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GJBX-82(77)

PRELIMINARY STUDY OF FAVORABILITY FOR URANIUM OF THE SANGRE DE CRISTO FORMATION IN THE LAS VEGAS BASIN, NORTHEASTERN NEW MEXICO

BENDIX FIELD ENGINEERING CORPORATION
Grand Junction Operations
Grand Junction, Colorado 81501

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SUMMARY

Uranium favorability of the Sangre de Cristo Formation (Pennsylvanian-Permian) in the Las Vegas basin has been evaluated. The Las Vegas basin project area, located in Colfax, Mora, and San Miguel Counties, New Mexico, comprises about 3,489 sq mi. The formation contains sedimentologic and stratigraphic characteristics that are considered favorable for uranium deposition.

Field investigations consisted of section measuring, rock sampling, and ground radiometric reconnaissance. North-south and east-west cross sections of the basin were prepared from well logs and measured sections. Petrographic, chemical, and spectrographic analyses were conducted on selected samples. Stratigraphic and sedimentologic information were used to determine depositional environments.

The most favorable potential host rocks include red to pink, coarse-grained, poorly sorted, feldspathic to arkosic lenticular sandstones with stacked sandstone thicknesses of more than 20 ft and sandstone-to-shale ratios between 1:1 and 2:1. The sandstone is interbedded with mudstone and contains carbonaceous debris and anomalous concentrations of uranium locally.

Areas of maximum favorability are found in a braided-stream, alluvial-plain depositional environment in the north-central part of the Las Vegas basin. There, carbonaceous material is well preserved, probably due to rapid subsidence and burial. Furthermore, uranium favorability is highest in the lower half of the formation because carbonaceous wood and plant fragments, as well as known uranium deposits, are concentrated in this zone. Piedmont deposits in the north and east, and meander-belt, alluvial-plain deposits in the south, are not considered favorable because of the paucity of uranium deposits and a minimum of carbonaceous material.

INTRODUCTION

This report presents the results of a preliminary study of the uranium favorability of the Sangre de Cristo Formation (Pennsylvanian-Permian) in the Las Vegas basin, northeastern New Mexico. Because known uranium deposits are confined mainly to the Sangre de Cristo, the following discussions are limited to this formation. The study focuses on sedimentologic and stratigraphic characteristics relevant to uranium deposition. The investigation was conducted by Bendix Field Engineering Corporation (BFEC) on behalf of the U.S. Energy Research and Development Administration (ERDA).

PURPOSE

The goal of this study was to determine if the Sangre de Cristo Formation in the Las Vegas basin, New Mexico, is a favorable uranium host. Secondary goals were to describe uranium occurrences and to delineate favorable areas.

PROJECT LOCATION

The Las Vegas basin project area comprises about 3,480 sq mi in parts of Colfax, Mora, and San Miguel Counties, New Mexico (Fig. 1). The region is shown on the south-central part of the Raton sheet and on the north-central part of the Santa Fe sheet of the U.S. Geological Survey 2° National Topographic Map Series. It extends between lats 30°20' and 35°35' N. and between longs. 104°30' and 105°20' W. Physiographically, the area lies in the Las Vegas Plateau and the extreme eastern part of the Sangre de Cristo Mountains (Fig. 2).

PREVIOUS WORK

Stratigraphic and tectonic aspects affecting the Sangre de Cristo in southeastern Colorado and northeastern New Mexico have been discussed by Read and Wood (1947), Sidwell and Warn (1956), Dixon (1967), Foster and Stipp (1961), Johnson (1975), Foster and others (1972) and Roberts and others (1976). The Coyote (copper-uranium) district in Mora County (Fig. 2) has been described by Lindgren and others (1910), Lasky and Wooton (1933), and Harley (1940). Bachman and Read (1952), Zeller and Baltz (1954), and Tschanz and others (1958) investigated the uranium and copper deposits in the district. Maps of the project area have been published by Northrop and others (1946), Wanek and others (1964), Baltz (1972), and Johnson (1970, 1972a, 1972b, 1973, 1976).

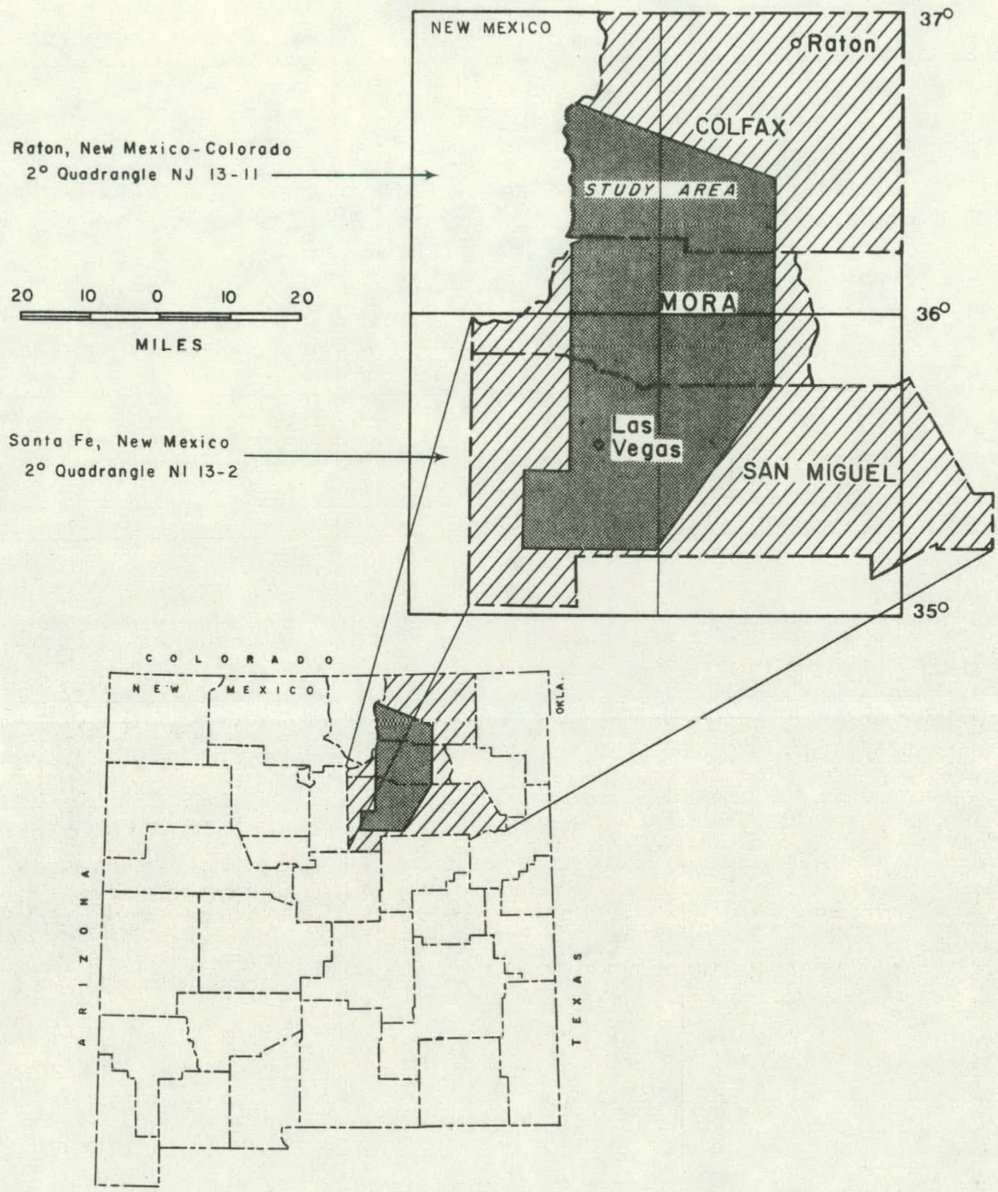
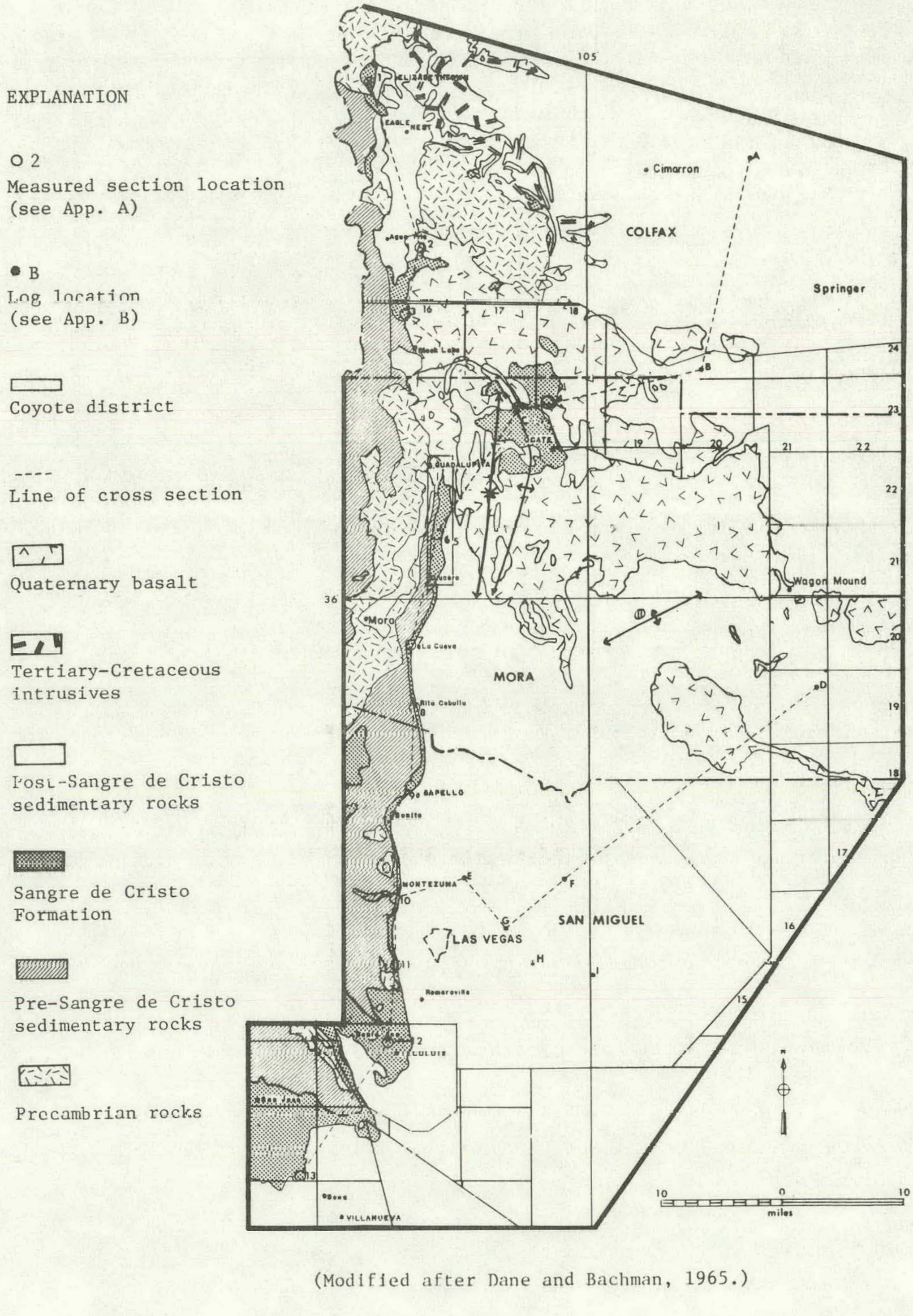


Figure 1. Location maps of study area in Colfax, Mora, and San Miguel Counties, New Mexico.



(Modified after Dane and Bachman, 1965.)

Figure 2. Generalized geologic map of Las Vegas basin study area.

GEOLOGY

STRATIGRAPHY

Rocks in and adjacent to the Las Vegas basin are Precambrian through Quaternary in age. The sedimentary section is more than 12,700 ft thick (Baltz, 1965). Brief descriptions are presented in the columnar section (Fig. 3).

The Sangre de Cristo Formation (Middle Pennsylvanian through Permian), first described by Hills (1899) from a section near Creston, Saguache County, Colorado (Lochman-Balk, 1972), is present in large areas in the Southern Rocky Mountains and the Great Plains provinces. It is probably equivalent, in part, to the Abo and Cutler Formations, which are present in southern and northwestern New Mexico.

