet above sea level while the high point is 6950 feet above sea level on the Tertiary piedmont slopes in the southwest corner of the reservation.

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). Winchester's report was an oil and gas report in name only; he measured many stratigraphic sections of coal-bearing Cretaceous rocks in the upper Rio Salado drainage basin during 1913 and 1914. Most of the sections contained coal beds and these unpublished measured sections provide the most comprehensive outcrop coal data available on the Datil Mountains coal field even today.

In 1957, Tonking mapped the Puertecito 15' quadrangle which encompasses nearly all of the Alamo Reservation. He was the first to apply the name Crevasse Canyon Formation to the coal-bearing sequence in the area. Field relationships defined by Tonking stand today but later work was necessary to refine Tonking's La Cruz Peak Formation (name since abandoned, comprised of intertonguing rocks of the Dakota Sandstone and Mancos Shale) into units that are regionally correlative and to make similar refinements in the Tertiary volcanic rock sequence. Givens (1957) split the La Cruz

Peak Formation into Dakota Sandstone and Mancos Shale units in a map of the Dog Springs quadrangle to the west.

Landis and others (1973) recognized the Twowells Tongue of the Dakota Sandstone in the area. Under the direction of C. E. Chapin, Mayerson (1979) and Jackson (1979) remapped the southeastern 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 show the Mancos Shale and Tres Hermanos Formation.

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 provided a mineral potential summary of the Indian lands to the Bureau of Indian Affairs in 1980. Their report recommended a study of the coal resource potential of the Alamo Band Navajo Reservation lands.

Acknowledgments

The author is grateful for the continuing cooperation of the Alamo Band Navajo Tribe in providing guides, driller's helpers and advice on land ownership, road conditions, and logistical problems. The stratigraphic drilling in the study could not have been accomplished without the tireless negotiations of Jessie Apachito, the President of the Alamo Band, and George Austin, Deputy Director of the New Mexico Bureau of Mines and Mineral Resources. Both Robert Gray and Dale Trubey of Santa Fe Mining, Inc. helped with ownership problems and gave us permission to drill on company property.

Stephen C. Hook provided helpful advice and suggestions on the stratigraphic problems in the area. G. Robert Osburn aided in the map compilation and also offered many suggestions on the volcanics and the regional structural framework.

This project has been done under a cooperative agreement with the U. S. Geological Survey, control number 9420-0067 and the drilling was partially funded by another contract with the U. S. Geological Survey, control number 14-08-0001-18722.

Special thanks go to E. R. Landis of the U. S. Geological Survey and S. C. Hook of Getty Oil Company. They critically reviewed this manuscript and tremendously improved all parts of this report.

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 opening of the Rio Grande Rift. In addition, there are a few, possibly historic, block faults (Plate 2).

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 (Robinson, 1980; Mayerson, 1979). However, 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. Recent work about 15 miles to the south on the Lion Mountain area by G. R. Osburn and Laroche (1981) show similar broad-scale folds with similar trends that fold the Oligocene volcanic section. This work suggests that not all the folding in the area is necessarily associated with the Laramide uplift; more work needs to be done on the implications of folding in an overall extensional regime (G. R. Osburn, oral communication, 1982).

Numerous small-displacement normal faults occur in the east-central portion of the reservation. All these faults trend north to northwest and are down to the west. Chapin and others (1979) suggest that these faults developed during the early stages of the development of the Rio Grande Rift.

Faults with different trends than those associated with the Rio Grande rift are also present in the area. These faults trend to the northeast and some have large displacements. For example, in the extreme northwest corner of the reservation, one of these faults cuts the Pliocene basalt flows on Tres Hermanos Mesa and juxtaposes the Twowells Tongue of the Dakota Sandstone against the Crevasse Canyon Formation, a displacement of at least 700 feet. Chapin and others (1979) attribute faults having this trend to periodic reactivation of the Tjeras lineament, a major northeast-trending basement fault zone of Precambrian ancestry.

STRATIGRAPHY

Triassic System

Triassic redbeds that make up the Chinle Formation are the oldest rocks exposed in the study area (about 200 million years old). The unit is a slopeformer and usually is poorly exposed except in stream cuts. The unit underlies broad valleys near the northern boundary of the reservation and just east 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. Paleocaliches have been seen in at least one exposure on the reservation (sec. 18, T. 3 N., R. 6 W.) and the unit is at least slightly calcareous throughout. A maximum thickness of 120 feet is exposed on the reservation but Massingill (1979) reports up to 500 feet 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. O'Sullivan (1977) suggested that the upper Triassic sediments were deposited by streams flowing northward across broad, contintental floodplains that covered much of New Mexico in Triassic time.

Cretaceous System

A minimum of 1900 feet of Upper Cretaceous rocks crop out on the Alamo Indian Reservation. These rocks record deposition from Cenomanian to Coniacian time and represent offshore marine, paralic and continental fluvial paleoenvironments (Robinson, 1980). Five 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 are mapped, the lower part of the Dakota Sandstone and the younger Twowells

Tongue. The Twowells Tongue apparently pinches out about two miles south of the Rio Salado and has not been recognized south of that point.

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 and has been mapped inconsistently by various workers. All of the mappers involved in this project 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 southern-most exposure of the Twowells Tongue is found in section 31, T. 2 N., R. 5 W. South of this point the Twowells apparently pinches out. Jackson (1979), Mayerson (1979), and Massingill (1979) all applied the name Alamito Well Tongue of the Mancos Shale to the strata above the Dakota Sandstone and below the Tres Hermanos Formation where the Twowells Tongue of the Dakota is not present; however, this is an informal name and will not be used in this report.

Mancos Shale

The name Mancos Shale was first applied to a 1200-foot thick sequence of dark colored shales cropping out near the town of Mancos in southwestern Colorado (Cross, 1899). The Mancos is split into multiple tongues in the San Juan, Zuni, and Acoma Basins in New Mexico. Recent workers have demonstrated marker faunal and bentonite beds in the Mancos tongues occurring in New Mexico that serve as useful stratigraphic correlation tools (Landis and others, 1973; Molenaar, 1974; Hook and others, 1978-1980; Hook and others, in preparation).

