MINERAL-RESOURCE ASSESSMENT OF LUNA COUNTY, NEW MEXICO

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Open-file Report OF-459

New Mexico Bureau of Geology and Mineral Resources

New Mexico Institute of Mining and Technology

Socorro, New Mexico 87801

September 2001

Prepared for the New Mexico State Land Office

SUMMARY

Luna County, in southwestern New Mexico (Fig. 1) is not well known for its mineral potential, but more than $16 million worth of metals and nonmetals have been produced from the county from 1876 to 2000. Much of this production has come from 11 types of metallic deposits and six types of industrial minerals (barite, fluorite, clay, crushed and dimension stone, and gems and mineral collecting) that are found in 16 mining districts in the county. The Cooke's Peak district ranks 5th in lead production in the state and 9th in zinc production and the Victorio district ranks 7th in lead production in the state. Native Americans were the first miners in New Mexico and used local sources of hematite and clay for pigments, and obsidian and chert for arrowheads. Their houses were made of stone, adobe, and clay. Clay also was used in making pottery. In 1848, New Mexico became part of the U. S. as a territory and the mining industry became a dominant force in much of the state, but not in Luna County for some 30 more years. Metals were first discovered in the Fremont district about 1860 and in the Florida Mountains and Cooke's Peak district about 1876. This was still Apache territory, so mining, travel, and settlement were treacherous. The first commercial mining of metals in Luna County was the lead-zinc-silver deposits in the Cooke's Peak district in 1876, which yielded approximately $3 million by 1900. Deposits in the Florida Mountains, Victorio, Old Hadley, and Tres Hermanas districts were soon discovered. Currently, agate, manganese, fire clay, and sand and gravel are being produced from Luna County.

This report assesses the potential of mineral and energy resources (excluding aggregate and petroleum resources) on the surface and within the subsurface in Luna County in southern New Mexico. Aggregate and petroleum resources will be assessed in separate reports. Resource potential is the likelihood for the occurrence of undiscovered concentrations of metals, nonmetals, industrial materials, and energy resources. The evaluation of mineral-resource potential involves a complex process based on geologic analogy of promising or favorable geologic environments with geologic settings that contain known economic deposits (geologic models). Such subjective assessments or judgements depend upon available information concerning the area as well as current knowledge and understanding of known deposits. This assessment will provide land managers with appropriate data to make land-use decisions. The project conforms to mineral assessment guidelines and procedures required by the U. S. Bureau of Land Management (Goudarzi, 1984). Based on detailed geologic, geochemical, and geophysical data there is high resource potential for beryllium, tungsten, and molybdenum in the Tres Hermanas-Victorio Mountains; silver, lead, and zinc in the Tres Hermanas-Victorio Mountains and Cooke's Range; manganese in the Cooke's Range and Florida-Little Florida Mountains; fluorite in the Fluorite-Goat Ridge; clay at Taylor Mountain; crushed stone in the Victorio Mountains; and gems and mineral collecting in the Burdick-Bisbee Hills and Carrizalillo-Cedar-Klondike Hills (Table 1).

FIGURE 1. Location of Luna County, New Mexico.

TABLE 1. Summary of mineral-resource potential for metals, selected industrial minerals, and energy resources in Luna County (except for petroleum and aggregates).

RESOURCE	AREA	POTENTIAL/ CERTAINTY	COMMENTS
Metallic mineral resources			
Beryllium	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Low/B	Rhyolite domes need examination
	Cooke's Range	Low/B	
	Florida-Little Florida Mountains	Low/B	Rhyolite domes need examination
	Fluorite-Goat Ridge	Low/B	
	Mimbres Basin	Low/B	
	Tres Hermanas-Victorio Mountains	High/D, moderate/C	
	Elsewhere in Luna County	None/D	
Bismuth	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	None/D	
	Cooke's Range	Low/B	
	Florida-Little Florida Mountains	None/D	
	Fluorite-Goat Ridge	None/D	
	Tres Hermanas-Victorio Mountains	Low/B	
	Elsewhere in Luna County	None/D	

RESOURCE	AREA	POTENTIAL/ CERTAINTY	COMMENTS
Copper	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Moderate/C	Calumet mine
	Cooke's Range	Moderate/B	
	Florida-Little Florida Mountains	Low/B	
	Fluorite-Goat Ridge	Moderate/B	
	Mimbres Basin	Low/B	
	Tres Hermanas-Victorio Mountains	Moderate/B	
	Elsewhere in Luna County	None/D	
Germanium	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	None/D	
	Cooke's Range	Low/B	
	Florida-Little Florida Mountains	Low/B	
	Fluorite-Goat Ridge	None/D	
	Mimbres Basin	None/D	
	Tres Hermanas-Victorio Mountains	Low/B	
	Elsewhere in Luna County	None/D	
Gold	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Moderate/B	Sedimentary-hosted
	Cooke's Range	Moderate/B	Sedimentary-hosted, skarn
		Moderate/B	High sulfidation epithermal
	Florida-Little Florida Mountains	Low/B	
	Fluorite-Goat Ridge	Low/B	
	Tres Hermanas-Victorio Mountains	Moderate/B	
	Snake Hills	Low/B	Sedimentary-hosted, skarn
	Mimbres basin	Unknown/A	
	Elsewhere in Luna County	None/D	Sedimentary-hosted, skarn
Iron	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Moderate/C	
	Cooke's Range	Moderate/B	
	Florida-Little Florida Mountains	Moderate/B	
	Fluorite-Goat Ridge	Low/B	
	Tres Hermanas-Victorio Mountains	Moderate/B	
	Elsewhere in Luna County	None/D	
Lead-zinc	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Moderate/C	
	Cooke's Range	High/D	
	Florida-Little Florida Mountains	Low/B	
	Fluorite-Goat Ridge	Low/B	
	Tres Hermanas-Victorio Mountains	High/D	
	Snake Hills	Low/B	
	Elsewhere in Luna County	None/D	
Manganese	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Moderate/C	
	Cooke's Range	High/D	
	Florida-Little Florida Mountains	High/D	
	Fluorite-Goat Ridge	Low/C	
	Mimbres Basin	Low/B	
	Tres Hermanas-Victorio Mountains	Moderate/C	
	Elsewhere in Luna County	None/D	
Molybdenum	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Moderate/C	
	Cooke's Range	Low/B	
	Florida-Little Florida Mountains	Low/B	
	Fluorite-Goat Ridge	Low/B	
	Mimbres Basin	Low/B	
	Tres Hermanas-Victorio Mountains	High/D	
	Elsewhere in Luna County	None/D	

RESOURCE	AREA	POTENTIAL/ CERTAINTY	COMMENTS
Niobium	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Low/B	
	Cooke's Range	None/D	
	Florida-Little Florida Mountains	Low/B	
	Fluorite-Goat Ridge	None/D	
	Mimbres Basin	None/D	
	Tres Hermanas-Victorio Mountains	None/D	
	Elsewhere in Luna County	None/D	
Silver	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Moderate/C	
	Cooke's Range	High/D	
	Florida-Little Florida Mountains	Moderate/C	
	Fluorite-Goat Ridge	Moderate/C	
	Mimbres Basin	Low/B	
	Tres Hermanas-Victorio Mountains	High/D	
	Snake Hills	Low/B	
	Elsewhere in Luna County	None/D	
Thorium and rare-earth elements (REE)	Florida-Little Florida Mountains	Low/C	
	Elsewhere in Luna County	None/D	
Tin	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Low/B	Rhyolite domes need examination
	Cooke's Range	None/D	
	Florida-Little Florida Mountains	Low/B	
	Fluorite-Goat Ridge	None/D	
	Mimbres Basin	None/D	
	Tres Hermanas-Victorio Mountains	None/D	
	Elsewhere in Luna County	None/D	
Tungsten	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	Low/B	
	Cooke's Range	None/D	
	Florida-Little Florida Mountains	None/D	
	Fluorite-Goat Ridge	None/D	
	Mimbres Basin	Low/B	
	Tres Hermanas-Victorio Mountains	High/D	
	Elsewhere in Luna County	None/D	
Industrial mineral resources (except aggregates)			
Alunite	Cooke's Range	Low/C	
	Elsewhere in Luna County	None/D	
Barite and fluorite	Camel Mountain-Eagle Nest	Low/B	Epithermal fluorite
	Carrizalillo-Cedar-Klondike Hills	Low/B	Epithermal fluorite
	Cooke's Range	Moderate/B	Epithermal fluorite
	Florida-Little Florida Mountains	Moderate/C	Epithermal fluorite
		Low/B	RGR deposits
	Fluorite-Goat Ridge	High/D	Epithermal fluorite
	Mimbres Basin	Low/B	
	Tres Hermanas-Victorio Mountains	Low/B	RGR deposits
	Elsewhere in Luna County	None/D	Epithermal fluorite
Clay	Taylor Mountain	High/D	Fire clay being produced
	Cooke's Range	Moderate/B	Mancos and Percha Shale exposures
	Goodsight Mountains/Uvas Valley	Moderate/B	Camp Rice Formation
	Florida-Little Florida Mountains	Moderate/C	Hydrothermal altered rhyolite
	Mimbres River (north)	Moderate/C	Mimbres River sediments
	Deming	High/D	Adobe, brick clay
	Elsewhere in Luna County	None/D	

RESOURCE	AREA	POTENTIAL/ CERTAINTY	COMMENTS
Crushed stone	Aden district, eastern Luna County	Moderate/D	Scoria, basalt
	Carrizalillo-Cedar-Klondike Hills	Moderate/C	Limestone, scoria, basalt
	Cooke's Range	Low/C	Scoria, basalt
		Moderate/B	Limestone
	Columbus	Low/C	Scoria, basalt
	Tres Hermanas	Unknown	Scoria, basalt
		Moderate/B	Limestone
	Victorio Mountains	High/D	Limestone
	Black Mountain	Low/B	Scoria, basalt
	Red Mountain	High/C	Rhyolite
	Elsewhere in Luna County	Unknown to None/D	Alluvial deposits may be suitable
Dimension stone	Burdick-Bisbee Hills	Low/B	Travertine
	Carrizalillo-Cedar-Klondike Hills	Moderate/C	Limestone
	Fluorite Ridge	Moderate/C	Sandstone
		Moderate/C	Granite
	Goat Ridge	Low/B	Travertine
	Tres Hermanas	Moderate/C	Granite
		Moderate/C	Travertine
	Victorio Mountains	Low/B	Marble, travertine, marble
		Moderate/C	Limestone
	Taylor Mountain	Moderate/C	Rhyolite
	Elsewhere in Luna County	None/D	
Garnet	Camel Mountain-Eagle Nest	Low/B	
	Carrizalillo-Cedar-Klondike Hills	None/D	
	Cooke's Range	None/D	
	Florida-Little Florida Mountains	None/D	
	Tres Hermanas-Victorio Mountains	Low/C	
	Elsewhere in Luna County	None/D	
Gems, semi-precious stones, and mineral collecting	Burdick-Bisbee Hills	High/D	Agate being produced
	Camel Mountain-Eagle Nest	Moderate/B	Mineral collecting
	Carrizalillo-Cedar-Klondike Hills	High/D	Mineral collecting, geodes produced
		High/D	Jasperoid
	Florida-Little Florida Mountains	Moderate/C	Psilomelane
	Elsewhere in Luna County	Unknown	
Limestone/ dolostone/ travertine/marble	Carrizalillo-Cedar-Klondike Hills	Moderate/B, Low/D	Aggregate, High-calcium
	Cooke's Range	Moderate/B, Low/D	Aggregate, High-calcium
	Tres Hermanas Mountains	Moderate/B, Low/D	Aggregate, High-calcium
	Victorio Mountains	Moderate/B, Low/D	Aggregate, High-calcium
	Elsewhere in Luna County	None/D	
Perlite	Carrizalillo-Cedar-Klondike Hills	Low/B	Rhyolite domes need examination
	Good Sight Mountains/Uvas Valley	Unknown	Rhyolite domes need examination
	Elsewhere in Luna County	None/D	
Pumice	Cooke's Range	Low/B	Sugarlump Tuff, Mimbres Fm
	Elsewhere in Luna County	None/D	
Silica	Fluorite-Goat Ridge	Low/D	Specialty uses
		Unknown	Silica flux
	Eagle Nest-Camel Mountains	Low/C	Mojado Formation
	Victorio Mountains	Low/C	Mojado Formation
	Elsewhere in Luna County	None/D	
Talc	Tres Hermanas-Victorio Mountains	Low/B	
	Elsewhere in Luna County	None/D	
Zeolites	Northern Luna County	Moderate/B	
Energy resources (except petroleum)			
Uranium	Tres Hermanas-Victorio Mountains	Low/C	
	Sierra Rica (Fremont district)	Low/C	
	Luna County	None/D	
Geothermal	Eastern Luna County	Low-moderate/B	<5 Ma basalts
	Columbus	Low-moderate/B	<5 Ma basalts
	Northern Luna County	Low-moderate/B	Nearby hot springs
	Elsewhere in Luna County	None/D	
Coal	Luna County	None/D	

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Study area

Luna County lies within the Basin and Range physiographic province in southern New Mexico (Fig. 1). Much of the county is relatively flat and is covered by alluvial material. Prominent physiographic features within the county include Cooke's Range to the north, the Victorio, Florida, and Little Florida Mountains in central Luna County, Carrizalillio Hills, Cedar Mountains, and Tres Hermanas Mountains in the south, and numerous small mountain ranges and hills throughout Luna County (Fig. 2). The Mimbres basin is the main basin in Luna County today (Fig. 2). The northeastern part of the Animas basin extends into southwestern Luna County. There are numerous canyons in the mountains, but the only river is the Mimbres River and it is dry most of the year. Although Luna County is not well known for its mineral potential, approximately $11 million worth of base and precious metals has been produced from the county from 1876 to 1965 (Table 2). More than $16 million dollars worth of minerals has been produced from Luna County since 1876 (Table 3, 4).

FIGURE 1. Location of Luna County, New Mexico.
FIGURE 2. Physiographic features within Luna County.

TABLE 2. Mineral production from Luna County (from Griswold, 1961; U. S. Geological Survey and U. S. Bureau of Mines Mineral Yearbooks, 1900-1993). Estimated total 1876–1965 is the best estimate of total production as determined from available published and unpublished data. * Production believed to have been made, but quantity and/or value not accurately known. † Estimated ‡ Data from State Mine Inspector's Annual Reports, fiscal years.

	Metals						Nonmetals			Total (dollars)
Year	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)	Total (dollars)	Manganese (tons)	Fluorspar (tons)	Total (dollars)	
Pre-1902	*	*	*	*	*	4,300,000†	—	—	—	4,300,000
1902	—	10,382	—	711,825	—	34,400†	—	—	—	34,400
1903	—	6,168	—	1,355,965	—	61,800†	—	—	—	61,800
1904	85	8,549	16,000	671,772	—	37,605	—	—	—	37,605
1905	—	5,199	—	463,956	225,000	38,221	—	—	—	38,221
1906	21	11,265	—	831,193	103,836	61,673	—	—	—	61,673
1907	687	8,633	—	1,022,773	—	73,646	—	—	—	73,646
1908	—	1,077	5,934	127,535	—	6,713	—	—	—	6,713
1909	160	6,916	1,115	682,906	—	36,314	—	—	—	—
1910	1	2,484	47	298,112	—	14,490	—	710	10,650†	46,964
1911	5	1,278	1,814	98,888	—	5,458	—			
1912	284	24,265	—	827,556	458,594	89,493	—			
1913	554	41,664	1,453	1,158,682	702,028	126,771	—			
1914	11	2,975	2,181	416,923	793,588	58,694	—			
1915	25	2,795	4,080	148,766	861,218	116,405	—			
1916	177	18,077	2,663	868,724	2,725,582	441,255	—			
1917	261	15,142	319	721,117	1,635,500	246,612	—			
1918	411	16,442	3,150	490,493	463,445	102,432	*			
1919	246	11,183	1,479	383,248	31,575	40,343	—	16,400†	530,000†	1,987,665†
1920	334	11,611	3,864	359,488	21,098	50,506	—			
1921	74	4,709	—	144,467	—	12,698	—			
1922	19	976	1,679	43,000	24,228	5,322	—			
1923	63	2,312	1,041	85,472	—	9,332	65			
1924	10	3,024	573	306,198	—	26,799	503			
1925	47	6,603	2,500	595,020	119,300	66,751	1,022			
1926	7	1,984	2,450	183,300	70,000	21,644	1,130			
1927	16	2,058	367	206,080	—	14,523	1,760			
1928	4	188	-	9,000	—	717	2,578			

	Metals						Nonmetals			Total (dollars)
Year	Gold (oz)	Silver (oz)	Copper (lb)	Lead (lb)	Zinc (lb)	Total (dollars)	Manganese (tons)	Fluorspar (tons)	Total (dollars)	
1929	12	1,666	2,585	40,700	—	4,151	1,961			
1930	15	904	500	51,000	—	3,269	1,329			
1931	—	—	—	—	—	—	1,032	—	21,700†	21,700
1932	—	—	—	—	—	—	—	*	*	*
1933	0.2	143	—	20,000	—	796	—	*	*	796
1934	1	1,245	200	49,100	—	2,670	—	700	10,500†	13,170
1935	6	380	—	7,400	—	786	—	2,675	62,500†	63,286
1936	4	745	250	16,700	—	1,515	—	*	*	1,515
1937	94	3,722	3,000	74,400	—	10,908	856	*	13,044	59,098
1938	397	13,676	6,000	256,700	—	35,146		*		
1939	455	17,397	9,500	332,800	9,000	44,832	339	*	6,460†	51,292
1940	113	4,175	2,600	107,000	49,000	15,665	—	*	*	15,665
1941	14	218	200	26,400	—	1,684	—	*	*	1,684
1942	—	339	—	32,000	—	5,851	1,000†	*	33,500†	39,351
1943	—	—	—	6,000	22,000	2,826	*	*	*	2,826
1944	—	—	—	—	—	—	—	*	*	*
1945	—	—	—	—	—	—	—	*	*	*
1946	—	26	—	—	—	21	—	*	*	21
1947	25	3,093	2,900	134,500	42,600	28,806	—	*	*	28,806
1948	2	958	—	14,678	—	15,615	—	*	*	15,615
1949	—	221	—	38,000	—	6,204	—	2,731	45,000†	51,204
1950	1	336	—	10,000	—	1,689	—	5,868	93,359†	95,048
1951	10	2,970	6,000	464,000	552,000	179,766	—	6,716‡	69,234†	249,000
1952	3	1,222	2,000	190,000	188,000	63,493	1,431‡	2,964‡	60,867‡	124,360
1953	—	57	—	4,000	—	581	5,948‡	3,279‡	234,919‡	235,500
1954	—	19	—	—	—	17	7,176‡	5,025‡	273,838‡	273,855
1955	1	175	—	2,000	—	491	4,886‡	—	141,136‡	141,627
1956	—	227	2,100	9,300	—	2,558	1,076‡	—	81,950‡	84,508
1957	—	272	—	6,000	2,000	1,336	2,200†	—	200,000†	201,336
1958	—	—	—	—	—	—	2,500†	—	225,000†	225,000
Total 1902–1958	4,640.2	282,145	90,544	15,105,137	9,099,592	6,531,293	38,792	47,068	2,113,657	8,644,950
Estimated total 1876–2000	13,500	389,600	73,000	6,791,000	8,064,000	11,000,000	40,000	107,900	5,000,000	>16,000,000

TABLE 3. Mining districts of Luna County, New Mexico. Names of districts are after File and Northrop (1966) wherever practical, but many districts have been combined and added. Estimated value of production is in original cumulative dollars and includes all commodities in the district, except aggregate (sand and gravel) and crushed and dimension stone. Type of deposit after North and McLemore (1986), McLemore and Lueth (1996), and McLemore (2001) and includes U. S. Geological Survey classification in parenthesis (Cox and Singer, 1986). Production data are modified from Lindgren et al. (1910), Anderson (1957), U. S. Geological Survey and U. S. Bureau of Mines Mineral Yearbooks (1900–1993), and Energy, Minerals and Natural Resources Department (1994–2000).

DISTRICT OR COAL FIELD (ALIASES)	YEAR OF DISCOVERY	YEARS OF PRODUCTION	COMMODITIES PRODUCED (PRESENT)	ESTIMATED CUMMULATIVE VALUE OF PRODUCTION (IN ORIGINAL DOLLARS)	TYPE OF DEPOSIT	REFERENCES
Aden (Potrillo, Black Mountain) (Doña Ana County)	1900s	1950s–present	Scoria, basalt	3,000,000–10,000,000	igneous	
Black Mountain	?	none	Scoria, basalt	—	igneous	This report
Burdick-Bisbee Hills	1950s	1950s–present	Agate, quartz	<50,000	hydrothermal	Colburn (1999)
Camel Mountain-Eagle Nest (*extends into Doña Ana County, Mexico*)	?	none	(Au, Ag, Pb, Zn, F, Mn)	—	volcanic-epithermal (25b,c,d,e), carbonate-hosted Pb-Zn, carbonate-hosted Ag-Mn (19a,b)	McLemore et al. (1996)
Carrizalillo (Cedar Mountains, Stonewall, Klondike Hills)	late 1800s	late 1800s, 1930, 1948	Cu, Pb, Ag, Au, agate, geodes (U, Mn, W, Zn, Mo, perlite)	<1,000	volcanic-epithermal (25b,c,d,e), carbonate-hosted Pb-Zn (19a)	McLemore et al. (1996)
Cooke's Peak (Jose)	1876	1876–1965	Cu, Au, Ag, Pb, Zn, F, Mn (U, Ba, Fe)	4,200,000	carbonate-hosted Pb-Zn, carbonate-hosted Mn (19a), polymetallic veins (22c)	Griswold (1961), McLemore et al. (1996)
Cooke’s Peak Manganese			Mn (F)	1,000	epithermal Mn (25g)	Farnham (1961)
Florida Mountains	1876	1880–1956	Cu, Pb, Zn, Au, Ag, Mn, F, agate (Ba, Ge, Fe)	107,000	epithermal fluorite (26b), epithermal Mn (25g), carbonate-hosted Mn, carbonate-hosted Pb-Zn (19a), polymetallic veins (22c)	McLemore et al. (1996)
Fluorite Ridge	1907	1909–1954	F (Ba, agate)	930,000–4,650,000	epithermal fluorite (26b)	This report
Fremont (*extends into Mexico, Hidalgo County*)	1860	1880–1951	Cu, Pb, Zn, Au, Ag, U, V (Bi)	17,000	volcanic-epithermal (25b,c,d,e), carbonate-hosted Pb-Zn (19a)	Elston (1963), McLemore and Elston (2000)
Little Florida Mountains (Black Rock)	1915	1918–1951	Ba, F, Mn, agate, geodes, clay	210,000–780,000	Rio Grande rift (32a), epithermal Mn (25g), epithermal fluorite (26b)	McLemore et al. (1996)
Old Hadley (Graphic)	1880	1880–1929	Cu, Pb, Zn, Au, Ag (Ba)	<10,000	volcanic-epithermal (25b,c,d,e)	McLemore et al. (1996)
Red Mountain	?	none	(Mn, crushed stone)	none		This report
Snake Hills	?	none	(Au, jasperoid)	none	carbonate-hosted	Griswold et al. (1989)
Taylor Mountain (Lucretia clay pit, Franklin)	1979	1979–present	Fire clay, stone	185,000	sedimentary	This report
Tres Hermanas (Cincinnati, Mahoney)	1881	1885–1951	Cu, Pb, Zn, Au, Ag, Mn, travertine (U, W, Ge, Be, F, Fe)	600,000	carbonate-hosted Pb-Zn (19a), skarn (18a,19a), polymetallic vein (22c)	Griswold (1961), McLemore et al. (1996)
Victorio (Gage)	1870s	1880–1959	Cu, Pb, Zn, Au, Ag, W (Be, U, Fe, F, Mo)	2,330,700	carbonate-hosted Pb-Zn (19a), Mo-W-Be contact-metasomatic deposits (14a), porphyry Mo-W (?) (16?)	McLemore et al. (1996)

TABLE 4. Reported and estimated base and precious metals production by district in Luna County. — no reported production. W withheld or not available. ( ) estimated data.

DISTRICT	PERIOD OF PRODUCTION	ORE (SHORT TONS)	COPPER (POUNDS)	GOLD (TROY OUNCES)	SILVER (TROY OUNCES)	LEAD (POUNDS)	ZINC (POUNDS)
Carrizalillo (Cedar, Stonewall)	late 1800s, 1930, 1945–1956	—	(<1,500)	(<100)	(<1,000)	(<1,000)	—
Cooke's Peak	1876–1965 1902–1956	— 29,159	(23,000) 22,607	(<1000) 672	(71,000) 70,862	(50,000,000) 8,483,509	(7,000,000) 6,469,702
Florida Mountains	1880–1956 1934–1956	— 116	(5,000) 4,150	(<10) 1	8,034	(>30,000) 25,980	W
Fremont	1880–1951 1947–1951	— 279	(2,000) 400	(10) 3	(10,000) 377	(190,000) 20,500	(4,000) —
Old Hadley	1880–1929	—	some	150	(550)	W	W
Tres Hermanas	1915–1957 1885–1957	1,998 —	550 550	7 7	3,948 (4,000)	193,136 (200,000)	978,956 (1,000,000)
Victorio	1904–1957 1880–1959	30,367 70,000–130,000	32,321 (41,000)	2,477 (12,200)	186,932 (581,500)	5,555,545 (17,500,000)	52,465 (>60,000)

The Spanish first entered New Mexico in 1534 with the expedition led by Alvar Nunez Cabeza de Vaca and followed in 1539 by Fray Marcos de Niza. Francisco Vasques de Coronado led an expedition in 1540 looking for gold (Jones, 1904; Christiansen, 1974). Coronado did not find any gold or silver, but he did find turquoise and led the way to future colonization. Early Spanish mining in New Mexico was centered around the Cerrillos and Old Placers districts in Santa Fe County, but some activity occurred near Silver City. The Pueblo Revolt in 1692 was in part attributed to Spanish enslaving the Native Americans into mining; but there is little documentation to support such accounts (Jones, 1904; Northrop, 1959; Northrop and LaBruzza, 1996).

After the Mexican War in 1850, the U. S. and Mexico disputed the southern border of New Mexico, including Luna County. President Franklin Pierce appointed James Gadsden to settle the dispute. The Gadsden Treaty purchase was ratified on April 25, 1854, making southern New Mexico officially part of the U. S. and providing an important southern route across the country (Clemons et al., 1980). In the late 1800s, Luna County was Apache territory, and travel and settlement were often treacherous. The Butterfield Overland Stage Route, established in 1857, passed through Luna County, north of Deming until 1869. It was the longest overland route in its time, beginning in Tipton, Missouri and ending in San Francisco, California. By the 1880s, Deming had grown to the point where it became attractive to the railroads, and in 1881, the Atchinson, Topeka, and Santa Fe (AT&SF) and Southern Pacific (SP) railroads met in Deming. This completed the southern circuit of railroads, providing not only the second transcontinental railroad in the U. S., but also the only railroad that was open year round. The ensuing rapid settlement of Luna County led to the eventual subduing of the Apache Indians.

Deming’s early years were fairly typical for a western U. S. settlement in the latter part of the nineteenth century. The settlement, consisting mostly of tents, was initially located approximately 10 mi east and was called New Chicago. Better access to water drew the growing village to its current location (Stanley, 1962; Julyan, 1996); irrigation from wells began in 1908 (Darton, 1933). The relocated settlement was named after Mary Anne Deming, the bride of Charles Crocker, who was one of the founders of the Southern Pacific Railroad (Stanley, 1962; Clemons et al., 1980). E. Germain and Company opened the first store in Deming, using old boxcars for storerooms. The El Paso and Southwestern Railroad also came through Deming, making Deming one of the few towns in New Mexico with depots of three independent railroads. Deming grew quickly and became the center of agriculture and commerce in southern New Mexico. It also attracted cattle rustlers, scalp hunters, and other lawless types (Stanley, 1962). Deming ground water was found to be so pure that it was bottled and shipped to El Paso and other points (Stanley, 1962).

Luna County was established in 1901 from the western portion of Doña Ana County and was named after a prominent political figure of the times, Don Salomon Luna. Deming is the largest city and the county seat. The southern boundary is with Chihuahua, Mexico, and Columbus, New Mexico is an international port of entry. Three state parks are found nearby: Rockhound (Little Florida Mountains), Pancho Villa (at Columbus), and City of Rocks (north of Deming).

Mining history and methods

Native Americans were the first miners in New Mexico and used local sources of hematite and clay for pigments and obsidian and chert for arrowheads. Their houses were made of stone, adobe, and clay. Clay also was used in making pottery. The earliest mining methods were crude and simple, using simple tools. Stone tools were shaped from local deposits of pebbles, jasper, chert, and obsidian. Locally, rock was broken and metals recovered by heating using fire and by quenching.

Probably the earliest mining by the Spanish in southwestern New Mexico was for turquoise in the Burro Mountains and at Santa Rita in Grant County (Paige, 1922; Gillerman, 1964). However, mining by the Spanish in New Mexico did not amount to much until ca. 1798, when an Apache Indian told Col. Manuel Carrasco about the copper deposits at what is now known as Santa Rita. By 1804, Francisco Manuel Elguea was mining copper at Santa Rita and transporting it by mule to Mexico City for coinage. These mule trains probably passed through Luna County. Elguea died in 1809 and mining at Santa Rita diminished as a result of increasing costs, difficult transportation, Native Americans uprisings, declining copper demands in Mexico, and finally the Mexican Revolution in 1810.

In 1848, New Mexico became part of the U. S. as a territory and the mining industry became a dominant force in much of the state, but not in Luna County for some 30 more years. Metals were first discovered in the Fremont district about 1860 and in the Florida Mountains and Cooke's Peak district about 1876 (Table 2). The first commercial mining of metals in Luna County was the lead-zinc-silver deposits in the Cooke's Peak district in 1876, which yielded approximately $3 million by 1900. Deposits in the Florida Mountains, Victorio, Old Hadley, and Tres Hermanas were soon discovered.

Times were exciting for the miner in the late 1800s and early 1900s as metal prices soared. At first, small companies of only a few miners developed the deposits. Later, large mining companies were formed, especially to develop the larger deposits. Mechanized production methods were not common until the 1880s, when new mining and metallurgical techniques were developed. Although most ore found in the early years occurred at the surface, in later years, underground shafts were common, connecting working level drifts, raises, and haulage drifts. Most underground mining utilized open stope and cut-and-fill techniques. In 1890, the Sherman Silver Act was passed, which increased the price and demand for silver. This boom was short lived as the Sherman Silver Act was repealed in 1893 and most silver mines in the Southwest closed, never to reopen. A depression resulted and, in some districts, only gold ore was important. The cyanide process was perfected in 1891 and revolutionized gold recovery. Exploration and production resumed for gold in many districts. In 1904, Daniel C. Jackling opened the first large, open-pit mine to produce low-grade copper ore (less than 2% Cu) at Bingham Canyon, Utah. At the same time, John M. Sully arrived at Santa Rita and recognized the similarity of ore at Santa Rita to that mined at Bingham Canyon. Areas throughout southern New Mexico were examined for similar deposits.

Other commodities became important after 1900. Fluorite was discovered and mined at Fluorite Ridge in 1909 and manganese was produced from the Little Florida Mountains in 1918 (Griswold, 1961). As Deming grew, crushed and dimension stone was quarried to construct buildings.

New Mexico became a state in 1912 and in 1914 World War I began. Metal prices and production increased, as metals were needed for the war effort. In 1918, World War I ended and was followed by a depression, which closed many mines (Northrop, 1959). Fluorite was produced from the Cooke's Peak district in 1918. In 1930, the price of copper dropped from 18 cents to less than 10 cents per pound, but production continued only at the big mines. Copper was only 5 cents per pound in 1932, forcing most of the copper mines to close (Northrop, 1959). Recovery did not occur until 1938.

World War II began in 1940 and once again a war increased demand for metals. On October 6, 1942, the U. S. War Department closed all gold and silver mines in the U. S. Only base metals and other strategic minerals such as tin, tungsten, manganese, beryllium, fluorite, and iron were mined. Exploration for these commodities increased and many mines went into production. The war ended in 1945, as did the Federal ban on gold and silver mining.

Mining in New Mexico continued after the war; booms and busts in exploration and production continued to be the trend. The Federal government initiated incentive buying programs for domestic production of manganese (Agey et al., 1959), tungsten, and uranium in 1951. Tungsten and uranium mines in the state began production and exploration intensified. Termination of these programs in 1956 (tungsten), 1959 (manganese) and 1965 (uranium) effectively closed these mines for good. Most districts in the area (Fig. 3) have seen some exploration since the 1960s as company after company examined the area, looking for the missed deposit. But most districts have not seen significant production since the 1950s (Table 2, 3, 4). Two of the state's largest lead and zinc producing districts are in Luna County; the Cooke's Peak district ranks 5th in lead production in the state and 9th in zinc production and the Victrio district ranks 7th in lead production in the state. Other mineral production is in Tables 5, 6, and 7. Currently, agate, manganese, fire clay, and sand and gravel are being produced from Luna County.

FIGURE 3. Mining districts in Luna County.

TABLE 5. Known fluorite production from mines in Luna County (from McAnulty, 1978).

DISTRICT	FLUORITE (TONS)	CUMMULATIVE ESTIMATED VALUE ($)	PERIOD OF PRODUCTION	REFERENCES
Cooke's Peak	452	4,000–20,000	1918–1954	Rothrock et al. (1946), Griswold (1961), Williams (1966)
Florida Mountains	200	2,000–10,000	?	Griswold (1961), McAnulty (1978)
Fluorite Ridge	93,827	930,000–4,650,000	1909–1954	Rothrock et al. (1946), Griswold (1961)
Little Florida Mountains	13,428	130,000–650,000	?	Griswold (1961), Williams et al. (1964)

TABLE 6. Manganese production from Luna County, 1883–1958 (from Farnham, 1961; Dorr, 1965).

MINE	DISTRICT	ORE PRODUCTION (LONG TONS)	GRADE %MN	CONCENTRATE PRODUCTION (LONG TONS)	GRADE %MN
Birchfield	Florida	1,421	22–30	—	—
Luna	Little Florida Mountains	6,593	19.1	1,522	30–45
Manganese Valley	Little Florida Mountains	12,933	21.4	19,871	45
Starkey (Ruth)	Cooke's Peak Manganese	—	—	450	33–46

TABLE 7. Tungsten production from Luna County (from Dale and McKinney, 1959; Hobbs, 1965; Richter and Lawrence, 1983).

DISTRICT	PERIOD OF PRODUCTION	PRODUCTION (POUNDS)	$\%WO_3$	ESTIMATED VALUE ($)
Victorio (Irish Rose)	1942	20,000 39,200	1 60	600

Ore processing

Initially, ore processing techniques were simple, requiring only crude adobe smelters (Christiansen, 1974). Gold was processed using stamp mills or arrastra mills. In the late 1800s, mills and smelters were built in many of the major mining districts. The Federal Mining Act of 1872 established procedures for patenting a millsite. Many millsites were patented, but the records are not always clear as to what kind of mill, if any, was established or if the mill operated. Mill histories are difficult to trace, because ownership changed; mills were typically dismantled at one site and rebuilt at another site. Most early mills were associated with a specific mine, but by the late 1800s, mills were established in or near large districts and would custom mill ore from distant locations. Known mills in Luna County are listed in Table 8.

TABLE 8. Known mills in Luna County (McLemore et al., 1996; Gundiler, 2000a, b). All of these mills except the Southwest American Minerals mill are inactive.

DISTRICT	NAME OF MILL	LOCATION	LATITUDE	LONGITUDE	TYPE OF MILL	COMMODITY	YEARS OPERATED
Carrizallilo	Carizallilo (Hermanas)	C 22 28S 11W	32.85178	107.950156	smelter	Cu, Ag, Au, slag	unknown
Cooke's Peak	Graphic	32 20S 8W	32.5283	107.6831	flotation mill	Ag, Pb	1922–1924
Cooke's Peak	Faywood	12–15 20S 8W	32.56528	107.74445	mill	F	1940s
Cooke's Peak	Lucky C	24 20S 9W	32.55360	107.71843	concentrator	Pb, Zn	?
Deming	Cyprus Pinos Altos Deming mill (ASARCO)	20 23S 9W	32.28461	107.78723	flotation mill	Zn, Ag, Pb, Cu	1949–1978, 1989–1995
Deming	Peru mill (La Purisima)	18 23 S 9W	32.30392	107.80643	flotation mill	Cu, Zn, Ag, Au, barite, F, pyrite	1928–1961, 1978
Deming	Southwest American Minerals	25 23S 9W	32.27703	107.73455	mill	Mn	1975–present
Florida Mountains	Copper Ridge mill	17 25S 7W	32.13864	107.588750	mill	Cu	?
Little Florida Mtns	Luna (Black Rock)	S18 24S 7W	32.21639	107.59918	concentrator	Mn	1926–1936
Little Florida Mtns	Manganese Valley	19, 20 24S 7W	32.20393	107.590029	concentrator	Mn	1918–1957
Old Hadley	Rock Island millsite	29, 32 20S 8W	32.52823	107.68609	mill	Pb, Ag	?
Tres Hermanas	Canon	14 28S 9W	31.87449	107.72330	leaching	Cu	1959
Victorio	Rambler	32 24S 12W	32.17796	108.093578	gravity mill	Cu, Pb, Zn	prior to 1961

The Deming area has been the site of numerous mills since 1928 when the Peru mill was first built, because of available flat land for disposal of tailings, abundant water, and access to the railroad. American Smelting and Refining Company (ASARCO) built a mill in Deming in 1949. Both mills processed lead-zinc ores from the Silver City area. Manganese was concentrated and shipped from a purchasing depot in Deming from 1953 to 1955 (Agey et al., 1959).

Purpose of study

This report assesses the potential of mineral and energy resources (excluding aggregate and petroleum resources) on the surface and within the subsurface in Luna County in southern New Mexico (Fig. 1). Resource potential is the likelihood for the occurrence of undiscovered concentrations of metals, nonmetals, industrial materials, and energy resources. The evaluation of mineral-resource potential involves a complex process based on geologic analogy of promising or favorable geologic environments with geologic settings that contain known economic deposits (geologic models; Cox and Singer, 1986). Such subjective assessments or judgements depend upon available information concerning the area as well as current knowledge and understanding of known deposits. This assessment will provide land managers with appropriate data to make land-use decisions. The project conforms to mineral assessment guidelines and procedures required by the U. S. Bureau of Land Management (Goudarzi, 1984).

Method of study

The current study began in February 2001, a preliminary draft was completed in June 2001, and the final report was completed in September 2001. References are cited in Appendix 1 along with a bibliography. This study utilized data obtained during an earlier mineral-resource assessment of the Mimbres Resource Area (Bartsch-Winkler, 1997) and includes an updated mineral-resource assessment utilizing new data obtained in recent years and collected specifically for this project. This study also provides databases of mines and mills (Appendix 2), the NURE data (Appendix 3; U. S. Geological Survey, 1994), chemical analyses of samples (Appendix 4), and new age determinations (Appendix 5), which were not included in Bartsch-Winkler (1997).

The most important stage in any geologic investigation is compilation and interpretation of all available published and unpublished geologic, geochemical, geophysical, and production data (Appendix 1). Mineral databases were examined, including the Mineral Resource Data System (MRDS) of the U. S. Geological Survey (Mason and Arndt, 1996), the Minerals Industry Location System (MILS) of the U. S. Bureau of Mines (U. S. Bureau of Mines, 1995), and unpublished files at the New Mexico Bureau of Geology and Mineral Resources (NMBGMR). Using these data, known mineral occurrences, deposits, mines, prospects, and mills are identified, plotted on base maps, and compiled in a database (Appendix 2). Geophysical data and Landsat satellite imagery of the project area were studied. The National Uranium Resource Evaluation (NURE) data also were examined and evaluated (Appendix 3); appropriate geochemical maps were plotted. Areas of anomalous structural complexity, hydrothermal alteration, and anomalous coloration were delineated and examined where possible during the field reconnaissance stage and samples were collected and analyzed (Appendix 4). Sample sites for geochemical analyses were identified prior to field examination using these data. Selected samples also were submitted to the New Mexico Geochronological Research Laboratory at New Mexico Institute of Mining and Technology (NMIMT) for age determinations by $^{40}Ar/^{39}Ar$ methods (Appendix 5); laboratory procedures are briefly described by McLemore et al. (1999a). Field examination and geochemical sampling occurred over a four-month period for this project.

Samples were analyzed by a variety of methods (Appendix 4). Most samples collected for this project were analyzed for trace elements by X-ray fluorescence (XRF) at the NMBGMR X-ray laboratory and by flame atomic absorption (FAAS) at the NMGMMR Chemistry Laboratory. Samples of igneous rocks, jasperoids, clay, and sandstone also were analyzed for major elements by XRF. Limestones collected for this project were analyzed by flame atomic absorption spectrometry (FAAS) and titration methods at the NMGMMR Chemistry Laboratory. Samples also were analyzed by instrumental neutron activation analysis (INNA) by XRAL Laboratories. Samples collected for the Mimbres project (Bartsch-Winkler, 1997) and other research in 1993–1999 were submitted to the U. S. Geological Survey for analyses by ICP and INNA; selected samples also were analyzed by XRF and FAAS at NMGMMR. In addition, Appendix 4 includes selected chemical analyses reported in the literature.

The final evaluation of the mineral-resource potential involves integration and interpretation of all available data to identify possible undiscovered mineral deposits that could occur within Luna County and delineate areas of potential occurrence. A number of factors must be evaluated, including host-rock favorability, structural controls, evidence of mineralization, previous mining and production, geochemical and/or geophysical anomalies, regional geologic setting, time of mineralization, alteration, mineralogy and mineral assemblages, processes affecting mineral deposits since their formation, geologic history, and appropriate mineral-deposit models. Goudarzi (1984), Shawe (1981), and McLemore (1985) explain in more detail, the process of evaluating mineral-resource potential.

Previous geologic studies

Several reports described the mineral resources within Luna County (Appendix 1). The earliest work describing the mineral deposits of Luna County included Lindgren et al. (1909a, b, 1910), with particular emphasis on the Tres Hermanas district, and extensive work by Darton (1911, 1916), which covered the mineral and water resources of the entire county. Kottlowski (1962) and Kottlowski and Anderson (1996) described the limestone resources. Griswold (1961) and McLemore et al. (1996) described the mineral deposits in the county and made brief comments on the mineral-resource potential in most areas. A mineral-resource assessment of the Mimbres Resource Area, including Luna County, is by Bartsch-Winkler (1997).

County-wide geologic studies included Kottlowski (1963), an analysis of Paleozoic and Mesozoic strata of the region; Lance and Keller (1981) and Wynn (1981), regional gravitational studies; Richter (1983), a regional mineral-deposit map; and Seager (1987, 1995), regional geology. Clemons (1991) completed a comprehensive study of the petrographic analysis of upper Paleozoic rocks in southern Luna County. Hill (1994) described the geochemistry of fluorite occurrences in southern New Mexico, including Luna County.

In the Tres Hermanas area, the geology was mapped by Balk (1961), and the trace metals, petrography, and alteration was described by Doraibabu and Proctor (1973). Also in the Tres Hermanas area, Homme (1958) examined the contact metamorphism. Mineralization in the Tres Hermanas mining district was discussed by Lindgren (1909a, b) and McLemore (2000c), and general geology in the area was by Seager (1988) and Leonard (1982).

The Florida Mountains area also has been extensively covered in a variety of studies, including a number of structural studies (Corbitt, 1971; Amato, 2000), and studies of mineral deposits and mining (Becker, 1914; Evans, 1949; Lasky, 1940; Clemons, 1988b; McLemore, 2000a). Matheny and Brookins (1983) and Wilks and Chapin (1997) described the geochronology of the area. More localized work on general geology has been by Brown (1982) on the Mahoney Mine-Gym peak area, Clemons (1982a) on the Florida gap quadrangle, and Clemons and Brown (1983) on the Gym Peak quadrangle, and in more detail by Clemons (1998) on the geology of the entire Florida Mountains.

Another geologically distinct area in Luna County, the Victorio Mountains, was examined by Bell (1983) on molybdenum and tungsten, and Holser (1953) on beryllium. Thorman and Drewes (1980) and McLemore et al. (2000b) discussed the geology and mineral deposits of the area.

Lucas et al. (1988) described the stratigraphy of the Cooke's Peak district, and Morris (1974a, b) described the general geology and mineral deposits. Russell (1947) examined the nearby Fluorite Ridge area, and Soulè (1946) described the White Eagle Fluorspar mine in detail. The José subdistrict was described by Storms (1945). Walters (1972) described the Old Hadley subdistrict.

The geology and environmental geology of the Mimbres Resource Area (BLM designation), which covers parts of Luna, Doña Ana, Hidalgo, and Grant Counties, was described by the BLM (1992), McLemore et al. (1996), Bartsch-Winkler (1997), and Anderson (1994). Neighboring areas such as the West Potrillo Mountains/ Mount Riley and the Aden Lava flow (Gese, 1985, Kilburn, 1988), and the more general Potrillo basalt field (Hoffer, 1976; Seager, 1989) have been described. Other studies of Luna County included Kuellmer (1956) who detailed the southern Black Range area, Rupert (1986) who examined the Klondike Hills, and Staples (1984) who described the geology and mineral deposits of the West Lime Hills area. Similarly, Strickland (1981) described the structure, stratigraphy, and economic geology of Goat Ridge, and Bromfield (1961) described the Cedar Hills. Geologic mapping also has been by Clemons (1979) in the Goodsight Mountains and Uvas Valley, the Massacre Peak quadrangle (1982b), the Capitol Dome quadrangle (1984), and the South Peak quadrangle (1985). Thorman and Drewes (1979, 1981) mapped the Grandmother Mountains East and Grandmother Mountains West quadrangles, and the Gage SW quadrangle. Varnell (1976) mapped the Hat Top Mountain quadrangle, and Broderick (1984) mapped the Granite Hill area. Elston (1957) described the geology and mineral resources of the Dwyer quadrangle, and Elston (1960a) described the geology of the Virden quadrangle. Jicha (1954) described the Lake Valley quadrangle.