Lower Boundary

The precise age of the lower Sangre de Cristo Formation is not known because of its basal complexity and the paucity of fossils. Basal unconformities are present near Paleozoic highs: for example, the Cimarron arch (Goodknight, 1976), the Sierra Grande arch (Baltz, 1965), and an unnamed paleohigh (Northrop and others, 1946; Baltz, 1965), which here is informally termed the Tecolote arch (Fig. 2). In the southern Las Vegas basin, Sangre de Cristo beds of Wolfcampian age conformably overlie Virgilian beds of the Madera Formation, although local angular unconformities are present (Northrop and others, 1946; Baltz, 1972). In the northern part of the basin (that is, at Mora River Gap), E. H. Baltz (oral commun., 1976) identified Desmoinesian fusulinids in lower Madera beds that are conformably subjacent to the Sangre de Cristo. Basal Sangre de Cristo beds may, therefore, be of Middle(?) or Late Pennsylvanian age in that area. Still farther north, Late Pennsylvanian fossils are allegedly present in the lower one-third of the Sangre de Cristo in the Coyote district (Tschanz and others, 1958). The above considerations suggest that the Sangre de Cristo interfingers with the Madera. Thus, the Sangre de Cristo of Middle(?) Pennsylvanian through Early Permian in the northern part of the basin, and of Early Permian in the south, is probably time-transgressive.

Upper Boundary

The upper boundary of the Sangre de Cristo Formation is as complex as the lower boundary. South of Guadalupita, the Sangre de Cristo is conformably overlain by the Yeso Formation (Leonardian). Brill (1952) and Bachman (1953) suggested that the Yeso grades into the Sangre de Cristo south of Lucero. During our study, the Yeso was traced northward as far as Guadalupita, where it is covered by basalt. Farther north, at Black Lake and Ocate, the Yeso was not recognized, and the Glorieta Sandstone of the San Andres Formation conformably overlies the Sangre de Cristo. North of Black Lake, however, the Glorieta also pinches out, and the Sangre de Cristo is unconformably overlain by a thin Upper Triassic section (Fig. 4).

ERA	SYSTEM	SERIES	GROUP	FORMATION	MEMBER	THICKNESS	LITHOLOGY	DESCRIPTION
CENOZOIC	Quaternary							Basalt, alluvium, colluvium and caliche
	Tertiary	Middle		Picuris Tuff(?)				Tuffaceous, Conglomerate, Remenant
				Poison Canyon		0-2500		Conglomeratic, arkosic, sandstone, mudstone
		Lower						
MESOZOIC	Cretaceous	Upper		Raton		0-2000		Sandstone, mudstone conglomerate, coal
				Vermejo		0-380		Sandstone, carbonaceous shale, coal
				Trinidad SS		0-255		Sandstone
				Pierre Sh		1300-2900		Marine shale with some sandy shale, sandstone, and thin bentonites
			Colorado	Niobrara	Smoky Hill (Apishapa)	300		Muddy limestone
					Ft. Hays Ls (Timpas Ls)	50		Limestone
				Benton	Carlile Sh	218		Dark gray shale, calcareous concretions, sandy limestone
					Greenhorn Ls	35		Alternating beds of limestone & shale
					Graneros Sh	250		Dark gray to black shale, bentonite at top
				Dakota Ss		50		Sandstone
		Lower		Purgatoire		100		Siltstone & Shale, sandstone
	Jurassic	Upper		Morrison		500		Shale, conglomeratic sandstone, nodular limestone, shale & siltstone with sandstone, sandstone with shale
			San Rafael	Bell Ranch		25-50		Light gray sandstone, brownish red siltstone
				Todilto Ls		5-10		Clastic to oolitic limestone, gypsum (non-marine)
				Ocate (Entrada)		50-175		Fine grained, cross laminated sandstone
	Triassic	Upper		Naranjo		150		Medium-coarse sandstone, cross-bedded
				Redonda		0-225		Variegated shale, argillaceous limestone, sandstone & siltstone
			Dockum	Chinle	Upper Sh	1000		Variegated shale, siltstone, sandstone
					Cuervos Ss			Variegated shale, siltstone, sandstone
					Lower Sh			Variegated shale, siltstone, sandstone
				Santa Rosa		100-425		Fine grained sandstone, limestone conglomerate, quartzitic conglomerate, red shale
PALEOZOIC	Permian	Guadalupian	Artesia	Bernal		50-150		Brownish red siltstone, fine grained sandstone, some gypsum & salt
		Leonardian		San Andres	San Andres Ls	5-40		Limestone, minor sandstone, gray shale, gypsum, dolomite, salt
					Glorieta	100-290		Fine grained sandstone, minor shale, some siltstone
				Yeso	San Ysidro	230-546		Find grained sandstone, siltstone, shale, dolomite, salt, gypsum, and anhydrite
					Meseta Blanca	150		
		Wolfcampian		Sangre de Cristo		500-5000		Arkosic conglomerate, mudstone, nodular limestone, siltstone, and arkosic sandstone
	Pennsylvanian	Virgilian	Magdalena	Madera Ls	Arkosic Ls	500		Conglomerate, limestone, siltstone, shale
		Missourian						
		Desmoinian			Gray Ls	500		Limestone
		Atokan		Sandia		900-1000		Conglomerate, shale, sandstone, siltstone, limestone
	Mississippian	Upper	Arroyo Penasco	Terrero	Cowles	1.5-30		Siltstone, shale limestone, mudstone, ostracods
					Manuelitas	30-60		Limestone, oolites, foraminifera
					Turquillo	4-15		Limestone, mudstone, foraminifera, stromatolites
					Macho	14		Limestone, mudstone, foraminifera, collapse breccia
		Lower		Espiritu Santo	Upper Ls Del Padre Ss	24-78		Dolomite & dedolomite Quartz conglomerate, sandstone, siltstone, shale
PRECAMBRIAN				Embudo Granite		2500		Quartz monzonite
				Vadito		4500		Schist Conglomerate & quartzite
				Ortega	Pilar phyllite	2300		Calcareous quartz-muscovite phyllite
					Rinconada Schist	1900		Hornfels, gneiss & schist, quartzite, phyllite
					Lower Quartzite	2500		Quartzite & thin-bedded gneiss

(Modified after Baltz and Bachman, 1956; Clark, 1966b; Kelley and Tranger, 1972; Pillmore, 1976; and Speer, 1976.)

Figure 3. Columnar section depicting rocks that crop out in the Las Vegas basin area, New Mexico.

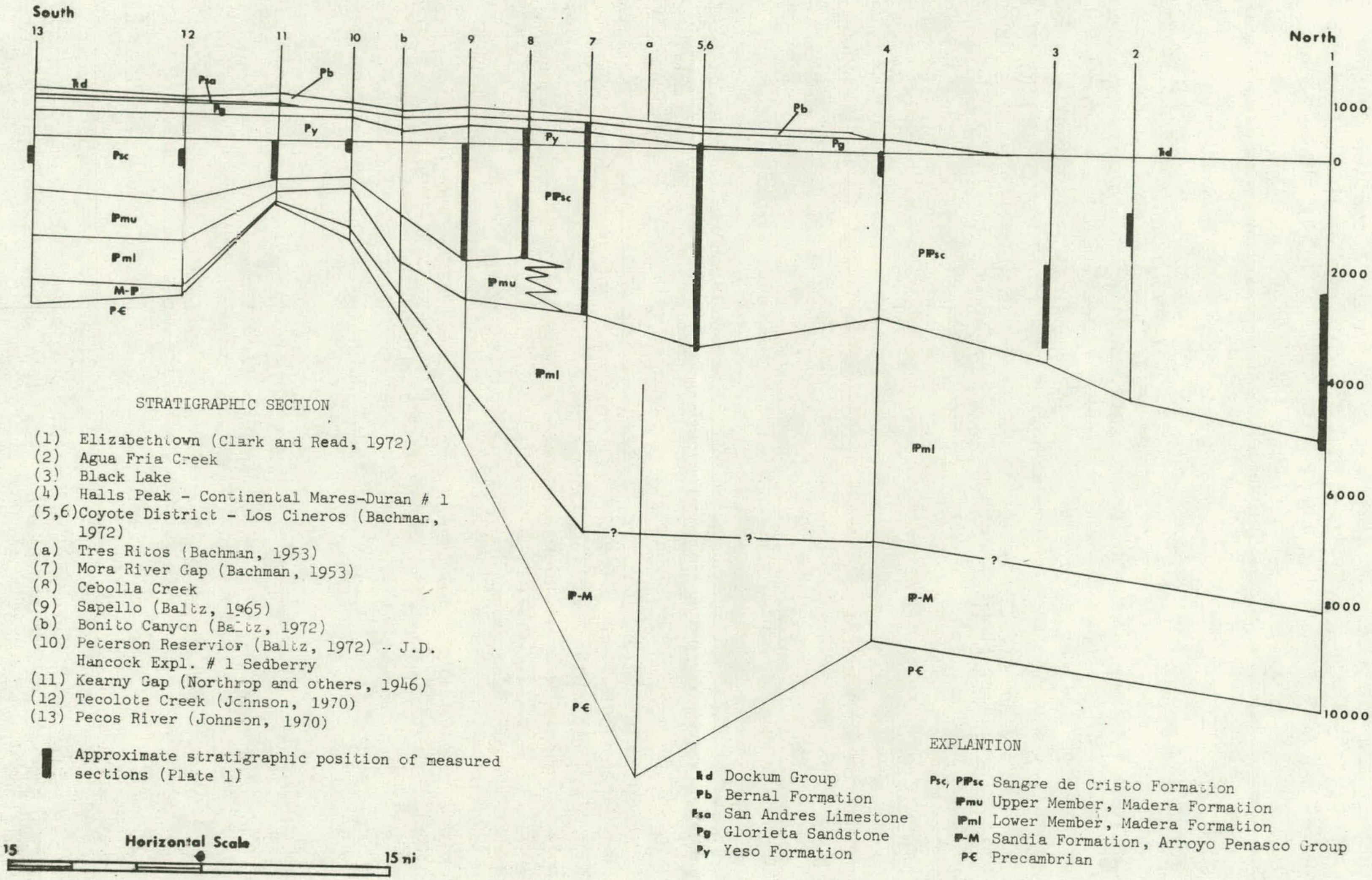


Figure 4. Generalized north-south cross section depicting stratigraphic correlations of beds adjacent to the Sangre de Cristo Formation. (Note thickening of the Permian-Pennsylvanian Sangre de Cristo Formation in the north.)

Thickness

The maximum thickness of the Sangre de Cristo Formation in the study area is about 5,000 ft, but it is nearly 10,000 ft in the Colorado part of the Raton basin (Clark and Read, 1972; Brill, 1952). Near Montezuma, in San Miguel County, New Mexico, the Sangre de Cristo is only a few hundred feet thick, possibly because of nondeposition on the Tecolote arch (Paleozoic) [Fig. 5].

Lithology

The formation consists of intercalated pebble and cobble conglomerate, sandstone, siltstone, shale, and carbonate rocks (Pl. 1). Common constituents of the coarse clastic are quartz, feldspar, rock fragments, and mica. Calcite is a common cement. Some sandstone is immature and may resemble granite in color and composition; it qualifies as granite wash. The similarity is caused by high potassium feldspar content, which is sometimes greater than that of quartz (Baltz and Bachman, 1956).

GEOLOGIC HISTORY

During Pennsylvanian and Early Permian time, the Las Vegas basin, a subbasin of the Raton basin, was part of the zuegogeosynclinal Rowe-Mora basin (Read and Wood, 1947; Brill, 1952). The basin was flanked by the San Luis - Uncompahgre highlands, the Sierra Grande uplift, Pedernal uplift, and the Apishapa uplift (Fig. 6).