Three Mancos tongues are mapped in the northern part of the area, the lower part of the Mancos below the Twowells Tongue of the Dakota, 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. To the south, beyond the pinchout of the Twowells Tongue, the entire shale sequence occurring stratigraphically between the Dakota Sandstone and the Tres

Hermanos Formation is called the lower part of the Mancos Shale.

Lower Part of the Mancos Shale

The lower part of the Mancos Shale in west-central New Mexico is made up of rocks of different time equivalency that cannot be included in established formal units because of complex intertonguing relationships that negate the original formational descriptions (Landis and others, 1973). On the Alamo Indian Reservation, the lower part of the Mancos Shale is a series of medium to dark gray shales and thin, silty sandstones between the underlying Dakota Sandstone and the overlying Twowells Tongue of the Dakota. Where the Twowells Tongue of the Dakota Sandstone is absent, the upper boundary of the lower part of the Mancos is at the base of the Tres Hermanos Formation. This unit ranges from 180-280 feet in thickness depending on whether or not the Twowells Tongue of the Dakota Sandstone is present.

The lower part of the Mancos exposed on the reservation was deposited in a low energy environment as an offshore, shelf mud. Minor silty sandstones throughout the tongue probably represent storm sedimentation (Mayerson, 1979).

Rio Salado Tongue of the Mancos Shale

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, in preparation). The Rio Salado Tongue is named for exposures along the Rio Salado near Puertecito on the Alamo Reservation. The Rio Salado is typically a medium-gray to brownish-gray silty mudstone with thin, light brownish-gray, nodular limestones throughout. About ten feet above the basal contact with the Twowells, the Rio Salado Tongue contains Sciponocerous gracile, a standard zone ammonite of the Western Interior Cretaceous (Cobban and Scott, 1972); the top of this ammonite zone was accepted as the Cenomanian-Turonian boundary. An oyster, Pycnodonte newberryi (Stanton), also occurs in the Sciponocerous 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, and it has a very limited vertical extent (Hook and Cobban, 1978). Cobban and Hook (1979) have identified Mammities depressus (Powell) and Collignoniceras woollgari woollgari in the upper part of the Rio Salado Tongue near D Cross Mountain to the west of the reservation. Several partial specimens of M. depressus have been found in concretions near the top of the Rio Salado Tongue on the

Alamo Reservation. The presence of these ammonites indicates a middle Turonian age for the upper part of the Rio Salado Tongue (Cobban and Hook, 1979).

D-Cross Tongue of the Mancos Shale

The D-Cross Tongue of the Mancos Shale was originally defined by Dane and others (1957) as the shale body between the lower part of the Gallup Sandstone and the Gallego Sandstone (now called the Tres Hermanos Formation and the Gallup Sandstone, respectively.) The type locality is at D Cross Mountain, about twelve miles west of the Alamo Reservation.

The D-Cross Tongue is Late Turonian in age (Hook and Cobban, 1979). Hook and Cobban have collected the same fossils in the lower part of the D-Cross Tongue that are present in the Juana Lopez Member of the Mancos Shale in the San Juan Basin; hence they consider the lower part of the D-Cross and the Juana Lopez Member time-equivalent units.

The D-Cross Tongue is a slope-forming unit present throughout the study area. Mayerson (1979) reports a maximum thickness in the area of 95 feet; graphical calculations done on Jackson's (1979) map to the north of Mayerson's map show a maximum thickness of about 140 feet. The unit can 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: Prinocyclus novimexicanus, Scaphites ferronenis, Coilopocerous 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. In addition, there are several light-colored sandstone beds less than one foot thick in the upper part of the D-Cross. Fossils identified from the upper part of the D-Cross include: Lopha sannionis, Prinocyclus novimexicanus, and Baculites yokoyami (Hook and Cobban, 1979). The contact of the D-Cross Tongue with the underlying Fite Ranch Member of the Tres Hermanos Formation is gradational over about 15 feet. 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 one foot (Robinson, 1980).

Robinson (1980) 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 name Tres Hermanos Sandstone was first used by Herrick (1900) to describe Cretaceous rocks that crop out east of the intrusive Tres Hermanos Peaks along the Rio Salado on the Alamo Indian Reservation. Since that time, the name has been applied to many different sandstone beds in the Upper Cretaceous sequence (Dane and others, 1971; Hook, personal communication, 1981). Hook and others (in preparation) have redefined the unit and have elevated the Tres Hermanos to formational status. The Tres Hermanos Formation comprises a basal coastal sandstone sequence, a middle paludal to continental sequence, and an upper, coastal sandstone sequence. They have defined the limits of the Tres Hermanos based on their interpretation of Herrick's original descriptions and have defined members. The members are called in ascending order: the Atarque Member, the Carthage Member, and the Fite Ranch Member. These members have not been separately mapped in the study area and it is beyond the scope of this project to remap the area to differentiate them.

The lower part of the Tres Hermanos, the Atarque Member, consists of about 70 feet of yellowish gray, thin to medium bedded sandstone. This sandstone shows a number of sedimentary structures including cross-bedding, bioturbation, ripples, and abundant fossils in concretions and lentils. Massingill (1979) collected the following fossils east of the reservation at Riley: _Collignoniceras woollgari woollgari_, _Baculites yokoyami_, _Proplacenticeras pseudoplacenta_, _Cardium pauperculum_, and _Gyrodes depressus_.

The middle part of the Tres Hermanos Formation, the Carthage Member, is a sequence of paludal shales and thin, calcareous sandstones. Petrified wood and large pelecypods are common on the east side of Tres Hermanos Mesa (Osburn, 1982). Sandstones in the Carthage Member are typically cross-bedded and have scoured, sharp bases. Thin coals, less than 1.2 feet, are present in the upper portion of the interval. These coals are typically lenticular. The Carthage Member probably represents sedimentation on a marshy coastal plain.

The upper part of of the Tres Hermanos Formation, the Fite Ranch Member, consists of 40-90 feet of fine to very fine-grained sandstone in the study area (Mayerson, 1979). This sandstone generally coarsens upward, is bioturbated, burrowed and in some places has medium-grained, fossiliferous sandstone lenses. Like the Atarque Member, the Fite Ranch Member represents deposition of a coastal barrier and shoreface sequence.