The geologic map used in this study (Fig. 4) is from computer data files used to produce the state geologic map (Anderson et al., 1994). This geologic map was compiled from a variety of sources. Stratigraphic correlations are summarized in Figure 5.

FIGURE 4. Geologic map of Luna County (Anderson et al., 1994).
FIGURE 5. Stratigraphic correlations. The entire section is intruded by a series of Mid-Tertiary intrusions (Table 10) that may be related to porphyry copper, copper-molybdenum, molybdenum deposits and related veins, skarns, and carbonate-hosted deposits.

Acknowledgments

Glen Jones produced the geological, geochemical, and resource-potential maps from GIS data. James McLemore and Ibrihim Gundiler assisted with field work. Maureen Wilks assisted with obtaining references for the bibliography, age determinations, and lists of active mines in the county and compiling the final report. George Austin provided the clay data. Phil Kyle and Chris McKee (NMBGMR) analyzed some samples by X-ray-fluorescence using the Phillips PW 2400 instrument purchased with funds from NSF grant EAR-9316467. U. S. Geological Survey and NMBGMR Chemistry Laboratory, Lynn Brandvold manager, provided additional chemical analyses. Lisa Peters and Rich Esser carried out the mineral separations and ^{40}Ar/^{39}Ar age determinations at the New Mexico Geochronology Laboratory at NMIMT. Homer Milford (New Mexico Energy, Minerals and Natural Resources Department) provided some of the historical data on some of the districts. Robert Eveleth provided access to historical data from the NMBGMR archives. William McIntosh assisted with volcanic stratigraphy and providing the caldera figure. Mrs. Velva Hurt is acknowledged for allowing access to Red Mountain. This project was partially funded by the New Mexico State Land Office.

GEOLOGIC SETTING

Regional structure

The regional structural evolution of the southwestern U. S. and northern Mexico, specifically Luna County, has been dominated by a succession of dynamic and sometimes rapidly changing plate tectonic settings from the Proterozoic to the Recent (Coney, 1978; Karlstrom and Bowring, 1988; Karlstrom et al., 1990). This prolonged history of complex continental tectonics can be divided into ten phases:

(1) Mazatzal orogeny, 1,660–1,600 Ma (Karlstrom and Bowring, 1988, 1993; Karlstrom et al., 1990),
(2) Late Proterozoic granitic plutonism, 1,450–1,350 Ma (Stacey and Hedlund, 1983; Karlstrom and Bowring, 1988; 1993; Adams and Keller, 1996; Karlstrom et al., 1997; Karlstrom and Humphreys, 1998),
(3) pre-Grenville extension and formation of continental margin at 1,300–1,200 Ma (Adams and Keller, 1994, 1996; Karlstrom et al., 1997; Karlstrom and Humphreys, 1998; Barnes et al., 1999),
(4) 1,200–1,000 Ma period of mafic, volcanic, and A-type granitic intrusions in Texas, New Mexico, and Arizona, coincident with the Grenville orogeny and perhaps extension (Adams and Keller, 1996; Smith et al., 1997; Mosher, 1998; Barnes et al., 1999; Reese et al., 2000; McLemore et al., 2000a; Bickford et al., 2000),
(5) Paleozoic period of alkaline and carbonatite magmatism and extension at ~500 Ma (McLemore and McKee, 1988b; McLemore et al., 1999a; McMillan et al., 2000b; McMillan and McLemore, in press),
(6) Paleozoic period of basin formation and uplift as part of the Ancestral Rocky Mountains (Florida uplift, Pedregosa Basin, Ross and Ross, 1986),
(7) Cretaceous continental arc, shallow marine deposition (Drewes, 1991),
(8) Laramide compressional deformation and magmatic arc volcanism and plutonism (Late Cretaceous to early Tertiary, Drewes, 1991) (Fig. 6),
(9) Mid-Tertiary calc-alkaline volcanism to bimodal volcanism with caldera formation (Datil-Mogollon and Boot Heel fields, McIntosh et al., 1991; McIntosh and Bryan, 2000) (Fig. 7), and
(10) Late Tertiary-Quaternary Basin and Range extensional deformation (Rio Grande rift; Coney, 1978).

Each of these tectonic periods left remnant structural trends that were either reactivated or crosscut by younger tectonic events and together have resulted in a structurally complex, relatively thin, brittle, and anisotropic crust. Most of the uplifts in Luna County trend northwest-southeast as a result of these tectonic events.

FIGURE 6. Structural features during the Laramide in southwestern New Mexico.
FIGURE 7. Map of Mid-Tertiary calderas in southwestern New Mexico (W. I. McIntosh, map, June 2001).

Many of the intrusive and volcanic centers in southwestern U. S. and Mexico appear to be controlled by regional lineaments (Mayo, 1958; Wertz, 1970a, b; Lowell, 1974; Chapin et al., 1978). For the purposes of this study, a lineament is defined as a broad, linear zone of topographic, structural, and magmatic features, including faults, alignment of volcanic and plutonic centers, uplifts, and basins (Bates and Jackson, 1980; Heyl, 1983). Current theories on the evolution of continental lineaments suggest that they are deep-seated, reactivated zones of crustal weakness that have been active sporadically since Proterozoic times (Heyl, 1983; Favorstiaya and Vinogradov, 1991).

The Texas lineament extends from Trans-Pecos Texas west-northwestward into Luna County and southeastern Arizona where it probably joins the Arizona transitional zone (Fig. 6; Muehlberger, 1980; Wertz, 1970a, b). It is a prominent 50–93 mi wide zone that is defined by basins, ranges, and structural features (Lowell, 1974; Wertz, 1970a, b; Turner, 1962; Schmitt, 1966; Drewes, 1991). Dip-slip (normal, steep reverse, or thrust) movements are common throughout this zone and locally strike-slip movement has been documented (Turner, 1962; Wertz, 1970a, b; Muehlberger, 1980; McLemore, 1993).

The Burro Mountains extend into northwestern Luna County and were an important feature during most of geologic time. During the latest Proterozoic and Cambrian, the Burro Mountains were uplifted and eroded, providing sediment to the basins in what is now Luna County. The Burro Mountains were either a highland during much of Phanerozoic time, or older sedimentary rocks were eroded before deposition of Cretaceous rocks when seas partially covered the mountain range. The Burro-Florida uplift formed the center of Luna County during Laramide (late Cretaceous-Eocene) times (Elston, 1958; Turner, 1962; Mack and Clemons, 1988), when this area underwent compressional deformation as a result of the collision of the North American and Farallon plates (Drewes, 1991). This belt of compressional deformation extended from El Paso, Texas westward to Las Vegas, Nevada and is called the Cordilleran orogenic belt. The northern edge of this Laramide belt as defined by Drewes (1991) cuts across Luna County (Fig. 6). This deformation belt (eastern intermediate zone of Drewes, 1991) in southwestern New Mexico is characterized by folding and thrusting of older rocks and local detachment along the crystalline basement.

Regional stratigraphy

Proterozoic rocks

Proterozoic rocks throughout New Mexico host a variety of mineral deposits that range in age from Proterozoic through Miocene and may be a source for other types of mineral deposits (North and McLemore, 1986; McLemore, 2001). The best exposures of Proterozoic rocks in southwestern New Mexico are in the Burro Mountains where rocks range in age from 1,632 to <1,220 Ma (Stacey and Hedlund, 1983; McLemore et al., 2000a, in press). The Burro Mountains comprises a complex Proterozoic terrain consisting of metamorphic rocks (1,550–1,570 Ma, Bullard Peak and Ash Creek Series) intruded by granitic and mafic rocks (Hewitt, 1959; Hedlund, 1980a, b; Drewes et al., 1985; McLemore and McKee, 1988a; McLemore et al., 2000a, in press). The granitic rocks include 1) Burro Mountain granite (oldest), 2) gneissic granite/granodiorite (1,447 Ma), 3) Jack Creek Rapakivi Granite (~1,461–1465 Ma), 4) Redrock Granite (1,220 Ma), 5) fine-grained alkali-feldspar and biotite granite dikes, 6) rhyodacite/dacite porphyry dikes, and 7) pegmatite dikes (youngest). The mafic rocks include 1) two or more periods of gabbro/diabase/diorite intrusions (<1,220 Ma, 1,630 Ma), 2) approximately 50 anorthosite xenoliths (1,225 Ma) within the Redrock Granite, and 3) several synplutonic lamprophyre (minette) dikes and numerous enclaves (~1461–1465 Ma) within the Jack Creek Rapakivi Granite.

Only a few small occurrences of Proterozoic rocks are found at the surface in Luna County and are similar in composition to those found in the Burro Mountains. Coarse-grained granite and amphibolite/diorite forms the base of Fluorite Ridge. Granite and amphibolite are exposed in a fault block in the Klondike Hills. Proterozoic rocks are exposed in the Florida Mountains. A small exposure of diamictite (very poorly sorted, boulder conglomerate that is probably a mudflow deposit) rests unconformably on Proterozoic hornblende and granitic gneisses and is unconformably overlain by the Cambrian-Ordovician Bliss Formation in the northwest Florida Mountains. The gneissic granite has been dated as 1,550–1,570 Ma (U-Pb, Evans and Clemons, 1988; Clemons, 1998). Proterozoic granite is exposed in the Cooke's Range, but only a small portion extends into Luna County. Proterozoic granite also is exposed at Eagle Nest (Broderick, 1984; Broderick et al., 1986; Seager and Mack, 1990) and west of Cow Springs in northwestern Luna County, which is probably an extension of the Proterozoic terrain exposed in the Burro Mountains.

A few wells have penetrated the Proterozoic in Luna County (Table 9). Granitic gneiss is found in drill core in the Victorio Mountains and has been intruded by the Victorio Granite, which also is found only in drill core (McLemore et al., 2000b). The quartzo-feldspathic gneiss consists of alternating metamorphosed siltstone, sandstone, and arkose layers. The amphibolite is composed of calcic plagioclase, hornblende, and biotite and shows weak to moderate contorted foliation. The texture of the amphibolite ranges from fine-grained foliated biotite schist to coarse-grained diabase.

Paleozoic rocks

Cambrian-Ordovician alkaline igneous rocks

A widespread Cambrian-Ordovician alkaline magmatic event occurred throughout New Mexico and southern Colorado and is evidenced by the intrusion of carbonatites, syenites, monzonites, and alkaline granites and associated K-metasomatism (Loring and Armstrong, 1980; McLemore, 1983; Evans and Clemons, 1988; Ervin, 1998; McLemore et al., 1999a). In the Florida Mountains, the Cambrian-Ordovician Bliss Formation unconformably overlies Cambrian syenites and alkali-feldspar granites (Clemons, 1998). Pebbles of the alkaline rocks are found within the overlying conglomerates of the Bliss Formation. The Cambrian alkaline rocks are unmetamorphosed and non-foliated, in contrast to the metamorphosed and foliated Proterozoic metamorphic and granitic rocks. Two U-Pb zircon crystallization ages of the Florida syenites/granites have been published: 503±10 Ma (Evans and Clemons, 1988) and 514±3 Ma (Matheny et al., 1988). These overlap at ca. 511 Ma, which probably represents the crystallization age of the pluton. The hornfels, which exhibits comagmatic textures with the syenite, has been dated as 504±10 Ma (Clemons, 1998). $^{40}Ar/^{39}Ar$ analyses on biotite and hornblende from the syenite yielded a biotite plateau age of 490.5±5.4 Ma and a less rigorous hornblende plateau age of 485.5±4.9 Ma (Ervin, 1998), and is consistent with the Cambrian-Ordovician U-Pb date. REE-Th-U (±Nb) veins may be found associated with alkaline rocks.

Recognition of widespread Cambrian-Ordovician magmatic activity in New Mexico, evidence of relatively rapid uplift and erosion in the Florida Mountains (Evans and Clemons, 1988; Clemons, 1998; Ervin, 1998), and the presence of carbonatites in central New Mexico (McLemore, 1983, 1987a) suggest that New Mexico was not a simple passive margin during the Cambrian-Ordovician; but rather experienced sufficient extension to perturb the mantle and initiate magmatism. This type of magmatic activity is consistent with continental rift and aborted rift systems, although geologic data such as rift-basin sediments and geophysical signatures are lacking to support a rift during this time period in New Mexico.

Cambrian-Ordovician sedimentary rocks

Cambrian-Ordovician strata are divided into three stratigraphic units in southern New Mexico (Fig. 5; in ascending order): Bliss Formation, El Paso Group, and Montoya Group. The Bliss Formation rests unconformably on Proterozoic or Cambrian-Ordovician igneous rocks. It is 50–185 ft thick in Luna County (Griswold, 1961) and consists of tan to light-brown, fine- to coarse-grained quartz sandstone and minor light-brown dolostone that were deposited in shoreline and shallow marine environments (Mack et al., 1999). The contact between the Bliss and the overlying El Paso Group is gradational. The El Paso Group is 831 ft to more than 1,000 ft thick in Luna County and consists of thin-bedded, finely crystalline, dark-gray limestones and dolostones and minor fine- to coarse-grained quartzose sandstones that were deposited in shallow subtidal and intertidal environments (Mack et al., 1999). The El Paso Group is divided into four members (in ascending order): Hitt Canyon, Jose, McKelligan, and Padre. The Montoya Group unconformably overlies the El Paso Group and is 270–340 ft thick. The Montoya Group consists of medium- to thick-bedded, finely-crystalline dolostone. Chert nodules are abundant in the upper part. The Montoya Group is divided into four members (in ascending order): Cable Canyon Sandstone, Upman, Aleman, and Cutter (or Valmont Dolomite) Members. Limestones can be hosts to a variety of replacement deposits and also is used as crushed and dimension stone and for other uses.

Silurian rocks

Silurian rocks consist of one stratigraphic unit, the Fusselman Formation. The contact of the Fusselman with the underlying Montoya Group is gradational in most places. The Fusselman Formation is 200–900 ft thick in Luna County and consists of dark-gray, thick-bedded, finely-crystalline dolostone. The Victorio Mountains contain one of the western most outcrops of the Fusselman Formation (Thorman and Drewes, 1980). Dolostones can be hosts to a variety of replacement deposits and also is used as crushed and dimension stone and for other uses.

TABLE 9. Summary of drill data in Luna County.

Well name	Company	Location (section, township, range)	Elevation Top of hole (ft)	Date completed	Total depth (ft)	Top of formation (ft)	Depth to Proterozoic (ft)
Angelus	Angelus Oil & Mining	8-20S-9W	5,597	10/31/26	150		No
1 Santa Maria DB R&R	XTER Inc.	19-21S-10W	4,797	4/29/89	1,150	Alluvium T.D.	No
#3 Angelus	Angelus Oil & Mining	20-21S-10W	4,823	12/1/31	6,171		No
Angelus	Angelus Oil & Mining	24-21S-11W	4,898		2,050?		No
#1 May Energy	May Energy	27-22S-7W	4,335 GR	7/29/85	5,900		No
Berry #1	Berry, O.D.	33-22S-10W	4,530	1/20/40	1,075		No
Berry #2	Berry, O.D.	33-22S-10W	4,527	8/10/40	1,187		No
#1 State L-6350	Sycor Newton	10-23S-11W	4,543 GR	4/9/73	10,071	Lobo 6,000 – 6,460 Montoya 6,460 – 7,110	No
#1 State	Seville-Trident Co.	15-23S-11W	4,524 GR	1/21/83	8,240	Cretaceous 2,720 Fusselman 6,440 Montoya 6,550 Bliss 7,770 Granite 7,920	7,920
#1 Diana	Guest & Wolfson	16-23S-11W	4,548 GR	3/21/73	7,915	Valley fill 2,600 Lobo 2,700 limestone 6,010 Fusselman 6,600 Bliss 7,907	No
	Angelus Oil & Mining Co.	26-23S-11W	4,488		80		No
State #1349-7-1	Cockrell Corp.	7-23S-10W	4,250 GR	11/5/69	7,375	Lobo 5,990–6,500 El Paso 6,500–7,110 Bliss 7,110–7,120	7,120?
#1 State	Florida Oil	14-23S-10W	4,429		2,315		No
Bickford Lease	Florida Oil	15-23S-10W	4,449		2,860		No
Burbick City		29-23S-8W	4,275		912		No
#1 McSherry	Seville-Trident Co.	4-24S-8W	4,255 GR	8/8/83	12,485	El Paso 9,980 Bliss 11,600 Granite 11,920	11,920
#1 City of Deming	Seville-Trident Co.	6-24S-8W	4,275 GR	8/9/83	4,225		No
#2 City of Deming	Seville-Tridnet Co.	6-24S-8W	4,282 GR	5/28/83	12,385	Cretaceous 4,080	11,660
#1 Hurt Ranch	Seville-Trident Co.	8-24S-10W	4,407 GR	3/30/83	7,723	Lake Valley 4,550 Fusselman 5,688 Montoya 6,180 Precambrian 6,990	6,990
Permian State #1	Permian Drilling	4-25S-6W	4,111	8/15/49	4,011		No
Angelus #1	Angelus Oil & Mining Co.	8-25S-6W	4,091		3,450		No
1 Bisbee Hills	Young Marshall R. Oil	11-26S-11W	4,274 GR	9/18/83	7,164		No
Angelus Oil & Mining #2	Angleus Oil & Mining	8-26S-8W	4,485		3,365		No
#1 Victorio Strat Test	Cockrell	29-28S-12W	4,617	9/3/70	4,005		No
#1 New Mexico C	Skelly Oil Co.	19-28S-5W	4,035	11/22/63	670		No
#1-A New Mexico C	Skelly Oil Co.	19-28S-5W	4,010 GL	1/13/64	9,437	Santa Fe 700 Fusselman 8,300 Montoya 8,655 Precambrian 8,810	8,810
1 NM Fed. R	Sunray Mid-cont. Oil	27-28S-5W	4,096 DF	3/24/62	6,616	Fusselman 2,885 Silurian 3,200–3,430 Montaya 4,015 Cable Canyon 4,354 El Paso 4,515 Precambrian 6,570	6,570
Prince 1	Valley Oil	16-29S-7W	4,023	2/5/20	2,385		No

Devonian rocks

Devonian rocks consist of one stratigraphic unit, the Percha Shale, which is divided into the Ready Pay (upper) and Box (lower) Members. The Percha Shale is an important stratigraphic marker between relatively indistinguishable carbonate rocks of the Fusselman and Lake Valley Formations. In the Cooke's Peak area, the Percha Shale is approximately 200–350 ft thick. The Box Member unconformably overlies the Fusselman Formation and consists of black fissile shale. The Ready Pay Member is gradational with the underlying Box Member and is unconformably overlain by the Lake Valley Formation. The Ready Pay member consists of greenish-gray shale containing limestone nodules. Shale is a source of clay, but these units have not been exploited in Luna County.

Mississippian rocks

Mississippian rocks consist of three units containing predominantly carbonate rocks, the Caballero, Lake Valley, and Rancheria Formations. The Caballero Formation consists of calcareous shale with thin limestone beds and is 36–70 ft thick in the Cooke's Range. The Lake Valley Formation overlies the Percha Shale and is subdivided into four members; Andrecito (lower nodular limestone), Alamogordo (blue limestone), Nunn (upper crinoidal limestone), and Tierra Blanca Members. The Alamogordo Member is thick- to medium-bedded, fine-grained to aphanitic, nodular limestone characterized by a conchoidal fracture. In contrast, the overlying Nunn Member is thin-bedded, contains numerous shale breaks and crinoids, and breaks along bedding planes. The Rancheria Formation consists of black, cherty, silty, thin-bedded limestone. Limestones can be hosts to a variety of replacement deposits and also is used as crushed and dimension stone and for other uses.

Pennsylvanian-Permian rocks

Pennsylvanian-Permian rocks are not well exposed in Luna County. The Pennsylvanian Magdalena Group is exposed in at Cooke's Peak and consists of chert, cherty limestone, and limestone. The Horquilla Formation is exposed in the Tres Hermanas and Florida Mountains and Klondike Hills and consists of sandstone, shale, and limestone. Limestones can be hosts to a variety of replacement deposits and also is used as crushed stone and for other uses.

The depositional transition between the continental red-bed sandstones, siltstones, limestones, and shales of the Abo Formation with the marine limestones of the Hueco Formation is in Luna County. The Hueco Formation is exposed in the Florida and Tres Hermanas Mountains. The Abo Formation, exposed in the Cooke's Range, is well known in New Mexico for hosting sedimentary-copper deposits (North and McLemore, 1985; McLemore, 2001).

The Yeso and San Andres Formations are exposed in the Tres Hermanas Mountains and Camel Mountain-Eagle Nest area (Seager, 1995). The older Yeso Formation consists of a few hundred feet of dolomitic limestone interbedded with silty limestone, limestone breccia, siltstone, and fine-grained sandstone. The San Andres Formation consists of a few hundred feet of limestone with local chert.

Mesozoic rocks

Mesozoic rocks are exposed in scattered areas of Luna County and are difficult to correlate. These rocks document diverse nonmarine and marine depositional environments. Lower Cretaceous sedimentary rocks in southwestern New Mexico, including those in Luna County, were deposited in an extension of the Chihuahua basin (Mack et al., 1986) or Bisbee seaway (Lucas and Estep, 2000).

Recently, rocks in the Eagle Nest area and Victorio Mountains have been correlated with the Lower Cretaceous Bisbee Group. The Bisbee Group is divided into three formations (in ascending order): Hell-to-Finish, U-Bar, and Mojado Formations (Lucas and Estep, 2000; McLemore et al., 2000b). The oldest unit is the Hell-to-Finish Formation that consists of a maximum of 300 ft of interbedded conglomerate, conglomeratic sandstone, calcarenite, and mudstone. The conglomerates consist of either limestone and chert clasts or quartzite clasts. Lucas et al. (2000) divided the U-Bar Formation in the Victorio Mountains into three members: Carbonate Hill (oldest), Victorio Mountains, and Still Ridge Members (youngest). The overlying U-Bar Formation is a maximum of 400 ft thick and consists of a lower oyster-bearing limestone, a middle sandstone and quartz-pebble conglomerate, and an upper calcarenite and grainstone. Lucas et al. (2000) correlated the Bisbee Group sediments in the Victorio Mountains to the Hell-to-Finish and U-Bar Formations on the basis of rare fossils, lithologies, and stratigraphic sections.

The Mojado Formation consists of four members (in ascending order): Flyingpan Spring, Sarten, Beartooth, and Rattlesnake Ridge Members. The Sarten and Beartooth Members are probably of the same age, according to Lucas and Estep (2000). The Sarten Member consists of fine-grained sandstones and interbedded siltstones, shales, and limestones. The Beartooth Member of the Mojado Formation (formerly Beartooth Quartzite) lies unconformably on or in fault contact with Proterozoic rocks or Abo Formation in the Burro Mountains-Silver City area and is conformably overlain by the Mancos Shale (formerly Colorado Shale). It typically forms ridges and caps mountaintops. The Beartooth Member consists of 80–115 ft of white to light gray to tan, coarse- to pebbly- to medium-grained orthoquartzite and arkosic to lithic sandstone, with minor interbeds of conglomerate, shale, and siltstone. Most of the unit consists of light gray to brown-gray, thick-bedded, well-sorted, fine- to medium-grained orthoquartzite, with quartz cement and rounded grains of quartz and trace amounts of magnetite, hematite, and lithic fragments. The unit was most likely deposited within a transgressive, epicontinental sea. These two units have potential for silica-sand deposits.

The Mancos Shale lies conformably on the Beartooth Member and typically crops out in valleys and saddles of ridges. It is as much as 300 ft in the Cooke's Range and consists of thin-bedded, fissile, silty, carbonaceous, brown to black shale. Locally, nodules of dark-gray limestone occur in the upper beds. These rocks were deposited in marine offshore and shoreface environments. Shale is a source of clay.

Cenozoic sedimentary and volcanic rocks

Conformably overlying the Bisbee Group is a sequence of conglomerate, sandstone, siltstone, and volcanic flows and breccias that are 700–900 ft thick. Purple to maroon to gray dacite flows and flow breccias occur in the Victorio Mountains that may correlate with the Hidalgo Formation (~71 Ma) exposed in the Little Hatchet Mountains (Lawton et al., 1993; Young et al., 2000; McLemore et al., 2000a). The dacite flows and flow breccias (~100 ft thick) are overlain by clastic sedimentary rocks that Lawton and Clemons (1992) correlated to the Eocene Lobo Formation (600–800 ft thick). The conglomerate is more prevalent in the upper part of the sequence and consists of angular to rounded granite, dacite, andesite, marble, limestone, and quartz clasts, as much as 10 cm long.

The Lobo Formation in the Cooke's Range was mapped as the Starvation Draw Member of the Rubio Peak Formation (Clemons, 1982b), a name that has been abandoned (Clemons, 1984, Clemons and Mack, 1988). The Lobo Formation ranges from 100–500 ft in the Florida Mountains to 1,000 ft in the Cooke's Range to 790 ft in the Eagle Nest area and unconformably overlies Precambrian to Cretaceous rocks and is unconformably overlain by the Rubio Peak Formation (Clemons, 1984; Clemons and Mack, 1988; Seager, 1995). The Lobo Formation and correlative units in the T or C area were deposited in basins adjacent to the Rio Grande and Burro uplifts.
Adjacent to the uplifts, alluvial-fan conglomerates were deposited and finer-grained sediment was deposited in the distal portions of the basins in distal fan, lacustrine, and fluvial environments. Late Eocene-Oligocene volcanic rocks overlie the Lobo Formation.

The Rubio Peak Formation includes andesites, latites, agglomerates, tuffs, breccias, sandstones, and conglomerates. It is at least 2,000 ft thick in the Goodsight Mountains (Clemons, 1979) and as much as 6,500 ft in the subsurface near Deming (Seager, 1995). Age determinations range from 44.7±1.9 to 32.6±2.1 Ma (Clemons, 1979, 1982a, b; Seager, 1995).

The Main Ridge of the Victorio Mountains is made up of Tertiary volcanic and volcaniclastic rocks, called the Victorio Peak dacite, which unconformably overlies the Lobo Formation. The Victorio Peak dacite consists of approximately 300–500 m of agglomerates, flow breccias, tuffs, and dacite lavas, including a 41.7±2 Ma dacite breccia (zircon, fission track; Thorman and Drewes, 1980). A 3–6 ft thick white to light gray, rhyolitic ash-flow tuff crops out in the upper part of the Victorio Peak dacite, north of the microwave towers. If the fission track age is correct, than the Victorio Peak dacite is correlative with the Rubio Peak Formation.

A series of ash-flow tuffs and andesite flows overlies the older rocks that are related to a major volcanic event in southern New Mexico. The Mogollon-Datil and Boot Heel volcanic fields are part of a regional late Eocene-Oligocene volcanic province that extends from west-central New Mexico southward into Chihuahua, Mexico (McDowell and Claubaugh, 1979; McIntosh et al., 1990a, b; McIntosh and Bryan, 2000). The southeastern edge of the Mogollon-Datil volcanic field extends into northern Luna County and the Boot Heel volcanic field extends into western Luna County (Fig. 7). In southwestern New Mexico, volcanic activity began about 40–36 Ma with the eruption of andesitic volcanism and, subsequently, episodic bimodal silicic and basaltic andesite volcanism followed from 36 to 24 Ma (Cather et al., 1987; Marvin et al., 1988; McIntosh et al., 1990a, b). Approximately 25 high- and low-silica rhyolite ignimbrites (ash-flow tuffs) were erupted and emplaced throughout the Mogollon-Datil volcanic field during this event; source calderas have been identified for many of the ignimbrites (Fig. 7; McIntosh et al., 1990a, b, 1992a). Approximately nine high- and low-silica rhyolite ignimbrites (ash-flow tuffs) were erupted and emplaced throughout the Boot Heel volcanic field (McIntosh and Bryan, 2000). Although there are no calderas in Luna County, many of the ignimbrites that erupted from calderas in the Mogollon-Datil and Boot Heel volcanic fields extended into the mountain ranges of Luna County. Some of these ignimbrites have been correlated to specific calderas, but the sources of many ignimbrites in Luna County have yet to be identified.

The Little Florida Mountains consist predominantly of interbedded mid-Tertiary andesite, dacite, ash-flow tuff, rhyolite, and fanglomerate intruded by rhyolite domes and dikes (Clemons, 1982a, 1984, 1998; Clemons and Brown, 1983). Altered sanidine and biotite from an ash flow near the base of the stratigraphic section at Little Gap give $^{40}Ar/^{39}Ar$ ages of 33.5±0.2 Ma and 32.9±0.2 Ma, respectively. This ash flow may correlate with the 33.5 Ma Oak Creek Tuff, erupted from the Juniper caldera in the northern Animas Range in the Boot Heel volcanic field

(McIntosh and Bryan, 2000). Additional rhyolite and andesite samples from the Rockhound State Park range in age from 24.4±0.4 to 28.5±0.3 Ma (groundmass, $^{40}Ar/^{39}Ar$; McLemore et al., 2000a). Ash-flow tuffs north of Gage at Antelope Hill have been dated as 33.7±1.1 Ma and may be correlative to calderas in the Boot Heel volcanic field (biotite, K/Ar; Marvin et al., 1988).

The volcanic rocks are overlain by sedimentary rocks of the Santa Fe Group (Camp Rice/Palomas, Rincon Valley, and Hayner Ranch Formations) and Gila Group (Mimbres Formation). Pediment-slope, basin fill, alluvial, and fluvial deposits comprise these groups.

Basaltic rocks have been erupted from widely scattered vents throughout southwestern New Mexico over the last 5 million years or so. Two compositional types were erupted (Hoffer, 1988; Anthony et al., 1992), alkaline basalts consisting of basanite, trachybasalt, and alkali basalt and subalkaline, tholeiitic basalts. More than 150 cinder cones and associated basaltic flows form the Potrillo volcanic field (Aden district) in western Doña Ana and eastern Luna Counties. The Deming flow in Fort Cummings Draw (Cooke's Range) consists of subalkaline basalt (Anthony et al., 1992); whereas the flows near Columbus, including Pancho Villa, are alkaline basalt and are 3.0 to 3.8±0.6 Ma (Seager et al., 1984; McLemore, 2000a, b). Pliocene cones are found in the southern Tres Hermanas Mountains north of Columbus (Seager, 1995). Basalt also is found at Black Mountain, northeast of Deming, and south of the Florida Mountains, but the composition, extent, and age are unknown. Scoria is found associated with some basalt flows. Scoria and basalt are utilized as crushed stone.

As much as several thousand feet of Miocene-Holocene sedimentary rocks typically fill the basins and partially overlie the Proterozoic through Miocene sedimentary and volcanic rocks. The Mimbres and Animas basins consist of the Gila Group in western Luna County and the Santa Fe Group in eastern Luna County, which are Oligocene through Pleistocene (Kennedy et al., 2000a). These rocks are overlain by Late Quaternary valley-fill stream and floodplain deposits, piedmont-slope deposits, and basin-fill surficial lake, playa, and stream deposits (Kennedy et al., 2000a). The Mimbres River, which starts in the Pinõs Altos Mountains to the north, flowed episodically throughout the Pleistocene and Holocene past Deming, and around the Florida Mountains, east of Columbus and into Mexico to fill the playa lakes south of Palomas in the Bolson de los Muertos (Kottlowski, 1989; Love and Seager, 1996). Today, the Mimbres River flows into the Mimbres basin east of Deming.

Tertiary intrusive rocks

Most mountain ranges in Luna County are dominated by Tertiary intrusions (Fig. 4). Magmas and the resulting igneous rocks are a common source of metals for many types of ore deposits and different magma compositions yield different types of ore deposits (Lindgren, 1933; Guilbert and Park, 1986; Cox and Singer, 1986). Thus, geochemical characteristics of igneous rocks when compared to known mineralizing igneous systems are a successful tool in evaluating an area for potential ore deposits. Many of these intrusions resemble the host rocks of porphyry copper deposits in southwestern New Mexico and southern Arizona and have been exploration targets in the past for porphyry copper, polymetallic vein, skarn, and carbonate-hosted deposits. Rhyolite dikes, plugs, and domes are common in many mountains in Luna County and may have potential for volcanic epithermal and/or rhyolite-hosted tin deposits.

Age of the Igneous Rocks

The igneous rocks in Luna County are Eocene to Miocene in age (Table 10). The oldest rocks are dikes and sills exposed in the Cooke's Range, Fluorite Ridge, and Victorio Mountains. These rocks are younger (41-22 Ma) than the porphyry copper deposits in southwestern New Mexico, which range in age from 75 to 54 Ma (McLemore, 2001).

TABLE 10. Summary of age dates of Tertiary intrusive rocks within and adjacent to Luna County. All dates have been corrected using the decay constants of Steiger and Jager (1977). * altered by hydrothermal activity.

NAME	AGE MA	REFERENCES
Camel Mountain-Eagle Nest		
Diorite, Prospect Hills (PROS 1)	36.8±4.7 (hornblende, $^{40}Ar/^{39}Ar$)	This report (Appendix 5)
Cooke's Range		
Granodiorite	38.8±1.4 (biotite, K/Ar)	Loring and Loring (1980)
Mafic dike	37.6±2 (whole rock, K/Ar)	Clemons (1982b)
Dacite	38±1.5 (biotite, K/Ar)	Clemons (1982b)
Dacite	44.7±1.9 (biotite, K/Ar)	Clemons (1982b)
Florida-Little Florida Mountains		
Spring Canyon rhyolite dike	25.4±0.7 (groundmass, $^{40}Ar/^{39}Ar$)	McLemore et al. (2000a)
Florida Peak rhyolite	29.1±1.3 (biotite, K/Ar)	Clemons and Brown (1983)
Rhyolite dike, Little Gap	23.6±1 (whole rock, K/Ar)	Clemons (1982a)
Fluorite-Goat Ridge		
Fluorite Ridge granodiorite	22.9±1.3 (hornblende, K/Ar)*, 38.82±0.57	Clemons (1982), this report (Appendix 5)
Diabase	26.38±0.20, 27.16±0.19	This report (Appendix 5)
Rhyolite dike	37.6±2.0 (whole rock, K/Ar)	Clemons (1982b)
Goodsight Mountains/Uvas Valley		
Intermediate dike	38.1±2 (biotite, K/Ar)	Clemons (1979)
Hornblende-biotite latite	37.6±2 (hornblende, K/Ar)	Clemons (1979)
Southern Burro Mountains	28.9±1.3	Thorman and Drewes (1979)
Tres Hermanas		
Quartz monzonite (Tres 7)	34.65±0.28 (hornblende, $^{40}Ar/^{39}Ar$)	McLemore (2000c), This report (Appendix 5)
Victorio Mountains		
Victorio Granite	35.09±0.08, 35.27±0.41 (biotite, $^{40}Ar/^{39}Ar$)	McLemore et al. (2000a), Donahue (in preparation)
Dacite	41.7±4.3 (zircon, FT)	Thorman and Drewes (1980)
Rhyolite porphyry	24.8±0.9 (zircon, FT)	Thorman and Drewes (1980)

Geochemistry of Tertiary igneous rocks

Selected igneous rocks from Luna County were submitted for chemical characterization for this study (Appendix 4). The geochemistry of the Luna County igneous rocks were compared with the geochemistry of igneous rocks from known mineralizing systems, including the Sierra Blanca tin-bearing rhyolites in Trans-Pecos Texas (Barker, 1980; Rubin et al., 1987), tin-bearing rhyolites from Sierra County, New Mexico (Lufkin, 1972; Correa, 1981; Goerold, 1981; Woodard, 1982; Duffield and Dahymple, 1990; Duffield and Ruiz, 1992), tin-bearing rhyolites from Utah (Christiansen et al., 1986) and porphyry copper deposits in New Mexico (McLemore, unpublished data; McLemore et al., 1999b, 2000c).

Rhyolites from throughout Luna County are calc-alkalic and peraluminous to metaluminous (Fig. 8). They are classified as Volcanic Arc Granites (VAG), Within Plate (WPG), or Syncollusional (Syn-COLG) granites using the classification of Pearce et al. (1984) (Fig. 9). Tertiary granitic rocks form the cores of several mountain ranges in Luna County (Fig. 4). Granitic rocks range from granite to granodiorite to quartz monzonite, are calc-alkaline, and peraluminous to metaluminous (Fig. 10). They are classified as Within Plate (WPG) or Syncollusional (Syn-COLG) granites using the classification of Pearce et al. (1984) (Fig. 9).

The fact that the rhyolites and granites do not plot in well-defined tectono-chemical fields suggests that their origin is more complex than simple collision of plates, subduction, or rifting, In accordance with these types of granites and rhyolites, the magma probably originated within the mantle and acquired a significant enrichment in lithophile-group elements during its movement through the crust. These data are consistent with either a continental rift or subduction-related back-arc extension settings. The rhyolites from the Carrizalillo and Florida Mountains are peraluminous, similar to tin-bearing rhyolites from Sierra County, Sierra Blanca, and Utah (Fig. 8). Although the Luna granitic rocks are similar in appearance to granitic rocks of New Mexico porphyry copper deposits, the Luna County granitic rocks are younger in age and differ in chemical composition from the porphyry copper deposits (Fig. 9, 10).

FIGURE 8. A scatter plot of ANK ($Al_2O_3/(Na_2O + K_2O)$) verses ACNK ($Al_2O_3/(CaO + Na_2O + K_2O)$) of rhyolites from Luna County and tin-bearing rhyolites. Analyses of Luna County rhyolites are in Appendix 4. Analyses of tin-bearing rhyolites are from Sierra County (Lufkin, 1972; Correa, 1981; Goerold, 1981; Woodard, 1982; Duffield and Dahymple, 1990; Duffield and Ruiz, 1992), East Grants Ridge (unpublished data), and Sierra Blanca (Barker, 1980; Rubin et al., 1987).

FIGURE 9. A scatter plot of Rb verses Y + Nb and Nb verses Y of granitic rocks and rhyolites from Luna County and granitic rocks from New Mexico porphyry copper deposits. Analyses of Luna County granitic rocks are in Appendix 4. Analyses of porphyry copper deposits from McLemore (unpublished data) and McLemore et al. (1999b, 2000c). Fields are from Pearce et al. (1984). WPG- within plate granites, ORG-orogenic granites, VAG-volcanic arc granites.

FIGURE 10. A scatter plot of ANK ($Al_2O_3/(Na_2O + K_2O)$) verses ACNK ($Al_2O_3/(CaO + Na_2O + K_2O)$) and SiO_2 verses $Na_2O + K_2O$ of granitic rocks from Luna County. Analyses of Luna County granitic rocks are in Appendix 4. Analyses of porphyry copper deposits from McLemore (unpublished data) and McLemore et al. (1999b, 2000a).

Regional geophysics

Aeromagnetic and gravity data

Published aeromagnetic and gravity data (U. S. Department of Energy, 1979a, b, 1981a, b; Cordell, 1983, 1984; Keller and Cordell, 1983, 1984; Abrams and Klein, 1997) were evaluated in conjunction with geological, geochemical, and aerial gamma-ray data to aid in evaluating the mineral-resource potential of Luna County. Aeromagnetic and gravity data can define margins of near-subsurface intrusions and major fault systems beneath sedimentary cover that may be related to areas of mineralization and/or hydrothermal alteration. Magnetic anomalies are typically caused by small differences in relative magnetite content of igneous rocks or by differences in depth to crystalline basement. Gravity anomalies reflect differences in density contrast between igneous, sedimentary, and metamorphic rocks. These data are reconnaissance in nature and are adequate to define only regional features.

The complete Bouguer gravity anomaly map shows variations in the gravitational field due to horizontal variations in the density of surface and subsurface rocks. Areas of high gravity values may correspond to uplifts, horst blocks, and dense mafic rock masses; areas of low gravity values may correspond to sediment-filled grabens, tuff-filled calderas, and felsic intrusions and batholiths. In Luna County, anomalies are mostly elongate in a northwest-southeast direction; gravity highs and parallel lows are caused by density contrasts between bedrock horsts and low-density basin fill. Gravity highs correspond to the Cedar Mountains-Carrizallilo Hills, Tres Hermanas-Victorio Mountains, Florida Mountains, and Fluorite-Goat Ridge. A north-south gravity anomaly corresponds to the Camel Mountain-Eagle Nest area in eastern Luna County.

Surface rocks in Luna County include mostly non-magnetic Tertiary and Quaternary sedimentary rocks and magnetitic intrusive igneous rocks (Abrams and Klein, 1997). Highest magnetic intensities are located over topographic highs where igneous rocks were closest to the surface. Hydrothermally-altered rocks show little to no magnetization and are associated with magnetic lows. Igneous and metamorphic rocks produce large magnetic anomalies because of high magnetite content. Sedimentary rocks are effectively non-magnetic. Thus, the sedimentary cover does not hinder detection of buried intrusive igneous rocks and structural trends within the buried crystalline basement rocks, except by placing the magnetic sources at greater distance from the sensor.

Between the Burro and the Tres Hermanas Mountains, several gravity and magnetic highs are present, many of which lack outcrop expression and typically are covered with Quaternary sediments (Abrams and Klein, 1997). In this area, gravity highs may be related to uplifted rocks, and magnetic highs may define possible concealed intrusions surrounded by carbonate rocks. The Victorio Granite and associated skarns and porphyry molybdenum deposits were found by drilling one of these anomalies (McLemore et al., 2000b). Drilling in the West Lime Hills area of the Tres Hermanas Mountains also encountered quartz monzonite and mineralized limestone along a gravity high (Leonard Resources, unpublished data). The Tres Hermanas Mountains corresponds to a gravity and magnetic high. Magnetic data are not available for southern Luna County, including the Tres Hermanas Mountains. The Florida Mountains are expressed by gravity and magnetic highs that may correspond to intrusions within carbonate rocks in the mountains and adjacent Mimbres Basin. Gravity and magnetic highs also correspond with the Fluorite-Goat Ridge area.

Aerial gamma-ray data

Aerial gamma-ray data can delineate zones of hydrothermal alteration and define major fault systems and were evaluated in conjunction with geological, geochemical, and other geophysical data. These data were acquired as part of the NURE program from surveys flown at 400 ft above ground level and at flight lines spaced 2–6 mi apart with north-south tie lines spaced 12–15 mi apart. The NURE gamma-ray surveys included measurements of the gamma-ray flux produced by the radioactive decay of K^{40} and by members of the radioactive decay series of U^{238} and Th^{232}. Published maps by Duval (1988), U. S. Department of Energy (1979a, b; 1981a, b), and Pitkin (1997) were used for this report.

The most radioactive rocks in Luna County are the Cambrian-Ordovician syenites and alkali-feldspar granites and Tertiary rhyolites. Scattered uranium highs on the regional map correspond to these rocks in the Florida Mountains and in central Luna County. The area south of Deming (Florida and Tres Hermanas Mountains, Mimbres Basin) exhibits high potassium and thorium on the regional maps, where higher Th (10–13 ppm), K (2.8–3.4%), and U (2.6–3 ppm) are found (Pitkin, 1997). A northwest trend of high potassium northwest of Deming corresponds with the Burro Mountains. The Cooke's Range exhibits relatively low values of K (1–1.6%), U (1.2–1.6 ppm), and Th (5–7 ppm) that correspond to Paleozoic and Mesozoic carbonate rocks (Pitkin, 1997).

Seismic data

Seismic data, including deep-crustal refraction traverses for university research programs and commercial seismic reflection profiles acquired for petroleum exploration, was collected and interpreted by Klein et al. (1997). They concluded that there are areas of probable uplift in Luna County where the depth to Mesozoic and Paleozoic rock is less than 2,100 ft; in a few localities, the depth is 300–600 ft. These areas, typically adjacent to the mountain ranges have potential for buried intrusions that may be associated with mineral deposits. For example, the Apache Hills-Cedar Range basin has more than 1,500 ft of low-velocity rocks that is probably alluvium and conglomerate. Further eastward along the Mexican border, the thickness of the alluvium varies from approximately 300 to 1,500 ft. High velocity rocks are within a few hundred feet of the surface near the Carrizalillo Hills and the Tres Hermanas Mountains (Klein et al., 1997). Gravity and seismic data indicates that there is probably potential for buried intrusions and associated mineral deposits within several hundred feet of the surface north, south, and east of the Victorio Mountains. East of the Tres Hermanas Mountains, low velocity rock was inferred to be carbonate rock and is within 1,500 ft of the surface. North of the Tres Hermanas Mountains, 900 ft of alluvium and volcanic rock are indicated by seismic data (Klein et al., 1997). West of the Florida Mountains seismic basement (5.2 km/sec) is less than 300 ft from the surface.

Regional geochemistry

National Uranium Resource Evaluation (NURE) Data

Geochemical data, collected as part of the National Uranium Resource Evaluation (NURE) program for detailed uranium exploration, were examined for this study (Sharp et al., 1978; Union Carbide Corporation, 1981a, b). Data are primarily for stream-sediment samples collected within the Douglas, Las Cruces, El Paso, and Silver City 1 x 2 degree-quadrangles (Appendix 3). More than 600 stream-sediment samples were collected within Luna County, but only uranium was determined for all samples. Less than 100 water samples from Luna County were collected and analyzed for the NURE project. Only stream-sediment data are used for this report. The stream-sediment samples were analyzed by Los Alamos and Oak Ridge National Laboratories by neutron activation analysis and plasma source emission spectrometry using partial extraction techniques (Cagle, 1977; Arendt et al., 1979). Since the focus of the NURE program was to assess for uranium, samples were not routinely analyzed for many pathfinder elements required for precious- and base-metals exploration. Therefore, the NURE data has limited value in the mineral-resource assessment. The NURE data are summarized in Table 11 and sample locations are in Figure 11.

FIGURE 11. Map of NURE sample locations in Luna County.

Interpretation of the NURE data

Interpretation of the NURE stream-sediment data has identified distribution patterns of selected elements on a regional scale that may be related to locally anomalous areas that may relate to mineralization or to possible underlying structures that may have served as conduits for metal-bearing fluids. Specific interpretations of the NURE data are included in the following discussions on specific mining districts and favorable areas.

TABLE 11. Summary of the NURE geochemical data. Terrestrial abundance is from Greenwood and Earnshaw (1986) for comparison. Anomaly threshold values are determined for selected elements of economic interest.