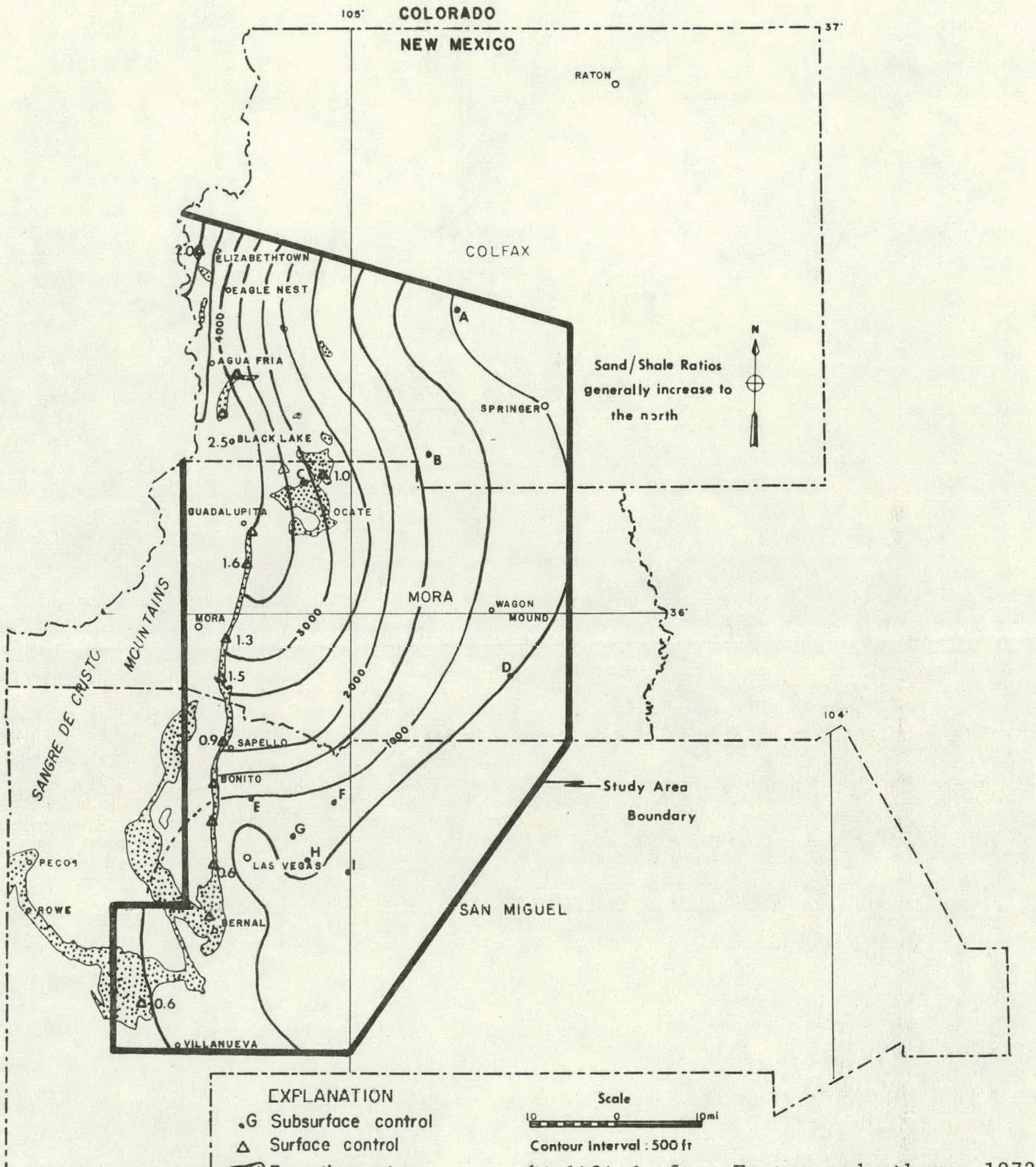
In Early to Middle Pennsylvanian time, marine and marginal marine sediments were deposited in the geosyncline. In Middle Pennsylvanian time, uplift of adjacent highlands was initiated, and sediments were provided to the Rowe-Mora basin. As a result of continued sedimentation during Late Pennsylvanian and Early Permian time, the basin was filled in and overlapped all the highlands except, possibly, the San Luis - Uncompahgre highlands (Baltz, 1965). Sediments, probably derived from the San Luis-Uncompahgre highlands, completely expelled the sea.

During Late Permian time, seas transgressed and retreated. Continental and shallow-marine deposition prevailed during Triassic and Jurassic time. Major marine transgression and regression occurred during Cretaceous time, with continental, near-shore continental, and shallow-marine deposition (Tschanz and others, 1958).

Laramide tectonic movement in early Tertiary time folded a part of the Rowe-Mora basin into a broad anticlinorium and formed the present Sangre de Cristo Mountains (Tschanz and others, 1958) and Raton - Las Vegas basin. Early Quaternary basalt blankets most of the northern Las Vegas basin.

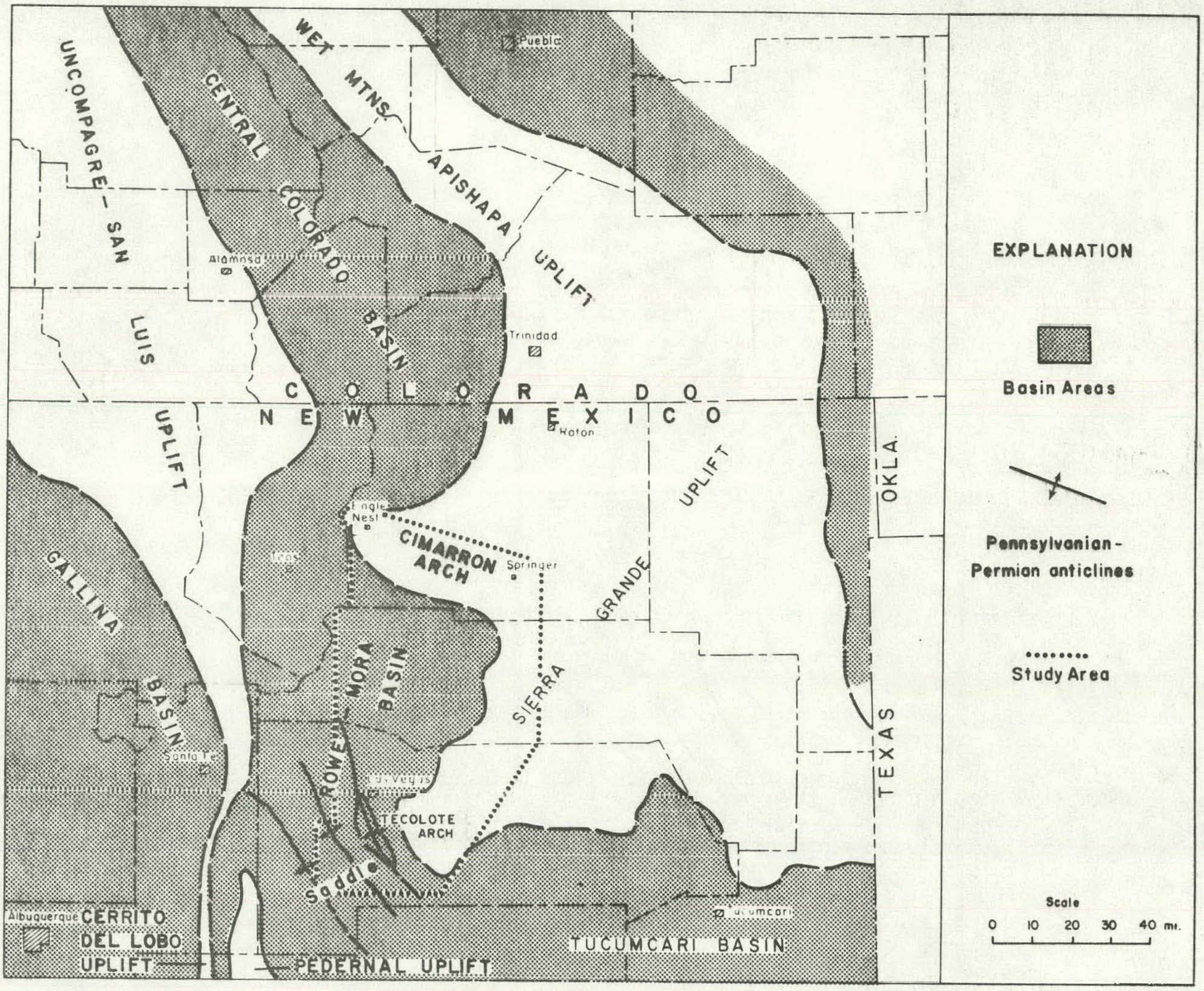
STRUCTURE

The Raton basin, and the genetically related Las Vegas basin, are separated by the Cimarron arch. The Sierra Grande uplift, the Pedernal uplift, Sangre de Cristo Mountains, and interbasinal Cimarron arch completely enclose the Las Vegas basin (Fig. 7).



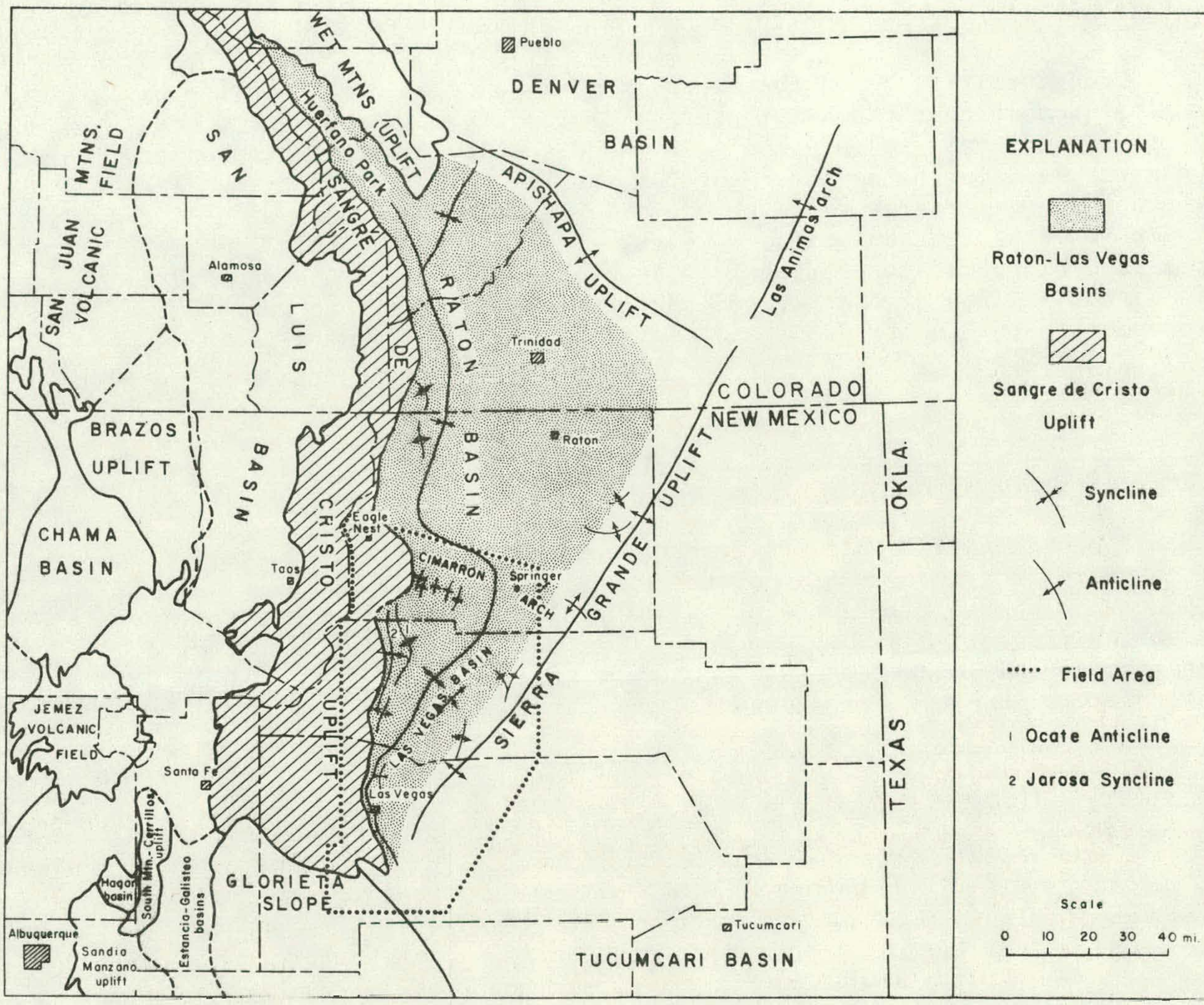
(Modified after Foster and others, 1972, and Roberts and others, 1976.)