MESAVERDE GROUP

Gallup Sandstone

The Gallup Sandstone in the study area is a cliffy, 30-70 foot thick sandstone that lies conformably above the D-Cross Tongue of the Mancos Shale. Winchester (1921) originally named this interval the Gallego Sandstone for exposures on Pueblo Viejo Mesa, about seven miles northwest of the reservation.

The contact of the Gallup Sandstone with the 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 cross-beds, and burrow mottling. This lower part of the unit represents a transitional zone between the offshore muds of the D-Cross Shale and 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.

Crevasse Canyon Formation

The Crevasse Canyon Formation crops out on the reservation as a southeast-trending band covering about 24 square miles (Plate 1). Outcrops appear as a series of gently dipping, low hills capped by thin, resistant, sandstone layers.

Allen and Balk (1954) applied the name Crevasse Canyon Formation to a coal-bearing sequence between the Gallup Sandstone and the Point Lookout Sandstone on the western flank of the San Juan Basin. Tonking (1957) extended the terminology into the study area.

The Crevasse Canyon Formation consists of a sequence of generally fine-grained sedimentary 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 about 60 feet above the Gallup Sandstone. This stratigraphic position has been documented both in measured sections and in the subsurface in a drill hole to the north on the Pueblo Viejo Mesa quadrangle (Osburn, 1982). 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 largely composed of fine-grained sandstone. Siltstones and mudstones with thin coals make up about 30 percent of the upper part of the formation. Coals present in this interval range in thickness from six inches to two feet. 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 or brackish water indicators thus indicating a lack of marine influence on the upper part of the Crevasse Canyon (Chapin and others, 1979).

TERTIARY SYSTEM

Tertiary rocks and their relations 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 Eocene Baca Formation. Volcanism to the south of the area during Oligocene time was the source of the volcanoclastic apron called 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, and piedmont deposits derived from erosion of earlier Tertiary deposits.

Eocene

Baca Formation

The Baca Formation is composed of sediments deposited during Laramide time in a large intermontane basin stretching from Carthage, New Mexico westward to the Arizona border (Cather, 1980). 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).

The Baca Formation in the study area comprises a redbed sequence of sandstones, siltstones, shales and conglomerates. Cather (1980) measured a 941-foot thick section of the Baca on the reservation. He recognized three informal map units in the area: a lower red unit, a middle sandstone unit, and an upper red unit, following the conventions of Potter (1970). 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. It is probable that this facies is buried under younger gravels in the southern portion of the reservation and that future uranium tests should be confined to this area.

Oligocene

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 volcanoclastic 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. Volcanic units constitute a greater proportion of the Spears sedimentary deposits to the south and southwest. The environment of deposition at this time consisted of alluvial fans prograding into the former Baca lake area. The sedimentary facies of the Spears show complex lateral facies relationships.

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 stratigraphicaly lowest horizon where recognizable volcanic detritus is found. In some areas, lacustrine sedimentation characteristic of the upper part of the Baca Formation may have continued into Spears time (S. M. Cather, personal communication, 1981).

Within the area immediately surrounding the Alamo Reservation, the Spears Formation is about 1000 ft thick. In areas to the west and south where more volcanic units are present within this formation, the Spears may be as much as 2000 feet thick.

Miocene

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 opening of the Rio Grande Rift (Chapin and others, 1974). The dikes are typically less than eight feet in width and range from a few feet to thousands of feet in length. These features resemble man-made rock walls in the field.

The 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 feet thick.

Pliocene

Basalt flows

Flows of basaltic composition cap Tres Hermanos Mesa in the northwestern part of the reservation. These flows typically have ropey 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 three to six million years before present (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.

Tertiary Gravels

Tertiary gravels cover much of the southwestern part of the reservation and are present throughout the Datil Mountains. 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 coming from the Gallinas Mountains. The gravels are of several different ages and were deposited on a deeply eroded surface of the Crevasse Canyon dipping to the north. The youngest gravels are equivalent to the Popotosa Formation. Studies north of the Rio Salado of the stratigraphically lowest Tertiary gravels show that these gravels were being deposited prior to the establishment of the Rio Salado drainage (Osburn, 1982). Gravels in the upper part of the Tertiary gravel sequence are piedmont slope deposits that clearly grade to the Rio Salado and, hence, are much younger than gravels in the lower part of the Tertiary gravel sequence.

Quaternary System

Quaternary deposits on the reservation can be divided according to type and relative age of the deposit. Most of the Quaternary deposits in the area have been grouped together and called undifferentiated alluvium. These deposits include floodplain deposits, blow sands, and piedmont-slope deposits in which the clasts range in size from silt to gravel. 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 comprised 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

Coal Quality

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). Coals in central New Mexico have previously been considered to be of subbituminous rank (Read and others, 1950). It is suspected that this inconsistency occurred because earlier workers generally analyzed samples of weathered coals obtained at surface outcrops. Outcrop samples typically yield lower rank determinations than fresh samples from mines or core drilling and should not be used except for a minimum rank determination. For comparision, coals from the Salt Lake coal field in west-central New

Mexico and coals of comparable age in the San Juan Basin are of lower rank than the Alamo coals (Table 2). It is possible that the higher heating values for the Alamo coals are a result of higher thermal maturation caused by being on the tectonically active edge of the Colorado Plateau (T. Hemler, Amoco Oil Co., personal communication, 1981).

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 (Appendix 2).

The sulfur content for the coals on the Alamo Reservation averages 0.6 percent. The samples were analysed with respect to forms of sulfur and it was found that an average of 83 percent of the sulfur present was organic sulfur with the remaining sulfur being pyritic. No sulfur was present as sulfate.