Trace element (ppm)	Number of samples above detection limit	Maximum	Minimum	Mean (samples above detection limit)	Standard deviation	Anomaly threshold	Terrestrial abundance
Ag	8	6	<2	na	na	na	0.08
Al	487	99,800	2,300	65,250	12,190	na	8,300
As	75	31	<5	9.5	4.3	15	1.8
B	189	52	<10	15	6.5	na	9
Ba	487	14427	45	706	652	900	390
Be	391	9	<1	1.8	1	2	2
Bi	11	9	<5	6	1	na	0.008
Ca	487	208,600	1,800	25,812	22,844	na	46,600
Ce	485	340	<10	77	37	na	66
Co	457	28	<4	10	5	18	29
Cr	487	222	1	47	28	100	122
Cs	91	19	<2	5	2	na	2.6
Cu	481	417	<10	27	22	55	68
Eu	94	2.3	<0.8	1.3	.03	na	2.1
Fe	487	147,200	4,400	37,929	20,350	na	62,000
Hf	119	80	<15	22	15	na	2.8
K	487	33,090	1,600	17,906	4,649	na	18,400
La	486	175	<2	37	18	na	35
Li	393	120	7	28	11	45	18
Mg	487	42,200	<1,988	7,914	4,136	na	27,640
Mn	487	29,830	25	742	1,374	1,300	1,060
Mo	5	19	<4	na	na	na	1.2
Na	486	27,300	<500	13,261	4,083	na	22,700
Nb	391	262	<20	18	21	25	20
Ni	440	113	<15	20	21	na	99
P	393	5,307	143	597	389	na	1,120
Pb	476	901	<10	33	67	40	13
Rb	86	209	<44	109	25	na	78
Sb	7	8	<3	na	na	na	0.2
Sc	486	17	<1	6	2	na	25
Se	92	17	3	8	na	na	0.05
Sn	2	14	<10	na	na	na	2.1
Sr	418	1,036	<411	339	166	na	384
Ta	39	8	<2	4	2	na	1.7
Th	460	51	<2	9	6	15	8.1
Ti	487	35,659	183	4,793	3,068	8,000	6,320
U	601	50	1	4	3	5	2.3
V	487	468	15	98	67	200	136
W	7	22	<15	na	na	na	1.2
Y	393	59	<15	18	7	40	31
Zn	452	581	<158	89	54	200	76
Zr	484	1,855	<2	156	234	na	162

POTENTIAL TYPES OF MINERAL DEPOSITS IN LUNA COUNTY

There are 19 types of metallic deposits that could occur within Luna County (Table 12). A variety of industrial minerals deposits also are found or could occur in Luna County. Brief descriptions follow.

TABLE 12. Types of mineral deposits that could occur within Luna County (after North and McLemore, 1986, 1988; Cox and Singer, 1986; McLemore and Chenoweth, 1989; McLemore and Lueth, 1996; McLemore, 2001). * denotes deposits that are suspected to occur in Luna County, but have not been identified.

NMBGMR CLASSIFICATION	USGS CLASSIFICATION (USGS MODEL NUMBER)	COMMODITIES
*Porphyry Cu, Cu-Mo (±Au) (75–50 Ma)	Porphyry copper (17, 20c, 21a)	Cu, Mo, Au, Ag
Laramide Cu and Pb-Zn skarn (75–50 Ma)	Skarn (18a, 18c, 19a)	Au, Ag, Cu, Pb, Zn
Polymetallic vein (75–50 Ma)	Polymetallic veins (22c)	Au, Ag, Cu, Pb, Zn
Porphyry Mo (±W)	Porphyry Mo-W (16, 21b)	Mo, W, Au, Ag
Mo-W-Be contact-metasomatic deposits	W-Be skarns (14a)	Mo, W, Be, Pb, Zn, Cu
Carbonate-hosted Pb-Zn (Cu, Ag) replacement	Polymetallic replacement (19a)	Pb, Zn, Cu, Ag
Carbonate-hosted Ag-Mn (Pb) replacement	Polymetallic replacement, replacement manganese (19a, b)	Ag, Mn, Pb, Zn
Carbonate-hosted Mn replacement	Replacement Mn (19b)	Mn
*Replacement Fe	Iron skarn (18d)	Fe
*Gold skarn	Gold skarn	Au, Ag
*Sedimentary-hosted gold deposits (Carlin deposits)	Sedimentary-hosted gold deposits (Carlin deposits)	Au
Volcanic-epithermal vein	Quartz-adularia, quartz-alunite, epithermal manganese (25b,c,d,e,g, 26b)	Au, Ag, Cu, Pb, Zn, Mn, F, Ba
Epithermal Mn	Epithermal Mn (25g)	Mn
Epithermal fluorite		F
*Rhyolite-hosted tin	Rhyolite-hosted tin (25h)	Sn
Rio Grande Rift barite-fluorite-galena (formerly sedimentary-hydrothermal)	None	Ba, F, Pb, Ag, U
*Vein and replacement deposits in Proterozoic rocks	Polymetallic veins, fluorite veins (22c, 26b)	Au, Ag, Cu, Pb, Zn, Mn, F, Ba
*REE-Th-U veins in alkaline rocks	Th-REE veins (10b, 11d)	REE, U, Th, Nb, Ta
*Sedimentary-copper deposits	Sediment-hosted copper (30b)	Cu, Ag, Pb, Zn, U, V
Alunite	—	Alunite
Clay	—	Clay
Crushed stone	—	Crushed stone
Dimension stone	—	Dimension stone
Garnet	—	Garnet
Gems, semi-precious stones, and mineral collecting	—	Gems
Limestone/dolostone/travertine/marble for cement and lime	—	Limestone
Perlite	—	Perlite
Pumice	—	Pumice
Silica	—	Silica
Talc	—	Talc
Zeolites	—	Zeolites

Metallic deposits

Porphyry Cu, Cu-Mo (±Au) deposits

Porphyry Cu, Cu-Mo (±Au) deposits are large, low-grade copper (<0.8% Cu) deposits that contain disseminated and stockwork veinlets of copper and molybdenum sulfides with gold and are associated with porphyritic intrusions (Fig. 12; Schmitt, 1966; Lowell and Guilbert, 1970; Kesler, 1973; Lowell, 1974). Mineralization typically occurs in and around porphyritic diorite, granodiorite, monzonite, and quartz monzonite plutons, which are surrounded by concentric zones of hydrothermal alteration (Lowell and Guilbert, 1970). In many deposits, the concentric zoning is destroyed and replaced by younger quartz-sericite alteration, such as at the Chino deposit. Low concentrations of silver and gold are present in most deposits and can be recovered as by-products by conventional milling techniques. Precious metals, including platinum-group metals (McLemore et al., 1989), can be recovered from the anode slimes remaining after copper is refined. They are found as particles of native species and as solid solutions or exsolved species in sulfide minerals.

FIGURE 12. Simplified porphyry system (from McLemore and Lueth, in press).

Laramide Cu and Pb-Zn skarn deposits

Laramide skarn deposits in New Mexico are contact-metasomatic deposits that formed in Paleozoic marine limestones and dolomitic limestones adjacent to calc-alkaline plutonic rocks emplaced during the Laramide compressional event from the Late Cretaceous (ca. 75 Ma) to early Eocene (ca. 45–40 Ma)(McLemore and Lueth, 1996). Three types of Laramide skarns occur in southern New Mexico: copper (typically associated with porphyry copper deposits; Einaudi et al., 1981; Einaudi, 1982; Lueth, 1984), lead-zinc (proximal and vein-type deposits; Meinert, 1987; Turner and Bowman, 1993; Lueth, 1996), and iron skarns (Lueth, 1984, 1996). These skarns, except the iron skarns, are either copper or zinc rich; lead and silver were produced as by-products. The largest Pb-Zn skarns are in the Fierro-Hanover and Piños Altos districts in Grant County. Late-stage veins carry gold and silver and cut the adjacent intrusive rocks. Laramide iron skarns are found in the Fierro-Hanover and Santa Rita districts.

Copper skarns are typically intimately associated with plutons (e.g. Santa Rita, Piños Altos), whereas the Pb-Zn skarns are locally distal to igneous rocks (Fig. 13). Some Pb-Zn skarns occur along faults distal from intrusive rocks (e.g. Groundhog, southwestern deposits at Piños Altos, Eureka). The largest zinc deposits in New Mexico are in the Fierro-Hanover district. Grades and size vary (McLemore and Lueth, 1996). District zoning is common in most areas with copper adjacent to the intrusive rocks grading outwards to Zn-Pb, Pb-Zn, Pb-Ag, and locally, Pb-Ag-Mn (Meinert, 1987; McLemore and Lueth, 1996).

FIGURE 13. Diagrammatic sketch showing mineralization and alteration patterns in Laramide skarns in southern New Mexico (modified from Lueth, 1984; McLemore and Lueth, 1996; McLemore and Lueth, in press). Garnet forms nearest the stock in the purer limestone of the Lake Valley Limestone and Oswaldo Formations. Garnet-clinopyroxine forms adjacent to the stock in the argillaceous carbonate rocks. A hornfels typically forms at the parting shale in the Oswaldo Formation. Wollastonite and marble form the outer zones. Chalcopyrite occurs in the garnet zone and sphalerite occurs in the clinopyroxene zone and at the contact between the skarn and marble.

The Laramide skarns in New Mexico formed from variable, but higher temperature and saline fluids compared to carbonate-hosted Pb-Zn replacement deposits in New Mexico (McLemore and Lueth, 1996). Most deposits probably formed from mixing of meteoric and magmatic fluids (Abramson, 1981; Ahmad and Rose, 1980; Lueth, 1984; Turner and Bowman, 1993).

Polymetallic vein deposits

Vein deposits of probable Laramide or Mid-Tertiary age (Late Cretaceous-Miocene, 75–25 Ma) occur in a number of districts. These veins exhibit different textures and mineralogies, but are similar in form and age. Laramide skarns are locally important in some districts with polymetallic vein deposits. Lindgren (1933) classified these veins as mesothermal veins and Cox and Singer (1986) classified them as polymetallic veins.

Proterozoic rocks are a common host rock, although Cretaceous to Early Eocene volcanic and plutonic rocks also are host rocks in some districts (i.e. Lordsburg, Hillsboro). Paleozoic and Cretaceous sedimentary rocks host the veins in the Bayard district. The veins were typically worked for both base and precious metals and locally contain uranium, tungsten, and beryllium. Mineralogies and metal associations are diverse, even within a district. Despite these differences, these deposits are grouped together because of similar form, association with Laramide intrusive rocks, and perceived origin at moderate to high temperatures and moderate depths.

The ores from polymetallic veins have potential for siliceous flux. Past production indicates that polymetallic vein deposits are small to medium tonnage.

Porphyry Mo (±W) deposits

Porphyry Mo (±W) deposits are large, low-grade molybdenum (0.1–0.2% Mo) deposits that contain disseminated and stockwork veinlets of molybdenum sulfides and are associated with porphyritic intrusions (Fig. 14). They occur in three areas in New Mexico (Questa, Lincoln County porphyry belt, Victorio Mountains); the largest deposits are at Questa in Taos County. Many deposits consist of thin veinlets, fracture coatings, and disseminations in granitic host rock and ore minerals include molybdenite, powellite, scheelite, beryl, helvite, bismuthinite, and wolframite. Three morphological forms of porphyry Mo deposits are found (Fig. 14; modified from P. S. Ross, personal communication, June 2001): horizontal breccia body and veins (i.e., Questa), vertical breccia pipe and veins (i.e., Victorio Mountains), and stockwork veins without any breccia (i.e., Climax, porphyry). Porphyry Mo deposits are classified on the basis of primary geochemical, hydrothermal, and tectonic characteristics as high-silica rhyolite-alkalic (Climax, transitional, alkalic subtypes) and differentiated monzogranite types (Cox and Singer, 1986; Carten et al., 1993). Known deposits in New Mexico are classified as transitional or alkalic (Carten et al., 1993).

FIGURE 14. Schematic sketch of forms of porphyry molybdenum deposits that are dependent upon amount of fluid in the source magma, overpressures, host rock permeability, and other physical/chemical characteristics.

Mo-W-Be contact metasomatic deposits

Mo-W-Be contact metasomatic deposits occur as small veins and replacement lenses within the limestones and dolostones in the vicinity of granitic or rhyolitic intrusions. Ore minerals include helvite, wolframite, scheelite, scheelite-powellite, molybdenite, galena, sphalerite, and beryl in a gangue of pyrite, quartz, calcite, Mn and Fe oxides, local grossularite, tremolite, pyroxene, idocrase, and phlogopite (Holser, 1953; Warner et al., 1959; McLemore et al., 2000a).

Carbonate-hosted Pb-Zn (Cu, Ag) replacement deposits

Carbonate-hosted Pb-Zn replacement deposits occur in southwestern New Mexico and were formed approximately 50–20 Ma (McLemore and Lueth, 1996). The deposits include replacements in carbonate rocks with little or no calc-silicate minerals, minor skarns with calc-silicate minerals, and minor veins in carbonate rocks and adjacent intrusive and sedimentary rocks. They are typically lead-zinc dominant, with by-product copper, silver, and gold. Galena and sphalerite are the predominant ore minerals with lesser amounts of chalcopyrite. Many deposits in New Mexico are oxidized near the surface and contain cerussite, anglesite, and smithsonite. Recognizable silver minerals are rare. These oxidized zones were typically the most productive in the past. Cox and Singer (1986) classify them as polymetallic, carbonate-hosted replacement deposits.

The host rocks are predominantly Paleozoic carbonate rocks, with a few smaller deposits in Cretaceous carbonate rocks. Many deposits are structurally controlled along fault, fracture, and contact zones. The localization of some deposits also is stratigraphically controlled, similar to skarn deposits. Replacements and minor skarns commonly occur along the contact between Fusselman Formation and overlying impermeable Percha Shale in some areas (Cooke's Peak; Organ Mountains).

The deposits vary in size and grade, ranging from a few thousands of short tons to a few hundreds of thousands of short tons and typically grading 5–30% combined lead and zinc; the amount of silver varies and gold is rare (McLemore and Lueth, 1996). In most carbonate-hosted Pb-Zn replacement districts in New Mexico, lead is the predominant metal, followed by zinc, and then copper. Manganese, locally with silver, occurs as replacements and epithermal veins peripheral to many carbonate-hosted Pb-Zn replacement deposits (McLemore et al., 1996). Skarns are poorly developed and rarely exhibit any mineral zonation. Fluid-inclusion data from five deposits indicates temperatures of formation between 147–367°C and low to moderate salinities (<10 eq. wt.% NaCl) (McLemore and Lueth, 1996).

The association between carbonate-hosted Pb-Zn replacement deposits and igneous activity is uncertain in many districts and these deposits could possibly be distal from porphyry deposits (Fig. 12). In the Hillsboro district, carbonate-hosted replacement deposits (Ag, Pb, Mn, V, Mo, Zn) are found in the southern and northern parts of the district, distal to the porphyry copper deposit and along strike of the vein deposits (McLemore et al., 1999b, 2000b). Tertiary intrusive rocks, ranging in age from 50 to 20 Ma, crop out in all districts except the Big Hatchet Mountains. In many districts, polymetallic veins and/or disseminations of sulfides occur in the adjacent intrusive rocks. Higher temperatures of formation and higher salinities are consistent, but not conclusive for, formation, entirely or in part, from magmatic fluids. The carbonate-hosted Pb-Zn replacement deposits are similar in form, mineralogy, texture, age, and temperature to the chimney, manto, and pod carbonate-hosted Ag-Pb-Zn(Cu) deposits in northern Mexico (Megaw et al., 1988). Geochemical, fluid inclusion, and stable-isotope data suggest that the Mexican deposits were formed by mixing of variable amounts of magmatic and meteoric fluids (Megaw et al., 1988) and a similar origin is reasonable for the New Mexico deposits. Future development of these deposits is dependent upon demand for zinc and lead.

Carbonate-hosted Ag-Mn (Pb) replacement deposits

Carbonate-hosted Ag (Mn, Pb) replacement deposits occur in southwestern New Mexico and were formed during the mid-Tertiary. The deposits contain predominantly silver and manganese oxides and include veins in carbonate rocks and replacements in carbonate rocks with little or no calc-silicate minerals. Over 20 million ounces of silver have been recovered from deposits of this type (North and McLemore, 1986; McLemore, 2001). Gold is rare in these deposits.

The deposits are hosted by Paleozoic limestones and dolomitic limestones, typically the Fusselman Formation and Lake Valley Formation. The Percha Shale commonly acts as the uppermost, impermeable cap on mineralization in the Fusselman Formation. Jasperoids are common to most deposits and also act as impermeable caps to mineralization. The mineralized host in some districts is the first significant carbonate unit stratigraphically above crystalline basement. The deposits typically consist of native silver, silver halides, cerussite, vanadinite, wulfenite, and smithsonite; argentite, argentiferous galena, polybasite, pyargyrite, stephanite, sphalerite, and chalcopyrite are rare to common in most districts. Oxidation has been important in concentrating the silver in these deposits. Skarn deposits are absent. At the Lake Valley district, the “Bridal Chamber” contained nearly pure chlorargyrite (Jicha, 1954). Although silver and manganese are the predominant metals, lead is next in abundance (McLemore and Lueth, 1996).

Geochemical data and age dates are generally lacking. These deposits are distal from mid-Tertiary plutons and carbonate-hosted Pb-Zn replacement deposits (Fig. 12). These deposits probably formed under similar conditions as the carbonate-hosted Pb-Zn replacement deposits in New Mexico; i.e. low- to moderate-temperatures and salinities, probably with some mixing of magmatic with meteoric fluids.

The carbonate-hosted silver replacement deposits are good exploration targets for small mining companies, because they tend to be high grade and small to medium size. The limestones are locally silicified and could be used as siliceous flux material. Metallurgical problems in recovering silver from the manganeriferous ore has hampered production in the past, but new recovery methods offer some hope for better recoveries in the future (Chase and Keane, 1985).

Carbonate-hosted Mn replacement deposits

Numerous replacement Mn deposits occur in carbonate rocks throughout New Mexico (Farnham, 1961; McLemore et al., 1996). Manganese-oxide minerals occur in veins, breccia cement, replacements, or cavity fillings in limestone and dolostone and form tabular or pod-shaped deposits. Most deposits in New Mexico are typically less than a few feet thick and less than a few 100s of feet long, but some ore shoots were larger (Farnham, 1961; McLemore et al., 1996). Most deposits in New Mexico are typically low grade (<50% Mn), small, and uneconomic.

Replacement-iron deposits

Replacement-iron deposits are typically small and consist of hematite and magnetite as lenses or irregular bodies in limestone or dolostone and as veins filling fractures, faults, and along bedding planes in limestone and dolostone and form tabular or pod-shaped deposits. Calc-silicate minerals are rare to absent. Most deposits in New Mexico are typically less than a few feet thick and less than a few 100s of feet long, but some ore shoots were larger. Most deposits in New Mexico are typically low grade, small, and uneconomic.

Gold skarn deposits

Gold skarn deposits are contact metasomatic deposits in carbonate rocks that contain at least 1 ppm Au and pyroxene, garnet, and other calc-silicate minerals (Theodore et al., 1991). They are typically distal from the intrusion as calcic exoskarns and are related to porphyry copper deposits, carbonate-hosted Cu, and other skarn deposits. Anomalous concentrations of Bi, Te, As, Se, and Co are geochemical signatures for gold skarn deposits. Host rocks exhibit hydrosilicate or jasperoid alteration. Grade and tonnage for known deposits average 8.6 ppm Au, 5 ppm Ag, and 213,000 tons (Theodore et al., 1991).

Sedimentary-hosted gold deposits (Carlin deposits)

Sedimentary-hosted gold deposits are mainly hosted in sedimentary rocks with low gold concentrations, but are large tonnage, so that large, low-cost open-pit mining methods are used to exploit them. Most common host rocks are thin-bedded, flaggy, mixed carbonate and silici-clastic rocks, although host rocks for some deposits include mafic volcanic, skarn, and felsic intrusions. These deposits typically contain 0.5 to 30 million ounces Au per deposit (Cox and Singer, 1992). Sedimentary-hosted gold deposits also are known as sedimentary rock-hosted, Carlin-type, carbonate-hosted, and disseminated gold deposits. The deposits consist of gold-bearing arsenopyrite, arsenic-rich pyrite, pyrite, marcasite, stibnite, realgar, orpiment, cinnabar, thallium-sulfide minerals, rare silver-antimony-mercury and lead-antimony sulfosalt minerals, sphalerite, chalcopyrite, and galena. Barite, calcite, and fine-grained quartz are common gangue minerals. Total sulfide mineral content in the ores ranges from less than 1 volume percent to local massive accumulations of pyrite. In calcareous rocks, stratabound replacement and local brecciation is common. In non-reactive rocks, orebodies are made of millimeter-sized stockwork veinlets to meter-sized vitreous quartz veins and jasperoid. Ore-associated alteration types typically are decalcification and dolomitization of carbonate strata, as well as argillization and silicification. Silicified rocks are present as jasperoid replacement, silica cementation, siliceous breccia bodies, or as open-cavity fillings of quartz veinlets. K–feldspar in the detrital sedimentary and igneous rocks alters to illite and kaolinite in the most intensely altered areas. Typically, deep basins are required to allow for heating of circulating mineralizing fluids. There have been no sedimentary-hosted gold deposits found in New Mexico, but favorable host rocks and alteration (jasperoidization) is widespread in southern New Mexico, including Luna County.

Volcanic-epithermal deposits

Lindgren (1933) defined the term "epithermal" to include a broad range of deposits that formed by ascending waters at shallow to moderate depths (<4,500 ft), low to moderate temperatures (50°–200°C), and which are typically associated with intrusive and/or volcanic rocks. It is now generally accepted that epithermal deposits were formed at slightly higher temperatures (50°–300°C) and relatively low pressures (a few hundred bars) based on fluid inclusion and isotopic data. Work by White (1955, 1981) established the now-recognized association between epithermal mineral deposits and active geothermal (or hot springs) systems. Subsequent work by Henley (1985) and associates (Henley and Brown, 1985) in New Zealand and many other researchers elsewhere confirmed this association. However, there are many small hot spring systems with no gold or base metals associated with them. The difficulty remains in identifying paleo-geothermal systems that contain economic concentrations of gold and/or base metals.

Epithermal mineral deposits in New Mexico, like elsewhere in the world, occur in structurally complex tectonic settings that provide an excellent plumbing system for circulation of hydrothermal fluids (Fig. 15). The characteristics of these deposits and a model for their formation were outlined by Buchanan (1981) and refined by later work (Rytuba, 1981; Henley, 1985; Henley and Brown, 1985; White and Hedenquist, 1990; McLemore, 1993, 1994b, 1996c). Not all epithermal deposits occur in igneous rocks; for example, the McLaughlin deposit in California is hosted in mafic and ultramafic metamorphic and sedimentary, and some sedimentary gold (Carlin-type) deposits appear to be epithermal and are found in sedimentary rocks (Bagby and Berger, 1985; Berger and Henley, 1989). However, most known epithermal deposits in New Mexico are restricted to volcanic terranes and areas immediately adjacent to volcanic fields and are called volcanic-epithermal deposits in this classification scheme.

FIGURE 15. Relationship between alteration and vein deposits along the Carlisle fault, Steeple Rock district, Grant County (McLemore, 1993).

The volcanic-epithermal deposits of New Mexico formed largely in faults and fissures in rhyolitic ash-flow tuffs and andesites of Oligocene-Miocene age (Fig. 15), locally within or adjacent to resurgent caldrons (Elston, 1978; 1994; Rytuba, 1981). Where isotopic ages are available, the ore deposits tend to be 10–12 Ma younger than the associated volcanic activity (McLemore, 1994b, 1996c). The association between bimodal volcanic activity and volcanic-epithermal deposits is probably one of a favorable plumbing system in an area of abundant water, high, recurrent heat flow, and favorable structural and chemical traps. These deposits were formed during neutral to extensional back-arc tectonic settings.

Typical volcanic-epithermal deposits in the state occur as siliceous vein fillings, breccia pipes, disseminations, and replacement deposits along faults and fractures in intermediate to silicic volcanic and volcaniclastic rocks. Common ore textures characteristic of epithermal deposits include: open-space and cavity fillings, drusy cavities, comb structures, crustifications, colloform banding, brecciation (typically multi-stage), replacements, lattice textures (quartz pseudomorphs after bladed calcite), and irregular sheeting (Buchanan, 1981; Dowling and Morrison, 1989). The mineralogy and metal associations of these deposits are diverse. Common ore minerals include auriferous pyrite, native gold, acanthite, chalcopyrite, bornite, argentiferous galena, native silver, and sphalerite. Quartz, calcite, and pyrite are common gangue minerals and common alteration minerals are chlorite, epidote, illite/sericite, adularia, and kaolinite. Both gold and silver are usually produced from these deposits with variable amounts of base-metal production. Other minerals produced from some deposits include fluorite, uranium, tellurium, and vanadium. Ore shoots within a specific vein form at intersections of faults or at areas with deflections in strike and/or dip. Most veins are less than 3 ft wide, but economic veins are as wide as 30 ft. District zoning also is diverse, and in some districts precious metals occur in the upper levels of the epithermal system and grade into base metals at depth, such as in the Chloride and Steeple Rock districts (Buchanan, 1981; Harrison, 1986, 1988; McLemore, 1993). Typical deposits are a few hundred thousand short tons or less grading 0.2 oz/short ton Au and 6–20 oz/short ton Ag or less (McLemore, 1996b).

The alteration mineral assemblage associated with these deposits varies with changes in temperature, pressure (depth), permeability, fluid composition, original host-rock composition, and duration of activity (Fig. 15; Silberman and Berger, 1985; Browne, 1978; P. R. L. Browne, written communication, 1992). Alteration assemblages include silicification, propylitic, argillic, advanced argillic, potassic, sericitic, illitic, and chloritic (Guilbert and Park, 1986). Alteration assemblages also may be referred to by the composition of the prevailing fluid type as alkali-chloride, acid-sulfate, bicarbonate, or mixed fluids (Browne, 1978; McLemore, 1993).

Most of the volcanic-epithermal deposits in New Mexico are of the low-sulfidation (quartz/adularia) class. Acid-sulfate alteration is present in five districts; Alum Mountain, Steeple Rock (Fig. 15; McLemore, 1993), San Jose (Forureu, 1984), Kline Mountain in Taylor Creek (Hall, 1978), and Old Hadley (Hall, 1978) and these altered areas may be indicative of high-sulfidation gold deposits, but none have been discovered in these areas to date (McLemore, 1994b, 1996b).

Volcanic-epithermal deposits in New Mexico also have potential for development of siliceous flux for local copper smelters. Siliceous flux is quartz-rich material that is required by the smelters for processing their low-silica ores. In some districts, dumps can be reworked for gold and silver by portable heap-leaching equipment, such as at the Mogollon district (Eveleth, 1979). Most districts in New Mexico have not been adequately explored at depth, and drilling and other exploration programs are needed to further evaluate the potential.

Epithermal Mn deposits

Numerous epithermal Mn deposits occur in volcanic and volcaniclastic rocks throughout New Mexico (Farnham, 1961; McLemore et al., 1996). Manganese-oxide minerals occur in veins, breccia cement, or cavity fillings and form vein, tabular, or pod-shaped deposits. Most deposits in New Mexico are typically less than a few feet thick and less than a few 100s of feet long, but some ore shoots were larger (Farnham, 1961; McLemore et al., 1996). Most deposits in New Mexico are typically low grade (<50% Mn), small, and uneconomic.

Epithermal fluorite deposits

During the formation of large magmatic systems, fluorite (rarely barite) may be deposited along fractures and faults along the fringes of the mineralizing system, or in more central areas as the mineralizing event wanes. Host-rock response to fluids varies with competency and carbonate content, producing vein or replacement deposits. If the core system subsequently is exposed, the zonal relationship between the two deposit types is evident. If the magmatic source is buried too deeply to be identified, fluorspar deposits may be the only manifestation of a larger system and may not be distinguished from deposits formed by other processes. Conversely, exposure of the magmatic system might indicate that distal fluorspar deposits have been eroded. Fluorite also may replace carbonate rocks adjacent to magmatic systems. These deposits are termed skarns or carbonate-hosted Pb-Zn and silver deposits by North and McLemore (1986) and McLemore (2001). Felsic (rhyolitic) and alkaline igneous systems are more likely to produce fluorite deposits than calc-alkaline systems. Felsic and alkaline igneous systems are relatively rare in Luna County, and the number of related deposits may be correspondingly small.

Rhyolite-hosted tin deposits

Rhyolite-hosted tin deposits consist of discontinuous veins and veinlets in rhyolite domes and volcanic centers (Cox and Singer, 1986; Christiansen et al., 1986). The tin deposits occur in the fractured and brecciated outer parts of flow-dome complexes and are hosted by high-silica (>75%), peraluminous rhyolites and/or pyroclastic deposits. Hematitic and argillic alteration is commonly associated with the tin deposits. The deposits are typically small in size (less than several hundred thousand tons of ore) and low grade (<2% Sn)(Cox and Singer, 1986). Four types of tin deposits are found in the altered Oligocene-Miocene rhyolite domes and tuffs in the Taylor Creek district, Sierra County (Maxwell et al., 1986; Eggleston and Norman, 1986): miarolitic cavities within rhyolite, thin veins and veinlets cutting rhyolite, disseminations in rhyolite, and placer deposits in streams and alluvial deposits adjacent to rhyolite domes and flows.

Rio Grande Rift deposits (RGR)

Rio Grande Rift barite-fluorite-galena (±Ag, Cu) (RGR) deposits are found throughout New Mexico (McLemore et al., 1998) and were formerly called sedimentary-hydrothermal deposits (North and McLemore, 1986, 1988) or Mississippi Valley-type deposits (Putnam et al., 1983). These deposits are low-temperature, open-space fillings with little or no replacement and are not obviously associated with any magmatic activity (Fig. 16). RGR deposits in New Mexico are predominantly barite-fluorite-galena deposits, although locally they may contain significant amounts of silver, copper, and zinc. Vanadium and molybdenum minerals are found in some deposits, such as those at Palomas Gap in the Caballo Mountains, Sierra County. Although gold is rare in these deposits, small amounts have been recovered from a few deposits in New Mexico (i.e. Hansonburg, Florida Mountains). Gold rarely exceeds 0.02 oz/short ton, whereas a few deposits may contain as much as 0.8 oz/short ton Ag.

FIGURE 16. Rio Grande Rift deposits (from McLemore and Lueth, 1996).

The deposits are typically in Paleozoic carbonate rocks as veins, breccia cements, cavity-fillings, and minor replacement bodies (i.e. Hansonburg, Salinas Peak; Kottlowski and Steensma, 1979; Smith, 1981; McLemore, 1994b). Locally, RGR deposits occur along faults, fractures, contact zones, shear zones, bedding planes, and solution cavities in Proterozoic, Paleozoic, and Tertiary rocks of varying lithologies. RGR deposits are widespread within or near the Rio Grande rift (van Alstine, 1976; McLemore and Barker, 1985; McLemore and Lueth, 1996; McLemore et al, 1998).

Most RGR deposits are found in structurally high bedrock (pre-Tertiary) adjacent to clastic-filled rift basins (McLemore et al., 1998). For many of these deposits, geohydrologic evidence and host lithology would suggest that RGR deposits are either pre-Tertiary or concurrent with rifting and basin development, but before host terrains were uplifted above a regional water table. However, previous workers have assigned these deposits to the mid-Tertiary (Allmendinger, 1974, 1975; Beane, 1974; Ewing, 1979; Putnam et al., 1983). More recent studies (McMahon, 1989;

Lueth and Goodell, 1996; Lueth et al., 1998; Goodell et al., 1997; Lueth and Heizler, 1997; Kelley et al., 1997) suggest that mineralization began as early as Middle Miocene and extended to Late Miocene-Early Pliocene (McLemore et al., 1998, table 5). These age determinations and field relationships suggest that RGR deposits formed during the last 12 Ma coincident with the later stages of rifting in central New Mexico. From Early Pliocene to the present, hydrothermal systems in the RGR have deposited minor amounts of barite, fluorite, sulfide, and manganese.

Most RGR deposits in New Mexico are small, typically less than a few thousand short tons of ore. Widths range as much as tens of feet and some deposits can be traced along strike for several thousand feet. The Hansonburg deposits are much larger and consist of subequal amounts of barite, fluorite, and galena. Locally, some deposits elsewhere in New Mexico contain pockets or zones of high-grade barite, fluorite, or lead-silver ore that were selectively mined in the past.

These deposits are similar to Mississippi Valley-type (MVT) deposits and were formed by low-temperature basin brines that were ejected along fractures, faults, and unconformities during early diagenesis or later compaction of sedimentary basins (Hanor, 1979; Ohle, 1980; Sangster, 1983; McLemore and Barker, 1985; Hill, 1994). The formation waters or basin brines accumulated in local sedimentary basins, possibly of varying age, and were heated by high heat-flow, magmatic activity, or radiogenetic heat from Proterozoic plutons. The warm convecting waters leached barium, sulfate, silver, and other ions from source rocks such as arkosic sediments, evaporites, Proterozoic rocks, and Proterozoic mineral deposits. In central New Mexico, these basins are continental instead of marine as in the classic Mississippi Valley area. The mineralized waters were ejected along open-spaces such as faults and fractures. Precipitation occurred as a result of cooling of the fluids, decrease in pressure, and/or mixing of the mineralized hydrothermal fluids with subsurface brines or meteoric water. Most of these deposits are too small to be exploited for barite, fluorite, or lead. If any were to be mined for barite, fluorite, or lead; silver could be recovered as a byproduct.

Vein and replacement deposits in Proterozoic rocks

Vein and replacement deposits containing base and precious metals occur sporadically throughout most of the Proterozoic terranes in New Mexico. However, production of metals has been limited from most districts. In addition, evidence suggests that Proterozoic deposits may be a significant source for younger deposits (LaPoint, 1976, 1979, 1989; Fulp and Woodward, 1990).

Base and precious metals occur in several types of deposits in Proterozoic terranes in New Mexico. Gold, silver, and copper are found in lenticular quartz veins along shear zones in Proterozoic greenstones in the Hell Canyon and Tijeras Canyon districts in central New Mexico. Silver with some gold and copper occurs in quartz veins along shear zones in Proterozoic granite and metamorphic rocks in the Zuni Mountains district, Cibola County (McLemore, 1989). Free gold occurs with quartz in several districts, most notably the Hopewell district. Copper minerals with gold and silver concentrations occur in shear zones and as disseminations in granitic and mafic rocks in many districts (i.e. Zuni Mountains, Pedernal Hills, Lemitar Mountains). Veins and small replacement bodies containing copper, gold, silver, tungsten, and bismuth are found along faults, fractures, shear zones, and contact zones within Proterozoic granitic and metamorphic rocks in the Grandview-Sulfur Canyons district (McLemore, 1994b).

The age of mineralization is uncertain in most districts. Many of these deposits are structurally controlled by schistosity or shear zones of Proterozoic age and are, therefore, syn- or post-metamorphic (Zuni Mountains, Grandview-Sulfur Canyons; McLemore, 1989, 1994b). Many vein and replacement deposits in Proterozoic rocks are associated with quartz veins, also presumed to be Proterozoic in age. In many districts, there is a strong spatial association of precious-metal veins with diabase or mafic dikes of presumed late Proterozoic age (Black Mountain, Glorieta, Grandview-Sulfur Canyon: Dunham, 1935; McLemore, 1994b; McLemore et al., 1996). Although the age of mineralization is uncertain in most of these districts, it is apparent that multiple periods of mineralization probably occurred and detailed geologic and geochronologic studies are needed to constrain the timing of mineralization. Most of the precious-metal deposits in Proterozoic terranes are small, low grade, and uneconomic.

REE-Th-U veins in alkaline rocks

REE-Th-U (±Nb) veins in alkaline rocks occur as spotty, discontinuous tabular bodies, narrow lenses, and breccia zones along faults, fractures, and shear zones. They typically vary from a few feet to 1,000 ft long and less than 10 ft wide and are of variable grade. The mineralogy of known deposits in New Mexico is poorly defined, but brookite, crandallite, xenotime, bastnaesite, allanite, eudialyte, monazite, and microlite are some of the more common minerals reported (McLemore, et al., 1988a, b). The host rocks are alkaline and vary in composition from trachyte, alaskite, nepheline syenite, syenite, diorite, alkali granite, and carbonatite. They are found at Laughlin Peak, Gallinas Mountains, Capitan Mountains, Cornudas Mountains, Caballo Mountains, Zuni Mountains, and Bromide district (McLemore et al., 1988a, b). The veins found in the Caballo Mountains district are probably Cambrian-

Ordovician in age, whereas the remaining deposits are mid-Tertiary in age and described as Great Plain Margin deposits. Similar alkaline rocks are found in the Florida Mountains, but no deposits have been found to date.

Sedimentary-copper deposits

Stratabound, sedimentary-copper deposits containing copper, silver, and locally gold, lead, zinc, uranium, vanadium, and molybdenum occur throughout New Mexico. These deposits also have been called "red-bed" or "sandstone" copper deposits by previous workers (Soulé, 1956; Phillips, 1960; Cox and Singer, 1986, #30b). They typically occur in bleached gray, pink, green, or tan sandstones, siltstones, shales, and limestones within or marginal to typical thick red-bed sequences of red, brown, purple, or yellow sedimentary rocks deposited in fluvial, deltaic, or marginal-marine environments of Pennsylvanian, Permian, or Triassic age. The majority of sedimentary-copper deposits in New Mexico occur at or near the base of these sediments; some deposits such as those in the Zuni Mountains and Nacimiento districts, are in sedimentary rocks that unconformably overlie mineralized Proterozoic granitic rocks.

The mineralized bodies typically are found as lenses or blankets of disseminated and/or fracture coatings of copper minerals, predominantly chalcopyrite, chalcocite, malachite, azurite, along with numerous other copper minerals. The deposits in New Mexico range in size from 3 to 60 ft thick and as much as several thousand feet long. Copper mineralization is dominant with some deposits containing up to 40–50% Cu. Silver averages about 0.5 oz/short ton (17 ppm) and typically increases with increasing copper concentrations. Gold is rare in these deposits. Some deposits in the Sacramento district are predominantly lead bearing with subordinate copper and silver. Other deposits, such as some in the Tularosa and Sabinoso districts, are predominantly uranium and vanadium bearing.

The sedimentary-copper deposits are typically associated with organic debris and other carbonaceous material. Locally, sedimentary features such as bedding, crossbedding, paleochannels, and intraformational slumping also appear to control mineralization. Local structures in some areas also are important mineralization controls, such as anticlinal folds in the Tecolote district and a shallow synclinal fold or structural depression at the Stauber deposit in the Pastura district.

The deposits range in size from small occurrences containing less than a short ton of ore (Black Mesa) to large deposits containing several hundred thousand short tons of ore (Stauber in the Pastura district). Most deposits were mined by open-pit methods, although underground methods were employed locally in many districts. In-situ leaching of the copper deposits was proposed and initiated at the Nacimiento mine in Sandoval County, but the operation was not successful.

Copper and other metals were probably transported in low-temperature solutions through permeable sediments, along bedding planes, and faults shortly after burial. Replacement textures and diagenic features of the organic material indicate mineralization occurred during or after diagenesis. Oxidizing waters could have leached copper and other metals from (1) Proterozoic rocks enriched in these metals, (2) Proterozoic base-metal deposits, and (3) clay minerals and detrital grains within the red-bed sequences (La Point, 1976, 1979, 1989; Brown, 1984). Sources for chloride and carbonate needed to form soluble cuprous-chloride or cuprous-carbonate and other metal complexes (Rose, 1976) occur in older Paleozoic evaporite and carbonate sequences. Metal-bearing waters moved laterally through the aquifers from Proterozoic highlands or, in some cases, by circulating, ascending fluids (Brown, 1984). Geologic, mineralogic, and isotopic studies of similar deposits elsewhere in the U. S. suggest that these waters are in approximate chemical equilibrium with quartz, feldspar, hematite, and mica at temperatures less than 75°C (Rose, 1976). Precipitation occurred at favorable oxidation-reduction interfaces in the presence of organic material or H_2S-rich waters. Subsequent ground water, igneous intrusive rocks (such as at Sacramento), and structural events may modify, alter, or even destroy some deposits (La Point, 1979).

Most deposits are low grade, low tonnage, and inaccessible to existing mills for current development for copper. They are generally low in silica and are not suitable as silica flux material. Production from the Pastura district amounts to 13.6 million lbs Cu, 42,492 oz Ag, and 58,723 lbs Pb. Production from the Naciemento district amounts to 7.7 million lbs Cu, 76,000 oz Ag, 1,783 lbs Pb, and 463 lbs Zn. The Nacimiento mine contains 6 million short tons of ore at a grade of 0.56% Cu and 13 million short tons of ore at a grade of 0.48% Cu as of 5/2/80. An in-situ leach project has been proposed for the deposit, but poor recovery and a depressed economy have hampered the project for years.

Industrial Minerals

An industrial mineral is defined as “any rock, mineral or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels, and gemstones; one of the nonmetallics” (Bates and Jackson, 1980).

Alunite

Alunite is a potential source of aluminum and has been mined in several places in the world for its aluminum content (Hall, 1978; Hall and Bauer, 1983). Nearly all of the aluminum used in the U. S. comes from foreign sources, primarily from bauxite deposits (U. S. Bureau of Mines, 1992). During World War I, alunite was used as a source of potassium fertilizer. In the 1960s, the Soviet Union produced alunite for its aluminum content; potassium sulfate and sulfuric acid were recovered as by products (Hall and Bauer, 1983). Alunite is one end member of a series of sulfates that occur in several geologic environments, all of which require base leaching of the host rock by acidic fluids. Minerals of the alunite group have the general composition $AB_3 (SO_3)_2 (OH)_3$ where A is typically K^+, Na^+, Pb^{++}, NH^{4+}, or Ag^+ and B is typically Al^{+3} or Fe^{+3} (Brophy et al., 1962). Nine of the more common species are (Brophy et al., 1962; Altaner et al., 1988):

Alunite—$KAl_3 (SO_4)_2 (OH)_6$
Natroalunite—$NaAl_3 (SO_4)_2 (OH)_3$
Ammonioalunite—$NH_4 Al_3 (SO_4)_2 (OH)_6$
Jarosite—$KFe_3 (SO_4)_2 (OH)_6$
Natrojarosite—$NaFe_3 (SO_4)_2 (OH)_6$
Ammoniojarosite—$NH_4 Fe_3 (SO_4)_2 (OH)_6$
Argentojarosite—$AgFe_3 (SO_4)_2 (OH)_6$
Plumbojarosite—$PbFe_6 (SO_4)_2 (OH)_6$

Solid solution between the species is common.

Alunite is found in one area in Luna County, the Old Hadley district where it is associated with volcanic-epithermal vein deposits (McLemore et al., 1996). Alunite typically occurs with a variety of minerals including quartz, kaolinite, jarosite, pyrophyllite, and iron oxides. Pure alunite deposits are not found in New Mexico. However, local zones contain as much as 30% alunite in the Alum Mountain and Steeple Rock districts (Hall, 1978). Age determinations of alunite suggest two periods of formation: alunite associated with volcanic-epithermal veins is between 28 and 33 Ma (McLemore, 1996c); alunite associated with supergene alteration of porphyry copper deposits is 46.5, 39.5, 25.4, 16–19, and 8.4 Ma (Cook, 1993; McLemore, 1996c; S. S. Cook, personal commun., October 1994). The latter period suggests at least five supergene events.

Barite and fluorite

Barite and fluorite are minerals that typically are found together. Barite ($BaSO_4$) is a relatively heavy mineral (specific gravity of 4.5) and can be colorless, blue, yellow, brown, or red. Barite is used primarily as a weighting agent in petroleum-well fluids, because of its high specific gravity. Minor uses include as ingredient in paint, rubber, glass, other applications such as filler, and in barium chemicals. Barite also is used to line the intestines when conducting X-rays. Barite also is used as an aggregate in heavy cement.

Fluorite (CaF_2) is the principal fluorine-bearing mineral and is almost any color, but more commonly it is clear, yellow, green, purple, lilac, pink, black, and white. The principal use of fluorite has been for the production of hydrofluoric acid, an essential raw material in the manufacture of synthetic cryolite and aluminum fluoride for the aluminum industry, and in many other applications in the chemical industry. Fluorite is used to manufacture a variety of products such as insulating foams, steel, refrigerants, and uranium fuel (Miller, 1997). In 1995, the last fluorspar mine operating in the U. S. closed, after 158 years of fluorspar production in the country. Fluorspar is imported from China, South Africa, and Mexico (Miller, 1997).

Rothrock et al. (1946), Williams (1966), McAnulty (1978), McLemore and Barker (1985), and McLemore et al. (1998) described barite and fluorite deposits in New Mexico. Barite and fluorite occur in RGR, epithermal deposits, and veins and replacements in Proterozoic rocks throughout New Mexico, including Luna County (Table 12). Most of these deposits are small and uneconomic. Epithermal fluorite deposits also are locally associated with topaz-rhyolites and alkaline rocks (Burt and Sheridan, 1987; Wooley, 1987).

Clay

Clay is a very fine-grained material composed of one or more of a group of crystalline minerals known collectively as the clay minerals. Clay minerals are hydrous silicates mainly of silica, alumina, and water; clay minerals also may contain significant amounts of the alkali metals, alkaline earths, and iron. As mineral commodities, clay can be classified into several distinct groups. Clay commodities are subdivided into common clay and specialty clays, such as bentonite, kaolin, and hormites (Murray, 1991).

Two types of clay are found in Luna County: common and kaolin or fire clay. Common clay is used for making bricks, roofing granules, quarry tile, and portland cement and also is used in pottery and as filler in paint. Commercial adobe yards are mostly in northern New Mexico and produce adobe bricks from local alluvial materials. One adobe plant operated in Deming in 1980 (Smith, 1981), but is now closed. A small quantity of bricks were made from clay deposits in Luna County prior to 1937 (Talmage and Wootton, 1937).