Figure 5. Thickness isopach and sandstone-to-shale ratios of the Sangre de Christo Formation in the Las Vegas basin, New Mexico.



(Modified after Baltz, 1965.)

Figure 6. Paleotectonic map of southeastern Colorado and northeastern New Mexico.



(Modified after Baltz, 1965; Woodward and Snyder, 1976.)

Figure 7. Structure map of southeastern Colorado and northeastern New Mexico.

Imbricated thrust-fault zones are present along the eastern front of the Sangre de Cristo Mountains, where Precambrian rocks were thrust eastward over Mississippian, Pennsylvanian, and Permian rocks during Laramide deformation. Regional compression formed a belt of hogbacks along the east flank of the thrust zone. In places, the beds are overturned. Diminution of compressive stresses is indicated by the shallow folding of the Jarosa syncline and Ocate anticline (Fig. 7).

Unconformities bound the Sangre de Cristo only locally in the basin: nonconformable contacts exist near Tecolote arch, Cimarron arch, and Sierra Grande uplift, and an angular unconformity with the Madera has been reported in the southern part of the Las Vegas basin (Baltz, 1972). The upper contact appears to be conformable in the southern part of the basin. North of Guadalupita, however, there may be a disconformable relationship between the Sangre de Cristo Formation and the San Andres Formation. North of Black Lake, the Triassic Dockum Group rests unconformably on the Sangre de Cristo; locally, the unconformity is angular.

METHODS OF INVESTIGATION

FIELD INVESTIGATION

Twelve stratigraphic sections of the Sangre de Cristo Formation were measured on the western side of the Las Vegas basin (Fig. 2; App. A). Short sections were measured across mineralized zones in the Coyote district (Fig. 2; App. A). Seventy-three rock samples were collected, and radiometric measurements of outcrops were made with a hand-held scintillometer. Known uranium deposits were investigated and sampled.

STRATIGRAPHIC ANALYSIS

A north-south cross section of the Sangre de Cristo Formation was constructed with 12 measured sections of the Sangre de Cristo Formation and from sections measured by other workers (Fig. 4). The measured sections of the Sangre de Cristo are the basis for the determination of depositional environments and, in part, provenance (Fig. 8; Pl. 1).

SUBSURFACE PROCEDURES

Electric and gamma-ray logs from nine petroleum test holes (Figs. 2, 5; App. B) were studied for stratigraphic information and to seek radioactivity anomalies. Seven of the logs were used in construction of cross sections (Figs. 4, 9, 10).

ANALYTICAL PROCEDURES

Rock composition and textures were determined by binocular microscope inspection of most of the samples, but 27 selected samples were studied

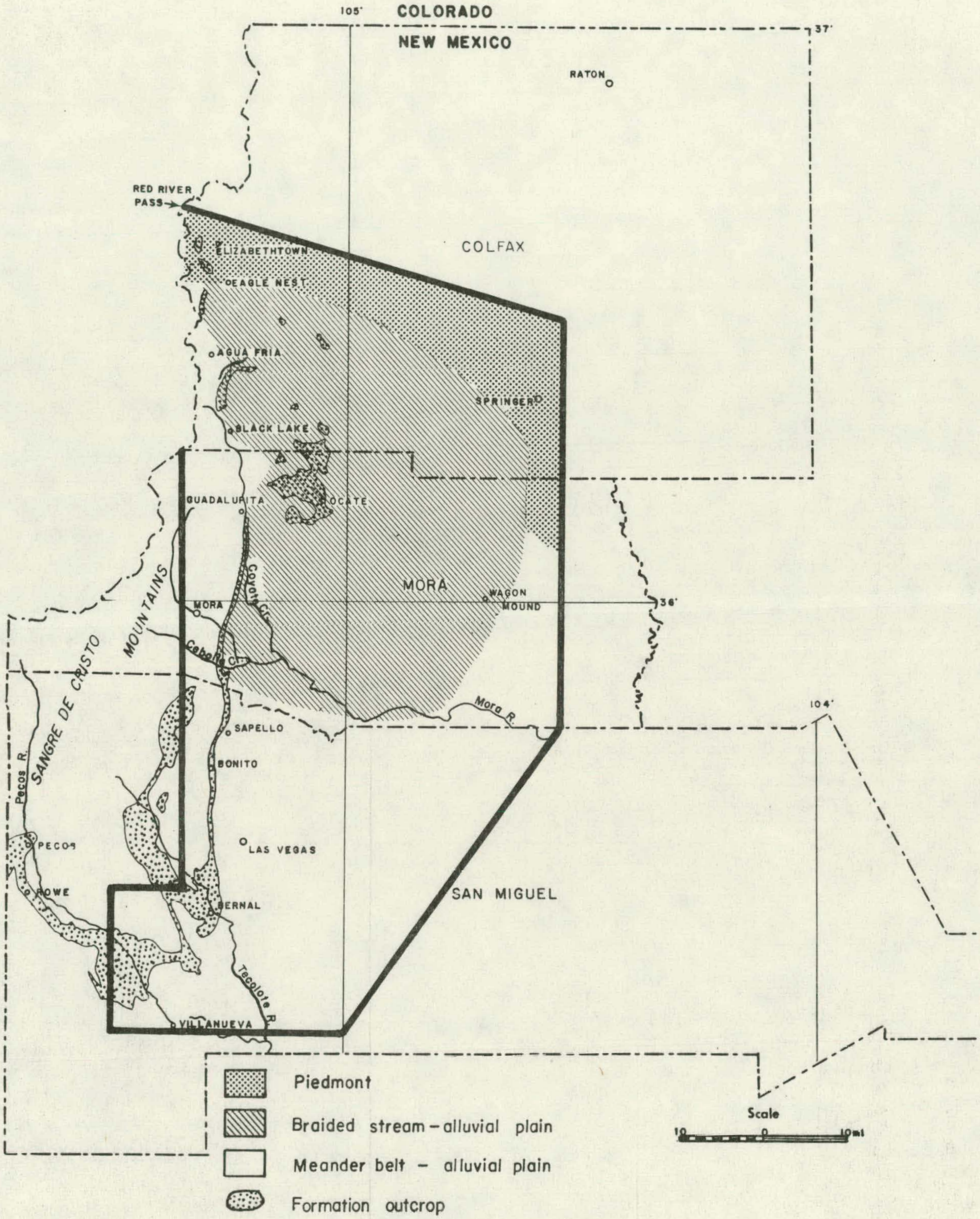


Figure 8. Generalized depositional environments of the Sangre de Cristo Formation in the Las Vegas basin.

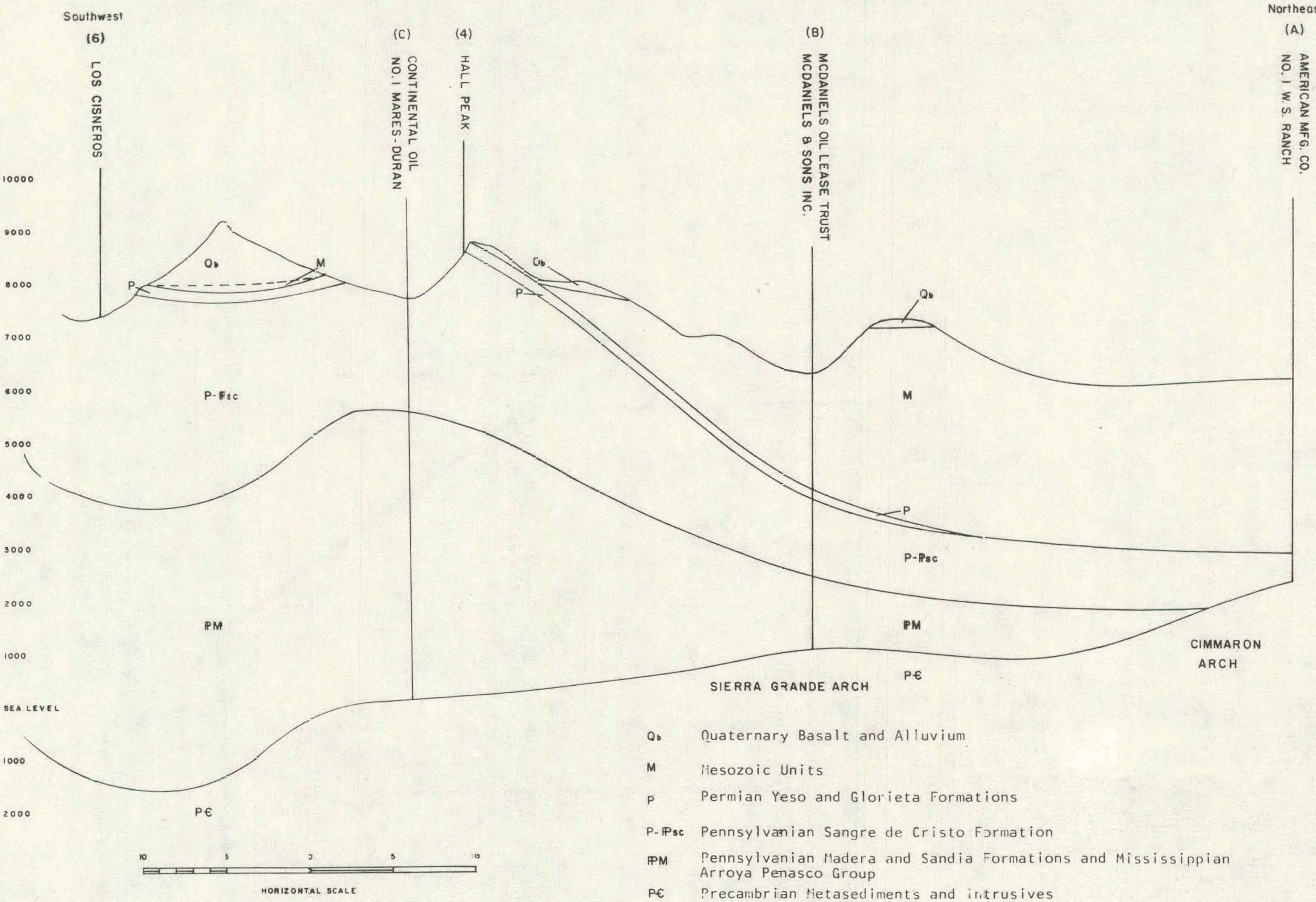


Figure 9. East-west cross section across the northern part of the Las Vegas basin, New Mexico.