Table 2

Comparison of Alamo coals with Salt Lake Coalfield and lower Mesaverde Group coals in the San Juan Basin
(all values on as-received basis; modified from Campbell, 1981)

	Alamo Reservation		Salt Lake coal field		lower Mesaverde Group coals San Juan Basin	
number of samples	8		12		109	
	mean	S.D.	mean	S.D.	mean	S.D.
	percent		percent		percent	
vol. mat.	39.7	3.2	34.6	3.3	36.3	4.3
Fixed Carb.	43.9	4.3	40.1	6.3	43.9	6.3
Carbon	66.8	4.4	56.7	7.8	58.1	9.3
Moisture	3.6	4.4	4.6	3.5	11.6	5.3
Hydrogen	5.2	0.4	4.4	0.4	4.9	0.5
Nitrogen	1.2	0.2	1.1	0.1	1.2	0.2
Oxygen	9.9	1.5	11.6	1.5	14.9	7.1
Sulfur	0.6	0.1	0.9	0.3	1.0	0.9
Ash	12.7	6.7	20.7	9.2	8.4	4.7
as received BTU/ lb.	12,135		9,920		11,255	

Coal Resources

A total of ten stratigraphic test holes were drilled on or near the reservation. The drillholes averaged 280 feet in depth and had a range of 197-320 feet. Drillhole summaries that include coal beds encountered, geophysical tests run, and other data available comprise Appendix 1. Samples of drill cuttings were taken at five-foot intervals and all holes were geophysically logged. The holes were located to test all stratigraphic portions of the Crevasse Canyon Formation and nine of the holes contained coal beds thicker than fourteen inches. Six of the nine holes were offset and redrilled to obtain core samples of the thicker coals for analysis. The lenticularity and discontinuous nature of the coal beds was shown during the core drilling; three seams greater than 2.5 feet thick were not present 20 feet 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 suggest that the coals were cut by migrating fluvial channels.

The coals present on the Alamo Reservation are bituminous in rank and hence, all resource calculations were done using a minimum thickness of fourteen inches according to U.S. Geological Survey practice. Coal seams range from 1.2 to 4.0 feet thick and average 2.0 feet thick. Coal resources were tabulated by thickness categories as established in U. S. Geological Survey Bulletin 1450-B (Table 3). To calculate the coal resources defined by a given data point, the thickness, lateral continuity, depth to coal, and areal extent were considered. Both measured and indicated categories for subeconomic resources were used as defined by Bulletin 1450-B (p. B6). The reliability of identified resource data depends on the distance that coal is assumed to extend from the data point. Measured coal is within a quarter mile of an observation point, and indicated coal is coal one-quarter to three-quarters of a mile from an observation point(Table 3). These areas were drawn on the geologic map and were measured using a planimeter.

TABLE 3

ESTIMATED RESOURCES OF BITUMINOUS COAL ON THE ALAMO RESERVATION

(in millions of short tons; all values rounded; 1800 short tons/ acre-foot used in calculations; dashes mean coal is absent in category shown; maximum depth, 350 ft; only townships with coal reported.)

	Measured thickness of coal bed in feet			Indicated thickness of coal bed in feet			
Location Twp. Rng.	1.2-2.3	2.3-3.5	>3.5	1.2-2.3	2.3-3.5	>3.5	Totals
1N. 6W.	0.95	--	--	--	--	--	0.95
2N. 6W.	4.00	5.00	0.52	15.06	2.55	--	27.13
2N. 7W.	1.74	--	--	5.55	--	--	7.29
TOTALS	6.69	5.00	0.52	20.61	2.55	0.00	35.37

The Crevasse Canyon Formation on the Alamo Reservation contains measured coal resources of 12.21 million tons considering both outcrop and subsurface data. Indicated resources are calculated using only subsurface data and equal 23.16 million tons. Hence, total resources for the Alamo Reservation total 35.37 million tons (Table 3). If coal resources for the reservation are separated into depth categories, it is noted that 66 percent or 23.31 million tons occur at depths of less than 150 feet, 22 percent or 7.66 million tons of coal occur between 150 and 250 feet, and the remaining 12 percent or 4.40 million tons are found between 250 and 350 feet. No data is currently available deeper than 350 feet from the surface (Table 4).

TABLE 4

COAL RESOURCES ON THE ALAMO RESERVATION IN DEPTH CATEGORIES
(in millions of short tons)

location twp. rng.	0-150 feet	150-250 feet	250-350 feet
1N. 6W.	0.95	0.00	0.00
2N. 6W.	18.66	4.07	4.40
2N. 7W.	3.70	3.59	0.00
	-----	----	----
	23.31	7.66	4.40

Stripping ratios of the thickness of the overburden to the thickness of the coal seam were calculated for the coals on the reservation (Table 5). The acceptable stripping ratio of a given coalbed is dependent on many factors including rank of coal, dip of coal bed, proposed method of mining, ease of mining of overburden and interburden, and distance to a railhead or major road. Mining companies in New Mexico currently will not consider coals with stripping ratios greater than fifteen feet of overburden to one foot of coal as mining targets for surface mines unless the rank of the coal is extremely high. Stripping ratios for the Alamo Reservation coals are too high for profitable surface mining considering current mining practices in the state. Eighty-three percent of the total coal resources on the reservation have stripping ratios greater than 20:1. The greater the amount of overburden that must be removed, the more expensive and difficult the mining operation. Only 6.14 million tons of coal on the reservation could be mined at stripping ratios of less than 10:1.

TABLE 5

STRIPPING RATIOS FOR COAL RESOURCES ON THE ALAMO INDIAN RESERVATION
(in millions of short tons)

location		stripping ratio		
twp.	rng.	10:1	10:1- 20:1	20:1
1N.	6W.	0.95	0.00	0.00
2N.	6W.	5.19	0.00	21.93
2N.	7W.	0.00	0.00	7.30
		----	----	-----
Totals		6.14	0.00	29.23

Potential for Mining

The coals present on the Alamo Reservation, though of excellent quality, are thin, lenticular, and discontinuous. The lower coal zone of the Crevasse Canyon 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. There are no major roads or railroads in the area and no population center nearby to use small amounts of coal. It is therefore concluded that 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 the 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, the 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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APPENDIX 1

Well Name: 26-7-1 Location: ne¼nw¼nw¼ sec 7 T2n R6w
Company: nmbm Footage: 1000 E of W line 4900 N of S line
Quadrangle: table mtn. Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: gamma, cal, dens, rest, sp, pors/neut
Total Depth: 261 ft Date Drilled: 8/4/81 Elevation: 6230 ft
Mineral Ownership: sf Surface Ownership: ab Analysis: y Cuttings: y

Formation	Depth	Elevation
Kcc	0.0	6230.

COAL 8.2

Thickness	Depth	Elevation
1.2	25.	6205.
1.5	107.	6123.
1.5	125.5	6104.5
2.5	188.	6042.
1.5	253.	5977.