Kaolin is a near-white clay deposit that consists of mostly kaolinite and has many industrial applications, including uses as fillers, coating agents, extenders, binders, whiteners, and in ceramics. A light-colored clay, probably kaolin, was mined about 1963 from a quarry in the Little Florida Mountains and mixed with other clays to produce a heavy clay product. New Mexico ranked 6^{th} in production of fire clay out of six states in 1999; production amounted to 1,100 short tons (Virta, 2000). Fire clay or refractory clay is quarried from Luna and Grant Counties for use in the copper smelters. At the Lucretia clay pit (Franklin) at Taylor Mountain, fire clay was mined from 1979 to the present. Fire clay also is reported in the Spalding area (Appendix 2).

Crushed stone

Crushed stone is one of the most accessible natural resources and is a major basic raw material used by construction, agriculture, and other industries. Despite the low value of its basic products, the crushed stone industry is a major contributor to and an indicator of the economic well being of any city, county, state, or country. Crushed stone is quarried throughout New Mexico and is used in concrete aggregate, bituminous aggregate, roadstone and coverings, riprap, railroad ballast, and other construction uses (Tepordei, 2000). The most common lithologies include basalt, granite, limestone, sandstone, shale, scoria, and volcanic cinder.

Granite

Commercial granites include all feldspathic crystalline rocks of interlocking grains and with individual mineral crystals that are visible to the naked eye and include rock types such as anorthosite, gneiss, granite, granodiorite, monzonite, syenite, and all other intermediate rock types. Primary colors are gray, pink, red, and white with brown and green being secondary colors. Most of the granitic rocks in Luna County are Proterozoic or Mid-Tertiary (Fig. 4). The Proterozoic rocks typically are too altered, weathered, and fractured to be used as crushed rock or dimension stone. The Mid-Tertiary intrusive rocks typically form the cores of many mountains in Luna County and could be used for crushed and dimension stone.

Rhyolite

Rhyolite is a light-colored rock with silica (SiO_2) content greater than 68 weight percent. Common mineral constituents include quartz, feldspar, and biotite and are typically found in a glassy matrix. Rhyolite is erupted at temperatures of 700–850° C. Rhyolite is found in several areas (Red Mountain, Cooke's Peak) throughout Luna County and could be utilized for crushed stone.

Basalt

Commercial basalt and traprock includes dark-colored, fine-grained igneous rocks, and includes extrusive igneous rocks (such as andesite, basalt, or dacite) and intrusive igneous rocks (such as amphibolites, diabase, diorites, fine-grained gabbros, peridotites, and pyroxenites). The name traprock is derived from the term "trappa," meaning stairway—the characteristic terraced or steplike appearance of certain basalt lava fields.

Basaltic rocks have been erupted from widely scattered vents throughout southwestern New Mexico over the last 5 million years or so (Fig. 4). More than 150 cinder cones and associated basaltic flows form the Potrillo volcanic field (Aden district) in western Doña Ana and eastern Luna Counties. The Deming flow in Fort Cummings Draw (Cooke's Range) and the flows near Columbus, including Pancho Villa, consists of basalt. Pliocene cones also are found in the southern Tres Hermanas Mountains north of Columbus. Basalt is found at Black Mountain, northeast of Deming, and south of the Florida Mountains. Basalt also is common in the Goodsight Mountains and Uvas Valley. Most of these localities could be used for crushed stone.

Limestone/dolostone/marble

Limestone is a sedimentary carbonate rock composed of 50% or more calcite or aragonite (both forms of $CaCO_3$). Dolostone (sometimes called dolomite, a term, which should be used exclusively to refer to the mineral) is a similar rock composed predominantly of dolomite, $CaMg(CO_3)_2$. Limestone and dolostone recrystallized by heat and pressure are both called marble. Limestone and dolostone are widespread throughout Luna County (Fig. 4; Kottlowski, 1962; Kottlowski and Armstrong, 1996) and are found in most mountain ranges. Limestone is typically crushed and used as an aggregate or in cement.

Scoria

Scoria and pumice are pyroclastic deposits formed as volcanic fragments ejected during explosive volcanic eruptions. Scoria or volcanic cinder is red to black to gray, vesicular, basaltic fragments. Most scoria occurs as loose and poorly consolidated fragments found in poor- to well-sorted cones or mounds (Osburn, 1979, 1982; Cima, 1978; Peterson and Mason, 1983; Geitgey, 1994). Scoria is quarried by digging and ripping with tractors and rippers, stockpiled, and then crushed and screened (Osburn, 1982). Most cinder cones contain approximately 75% scoria (Cima, 1978; Osburn, 1979, 1982). Scoria is denser and more coarsely vesicular than pumice (Peterson and Mason, 1983), which is typically light in color, vesicular, and of dacitic to rhyolitic composition (Geitgey, 1994).

Scoria (volcanic cinder) and pumice (pumicite) are distinct types of pyroclastic deposits formed as volcanic fragments ejected during explosive volcanic eruptions. Both are vesicular, but scoria is denser and more coarsely cellular (vesicles are larger) than most pumice (Peterson and Mason, 1983). The vesicular nature of scoria and pumice results in lower density and higher porosity than most rock types. These properties result in commercial use as lightweight aggregates, insulators, absorbents, and abrasives (Geitgey, 1994; Harben and Bates, 1984). Scoria typically has a higher crushing strength than pumice and is more desirable for certain aggregate uses. Scoria is red, black, or gray, and of basaltic composition (50–60% SiO_2). Most scoria deposits are poorly consolidated, poorly to well-sorted and stratified cones or mounds (Geitgey, 1994; Peterson and Mason, 1983; Osburn, 1979, 1982; Cima, 1978). Ejected material ranges in size from volcanic ash or cinder and scoria with particle diameters ranging to 100 mm to smooth-sided volcanic bombs and angular blocks with diameters in excess of 100 mm. The morphology of the cinder cone or volcano is important in determining the economic viability of potential scoria deposits. The aspect ratio (Osburn, 1979, 1982) is the ratio of the height of the cinder cone or volcano to its average basal diameter. Most economic deposits occur within cones with aspect ratios between 0.1 and 0.2 (Osburn, 1982). Cones with lower aspect ratios (<0.1) tend to have thick, lava flows undesirable for mining; those with higher aspect ratios (>0.2) tend to consist of large amounts of agglutinate (scoria blocks welded to dense lava blocks) and approach spatter cones. Agglutinate deposits require blasting, increasing production costs. Economic considerations of a scoria deposit include its color, grain size, sorting, density, and consolidation.

Most scoria in New Mexico is used to manufacture cinder block and concrete. Some scoria also is used as a decorative stone for landscaping. Use in landscaping depends on select size and color (reddish-brown is most popular). Cinders are used on highways during winter storms to improve traction and on steep slopes to control erosion. Scoria typically has a higher crushing strength than pumice, making it more desirable for certain aggregate uses. In the 1950s, scoria was used as railroad ballast and road aggregate. Other applications include uses in the roofing industry. Scoria is typically a low-cost commodity that is sold locally. In southern New Mexico, most scoria is utilized in the Las Cruces and El Paso areas.

Sandstone

Commercial sandstone is a lithified sand composed chiefly of quartz and/or feldspar of fragmental (clastic) texture and includes arkose (abundant feldspar grains), conglomerates, and graywacke (abundant rock fragments). Sandstone contains interstitial cementing materials such as calcite, clay, iron oxides, or silica. Sandstone is found throughout Luna County and much of it could be used as crushed stone.

Dimension stone

Dimension stone is a natural rock material quarried for the purpose of obtaining blocks or slabs that meet specifications as to size (width, length, thickness), hardness, and shape. Color, grain texture and pattern, and surface finish of the stone are typical requirements. Durability (essentially based on mineral composition and hardness and past performance), strength, and the ability of the stone to take a polish are other important selection criteria locally. Dimension stone is used primarily in blocks, building construction, monuments, curbing, and rubble. Dimension stone may be quarried in large blocks that are later cut for final finishing, or it may be sold in natural or broken pieces that remain unfinished. Dimension stone mainly is used in the construction of buildings, monuments, civil structures, and in landscaping. In general, commercial dimension stone comes from production from deposits of durable rock that contains few fractures.

The average 1999 value for dimension stone produced in New Mexico was $204 per metric ton—an increase of 3.6% from that of 1998 (Dolley, 2000). The average unit values for different types of dimension stone throughout the U. S. were granite, $263 per ton; limestone, $168 per ton; sandstone, $132 per ton; marble, $237 per ton; and slate, $490 per ton. Available price data show considerable variation, not only for the type of stone, but also for appearance of the same type of stone. Color, grain structure, and finish contribute significantly to price and marketability (Dolley, 2000).

Granite

Most of the granitic rocks in Luna County are Proterozoic or mid-Tertiary (Fig. 4). The Proterozoic rocks typically are too altered, weathered, and fractured to be used as crushed rock or dimension stone. The mid-Tertiary intrusive rocks typically form the cores of many mountains in Luna County and could be used for crushed and dimension stone.

Limestone/dolostone

Limestone and dolostone are widespread throughout Luna County (Fig. 4; Kottlowski, 1962; Kottlowski and Armstrong, 1996) and are found in most mountain ranges.

Travertine

Travertine is a carbonate rock similar to limestone that is deposited by warm or cold bicarbonate-waters, mainly from springs. Varieties of travertine also are known as tufa, calcareous sinter, marble, Mexican onyx, or onyx marble (Austin and Barker, 1998). Travertine occur in several areas in the southern Tres Hermanas Mountains (Griswold, 1961; Barker et al., 1996). The deposits consist of thick veins of calcite, locally slightly radioactive and fluorescent (Northrop and LaBruzza, 1996), that are hosted by latite (Fig. 17). Two stages of deposition are found: an early onyx stage followed by brecciation and later massive calcite cement and vein filling. The onyx is white to light cream to honey yellow and is cemented by white to colorless calcite. Banded varieties, botryoidal masses, and dog-tooth crystals are common locally. Some deposits are as wide as 5 ft or more. These deposits were probably formed by low-temperature springs. Material is quarried, cut, and polished for decorative stone and ornaments. The Tres Hermanas Onyx Co. quarried onyx for lamp bases. Travertine or onyx deposits also form thin veins at Mine Hill in the Victrio district (Griswold, 1961) and at Goat Ridge (Barker et al., 1996). Thin beds of travertine also are found in the Burdick-Bisbee Hills (Seager, 1995).

FIGURE 17. Travertine, southern Tres Hermanas Mountains (V. T. McLemore photo).

Marble

Marble is found in the Tres Hermanas and Victorio Mountains and forms small outcrops of coarsely to medium crystalline texture and white to mottled white and gray color. These occurrences are formed by contact metamorphism of limestone adjacent to igneous intrusions or within the outer zones (Fig. 13). Most of these occurrences are fractured, irregular in texture, and small in size.

Sandstone

. Sandstone is found throughout Luna County and much of it could be used as dimension stone. The quartz sandstone of the Sarten Sandstone (Majado Formation) was quarried near Fluorite Ridge and used in constructing the courthouse in Deming. The Sarten Sandstone is medium to thick bedded, medium to coarse grained, and of a consistent texture.

Garnet

Garnets are a group of silicate minerals common to skarns and igneous rocks and is the general name for a group of complex silicate minerals with similar crystalline structures and diverse chemical compositions. The general chemical formula is $A_3B_2(SiO_4)_3$, where A can be calcium, magnesium, ferrous iron, or manganese and B can be aluminum, chromium, ferric iron, or rarely, titanium. Angular fractures, high hardness, and an ability to be recycled characterize industrial garnet. The complex mineralogy of garnet determines its utility for a variety of uses, including water filtration, waterjet cutting, abrasive, in sand blasting media, and water filtration. Garnet deposits must be large enough to sustain production for 10–20 years, contain the right type and size of garnet for the end-user, be easily and inexpensively processed, and be close to markets and/or transportation routes. The U. S. produces approximately one-third of the world's production of garnets; in 1996, six companies produced 68,200 tons of crude garnet from mines in the U. S. (Balazik, 1997). Although garnet has not been produced in New Mexico in 1998–2000, at least one company is examining areas in the state for potential resources for uses as an abrasive. Garnet typically is found in skarn deposits in southern and central New Mexico and in some areas, garnet is a major constituent of waste rock piles remaining after recovery of metals (Lueth, 1996). For example, approximately 149,000 short tons of 20–36% garnet is estimated to occur in four tailings piles at Hanover (Cetin et al., 1996). Average values for crude garnet concentrates ranged from approximately $55 to $120 per ton in 1999 (Olson, 2000).

In Luna County, garnet is found in the Victorio and Tres Hermanas districts. The garnet occurrences in Luna County are small and consist of massive, not crystalline garnet.

Gems, semi-precious stones, and mineral collecting

Gemstones and semi-precious stones produced in Luna County include geodes, agate, fluorite, onyx, and smithsonite. Production statistics for 1998–2000 are withheld for gemstones and semi-precious stones in New Mexico; many non-commercial collectors do not report their income. In 1993, the value of gemstone production state-wide was $22,000 and the average over the previous five years was approximately $76,000, mostly from turquoise (Austin, 1994). However, depletion of the known deposits and difficulty in and expense of adhering to federal, state, and local environmental regulations have closed most of the commercial mines.

Agate, jasper, chert, and petrified wood (all varieties of quartz) are found in many different geological settings in 15 counties throughout New Mexico, including Luna County (Fig. 18, 19). Rockhound State Park is set aside for non-commercial collecting of gray perlite, thundereggs, geodes, jasper, onyx, agate, crystalline rhyolite, Apache tears (obsidian), and quartz crystals (McLemore and Dunbar, 2000). Mining claims in Luna County remain active and commercial mining occurs periodically. Agate from Luna County wholesaled for $50.00 per 100 pounds and retailed at $1.00 per pound. "Picture" and dendritic jasper are found south of Gage in Luna County. The dendritic-type jaspers in these deposits are sold for $1–12.

FIGURE 18. Geodes and agate in Luna County.

FIGURE 19. A cut and polished face of a thunderegg from the Baker Egg mine showing two amethyst quartz-plugged fill-tubes (from Colburn, 1999).

Geodes are found throughout southern New Mexico, including Luna County (Colburn, 1999). “Geodes” are hollow or near-hollow, crystal-lined cavities found in igneous and sedimentary rocks. “Thundereggs”, also known as spherulites, are solid or near-solid nodules formed by magmatic and volcanic processes and are found only in volcanic rocks. Many thundereggs found in southern New Mexico are spherical and consist of two distinct parts: a dark-gray to pinkish outer part, and a white, blue, or gray inner part, or core, which is recognizable as agate, chalcedony, and quartz crystals, all forms of the compound SiO_2. Some thundereggs, or spherulites, do not contain the filling; they are composed of solid dark-gray to pinkish shell material or can be partly hollow. Geologically distinct processes form the two parts of the thundereggs. Complex magmatic processes (i.e.forming spherulites) form the outer part of the thundereggs, and then the inner part is formed and modified by multiple cycles of late-stage hydrothermal and meteoric fluids. The agate, chalcedony, and quartz veins and open-space-fillings within voids in the spherulites formed later by multiple cycles of hydrothermal and/or meteoric fluids (Colburn, 1999; McLemore and Dunbar, 2000). The high-grade rough (uncut) thundereggs wholesale for $8 per pound and select cut specimens range as high as several hundred dollars.

Dumortierite, an aluminium borosilicate, is found in the Tres Hermanas Mountains as a transulucent, blue fibrous to columnar aggregates in quartz veins. The veins are less than one inch wide. Selected pieces were cut and polished as decorative stones.

Spurrite, a pale gray to purple silicate and carbonate mineral, is found on South Sister Peak in the Tres Hermanas Mountains. The original deposit was 20 ft long and up to 5 ft wide. Selected pieces were cut and polished as decorative stones. Other minerals are collected on a small scale from most mining districts in Luna County, but total production is unknown.

Limestone/dolostone/travertine/marble

Limestone, dolostone, travertine, and marble typically have many additional uses besides crushed and dimension stone, as previously discussed. Additional uses of limestone, dolostone, travertine, and marble are dependent upon the physical and chemical characteristics, which are a result of the environment of deposition and tectonic history. Variable mixtures of calcite, dolomite, and other carbonate minerals occur in many formations, and most limestone and dolostone contain impurities, most commonly clay, chert, and organic matter.

The long-term demand for limestone and dolostone is expected to grow at an annual rate of approximately 2.0–2.5% (Carr and others, 1994). Demand could be stimulated by the need for limestone and lime for flue gas desulfurization based on the 1990 Clean Air Act Amendment. The long-term outlook for cement consumption is one of steady but moderate growth. The domestic portland cement industry grew 5.6% in 1996 (production + imports) and prices rose again on top of the 11% increase in 1994–1995 (MacFadyen, 1997). Over 90% of production was Types I and II gray portland cement. Demand and prices should be firm in the near future, although capacity increases planned over the next 2–4 years could soften them (MacFadyen, 1997).

Prices for limestone, dolostone, lime products, and cement depend substantially on the grade of limestone and dolostone, or lime, or the specific product requirements. Crushed limestone for aggregate uses and agricultural applications is generally priced at $4 to $10 per mt (Harben, 1995). The prices for fillers ranges from $40 per mt for coarse filler and $292 per mt for ultrafine fillers (Harben, 1995). Grades for cement powder also may vary considerably, but Solomon (1995) gives an average domestic price for portland cement in 1994 at about $60 per mt. The average price in 1995 was $66.89 per mt for portland cement, $85.64 per mt for masonry cement and $174.66 per mt for white portland cement (MacFadyen, 1997). Regional price differences are evident across the U. S.

Cement

Limestone, dolostone, travertine, and marble typically are the main ingredient in the manufacture of cement and concrete and most cement plants are near large deposits. Economical limestone for cement contains $CaCO_3$ contents greater than 70–75%. Raw materials for cement making are typically untreated prior to use. Cement consists of four main oxide constituents (approximately 90%) that are mixed in various proportions rather than as a precise chemical formula. Limestone is the most common source of calcium (CaO), shale or clay provide silica (SiO_2) and alumina (Al_2O_3), and iron minerals (Fe_2O_3), usually hematite or magnetite, are all added to portland cement. The remaining 10% consists of minor oxides and trace materials of which gypsum ($CaSO_4 \cdot ½H_2O$) is the most important, because it is added up to a few percent to retard setting. Magnesium is generally the most critical impurity, so $MgCO_3$, primarily dolomite, is limited to about 5 wt.% in any raw cement mix. The American Society of Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) requires that the magnesium oxide (MgO) content in portland cement not exceed 6% or 12.6% $MgCO_3$ (Ames et al., 1994). Contents of other elements, particularly Na, K, P, Mn, S, and F also play critical roles in the selection of limestone for cement.

The raw ingredients for cement are crushed and ground then passed through a high-temperature rotating kiln where chemical reactions produce cement clinker. The clinker is mixed with various materials depending on the type of cement and ground in a ball mill to fine powder for sale. Cement is sold in a wide variety of formulations categorized into five main types developed by Kosmatka and Panarese (1988) and summarized in Austin and Barker (1998):

Type I—Cement qualified for a wide range of uses, mainly in construction when neither sulfate attack nor high heat of hydration is considered a problem.

Type II—Cement qualified for general construction that requires moderate resistance to sulfates and moderate heat of hydration. It is used in structures of considerable mass, such as large piers, heavy abutments, and retaining walls. Type II cement has better workability and lower permeability than Type I due to its finer ground particles. Its use will reduce temperature rise, which is especially important when concrete is placed in warm weather.

Type III—Cement developed for high early-strength uses, such as in the production of cinder blocks and shotcrete, in concrete placed in cold weather, and quick reuse of framework forms. It is chemically and physically similar to Type I, except that its particles are ground finer.

Type IV—Cement developed for uses in which low heats of hydration are desired, as in massive structures such as dams, where thermal expansion must be kept to a minimum.

Type V—Cement developed for uses requiring high sulfate resistance and construction in or near seawater.

These five cement types are further modified or combined with other materials for more specialized uses.

White portland cement differs from other portland cement chiefly in that it hardens with a white color (Kosmatka and Panarese, 1988). Raw materials are selected so that the mixture has negligible amounts of iron and manganese, substances that give cement its gray color. White portland cement is used primarily for architectural purposes such as precast curtain walls and facing panels, terrazzo surfaces, stucco, cement paint, tile grout, and decorative concrete.

The sole cement producer in New Mexico is Rio Grande Portland Cement, supplying about 500,000 mt per year of cement from its Tijeras plant near Albuquerque to markets in New Mexico and southern Colorado. Limestone raw material for this operation is the Mississippian Madera Limestone that is mined nearby. There is no cement production in El Paso, but Cementos de Chihuahua has two plants in the Juarez area supplying cement to the El Paso market. The older Juarez plant is capable of producing about 500,000 mt annually. The newer Samalayuca plant is rated at 1.2 million mt. Cementos de Chihuahua also is the parent company of Rio Grande Portland Cement. Southdown, Inc., operates a cement plant at Odessa, Texas, about 250 mi east of El Paso, which has a rating of approximately 750,000 mt. These four cement plants produce almost all the cement needed in the New Mexico-west Texas area.

Lime

Lime is a major commodity used in chemical and industrial industries, manufacturing of steel, environmental industry, and construction. Limestone is calcined at temperatures of between 1,000° and 1,300°C to form lime (CaO). The suitability of a limestone or dolostone for calcination can only be tested under actual kiln conditions, and test results may depend upon factors such as kiln type and particle size. Limestone that is used to make lime must contain at least 97% $CaCO_3$ (Freas, 1994) and less than 1% SiO_2 (Harben, 1995).

Refractories

Calcined products also are produced from dolostone; dolime is prepared as a hydrated dolomitic lime and dead-burned dolostone is used as a refractory material.

Fillers and extenders

Carbonate fillers are produced from high-quality white limestone and dolostone. White carbonate fillers are produced by fine grinding, and range from coarse filler with a mean particle size of 9 to 17μm to ultra-fine filler at 0.5μm (Harben, 1995). Coarser non-white particles are used as asphalt fillers and extenders.

Agriculture

Limestone and dolostone are used in agriculture as a soil conditioner, to supply plant nutrients, as ingredients in certain animal feeds, and as poultry grit.

Other Uses

Limestone is used in glass making, but must contain at least 97.8% $CaCO_3$, less than 1.25% $MgCO_3$, and less than 0.095% Fe_2O_3 (Carr et al., 1994). Limestone and lime also are used extensively in the environmental industry for water and waste treatment and flue gas desulfurization.

Perlite

New Mexico ranks 1st in perlite production in the U. S. out of six states. Perlite is weathered (hydrated), natural glass that is formed by the rapid cooling of viscous, high-silica rhyolite lava. In New Mexico, perlite is found in high-silica rhyolite lava flows and lava domes that are typically 3.3–7.8 Ma (Chamberlin and Barker, 1996; Barker et al., 1996). The distinguishing feature of perlite from other volcanic glasses is that when heated above 1,600ºF, it expands or pops to four to 20 times its original volume to form lightweight, glass foam. This expansion is due to the presence of 2–6% combined water in the mined perlite. This expansion also results in a white color. While the mined perlite may range from waxy to pearly, light gray to black or even brown, blue, or red; the color of expanded perlite ranges from snowy white to grayish white. Perlite is used in building construction products, horticultural aggregate, filter aid, fillers, and other uses. Perlite is produced from four mines in New Mexico (Chamberlin and Barker, 1996).

Pumice

New Mexico is the 2nd leading producing state of pumice in the U. S. and the majority of New Mexico production comes from deposits in the Jemez Mountains in northern New Mexico. Pumice is a light-colored, lightweight rhyolitic volcanic rock with a vesicular structure (Hoffer and Hoffer, 1994; Austin, 1994). The main use for pumice is as a lightweight aggregate in lightweight building blocks and assorted building products and as an abrasive. Other major applications for pumice and pumicite include abrasive, absorbent, concrete aggregate and admixture, filter aid, horticultural (including landscaping), and the stonewashing of denim. Coarse pumice, greater than 1.9 cm, is desirable for soaps (Hoffer and Hoffer, 1994). Although commercial pumice deposits have not been found in Luna County, pumice is found in the Sugarlump Tuff and Mimbres Peak Formation in the Cooke's Range just north of the county line (Elston, 1989; McIntosh et al., 1991; Hoffer and Hoffer, 1994) and similar deposits could occur in northern Luna County.

Silica

There are four types of silica that are considered economic: industrial sand and gravel, quartz crystals, special silica stone products, and tripoli. There is no potential for quartz crystals, special silica stone products, or tripoli in Luna County. Industrial sand and gravel also is known by a variety of terms, including silica, silica sand, and quartz sand, and basically includes sands and gravels and sandstones with high SiO_2 content. These sands are used in glassmaking; for foundry, abrasive, ground silica as a filler and pigment extender, filtration sand, blasting sand, hydraulic fracturing applications, and for many other industrial uses. The specifications for each use vary, but silica resources for most uses are abundant. The economic deposit generally must be homogeneous and located close to the potential market and to transportation facilities. Silica as sandstone, shale, quartzite, clay, and claystone is used as an additive in the manufacture of cement and concrete. Health concerns about the use of silica as an abrasive and stricter legislative and regulatory measures concerning silica exposure could reduce demand in many silica markets.

Silica for flux is mined from two quarries near the copper smelter at Hurley. A silica flux mine also operated in the Little Hatchet Mountains near the Hidalgo smelter at Playas, but it closed when the Playas smelter closed in 1999. A silica flux mine in Luna County at Goat Ridge also has operated in the past, but is now closed.

Talc

Talc is a hydrous magnesium silicate mineral that is used commercially because of its fragrance retention, luster, purity, softness, whiteness, chemical inertness, high dielectric strength, high thermal conductivity, low electrical conductivity, and oil and grease adsorption. Major markets for talc are ceramics, paint, paper, and plastics where it used in a variety of products, including talcum powder, paint, paper, ceramics, cosmetics, plastics, roofing, rubber, and in the automotive industry as lubricants, body putty, and undercoating (Piniazkiewicz et al., 1994). Talc in Luna County is found in metamorphosed carbonate rocks adjacent to Mid-Tertiary intrusions in the Tres Hermanas and Victorio Mountains.

Zeolites

Zeolites are hydrated aluminosilicates of the alkaline and alkaline-earth metals. Approximately 40 natural zeolites have been identified during the past 200 years; the most common are analcime, chabazite, clinoptilolite, erionite, ferrierite, heulandite, laumontite, mordenite, and phillipsite. Zeolites are minerals found disseminated in altered volcanic ash and clinoptilolite is the predominant mineral in New Mexican deposits. Zeolites have unique physical, chemical, and cation exchange properties for uses in agriculture, industrial, and environmental applications. Markets include odor control and hygiene products (cat litter), industrial fillers and absorbents, filtration media, environmental products, animal feed supplements, soil conditioners, floor-drying agents, mineral fillers, water and wastewater treatment, air filtration media, and cation exchanged products.

St. Cloud Mining Co. (a subsidiary of The Goldfield Corporation) operates the largest zeolite mine in the U. S. at the Stone House mine in Sierra County. The company has operated the open-pit mine since 1990. The mining properties consist of approximately 1,500 acres and contains 18.3 million tons of reserves (The Goldfield Corporation, 2000). Clinoptilolite is found in the altered Tertiary tuff of Little Mineral Creek (White et al., 1996). Clinoptilolite is mined, crushed, dried, and sized without beneficiation and shipped packaged to meet customer's specifications.

Energy resources (except petroleum)

Uranium Resources

Uranium is an important energy source for electricity in nuclear power plants and in nuclear weapons. Production of uranium in New Mexico has been significant in the past (McLemore and Chenoweth, 1989), but the decline in demand forced all conventional uranium mines in the state to close in the early 1980s. The only uranium produced in New Mexico is from mine-water recovery at Ambrosia Lake. However, several companies are currently exploring for uranium in sandstones in the Grants uranium district (northwestern New Mexico) for possible in-situ leaching. Most uranium was produced from sandstone-uranium deposits of Jurassic age (McLemore and Chenoweth, 1989); similar sandstone-uranium deposits do not occur in Luna County. Other types of uranium deposits have been mined in the past from throughout New Mexico (McLemore and Chenoweth, 1989). Minor occurrences of uranium are found in Luna County, but none of these deposits yielded any uranium production.

Geothermal Resources

Geothermal resources occur where heat flow from the earth's interior is higher than normal. Heat can be transferred convectively or conductively. When water transports heat conductively, it is possible to harness the thermal energy as hydrothermal power. Convection of water is the result of heated water overcoming flow resistance and circulating freely. Differences in water-table elevation causes ground water to flow from high to low water levels. Hydraulic potential from the changes in water-table elevation can cause deeply circulating ground-water flow. This can transfer heat from deep levels to shallow reservoirs.

Southwestern New Mexico has geothermal potential due to shallow intrusions producing high-heat gradients and permeable rocks due to high degree of fracturing. Convective thermal zones are created by large variations in the water table coupled with large subsurface structures allowing water to flow.

Many authors have examined Luna County as part of regional geothermal studies, such as resources along ring-fracture zones of calderas (Elston, 1981; Elston et al., 1983). Other studies have examined the geothermal potential across the Rio Grande Rift valley including: Decker and Smithson (1975), Harder et al. (1980), Morgan et al (1981), Morgan et al (1986), Reiter et al (1975), Reiter et al (1978), and Seager (1975). Freeze and Witherspoon (1966), Freeze and Witherspoon (1967), and Summers (1976) studied characterized geothermal waters and ground-water flow throughout New Mexico. The University of New Mexico at Las Cruces also has conducted studies on the geothermal resources in New Mexico.

Southwestern New Mexico experienced three major geologic events that give this region a characteristic tectonic setting, which facilitate geothermal flow. The Laramide orogeny, mid-Tertiary Basin and Range extension, and late Tertiary rifting resulted in the region to become highly faulted, with deep alluvium-filled basins and a high degree of volcanism. Anomalous warm spring waters occur adjacent to drainages at lower elevations. In northern Luna County, the Mogollon-Datil volcanic field is the main source of high-heat flow in the region. Witcher (1988) shows a map of deep tertiary basins with conductive thermal sources. The physiographic setting of the thermal springs in this region suggests that forced convection is the predominate process for geothermal-water flow.

Conductive hydrothermal resources are found in late Tertiary basins. Temperature gradients in these basins typically range between 35°C/km and 45°C/km. Temperature gradients can reach up to 70°C/km over short possible intervals of less then 300 ft in the middle of the basins. Heat-flow values in the Mimbres basin are typically 60 to 110 mWm^{-2} and shallow geothermal gradients are typically 30 to 50°C/km (Swanberg, 1982). Typical water temperatures range between 26°C to 36°C from wells that are approximately 1,000 ft deep.

Convective sources are dynamic systems that can be difficult to completely model. Circulation, heat sources, and recharge sources for each spring and well may not be possible to characterize even after extensive study. Witcher (1988) complied a list of thermal springs and wells to compare the discharge site and productions zones for southern New Mexico and Arizona. The results indicate that convective systems are mostly restricted to Tertiary volcanisms, Paleozoic carbonate rocks, and Proterozoic plutonic and metamorphic rocks. Swanberg (1978, 1979, 1983) observed that the amounts of total dissolved solids and other water chemistry is related to the type of rocks the thermal waters flow through.

Convective systems discharge occurs most often over Laramide and older uplifts. Low-relief and sediment covered horst blocks, and ring-fracture zones of Tertiary calderas (Fig. 7) offer another setting for convective system discharge. This is due to the common characteristics of exposed faulted and fractured bedrock. Geohydrologic windows are areas where hydrothermal waters discharge. The geohydrologic windows are outcrops and suboutcrop areas where permeable rock is overlain by aquatards that have been eroded or tectonically removed. The structurally high, permeable bedrock at lower elevations allow geothermal waters to discharge through confining layers of Cenozoic and Mesozoic bedrock. Geohydrologic windows channel geothermal waters vertically and discharge into buried or low-relief horst blocks commonly. In areas effected by Laramide uplift of Tertiary ring-fracture calderas the confining layers are usually thin or non-existent. Fractured and discordant rhyolite-dacite dikes, plugs, and domes are ways of piercing confining layers.

Witcher (1988) complied a list of several factors that are associated with convective geothermal systems in southwestern New Mexico.

1. Mesozoic and Laramide uplift provide regions where aquatards are thin or absent.
2. Low elevations adjacent to regional drainages provide discharge sites for deep-seated regional ground-water flow system.
3. Mid-Tertiary caldera ring-fracture zones can provide favorable geologic settings for vertical ground-water flow.
4. Low-relief and buried late-Tertiary horst blocks expose fractured and permeable bedrock aquifers. Fractured Tertiary rhyolite and dacite dikes, plugs, and domes pierce aquatards to allow outflow of thermal ground waters.
5. Favorable reservoir rocks are found at depth.
6. Late Tertiary and Quaternary faults may provide fractured volumes of rock or can divert waterflow vertically.

Conductive-hydrothermal resources are most favorable in settings where large and deep sediment basins may store large amounts of hot water at depths greater than 1,000 ft. Late Tertiary basins with clayey fluvial, lacustrine, or playa deposits can have temperature gradients between 35°C and 45C/km. Basins filled with coarser materials will have lower temperature gradients. There are no anomalous flowing springs that have been identified in Luna County. There are hot springs just north of the county line (Table 13; Faywood, Mimbres). Several deep wells in Luna County, near Columbus, pump warm to hot waters, where <5 Ma basalts crop out, indicating relatively recent volcanic activity (Callender et al., 1983). However, these wells most likely represent conductive, not convective, sources of thermal waters. Current geothermal producers in New Mexico use wells that are much shallower and have higher-temperature gradients. Deep irrigation and water-supply wells in the Columbus and Deming area have encountered hot waters that may be developed economically (Young et al., 1981; Swanberg et al., 1981). The East Potrillo volcanic field also may have hot waters (Snyder, 1986).

TABLE 13. Summary of geothermal wells and springs in and near Luna County (from Callender et al., 1983).

Well/spring number	Longitude	Latitude	Category	County
405	32.371	107.662	bottom-hole temp <50°C, gradient >50°C/km	Luna
Faywood Hot springs	32.552	107.99	surface temp >50°C	Grant
Mimbres Hot Springs	32.763	107.84	bottom-hole temp >50°C, gradient >50°C/km	Grant
Apache Tejo Warm springs	32.66	107.124	bottom-hole temp <50°C, gradient >50°C/km	Grant
Kennecott Warm springs	32.55	108.015	bottom-hole temp <50°C, gradient >50°C/km	Grant
none	31.802	107.83	bottom-hole temp <50°C, gradient 40–50°C/km	Luna
none	31.815	107.473	bottom-hole temp <50°C, gradient 40–50°C/km	Luna
none	32.268	107.583	bottom-hole temp <50°C, gradient 40–50°C/km	Luna
Carne	32.253156	107.580236	No data	Luna

Coal Resources

There are no known coal deposits in Luna County (Hoffman, 1996; Sanchez, 1997). Lower Cretaceous rocks in the study area are non-coal-bearing limestone, conglomerate, sandstone, siltstone, and shale of the Hell-to-Finish, U-Bar, and Mojado Formations; Tertiary non-coal-bearing rocks are predominantly sandstone, siltstone, shale, conglomerate, limestone, and volcanic rocks. Although Cretaceous and Tertiary rock units are coal-bearing in other parts of New Mexico, the tectonic and sedimentary history during deposition in Luna County precludes the formation of coal. Coal is mined in the San Juan Basin in northwestern New Mexico and Raton Basin in northeastern New Mexico from Cretaceous age rocks (Hoffman, 1996). Power plants in the San Juan Basin burn coal to generate electricity. Coal from Raton is shipped to other power plants and has been used in steel furnaces as flux.

DISCRIPTION OF MINING DISTRICTS AND FAVORABLE AREAS

Burdick-Bisbee Hills

Location and mining history

The Burdick-Bisbee Hills, southwest of Deming (Fig. 3), consists of a group of small hills where an undetermined amount of agate and quartz crystals have been mined from Tertiary volcanic rocks. Only surface workings have exposed the deposits (Appendix 2). Thin beds of travertine also are reported.

Geology

Most of the Burdick-Bisbee Hills area consists of Tertiary fanglomerate, which is overlain by as much as 500–700 ft of dacite flows, rhyolitic air-fall tuff, vitric tuff, volcaniclastic rocks, sandstones, conglomerates, and shales. Some of the older latite/dacite flows are slightly porphyritic and correlative to similar flows in the Carrizalillo Hills (Seager, 1995). A petroleum test well (Bisbee Hills Unit #1, sec. 11, T26S, R11W) in the northern Bisbee Hills indicates that these rocks are underlain by the Rubio Peak and Lobo Formations (Lawton and Clemons, 1992).

Mineral deposits

Agate and quartz crystals are found in white to light gray, rhyolitic air-fall tuff and tuffaceous sandstone (unit Ttu of Seager, 1995), which is approximately 100 ft thick. The agate is found in thin veins (few inches to few feet wide, few feet to tens of feet long) within altered and weathered tuff. The veins are found along randomly oriented fractures and small displacement faults; larger displacement faults appear to be barren. This deposit is unusual, not in the quantity of agate, which is relatively small, but in the variety of colors that are found. The agate ranges in color from varigated reds and browns to blues, greens, and grays; rare fire agate also is found. Most pieces are smaller than fist size. Quartz crystals are typically as aggregates, small (less than an inch), and white to colorless. Quartz is an abundant mineral associated with the agate and must be removed from the economic material by hand. Thin beds of travertine also are reported in the area that may be related to local faults (Seager, 1995).

Mineral-resource potential

The potential for small-scale collecting of agate and quartz crystals is high. Active mining claims cover parts of the area for mineral collecting of agate and quartz crystals. The workings are shallow pits and probably have not reached the base of the productive zone.

Environmental assessment

There are no environmental concerns in this area. Some of the shallow surface workings have been backfilled and seeded.

Camel Mountain-Eagle Nest district

Location and mining history

The Camel Mountain-Eagle Nest district is located along the Doña Ana-Luna County boundary, west of the Potrillo Mountains (Fig. 3, 20). No production is known from the area; only a few shallow prospect pits and shafts (Appendix 2) have exposed the small, discontinuous volcanic-epithermal veins and carbonate-hosted Pb-Zn and carbonate-hosted Ag-Mn deposits.

FIGURE 20. Mines and prospects in the Camel Mountain-Eagle Nest district, Luna County.

Geology

The area consists of several small, isolated hills of poorly exposed, altered igneous rocks that have intruded Paleozoic and Mesozoic limestone, such as at Prospect Hill. Tertiary volcanic and sedimentary rocks form other hills, such as at Camel Mountain (Fig. 21). Two of the more prominent hills are the Eagle Nest (Fig. 22) and Granite Hills, where granite of suspected Proterozoic age is overlain by Cretaceous-Tertiary sedimentary rocks. Permian sedimentary rocks are exposed at Eagle Nest Hill. Normal faults have uplifted these hills during Basin and Range extension (Seager, 1989). The hills are surrounded by blow sand and other Recent alluvial deposits, which may conceal additional, more economically promising, volcanic-epithermal and carbonate-hosted deposits. Seismic surveys indicate the presence of elevated velocity rocks within 900–1,200 ft of the surface, which could represent carbonate rocks.

Porphyritic andesite to diorite has intruded the Proterozoic granite and Cretaceous-Tertiary sedimentary rocks (Broderick, 1984; Broderick et al., 1986; Seager and Mack, 1990; FN 5/29/95). Diorite at Prospect Hills has an age of 36.8±4.7 Ma (hornblende; Appendix 5). The sample collected from Eagle Nest Hills has a complex age spectrum and may represent a Cretaceous age (Appendix 5). The diorites are calc-alkaline and metaluminous.

FIGURE 21. Camel Mountain, looking north. A prospect pit is on the top of the east ridge, which is formed by a rhyolite dike (V. T. McLemore photo).

FIGURE 22. Eagle Nest Hill, looking north. A prospect pit is near the western crest (V. T. McLemore photo).

Mineral deposits

The Camel Mountain prospects consist of volcanic-epithermal veins filling fault and fracture zones near a rhyolite dike striking N70°E (Fig. 23). The veins consist of Fe and Mn oxides, calcite, fluorite, and quartz. A sample assayed 0.028 oz/ton Au, no Ag, 9.6 ppm Cu, 32 ppm Pb, 87 ppm Zn, and 0.06 ppm Hg (#2485, Appendix 4). Gese (1985) reports an assay of 0.2 oz/ton Ag, 39 ppm Pb, 76 ppm Zn, and 2.1% Mn.

The Prospect Hill prospects consist of small, discontinuous carbonate-hosted replacement bodies of quartz, calcite, barite, gehlenite, and clinohumite (Griswold, 1961). No metallic sulfides have been found. Gehlenite and clinohumite are rare silicate minerals valued as mineral specimens (Griswold, 1961). Gese (1985) reports a sample assayed 55 ppm Zn.

Eagle Nest is perhaps the most economically interesting area in the district. A volcanic-epithermal vein of quartz, calcite, siderite, iron oxides, pyrite, barite, fluorite, sphalerite, and galena are found in a mafic dike along a fault trending N50°E (Fig. 23; FN 5/29/95; Broderick, 1984; Gese, 1985). Chloritic and sericitic alteration, locally pervasive, affect adjacent conglomeratic rocks. A sample assayed 340 ppm Cu, 75,000 ppm Pb, 1,100 ppm Zn, no Au, and 14.98 ppm Ag (ENG 1, Appendix 4). Gese (1985) reports a dump sample assayed 5.7 oz/ton Ag, 4.5% Pb, and 1.6% Zn.

FIGURE 23. Vein containing calcite, quartz, siderite, galena, and pyrite striking east-west at Eagle Nest Hill (V. T. McLemore photo).

Mineral-resource potential

The mineral-resource potential of this area is speculative at best. No production is reported. Geochemical anomalies in the stream-sediment samples are scattered and low; anomalous concentrations of As, Co, Cr, K, Mn, and Ti occur locally. However, the presence of volcanic and intrusive rocks provides a source of metals and heat for mineral deposits. The lack of outcrop exposure in the area presents challenges for exploration.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns. Anomalous concentrations of As in the stream sediments is consistent with the volcanic rocks in the area. The presence of carbonate rocks provides a natural neutralizing environment for any potential acid drainage that might occur from future exploration and mining.

Carrizalillo district

Location and Mining History

The Carrizalillo (Cedar Mountains, Stonewall, Klondike Hills, Carrisillo, Carrisillio) district includes a broad region in southwestern Luna County that includes the Carrizalillo Hills, Cedar Mountains, and Klondike Hills (Fig. 3, 24, 25). The mineral occurrences are scattered throughout all three ranges and consist of volcanic-epithermal and carbonate-hosted deposits (Appendix 2). The district was first prospected in the late 1800s; but very little is known concerning the mining history and development. Numerous pits, shafts, and a few adits occur in the area, but none are very extensive. Ruins of a smelter are found near Hermanas (22 T28S R11W). Only a small area is disturbed with very little slag, suggesting that production was probably small (Gates, 1985). Copper, gold, silver, and lead production in the late 1800s, 1930, 1947–1948, and 1956 has been minor; less than 1,000 oz Ag, less than 1,500 lbs Cu, and less than 1,000 lbs Pb have been produced (Table 2). Past exploration by various companies, including Canyon Resources Corporation, Dome Exploration (in 1985), Westmont (in 1989), and FMC Corporation has failed to discover any economic mineral deposits. Canyon Resources Corporation drilled 28 holes for a total of 8,490 ft; one 5-ft interval assayed 0.35 oz/ton Au and 35 oz/ton Ag (Canyon Resources Corporation unpublished prospectus, 1985, 68 pp.). The Cedar Mountains Wilderness Study Area occurs in the center of the Cedar Mountains.

FIGURE 24. Mines and prospects in the Carrizalillo mining district, Luna County.

FIGURE 25. Mines, prospects, and assay values in the Carrizalillo Hills, southern Carrizalillo mining district (chemical analyses from Gates, 1985).

Geology

The Carrizalillo Hills and Cedar Mountains consist predominantly of Tertiary calc-alkaline basaltic and andesitic flows, rhyolitic ash-flow tuffs, and volcanic breccias, tuffs, and andesite flows (Griswold, 1961; Bromfield and Wruke, 1961; Varnell, 1976; Thorman and Drewes, 1981; Gates, 1985; Seager and Clemons, 1988). Calc-alkaline, peraluminous rhyolite dikes and domes have intruded the volcanics. The ash-flow tuffs are outflow sheets from distal unidentified calderas. Two of the tuffs from the Cedar Mountains have been dated as 33.37±0.12 and 33.20±0.61 Ma and one tuff from the Carrizalillo Hills has been dated as 34.89±0.09 Ma (McIntosh and Bryan, 2000). In the southern Cedar Mountains and Klondike Hills, Cambrian-Ordovician through Cretaceous sandstones, shales, and limestones are exposed (Griswold, 1961; Varnell, 1976). The Cedar Mountains form a homocline that is offset by normal faults. Faulting is predominantly northwest, except in the vicinity of the rhyolite domes. In the Klondike Hills, Proterozoic granite dated as 1,390 Ma (Rb-Sr) is overlain by Cambrian through Cretaceous sedimentary rocks (Rupert, 1986; Rupert and Clemons, 1990).