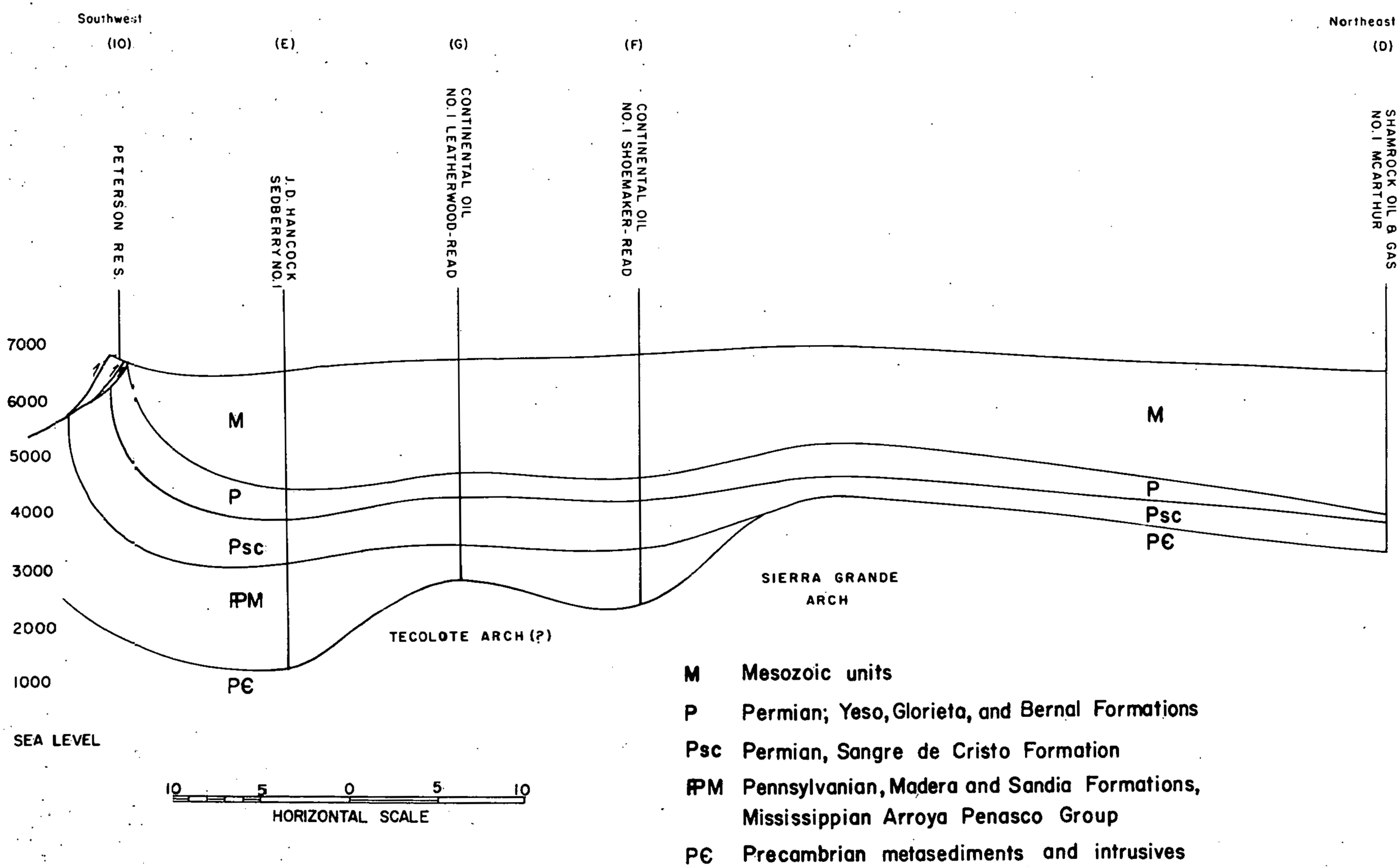


Figure 1C. East-west cross section across the southern part of the Las Vegas basin, New Mexico.

petrographically by thin-section analysis (Table 1). Mineral percentages were tabulated, and grain-to-grain relations, cements, and alterations were noted. Nine of the samples underwent heavy-mineral separation (bromoform, specific gravity 2.85) and analysis. Four samples were analyzed by x-ray diffraction for clay-mineral identification. Twenty-six samples were analyzed for equivalent uranium, equivalent potassium, and equivalent thorium by gamma-ray spectrometry (Table 2). These samples were also analyzed chemically for uranium, organic carbon, and total carbon. Total semiquantitative emission spectrographic analysis for 48 elements was performed on 26 samples (Table 1).

RESULTS

STRATIGRAPHY

The Sangre de Cristo thins southward from approximately 5,000 ft at Elizabethtown in the north, to 650 ft near Montezuma (Fig 4). Sandstone-to-shale ratios decrease southward as well (Fig. 4). A principal source area to the north is thereby indicated. Gradual thinning of the Sangre de Cristo eastward toward the Sierra Grande uplift and rapid subsidence in the north-central part of the Las Vegas basin are inferred from subsurface data (Figs. 9, 10).

PETROLOGY-PETROGRAPHY

Conglomerates

Conglomerates are pink and contain particles that are cobble to silt in size; average grain size is about 5 mm. Granitic rock fragments are generally abundant; metamorphic rock fragments are locally abundant. The matrix is arkosic.

Sandstones

Exposed sandstones are pink, reddish-brown, and brown. Local bleaching has altered sandstone coloration to pink and gray. Sandstones in the Sangre de Cristo consist of about 50 percent quartz and about 25 percent feldspar (predominantly potassic), plutonic and sedimentary rock fragments, calcite cement, heavy minerals, and matrix materials. Plutonic rock fragments average about 5 percent but are as much as 68 percent in one sample. Heavy-mineral suites constitute less than 0.3 percent of each sample and consist of apatite, biotite, hornblende, muscovite, tourmaline, garnet, and zircon, which suggests a granitic provenance. Epidote and garnet, however, may indicate some metamorphic rock contribution (Pettijohn, 1975). Carbonaceous trash is sparse to abundant, and asphaltic pellets and other residues are present (Northrop and others, 1946; Baltz and Bachman, 1956; Finch, 1972). The sandstone is poorly to moderately well sorted (average Trask sorting coefficient of 1.70; Trask, 1932). Clasts range from fine grained to granule size but are predominantly coarse grained.

TABLE 1. PETROGRAPHIC, CHEMICAL, AND EMISSION SPECTROGRAPHIC ANALYSES OF SELECTED SAMPLES

Location no. (Fig. 2)	Sample no.	Reference no.	Lithologic description	Chemical: U_3O_8 (ppm)	Chemical: Total C (%)	Chemical: Organic C (%)	Semiquantitative emission spectrographic analyses (%): Ba	Be	Cu	Mn	Pb	V
3	1	19321	Black carbonaceous shale: illite 60%, kaolinite 20%, mixed layer 20%; 1.5 ft thick, 5 ft long (?): Mo 0.0008%.	105	5.81	5.73	0.0300	0.0007	0.0500	0.0200	0.0100	0.0400
3	2	19322	Gray-brown pebbly arkosic wacke, fining-upwards sequence; 4 ft thick underlain by 1 ft of carbonaceous shale; tyuyamunite; high content of vanadium; Nb detected; radiometric anomaly on outcrop indicated 2.20% eU_3O_8.	345	1.13	0.91	0.2000	0.0010	0.0400	0.1500	0.2000	>1
5	3	19298	Arkosic arenite; gold-colored; 6 in. mineralized: malachite, oxidized pyrite; abundant carbonaceous material, surrounding sandstone is bleached pink.	76	0.14	0.13	0.0400	0.0005	0.0200	0.1000	0.0050	0.1500
5	4	19299	Sandy siltstone in a channel scour; bleached from red to light green; carbonaceous Mo 0.0080%.	247	0.23	0.19	0.2500	0.0010	0.1000	0.0500	0.0030	0.0200
5	5	19300	Arkosic, arenite; malachite, and chalcocite; medium cross-bedding; carbonaceous material abundant.	64	0.36	0.04	0.0200	0.0002	0.3000	0.1500	0.0070	0.0500
5	6	19301	Calcareous arkosic arenite; abundant carbonaceous wood fragments; pyrite.	182	0.83	0.06	0.0400	0.0005	0.0040	0.0400	0.1000	0.1500
5	7	19302	Sandy siltstone associated with carbonaceous, micaceous shale; bleached.	90	0.15	0.15	0.0400	0.0008	0.1000	0.1500	0.0020	0.0080

TABLE 1. (continued)

Location no. (Fig. 2)	Sample no.	Reference no.	Lithologic description	Chemical U_3O_8 (ppm)	Chemical Total C (%)	Chemical Organic C (%)	Semiquantitative emission spectrographic analyses (%) Ba	Be	Cu	Mn	Pb	V
5	8	19304	Sparite; gold- to gray-colored; highly fractured; 2 ft thick; siltstone below is malachite-stained.	25	9.14	7.99	0.0800	0.0003	0.3000	0.3000	0.0005	0.0050
5	9	19305	Calcareous siltstone; illite 40%, chlorite 40%, mixed layer 20%, light gray; carbonaceous filaments; malachite.	21	0.88	0.36	0.0200	0.0010	0.4000	0.0200	0.0002	0.0070
5	10	19306	Clayey siltstone, chocolate-colored, bleached gray; containing malachite; micaceous; carbonaceous filaments.	125	0.37	0.24	0.0400	0.0005	0.1000	0.1500	0.0005	0.0070
5	11	19324	Sparite; silty; abundant carbonaceous material; gold-colored, fractured; grades downward into a siltstone; malachite.	35	2.02	1.94	0.0300	0.0005	0.0080	0.1000	0.0001	0.0050
5	12	19325	Calcareous lithic arenite; gray colored; 2 ft thick within an 11-ft-thick siltstone; malachite.	3	1.76	1.76	0.0200	0.0004	0.3000	0.1000	0.0020	0.0400
5	13	19303	Calcareous arkosic arenite; gray-black colored with some limonite (oxidized pyrite); very abundant carbonaceous trash and plant fragments; mud clasts are green; Tschanz and others (1958) reported sample of 0.85% U_3O_8 from this location.	119	0.92	0.50	0.0500	0.0004	0.0008	0.0300	0.0100	0.1500

TABLE 1. (continued)

Location no. (Fig. 2)	Sample no.	Reference no.	Lithologic description	Chemical			Semiquantitative emission spectrographic analyses (%)					
				U_3O_8 (ppm)	Total C (%)	Organic C (%)	Ba	Be	Cu	Mn	Pb	V
6	14	19307	Siliceous lithic arenite; pink-colored; near the base of a small channel scour; medium cross-bedding; is the only sample with silica as dominant cement.	4	0.12	0.11	0.0300	0.0006	0.0010	0.0100	0.0003	0.0010
6	15	19308	Calcareous arkosic arenite; pink-colored; from an 8-ft massive sandstone, below 4-ft limestone; some barite cement.	6	1.11	0.08	0.0300	0.0004	0.2000	0.2000	0.0040	0.0040
6	16	19314	Lithic arenite; sandstone in 4-cm pebble conglomerate near top of section.	3	0.18	0.18	0.0500	0.0003	0.0080	0.0100	0.0001	0.0010
7	17	19317	Siliceous arkosic arenite; micaceous; poorly sorted; in axis of a small fold; some carbonaceous material; malachite.	20	0.07	0.06	0.0300	0.0030	0.1000	0.0300	0.0006	0.0080
7	18	19318	Silty feldspathic wacke; from prospect pit; mineralized area is 8 ft by 10 ft (?) in a small scale cross-bedded and rippled siltstone; very micaceous; malachite; arkosic sandstone above pit is bleached; abundant silicified logs were found in the sandstone.	60	0.71	Nil	0.0600	0.0008	0.1500	0.1500	0.0004	0.0060
7	19	19319	Arkosic arenite; abundant vegetal matter; coarse grained; channel deposit; chalcocite, malachite; azurite is very abundant.	26	0.50	0.16	0.0200	0.0005	>1	0.0100	0.0003	0.0800

TABLE 1. (continued)

Location no. (Fig. 2)	Sample no.	Reference no.	Lithologic description	Chemical: U_3O_8 (ppm)	Chemical: Total C (%)	Chemical: Organic C (%)	Semiquantitative emission spectrographic analyses (%): Ba	Be	Cu	Mn	Pb	V
7	20	19320	Siltstone; (1,500 ft below sample 18) micaceous, quartzose, some bleaching in stringers; carbonaceous material.	148	0.22	0.22	0.0400	0.0020	0.1000	0.0300	0.0008	0.0100
9	21	19315	Arkosic arenite; pink; coarse-grained: with a high percentage of GRF; abundant dead oil.	4	0.22	0.09	0.0200	0.0003	0.0004	0.0300	0.0002	0.0005
10	22	19309	Calcareous arkosic arenite; tan colored; medium grained; some barite cement; dead oil.	3	0.99	0.01	0.0400	0.0003	0.0020	0.0300	0.0001	0.0030
10	23	19310	Arkosic arenite; medium grained; massive.	1	0.10	0.09	0.0500	0.0001	0.0005	0.0010	0.0002	0.0005
11	24	19311	Calcareous lithic arenite; pink; coarse-grained; 8 ft thick; just below Sangre de Cristo-Yeso contact, some silica cement.	2	0.90	0.17	0.0300	0.0030	0.0020	0.0100	0.0003	0.0080
11	25	19312	Calcareous lithic arenite; 2 ft thick; medium-scale cross-bedding; micaceous; feldspathic.	--	--	--	--	--	--	--	--	--
11	26	19313	Silty mudstone; illite 80%, kaolinite 20%, bleached green-white below channel sandstone; contained clay clasts.	12	0.43	0.10	0.1500	0.0030	0.0100	0.0200	0.0003	0.0200
13	27	19316	Arkosic arenite; medium cross-bedded to massive; near Yeso contact with Sangre de Cristo.	2	0.10	0.06	0.0300	0.0001	0.0004	0.0050	0.0002	0.0010