Well Name: 26-9-1 Location: se¼se¼sw¼ sec 9 T2n R6w
Company: nmbm Footage: 2500 E of W line 400 N of S line
Quadrangle: puertecito Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: gam, cal, dens, rest, sp, neut/pors
Total Depth: 300 ft Date Drilled: 8/18/81 Elevation: 6160 ft
Mineral Ownership: sf Surface Ownership: ab Analysis: y Cuttings: y

Formation	Depth	Elevation
Kcc	0	6160.

COAL 7.5

Thickness	Depth	Elevation
1.2	59.	6136.
2.0	124.	6036.
1.5	249.5	5910.5
2.8	254.2	5905.8

Well Name: 26-15-1 Location: nw¼se¼sw¼ sec 15 T2n R6w
Company: nmbm Footage: 1800 E of W line 700 N of S line
Quadrangle: puertecito Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: gamma, rest, cal, dens, sp, neut/pors
Total Depth: 301 ft Date Drilled: 8/20/81 Elevation: 6350 ft
Mineral Ownership: sf Surface Ownership: ab Analysis: y Cuttings: y

Formation	Depth	Elevation
Kcc	0	6350.

COAL 3.0

Thickness	Depth	Elevation
1.2	285.8	6064.2
1.8	290.	6060.

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Well Name: 26-17-1 Location: ne¼nw¼nw¼ sec 17 T2n R6w
Company: nmbm Footage: 1300 E of W line 5000 N of S line
Quadrangle: puertecito Confidential: n
Field: datil mtns. County: socorro Water: 212., 40 gpm
Geophysical logs: gamma, cal, rest, dens, sp, neut/pors
Total Depth: 300 ft Date Drilled: 8/17/81 Elevation: 6180 ft
Mineral Ownership: sf Surface Ownership: ab Analysis: n Cuttings: y

Formation	Depth	Elevation
Kcc	0	6180.

COAL 1.7

Thickness	Depth	Elevation
1.7	78.5	6101.5

Well Name: 26-25-1 Location: se¼se¼sw¼ sec 25 T2n R6w
Company: nmbm Footage: 2300 E of W line 300 N of S line
Quadrangle: indian springs canyon Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: gamma, cal, dens, rest, sp, neut/pors
Total Depth: 319 ft Date Drilled: 9/1/81 Elevation: 6360 ft
Mineral Ownership: sf Surface Ownership: ab Analysis: n Cuttings: y

Formation	Depth	Elevation
Kcc	0.0	6360.

COAL 2.7

Thickness	Depth	Elevation
1.2	160.0	6200.
1.5	285.	6075.

Well Name: 26-25-2 Location: ne¼sw¼se¼ sec 25 T2n R6w
Company: nmbm Footage: 4500 E of W line 700 N of S line
Quadrangle: indian springs canyon Confidential: n
Field: datil mtns. County: socorro Water: 25-30, 20 gpm
Geophysical logs: gamma, cal, dens, rest, sp, neut/pors
Total Depth: 197 ft Date Drilled: 9/24/81 Elevation: 6310 ft
Mineral Ownership: sf Surface Ownership: ab Analysis: y Cuttings: y

Formation	Depth	Elevation
Kcc	0.0	6310.

COAL 6.7

Thickness	Depth	Elevation
1.3	36.	6274.
1.2	135.	6175.
2.0	138.	6172.
2.2	140.	6170.

Well Name: 26-26-1 Location: sw¼se¼ne¼ sec 26 T2n R6w
Company: nmbm Footage: 4400 E of W line 2600 N of S line
Quadrangle: indian springs canyon Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: gamma, cal, dens, rest, sp, neut/pors
Total Depth: 200 ft Date Drilled: 8/27/81 Elevation: 6260 ft.
Mineral Ownership: ia Surface Ownership: ia Analysis: n Cuttings: y

Formation	Depth	Elevation
Kcc	0	6260.

COAL 0.0

Well Name: 27-1-1 Location: nw¼nw¼nw¼ sec 1 T2n R7w
Company: nmbm Footage: 600 E of W line 5000 N of S line
Quadrangle: table mtn. Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: gamma, cal, dens, rest, sp, neut/pors
Total Depth: 199 ft Date Drilled: 7/23/81 Elevation: 6210 ft
Mineral Ownership: sf Surface Ownership: pr Analysis: y Cuttings: y

Formation	Depth	Elevation
Kcc	0	6210

COAL 11.

Thickness	Depth	Elevation
4.0	36.	6174.
2.0	76.	6138.
2.5	111.5	6098.5
1.3	168.2	6041.8
1.6	194.	6016.

Well Name: 27-1-1a Location: nw¼nw¼nw¼ sec 1 T2n R7w
Company: nmbm Footage: 600 E of W line 5000 N of S line
Quadrangle: table mtn. Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: none
Total Depth: 32o ft Date Drilled: 10/7/81 Elevation: 6210 ft
Mineral Ownership: sf Surface Ownership: pr Analysis: n Cuttings: y

Formation	Depth	Elevation
Kcc	200	6010

COAL 515

Thickness	Depth	Elevation
4.0	204.	6006.
1.5	250.	5960.

Well Name: 27-12-1 Location: ne¼ne¼se¼ sec 12 T2n R7w
Company: nmbm Footage: 5100 E of W line 2400 N of S line
Quadrangle: table mtn. Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: gamma, cal, dens, rest, sp, neut/pors
Total Depth: 300 ft Date Drilled: 8/9/81 Elevation: 6210 ft
Mineral Ownership: i Surface Ownership: ia Analysis: n Cuttings: y

Formation	Depth	Elevation
Kcc	8	6202

COAL 3.5

Thickness	Depth	Elevation
1.5	78.5	6131.5
2.0	241.	5969.

Well Name: 27-13-1 Location: se¼nw¼ne¼ sec 13 T2n R7w
Company: nmbm Footage: 4000 E of W line 4300 N of S line
Quadrangle: table mtn. Confidential: n
Field: datil mtns. County: socorro Water: n
Geophysical logs: gamma, cal, dens, rest, sp, neut/pors
Total Depth: 300 ft Date Drilled: 8/12/81 Elevation: 6280 ft
Mineral Ownership: sf Surface Ownership: ab Analysis: 6 Cuttings: y

Formation	Depth	Elevation
Kcc	5	6275

COAL 4.