Mineral deposits

Small, discontinuous volcanic-epithermal and carbonate-hosted deposits occur scattered throughout the area (Fig. 24, 25). Volcanic-epithermal quartz veins and stringers with local galena, chalcopyrite, and sphalerite fill faults and contact zones of rhyolite and andesite dikes in the Carrizalillo Hills. The largest deposit is the Calumet mine, which accounted for most of the production (Appendix 2). The veins are along a rhyolite dike intruding andesite and contain malachite, chrysocolla, azurite, pyrite, limonite, quartz, manganese oxides, barite, argentite, gold, silver, chalcocite, and calcite (Griswold, 1961; Gates, 1985; V. T. McLemore, field notes, 12/22/01). The host rocks exhibit silicification, epidotization, and chloritization. The vein system strikes N20°W to N50°E and dips 60°W and is less than 3 ft wide. Minor production also occurred from the Hermanas mine in 1946. Additional veins cut calcite in the area near the Johnson Ranch (Appendix 2). Assays of veins range as high as 0.18 oz/ton Au, 16.88 oz/ton Ag, and 35,200 ppm Cu (Gates, 1985). Quartz veins and breccia zones are up to 20 ft wide. Manganese oxides, quartz, calcite, chrysocolla, malachite, chalcocite, and azurite are common. In the Cedar Mountains, the Lucky mine consists of carbonate-hosted lead replacement and vein deposits along a north-east-trending fault in Paleozoic limestone (Griswold, 1961; V. T. McLemore, field notes, 4/01/01). Steeply-dipping vein and replacement deposits contain galena, quartz, calcite, pyrite, sphalerite, smithsonite, and malachite. Jasperoids are common. In the Klondike Hills, localized zones in carbonate rocks belonging to the Hachita Formation (Mississippian) and Hitt Canyon Member of the El Paso Formation are replaced by silica, copper, and lead minerals forming jasperoids, and are especially common along faults (Rupert, 1986; V. T. McLemore, field notes, 3/31/01). Chlorargyrite, stephanite, and stromeyerite also are reported from the district (Northrop and LaBruzza, 1996).

Silicification and argillic alteration is widespread in the limestones, andesites, and rhyolites in the Carrizalillo district (Griswold, 1961; Varnell, 1976; Gates, 1985; Seager and Clemons, 1988), and may be responsible for a large, regional gravity low (Bartsch-Winkler, 1997). Jasperoids occur as void fillings and replacement deposits in the Paleozoic limestones and locally contain trace amounts of pyrite, galena, barite, and malachite. Argillic alteration is characterized by chlorite, calcite, quartz, and, locally, epidote. Silicification and potassic metasomatism also are associated with quartz-calcite veins, many of which carry gold and silver (Appendix 4). Potassic alteration is characterized by K-feldspar, clays, sericite, chlorite, quartz, calcite, and iron oxides (Seager and Clemons, 1988). Argillic alteration increases in intensity towards many of the veins.

Thundereggs and geodes are found in rhyolite flows at the Baker Egg mine (Fig. 26). Rare geodes are lined with amethyst (Northrop and LaBruzza, 1996).

FIGURE 26. Baker Egg No. 1 geode quarry, Carrizalillo Hills (V. T. McLemore, photo).

Poorly exposed and devitrified perlitic pitchstone is found near Hermanas (Appendix 2; Weber, 1965; Weber and Austin, 1982). The perlite is interlayered with altered rhyolite flows, thereby making the deposit uneconomic. However, rhyolite domes are scattered throughout the Carrizalillo district and could be associated with additional perlite deposits.

Mineral-resource potential

Reports of a molybdenum discovery in the area (Leonard, 1982) could not be confirmed for this report, but the geology, alteration, and geochemistry suggests such a possibility. Geochemical anomalies in the stream-sediment samples are scattered and low. Anomalous concentrations of As, Ba, Cd, Co, Cr, La, Mn, Sb, Th, and Y occur in stream-sediments from throughout the area.

Some of the highest gold assays in Luna County come from selected samples in the Carrizalillo district (as much as 21.1 ppm Au; Appendix 4) and could be indicative of concealed sedimentary-hosted gold deposits and/or gold skarn deposits. Drilling of favorable areas is required to determine if such deposits exist.

Environmental assessment

With a few exceptions, most known mineralized areas in the district do not pose any environmental concerns. Some areas contain galena and other lead minerals. Anomalous concentrations of As in the stream sediments is consistent with the volcanic rocks in the area. The presence of andesites and carbonate rocks provides a natural neutralizing environment for any potential acid drainage that might occur from future exploration and mining. Slag from the smelter near Hermanas contains elevated concentrations of lead (Appendix 4) and the area surrounding the smelter should be examined for lead concentrations in the soil.

Cooke's Peak district

Location and Mining History

The Cooke's Peak district, located in the Cooke's Range of northern Luna County (Fig. 27), is the most productive district in Luna County. The district is adjacent to and extends into the Cooke's Range Wilderness Study Area. The Cooke's Peak mining district has, at various times, been identified as containing two or three subdistricts; the Jose subdistrict, the Cooke's subdistrict, and the Old Hadley (Hadley or Graphic) subdistrict. While there's much confusion in relevant literature as to which individual mine belongs in what subdistrict, this report recognizes the eastern group of deposits as the Cooke's subdistrict and the prospects on the western side as the Jose subdistrict. The Old Hadley is a separate district in this report (sections 29, 32 T20S, R8W). Each of these reflects the historical development of the district as well as geographic location.

FIGURE 27. Mines and prospects in the Cooke's Peak mining district, Luna County.

The district was discovered in 1876 by Ed Orr (Howard, 1967) and by 1900, approximately $3 million worth of ore was produced from carbonate-hosted Pb-Zn and polymetallic vein deposits. Large-scale mining ceased in 1905, but in 1951 H. E. McCray reopened the district and produced until 1953. Estimated total production from 1876 to 1965 is $4.2 million worth of Pb, Zn, Cu, Ag, and Au, including approximately 50 million lbs Pb and 7 lbs Zn (Table 14, 15). The average grade produced from 1902 to 1947 was 15.3% Pb, 11.5% Zn, and 2.51 oz/ton Ag (Griswold, 1961). In addition, 452 tons of fluorite and 450 long tons of 33–46% Mn have been produced from carbonate-hosted deposits (Rothrock et al., 1946; Elston, 1957; Farnham, 1961). Newmont Exploration Ltd. examined the district in the late 1980s and drilled several holes; the results of their exploration program are unknown.

TABLE 14. Reported metal production from the Cooke's Peak district, Luna County (from U. S. Geological Survey, 1902–1927; U. S. Bureau of Mines, 1927–1990; Jicha, 1954). Estimated total 1876–1965 is the best estimate of total production as determined from available published and unpublished data. — none reported.

YEAR	ORE (SHORT TONS)	COPPER (LBS)	GOLD (OZ)	SILVER (OZ)	LEAD (LBS)	ZINC (LBS)	TOTAL VALUE ($)
1902	1,778	—	—	9,275	663,300	—	31,176
1903	2,050	—	—	5,748	1,343,361	—	59,500
1904	1,078	—	—	4,401	576,795	—	27,355
1905	846	—	—	5,199	463,956	—	24,977
1906	1,133	—	—	7,519	627,544	—	40,883
1907	811	—	615	4,739	592,151	—	47,225
1908	253	—	—	1,009	127,535	—	5,891
1909	695	46	—	4,317	597,488	—	27,943
1910	457	47	—	1,917	242,137	—	11,695
1911	45	—	—	200	32,638	—	1,575
1912	927	—	—	960	142,680	433,129	36,897
1913	1,271	1,395	—	1,248	255,901	695,697	51,189
1914	1,995	2,181	302	2,423	381,324	793,585	57,043
1915	1,352	—	7	432	64,382	647,210	83,506
1916	2,562	—	—	433	56,275	1,390,119	190,444
1917	2,330	99	1	3,602	272,140	1,067,853	135,340
1918	1,252	3,150	1.5	1,947	156,549	463,445	56,046
1919	122	941	—	745	26,473	31,575	4,717
1920	136	2,223	.5	1,322	52,738	21,098	7,788
1921	—	—	—	—	—	—	—
1922	81	1,130	—	72	9,087	24,228	2,106
1923	8	13	—	15	1,988	—	153
1924	454	573	—	1,658	152,199	—	13,432
1925	1,740	1,200	5.3	2,657	416,230	119,300	47,402
1926	319	242	—	492	106,500	42,000	12,011
1927	1,006	367	12	1,334	162,238	—	11,283
1928–1931	—	—	—	—	—	—	—
1933	28	—	.29	143	20,000	—	796
1934–1935	—	—	—	—	—	—	—
1936	3	—	—	7	1,000	—	51
1937	6	—	.11	13	1,300	—	91
1938	50	—	–	393	46,700	—	2,402
1939	106	800	2	595	54,000	9,000	3,563
1940	152	--	—	152	27,000	49,000	4,545
1941	45	200	—	218	26,400	—	1,684
1942	17	—	14	97	11,000	—	1,296
1943–1946	—	—	—	—	—	—	—
1947	77	—	—	95	15,900	—	2,376
1948	408	—	—	326	58,000	—	10,677
1949	69	—	—	221	38,000	—	6,204
1950	5	—	—	9	2,000	—	278
1951	2,714	6,000	10	2,939	456,000	495,400	173,513
1952	749	2,000	3	1,201	189,500	187,000	63,228
1953	12	—	—	63	4,000	—	581
1954	3	—	—	19	—	—	17
1955	—	—	—	—	—	—	—
1956	4	—	—	101	9,300	—	1,551
TOTAL 1902–1956	29,149	22,607	973.7	70,256	8,483,709	6,469,639	1,260,430
ESTIMATED TOTAL 1876–1965	—	23,000	<1,000	71,000	50,000,000	7,000,000	4,000,000

TABLE 15. Metal production from individual mines in the Cooke's Peak district, Luna County (Jicha, 1954; unpublished data, NMBGMR). Some mines listed by Jicha (1954) are not within Cooke's Peak district and are not included herein. Also, Jicha (1954) listed some mines by alias names listed in Appendix 2. ? = Exact location unknown. — = none reported.

Mine	Location (section, township, range)	Period	Ore (short tons)	Gold (oz)	Silver (oz)	Copper (lbs)	Lead (lbs)	Zinc (lbs)
Busted Banker	24, 14 20S 9W	1941	12	—	43	111	7,109	—
Clara K	20S 9W	1911–1912	29	—	126	—	21,634	—
Desdemona	24 20S 9W	1904–1942	9,073	9.5	14,974	2,271	2,214,698	2,984,645
Ethel (85 Group)	13, 14, 22, 23 20S 9W	1936–1947, 1949	148	14.95	590	188	89,781	17,159
Ethel (Faywood)	14 20S 9W	1904–1937	2,371	0.39	13,899	12	1,285,402	239,442
Gladys	13 20S 9W	1941–1947	51	—	52	44	9,085	—
Goodwill	?	1947–1948	214	—	124	29	22,807	—
Hope, Faith, and Constant	25, 36 20S 9W	1909–1919	63	—	675	—	50,399	—
Inez	13 20S 9W	1904–1927	1,756	11.62	3,292	2,647	637,812	105,327
Lead King	24 20S 9W	1904–1917	447	—	—	—	—	—
Little Mary	24 20S 9W	1918	13	—	51		8,931	—
Lookout	14 20S 9W	1938–1942	71	0.85	541	—	61,970	10,888
Mickey	14, 24 20S 9W	1939, 1941–1942	56	—	259	—	48,734	—
Mocking Bird	?	1902	100	—	115		18,500	—
Montezuma	13 20S 9W	1947–1948	7	—	1	8	1,971	—
Old Commodore	?	1910–1912	27	—	171	—	29,195	—
Poe	24 20S 9W	1914	922	3.18	1,274	481	307,973	481,553
Rimrock	N14 20S 9W	1948–1956	234	—	391	149	61,679	—
Summit	13 20S 9W	1904–1949	3,325	0.34	5,594	140	1,063,802	1,530,888
Sunny Slope	?	1909	15	0.15	39	4,917	—	—
Surprise (Contention)	24 20S 9W	1904–1918	1,488	0.2	1,412	3,292	108,944	880,531
Surprise, Mahonney	N24 20S 9W	1942	5	—	33	—	4,656	—
Sycamore, Burrell and Florida	24 20S 9W	1923–1924	19		37	16	4,640	
Webster	N1/2 24 20S 9W	1920	42	—	378	—	33,611	—
West Side	24 20S 9W	1912	55	—	49	—	7,382	—
White Oaks	24 20S 9W	1906–1908	301	—	3,102	—	386,878	—

Geology

Paleozoic through Cretaceous sedimentary rocks unconformably overlie Proterozoic granite in the district (Jicha, 1954); the mineral deposits are predominantly in the Fusselman Formation, beneath the Percha Shale. The sedimentary rocks in the district form a plunging anticline. Cooke's Peak consists of intrusive granodiorite porphyry, which has been dated as 38.8±1.4 Ma (biotite, K-Ar; Loring and Loring, 1980); dikes radiate outwards from the center. Fractures in the Cooke's Peak district parallel some of these dikes. The Deming flow in Fort Cummings Draw (Cooke's Range) consists of subalkaline basalt (Anthony et al., 1992) and could have potential for scoria and basalt for use as crushed stone.

Mineral Deposits

The major deposits of the Cooke's Peak district are carbonate-hosted Pb-Zn replacements and veins (Appendix 2, Fig. 27) and occur along northeast-trending fractures in the Fusselman Formation beneath jasperoid bodies and/or the Percha Shale. Locally, the shale is iron-stained and silicified. The jasperoids contain fluorite, calcite, quartz, and locally pyrite and cerussite. The ore bodies range in shape from irregular, tabular to kidney-shaped (mantos) to pipe-like (chimneys); most bodies are small and less than 100 ft long, 50 ft wide, and as much as 20 ft thick (Jicha, 1954). They are controlled by faults, fractures, and, locally, anticlinal folds. Veins along faults are common in the western portion of the district and locally widen into tabular replacement bodies (Elston, 1957). Individual mines rarely produced more than 2,000 short tons of ore (Table 15). The primary ore minerals are galena and sphalerite with stephanite, prousitite, and pyrargyrite in a gangue of pyrite, fluorite, and ankerite (Table 16; Jicha, 1954). Oxide minerals include cerussite, smithsonite, and anglesite. Plumbojarosite was discovered in the district in

1905 (Clarke et al., 1905). Lead typically exceeds zinc and copper in abundance in most mines. However, ore at the Summit mine averaged 16% Pb, 23% Zn, and 1.7 oz/ton Ag (NMBGMR file data). The upper levels were oxidized and have been completely mined out. Silicification, mostly as jasperoids, is prevalent in the district and surrounds most ore bodies; brecciation and recementation are common.

Small pockets of ore, typically as polymetallic veins, occur in the granodiorite porphyry and in the Sarten Sandstone Member (Cretaceous). They contain quartz, pyrite, calcite, chalcopyrite, galena, and sphalerite. These veins were generally higher grade than the carbonate-hosted deposits, but much smaller in size (Jicha, 1954). Disseminations of sulfides, typically pyrite and chalcopyrite, are locally present in the granodiorite.

Fluorite and manganese are common in the district. The Lookout mines were produced for fluorite (Table 5). Placer manganese deposits in the southern part of the district were worked in 1959 by Q. M. Drunzer (Griswold, 1961).

TABLE 16. Selected minerals found in the Cooke's Peak mining district (from Griswold, 1961; Northrop and LaBruzza, 1996).

MINERAL	CHEMICAL FORMULA	MINERAL	CHEMICAL FORMULA
SILICATES		SULFIDES, SULFATES, METALS	
Actinolite	$Ca_2\,(Mg,Fe^{++})_5Si_8O_{22}\,(OH)_2$	Pyrite	FeS_2
Andesine	$(Na,Ca)(Si,Al)_4O_8$	Chalcopyrite	$CuFeS_2$
Glauconite	$(K,Na)(Fe^{+3},Al,Mg)_2(Si,Al)_4O_{10}(OH)_2$	Sphalerite	(Zn, Fe)S
Hypersthene	$(Mg,Fe^{++})_2Si2O_6$	Argentite	Ag_2S
Sanidine	$(K,Na)(Si,Al)_4O_8$	Pyrargyrite	Ag_3SbS_3
Microcline	$KAlSi_3O_8$	Chlorargyrite	AgCl
Muscovite, sericite	$KAl_2\,(Si3Al)O_{10}(OH,F)_2$	Galena	PbS
Olivine	$(Mg,Fe)_2SiO_4$	Anglesite	$PbSO_4$
Hemimorphite	$Zn_4Si_2O_7(OH)_2{\cdot}H_2O$	Gypsum	$CaSO_4{\cdot}2(H_2O)$
Quartz	SiO_2 (1, 2)	Natrojarosite	$NaFe^{+++}3(SO_4)_2\,(OH)_6$
Zoistite	$Ca_2Al_{23}(SiO_4)_{23}(OH)$	Plumbojarosite	$PbFe^{+++}{}_6(SO_4)_{24}(OH)_{12}$
Titanite	$CaTiSiO_5$	Prousitite	Ag_3AsS_3
Orthoclase	$KalSi_3O_8$	Pyrostilpnite	Ag_3SbS_3
CARBONATES		Stephanite	Ag_5SbS_4
Calcite	$CaCO_3$	Idaite	Cu_5FeS_6
Smithsonite	$ZnCO_3$	OTHER	
Dolomite	(Ca, Mg) CO_3	Fluorite	CaF_2
Cerussite	$PbCO_3$	Alunogen	$Al_2\,(SO_4)_3{\cdot}17(H_2O)$
OXIDES		Nitratine	$NaNO_3$
Psilomelane	Mn oxide		
Magnetite	Fe_3O_4		
Vanadinite	$Pb_5(VO_4)_3Cl$		
Plattnerite	PbO_2		
Hematite	Fe_2O_3		

Mineral-resource potential

Most exploration in the district concentrated on extending known ore bodies. Much of the Fusselman Formation west of the district may have potential, especially beneath the Percha Shale and in the vicinity of jasperoids (Jicha, 1954); drilling is required to assess the potential. Although this district was not examined for this study and samples were not collected; known mineralization, alteration, minor gold production, and host lithology suggest that concealed sedimentary-hosted gold deposits and/or gold skarn deposits could occur in this district. Drilling of favorable areas is required to determine if such deposits exist. Local Ba, Be, Cr, and Mn anomalies occur in stream-sediment samples from the area.

The Deming basaltic flow in Fort Cummings Draw could have potential for scoria and basalt for use as crushed stone. However, reliable roads are rare in this remote area. Geodes are found north of Fort Cummings in rhyolitic tuff and agate is found throughout the Cooke's Peak district.

Environmental assessment

With a few exceptions, most known mineralized areas in the district do not pose any environmental concerns. Lead is high in many deposits, but there is no acid-generating rock, therefore the lead is not likely to be mobilized. The presence of andesites and carbonate rocks provides a natural neutralizing environment for any potential acid drainage that might occur from future exploration and mining.

Cooke's Peak Manganese district

Location and mining history

The Cooke's Peak Manganese district is south of the Cooke's Peak district and east of the Fluorite Ridge district; the epithermal manganese deposits that are found in the district have been previously described as being in both the Cooke's Peak and Fluorite Ridge districts. Less than 1,000 short tons of low-grade manganese ore have been produced from the southern part of the district, primarily from the Ruth and Starkey mines. Production began in 1918, but with the end of World War I, production soon ceased. A small jig mill operated in 1929–1930. Major production didn't occur until the Federal manganese purchasing program began in 1952 and production ceased in 1959.

Geology

The southern Cooke's Range where the Cooke's Peak Manganese district is located consists of mostly andesitic volcanic and volcaniclastic rocks of mid-Tertiary age (Seager et al., 1982; Seager, 1995). Only minor faults are found in the district.

Mineral deposits

Epithermal Mn vein deposits occur throughout the southern Cooke's Range. The veins are typically small; veins are generally less than 3 ft wide. Psilomelane is the predominant mineral with minor amounts of calcite and fluorite.

Mineral-resource potential

Although the Cooke's Peak Manganese district has high potential for small, low- to medium-grade epithermal manganese vein deposits, these deposits are not likely to be mined in the near future because larger, higher-grade deposits are currently being mined overseas for manganese.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns. Only manganese minerals are found in the district, which are not known for any high concentrations of metals or acid-generating rock.

Florida Mountains district

Location and mining history

The Florida Mountains district, discovered in 1876, is located east of Deming and includes only the main Florida Mountains, south of Florida Gap (Fig. 3, 28). The district is adjacent to the Florida Mountains Wilderness Study Area. From 1880 to 1956, 5,000 lbs Cu, <10 oz Au, 8,034 oz Ag, and >30,000 lbs Pb worth approximately $102,000 were produced from carbonate-hosted Pb-Zn and polymetallic vein deposits in the district, mostly from 1880 to 1920 (Table 17). The Mahoney and Silver Cave mines are the largest metal producers. In addition, 200 short tons of fluorite and 1,421 long tons of 22–30% Mn have been produced from epithermal veins in the area (Rothrock et al., 1946; Farnham, 1961). Manganese was mined from veins on the southeast slopes during the Government purchasing program in the 1950s.

TABLE 17. Reported metal production from the Florida Mountains, Luna County (from U.S. Geological Survey, 1902–1927; U.S. Bureau of Mines, 1927–1990; Griswold, 1961). — none reported.

YEAR	ORE (SHORT TONS)	COPPER (LBS)	GOLD (OZ)	SILVER (OZ)	LEAD (LBS)	TOTAL VALUE ($)
1934	38	200	—	170	15,000	681
1936	19	100	0.20	80	4,200	271
1937	22	1,850	0.12	6,100	4,780	478
1948	2	—	—	12	2,000	369
1956	35	2,000	—	29	—	876
TOTAL 1934–1956	116	4,150	0.32	6,391	25,980	2,675
ESTIMATED TOTAL 1880–1956	—	5,000	<10	6,391	>30,000	102,000

FIGURE 28. Mines and prospects in the Florida Mountains district, Luna County.

Geology

The Florida Mountains form the northern portion of the Laramide thrust belt as defined by Drewes (1991) and are along the Texas lineament. Rocks in the area consist of Paleozoic through lower Tertiary sedimentary rocks overlying Proterozoic rocks and Cambrian granite and syenite plutons (Clemons and Brown, 1983; Clemons, 1984). Laramide tilting, thrusting, and uplift, followed by Tertiary basin and range uplift have deformed the rocks. The district coincides with gravity and magnetic highs. Tertiary rhyolite, diorite, and andesite intruded the older lithologies. A rhyolite dike at the head of Spring Canyon has been dated as 25.4 ± 0.7 Ma (groundmass, $^{40}Ar/^{39}Ar$;

McLemore et al., 2000). Another rhyolite west of Florida Peak was dated as 29.1±1.3 Ma (feldspar, K-Ar; Clemons and Brown, 1983). The rhyolites are peraluminous and calc alkaline (Fig. 8).

Two U-Pb zircon crystallization ages have been published on the syenite-granite pluton: 503 ±10 Ma (Evans and Clemons, 1988) and 514 ± 3 Ma (Matheny et al., 1988). These overlap at ca. 510 Ma, which is probably the crystallization age of the pluton. $^{40}Ar/^{39}Ar$ analyses on biotite and hornblende from the syenite yielded a biotite plateau age of 490.5 ± 5.4 Ma and a less rigorous hornblende plateau age of 485.5 ± 4.9 Ma (Ervin, 1998). The Cambrian-Ordovician Bliss Formation unconformably overlies the Cambrian syenites in the Florida Mountains, confirming the Cambrian-Ordovician age (Clemons, 1998). The syenites are alkaline and metaluminous and the granites are calc alkaline (Fig. 29).

FIGURE 29. A scatter plot of Na_2O+K_2O verses SiO_2 and ANK verses ACNK of the Florida syenite-granites.

Mineral Deposits

Carbonate-hosted Pb-Zn replacement and polymetallic vein deposits occur throughout the district (Fig. 28, Appendix 2). The carbonate-hosted deposits are typically in Fusselman Formation and follow fracture and/or fault zones. The deposits occur as fissure veins or manto-replacement bodies that contain smithsonite, cerussite, malachite, azurite, barite, quartz, calcite, and local galena and sphalerite (Griswold, 1961). Lead typically exceeds zinc and copper in abundance. The deposits are typically small, less than 5 ft wide and several hundred feet long.

Polymetallic veins occur along fractures and faults within Cambrian syenite-granite, and Tertiary agglomerate (Appendix 2). The Park mine occurs along a fault separating Proterozoic granite and Paleozoic sedimentary rocks. Production from these veins has been small, but locally, they are higher in grade than the carbonate-hosted Pb-Zn deposits. The veins are typically less than 5 ft wide, several hundred feet long, of variable dips, and contain quartz, pyrite, calcite, iron and manganese oxides, chalcopyrite, and local galena, sphalerite, fluorite, and barite.

Fluorite occurs as veins, void fillings, and replacements of limestones (Appendix 2). Breccias and jasperoids are common. Most of the fluorite veins and fissures occur along faults and fractures. Fluorite and quartz are the predominant minerals in a gangue of calcite, clay, and rare barite and pyrite. Fluid inclusion data of fluorite from the Florida Mountains indicates formation from low temperature (146–194° C) and low salinity (6.2–8.4 eq. wt.% NaCl) fluids, suggesting a meteoric origin (North and Tuff, 1986).

The Waddell Atir mine was first prospected in 1910 (Williams et al., 1964), but there is no reported production. In 1980, Barite Corporation of America drove a 775-ft long adit to intersect the vein, but did not find enough ore to produce. The vein strikes N60°E and dips 55°SE and consists of barite, fluorite, galena, calcite, and quartz. It is 5–12 ft wide and 200 ft long and occurs in Cambrian syenite. A sample assayed 41% $BaSO_4$, 19.7% CaF_2, and 1.8% Pb (Williams et al., 1964).

Epithermal and carbonate-hosted Mn deposits occur throughout the Florida Mountains. The veins and replacements are typically small; veins are generally less than 3 ft wide and the largest replacement deposits at the Birchfield mine are only 8 ft wide. The deposits follow bedding planes that strike northeast. Locally, the deposits form cross-cutting pipe-like bodies, i.e. chimneys.

Mineral-resource potential

The potential for additional barite-fluorite and Mn deposits in the Florida Mountains is probably good, but not likely to be produced in the near future because of poor market conditions. Additional carbonate-hosted Pb-Zn and vein deposits are likely to be found along strike of most deposits. Areas of alluvial cover also should be examined. Anomalous As, Ba, Be, Cd, Cr, Cu, La, Mn, Nb, Pb, Sn, Th, Y, and Zn occur in stream-sediment samples from the area.

The geochemistry of the syenite-granite complex and the presence of La, Nb, Th, and Y anomalies in the Florida Mountains suggest that there is some possibility that Th-REE-Nb veins could occur, but none have been found to date.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns. Lead is high in many deposits, but there is no acid-generating rock, therefore the lead is not likely to be mobilized. The presence of andesites and carbonate rocks provides a natural neutralizing environment for any potential acid drainage that might occur from future exploration and mining.

Fluorite Ridge district

Location and mining history

The Fluorite Ridge mining district is located approximately 10 mi north-northeast of Deming, south of Cooke's Peak. The deposits group into two areas: Lower Camp in the southeast and the Upper Camp in the central part of the ridge (Fig. 30). The district includes Goat Ridge to the west. It was discovered in 1907 and production began in 1909. Epithermal fluorite veins are found in the district. There has been no base- or precious-metal production from the district, although minor amounts of galena and sphalerite have been found. Fluorite production from 1909 to 1954 is estimated as 93,827 tons. The Saddler and Greenleaf mines were the largest fluorite producers. Much of the ore was shipped to Deming.

FIGURE 30. Mines and prospects in the Fluorite Ridge mining district, Luna County.

Geology

Fluorite Ridge consists predominantly of granodiorite porphyry, which is similar to the intrusive rock in the Cooke's Peak district that has been dated as 38.8±1.4 Ma (biotite, K-Ar, Loring and Loring, 1980; Clemons, 1982b). The Fluorite Ridge granodiorite porphyry had been previously dated as 22.9±1.3, which is too young and reflects the hydrothermal activity (Wilks and Chapin, 1997). A new $^{40}Ar/^{39}Ar$ age determination of 38.82±0.57 Ma (hornblende) is reported in Appendix 5 and considered a better date. Two diabase dikes also were dated and found to be 26.38±0.20 and 27.16±0.19 Ma (groundmass, Appendix 5). A dike cutting the northern exposure of the porphyry on Fluorite Ridge has a date of 37.6±2.0 Ma (whole rock, K-Ar; Clemons, 1982b). Griswold (1961) interprets the Fluorite Ridge granodiorite porphyry to be a separate pluton from the Cooke's Peak porphyry, but the age determinations suggest that the two are of a similar age. The porphyry is surrounded by Proterozoic granite and Cambrian, Permian, Pennsylvanian, Cretaceous, and early Tertiary sedimentary rocks (Clemons, 1982b) and are overlain by Tertiary conglomerate. The entire district is faulted, and the sedimentary rocks form a dome with the granodiorite porphyry in the center. A basalt southwest of Goat Ridge has a K-Ar date of 37.6±2 (Clemons, 1982b).

Mineral Deposits

Numerous mines and prospects have developed the epithermal fluorite veins on Fluorite Ridge, where 10 mines and prospects have produced 87,533 short tons of fluorspar, with 76,000 short tons derived from the Greenleaf and Sadler mines (McAnulty, 1978) (Table 5, Fig. 30). Most of the fluorite veins and fissures occur along faults and fractures; the largest veins occur at intersections of fault and fracture zones (Rothrock et al., 1946; Russell, 1947). One group of faults strikes N17–27°E and the other group strikes N6°E–N18°W (Burchard, 1911). Quartz, clay, sericite, pyrite, and clay minerals fill some of the fault zones. The Tip Top and Hilltop Spar deposits occur as fillings in solution cavities in the limestone (Appendix 2; Rothrock et al., 1946). In all deposits, fluorite and quartz are the predominant minerals in a gangue of calcite, clay, and rare barite and pyrite. Brecciation, crustification, vug filling, and recementation are common and indicative of an epithermal origin. The veins occur mostly in the granodiorite porphyry, but smaller veins do cut most of the lithologies on Fluorite Ridge. The veins range in size to as much as 20 ft wide and 100 ft long (Burchard, 1911; Rothrock et al., 1946). A few of the mines are as much as 300 ft deep. Grades in 1911 ranged from 60.9 to 95.6% CaF_2 by hand sorting (Burchard, 1911); lower grades were shipped in later years with less hand sorting. None of the deposits have been completely mined out. Silicification is common, but extensive wall-rock alteration is minor. Jasperoids are found in adjacent limestones (Fig. 31).

FIGURE 31. Lucky mine, south end of Fluorite Ridge. Jasperoid capped hill is in skyline (V. T. McLemore, photo).

Temperatures of homogenization in fluid inclusions of fluorites from the district range from 170 to 223°C and salinites are less than 10 eq. wt.% NaCl (Hill, 1994). Geochemical, fluid inclusion, and stable-isotopic data indicate that the fluorite in the Fluorite Ridge district was formed from low salinity, low temperature meteoric fluids (Hill, 1994). Fluorite occurs in Gila conglomerate and in a basaltic dike at the Gratton mine, indicating a late Tertiary or early Quaternary age (Griswold, 1961).

Mineral-resource Potential

Most of the veins were never explored at depth and fluorite resources undoubtedly remain. Additional fluorite most likely occurs in the subsurface surrounding the ridge and in the area between the Greenleaf and Valley mines. Selected samples in the Fluorite Ridge district contain anomalous concentrations of gold and silver (as much as 182 ppb Au and 6 ppm Ag; Appendix 4) and could be indicative of potential base and precious metals at depth. Anomalous concentrations of As, Be, Ba, Cd, Cr, Cu, Mn, Pb, Th, Ti, and Zn occur in stream-sediment samples from the area, further suggesting that the veins could be indicative of potential base and precious metals at depth. Drilling of favorable areas is required to determine if such deposits exist.

Travertine occurs at Goat Ridge and could be quarried for local use. The Sarten Sandstone was quarried for building stone at the Rimrock (Fryingpan Spring) mine and used in the Deming courthouse prior to 1916 (Darton, 1916). The sandstone is massive, white to buff medium to thick bedded with no major fractures and is suitable for dimension and crushed stone.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns.

Fremont district

Location and mining history

The Fremont district in the northwestern Sierra Rica, at the junction of Luna and Hidalgo Counties and Mexico (Fig. 32), was discovered in 1860, and has produced 190,000 lbs Pb, 10,000 oz Ag, 2,000 lbs Cu, 10 oz Au, and 4,000 lbs Zn from volcanic-epithermal vein and carbonate-hosted Pb-Zn replacement deposits (McLemore and Lueth, 1996; McLemore, 2001). Most of this production has come from the International mine in Luna County with minor production from the Napone and Eagle mines.

FIGURE 32. Map of the mines and prospects in the Fremont mining district, Hidalgo and Luna Counties.

Geology

Paleozoic carbonate rocks and Cretaceous clastic rocks are overlain by mid-Tertiary volcanic rocks and intruded by quartz monzonite and monzonite (27.0±0.6 Ma, K-Ar, feldspar; Peterson, 1976; Deal et al., 1978) stocks (Strongin, 1957a, b; van der Spray, 1970; Peterson, 1976; Griswold, 1961; Chuchla, 1981; Garcia-Esparza, 1988; Drewes, 1991b). Thrust faults are common. Most of the volcanic rocks were mapped as the Chapo Formation (Peterson, 1976), but Bryan (1995) correlated the rhyolite ash flow tuffs to the Gillespie (32.7 Ma; $^{40}Ar/^{39}Ar$) and Oak Creek (33.5 Ma; $^{40}Ar/^{39}Ar$) Tuffs. Rhyolite, latite, felsite, and lamprophyre dikes are common. The limestones are silicified and metamorphosed to marble and hornfels and the volcanic rocks exhibit argillic alteration.

Mineral deposits

The International mine has produced 879 tons of ore since 1880 (Griswold, 1961). The best ore was a 10-ton shipment grading 40% Pb and $62 per ton Ag (at 95 cents per ounce; Lindgren et al., 1910). Between 1910 and 1959, 14 railroad cars of approximately 50 tons each and another 129 tons were shipped. Additional shipments probably were made, but not reported. The mine exploited a 3,600 ft long, 0.6–9-ft wide volcanic-epithermal vein in a fault cutting Cretaceous sedimentary rocks (Griswold, 1961). The ore minerals are galena, sphalerite, and chalcopyrite accompanied by gold and silver and quartz, calcite, iron oxides, and pyrite as gangue.

Mineral-resource potential

Numerous other prospects and mines occur in the area (McLemore et al., 1996c; McLemore and Elston, 2000). Most are shallow and the mineral potential at depth is unknown. A core-drilling program might find additional ore in the veins, but the value of the ore would probably not pay for the cost of exploration, development, mining, and transportation.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns.

Goodsight Mountains/Uvas Valley

Location and Mining History

Goodsight Mountains/Uvas Valley area lies west of the Rio Grande within the rift, along eastern Luna County and western Doña Ana County. There is no known mineral deposits in the area.

Geology

The Goodsight Mountains and Uvas Valley area is composed of rock units that range in age from Eocene to Holocene mostly of the Rubio Peak Formation (Seager, 1975), and forms the west limb of the northward-plunging Uvas Valley syncline (the Sierra de las Uvas forms the east limb) and the Goodsight-Cedar Hills depression (Seager, 1975). The Goodsight-Cedar Hills depression (Seager, 1973, 1975), an Oligocene to Miocene feature, lies within and parallel to the Rio Grande rift in western Doña Ana County and eastern Luna County, extending from the Goodsight Mountains on the west to the Cedar Hills on the east. It is filled with volcanic tuffs, flows, and related clastic rocks of the 33–39-Ma Bell Top Formation and 26 Ma Uvas Andesite. The Rubio Peak Formation consists of latite-andesite volcaniclastic rocks, flows, dikes, plugs, and small stocks. The Goodsight Mountains contain dikes, plugs, stocks, and massive intrusive-extrusive complexes (Clemons, 1979) clustered in a north-trending zone. The zone has been named the Goodsight Mountains vent zone (probably a zone of coalescing vents and conduits)

(Clemons, 1979). The vent zone may be contemporaneous with the Cedar Hills vent zone. A normal fault is inferred along the west side of the range (Seager, 1975; Ramberg et al., 1978). A northeast-trending fault is exposed in the northern part of the range that is one of several en echelon faults extending from Deming to the Caballo Mountains (Clemons, 1979).

Mineral deposits

There has been no reported mining in the Goodsight Mountains/Uvas Valley, except a few scattered aggregate pits. Bentonite has been mined from clay zones in the Camp Rice Formation near Hatch in Doña Ana County (Patterson and Holmes, 1965; Clemons, 1979) and similar zones may exist in the Goodsight Mountains (Clemons, 1979). Nutt Mountain (north end of Goodsight Mountains in Sierra County) is a perlitic rhyolite dome.

Mineral-resource potential

The area has potential for clay, crushed stone, and aggregate. The rhyolite domes need examination for perlite resources.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns.

Little Florida Mountains district

Location and Mining History

The Little Florida Mountains are northeast of the Florida Mountains; Florida Gap separates the two ranges (Fig. 33). Rockhound State Park is in the southwestern part of the range. Two types of deposits occur in the district (also known as Black Rock): epithermal fluorite veins and epithermal manganese veins. There has been no precious- or base-metal production from the district. Fluorite was produced from 1925 to 1951 and production is estimated as 13,428 short tons, mostly from the Spar mine (McAnulty, 1978). Manganese was produced from 1918 to 1959 and production is reported as 19,527 long tons of ore and 21,393 long tons of concentrate (Table 6; Farnham, 1961). The Manganese mine is one of the larger manganese mines in the district (DeVaney et al., 1942a, b). Production of manganese ceased in 1959 when the Federal government ended its buying program. In 1923, a small mill was erected at the Luna mine for processing manganese, but the gravity concentration was not efficient and the mill closed.

FIGURE 33. Mines and prospects in the Little Florida Mountains mining district, Luna County.

Geology

The Little Florida Mountains consist predominantly of interbedded mid-Tertiary andesitic, dacitic and rhyolitic ash-flow tuffs and lavas, and volcanic-derived fanglomerates intruded by rhyolite domes and dikes (Fig. 4; Clemons, 1982a, 1984, 1998). The earliest evidence of volcanic activity in the Little Florida Mountains are small outcrops of ash-flow tuffs exposed approximately one mile north of the state park (Fig. 4) and farther north, near Little Gap. Altered sanidine and biotite from an ash flow near the base of the stratigraphic section at Little Gap give $^{40}Ar/^{39}Ar$ ages of 33.5 Ma and 32.9 Ma, respectively. This ash flow may correlate with the 33.5 Ma old Oak Creek Tuff that erupted from the Juniper caldera in the northern Animas Range in the Boot Heel volcanic field in Hidalgo County to the west. The ash-flow tuff is overlain by andesite flows (andesite of Little Florida Mountains) that were probably erupted from shield or stratovolcanoes. The vents of these once prominent volcanoes are difficult or impossible to find because of local faulting and rapid erosion. The andesites subsequently were intruded by rhyolite domes and covered by rhyolite lavas and tuffs (rhyolite tuff [Tlt] and rhyolite [Tlr] of Little Florida Mountains, Clemons, 1982a). Volcanic activity was relatively brief in geologic terms; rhyolite and andesite samples from the state park range in age from 28.5 to 24.4 Ma. ($^{40}Ar/^{39}Ar$; New Mexico Geochronology Research Laboratory). Seismic data suggest that there is only 600 ft of volcanic rock in the subsurface in the area of the state park.

Erosion of the volcanic rocks began during and after eruption. The fanglomerate of Little Florida Mountains was the first of the deposits that formed by erosion of the volcanic rocks and is Miocene in age (Clemons, 1982a; Kiely and James, 1988). Dacite flows were erupted onto the fanglomerate of Little Florida Mountains. During and after this brief period of volcanic activity, regional tectonics (i.e. mountain building by block faulting) related to the Rio Grande rift uplifted the Little Florida and Florida Mountains; erosion has since worn the mountains down to their present elevation above the surrounding desert.

Mineral Deposits

The deposits in the Little Florida Mountains consist of epithermal fluorite and manganese veins in fanglomerate and Tertiary volcanic rocks (Fig. 33, Appendix 2). The fanglomerate is interpreted as being 23.6 Ma, similar in age as the rhyolite (Clemons, 1982a); therefore mineralization is younger than 23.6 Ma. Silicification is common in breccias along faults (called jasperoids by Lasky, 1940).

Fluorite and barite occurs in veins along faults with manganese oxides, calcite, quartz, and rare pyrite and galena (Griswold, 1961; McAnulty, 1978). Most veins can be traced easily in outcrop by prominent silicified breccias. Local veins are as much as 6 ft thick; most are less than 3 ft thick. Brecciation, crustification, and silicification are common and indicative of an epithermal origin. The ore grades are estimated as 20–60% CaF_2 (Griswold, 1961). Barite is predominant at the Apache mine (sec. SE7 T24S R7W); whereas fluorite is predominant at the Spar mine (sec. 7,8 T24S R7W). A sample at the Spar (Florida) mine assayed 74% $BaSO_4$ and 9.5% CaF_2 (Williams et al., 1964).

The manganese veins occur along faults and fracture zones and as breccia cement in the fanglomerate and contain various manganese oxides, including cryptomelane, manganite, psilomelane, and pyrolusite. Few ore shoots contained more than 60,000 short tons of ore (Lasky, 1940). Most deposits decreased in size and grade at 200–400 ft depths and manganiferous calcite becomes more abundant (Farnham, 1961). The average grade is 15–20% Mn with varying amounts of silica, calcite, iron, phosphorus, and barite. Trace amounts of copper, lead, zinc, silver, and arsenic are present locally in some veins (Lasky, 1940); but can not be recovered economically. Stibiconite, antimony oxide hydroxide, is reported from the district (Northrop and LaBruzza, 1996).

Geodes and thundereggs are collected at Rockhound State Park (Fig. 34) and elsewhere in the southern Little Florida Mountains (Fig. 35). Opal, Apache Tears (obsidian), and thomsonite also are found.

FIGURE 34. A thunderegg from the Never Again mining claim one mile southeast of Rockhound State Park, Deming, New Mexico (from Colburn, 1999).

FIGURE 35. A pair of star geodes (hollow thundereggs) with smokey quartz crystals from the Sugar Bowl mine, Little Florida Mountains district (from Colburn, 1999).

The Little Florida Mountains clay deposit consists of altered, white rhyolite in the southeastern part of the mountain range (N5 25S 7W). Samples from the quarry contain smectite and mixed illite/smectite (Table 18), although kaolinite was reported (Lasky, 1940). The presence of cristobalite and gypsum make this clay unsuitable for most uses.

TABLE 18. Clay mineral analyses of samples from the Little Florida Mountains clay deposit and Lucretia quarry, Taylor Mountain. In parts per ten of clay-sized material.

Sample Number	Kaolinite	Illite	Chlorite	Smectite	Mixed illite/smectite	Other minerals
FL 105	—	—	—	10	—	Aluminite, gypsum
FL 106	—	—	—	5	5	Cristobalite, aluminite, gypsum
LUC 1	Trace	2	Trace	2	5	Quartz, feldspar
LUC 2	Trace	2	Trace	2	5	Quartz, feldspar

Mineral-resource potential

Barite and fluorite can be mined in the Little Florida Mountains only if there is a local demand for these commodities. It is unlikely that manganese will be mined again in the Little Florida Mountains, even though manganese resources are still present, because of low grades and thin deposits. Lasky (1940) estimated that 550,000–1,000,000 short tons of manganese ore remains in reserves, but Farnham (1961) estimates remaining reserves are less than 75,000 short tons of 10–18% Mn. Anomalous concentrations of As, Ba, Be, Cd, Cr, Cu, La, Mn, Pb, Ti, and Zn are found in stream-sediment samples from the area.

Rockhound State Park is one of the few state parks in the U. S. that allows collecting of rocks and minerals within the park boundaries. Visitors from throughout the U. S. collect agates, geodes, and jasper; total production from the park is unknown. Other deposits are found throughout the Little Florida Mountains.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns.

Mimbres Basin

Location and mining history

The Mimbres basin is the westernmost of the deep sedimentary basins that comprise the Rio Grande rift and is bounded on both sides by normal faults that have been active during the Quaternary. The basin is bounded on the southeast by the West Potrillo Mountains and extends northward along the Mimbres River to west of the Cooke's Range. The north-trending eastern boundary fault of the Mimbres basin is rift-related.

Geology

Examination of wildcat exploration holes in the vicinity of Deming shows that the Mimbres basin is filled to a depth of about 3,600 ft with middle Pleistocene and older fluvial, alluvial-fan, and playa deposits (Table 9; Clemons, 1986). Prior to Laramide time, the area was part of the Florida Moyotes uplift, and before development of Basin and Range faulting, the area was covered with volcanic rocks of Eocene to Miocene age, which provided a source for later basin fill. Tertiary, Cretaceous, and Paleozoic rocks rest unconformably on Precambrian basement (Table 9).

Mineral deposits

There are no known mineral deposits in the basin except for aggregate (crushed stone).

Mineral-resource potential

Favorable areas within the Mimbres basin include areas where volcanic and intrusive rocks of Late Cretaceous and Tertiary age are near the surface and where geophysical anomalies indicate the presence of buried intrusions, which could provide thermal energy, pressure, and hydrothermal fluids to create a mineralized porphyry system. Additionally, areas of densely spaced faults and fractures and areas of argillic and propylitic alteration would be favorable.

Environmental assessment

There are not any environmental concerns known in this area.

Old Hadley district

Location and mining history

The Old Hadley (or Graphic) district, sometimes described as part of the Cooke's Peak district (Griswold, 1961), is located southeast of the Cooke's Peak district in northern Luna County (Fig. 3, 36). The district is east of the Cooke's Range Wilderness Study Area. Production from 1880 to 1929 is estimated as 150 oz Au, 550 oz Ag, and minor Cu, Pb, and Zn from volcanic-epithermal veins. ASARCO examined the district in the late 1980s and drilled at least one hole; the results of their exploration program are unknown.

The Graphic lode was discovered in 1881. The property changed hands many times until it was acquired by Walter C. Hadley who worked the mine until 1888, at which point it was sold to the Cooke's Peak Mining Company who in turn worked the mine until it closed in 1893. Mining occurred in the northern part of the district until 1938.

FIGURE 36. Mines and prospects in the Old Hadley mining district, Luna County.

Geology

The predominant rock in the district is the Macho Andesite, which is overlain in places by the Rubio Peak Formation (Jicha, 1954). A latite tuff from the Macho Andesite is dated as 40.7±1.4 Ma (biotite, K-Ar; Loring and Loring, 1980). Numerous faults cut the andesite. Silicification and argillic alteration is prominent; acid-sulfate alteration, characterized by alunite and kaolinite, is locally pervasive in Rattlesnake Canyon (Hall, 1978).