TABLE 2. RADIOACTIVE CONSTITUENTS IN SELECTED SAMPLES FROM SANGRE DE CRISTO FORMATION

Location no. (Fig. 2)	Sample no. (App. A)	Reference no.	U_3O_8 (ppm)	eU_3O_8 (ppm)	Ratio eU/U	eTh* (ppm)	Ratio U_3O_8/eTh	eK* (%)
3	1	19321	105	145	1	17	6	3.2
3	2	19322	345	400	1	6	58	1.8
5	3	19298	76	151	2	5	15	1.4
5	4	19299	247	379	2	9	27	1.1
5	5	19300	64	142	2	9	7	1.7
5	6	19301	182	301	2	6	30	1.4
5	7	19302	90	162	2	8	11	2.5
5	8	19304	25	29	1	4	6	0.5
5	9	19305	21	29	1	13	2	1.9
5	10	19306	125	217	2	18	7	2.5
5	11	19324	35	41	1	7	5	1.0
5	12	19325	3	2	1	5	1	1.8
5	13	19303	119	372	3	6	20	1.4
6	14	19307	4	2	2	4	1	2.1
6	15	19308	6	4	1	5	1	2.2
6	16	19314	3	1	0.3	7	0.4	3.6
7	17	19317	20	32	2	15	1	2.4
7	18	19318	60	94	2	9	7	2.9
7	19	19319	26	27	1	11	2	2.4
7	20	19320	148	219	1	14	11	2.5
9	21	19315	4	3	1	3	1	1.5
10	22	19309	3	1	0.3	1	3	3.5
10	23	19310	1	1	1	3	0.3	4.1
11	24	19311	2	6	3	16	0.1	4.3
11	26	19313	12	15	1	16	1	3.2
13	27	19316	2	1	1	3	1	3.2

*counting time, 40 min per sample.

Grain contacts are point and long grain-to-grain, although floating grains and concavo-convex contacts are seen; only minor pressure solution is suggested. Consequently, the sandstone may be moderately porous except in areas of abundant cement.

The sandstone is cemented predominantly with carbonate, but silica, iron oxide, sulfate, and clay are also present as cementing agents. Fine- to medium-grained patches of sparitic and micritic calcite cement are evident. Micrite shows a strong relationship with intraformational clasts and was probably derived from the destruction of those fragments. Barite is intimately associated with calcite in two samples.

Replacement of quartz and feldspar by calcite is common. Tschanz and others (1958) inferred that such replacement in the Coyote district was caused by hydrothermal solutions that remobilized uranium from low-grade syngenetic deposits and precipitated it as higher-grade epigenetic deposits. Our data do not support such a hypothesis. (For example, faults in the area do not appear to be mineralized, and no high-temperature mineral suites were found. On the other hand, replacement by means of cold solutions is possible if the solutions are under-saturated in silica, are saturated with respect to carbonate, or both.)

Alteration of feldspar to kaolinite and petrographic sericite is evident in all samples. Plagioclase is more intensely altered than potassium feldspar.

Siltstones, Mudstones, and Shales

Siltstones, mudstones, and shales in the Sangre de Cristo are generally reddish-brown to maroon or variegated; some shales are dark (carbonaceous). The siltstones are clayey and micaceous and generally contain approximately the same proportions of quartz and feldspar as the sandstones.

Limestones

Limestones are gray to red, micritic carbonates that contain quartz, feldspar, and micritic rock fragments. They are generally nonfossiliferous except at Mora River Gap where some fossils are found. Thin, red dolomites are present in the southern part of the basin.

GEOCHEMISTRY

Uranium oxide does not correlate with mineral carbon (Tables 1, 3); thus, there is no apparent relation between uranium deposition and calcification. The data are not conclusive, however, because the relationship may be one of calcification enveloping both mineralized and barren rock. Laboratory analyses of small grab samples did not indicate a correlation between organic carbon and uranium oxide. However, field observations, made in the general area of the uranium deposits, indicate an abundance of carbonaceous trash. Conversely, when no carbonaceous material is found, the general absence of uranium is noted.

There is fair correlation between uranium and barium; poor correlation between uranium and lead, and uranium and vanadium; and no correlation between uranium and copper, beryllium, or iron. There is, therefore, no apparent indication from statistical analyses that deposition of these elements was directly related to uranium deposition. The relationship between uranium and barium is not clear. Harshman (1972) noted that, in the Shirley basin (Wyoming) deposits, barium was slightly more abundant in mineralized sandstones than in unaltered sandstones. Correlation between barium and uranium may be related to coincidental deposition of uranium and barium from sulfate-bearing ground waters.

TABLE 3. CORRELATION COEFFICIENTS BETWEEN CHEMICAL URANIUM OXIDE AND NINE OTHER CONSTITUENTS

	V	C(org.)	C(min.)	Ba	Cu	Pb	Be	Ca	Fe
U	0.68	0.32	0.05	0.84	0.32	0.76	0.63	0.04	0.54

The equivalent-uranium to chemical-uranium (eU/cU) ratios suggest that the system is essentially in radiometric equilibrium (Table 2). Two samples (13 and 24) are slightly out of equilibrium, which suggests that uranium was leached locally, possibly by surface water.

Uranium-to-thorium (U/Th) ratios for sandstone are about 0.25 (Adams and others, 1959) to 0.36 (Vine and Tourtelot, 1973). Departures of uranium-to-thorium ratios from these general averages may indicate anomalous circumstances. Uranium-to-thorium ratios of samples collected during the present study range from 0.1 to 58 and average about 9. Samples that contain more than 50 ppm uranium have an average uranium-to-thorium ratio of 19. Uranium enrichment or thorium impoverishment is thereby indicated. Depletion of thorium is unlikely, because it is insoluble in cold solutions (Adams and others, 1959); therefore, the ratios suggest that uranium was added to the sandstone.

SEDIMENTOLOGY

Internal Features

Medium-scale cross stratification and sharp, erosional, lower and lateral contacts are the most common sedimentary structures. Although obscured in some of the pebbly sandstone, the sandstone is generally coarsest at the base and becomes finer grained upward. Large intraformational pebbles and cobbles are present in some of the sandstone at several stratigraphic levels. Some sandstone, however, is massive, is bounded by horizontal bedding planes, and lacks internal structure except for irregularly distributed claystone pebbles. Small- and large-scale cross-bedding, ripple marks, animal burrows, and penecontemporaneous deformation are found locally.

Depositional Environments

The Sangre de Cristo Formation represents several depositional environments. The sediments are mainly alluvial (Northrop and others, 1946; Brill, 1952; Baltz and Bachman, 1956; Tschanz and others, 1958; Bolyard, 1959; Baltz, 1965; Clark and Read, 1972) and consist of upper flood-plain, lower flood-plain (overbank), and paludal deposits; lacustrine deposits are also present. Much of the formation consists of genetic, multistoried, and multilateral sandstone units.

Piedmont deposits (boulder and cobble conglomerates) are found near Elizabethtown and the Red River Pass (near the Cimarron arch; Fig. 8) (Clark and Read, 1972). However, the formation in the northern two-thirds of the basin is characterized by braided-stream deposits that were laid down near source areas and are typical of upper alluvial-plain environments. Black carbonaceous shale in this part of the basin may have been derived from flood-plain or paludal deposits.

Lacustrine environments are suggested by the presence of thin, iron-oxide-stained, generally unfossiliferous limestone. The limestone is present mainly in the lower part of the Sangre de Cristo.

To the south, near Tecolote Creek and Pecos River areas, alluvial-plain, meander-belt deposits predominate (Fig. 8). Thin dolomites and siltstones with abundant burrows in the Pecos River section (Fig. 8; Pl. 1) indicate that tidal-flat environments may also be present in the southern Las Vegas basin.

EVIDENCE OF FAVORABILITY FOR URANIUM

SURFICIAL DEPOSITS

Uranium deposits in the Sangre de Cristo Formation are known in three areas: near Black Lake, in the Coyote district, and at the Mora River Gap (Fig. 2). Only the Coyote district deposits are described in the literature; those near Black Lake and the Mora River Gap were discovered during the present project.

Black Lake

There is a small uranium-vanadium deposit approximately 2 mi north of Black Lake, by Highway 38 (Fig. 2, loc. 2), in strata that are slightly overturned and strike due north. Radiometric measurements with a hand-held scintillometer indicated up to 2,200 ppm equivalent U_3O_8 in the outcrop; a sample assayed 345 ppm chemical U_3O_8 (Table 1, sample 2). The deposit is in a 6-ft-thick channel sandstone and an overlying 1-ft-thick, black, carbonaceous mudstone, and extends upward into a 4-ft-thick channel sandstone. It is about 1,500 ft above the base of the Sangre de Cristo. Lateral extent is unknown because of cover but is at least 15 ft along strike.

The sandstones are very coarse grained and granule size, pebbly and cobbly, and consist mainly of quartz feldspar; plutonic, metamorphic, and sedimentary rock fragments; and calcite cement. Some carbonaceous debris is present and is probably responsible for the bleaching of the beds from maroon to golden brown. Tyuyamunite is present as grain coatings and as thin streaks on bedding planes. More than 1 percent vanadium is present and may have fixed the uranium.

A small radioactivity anomaly (105 ppm cU_3O_8) is present in the roadcut southwest of the uranium-vanadium deposit and is stratigraphically about 1,000 ft below it. It is in a 3-ft-thick, wet, sticky, black, carbonaceous claystone (Table 1, sample 1) that may consist of nontronite.

Coyote District

There are several copper-uranium-vanadium deposits in a north-south belt about 6 mi long and almost 1,500 ft wide, 8 to 12 mi northeast of Mora. The deposits are in the lower 1,700 ft of the Sangre de Cristo. Individually, they are small; zones containing greater than 0.03 percent U_3O_8 are generally less than 1 ft thick by 6 to 8 ft long. Only small production from the area is known.

The deposits are generally in channels or at the base of festoon cross beds, where wood fragments and intraformational mud clasts abound. Host rocks are gray to pink, medium- to coarse-grained, calcareous arkosic arenites (Table 2, samples 3-13). Uranium is also in nodular limestone, siltstone, and black, carbonaceous mudstone. Chalcocite, other copper sulfides, secondary copper minerals, metatyuyamunite, possible roscoelite (Tschanz and others, 1958), uraninite associated with copper sulfide nodules, and a uraniferous substance are present (Zeller and Baltz, 1954; Tschanz and others, 1958).

No uranium-copper deposits were noted in the Coyote district during the present study. Uranium content is generally inverse to copper content; high uranium content is usually found in sandstone, while high copper content is associated with shale or mudstone. This may suggest different trapping mechanisms, different periods of mineralization, or syngenetic copper and epigenetic uranium mineralization.

Uranium grade is as high as 850 ppm U_3O_8 (Tschanz and others, 1958). Average grade is about 100 to 200 ppm U_3O_8 (Table 2, samples 3-13).

Mora River Gap

Two small deposits are present in roadcuts north of the Mora River about 4 mi east of Mora on Highway 3 (Fig. 2). They are about 1,200 ft above the base of the Sangre de Cristo and are approximately 1,500 ft apart along strike. Sample analyses indicate a uranium content averaging 100 ppm U_3O_8.

One deposit, exposed over an area of approximately 8 by 10 ft, is in a silty, feldspathic, micaceous wacke with small-scale cross-bedding. Its lateral extent is obscured by cover. Silicified logs are abundant in the overlying bleached, arkosic sandstone, but no carbonaceous material is evident in the zone of anomalous radioactivity nor are uranium minerals evident (Table 2, sample 18).

The other deposit is in a 3-ft-thick, micaceous, quartzose siltstone. Some carbonaceous material is present, and bleaching is evident (Table 1, sample 20).