Thickness	Depth	Elevation
2.5	100.5	6179.5
1.5	158.	6122.

This appendix is a portion of a computerized listing of all the drilling data available in the Central Datil Mountains. Drillholes are numbered by township, range, section, and the ordinal number in which the holes were drilled in the section. For example, the first known drillhole location placed in T. 2N., R. 7W. sec. 6 would be numbered 27-6-1. Many abbreviations are used in the drillhole listing to save space. These abbreviations are as follows:

ab - Alamo Band Navajo

cal - caliper log

dens - density log

ft - feet

gpm - gallons per minute

kcc - Crevasse Canyon Formation

mtns - Mountains

nmbm - New Mexico Bureau of Mines and Mineral Resources

n - no

neut/por - neutron/porosity log

rest - resistivity log

sf - Santa Fe Railroad

sp - spontaneous potential log

APPENDIX 2

Proximate and Ultimate Data for Alamo Coals

(as received)

Drill hole number	Depth interval analyzed	Volatile matter	Fixed carbon	Water	Ash	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen
26-7-1	188-190.5'	37.27	44.78	6.93	11.02	65.51	4.92	1.09	0.66	9.87
26-91	59-60.2'	38.96	33.07	2.12	25.85	57.22	4.64	1.08	0.58	8.51
26-9-1	124-126'	41.32	47.42	2.93	8.33	71.90	5.46	1.03	0.72	8.33
26-15-1	285.8-287'	40.50	42.75	3.25	13.25	66.03	5.30	1.06	0.55	10.31
26-25-2	140-142'	33.77	45.10	0.34	20.79	65.64	4.80	1.02	0.50	6.91
27-1-1	38-40'	38.20	46.97	3.22	11.61	66.71	5.10	1.40	0.54	11.42
27-1-1	72-74'	43.98	46.39	3.80	5.83	72.26	5.70	1.54	0.44	10.43
27-12-1	100.5-104'	43.76	44.93	6.28	5.03	69.21	5.50	1.46	0.41	12.11

EXPLANATION, PLATES 1 AND 2
(numbers in parentheses is thickness range of each unit, in feet)

QUATERNARY

[Qa] - UNDIFFERENTIATED ALLUVIUM: includes floodplain, blow-sands, and piedmont-slope deposits comprised of sands, silts, and gravels.

[Qs] - SAND AND GRAVEL DEPOSITS: in modern ephemeral stream channels.

[Qtc] - TALUS/COLLUVIUM DEPOSITS: consisting of unconsolidated talus, soil-stabilized talus and slope wash deposits.

TERTIARY
Pliocene

[Tg] - TERTIARY GRAVELS: (10-200 ft) volcaniclastic unit made up of clasts of Oligiocene ash flow tuffs, and mudflow deposits in a silty sand matrix. Typically the unit is made up of a calichified, unconsolidated silty sandstone containing occasional volcanic pebbles and a lag gravel of volcanic pebbles at the top of the unit.

[Tbf] - BASALT FLOWS: (20-100 ft) vesicular and porphyritic, clearly becoming younger to the east. Interbedded with TERTIARY GRAVELS.

Miocene

[Ti] - MAFIC INTRUSIVE DIKES, PLUGS, AND SILLS: (2-10 ft).

Oligocene

[Ts] - SPEARS FORMATION: (1000 ft) grayish purple to yellowish gray, intermediate-composition laharic breccias, sandstones, and mudstones.

Eocene

[Tb] - BACA FORMATION: (950 ft) red to brown sandstones, calcareous mudstones, and minor conglomerates. Sandstones are very fine-grained to coarse-grained and commonly have parallel laminations and minor cross-bedding.

CRETACEOUS

MESAVERDE GROUP

[Kcc] - CREVASSE CANYON FORMATION: (10-700+ ft) continental sequence of thinly bedded sandstones, gray mudstones, carbonaceous mudstones, and coals. Coals are concentrated in the lower half of the formation but thin coals occur throughout the unit.

[Kg] - GALLUP SANDSTONE: (10-85 ft) yellow brown, fine to medium grained sandstone sequence characterized by stacked planar crossbeds, burrows (Ophiomorpha), and a distinctive bedding plane split often containing the guide-fossil *Lopha sannionis*.

[Kth] - TRES HERMANOS FORMATION: (240 ft) sequence consisting of a basal marine sandstone that is generally light gray to orange gray and contains both planar and trough crossbeds, top is marked by a dark brown coquina; a medial paludal unit consisting of medium to dark gray mudstones and thin light brown channel sandstones; and an upper marine sandstone that is typically light gray, crossbedded, burrowed, bioturbated, and concretion-bearing.

The continental sequence is locally coal-bearing, contains both brackish-water pelecypods and minor vertabrate fossils, and wood.

MANCOS SHALE: a paludal to offshore silty mudstone that intertongues with the DAKOTA SANDSTONE. Commonly green-gray to medium gray with abundant fossils ususally found in concretions, especially in the D-CROSS TONGUE.

[Kmd] - D-CROSS TONGUE: (40-165 ft) medium gray to moderate olive gray, non to slightly calcareous, bioturbated silty mudstone containing abundant, fossil-bearing concretions. Identified fossils include: *Prinocyclus novimexicanus*, *Coilopscerous inflatum*, and *Lopha bellaplicata*.

[Kmr] - RIO SALADO TONGUE: (60-70 ft) gray, calcareous mudstone at base grading upward to a medium brown noncalcareous mudstone within 20 feet of the top of the unit. Guide fossil *Pycnodonte newberryi* occurs abundantly 10 feet above the base of this tongue.

[Kml] - LOWER PART OF THE MANCOS: (180-280 ft) medium to dark gray diachronous, marine mudstones.

DAKOTA SANDSTONE

[Kdt] - TWOWELLS TONGUE: (10-30 ft) light gray, fine-grained sandstone characteristized by 2-3 inch upward-fining cycles of a bioturbated cycle followed by a burrowed cycle.

[Kdm] - MAIN-BODY DAKOTA: (10-30 ft) yellow brown, medium-grained sandstone unit with trough crossbeds. Base of this unit marked by a lag gravel of well-rounded quartzite pebbles , probably reworked from the Triassic and Jurassic.