Mineral Deposits

Volcanic-epithermal veins occur in altered Macho Andesite in the Old Hadley district (Fig. 36, Appendix 2). The veins are steeply dipping, associated with gypsum and clay alteration, as much as 300 ft long, and typically less than 4 ft wide. Silicification is prevalent adjacent to the veins. The veins trend N0–15°W to N55–65°E and parallel faults and fracture zones. They contain chalcopyrite, galena, sphalerite, and oxidized minerals such as malachite, azurite, chrysocolla, cuprite, and melaconite in a gangue of quartz, barite, pyrite, iron oxides, sericite, chlorite, and other clay minerals (Jicha, 1954; Walters, 1972). Brecciation, silicification, vug filling, and recementation are common, indicating an epithermal origin. The veins are similar to those in the Cooke's Peak district, except the Old Hadley veins contain more gold, barite, and quartz. Alunite is found in an extensively altered area. Anomalous concentrations of As, Bi, Cd, Mo, Pb, Sn, U, and Zn occur in stream-sediment samples in the area and spotty concentrations of silver and antimony are found locally.

Mineral-resource potential

The district has moderate potential for additional volcanic-epithermal vein deposits, including both high sulfidation and low sulfidation deposits. Walters (1972) suggests the area has potential for molybdenum deposits.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns.

Taylor Mountain

Location and mining history

Taylor Mountain is in the northwestern corner of Luna County (Fig. 3). Fire clay has been mined from the district since 1979, amounting to an estimated $185,000 worth of production. Stone also has been produced, but production figures are unknown.

Geology

Taylor Mountain consists of shales and sandstones of the McCrae Formation, which is overlain by rhyolite flows.

Mineral deposits

Clay is quarried from the McCrae Formation(?) at Lucretia quarry at Taylor Mountain (Fig. 37), where rhyolite flows overlie shale beds. Samples collected from the quarry contain illite, smectite, and trace amounts of kaolinite and chlorite (Table 18). The clay is used in smelting copper at the Hurley smelter, north of the quarry.

FIGURE 37. Lucretia clay pit, Taylor Mountain (V. T. McLemore, photo).

Mineral-resource potential

The resource potential for clay is high and moderate for crushed and dimension stone.

Environmental assessment

Known mineralized areas in the district do not pose any environmental concerns.

Tres Hermanas district

Location and mining history

The Tres Hermanas (Mahoney, Cincinnati) district in the Tres Hermanas Mountains near Columbus (Fig. 3) was discovered in 1881. Total production from Pb-Zn skarn, carbonate-hosted Pb-Zn, and vein deposits in the district is unknown; but is estimated from 1885–1957 as $600,000 worth of zinc, lead, silver, gold, and copper (Table 19; McLemore et al., 1996). In 1954, 11.3 tons of manganese ore also was produced (Howard, 1967). The largest mines, Cincinnati, Hancock, and Mahoney, were active in 1905 (Fig. 38; Lindgren et al., 1910) and the Mahoney mine remained in production until 1920 (Griswold, 1961). In 1906–1907, ore was shipped to the Mississippi Valley area for smelting (Lindgren, 1909a, b). Drilling occurred at the Mahoney mine in 1952–1953; but no reserves were found. Eagle-Picher Co. drilled one hole in sec. 35 T27S R8W and three holes in sec 3 T28S R8W in 1959. Assays of altered quartz monzonite were low (0–0.1 oz/ton Au, 0–0.7 oz/ton Ag, 0.1–0.7% Pb, 0.1–2.0% Zn). The results of exploratory drilling in the early 1980s are unknown. Jerry Keaton drilled a hole in 1997, but no mineralized zones were encountered. New mining claims are being staked in the West Lime Hills area in the winter of 2001.

FIGURE 38. Mines and prospects in the Tres Hermanas mining district, Luna County.

Geology

The Tres Hermanas Mountains consist predominantly of a quartz monzonite stock (Fig. 39), originally dated as 50.3±2.6 Ma (hornblende, K-Ar; Leonard, 1982), but McLemore (2000) reports a more accurate $^{40}Ar/^{39}Ar$ age of 34.65±0.28 Ma (Appendix 5). The stock is surrounded by a thick sequence of predominantly Paleozoic and Paleocene sedimentary rocks and Tertiary volcanic rocks (Balk, 1961; Griswold, 1961; Leonard, 1982; Lucas and Estep, 2000). The stock extends beneath the Mahoney and West Lime Hills areas as determined from drill holes. Thrust faults are common; in the West Lime Hills, Permian rocks are thrusted over Late Paleozoic carbonates and Paleogene Lobo Formation (Drewes, 1991). Previous works identified conglomerate and carbonate strata exposed in the western part of the range as Cretaceous (Balk, 1961; Kottlowski and Foster, 1962; Kottlowski, 1963; Drewes, 1991). However, Lucas and Estep (2000) identified the fossils as Late Paleozoic and Paleocene. Many of the Paleozoic limestones have been recrystallized or metamorphosed by the quartz monzonite (Homme, 1958; Homme and Rosenzweig, 1970). A chemical variation with time from older metaluminous andesite, dacite, and rhyolite to younger alkaline rhyolite and latite occurs in the calc-alkaline rocks in the Tres Hermanas Mountains (Leonard, 1982). Basaltic dikes locally intruded the quartz monzonite and Paleozoic rocks. Pliocene cones also are found in the southern Tres Hermanas Mountains north of Columbus (Seager, 1995).

FIGURE 39. Geologic map of Tres Hermanas Mountains (simplified from Balk, 1962).

TABLE 19. Reported metal production from the Tres Hermanas district, Luna County (from U.S. Geological Survey, 1902–1927; U.S. Bureau of Mines, 1927–1990; Griswold, 1961). Estimated total 1876–1965 is the best estimate of total production as determined from available published and unpublished data. — none reported.

YEAR	ORE (SHORT TONS)	COPPER (LBS)	GOLD (OZ)	SILVER (OZ)	LEAD (LBS)	ZINC (LBS)	TOTAL VALUE ($)
1885–1908	—	—	—	—	—	—	200,000
1915	169	—	—	—	—	110,188	14,400
1916	650	—	—	54	8,400	431,360	54,900
1917	412	—	—	194	15,544	281,122	9,000
1918	137	—	—	180	27,420	74,686	8,000
1919	—	—	—	—	—	—	—
1920	41	—	—	381	34,604	—	3,000
1921–1925	—	—	—	—	—	—	—
1926	19	—	—	135	14,668	—	3,000
1927–1933	—	—	—	—	—	—	—
1934	41	—	0.92	1,075	34,100	—	1,989
1935	14	—	0.60	121	2,500	—	208
1936	54	150	4.00	647	11,400	—	1,179
1937–1939	—	—	—	—	—	—	—
1940	6	—	—	42	1,300	—	95
1941	—	—	—	—	—	—	—
1942	105	—	—	242	21,000	32,000	4,555
1943	61	—	—	—	6,000	22,000	2,826
1946	2	—	—	26	—	—	21
1947	24	300	—	344	500	—	446
1948	67	—	1.00	273	4,000	—	998
1950	13	—	—	52	2,000	—	317
1951	79	—	—	31	8,000	26,600	6,253
1952	7	—	—	21	500	1,000	265
1956	92	100	—	97	—	—	131
1957	5	—	—	33	1,200	—	202
PRODUCTION 1915–1957	1,998	550	7	3,948	193,136	978,956	111,785
ESTIMATED PRODUCTION 1885–1957	—	550	7	4,000	200,000	1,000,000	600,000

Mineral Deposits

Three types of deposits, Pb-Zn skarn, carbonate-hosted Pb-Zn, and vein deposits, occur in the Tres Hermanas district. The age of the mineral deposits is Tertiary; they most likely formed after intrusion of the quartz monzonite, but prior to intrusion of basaltic dikes (Griswold, 1961; Doraibabu and Proctor, 1973). Geochemical data are consistent with a source of mineralization from the quartz monzonite, although locally the older bedrock may have contributed metals (Doraibabu and Proctor, 1973). Multiple periods of mineralization are likely, as suggested by variation in mineralization style and alteration.

The most productive deposits are the Pb-Zn skarn and carbonate-hosted Pb-Zn occurrences in the Escabosa Limestone (Mississippian) and overlying Pennsylvanian sedimentary rocks. Tabular- to pod-shaped mantos or skarns, commonly silicified, are controlled by fractures and faults, which trend east-west and north-south. Mantos or skarns are locally common in limestone xenoliths in the quartz monzonite and in limestone adjacent to the stock. Ore minerals consist predominantly of sphalerite, galena, chalcopyrite, willemite, calamine, smithsonite, and other oxidized lead-zinc minerals in a gangue of calcite, quartz, pyrite, and calc-silicate minerals (Table 20; Lindgren et al., 1910; Wade, 1913; Homme and Rosenwieg, 1970). Ore at the Mahoney mine averaged 26.7% Pb, 34.5% Zn, and 5.9 oz/short ton Ag. Gold assays range as high as 1,500 ppb Au (Griswold et al., 1989). The Mahoney and Lindy Ann mines were the largest producers. Scheelite is reported in a skarn near South Peak (Griswold, 1961).

TABLE 20. Selected minerals found in the Tres Hermanas mining district (from Holser, 1953; Griswold, 1961; DeMark, 1992; Northrop and LaBruzza, 1996).

MINERAL	CHEMICAL FORMULA	MINERAL	CHEMICAL FORMULA
SILICATES		**SULFIDES, SULFATES, METALS**	
Actinolite	$Ca_2 (Mg,Fe^{++})_5Si_8O_{22} (OH)_2$	Pyrite (1, 2)	FeS_2
Biotite	$K(Mg,Fe^{++})_2[AlSi_3O_{10}(OH,F)_2$	Chalcopyrite (1, 2)	$CuFeS_2$
Epidote	$Ca_2 (Fe,Al)Al_2 (SiO_4)(Si_2O_7)O(OH)$	Sphalerite (1, 2)	(Zn, Fe)S
Dumortierite	$Al_{26.5-7}(BO_3)(SiO_4)_3(O,OH)_3$	Argentite (1)	Ag_2S
Sanidine	$(K,Na)(Si,Al)_4O_8$	Chlorargyrite (1)	AgCl
Microcline	$KAlSi_3O_8$	Galena (1, 2)	PbS
Muscovite var. sericite	$KAl_2 (Si_3Al)O_{10}(OH,F)_2$	Anglesite (1)	$PbSO_4$
Diopside	$CaMgSi_2O_6$	Arsenopyrite	FeAsS
Hemimorphite (1)	$Zn_4Si_2O_7(OH)_2{\cdot}H_2O$	**OXIDES**	
Quartz (1, 2)	SiO_2	Pyrolusite	MnO_2
Zoistite var. saussurite	$Ca_2Al_{23}(SiO_4)_{23}(OH)$	Gehlenite	$Ca_2Al(AlSi)O_7$
Titanite	$CaTiSiO_5$	Magnetite (2, 3)	Fe_3O_4
Orthoclase	$KalSi_3O_8$	Zincite	Zn,Mn)O
Grossular	$Ca_3Al_2 (SiO_4)_3$	Hematite	Fe_2O_3
Merwinite	$Ca_3Mg(SiO_2)_2$	Wulfenite	$PbMoO_4$
Monticellite	$CaMgSiO_4$	**OTHER**	
Willemite	Zn_2SiO_4	Fluorite (2)	CaF_2
Wollastonite	$CaSiO_3$	Antigorite	$(Mg,Fe^{++})_3Si_2O_2(OH)_4$
CARBONATES		Bromargyrite	AgBr
Calcite (1, 2)	$CaCO_3$	Conichalcite	$CaCu(AsO_4)(OH)$
Smithsonite (1)	$ZnCO_3$	Fornacite	$(Pb,Cu)_3[(Cr,As)O4]_2 (OH)$
Dolomite	(Ca, Mg) CO_3	Vesuvianite	$Ca10Mg_2Al_4(SiO_4)_25(Si_2O_7)_2 (OH)_4$
Cerussite (1)	$PbCO_3$	Scapolite	$(Na,Ca)_24[Al_3Si_9O_{24}]Cl$
Aragonite	CaCO3	Gold	Au
Azurite	$Cu_2(CO_3)_2 (OH)_2$	Silver	Ag
Malachite	$Cu_2 (CO_3)(OH)_2$	Hydrogrossular	$Ca_3Al_2 (Si_4)_{3-x}(OH)_{2x}$(x=0.2-1.5)
Spurrite	$Ca_2(SiO_4)_2 (CO_3)$	Hydrozincite	$Zn_5(CO_3)_2(OH)_6$
		Molybdofornacite	$Pb_2Cu[(As,P)O_4][(Mo,Cr)O_4](OH)$
		Prehnite	$Ca_2Al_2Si_3O_{10}(OH)_2$

Fissure veins in quartz monzonite contain galena, willemite, smithsonite, and hydrozincite, and samples assayed 29–37% Zn, 11–40% Pb, and 68.5 ppm Ag (Lindgren, 1909a, b). Veins also occur along faults and fractures in Paleozoic sedimentary clastic rocks, quartz monzonite, and Tertiary volcanic rocks. The most productive veins, such as the Cincinnati, trend east-west; the north-trending veins have been less productive (Doraibabu and Proctor, 1973). The Cincinnati vein strikes N75°E, dips 75–80° S, and is 90–150 ft long. Most veins are less than 4 ft wide. Disseminated pyrite, chalcopyrite, sphalerite, and galena occur sporadically throughout the quartz monzonite stock, suggesting the potential for a porphyry copper and/or copper-molybdenum deposit; although the stock is not extensively altered as typical porphyry copper deposits. However, drilling in the stock has failed to reveal any economic concentrations (Griswold, 1961; NMBGMR file data).

A leaching operation occurred at the Cannon mine (Fig. 40) where copper minerals are found disseminated and in thin stockwork veins in andesite (Fig. 41).

FIGURE 40. Leach tanks at the Canon mine, Tres Hermanas district (V. T. McLemore, photo).
FIGURE 41. Fracture disseminated and stockwork veins at the Canon mine (V. T. McLemore, photo).

Mineral-resource potential

Most of the mines in the Tres Hermanas district are shallow; only a few reach depths of 300–500 ft. None of the deposits have been explored at greater depths, especially in the Mahoney and Cincinnati mines (Griswold, 1961). Areas of pyrite disseminations need examination, for example secs. 26, 27, T27S, R9W. Where alluvium covers the extensions of these deposits also are favorable, but requires drilling. Anomalous concentrations of As, Ba, Be, Co, Cd, La, Mn, Mo, Pb, Sb, Th, Ti, Y, and Zn are found in stream-sediment samples from the area.

Locally, marble occurs adjacent to the quartz monzonite surrounding the Tres Hermanas Mountains (Griswold, 1961; Leornard, 1982). The marble was originally Paleozoic limestone and dolostone and is medium to coarse grained with local intercalculated bands of garnet. The quantity of resources of marble for dimension stone is unknown. Yellow and white travertine (Mexican onyx) occurs in bands as much as 5 ft thick in latite on the southern slopes of the Tres Hermanas Mountains (sec. 24, T28S, R9W) and could be mined for local use. Spurrite, a rare pale-gray to purple mineral valued by collectors and used as an ornamental stone, occurs in a limestone xenolith in quartz monzonite on the east slope of South Sister Peak (Griswold, 1961).

The Pliocene cones in the southern Tres Hermanas Mountains need to be examined for potential for scoria and basalt.

Environmental assessment

With a few exceptions, most known mineralized areas in the district do not pose any environmental concerns. Lead is high in many deposits, but there is no acid-generating rock, therefore the lead is not likely to be mobilized. The presence of carbonate rocks provides a natural neutralizing environment for any potential acid drainage that might occur from future exploration and mining. Two mines should be examined in more detail; Canon and Homestake. A leaching operation existed at the Canon mine and acid drainage is found at the Homestake mine.

Victorio district

Location and mining history

The Victorio (Mine Hill, Middle Hill) district is in central Luna County, west of Deming (Fig. 42) and was discovered in the late 1800s. Production of carbonate-hosted Pb-Zn (Ag, Cu) deposits began about 1880. Most of the early production was from the Chance and Jessie mines where $800,000–$1,600,000 worth of lead, zinc, and silver were produced (Jones, 1904; Lindgren et al., 1910). Mining continued until 1957. An estimated 70,000 to 130,000 short tons of ore were mined between 1880 and 1957 and yielded approximately $2.3 million worth of lead, zinc, silver, gold, and copper, including 17.5 million lbs Pb and >60,000 lbs Zn (Table 21; McLemore and Lueth, 1996).

The Victorio district was discovered in the late 1800s by three prospectors, William Kent, William Hyters, and J. L. Doughterty and was developed by George Hearst and his partners. George Hearst was father of William Randolph Hearst. The district and surrounding mountains were probably named after Hearst's ranch, Victorio, which may have been named after the Apache war chief. Production of carbonate-hosted Pb-Zn replacement deposits began about 1880, coinciding with the arrival of the Southern Pacific Railroad. Most of the early production (1880–1886) was from the Chance and Jessie mines where $800,000–$1,600,000 worth of lead, zinc, and silver were produced by Hearst (Fig. 42; Jones, 1904; Lindgren et al., 1910). The Gage Mining Co. controlled most of the mines on Mine Hill in 1914. The Victorio Mining Co. operated the Jessie and Chance mines in 1936–1940.

Beryllium and tungsten vein and skarn deposits were discovered in the Victorio Mountains in the early 1900s (Griswold, 1961; Holser, 1953; Dale and McKinney, 1959). Tungsten was produced from 1942 to 1944 from the mines at Tungsten Hill (Fig. 42). In 1942, approximately 20,000 short tons of ore containing an average of 1% WO_3 were produced from the Irish Rose claim and was worth nearly $70,000 (Dale and McKinney, 1959). The ore contained mostly scheelite with some galena, smithsonite, and helvite. In addition, 19.6 short tons of 60% WO_3 were produced from the mine in later years.

FIGURE 42. Mines and prospects in the Victorio mining district, Luna County.

Mining continued in the district sporadically until 1957, mostly from the carbonate-hosted Pb-Zn replacement deposits (Table 21). Total production is estimated as 70,000–130,000 short tons of ore mined between 1880 and 1957, which yielded approximately $2.3 million worth of lead, zinc, silver, gold, and copper, including 17.5 million lbs Pb and >60,000 lbs Zn (Table 21; McLemore and Lueth, 1996; McLemore et al., 1996). Limestone also was quarried for aggregate for highway construction.

TABLE 21. Reported metal production from the Victorio district, Luna County (from U. S. Geological Survey, 1902–1927; U. S. Bureau of Mines, 1927–1990; Griswold, 1961). Estimated total 1876–1965 is the best estimate of total production as determined from available published and unpublished data. — none reported.

YEAR	ORE (SHORT TONS)	COPPER (LBS)	GOLD (OZ)	SILVER (OZ)	LEAD (LBS)	ZINC (LBS)	TOTAL VALUE ($)
1880–1903	—	—	—	—	—	—	1,150,000
1904	274	—	—	2047	76,465	—	6170
1905	—	—	—	—	—	—	—
1906	620	—	19.98	2876	186,000	—	12,971
1907	1200	—	—	3600	408,000	—	24,992
1908	—	—	—	—	—	—	—
1909	183	1069	—	2460	85,418	—	5381
1910	22	—	—	267	21,318	—	1085
1911	180	1598	5.03	883	66,250	—	3753
1912	2123	—	275.11	23,305	684,867	7865	51,382
1913	3895	58	536.24	40,416	902,781	—	75,227
1914	132	—	—	552	35,599	—	1851
1915	216	2320	—	1476	53,958	—	4147
1916	1804	—	171.01	8436	381,000	—	35,375
1917	1505	270	—	11,301	428,907	—	51,449
1918	1631	—	—	14,358	323,493	—	45,497
1919	1728	538	238.30	10,438	356,775	—	35,626
1920	1331	1641	—	10,167	298,113	—	41,894
1921	676	—	71.98	4709	144,467	—	12,698
1922	158	—	—	583	28,622	—	2529
1923	468	1028	62.89	2195	64,930	—	7796
1924	285	—	—	485	47,975	—	4295
1925	609	1000	—	2833	116,600	—	13,075
1926	129	—	7.20	633	22,500	—	2344
1927	28	—	—	224	7398	—	638
1928	40	—	—	188	9000	—	717
1929	278	284	—	1004	27,000	—	2516
1930–1934	—	—	—	—	—	—	—
1935	40	—	5.60	259	4900	—	578
1936	<1	—	—	11	100	—	14
1937	1009	2815	93.40	3589	67,000	—	10,339
1938	3595	6000	397.4	13,283	210,000	—	32,744
1939	3493	8700	453	16,802	278,800	—	41,269
1940	903	2600	113	3981	78,700	—	11,015
1941–1946	—	—	—	—	—	—	—
1947	1509	2400	24	2535	107,800	42,600	24,316
1948	119	—	1.0	347	18,000	—	3571
1949	—	—	—	—	—	—	—
1950	73	—	1.0	275	6000	—	1094
1951–1954	—	—	—	—	—	—	—
1955	57	—	1	175	2000	—	491
1956	—	—	—	—	—	—	—
1957	53	—	—	239	4809	2000	1134
TOTAL 1904–1957	30,367	32,321	2477.14	186,932	6,233,492	52,465	569,973
ESTIMATED TOTAL 1880–1959	70,000–130,000	41,000	12,200	581,500	17,500,000	>60,000	2,330,700

Most of the workings are on Mine Hill in the southern part of the Victorio Mountains (Fig. 42), coinciding with the area of significant production from carbonate-hosted Pb-Zn replacement deposits (Griswold, 1961). Several shafts are 250 ft deep and underground workings are extensive (Griswold, 1961; V. T. McLemore, unpublished field notes, December 1993). Most of these workings have been closed by the New Mexico Abandoned Mine Lands Bureau in 1994. The W-Be-Mo skarn/vein deposits are found in the Middle Hills north of Mine Hill.

Exploration since the 1950s has been modest; most companies were exploring for porphyry copper deposits. In 1969–1970, Humble Oil Co. drilled four holes and encountered skarns, but they did not find any significant porphyry copper deposits. Keradamex drilled two holes in 1971 without encountering any significant mineralized zones. Asarco, Rosario Exploration, Southern Union Co., Newmont, Donegan and Donegan, Leonard Resources, and Bethlehem Copper Corp. also examined the area. Gulf Minerals Resources, Inc. drilled 71 holes in 1977–1983 and delineated a porphyry Mo and Mo-Be-W skarn deposit northwest of Mine Hill and south of Middle

Hills (Fig. 42). At a cut-off grade of 0.02% WO_3, resources were estimated as 57,703,000 tons of 0.129% Mo and 0.142% WO_3. Open pit resources were estimated as 11,900,000 tons of 0.076% WO_3 and 0.023% Be (Bell, 1983). In 1987–1988, Cominco American Resources examined the district for gold potential and drilled 15 holes on and around Mine Hill, and found minor intercepts of mineralized zones. Santa Fe Pacific Mining, Inc., drilled 18 holes in 1990–1991 and Echo Bay Exploration, Inc., drilled 8 holes in 1993. Gage Mining Co. owns most of the patented claims on Mine Hill and the Middle Hills is mostly federal land.

Geology

Proterozoic rocks and the Cambrian-Ordovician Bliss Formation were encountered in drill cores from the Victorio district despite not being exposed at the surface (Fig. 43, 44). Proterozoic rocks consist of quartzo-feldspathic gneiss and amphibolite. In the subsurface, the Bliss Formation is variable in thickness, ranging from 100 to 125 ft (Fig. 44; Heidrick, 1983). The Bliss Formation lies unconformably on Proterozoic basement with a 3-ft-thick basal conglomerate consisting of subangular to subrounded Proterozoic metamorphic rocks and quartz pebbles in a fine sand matrix. The next 12–20 ft is typically a clean orthoquartzite. The upper 75 ft of the Bliss Formation has two distinct lithologies, a silty quartzite unit and a limey to dolomitic siltstone. In drill core, both of these lithologies host significant W-Be-Mo skarn/vein deposits.

FIGURE 43. Simplified cross section of the Victorio Mountains (modified from company drill data and unpublished mapping by V. T. McLemore). Some of the drill holes are projected onto the cross section.

FIGURE 44. Simplified geologic map of the Victorio Mountains (modified from Kottlowski, 1960a, 1963; Thorman and Drewes, 1980; unpublished mapping by Gulf Resources, Inc.; unpublished mapping by V. T. McLemore). Line A-A' is shown in Figure 43.

The oldest rocks exposed at the surface in the area are Ordovician thin- to medium-bedded limestones, dolostones, and calcarenites with chert interbeds of the El Paso Group (Figs. 43, 44; Kottlowski, 1960a, 1963; Thorman and Drewes, 1980). Locally the El Paso Group unconformably overlies the Bliss Formation in the subsurface and is conformably overlain by the Montoya Group. The Fusselman Formation lies conformably on the Montoya Group and consists of 30–900 ft of fine- to coarse-grained dolostone. The Victorio Mountains contain one of the western most outcrops of the Fusselman Formation (Thorman and Drewes, 1980). The Fusselman Formation is thickest at Mine Hill and thins to the north.

Lucas et al. (2000) correlated the Lower Cretaceous Bisbee Group sediments to the Hell-to-Finish and U-Bar formations on the basis of rare fossils, lithologies, and stratigraphic sections. Conformably overlying the U-Bar Formation is a sequence of conglomerate, sandstone, siltstone, and volcanic flows and breccias. Purple to maroon to gray dacite flows and flow breccias occur at the base that may correlate with the Hidalgo Formation (~71 Ma) exposed in the Little Hatchet Mountains (Lawton et al., 1993; Young et al., 2000). The dacite flows and flow breccias are overlain by clastic sedimentary rocks that Lawton and Clemons (1992) correlated to the Eocene Lobo Formation.

The Main Ridge of the Victorio Mountains is made up of Tertiary volcanic and volcaniclastic rocks, called the Victorio Peak dacite, which unconformably overlies the Lobo Formation. The Victorio Peak dacite consists of agglomerates, flow breccias, tuffs, and dacite lavas, including a 41.7±2 Ma dacite breccia (zircon, fission track; Thorman and Drewes, 1980). A 3–6-ft thick white to light gray, rhyolitic ash-flow tuff crops out in the upper part of the Victorio Peak dacite, north of the microwave towers. Ash-flow tuffs also make up South Hills, south of the mapped area shown in Figure 44. If the fission track age is correct, than the Victorio Peak dacite is correlative with the Rubio Peak Formation.

The Victorio Granite is 35 Ma (McLemore et al., 2000b) and it is found only in the subsurface. Based on petrographic observation, it is medium–coarse grained and consists of K-feldspar, plagioclase, quartz, biotite, ±muscovite, with trace pyrite, scheelite, apatite, garnet, fluorite, and zircon. The southern portion of the granite is a two-mica muscovite-biotite granite, whereas the northern portion is a biotite granite. The Victorio Granite mostly intrudes Proterozoic rocks, but also cuts the Bliss Formation in two drill holes (Fig. 43). Furthermore, there are several rhyolite dikes that branch upward from the main granitic body. The Victorio Granite is mostly unaltered with only small amounts of weak argillic to weak phyllic alteration. Molybdenite and scheelite also have been found in the Victorio Granite.

Sills and steeply-dipping dikes of basalt, andesite, dacite, and rhyolite porphyry intruded the Paleozoic and Cretaceous sedimentary rocks, especially in the Middle Hills area (Fig. 43). The altered Irish Rose rhyolite porphyry dike at the Irish Rose mine in the Middle Hills is nearly flat lying, but cuts bedding in the limestone and dolostone.

An altered rhyolite dike intruded a fault at the Rambler-Excess mines at Mine Hill (Griswold, 1961). Altered andesite and rhyolite dikes also intruded the limestones and dolostones on East Hills.

A breccia pipe crosscuts the limestone in the Middle Hills (Fig. 43, 44). It consists of angular and brecciated fragments of quartz, quartz sandstone, conglomerate, limestone, granite, marble, andesite, rhyolite, quartzo-feldspathic gneiss, and is cemented mostly by quartz, rock flour, and hematite. Based on the presence of what are interpreted to be granite fragments in the breccia pipe, the breccia pipe is thought be related to a late stage of Victorio Granite crystallization. Quartz veins, some of which contain trace amounts of pyrite and possibly molybdenite, locally cut the breccia pipe. A rhyolite dike intruded the breccia pipe and was dated as 24.8 Ma (fission track, zircon, Thorman and Drewes, 1980). These field relationships indicate that rhyolite intrusion occurred before and after formation of the breccia pipe and that the breccia pipe is younger than the marble formation.

Mineral Deposits

Based on field mapping and examination of drill core, three types of deposits have been found in the Victorio Mountains: 1) carbonate-hosted Pb-Zn replacement, 2) W-Be-Mo skarn/vein, and 3) porphyry Mo deposits. The porphyry Mo deposits are not exposed at the surface and found only in drill core in the Victorio Granite.

The carbonate-hosted Pb-Zn replacement deposits occur as oxidized vein and replacement deposits within Ordovician and Silurian dolostones and limestones at Mine Hill. The deposits include replacements in carbonate rocks with little or no calc-silicate minerals and minor replacement veins in carbonate rocks. They are typically lead/zinc dominant, with by-product copper, silver, and gold (Appendix 4). Recognizable silver and gold minerals are rare; reported minerals are in Table 22. The more productive deposits in the Victorio district occur along faults or fractures that strike N30–65°E (Fig. 44). Some veins are as much as 800 ft long. Brecciation, dissolution, and recrystallization of the dolostones are common in the vicinity of the mineral deposits (Fig. 45, 46). The faults exhibit both pre- and post-mineralization movement (Griswold, 1961). Ore minerals include galena, smithsonite, cerussite, and anglesite with rare sphalerite and chalcopyrite in a gangue of quartz, calcite, and iron oxides. Ore produced from the Rambler mine averaged 12.5% Pb and 3.9% Zn (NMBGMR file data). Gold assays range as high as 5.5 ppm (Appendix 4; Griswold et al., 1989).

At the surface, the W-Be-Mo skarn/vein deposits occur as small veins and replacement lenses within the Ordovician limestones and dolostones in the vicinity of rhyolite intrusions. Samples assayed by Warner et al. (1959) ranged from 0.002 to 0.3% Be and 0.01 to 0.04% W. In drill core, nearly all of the Ordovician and Cambrian sedimentary rocks are mineralized to some extent. Based on optical examination, ore minerals include helvite, wolframite, scheelite, molybdenite, galena, sphalerite, and beryl in a gangue of quartz, calcite, and local talc, grossularite, tremolite, pyroxene, idocrase, and phlogopite (Holser, 1953; Warner et al., 1959; Richter and Lawerence, 1983; Northrop and LaBruzza, 1996; McLemore et al., 2000b). Campbell and Robinson-Cook (1987) found that fluid inclusions in wolframite from the Victorio mining district had temperatures of homgenization of 280–380ºC and salinities of 5.4–8.9 eq. Wt. % NaCl. Quartz fluid inclusions had temperatures of homgenization of 141–320ºC and salinities of 1.3–10 eq. Wt. % NaCl.

Several samples of W-Be-Mo skarn/vein deposits from drill cores were examined using the electron microprobe. A diverse mineral assemblage consistent with that observed petrographically was found within the skarn replacement and vein samples. Sulfides and associated metallic phases include molybdenite, pyrite, sphalerite, scheelite-powellite solid solution, galena and Fe-oxides. Other phases include garnet, pyroxene, actinolite, serpentine, phlogopite, calcite, quartz, talc, and fluorite.

A wide range of sulfides and other metallic minerals are observed in the skarn samples (McLemore et al., 2000b), and these also were examined using the microprobe. These include euhedral rods or masses of molybdenite, sphalerite, fine galena, a blocky iron sulphide, probably pyrite, Fe oxides, blocky masses of scheelite ($CaWO_4$), powellite ($CaMoO_4$), and a more-or-less complete solid solution between scheelite and powellite. The Fe oxides are typically finely dispersed throughout the sample. These metal-bearing minerals are more abundant in the samples that show a distinct vein morphology as compared to the skarn replacement samples. In some samples, distinct bands of concentrated metal-bearing phases are present along vein margins, suggesting intervals of favorable conditions for ore formation during the growth of the veins. However, in other samples, the metal-bearing minerals are dispersed throughout the sample.

The distribution and composition of W-Be-Mo skarn/vein deposits appear to be stratigraphically controlled. In the Bliss Formation, the three major lithologies have distinct differences in Mo-W ratios, vein thickness, and vein density. Lenses of dense mineralization occur in some Bliss lithologies, whereas others are nearly barren. The calcium-poor orthoquartzite contains very little scheelite, which occurs as thin veinlets. The silty glauconitic facies is richer in calcium and has intermediate tungsten values. The molybdenite in this facies is vein-controlled while the scheelite is predominantly disseminated. The silty limestone facies contains enough calcium to precipitate significant disseminated scheelite. The veins in this facies are thicker and more common. Molybdenum mineralization is primarily vein-controlled with minor dissemination. There also is a strong positive correlation between disseminated and vein-controlled W-Mo mineralization and disseminated fluorite mineralization (Heidrick, 1983).

Gulf Minerals Resources, Inc. drilled 71 drill holes northwest of Mine Hill and found a subeconomic Mo-W-Be deposit at depths ranging from 800 to 1400 ft. Ore minerals include molybdenite, powellite, scheelite, beryl, helvite, bismuthinite, and wolframite.

Two small copper-veins cut dacite flows on the Main Ridge in the Victorio Mountains and are the only mineralized zones encountered north of the Victorio Mountains fault. The veins are less than 3 ft wide, a several feet long, and consist of calcite, quartz, malachite, azurite, and trace amounts of oxidized pyrite. They strike N40–45°E and are steeply dipping. The Highway Department operated a limestone quarry for use in road construction (Fig. 47).

FIGURE 45. Close-up view of a 3-ft wide vein in limestone at Mine Hill, Victorio mining district. Center of vein consists of calcite, smithsonite, anglesite, cerussite, and iron oxides (V. T. McLemore photo).

FIGURE 46. Fissure vein in limestone at the Parole mine, Mine Hill, Victorio mining district. Limestone to the left of the vein is relatively unaltered, whereas the limestone to the right of the vein is replaced by iron and manganese oxides (V. T. McLemore photo).

FIGURE 47. Limestone quarry in Victorio Mountains (V. T. McLemore photo).

Mineral-resource potential

Gulf Minerals Resources, Inc. drilled 71 holes in 1977–1983 and delineated a porphyry Mo and Mo-Be-W skarn deposit, northwest of Mine Hill, south of the Middle Hills. At a cut off grade of 0.02% WO_3, resources were estimated as 57,703,000 tons of 0.129% Mo and 0.142% WO_3. Open pit resources were estimated as 11,900,000 tons of 0.076% WO_3 and 0.023% Be (Bell, 1983).

The district yielded minor gold production (Table 21) and some of the higher gold assays come from selected samples in the Victorio district (as much as 2.7 ppm Au; Appendix 4) and could be indicative of concealed sedimentary-hosted gold deposits and/or gold skarn deposits. Drilling of favorable areas is required to determine if such deposits exist.

Environmental assessment

With a few exceptions, most known mineralized areas in the district do not pose any environmental concerns. Lead is high in many deposits, but there is no acid-generating rock, therefore the lead is not likely to be mobilized. The presence of carbonate rocks provides a natural neutralizing environment for any potential acid drainage that might occur from future exploration and mining. Arsenic has been reported in the lead-silver ore.

TABLE 22. Selected minerals found in the Victorio mining district (from Holser, 1953; Griswold, 1961; DeMark, 1992; Northrop and LaBruzza, 1996; Beyer, 1997; McLemore et al., 2000a; Gulf Minerals company reports). Minerals in bold are newly reported by McLemore et al. (2000a). Type of deposit in parenthesis: 1—carbonate-hosted Pb-Zn replacement deposits, 2—Be-Mo-W skarn/vein deposits, and 3—porphyry Mo deposits.

MINERAL	CHEMICAL FORMULA	MINERAL	CHEMICAL FORMULA
SILICATES		**SULFIDES, SULFATES, METALS**	
Chondrodite (2)	$(Mg, Fe)_5(SiO_4)_2(F, OH)_2$	**Pyrrhotite** (1, 2, 3)	Fe_xS
Humite (2)	$(Mg, Fe)_7(SiO_4)_3(F, OH)_2$	**Marcasite** (1, 2)	FeS_2
Clinohumite	$(Mg, Fe)_9(SiO_4)_4(F, OH)_2$	Pyrite (1, 2, 3)	FeS_2
Helvite (2)	$Mn_4Be_3(SiO_4)_3S$	**Chalcopyrite** (1, 2)	$CuFeS_2$
Danalite (2)	$Fe_4Be_3(SiO_4)_3S$	Bornite (1)	Cu_5FeS_4
Willemite (1)	Zn_2SiO_4	Tetrahedrite (2?)	$(Cu,Fe)_{12}Sb_4S_{13}$
Zircon (3)	$ZrSiO_4$	Sphalerite (1, 2)	(Zn, Fe)S
Garnet (2, 3)	Range of compositions	**Wurtzite** (1)	(Zn,Fe)S
Allanite (3)	$(Y, Ce, Ca)_2(Al, Fe)_3(SiO_4)_3(OH)$	Molybdenite (2, 3)	MoS_2
Beryl (2, 3)	$Be_3Al_2Si_6O_{18}$	Gold (1)	Au
Diopside (2)	$CaMgSi_2O_6$	Argentite (1)	Ag_2S
Augite (2)	$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$	Chlorargyrite (1)	AgCl
Tremolite (2)	$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	Galena (1, 2)	PbS
Phlogopite (2)	$KMg_3Si_3AlO_{10}(F, OH)_2$	Anglesite (1)	$PbSO_4$
Serpentine (2)	$(Mg, Fe, Ni)_3Si_2O_5(OH)$	Friedrichite (1)	$Pb_5Cu_5Bi_7S_{18}$
Talc (2)	$Mg_3Si_4O_{10}(OH)_2$	**Galenobismutite** (2, 3)	$PbS \cdot Bi_2S_3$
Hemimorphite (1)	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$	**Bismuthinite** (2, 3)	Bi_2S_3
Quartz (1, 2, 3)	SiO_2		
Scapolite (2)	$(Na,Ca)_4Al_{3\text{-}6}Si_{6\text{-}9}O_{24}$ (Cl,CO_3,SO_4)	**OXIDES**	
		Adamite (1)	$Mg_5B_{12}O_{20} \cdot 15H_2O$
CARBONATES		Psilomelane (1, 2)	Mn oxide
Calcite (1, 2, 3)	$CaCO_3$	Magnetite (2, 3)	Fe_3O_4
Rhodochrosite (3)	$MnCO_3$	**Cassiterite** (2?)	SnO_2
Reevesite (1)	$Ni_6Fe_2(CO_3)(OH)_{16} \cdot 4H_2O$	Wulfenite (1, 2)	$PbMoO_4$
Smithsonite (1)	$ZnCO_3$	Vanadinite (1, 2)	$Pb_5(VO_4)_3Cl$
Cerussite (1)	$PbCO_3$	Mimetite (1)	$Pb_5(AsO_4)_3Cl$
Beyerite (2)	$(Ca, Pb)Bi_2(CO_3)_2O_2$	Descloizite (1)	$PbZn(VO_4)(OH)$
Bismutite (2)	$Bi_2(CO_3)O_2$		
Aurichalcite (1)	$(Zn, Cu)_5(CO_3)_2(OH)_6$	**OTHER**	
Kettnerite (1)	$CaBi(CO_3)OF$	Fluorite (2, 3)	CaF_2
		Kolfanite (1)	$Ca_2Fe_3O_2(AsO_4)_3 \cdot 2H_2O$
TUNGSTATES		Bromargyrite (1)	AgBr
Scheelite (2)	$CaWO_4$	Carminite (1)	$PbFe_2(AsO_4)_2(OH)_2$
Powellite (2)	$CaMoO_4$	Beudantite (1)	$PbFe_3(As,O_4)(SO_4)(OH)_6$
Hübnerite (2)	$MnWO_4$	Pyromorphite (1)	$Pb_5(PO_4)_3Cl$
Wolframite (1, 2)	$(Fe, Mn)WO_4$		
Stolzite (2)	$PbWO_4$		

Other areas in Luna County

Aden district

Scoria deposits occur in more than 150 cinder cones in the Aden (Potrillo, Black Mountain) district in the Potrillo Mountains, Doña Ana and Luna Counties (Seager and Mack, 1995; Seager, 1995; McLemore, 1998), but only a few have been quarried and none in Luna County. Total production is unknown, but value of production from 1950–1994 is estimated as $10 million (McLemore, 1998). In the West Potrillo Mountains, Mt. Riley, and Aden Lava Flow Wilderness Study Areas, Kilburn et al. (1988) estimates an inferred resource of at least 400 million cubic yards. Active operations are located in Doña Ana County outside of these restricted areas. A few cones occur in eastern Luna County, but it is unlikely that they would be mined because existing mines closer to Las Cruces and El Paso have sufficient reserves for the near future.

Black Mountain

Black Mountain is northwest of Deming and was used as a firing range by the Army National Guard. It consists of basaltic andesite overlying Tertiary volcaniclastic sediments. Scoria and black cinder is reported at Black Mountain (Weber, 1965; Griswold, 1961). The mountain is approximately 2,500 ft in diameter at the base and 530 ft high (McLemore et al., 1996). This area needs examination to determine the resource potential for scoria and basalt.

Columbus

Basaltic flows near Columbus, including Pancho Villa and El Malpais are alkaline basalt and are 3.0 to 3.8 Ma (Seager et al., 1984; McLemore, 2000a, b). This area needs examination to determine the resource potential for scoria and basalt.

Deming

A small quantity of bricks were made from clay deposits in Luna County prior to 1937 (Talmage and Wootton, 1937). Adobe bricks were made in Deming in the early 1980s from Quaternary alluvial and valley fill deposits. As Deming continues to grow, adobe bricks manufacture could again become economical. The resource potential for common clay in the Deming area for adobe bricks is high.

Deming also is the site of a small gravity-separation mill, now operated by Southwest American Minerals, Inc. Manganese ores were mined from throughout New Mexico and shipped to the federal manganese stockpile in Deming (Gundiler, 2000a, b). The Deming depot was closed in 1965 and Southwest American Minerals, Inc. bought the remaining reserves in Deming. Since 1990, the company has been reprocessing the low-grade tailings at a rate of 400–600 short tons per day for use in industrial markets, primarily as additives to glass, glazes, and bricks.

Red Mountain

Red Mountain consists of flow-banded rhyolite and probably represents a dome. Several pits are found on the northeast flank (Appendix 2) and are developed mostly in unaltered rhyolite. Some of the dump material exhibits Mn oxides along fractures, but no obvious additional alteration is present. The rhyolite could be used for crushed stone, but it is too fractured and foliated to be used as dimension stone.

Snake Hills

There is no evidence of prospecting in the Snake Hills, south of Deming where carbonate rocks belonging to the Bliss Formation and El Paso and Montoya Groups are exposed (Seager, 1995). However, some of these carbonate rocks have been recrystallized and contain 2–42 ppb Au (Griswold et al., 1989). Detailed geochemical sampling followed by drilling is required in the Snake Hills to fully assess the economic potential.

ASSESSMENT OF MINERAL-RESOURCE POTENTIAL

Introduction

Definitions

Mineral resources are the naturally occurring concentrations of materials (solids, gas, or liquid) in or on the earth's crust that can be extracted economically under current or future economic conditions. Reports describing mineral resources vary from simple inventories of known mineral deposits to detailed geologic investigations.

A *mineral occurrence* is any locality where a useful mineral or material occurs. A *mineral prospect* is any occurrence that has been developed by underground or above ground techniques or by subsurface drilling. These two terms do not have any resource or economic implications. A *mineral deposit* is a sufficiently large concentration of a valuable or useful mineral or material that was extracted or may be extracted under current or future economic conditions. A *mine* is any prospect that produced or is currently producing a useful mineral or commodity.

The *mineral-resource potential* of an area is the probability that a mineral will occur in sufficient quantities so that it can be extracted economically under current or future conditions (Taylor and Steven, 1983). Mineral-resource potential is preferred in describing an area, whereas mineral-resource favorability is used in describing a specific rock type or geologic environment (Goudarzi, 1984). The mineral-resource potential is not a measure of the quantities of the mineral resources, but is a measure of the *potential* of occurrence. Factors that could preclude development of the resource, such as the feasibility of extraction, land ownership, accessibility of the minerals, or the cost of exploration, development, production, processing, or marketing, are not considered in assessing the mineral-resource potential.

Classification

Classification of mineral-resource potential differs from the classification of mineral resources. Quantities of mineral resources are classified according to the availability of geologic data (certainty), economic feasibility (identified or undiscovered), and as economic or uneconomic. Mineral-resource potential is a qualitative judgement of the probability of the existence of a commodity. Mineral-resource potential is classified as high, moderate, low, or no potential according to the availability of geologic data and relative probability of occurrence (Fig. 48).

FIGURE 48. Classification of mineral-resource potential and certainty of assurance (modified from Goudarzi, 1984).

High mineral-resource potential is assigned to areas where there are known mines or deposits where the geologic, geochemical, or geophysical data indicate an excellent probability that mineral deposits occur. All active and producing properties fall into this category as well as identified deposits in known mining districts or in known areas of mineralization. Speculative deposits, such as reasonable extensions of known mining districts and identified deposits or partially defined deposits within geologic trends are classified as high mineral-resource potential when sufficient data indicate a high probability of occurrence.

Moderate mineral-resource potential is assigned to areas where geologic, geochemical, or geophysical data suggest a reasonable probability that undiscovered mineral deposits occur in formations or geologic settings known to contain economic deposits elsewhere. Speculative deposits in known mining districts or mineralized areas are assigned a moderate potential if evidence for a high potential of economic deposits is inconclusive. This assignment, like other classifications, can be revised when new information, new genetic models, or changes in economic conditions develop.