SUBSURFACE ANOMALY

A 25-ft-thick zone of anomalous radioactivity at about 2,858 ft depth was noted on logs in 1954 during the Continental Leatherwood-Reed No. 1 oil-test hole about 5 mi east of Las Vegas, in sec. 15, T. 16 N., R. 17 E. (Fig. 2, loc. G). American Minerals Co. drilled two offsets during 1968. Samples collected at that time indicate that the host rock is an immature micaceous arkose or granite wash. Black uranyl-organic pellets are concentrated in thin layers along bedding planes and may have supplied a reductant. Samples taken at 1-ft intervals contain clausthalite (PbSe), gold, silver, and uranium, in anomalous quantities (Finch, 1972).

Gamma-ray logs from three oil-test holes provided no evidence of subsurface anomalies downdip of the Leatherwood-Reed No. 1. Only five gamma-ray logs were available for the entire basin; therefore, evidence concerning radioactivity anomalies in the subsurface is sparse.

FAVORABILITY CRITERIA PRESENT

Favorability criteria for epigenetic uranium deposits in sandstone (Grutt, 1972; Fisher, 1974) that are applicable to the present study include: possible uranium sources; host-rock types; depositional environment of host rocks; presence and amount of carbonaceous matter; uranium deposits; host-rock thicknesses and lenticularity; and alteration (Table 4).

TABLE 4. FAVORABILITY CRITERIA PRESENT IN SANGRE DE CRISTO FORMATION

Criteria	Northern area	Central area	Southern area
Tectonic regime	Intracratonic basin	Intracratonic basin	Intracratonic basin
Depositional environment	Piedmont and braided stream of alluvial plain	Alluvial fan and braided stream of alluvial plain	Meander belt deposited on alluvial plain
Lithology of host rock	Arkosic, pebbly sandstone; carbonaceous shale	Arkosic sandstone; micaceous sandstone	Arkosic sandstone
Provenance of host rock	Granitic, metamorphic, and limestone terranes	Granitic terrane with a minor metamorphic contribution	Granitic terrane
Grain size of host rock	Pebble to medium sand	Coarse to silty sand	Fine sand**
Sandstone thickness	4 to 20 ft	8 to 35 ft; multistoried	6 to 8 ft
Sandstone-shale ratio	Approximately 2:1	Approximately 1.5:1	Approximately 1:1.8
Attitude of beds at surface	80°	75° overturned to 7°	80° overturned to 6°
Flattening of beds in basin	Within 6 mi of deposit strata are horizontal	Within 1/2 mi of deposits, dip decreased to <7°	<6° (?)
Unconformities	Present at the top of the section from Black Lake northward and nonconformity at the base near the Cimarron and Sierra Grande arches	Nonconformity present at the base of the Sangre de Cristo near the Sierra Grande arch	Nonconformity present at the base of the section near Tecolote-Sierra Grande arches; angular unconformity with the Madera*
Unoxidized sandstone (contains sulfides)	--	Contains copper and iron sulfides	Contains sulfides

TABLE 4. (continued)

Criteria	Northern area	Central area	Southern area
Limonite-hematite stained (anomalous)	Hematite stained aureole	Small blebs of limonite	--
Bleaching	Bleaching evident around deposit	Bleaching abundant near sandstones	Bleaching common near base of sandstones
Reducing agents (traps)	Carbonaceous debris, carbonaceous mudstone, vanadium	Carbonized wood, carbonaceous trash, carbonaceous shales, sulfides, asphalt,* dead oil, shows of petroleum, natural gas§§	Shows of petroleum,ǂ asphalt**
Groundwater anomaly	--	15 ppb (only analysis available)+	--
Host-rock anomalies (maximum)	0.2% eU_3O_8	0.85% cU_3O_8§	0.1% cU_3O_8**
Uranium minerals on outcrop and in subsurface	Tyuyamunite	Uraninite,+ metatyuyamunite,+ uraniferous humate(?), and uraniferous ferric substance§(?)	Uranyl-organic material**
Elements associated with uranium	Vanadium, molybdenum, manganese, copper, silver	Vanadium, molybdenum, manganese, copper, silver	Selenium, gold, silver,** copper

* Northrup and others (1946)
\+ Zeller and Baltz (1954)
§ Tschanz, Laub, and Fuller (1958)
** Finch (1972)
ǂ Baltz (1965)
§§ Speer (1976)

Possible Sources of Uranium

Thickness (Fig. 5), sandstone-shale ratios (Fig. 5), and depositional environments (Fig. 8) indicate that the main source areas for Sangre de Cristo sediments in the Las Vegas basin are to the north. Sandstone compositions and textures indicate first-cycle sedimentation from a predominantly granitic provenance. The granitic source rocks for the arkosic sediments (that is, the Sierra Grande uplift, Cimarron arch, and San Luis - Uncompahgre highlands) could have supplied uranium to the Las Vegas basin during Late Pennsylvanian and Early Permian time. Granitic terranes in the Pedernal uplift and Tecolote arch may have contributed arkosic sediments and uranium.

No tuffaceous beds are known in the Sangre de Cristo or in the overlying Permian beds. Volcanic rocks in the area are mainly mafic basalts and are not a likely source of uranium. There is, however, a tuffaceous conglomerate remnant, probably correlative with the Tertiary Picuris Tuff of the Sangre de Cristo uplift (Wanek and Read, 1956), along the western boundary of the study area, near Palo Flechado Pass. The beds may have been more extensive and could have been a source of uranium.

Host Rocks

The alluvial, medium- to coarse-grained, feldspathic to arkosic, lenticular sandstones, which are laterally continuous over distances of at least several miles and are more than 20 ft thick in many parts of the area, constitute favorable host rocks. Carbonaceous material is present locally; although it is not abundant in outcrops, it may be present in greater abundance in the subsurface. Carbonaceous shale and local uranyl-organic pellets are also favorable features. Host-rock bleaching is present locally. The criteria of host-rock favorability are met in the project area, especially in the north-central part of the basin (Table 4).

CONCLUSIONS

URANIUM FAVORABILITY

Uranium Source

Provenance of the potential host rocks was predominantly granitic. Granitic terranes are exposed along the western and northern boundaries of the project area in the Sangre de Cristo and Cimarron Mountains. The Picuris Tuff (?) may have been more extensive than it is presently and may have served as a uranium source.

Uranium Transport

The potential host rocks were moderately permeable before calcite cementation and could have permitted the infiltration and passage of uraniferous solutions. Unconformities bound the Sangre de Cristo only locally; their influence on regional transmissivity was probably not great except in areas of basal unconformity near the Tecolote arch, Cimarron arch, and Sierra Grande uplift. There is no spatial relationship between the unconformities and the known deposits.

Structure

On the western edge of the Las Vegas basin, beds dip steeply or are overturned along the outcrop belt where all known deposits are found. Uranium favorability is generally low in areas of steep dips, but the beds flatten to the east within a couple miles of the outcrop, and dip gently into the Las Vegas basin, usually at less than 7°. Gentle folding in the basin may have aided uranium deposition by inhibiting ground-water flow.

Reductant

Carbonaceous material is not present in all the low-grade uranium deposits, but it is found with the higher-grade deposits. Carbonaceous material is locally abundant in the north but was not detected in the south. The abundance of debris in the subsurface is unknown. This subject relates to depositional environment and is further discussed below.

Depositional Environments

Although most of the Sangre de Cristo Formation was deposited under alluvial conditions in the Rowe-Mora basin, certain subenvironments are more favorable than others. Piedmont deposits in the extreme northern Las Vegas basin and alluvial-plain, meander-belt deposits in the southern part of the basin (Fig. 8) contain no discernible carbonaceous trash and are highly oxidized; either carbonaceous trash was not deposited to any great degree or it was destroyed by oxidation before deep burial. On the other hand, braided alluvial-plain deposits in the north-central part of the basin contain more carbonaceous material than the piedmont and alluvial-plain, meander-belt deposits. The braided-stream deposits in the north were probably buried more quickly than the alluvial-plain, meander-belt deposits to the south.

FAVORABLE AREAS

The most favorable area for uranium deposits is in the north-central part of the Las Vegas basin, especially in Tps. 20 through 24 N. and Rs. 16 through 17 E. (Fig. 11). There, the Sangre de Cristo is characterized by medium- to coarse-grained lenticular sandstones and by

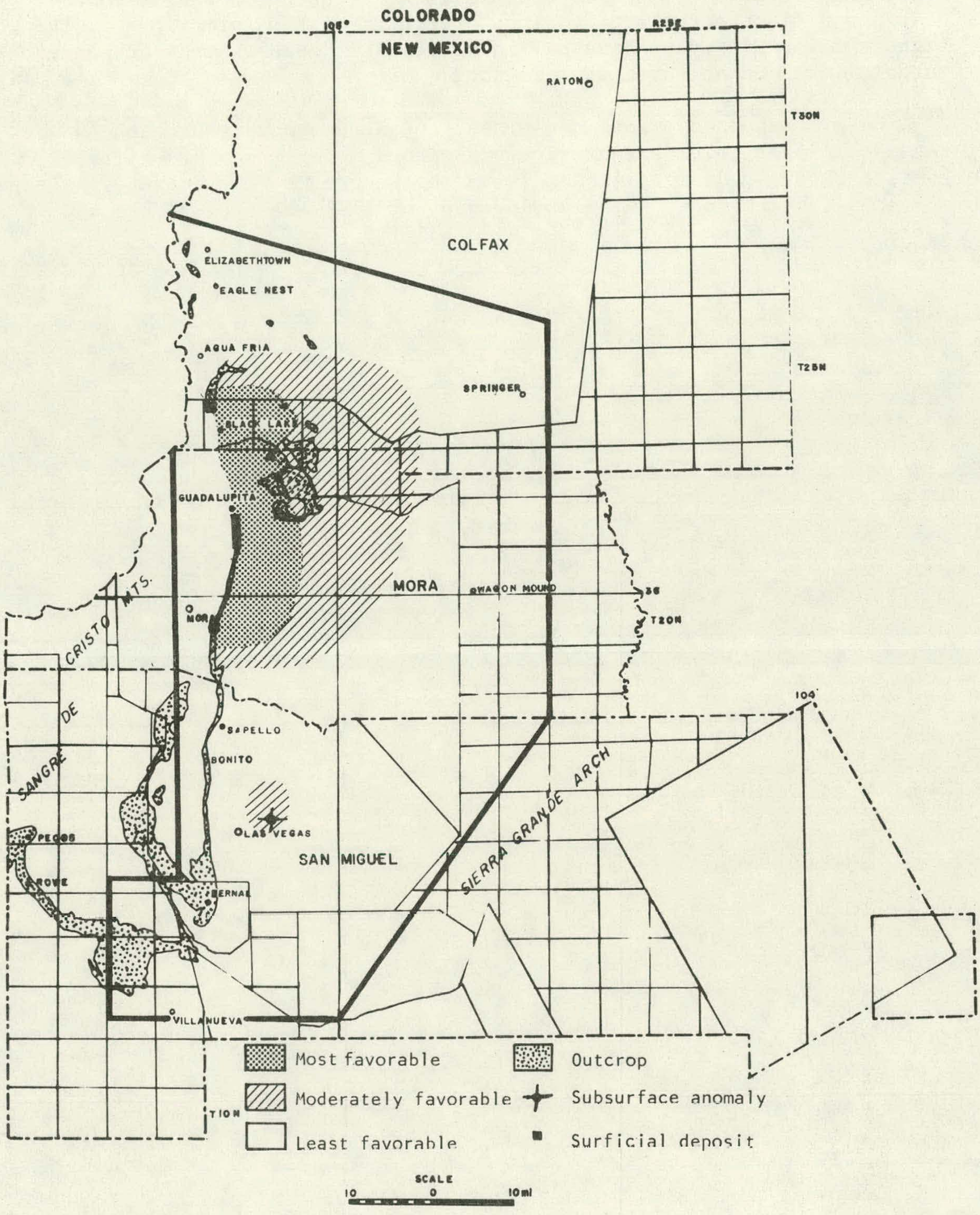


Figure 11. Uranium favorability map of the Sangre de Cristo Formation, Las Vegas basin, New Mexico.

sandstone-shale ratios of between 1:1 and 2:1 (Fig. 5). In terms of paleoenvironments, areas of upper alluvial-plain deposits are more favorable than the areas of piedmont deposition to the north and of meanderbelt deposition to the south. The lower half of the formation has the highest favorability because all known uranium deposits and carbonaceous material are concentrated in this zone.