TRIASSIC

[₮c] - CHINLE FORMATION: (120 ft) series of interbedded mudstones and siltstones. Mudstones are typically red to lavender, mottled and silty.

SYMBOLS

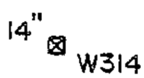
geologic contact, dashed where approximate

fault, dashed where approximate, ball on downthrown block

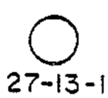
strike and dip of bedding

trace of anticlinal axis, dashed where approximate

trace of synclinal axis, dashed where approximate



measured coals (outcrop) - left of symbol is thickness in inches, right of symbol is Winchester's (1913) outcrop number. All locations rechecked by NMBMMR staff.



drill holes - numbered by township, range and section and ordinal number of drillhole drilled in that section

Geology of the Alamo Band Navajo Reservation 1982

Compiled by J.C. Osburn

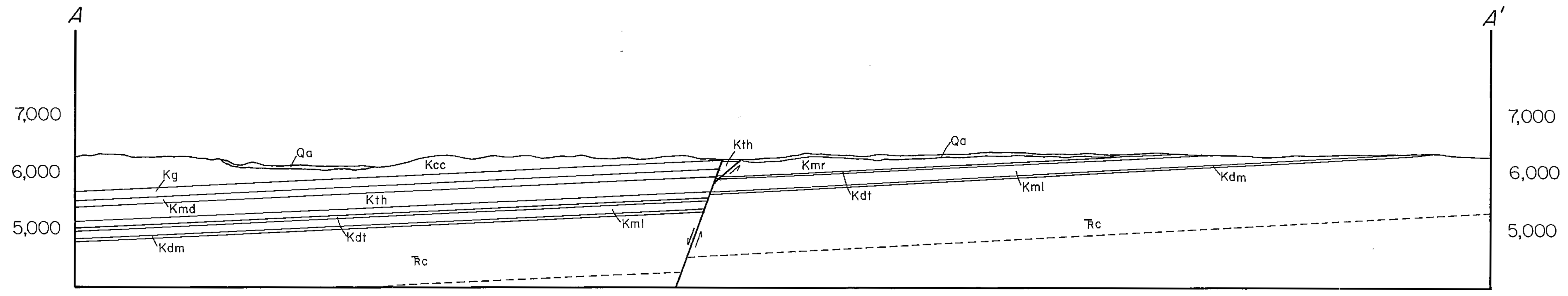
PLATE I

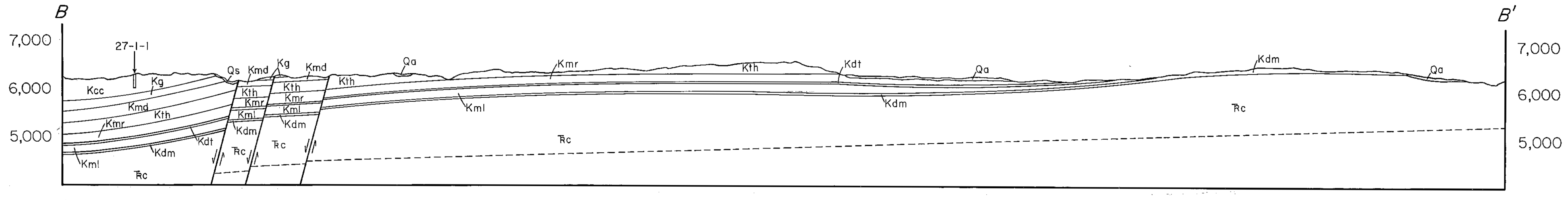
OF160

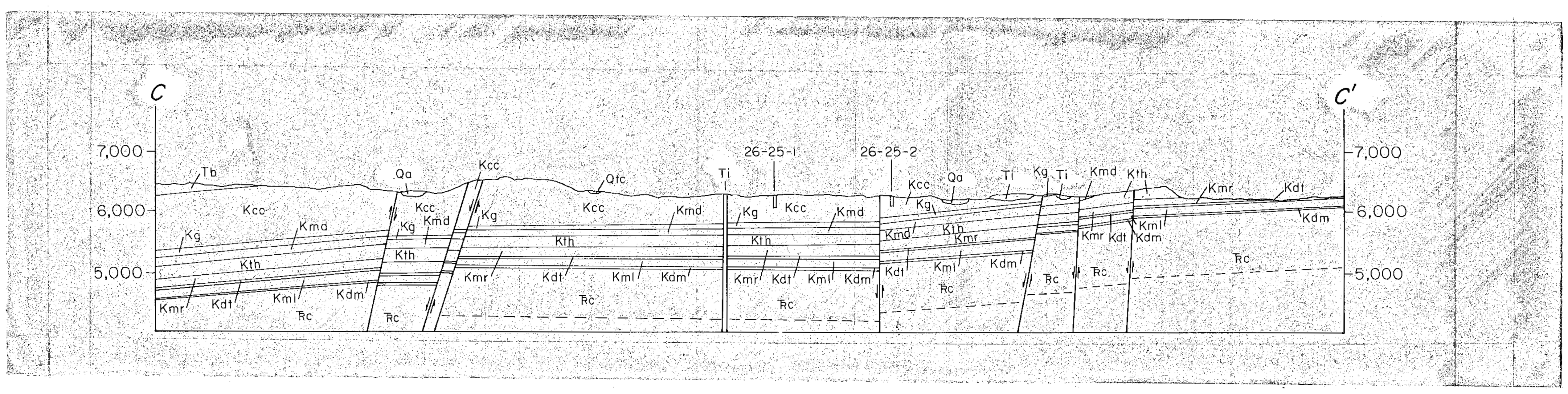
Geologic Cross Sections of the Alamo Band Navajo Reservation, Socorro County, New Mexico