Low mineral-resource potential is assigned to areas where available data imply the occurrence of mineralization, but indicate a low probability for the occurrence of an economic deposit. This includes speculative deposits in geologic settings not known to contain economic deposits, but which are similar to geologic settings of known economic deposits. Additional data may be needed to better classify such areas.

No mineral-resource potential is assigned to areas where sufficient information indicates that an area is unfavorable for economic mineral deposits. This evaluation may include areas with dispersed but uneconomic mineral occurrences as well as areas that have been depleted of their mineral resources. Use of this classification implies a high level of geologic assurance to support such an evaluation, but it is assigned for potential deposits that are too deep to be extracted economically, even though there may not be a high level of geologic assurance. These economic depths vary according to the commodity and current and future economic conditions.

Unknown mineral-resource potential is assigned to areas where necessary geologic, geochemical, and geophysical data are inadequate to classify an area otherwise. This assessment is assigned to areas where the degree of geologic assurance is low and any other classification would be misleading.

Favorable areas for mineralization

Camel Mountain-Eagle Nest

The Camel Mountain-Eagle Nest area includes the Camel Mountain-Eagle Nest mining district in eastern Luna County. Only a few small hills contain rock outcrops; alluvium or basalt covers most of the area. The geophysical coverage in this area is low as well. The mineral-resource potential of this area is speculative at best. No production is reported. Geochemical anomalies in the stream-sediment samples are scattered and low; anomalous concentrations of As, Co, Cr, K, Mn, and Ti occur locally. However, the presence of volcanic and intrusive rocks provides a source of metals and heat for mineral deposits. The lack of outcrop exposure in the area presents challenges for exploration.

Carrizalillo-Cedar-Klondike Hills

The Carrizalillo-Cedar-Klondike Hills area includes the Carrizalillo mining district. Known mineral deposits include carbonate-hosted replacements and volcanic-epithermal veins deposits. Geochemical and geophysical anomalies may be evidence of undiscovered mineral deposits. The district lies along gravity and magnetic lows and occurs southeast of a gravity high. Stream-sediment samples have indicated geochemical anomalies of As, Ba, La, Pb, Zn, Sb, Th, and Y. A Cd anomaly surrounds the district, and Cr and Mn are anomalous at the south end of the district. Aeroradioactivity measurements for K, U, and Th show that K is moderate and U and Th are average.

Cooke’s Range

The Cooke’s Range favorable area includes the Cooke’s Range, Old Hadley, and Cooke’s Manganese mining districts and exposures of favorable carbonate and igneous intrusive rocks. Known mineral deposits include carbonate-hosted replacements and polymetallic veins deposits. The area is defined by a gravity high underlying the mineralized area. Magnetic culminations occur beneath the northern and southern parts of the area. A magnetic high in the northern Potrillo Mountains forms the southern boundary. A seismically-defined uplift occurs in the southern part of the area.

Florida-Little Florida Mountains

The Florida-Little Florida Mountains area is delineated by a gravity high covering known mineral occurrences. A magnetic high occurs in the southwestern part of the favorable area that lies at the northern boundary of a thrust belt and at the southern margin of the Texas lineament. Known mineralization includes epithermal and hydrothermal deposits that have had moderate production. Within the Florida Mountains district there are geochemical anomalies of Ba, Be, spot Bi and Cd, Co, Cr, Cu, K, La, Mn, Nb, Pb, Sn, Th, and Ti, and at the south end, Y and Zn occur. The north end of the district has additional As and Sb anomalies. Geochemical anomalies of

Ba, Be, Co, Cu, K, La, Mn, Nb, Pb, Sb, Sn, Th, Y, Zn, and spot Bi, Cd, Mo, and Ti occur in stream-sediment samples in drainages from the Little Florida Mountains. There is an aeroradiometric K relative low in the district. Aeroradiometric U and Th are undistinguished in both districts. The western part of the area was selected as being favorable for the occurrence of skarn deposits owing to the suspected presence of buried Paleozoic carbonate rocks in close proximity to Tertiary intrusive rocks.

Fluorite-Goat Ridge

The Fluorite-Goat Ridge area is delineated by the presence of epithermal mineralization in the Fluorite Ridge mining district, and, using seismic data, by recognition that approximately 600 ft of volcanic rock overlies bedrock that may host hydrothermal veins. The area is located along a gravity high; a magnetic high lies to the northwest. Geochemical stream-sediment anomalies include As, Ba, Cd, Cr, Cu, La, Mn, Mo, Pb, Ti, and Zn. Tertiary granodiorite intrudes Paleozoic limestone and is capped by late Tertiary conglomerate. Epithermal fluorite veins were formed after deposition of the conglomerate.

Mimbres Basin

Favorable areas within the Mimbres basin include areas where volcanic and intrusive rocks of late Cretaceous and Tertiary age are near the surface and where geophysical anomalies indicate the presence of buried intrusions, which could provide thermal energy, pressure, and hydrothermal fluids to create a mineralized magmatic system. Additionally, areas of densely spaced faults and fractures and areas of silicic, argillic, and propylitic alteration would be favorable.

Tres Hermanas-Victorio Mountains

The Tres Hermanas-Victorio Mountains area consists of the Tres Hermanas and Victorio mining districts and surrounding area. The boundaries are delineated by anomalous gravity high, seismic data, and an aeroradiometric K low (Bartsch-Winkler, 1997). A magnetic anomaly on the southwestern edge of the Burro uplift and geology indicates possible steeply-dipping carbonate host rocks (Bartsch-Winkler, 1997). Seismic data (Bartsch-Winkler, 1997), suggests that bedrock is within approximately 900 ft of the surface. Geochemical anomalies for As, Ba, Be, Bi, sporadic Cd, Co, Cr, K, La, Mn, Mo, Pb, Sb, Th, Ti, Y, and Zn have been identified in stream-sediment data (Bartsch-Winkler, 1997; Appendix 3). Known deposits include Pb-Zn skarn, carbonate-hosted Pb-Zn, polymetallic vein, Mo-W-Be contact-metasomatic deposits, and porphyry Mo-W. Past production of silver, copper, and gold from these districts was the largest in the county and significant lead and zinc also was produced (Table 4). The area has potential for porphyry Cu, Cu-Mo (±Au), Laramide Cu and Pb-Zn skarn, polymetallic vein, porphyry Mo (±W), Mo-W-Be contact-metasomatic, carbonate-hosted Pb-Zn (Cu, Ag) replacement, carbonate-hosted Ag-Mn (Pb) replacement, carbonate-hosted Mn replacement, replacement iron, gold skarn, and sediment-hosted gold deposits.

Other areas in Luna County

There is low potential with B level of certainty for carbonate-hosted Pb-Zn and Ag replacement and sedimentary-hosted gold deposits in the Snake Hills on the basis of favorable host rocks and two anomalous gold assays (Griswold et al., 1989).

TABLE 23. Summary of resource potential for metallic deposits and criteria for favorable areas summarized in Figure 49–71 (modified from Bartsch-Winkler, 1997).

Area **District**	Camel Mountain-Eagle Nest	Carrizalillo-Cedar-Klondike Hills	Cooke's Range	Florida Mountains-Little Florida Mountains
Deposit type				
Porphyry Cu, Cu-Mo (±Au)	Low/B	Moderate/C	Moderate/B	Low/B
Laramide Cu and Pb-Zn skarn	Low/B	Moderate/C	Moderate/B	Low/B
Polymetallic vein	Low/B	Moderate/C	Moderate/B	Low/B
Porphyry Mo (±W)	Low/B			
Mo-W-Be contact-metasomatic deposits	Low/B	Low/B	Low/B	Low/B
Carbonate-hosted Pb-Zn (Cu, Ag) replacement	Low/B	Moderate/C	High/D	Low/B
Carbonate-hosted Ag-Mn (Pb) replacement	Low/B	Moderate/C	High/D	Low/B
Carbonate-hosted Mn replacement	Low/B	Moderate/C	High/D	High/D
Replacement Fe	Low/B	Moderate/C	Moderate/B	Moderate/B
Gold skarn	Low/B	Low/B	Moderate/B	Low/B
Sedimentary-hosted gold deposits	Low/B	Moderate/B	Moderate/B	Low/B
Volcanic-epithermal vein	Low/B	Moderate/C	Moderate/B	Low/B
Epithermal Mn	Low/B	Moderate/C	High/D	High/D
Epithermal fluorite	Low/B	Low/B	Moderate/B	Moderate/C
Rhyolite-hosted tin	Low/B	Low/B	None/D	None/D
Rio Grande Rift barite-fluorite-galena	Low/B	Low/B	Moderate/B	Moderate/C
Vein and replacement deposits in Proterozoic rocks	Low/B	Low/B	Low/B	Moderate/B
REE-Th-U veins in alkaline rocks	None/D	None/D	None/D	Moderate/B
Sedimentary-copper deposits	None/D	None/D	None/D	None/D
Criteria for delineating area				
Gravity high	X	X	X	X
Magnetic high			X	X
Seismic shows favorable lithology within 2500 ft				
Aeroradiometric anomalies			X	
Geochemical anomalies	X	X	X	X
Metal association			X	X
Favorable mineral assemblage			X	X
Known mineral occurrences	X	X	X	X
Associated mineral deposits present			X	X
Suspected porphyry				
Past production	X	X	X	X
Tertiary volcanic rocks	X	X	X	X
Favorable carbonate rocks	X	X	X	X
Tertiary intrusive rocks	X	X	X	X
Proterozoic rocks	X	X		X
Faults or other structural control	X	X	X	X
Alteration appropriate for deposit type	X	X	X	X

TABLE 23. continued

District / Area	Fluorite-Goat Ridge	Mimbres Basin	Tres Hermanas-Victorio
Deposit type			
Porphyry Cu, Cu-Mo (±Au)	Low/B	Low/B	Low/B
Laramide Cu and Pb-Zn skarn	Low/B	Low/B	Low/B
Polymetallic vein	Low/B	Low/B	Low/B
Porphyry Mo (±W)	Low/B	Low/B	High/D
Mo-W-Be contact-metasomatic deposits	Low/B	Low/B	High/D
Carbonate-hosted Pb-Zn (Cu, Ag) replacement	Low/B	Low/B	High/D
Carbonate-hosted Ag-Mn (Pb) replacement	Low/B	Low/B	High/D
Carbonate-hosted Mn replacement	Low/B	Low/B	High/D
Replacement Fe	Low/B	Unknown	Low/B
Gold skarn	Low/B	Unknown	Moderate/B
Sedimentary-hosted gold deposits	Moderate/B	Unknown	Moderate/B
Volcanic-epithermal vein	Low/B	Unknown	Low/B
Epithermal Mn	Low/B	Low/B	Low/B
Epithermal fluorite	High/D	Unknown	Low/B
Rhyolite-hosted tin	Low/B	Unknown	Low/B
Rio Grande Rift barite-fluorite-galena	Low/B	Unknown	Low/B
Vein and replacement deposits in Proterozoic rocks	None/D	None/D	None/D
REE-Th-U veins in alkaline rocks	None/D	None/D	None/D
Sedimentary-copper deposits	None/D	None/D	None/D
Criteria for delineating area			
Gravity high	X	X	X
Magnetic high	X	X	X
Seismic shows favorable lithology within 2500 ft		X	X
Aeroradiometric anomalies			X
Geochemical anomalies	X		X
Metal association			X
Favorable mineral assemblage			X
Known mineral occurrences	X		X
Associated mineral deposits present			X
Suspected porphyry			X
Past production			X
Tertiary volcanic rocks	X	X	X
Favorable carbonate rocks	X	X	X
Tertiary intrusive rocks	X	X	X
Proterozoic rocks	X		X
Faults or other structural control	X	X	X
Alteration appropriate for deposit type			X

Metallic mineral resources

The economics of each metal is discussed, followed by a discussion of the mineral-resource potential for each type of deposit that are favorable to occur in Luna County. A summary of the resource potential is in Table 1.

Beryllium

Beryllium (Be) is one of the lightest of all metals and has one of the highest melting points of any light metal. It is used as an alloy, oxide, and metal in electronic components, aerospace and defense applications, appliances, and computers. Beryllium-copper alloys are used in a wide variety of applications because of their electrical and thermal conductivity, high strength and hardness, good corrosion and fatigue resistance, and nonmagnetic properties. Beryllium oxide is an excellent heat conductor, with high strength and hardness, and acts as an electrical insulator in some applications. Only two beryllium minerals, beryl and bertrandite, are of commercial importance; bertrandite contains less than 1% Be, and beryl contains about 4% Be. Bertrandite is the principal beryllium mineral mined in the U. S., and beryl is the principal mineral produced in the rest of the world.

Only one mine in the U. S. produces beryllium, Spor Mountain in Utah. At Spor Mountain, bertrandite replaces dolomite fragments in a tuffaceous surge deposit associated with topaz-rhyolite flows and domes (Burt et al., 1982; Burt and Sheridan, 1987). Beryllium deposits also are found elsewhere in skarns, contact-metasomatic deposits, greisen-bordered veins, and pegmatites (Burt et al., 1982; Kramer, 1994). Associated igneous rocks include topaz-bearing rhyolites (Burt et al., 1982) and high-silica rhyolites (Levinson, 1962; McAnulty et al., 1963; McAnulty, 1980). Beryllium also is found associated with alkaline plutonic rocks (Warner et al., 1959; Holser, 1959; Mutschler et al., 1985, 1991). Combined reserves of bertrandite at Spor Mountain and Sierra Blanca in Texas are estimated as 20,000 tons. In 1995, production amounted to 222.2 tons beryllium metal from the U. S. (Kramer, 1995). Current production meets or exceeds estimated consumption in the U. S.

The beryllium mineral-resource potential is high with a D level of certainty in the Victorio Mountains (Fig. 49, Table 1) where W-Be-Mo skarn/vein deposits have been found by drilling. Elsewhere in the Tres Hermanas-Victorio Mountains the mineral-resource potential is moderate because geochemical anomalies, similar igneous rocks, and geophysical anomalies exist that indicate similar deposits could occur. The beryllium mineral-resource potential is low with a B level of certainty in the Camel Mountain-Eagle Nest, Carrizalillo-Cedar-Klondike Hills, Cooke's Range, Florida-Little Florida Mountains, Fluorite-Goat Ridge, and Mimbres basin, because of similar geophysical and geochemical anomalies and presence of igneous and carbonate rocks. There is no mineral-resource potential elsewhere in the county.

FIGURE 49. Beryllium mineral-resource potential in Luna County.

Bismuth

Bismuth (Bi) is a heavy, nontoxic metal that is mainly a byproduct of processing metallic ores, especially lead. Bismuth is used in solders, a variety of other alloys, metallurgical additives, medications, and in atomic research. Bismuth is being considered as a nontoxic replacement for lead in such uses as ceramic glazes, fishing sinkers, food processing equipment, free-machining brasses for plumbing applications, lubricating greases, and shot for waterfowl hunting. Since 1997, the U. S. has been completely dependent on imports for its supply of primary bismuth. The average price for bismuth in 2000 was $3.50 per pound (Brown, 1999a). Bismuth in Luna County is found in trace amounts in zinc deposits.

The bismuth mineral-resource potential is low with a B level of certainty in the Camel Mountain-Eagle Nest, Cooke's Range, and Tres Hermanas-Victorio Mountains (Fig. 50, Table 1), because carbonate-hosted Pb-Zn and polymetallic vein deposits are known to occur in these areas that could contain anomalous bismuth. There is no mineral-resource potential elsewhere in the county.

FIGURE 50. Bismuth mineral-resource potential in Luna County.

Copper

Copper (Cu) is a major component in structural and electrical use in building construction, electrical products, machinery and equipment, and consumer general products (Edelstein, 1997). The U. S. is the largest producing country of copper and much of that production comes form Arizona and New Mexico. Only one copper smelter is operating in New Mexico at Harley (operated by Phelps Dodge Corp.). Copper occurs in a variety of deposits in New Mexico (McLemore, 1994c).

The granitic rocks in Luna County are chemically different than the chemical composition of host rocks of porphyry copper deposits in southwestern New Mexico (Fig. 9, 51), suggesting that the Luna County granitic rocks were formed by slightly different magmatic fraction processes. Therefore, the copper mineral-resource potential is low with a B level of certainty in the Camel Mountain-Eagle Nest, Florida-Little Florida Mountains, and Mimbres Basin (Fig. 52, Table 1), because carbonate-hosted Pb-Zn and polymetallic vein deposits are known to occur in these areas. The copper mineral-resource potential is moderate with a B or C level of certainty in the Carrizalillo-Cedar-Klondike Hills, Cooke's Range, Fluorite-Goat Ridge, and Tres Hermanas Mountains. There is no mineral-resource potential elsewhere in the county.

FIGURE 51. Cu-Pb-Zn and Ba-Rb-Sr plots of granitic rocks from Luna County compared with porphyry copper deposits in southwestern New Mexico.
FIGURE 52. Copper mineral-resource potential in Luna County.

Germanium

Germanium (Ge) is a brittle (like glass), hard, grayish-white element with a metallic luster and the same crystal structure as diamond and is mainly a byproduct of processing metallic ores, especially zinc. Germanium is a semiconductor, with electrical properties between those of a metal and an insulator. The demand for germanium in transistors, in fiber optics communication networks, infrared night vision systems, and polymerization catalysts has increased dramatically. The price of germanium in 2000 was $1,150 per kilogram. In 1999, the domestic germanium industry consisted of two zinc mining operations in Alaska and Tennessee, which supplied byproduct germanium concentrates for export (Brown, 1999b).

The germanium mineral-resource potential is low with a B level of certainty in the Camel Mountain-Eagle Nest, Cooke's Range, Florida-Little Florida Mountains, and Tres Hermanas Mountains (Fig. 53, Table 1). There is no mineral-resource potential elsewhere in the county.

FIGURE 53. Germanium mineral-resource potential in Luna County.

Gold

Gold (Au) is a precious metal that is used in bullion, jewelry, electrical/electronics circuits, and dental work (Sehnke, 1997). Gold production in the U. S. is second in the world with most of the production coming from Nevada. South Africa produces more gold then the U. S. (Sehnke, 1997). Gold occurs in a variety of deposits in New Mexico, but production from Luna County has been relatively small (Table, 2; North and McLemore, 1986, 1988; McLemore, 2001).

The resource potential for gold is moderate, generally with B level of certainty, in the Carrizalillo-Cedar-Klondike Hills, Cooke's Range, and Tres Hermanas-Victorio Mountains (Fig. 54, Table 1). The resource potential for gold is low with B level of certainty in the Camel Mountain-Eagle Nest, Florida-Little Florida Mountains, Fluorite-Goat Ridge, and Snake Hills and unknown in the Mimbres basin. There is no mineral-resource potential elsewhere in the county.

FIGURE 54. Gold mineral-resource potential in Luna County.

Iron

Iron ore (Fe) is essential to the economy of the U. S. because it is the prime metal used in steel. Domestic iron ore production reached its highest level in 1995 since 1981 with 62.5 million tons produced (Kirk, 1997). Nearly all of the domestic production comes from mines in Minnesota. Iron-oxide materials also are produced for yellow, red, brown, and black pigments and ochres in construction materials and coatings (Potter, 1996). In 1995, production of finished natural iron-oxide pigments was 76,200 tons (Potter, 1996). Iron ores and pyrite are used as additives in the manufacture of cement and concrete. In New Mexico, iron ore occurs predominantly in small- to medium-sized skarns and carbonate-hosted replacement deposits (Kelley, 1949; Harrer and Kelly, 1963).

In many areas of Luna County, iron occurs in jasperoids where the silica content is too high to be economic for iron. Most of the high iron anomalies in the NURE stream sediment samples are associated with areas high in other elements. Therefore, the mineral-resource potential for iron in the Camel Mountain-Eagle Nest and Fluorite-Goat Ridge is low with a B level of certainty (Fig. 55, Table 1). The mineral-resource potential for iron in the Carrizalillo-Cedar-Klondike Hills, Cooke's Range, Florida-Little Florida Mountains, and Tres Hermanas-Victorio Mountains is moderate with a B or C level of certainty. There is no mineral-resource potential elsewhere in the county.

FIGURE 55. Iron mineral-resource potential in Luna County.

Lead-zinc

In New Mexico, lead (Pb) and zinc (Zn) typically are found together (Thompson, 1965a, b). Lead is used in automotive batterie, gasoline additives, solders, seals, bearings, electronic/electrical applications, TV glass, shielding, ammunition, and a variety of other uses. Lead is processed at two smelter-refineries in Missouri, a smelter in Montana, and a refinery in Nebraska (Smith, 1997). Most of the lead comes from mines in Alaska and Missouri. Zinc is used to produce brass, bronze, alloys, chemicals, zinc oxide, and zinc slab (Plachy, 1997). There are three smelters operating in the U. S. in Illinois, Tennessee, and Pennsylvania. The Red Dog mine in Alaska is the largest zinc producing mine in the U. S. Deposits in southern New Mexico are small, low grade, far from existing smelters, and uneconomic.

The mineral-resource potential for lead-zinc in the Camel Mountain-Eagle Nest, Florida-Little Florida Mountains, Fluorite-Goat Ridge, and Snake Hills is low with a B level of certainty (Fig. 56, Table 1). The mineral-resource potential for lead-zinc in the Carrizalillo-Cedar-Klondike Hills is moderate with a B or C level of certainty. The mineral-resource potential for lead-zinc in the Cooke's Range and Tres Hermanas-Victorio Mountains is high with a D level of certainty. There is no mineral-resource potential elsewhere in the county.

FIGURE 56. Lead-zinc mineral-resource potential in Luna County.

Manganese

Manganese (Mn) is an essential ingredient in iron and steel production because of its sulfur fixing, deoxidizing, and alloying properties (Jones, 1997). It also is used in a variety of additional applications, including aluminum alloys, dry cell batteries, paints, fertilizers, and in coloration of bricks. There are over a hundred minerals containing manganese.

The mineral-resource potential for manganese in the Camel Mountain-Eagle Nest, Fluorite-Goat Ridge, and Mimbres bBasin is low with a B or C level of certainty (Fig. 57, Table 1). The mineral-resource potential for manganese in the Carrizalillo-Cedar-Klondike Hills and Tres Hermanas-Victorio Mountains is moderate with a C level of certainty. The mineral-resource potential for manganese in the Cooke's Range and Florida-Little Florida Mountains is high with a D level of certainty. Manganese is being produced from stockpiles in Deming and reserves remain. There is no mineral-resource potential elsewhere in the county.

FIGURE 57. Manganese mineral-resource potential in Luna County.

Molybdenum

Molybdenum (Mo), or moly for short, is a silvery-white to gray, soft (hardness 5.5), refractory metal that can be confused with graphite and lead ore. Molybdenum is typically found as deposits of molybdenite (MoS_2) or is recovered as a by-product of copper and tungsten production. Molybdenum is used as an alloying agent in steel, cast iron, and superalloys (typically with chromium, columbium, manganese, nickel, tungsten) to enhance hardness, strength, toughness, and wear and corrosion resistance. It is used in electrodes for electrically heated glass furnaces, nuclear energy applications, missile and aircraft parts, filament material in electrical applications. It also is used as catalysts, lubricants, and pigments (molybdenum orange). Molybdenum is an essential trace element in plant nutrition. The pure metal in the form of thin sheets or wire is used in X-ray tubes, electronic tubes, and electric furnaces because it can withstand high temperatures. It was used in early incandescent light bulbs. Useful compounds of molybdenum include molybdenum disulfide, used as a lubricant, especially at high temperatures where normal oils decompose; ammonium molybdate, used in chemical analysis for phosphates; and lead molybdate, used as a pigment in ceramic glazes. In New Mexico, molybdenum is produced from the Questa mine in Taos County and as a by-product of copper smelting in Grant County and was produced from a variety of deposits in the past. The annual average prices in 1999 were molybdenum concentrates, $3.840; molybdic oxide, $5.861; and ferromolybdenum, $8.157 per kilogram (Blossom, 2000).

The mineral-resource potential for molybdenum in the Camel Mountain-Eagle Nest, Cooke's Range, Florida-Little Florida Mountains, Fluorite-Goat Ridge, and Mimbres basin is low with a B level of certainty (Fig. 58, Table 1). The mineral-resource potential for molybdenum in the Carrizalillo-Cedar-Klondike Hills is moderate with a C level of certainty. The mineral-resource potential for molybdenum in the Tres Hermanas-Victorio Mountains is high with a D level of certainty. There is no mineral-resource potential elsewhere in the county.

FIGURE 58. Molybdenum mineral-resource potential in Luna County.

Niobium

Niobium (Nb, columbium) is a critical metal used mostly as an alloying element in steels and in superalloys.

Appreciable amounts of niobium are used in nickel-, cobalt-, and iron-base superalloys for such applications as jet engine components, rocket subassemblies, and heat-resisting and combustion equipment. Domestic deposits are low grade, uneconomic, and not in current production. Most of the niobium is imported from Canada and Nigeria (Cunningham, 1996). Niobium is found in alkaline rocks and is associated with areas of brecciation and alkali metasomatism (Mutschler et al., 1985, 1991).

Niobium anomalies are found in the NURE geochemical data in the Florida Mountains, Red Mountain, and Victorio Mountains. The mineral-resource potential for niobium in the Camel Mountain-Eagle Nest, Carrizalillo-Cedar-Klondike Hills, and Florida-Little Florida Mountains is low with a B level of certainty (Fig. 59, Table 1). There is no mineral-resource potential elsewhere in the county.

FIGURE 59. Niobium mineral-resource potential in Luna County.

Silver

Silver (Ag) is a precious metal that is used in photographic products, electrical and electronic components, electroplated ware, sterlingware, and jewelry. Approximately 1.64 million kg of silver was produced from 83 mines in the U. S. in 1995; production from New Mexico in 1995 was 19,900 kg (Reese, 1997). Silver occurs in a variety of deposits in New Mexico (North and McLemore, 1986, 1988; McLemore, 2001). The Chino mine in Grant County (porphyry copper deposit) is the largest silver-producing mine in New Mexico.

The mineral-resource potential for silver in the Camel Mountain-Eagle Nest, Mimbres basin, and Snake Hills is low with a B level of certainty (Fig. 60, Table 1). The mineral-resource potential for silver in the Carrizalillo-Cedar-Klondike Hills, Florida-Little Florida Mountains, and Fluorite-Goat Ridge is moderate with a C level of certainty. The mineral-resource potential for silver in the Cooke's Range and Tres Hermanas-Victorio Mountains is high with a D level of certainty. There is no mineral-resource potential elsewhere in the county.

FIGURE 60. Silver mineral-resource potential in Luna County.

Thorium and rare-earth elements (REE)

In New Mexico, thorium (Th) and rare-earth elements (REE) typically are found together. Thorium is a soft, ductile, silvery-white, radioactive metal that is used in the manufacture of high-strength, high-temperature alloys and refractory ceramics (Hedrick, 1996). Most of the thorium production in the U. S. is a by-product produced from monazite that is mined for rare-earth elements. Most of the thorium produced is discarded in waste piles, because production exceeds demand. The rare-earth elements (REE) are a group of related elements that are used in a variety of applications, including automotive catalytic converters, permanent magnets, and rechargeable rare-earth-nickel hydride batteries (Hedrick, 1997). In 1995, 24,420 tons of rare earth oxides were produced from the U. S. from one mine in California, where bastnasite is mined by open-pit methods from the Mountain Pass carbonatite. In New Mexico, thorium and REE occur predominantly in Precambrian pegmatites, Cambrian-Ordovician carbonatites and alkaline intrusions, and Tertiary veins and breccia deposits associated with alkaline intrusions (i.e. Great Plains Margin deposits) (McLemore et al., 1988a, b). Widespread alkali metasomatism is common surrounding known deposits.

The only alkaline rocks found in Luna County are in the Florida Mountains where syenite and alkali granite are found. Thorium, REE, Nb, and U anomalies are found in the NURE data and suggest a possibility that Th-REE-Nb veins could occur, but none have been found to date. The mineral-resource potential for thorium and rare-earth elements in the Florida-Little Florida Mountains is low with a C level of certainty (Fig. 61, Table 1). There is no mineral-resource potential elsewhere in the county.

FIGURE 61. Thorium and rare earth elements mineral-resource potential in Luna County.

Tin

Tin (Sn) as a metal is used in cans and containers, electrical applications, construction, transportation, and other minor uses. Tin has not been produced from mines in the U. S. since 1993, when a few small tin mines were in production. Approximately one-fifth of the tin used in the U. S. comes from recycling; the remaining tin consumed in the U. S. is imported (Carlin, 1997). World tin reserves are estimated as 7 million tons and are more than adequate to meet current demand. Tin is found associated with high-silica rhyolites in New Mexico and Proterozoic granitic rocks in the Franklin Mountains, Texas. Both deposits have yielded minor production in the past.

The presence of tin in Proterozoic granite in the Franklin Mountains suggests that a source of tin may exist locally in the Precambrian crust in southern New Mexico. The presence of Mo-W-Be contact-metasomatic deposits in the Victorio Mountains also suggest that tin deposits could exist in southern New Mexico. Some of the rhyolites in Luna County are grossly similar in chemical composition to topaz-rhyolites that are typically associated with tin and beryllium deposits (Burt et al., 1982; Christiansen et al., 1986; Price et al. 1990). However, none of the samples collected from Luna County contained any detectable tin (<10 ppm Sn, Appendix 3, 4). Therefore, the mineral-resource potential for rhyolite-hosted tin deposits in the Camel Mountain-Eagle Nest, Carrizalillo-Cedar-Klondike Hills, and Florida-Little Florida Mountains is low with a B level of certainty and there is no potential for rhyolite-hosted tin deposits elsewhere in Luna County, with a D level of certainty (Fig. 62, Table 1).

FIGURE 62. Tin mineral-resource potential in Luna County.

Tungsten

Tungsten (W) is a metal used primarily as tungsten carbide in cemented carbides (also called hardmetals), which are wear-resistant materials used by the metalworking, mining, and construction industries. Tungsten metal wires, electrodes, and/or contacts are used in lighting, electronic, electrical, heating, and welding applications. Tungsten also is used to make heavy metal alloys for armaments, heat sinks, and high-density applications, such as weights and counterweights, superalloys for turbine blades, tool steels, and wear-resistant alloy parts and coatings. Tungsten composites are used as a substitute for lead in bullets and shot. Tungsten chemical compounds are used in catalysts, inorganic pigments, and high-temperature lubricants. There is no current production of tungsten in the U. S.

The mineral-resource potential for tungsten in the Camel Mountain-Eagle Nest, Carrizalillo-Cedar-Klondike Hills, and Mimbres basin is low with a B level of certainty. The mineral-resource potential for tungsten in the Tres Hermanas-Victorio Mountains is high with a D level of certainty. There is no potential for tungsten elsewhere in Luna County, with a D level of certainty (Fig. 63, Table 1).

FIGURE 63. Tungsten mineral-resource potential in Luna County.

Industrial mineral resources (excluding aggregates)

Assessment of resource potential for industrial minerals is different from that of metallic minerals. Ore deposit models are not typically used to evaluate industrial minerals as they are for the metallic minerals. Geology is only one of four factors that determine economic viability and in many cases geology is not the major factor determining an economic resource. The four factors that must be evaluate for most industrial minerals are geology (exploration and development), production (mining, milling, other processing), transportation, and marketing (specifications set by the end user). The factors other than geology have a profound impact on the economics of any industrial mineral deposit, especially for the high-bulk, low-value commodities most common in Luna County. Transportation may be the single factor that will ultimately determine if a commodity is economic. Although Luna County has a major interstate highway and railroad running east-west through the center of the county, the county is quite far from potential markets and transportation costs alone would be prohibitive for most high-bulk, low-value commodities. In addition, good paved roads are not always accessible for much of Luna County where some of these commodities are found. In general, it is more difficult to find an end user willing to buy a commodity than it is to find a deposit of the commodity. This relationship is further complicated by the need to mine, mill, and transport the material to the end user at an acceptable price. For any resource assessment of industrial minerals, one must carefully weigh both the resource potential rating and the modifiers applied by the rater. Only by utilizing both will a complete picture of industrial minerals resource potential be achieved.

Typically, the evaluation of industrial mineral-resource potential is defined by regional geology and refined by drilling and sampling, which are beyond the scope of this report. Only reconnaissance sampling has been done (Appendix 4). Therefore this assessment is based on limited geologic information about the few industrial minerals possibilities associated with the known geology within Luna County. Production, transportation, and marketing conditions change with time and are only briefly mentioned where appropriate in the discussion of specific industrial minerals. Many of the industrial minerals in Luna County probably will never be developed, but their resource potential are assessed in this report because economic conditions change constantly and one or more of these commodities may become of economic interest because of these unforeseeable circumstances. A summary of the mineral-resource potential is in Table 1.

Alunite

Alunite deposits in the Old Hadley district in Luna County, as in other localities in the U.S., are currently uneconomic. Technology needed to produce aluminum from alunite is expensive, and the deposits contain many impurities. Nevertheless, since the U. S. imports all of its required aluminum, the potential in southern New Mexico could change if foreign supplies are threatened or exhausted. Therefore, the mineral-resource potential for alunite in the Cooke's Range is low with a C level of certainty (Fig. 64, Table 1). There is no potential for alunite elsewhere in Luna County.

FIGURE 64. Alunite and barite-fluorite mineral-resource potential in Luna County.

Barite and fluorite

Barite and fluorite occur in RGR deposits throughout New Mexico adjacent to mid-Tertiary and late-Tertiary basins (McLemore et al., 1998; McLemore, 2001). All of these deposits are small and uneconomic.

Therefore, there is a low mineral-resource potential for RGR deposits containing barite and fluorite with a B level of certainty in the Little Florida Mountains and the Mimbres Basin.

There is a high potential with a D level of certainty for epithermal fluorite deposits in the Fluorite-Goat Ridge area (Fig. 64, Table 1). There is a moderate potential with a B level of certainty for epithermal fluorite deposits in the Cooke's Range and a moderate potential with a C level of certainty for epithermal fluorite deposits in the Florida-Little Florida Mountains. There is a low potential with a B level of certainty for epithermal fluorite deposits in the Camel Mountain-Eagle Nest, Carrizalillo-Cedar-Klondike Hills, and Tres Hermanas-Victorio Mountains. There is no potential for barite and fluorite elsewhere in Luna County.

Clay

The resource potential for clay in the Cooke's Range, Goodsight Mountains/Uvas Valley, Florida-Little Florida Mountains and the Mimbres River area in northern Luna County is moderate with a B or C level of certainty (Fig. 65, Table 1). There is a high potential with a D level of certainty for clay in the Taylor Mountain and Deming areas. There is no potential for clay elsewhere in Luna County.

FIGURE 65. Clay mineral-resource potential in Luna County.

Crushed stone

In Doña Ana and Luna Counties, scoria deposits are found in the Potrillo Mountains and adjacent areas, encompassing an area of more than 200 mi^2 and about 150 cinder cones. Some cones have been quarried, but total production is unknown. Production from 1975–1988 totaled $1.75 million. In the West Potrillo Mountains, Mt. Riley, and Aden Lava Flow Wilderness Study Areas, Kilburn et al. (1988) estimated an inferred resource of at least 400 million yd^3.

Scoria resources in Doña Ana and Luna Counties are large and should be sufficient to meet local demand in the near future (Austin et al., 1982; Osburn, 1982). Much of the scoria in the Potrillo Mountains are within Wilderness area boundaries; however, active mining operations are located outside of restricted areas. Therefore, the mineral-resource potential for scoria and basalt in the Aden district, eastern Luna County and Carrizalillo-Cedar-Klondike Hills is moderate with a D or C level of certainty (Fig. 66, Table 1). There is a low potential for scoria and basalt south of the Cooke's Range (Fort Cummings Draw), Columbus, and Black Mountain (northwest of Deming) with a C or B level of certainty. There is a moderate potential for for limestone in Cooke's Range and Tres Hermanas Mountains. There is an unknown potential for scoria and basalt in the southern Tres Hermanas and south of the Florida Mountains. There is a high mineral-resource potential for limestone in the Victorio Mountains and for rhyolite at Red Mountain. Most areas have a moderate to high resource potential for sandstone.

FIGURE 66. Crushed stone mineral-resource potential in Luna County.

Dimension stone

The resource potential of travertine and marble deposits in the Burdick-Bisbee Hills, Goat Ridge, and Victorio Mountains is low with a B level of certainty owing to their small size, distance to potential markets, and inconsistent textures (Fig. 67, Table 1). The resource potential of limestone is moderate with a C level of certainty in the Carrizalillo-Cedar-Klondike Hills and Victorio Mountains. The resource potential of sandstone and granite is moderate with a C level of certainty in the Fluorite Ridge area. The resource potential of rhyolite is moderate with a C level of certainty in the Taylor Mountain area.

FIGURE 67. Dimension stone mineral-resource potential in Luna County.

Garnet

The garnet occurrences in Luna County are small and consist of massive, not crystalline garnet. Therefore, garnet has a low mineral-resource potential with a C level of certainty near Tertiary intrusions in the Tres Hermanas-Victorio and Camel Mountain-Eagle Nest (Fig. 68, Table 1). Elsewhere in Luna County, there is no mineral-resource potential for garnet.

FIGURE 68. Garnet mineral-resource potential in Luna County.

Gems, semi-precious stones, and mineral collecting

Agate, geodes, and jasperoid are being produced on a small scale in the Burdick-Bisbee Hills and Carrizalillo-Cedar-Klondike Hills, therefore the resource potential for gems, semi-precious stones, and mineral collecting is high with a D level of certainty in these areas (Fig. 69, Table 1). The resource potential for mineral collecting in the Camel Mountain-Eagle Nest area is moderate with a B level of certainty and for collecting psilomelane in the Florida-Little Florida Mountains is moderate with a C level of certainty. The resource potential for gems, semi-precious stones, and mineral collecting elsewhere in Luna County is unknown.

FIGURE 69. Gems, semi-precious stones, and mineral collecting mineral-resource potential in Luna County.

Limestone/dolostone/travertine/marble

Selected limestones collected from areas in Luna County do not contain enough CaO to be classified as high calcium limestones (Table 24). Some of the travertines and marbles probably contain more CaO and could be high-calcium limestones, but these deposits are small and discontinuous. Furthermore, the distance from Luna County to cement plants at El Paso, Juarez, and Tijeras is too far for it to be economic. Therefore the resource potential for high-calcium limestone in the Carrizalillo-Cedar-Klondike Hills, Cooke's Range, Tres Hermanas Mountains, and Victorio Mountains in Luna County is low with a D level of certainty (Fig. 70, Table 1). Most limestone in Luna County has a moderate resource potential with a B level of certainty for aggregate.

FIGURE 70. Limestone/dolostone/travertine/marble mineral-resource potential in Luna County.

TABLE 24. Chemical analyses of selected limestones from Luna County. Major oxides are by FAAS except for CaO%, which is by titration. Trace elements are by XRF. Additional chemical analyses are in Appendix 4. [1] from Freas (1994). [2] from Carr et al. (1994).

Sample	VIC-603	VIC-611	VIC-612	TRES-87	CED-4	High calcium quicklimes[1]	Glass-grade Limestone[2]
Location	Victorio Mountains	Victorio Mountains	Victorio Mountains	Tres Hermanas Mountains	Cedar Hills		
Latitude, longitude	32.17532, 108.09347	32.18791, 108.10567	32.18892, 108.08562	31.89131, 107.78398	32.0285, 108.16351		
CaO%	28.82	30.46	46.64	52.85	52.57	93.25–98.00	97.80
MgO%	20.65	20.41	1.72	0.33	0.31	0.30–2.50	1.25
K_2O%	0.01	0.09	0.38	0.02	0.03		
Na_2O%	0.07	0.07	0.05	0.05	0.05		
MnO%	0.02	0.05	0.03	0.02	0.02		<0.01
Fe_2O_3%	0.22	0.70	0.63	0.23	0.27	0.10–0.40	0.095
Al_2O_3%	0.04	0.31	0.96	0.09	0.09	0.10–0.40	0.23
Insoluble%	0.67	7.19	10.55	4.23	3.51	0.40–1.50	
CO_2%	46.31	38.83	37.22	42.08	41.55		
Total	96.81	98.11	98.18	99.9	98.4		
Ni							<0.002
Cr_2O_3							<0.001
SrO							0.03

Perlite

The devitified nature of the perlitic pitchstone near Hermanas and the interlayering with altered rhyolite flows makes this deposit uneconomic (Appendix 2; Weber, 1965; Weber and Austin, 1982). Rhyolite domes are scattered throughout the Carrizalillo district and could be associated with additional perlite deposits. However, the area is remote and difficult to develop and transport any perlite. Therefore, the resource potential for perlite is low with a B level of certainty (Fig. 71, Table 1). The rhyolite domes in the Goodsight Mountains/Uvas Valley need examination for perlite resources; the perlite mineral-resource potential is unknown. Elsewhere in Luna County, there is no mineral-resource potential for perlite.

FIGURE 71. Perlite, pumice, silica, talc, and zeolites mineral-resource potential in Luna County.

Pumice

The potential for pumice in volcanic rocks in the Cooke's Range is low with a B level of certainty (Fig. 71, Table 1). There is no potential for pumice elsewhere in Luna County, because of the lack of host rocks.

Silica

Selected samples of high-silica rocks from the Fluorite-Goat Ridge area do not contain enough silica to be used for flat glass, fiberglass, ground silica, or filtration sand (Table 25). Additional tests are required to see if the smelter at Hurley could utilize these deposits. The Mojado Formation in the Eagle Nest-Camel Mountains and Victorio Mountains is similar to the samples collected from the Fluorite-Goat Ridge area. The deposits are consolidated sandstone and would have to be crushed to specific specifications, which increases the cost of the material. Therefore the resource potential for silica for specialty uses (flat glass, fiberglass, ground silica, or filtration sand) in the Fluorite-Goat Ridge, Eagle Nest-Camel Mountains, and Victorio Mountains in Luna County is low with a D or C level of certainty and the resource potential for silica for use in as silica flux for the smelter is unknown (Fig. 71, Table 1). Elsewhere in Luna County, there is no mineral-resource potential for silica.

TABLE 25. Selected chemical analyses of silica deposits in the Fluorite-Goat Ridge area, Luna County. Samples (Max 2) from the Maxwell silica pit in the Little Hatchet Mountains, Hidalgo County for comparison. Silica from the Maxwell pit was quarried and shipped to the Playas smelter before it closed in 1999. Additional chemical analyses are in Appendix 4. [1] from Zdunczyk and Linkous (1994).

	Latitude	Longitude	SiO_2	TiO_2	Al_2O_3	Fe_2O_3T	MnO	MgO	CaO	K_2O	Na_2O	P_2O_5	LOI	SUM
Goat 1	32.44927	107.7961	93.82	0.10	2.74	0.22	0.004	0.06	0.77	0.09	0.06	0.03	1.63	99.53
Goat3	32.43757	107.78936	95.24	0.06	0.89	1.04	0.021	0.20	0.66	0.13	0.05	0.42	0.68	99.39
Goat4	32.43757	107.78936	60.74	0.02	0.35	1.60	0.046	0.14	19.99	0.05	0.04	0.40	15.77	99.15
Goat5	32.44927	107.7961	81.65	0.39	6.27	2.54	0.014	0.55	1.93	0.66	0.06	0.04	4.05	98.15
Pony 1	32.446117	107.727068	95.16	0.06	2.44	0.22	0.019	0.06	0.49	0.08	0.04	0.31	1.41	100.28
Max 2	31.868	108.438	87.07	0.30	6.31	1.68	0.41	0.98	0.50	0.71	0.03	0.04	2.74	100.83
Flat glass[1]			>99.5	<0.10	<0.30	<0.04	<0.002						<0.05	
Fiberglass[1]			>99		<0.30	<0.50				<0.1	<0.10		<0.50	
Ground silica[1]					<0.38	<0.10				<0.1	<0.10			
Filtration sand[1]			99.39	0.12	0.19	0.24		0.004	0.01				0.046	

Talc

Talc deposits in the Tres Hermanas-Victorio Mountains are small, discontinous, and of poor quality. Therefore, the mineral-resource potential for talc in the Tres Hermanas-Victorio Mountains is low with a B level of certainty (Fig. 71, Table 1). Elsewhere in Luna County, there is no mineral-resource potential for talc.

Zeolites

Zeolites have been reported from the Oligocene tuffaceous rocks near Dwyer (R.A. Sheppard, unpub. data, 1993; Bartsch-Winkler, 1997) where a brief reconnaissance indicates widespread zeolitization. Zeolitic tuffaceous rocks were recognized along NM-61, west of the Mimbres River, from SE1/4SE1/4 sec. 2, T19 S, R10W to NW1/4SE1/4 sec. 6, T20S, R11W, extending into northern Luna County. These tuffaceous rocks were mapped by Elston (1957) as the Sugarlump Tuff and the Rubio Peak Formation and are white, light pink, and green and include well-bedded, reworked tuffs as well as massive, nonwelded lapilli tuffs. All of these tuffaceous rocks contain variable amounts of obvious, angular pumice, lithic, and crystal fragments. Except for probable andesitic flows and welded, silicic ash flows, much of the volcaniclastic rocks in this area contain at least a trace of diagenetic clinoptilolite. Sampled zeolitic tuffaceous rocks range in thickness from approximately 6 ft to at least 90 ft. X-ray diffractometer analyses of sampled tuffs indicate that a green tuff unit in the Sugarlump Tuff in the SE1/4SE1/4 sec. 32, T20S, R11W contains as much as 80% clinoptilolite and varying amounts of diagenetic chabazite, mordenite, smectite, and quartz. The finely crystalline quartz makes up 10–30% of the rocks and is responsible for their characteristic hardness. Much additional work needs to be done in the Dwyer area before the zeolite potential can be evaluated. A regional investigation should determine the distribution of clinoptilolite and coexisting authigenic minerals, determine the pattern of alteration, and evaluate the chemical and physical properties of the zeolitic rocks. Inasmuch as Elston (1957) mapped a broad band of tuffaceous rocks in the western half of the Dwyer quadrangle (chiefly west of the Mimbres River), a potentially vast tonnage of clinoptilolite-bearing rock may exist in Grant and Luna Counties.