Despite the above considerations, the area around the Leatherwood-Reed No. 1 test hole is tentatively assigned moderate favorability because of the radiometric anomaly in the Sangre de Cristo there. Although no anomalies are known in holes downdip, drill holes are sparse, and further work is needed to assess favorability.

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APPENDIX A

MEASURED SECTION AND SAMPLE LOCATIONS
IN THE SANGRE DE CRISTO FORMATION,
LAS VEGAS BASIN, NEW MEXICO

APPENDIX A. MEASURED SECTION AND SAMPLE LOCATIONS IN THE SANGRE DE CRISTO FORMATION, LAS VEGAS BASIN, NEW MEXICO

Locality no. (Fig. 2)	Measured section or district name	Location	Sample no. (Tables 1, 2)	Reference no.
1	Elizabethtown section	sec. 2(?), T. 27 N., R. 15 E.; 1 mi WNW of G. Mute Ranch, Colfax Co.	--	--
2	Agua Fria Creek section	sec. 9(?), T. 25 N., R. 16 E.; 3.2 mi ESE of Agua Fria, Colfax Co.	--	--
3	Black Lake section	NW¼ sec. 6, T. 24 N., R. 16 E.; near El Borco Trailer Park, Colfax Co. (approximately 0.06 mi SW of sample 1)	1	19321
4	Ocate section	NE¼NE¼ sec. 18, T. 23 N., R. 18 E.; 3.8 mi on the west flank of Halls Peak, NW of Ocate, Mora Co.	2	19322
5	Coyote district	secs. 23, 26, 34, 35(?), T. 22 N., R. 16 E.; secs. 3, 10, 11, 15, T. 21 N., R. 16 E.; 1.5 mi SE of Guadalupita, Mora Co.	--	--
		sec. 26(?), T. 22 N., R. 16 E.; area B (Tschanz and others, 1958)	3	19298
		sec. 26(?), T. 22 N., R. 16 E.; area B (Tschanz and others, 1958)	4	19299
		sec. 26(?), T. 22 N., R. 16 E.; area B (Tschanz and others, 1958)	5	19300
		sec. 26(?), T. 22 N., R. 16 E.; area B (Tschanz and others, 1958)	6	19301
		sec. 26(?), T. 22 N., R. 16 E.; area C (Tschanz and others, 1958)	7	19302
		sec. 26(?), T. 22 N., R. 16 E.; area C (Tschanz and others, 1958)	8	19304
		sec. 26(?), T. 22 N., R. 16 E.; area C (Tschanz and others, 1958)	9	19305
		sec. 26(?), T. 22 N., R. 16 E.; area C (Tschanz and others, 1958)	10	19306
		sec. 26(?), T. 22 N., R. 16 E.; area C (Tschanz and others, 1958)	11	19324
		sec. 26(?), T. 22 N., R. 16 E.; area C (Tschanz and others, 1958)	12	19325
		sec. 3(?), T. 21 N., R. 16 E.; area F (Tschanz and others, 1958)	13	19303
6	(Los Cisneros section)	secs. 3, 10, 11(?), T. 21 N., R. 16 E.; Mora Co.	--	--
		sec. 3(?), T. 21 N., R. 16 E.; along improved dirt road	14	19307
		sec. 3(?), T. 21 N., R. 16 E.; near junction of two roads	15	19308
		sec. 11(?), T. 21 N., R. 16 E.; near contact with Yeso just below Lefebres Mesa	16	19314

APPENDIX A. (continued)

Locality no. (Fig. 2)	Measured section or district name	Location	Sample no. (Tables 1, 2)	Reference no.
7	Mora River Gap section	secs. 15, 16, 17(?), T. 20 N., R. 16 E.; along Highway 3 from La Cueva to St. Joseph's Church, Mora Co.	--	--
		sec. 16(?), T. 20 N., R. 16 E.; along Highway 3, 0.78 mi from La Cueva	--	--
		sec. 16(?), T. 20 N., R. 16 E.; along Highway 3, 0.92 mi from La Cueva, and 0.3 mi north	18	19318
		sec. 16(?), T. 20 N., R. 16 E.; 1.0 mi west of La Cueva, and 0.22 mi north	19	19319
		sec. 16(?), T. 20 N., R. 16 E.; 0.95 mi west of La Cueva on Highway 3	20	19320
8	Rita Cebolla section	secs. 20, 21(?), T. 19 N., R. 16 E.; 0.70 mi due south of the Rita Cebolla Highway 3 junction, Mora Co.	--	--
9	Sapello section	sec. 20(?), T. 18 N., R. 16 E.; 0.45 mi west of Sapello on Highway 94, San Miguel Co.	--	--
		sec. 20(?), T. 18 N., R. 16 E.; near first road intersection on Highway 94, west of Sapello	21	19315
10	Peterson Reservoir section	sec. 6(?), T. 16 N., R. 16 E.; along irrigation ditch along north end of Peterson Reservoir, near Montezuma, San Miguel Co.	--	--
		sec. 6(?), T. 16 N., R. 16 E.; approximately 50 ft west of boat dock	22	19309
		sec. 6(?), T. 16 N., R. 16 E.; approximately 60 ft above the base of the Sangre de Cristo	23	19310
11	Kearny Gap section	sec. 4(?), T. 15 N., R. 16 E.; 3 mi SW of Las Vegas, on road to Mineral Hill, San Miguel Co.	--	--
		sec. 4(?), T. 15 N., R. 16 E.; 10 ft below Yeso-Sangre de Cristo contact near a bridge over an arroya	24	19311
		sec. 4(?), T. 15 N., R. 16 E.; from a road cut in several sandstones along Mineral Hill Road	25	19312
		sec. 4(?), T. 15 N., R. 16 E.; 50 ft west of sample 25, at the base of the sandstone in the road cut	26	19313

APPENDIX A. (continued)

Locality no. (Fig. 2)	Measured section or district name	Location	Sample no. (Tables 1, 2)	Reference no.
12	Tecolote Creek section	sec. 1(?), T. 14 N., R. 16 E.; sec. 36(?), T. 15 N., R. 16 E.; near Santa Ana, 1.5 mi NE of Tecolote, San Miguel Co.	--	--
13	Pecos River section	secs. 25, 26, T. 13 N., R. 14 E.; along Highway 3 between Lower Pueblo and Sena, San Miguel Co.	27	19316
		SE¼SW¼ sec. 25, T. 13 N., R. 14 E.; just below Yeso-Sangre de Cristo contact, north of Sena Dam	--	--

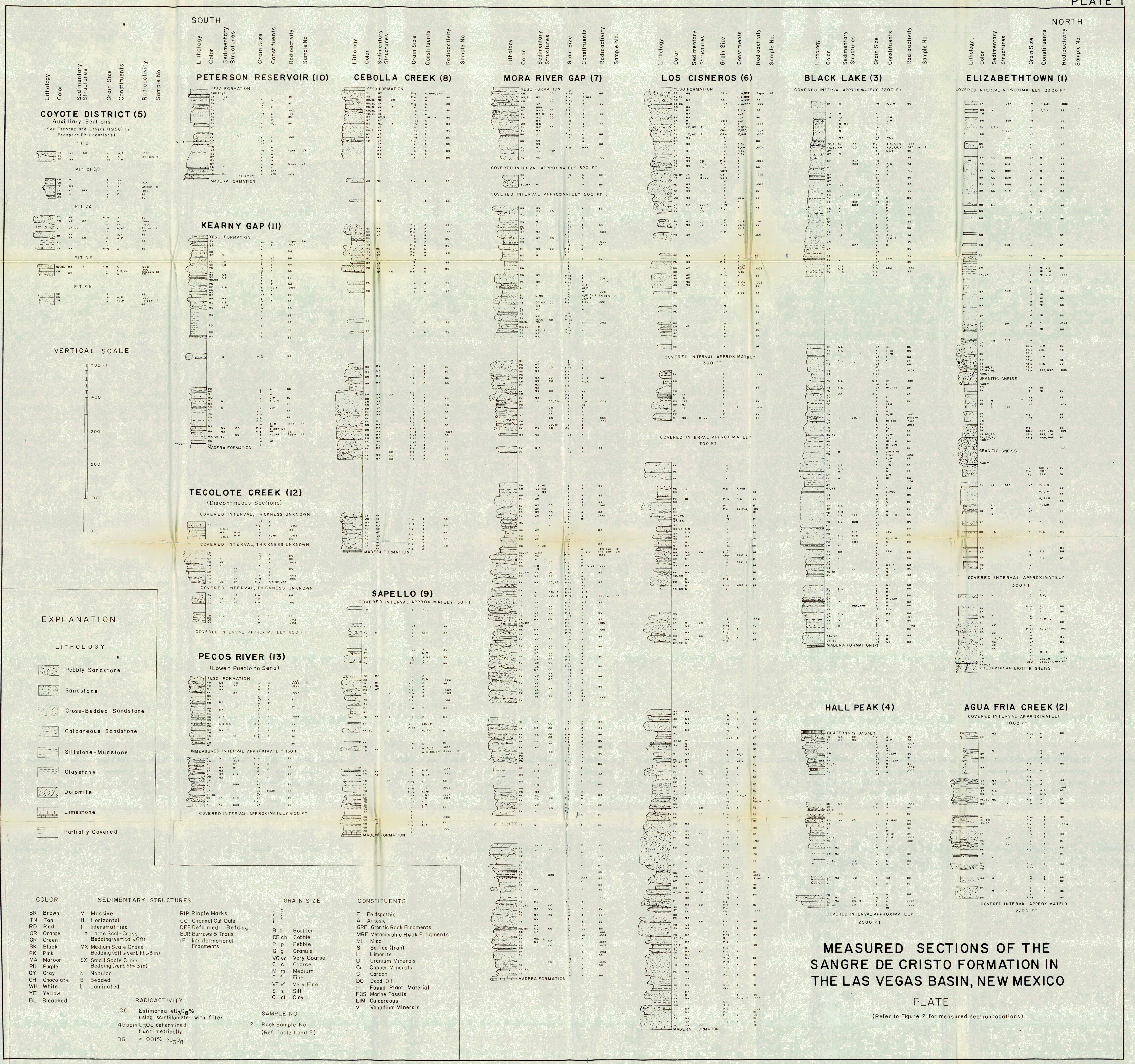
APPENDIX B

LOCATIONS OF PETROLEUM TEST-HOLE LOGS
IN THE LAS VEGAS BASIN, NEW MEXICO

APPENDIX B. LOCATIONS OF PETROLEUM TEST-HOLE LOGS IN THE LAS VEGAS BASIN, NEW MEXICO

Location symbol (Fig. 2)	Company	Name	Log type	Location	County
A	American Mfg.	No. 1 W.S. Ranch	ES	sec. 1, T. 26 N., R. 20 E.	Colfax
B	McDaniels Oil Lease Trust	McDaniels & Sons Inc.	IES	sec. 32, T. 24 N., R. 20 E.	Colfax
C	Continental Oil	No. 1 Mares-Duran	GRN, IES	sec. 14, T. 23 N., R. 17 E.	Mora
D	Shamrock Oil & Gas	No. 1 MacArthur	ES	SW¼SW¼SW¼ sec. 12, T. 19 N., R. 21 E.	Mora
E	J.D. Hancock Expl.	No. 1 Sedberry	IES, SNP	sec. 25, T. 17 N., R. 16 E.	San Miguel
F	Continental Oil	No. 1 Shoemaker-Reed	GRN, ES	sec. 28, T. 17 N., R. 18 E.	San Miguel
G	Continental Oil	No. 1 Leatherwood-Reed	GRN, ES	sec. 15, T. 16 N., R. 17 E.	San Miguel
H	Continental Oil	No. 1 Emma V. Hunker	GRN, ES	sec. 36, T. 16 N., R. 17 E.	San Miguel
I	Phillips Petr.	No. 1 Leatherwood	ES	sec. 2, T. 15 N., R. 18 E.	San Miguel

Note: ES, electrolog; IES, induction electrolog; GRN, gamma ray-neutron; SNP, sidewall neutron porosity (with gamma ray).



MEASURED SECTIONS OF THE SANGRE DE CRISTO FORMATION IN THE LAS VEGAS BASIN, NEW MEXICO

PLATE I

(Refer to Figure 2 for measured section locations)