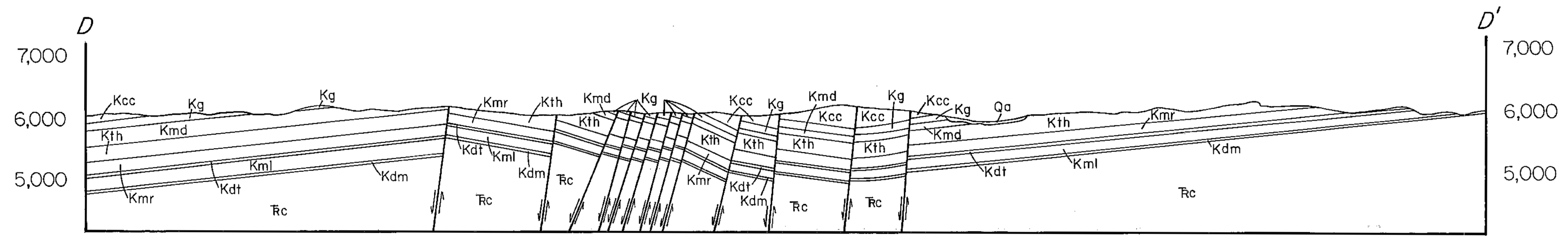
By J.C. Osburn

1982



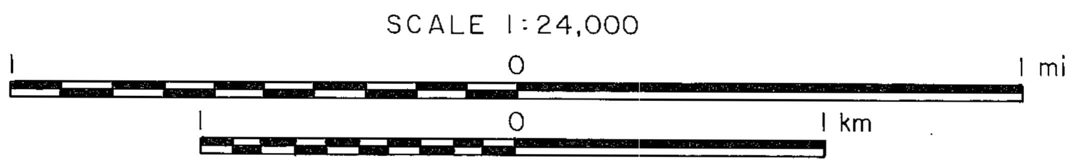


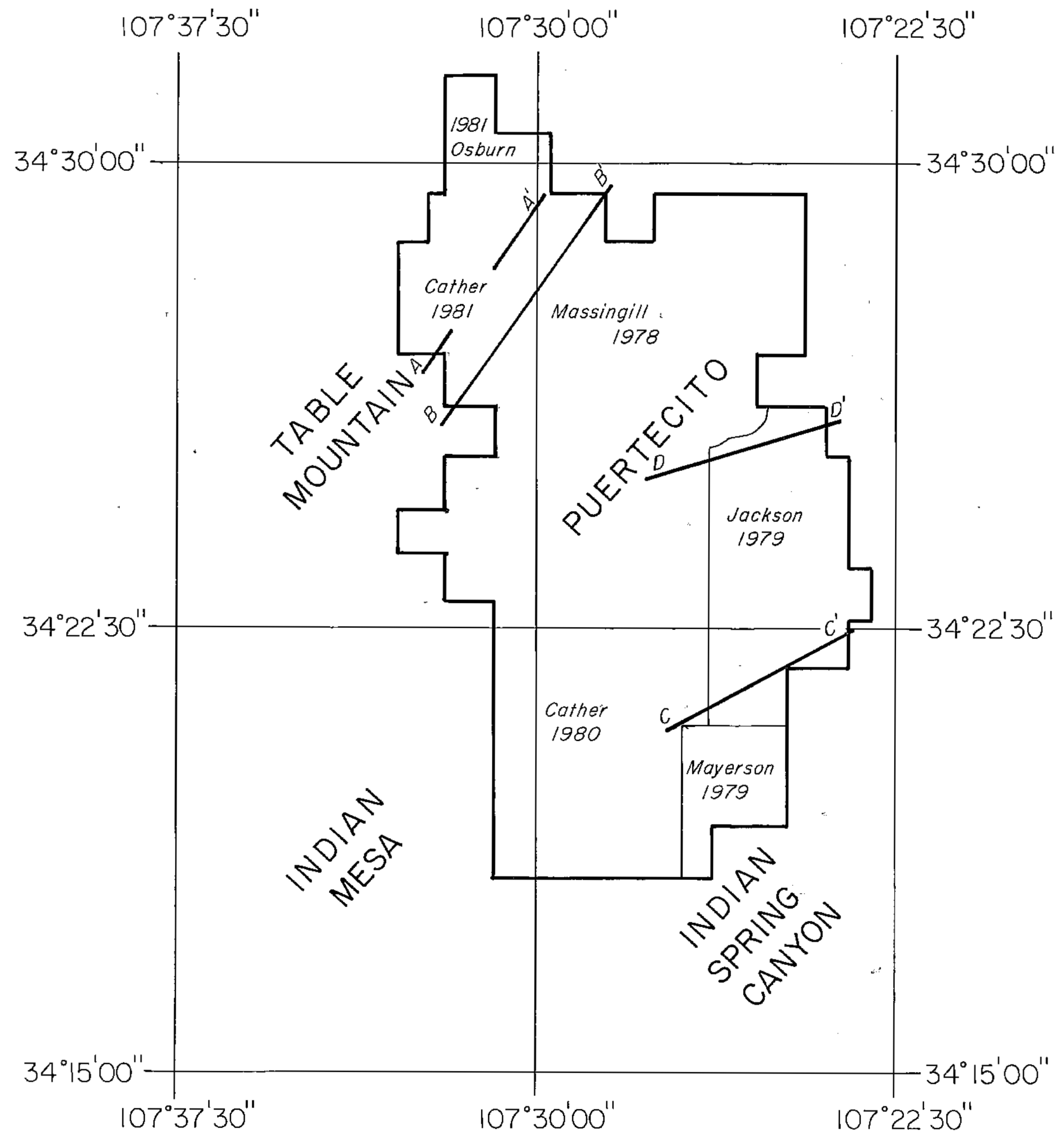




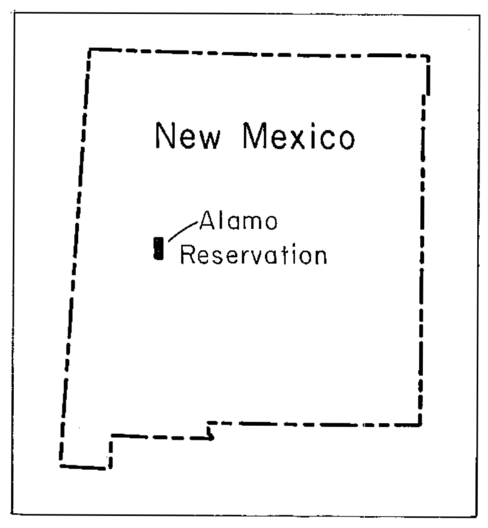
All cross sections face northwest

No vertical exaggeration





Mapping Responsibilities



Location Map

PLATE 2