Areas of potentially commercial zeolite deposits in Luna County would be found in areas underlain by Cenozoic volcaniclastic rocks that originally contained abundant silicic glass. Zeolites can form from a variety of aluminosilicate materials during diagenesis, providing the interstitial water has a relatively high pH and high concentration of alkalis. High-grade zeolite deposits formed from silicic, vitric ash that lacked crystal and lithic fragments. Prospecting for bedded zeolite deposits is difficult because the zeolites are finely crystalline and resemble bedded diatomite, feldspar, or bentonite in the field. Zeolitic tuffs generally have an earthy luster and are resistant. Although some zeolitic tuffs are pastel shades of yellow, brown, red, or green, many are white or light gray. X-ray powder diffraction analysis of bulk samples is the technique generally used for identification of the zeolites and associated minerals in sedimentary rocks. This method also permits a semiquantitative estimate of the abundance of mineral phases in the samples. Tuffaceous strata are sampled, and then the samples are brought to the laboratory for examination by X-ray diffraction. Fresh (unaltered) tuff is generally distinguishable from altered tuff in the field, so only the altered parts of the tuffaceous rocks are sampled in both vertical and lateral directions. Once zeolites have been identified by X-ray diffraction, an additional sampling is commonly necessary to ascertain the distribution and abundance of the zeolites and coexisting authigenic minerals. Potential targets for undiscovered zeolite deposits in Luna County include: (1) the Oligocene Sugarlump Tuff and equivalent strata in a band between Bayard-Hurley and the Mimbres River, (2) Tertiary rhyolitic tuffs in the Cedar Mountains, and (3) lacustrine facies of the Gila Conglomerate and equivalent strata. Air-fall, silicic tuffs that were deposited in water are particularly good targets, but even land-laid, silicic, nonwelded ash-flow tuffs should not be overlooked. Most of Luna County area was shown by Schmidt (1987, p. 14) to be favorable for potential zeolite occurrences. The potential for zeolites in northern Luna County is moderate with a B level of certainty (Fig. 71, Table 1). Elsewhere in Luna County, there is no mineral-resource potential for zeolites.

Energy resources (excluding petroleum)

Uranium Resources

Minor occurrences of uranium minerals are found in the Victorio, Tres Hermanas, and Carrizalillo districts (McLemore, 1983; McLemore and Chenoweth, 1989), but these are small and uneconomic. Minor production (35 lbs of U_3O_8, grade 0.19% U_3O_8) was from a skarn deposit in the Hidalgo County portion of the Fremont district, but the deposit was small and low grade (McLemore, 1983; McLemore and Chenoweth, 1989). The highest value in the NURE stream-sediment data is 4.96 ppm (Appendix 3). This sample is found adjacent to the railroad and probably represents an anomaly associated with the railroad bed or some other artificial source. The remaining values are too low and too widely distributed for the favorability of occurrence of economic uranium deposits. The most radioactive rocks in Luna County are the Cambrian-Ordovician syenites and alkali-feldspar granites and Tertiary rhyolites. Scattered uranium highs on the regional map correspond to these rocks in the Florida Mountains and in central Luna County. The area south of Deming (Florida and Tres Hermanas Mountains, Mimbres Basin) exhibits high potassium and thorium on the regional maps, where higher Th (10–13 ppm), K (2.8–3.4%), and U (2.6–3 ppm) are found (Pitkin, 1997). A northwest trend of high potassium northwest of Deming corresponds with the Burro Mountains. The Cooke's Range exhibits relatively low values of K (1–1.6%), U (1.2–1.6 ppm), and Th (5–7 ppm) that correspond to Paleozoic and Mesozoic carbonate rocks (Pitkin, 1997). These anomalies are too low to be related to economic uranium deposits. Therefore, the uranium mineral-resource potential in the Tres Hermanas-Victorio Mountains and Sierra Rica (Fremont district) is low with a C level of certainty (Fig. 72, Table 1). There is no uranium-resource potential elsewhere in Luna County with a D level of certainty.

FIGURE 72. Uranium and geothermal mineral-resource potential in Luna County.

Geothermal Resources

Currently, conductive hydrothermal resources for deep wells (>300 m) are subeconomic due to high cost, risk, and slow investment returns. Forced convective hydrothermal systems; however, are currently being used in southwestern New Mexico. New Mexico State University (NMSU) at Las Cruces in Doña County is one of the largest direct-uses systems in the nation. The NMSU system supplies space heating and hot water from the Las Cruces East Mesa-Tortugas Mountain geothermal system. Geothermal resources also can be utilized for greenhouses or drying factories for spices and other foods. Another possible direct use is small-scale electrical power generators, which has been done in Grant County at the Gila Hot Springs.

Eastern Luna County and Columbus have a low to moderate potential with a B level of certainty, because of the presence of warm to hot wells and <5 Ma basalts (Fig. 72, Table 1). Northern Luna County has a low to moderate potential with a B level of certainty, because of nearby hot springs and wells. The remainder of Luna County has no potential for geothermal resource with a D level of certainty.

Coal Resources

There are no known coal deposits in Luna County. There is no coal-resource potential in Luna County with a D level of certainty.

RECOMMENDATIONS FOR FUTURE STUDIES

(1) Much of Luna County has not been mapped at 1:24,000 scale, which is needed to fully understand the geology, structure, hydrology, and mineral-resource potential of the area, especially in western Luna County.
(2) Camp Rice Formation in the Goodsight Mountains should be examined for clay potential.
(3) Sample jasperoids in the county to assess the potential for sedimentary-hosted gold deposits.
(4) Examine alluvial material and Cretaceous and Devonian shales for clay potential.
(5) Northern Luna County needs to be examined for zeolite potential.
(6) Examine additional mines and deposits in the Carrizalillo, Tres Hermanas, Cooke's Peak, Old Hadley, Florida, and Fremont districts.
(7) Examine rhyolite domes throughout Luna County for tin and perlite potential.

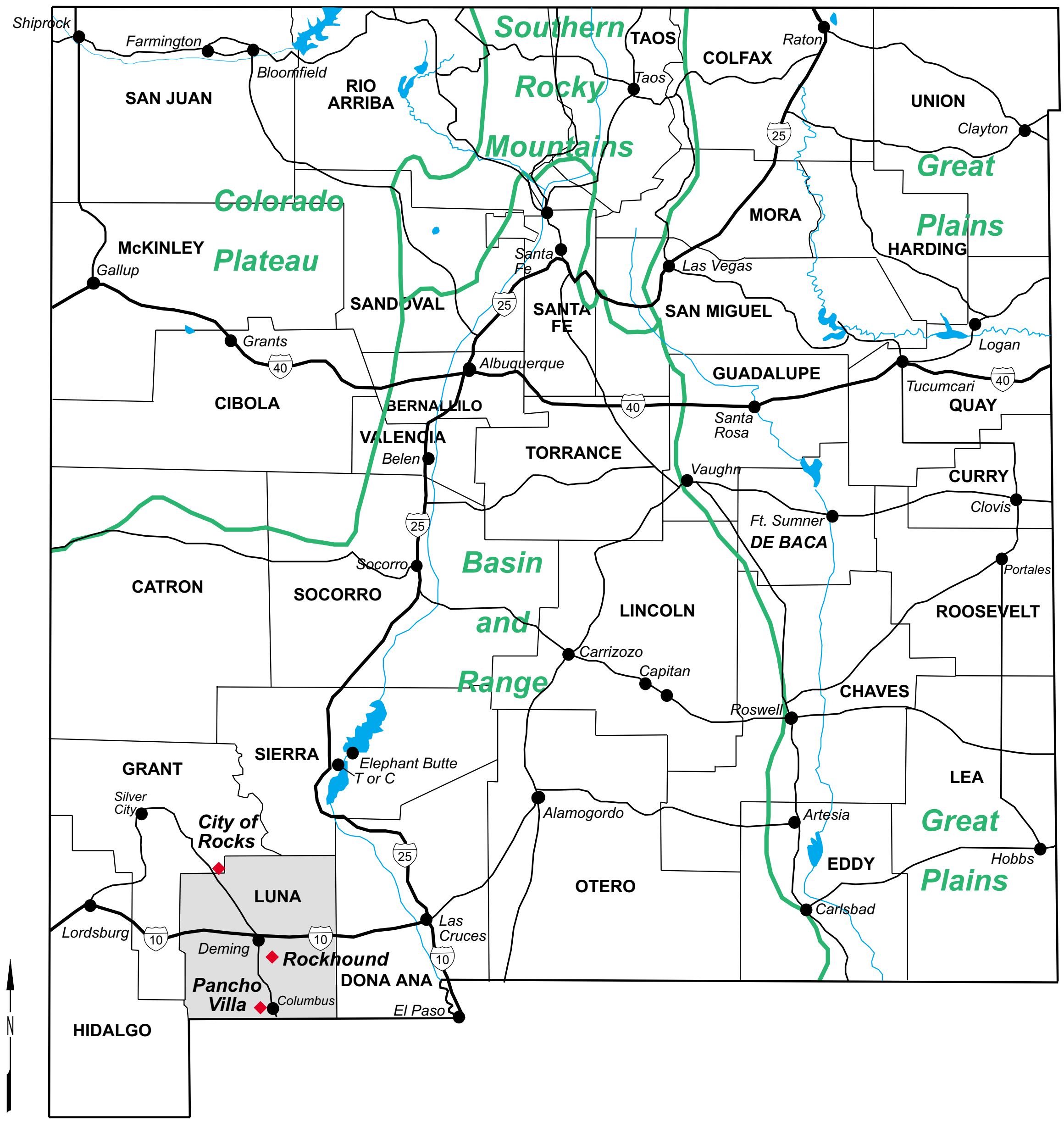

FIGURE 1. Location of Luna County, New Mexico.

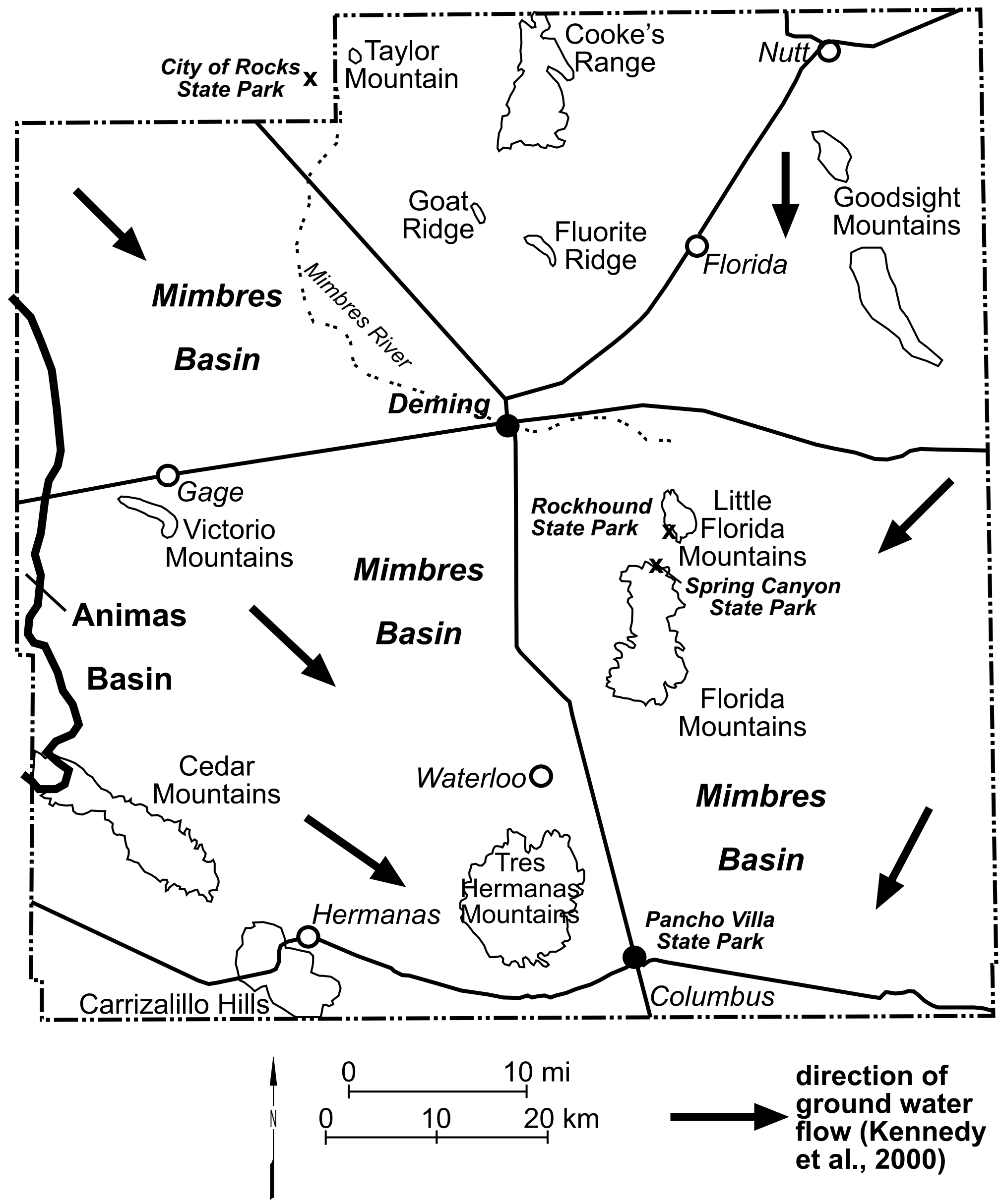

FIGURE 2. Physiographic features within Luna County.

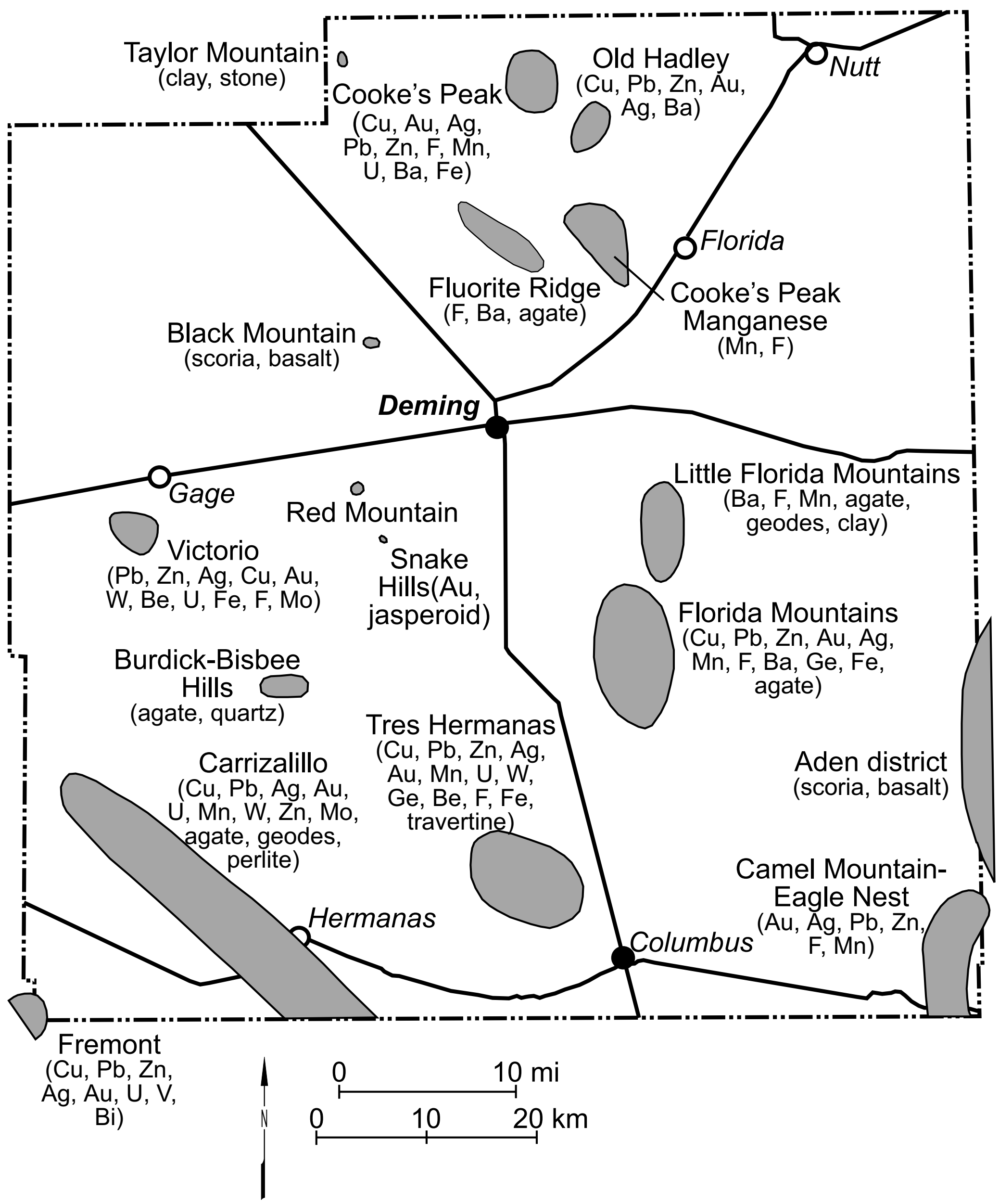

FIGURE 3. Mining districts in Luna County.

Legend

<all other values>

NAME

Map Border

Ti dikes

contact

dotted faults

solid faults

Value

High : 254

Low : 0

<all other values>

NAME

- &
- D
- Kbm
- Kl
- Ku
- M
- MD
- O_p
- P&
- Pa
- Ph
- Pys
- Pz
- QTg
- QTp
- QTs
- Qa
- Qbo
- Qe
- Qoa
- Qp
- SO
- SO_
- Ti
- Tla
- Tli
- Tlrf
- Tlrp
- Tlv
- Tnb
- Tnv
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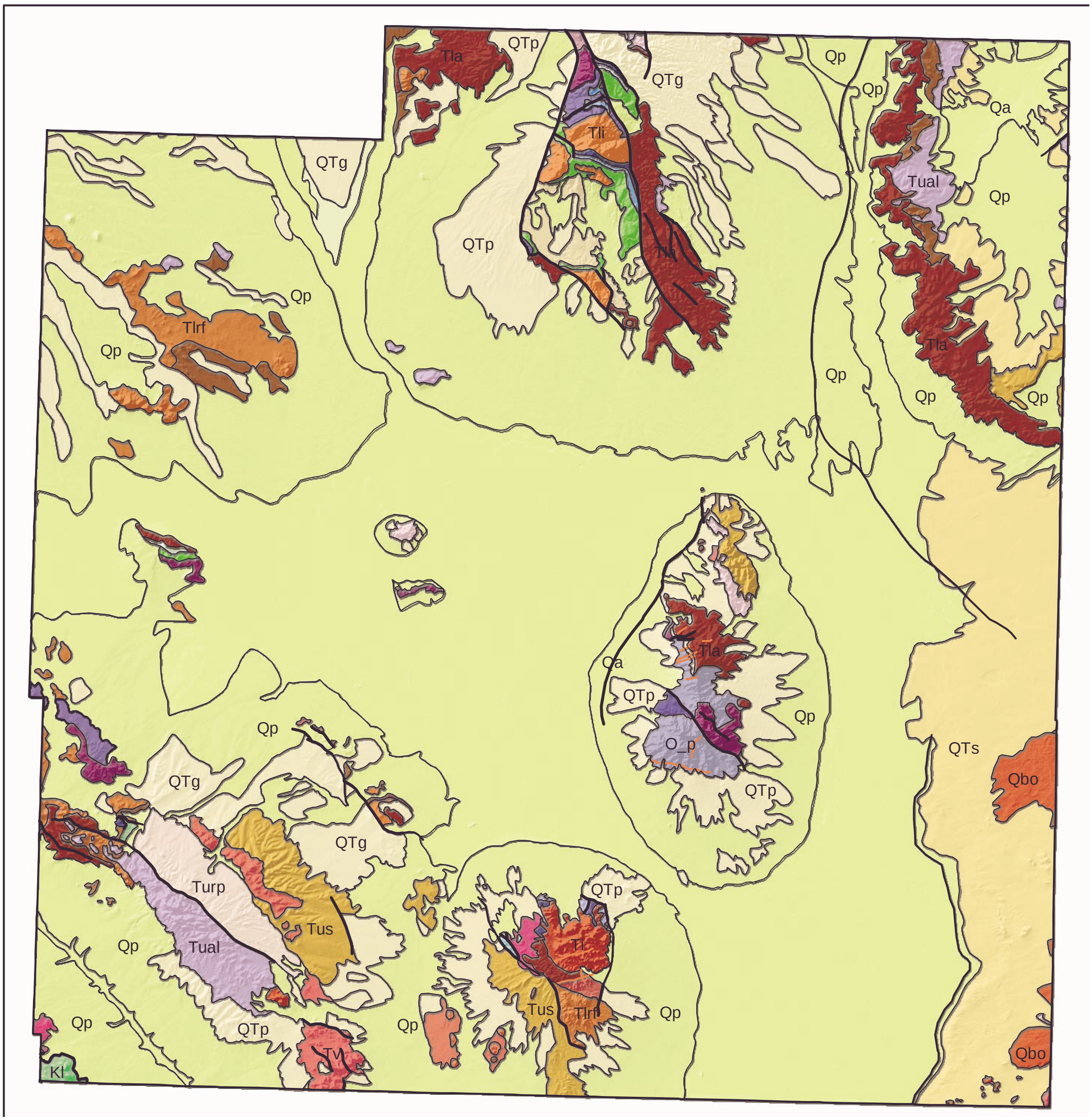
- Tsf
- Tual
- Tui
- Turf
- Turp
- Tus
- Tuv
- Tv
- Yp



<table>
<tr><td>Quaternary</td><td colspan="2">Playa, lacustrine, eolian, and alluvial deposits
Basalt flows</td><td>Clay, crushed stone
Basalt, scoria</td></tr>
<tr><td>Oligocene-Pleistocene</td><td>Gila Group
Mimbres Formation

middle
lower</td><td>Santa Fe Group
Camp Rice/Palomas Formations
Rincon Valley Formation
Hayner Ranch Formation</td><td>
Clay, stone</td></tr>
<tr><td>Miocene-Eocene</td><td colspan="2">Kneeling Nunn Tuff (35 Ma)
Sugarlump Tuff
Uvas Formation
Bell Top Formation
Additional ash flow tuffs and other volcanic rocks</td><td></td></tr>
<tr><td>Eocene</td><td colspan="2">Rubio Peak Formation
Macho Andesite
Victorio Peak dacite
Palm Park Formation</td><td></td></tr>
<tr><td>Paleocene-Eocene</td><td colspan="2">Lobo Formation</td><td></td></tr>
<tr><td>Cretaceous</td><td colspan="2">Andesite/dacite flows (Hidalgo Formation?)
MacRae Formation
Mancos (Colorado) Shale
Bisbee Group
Mojado Formation
Rattlesnake Ridge Member
Sarten/Beartooth Member
Flyingpan Spring Member
U-Bar Formation
Still Ridge Member
Victorio Mountains Member
Carbonate Hill Member
Hell-to-Finish Formation</td><td>
Clay
Clay
Silica</td></tr>
<tr><td>Pennsylvanian-Permian</td><td colspan="2">Magdalena Group
San Andres Formation
Yeso Formation
Abo/Hueco Formations
Horquilla Formation</td><td>

Sedimentary Cu</td></tr>
<tr><td>Mississippian</td><td colspan="2">Rancheria Formation
Lake Valley Formation
Tierra Blanca Member
Nunn Member
Alamogordo Member
Andrecito Member
Caballero Formation</td><td>
Carbonate-hosted

Limestone</td></tr>
<tr><td>Devonian</td><td colspan="2">Percha Shale
Box Member
Ready Pay Member</td><td>Clay</td></tr>
<tr><td>Silurian</td><td colspan="2">Fusselman Formation</td><td>Carbonate-hosted</td></tr>
<tr><td>Upper Ordovician</td><td colspan="2">Montoya Group
Cutter Member (Valmont Dolomite)
Aleman Member
Upman Member
Cable Canyon Sandstone Member</td><td>Carbonate-hosted</td></tr>
<tr><td>Lower Ordovician</td><td colspan="2">El Paso Group
Padre Member
McKelligan Member
Jose Member
Hitt Canyon Member</td><td>Skarn, carbonate-hosted</td></tr>
<tr><td>Cambrian-Ordovician</td><td colspan="2">Bliss Formation</td><td>Silica</td></tr>
<tr><td>Cambrian-Ordovician</td><td colspan="2">Alkaline intrusive rocks</td><td>REE-Th-U (±Nb) veins</td></tr>
<tr><td>Proterozoic rocks</td><td colspan="2">Granite, amphibolite, metamorphic rocks</td><td></td></tr>
</table>

FIGURE 5. Stratigraphic correlations. The entire section is intruded by a series of Mid-Tertiary intrusions (Table 10) that may be related to porphyry copper, copper-molybdenum, molybdenum deposits and related veins, skarns, and carbonate-hosted deposits.

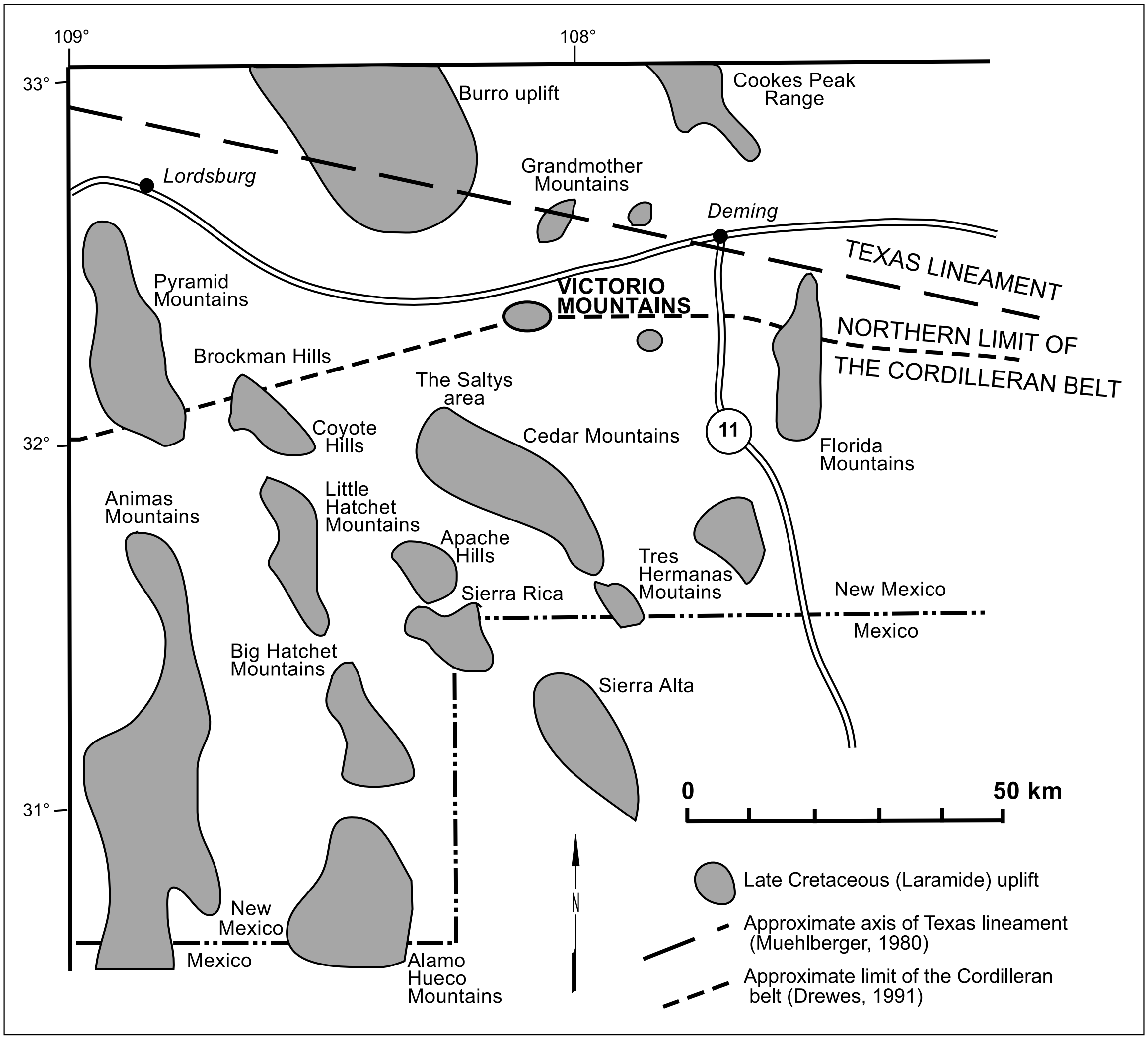


FIGURE 6. Structural features during the Laramide in southwestern New Mexico.

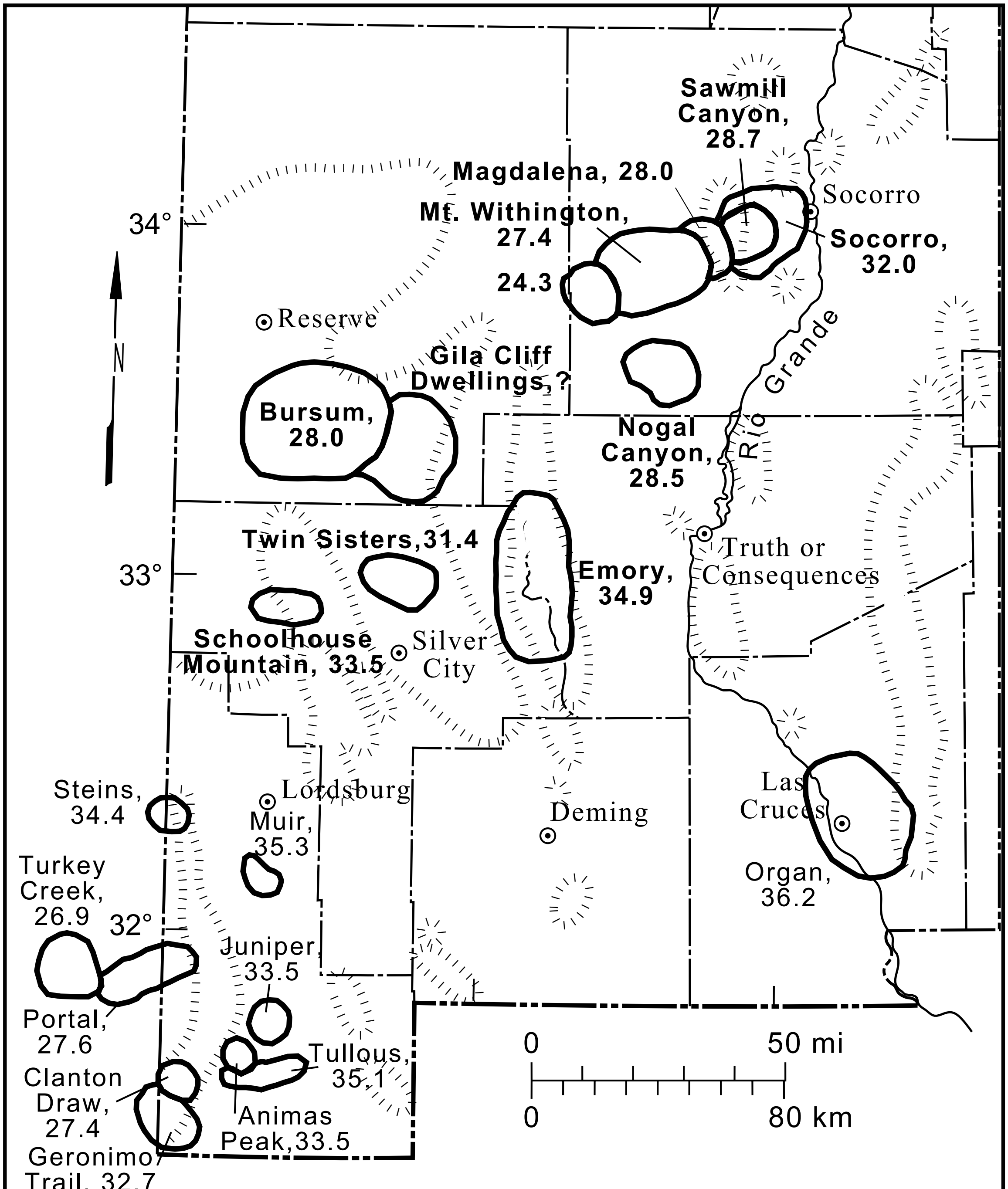
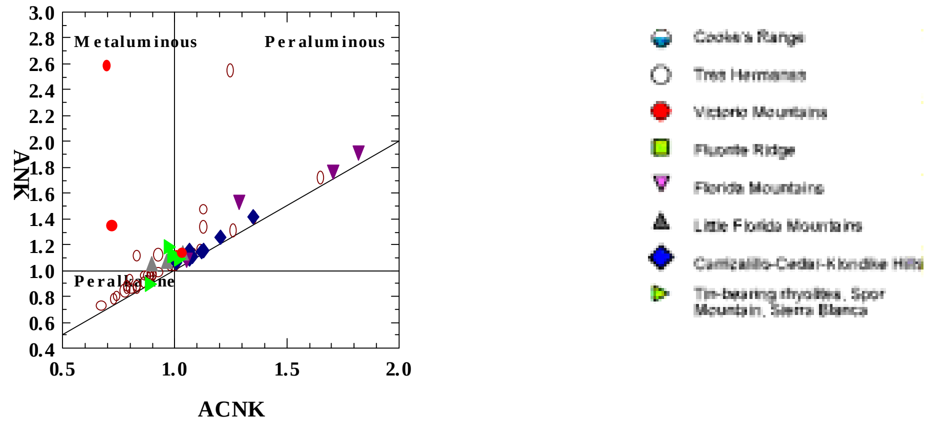
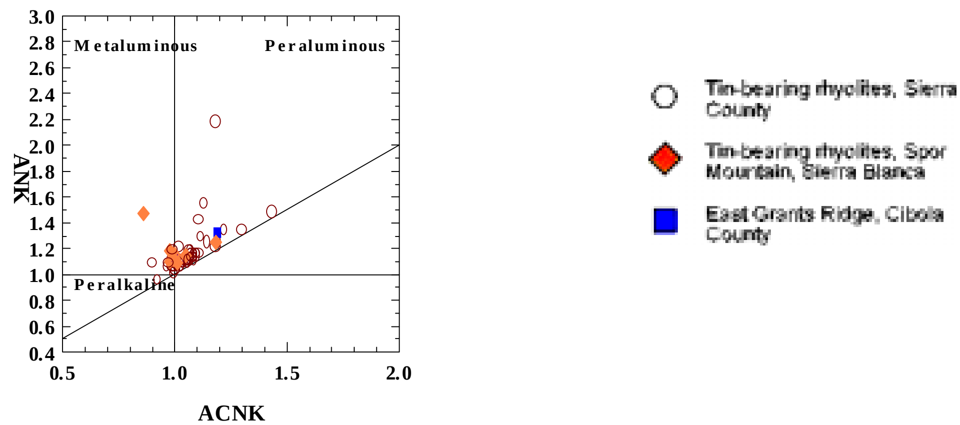


FIGURE 7. Map of Mid-Tertiary calderas in southwestern New Mexico (W. I. McIntosh, map, June 2001). Ages are in million years.

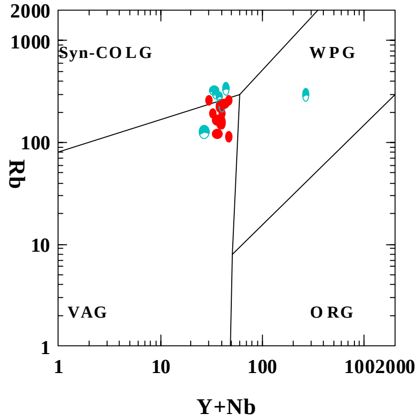


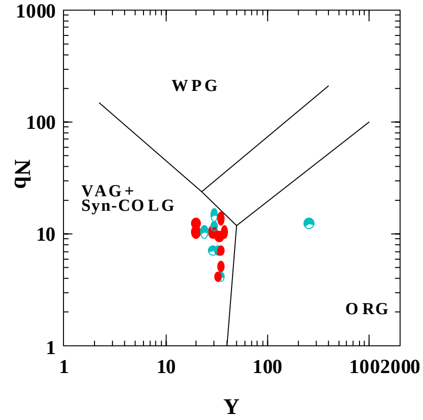
Luna County rhyolites



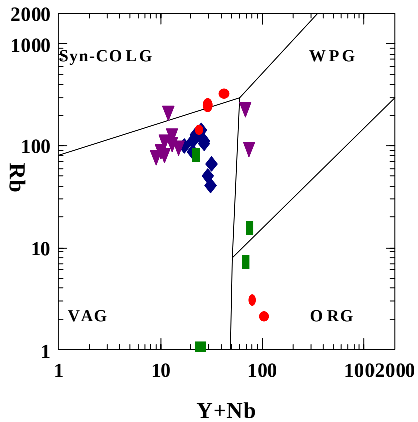
Tin-bearing rhyolites

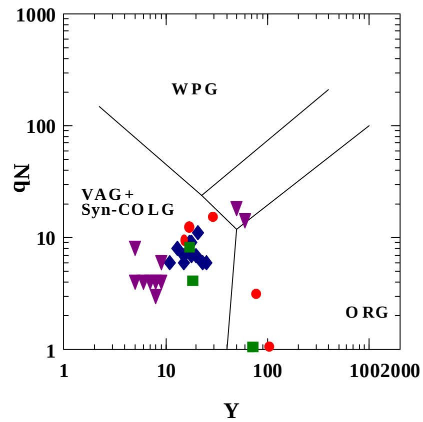
FIGURE 8. A scatter plot of ANK ($Al_2O_3/(Na_2O + K_2O)$) verses ACNK ($Al_2O_3/(CaO + Na_2O + K_2O)$) of rhyolites from Luna County and tin-bearing rhyolites. Analyses of Luna County rhyolites are in Appendix 4. Analyses of tin-bearing rhyolites are from Sierra County (Lufkin, 1972; Correa, 1981; Goerold, 1981; Woodard, 1982; Duffield and Dahymple, 1990; Duffield and Ruiz, 1992), East Grants Ridge (unpublished data), and Sierra Blanca (Barker, 1980; Rubin et al., 1987).



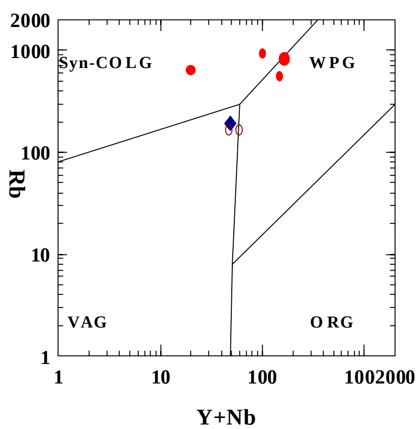


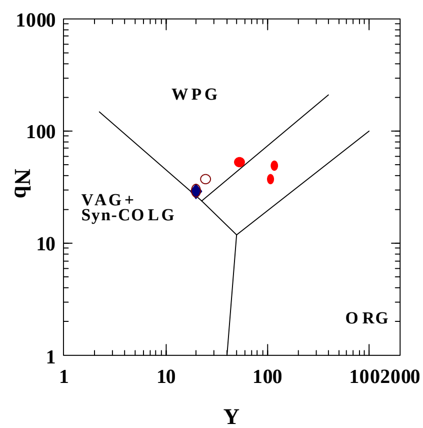
Copper Flat porphyry, Sierra County





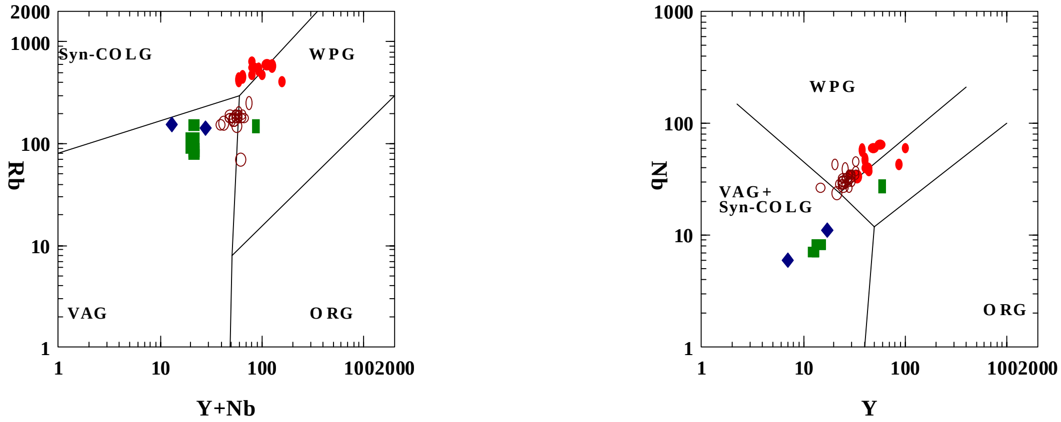
Porphyry copper deposits, NM





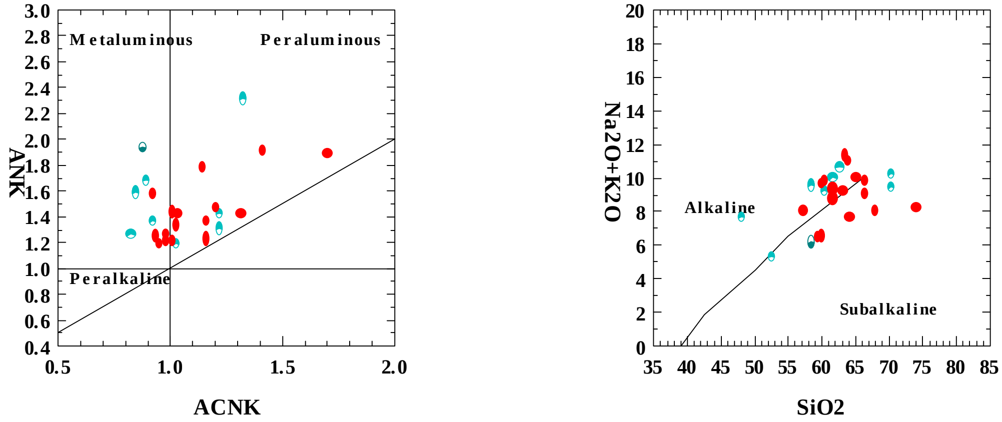
Luna County rhyolites (see key in Figure 8).

Figure 9 continued on next page.

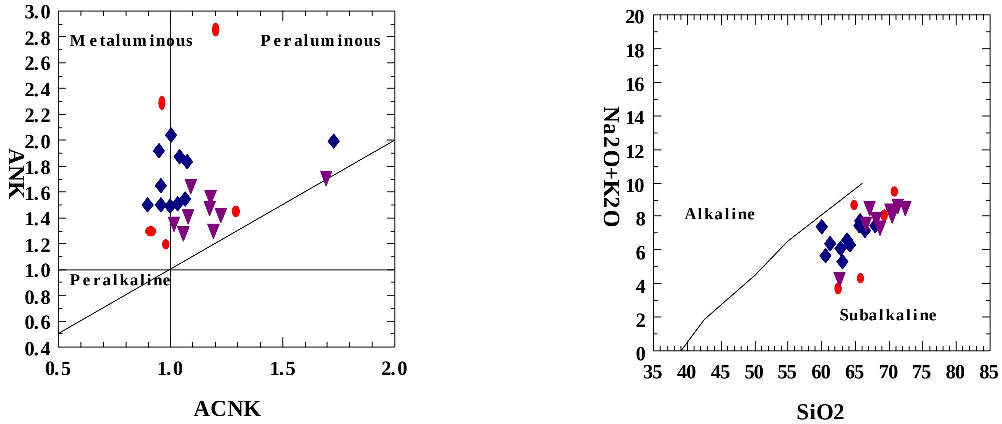


Luna County granitic rocks

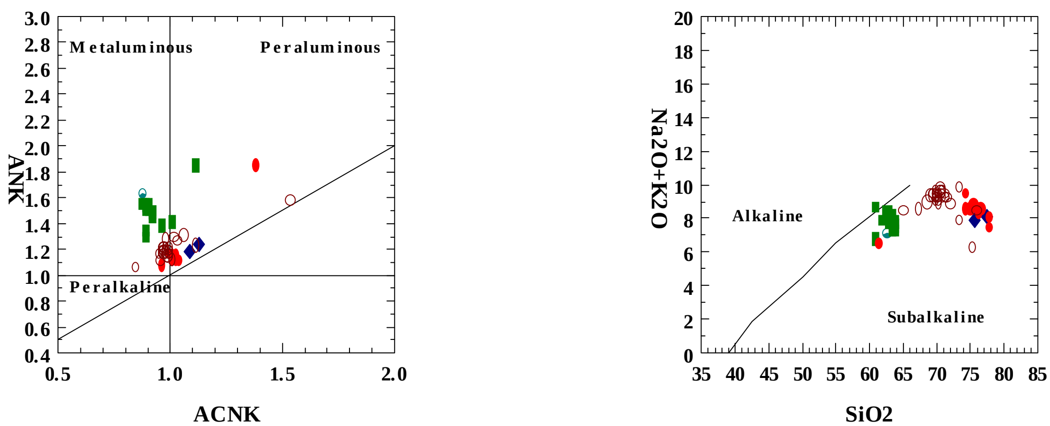
FIGURE 9. A scatter plot of Rb verses Y + Nb and Nb verses Y of granitic rocks and rhyolites from Luna County and granitic rocks from New Mexico porphyry copper deposits. Analyses of Luna County granitic rocks are in Appendix 4. Analyses of porphyry copper deposits from McLemore (unpublished data) and McLemore et al. (1999b, 2000c). Fields are from Pearce et al. (1984). WPG- within plate granites, ORG- orogenic granites, VAG-volcanic arc granites.



Copper Flat porphyry, Sierra County (red circles are unmineralized monzonite, green half-filled circles are mineralized monzonite).



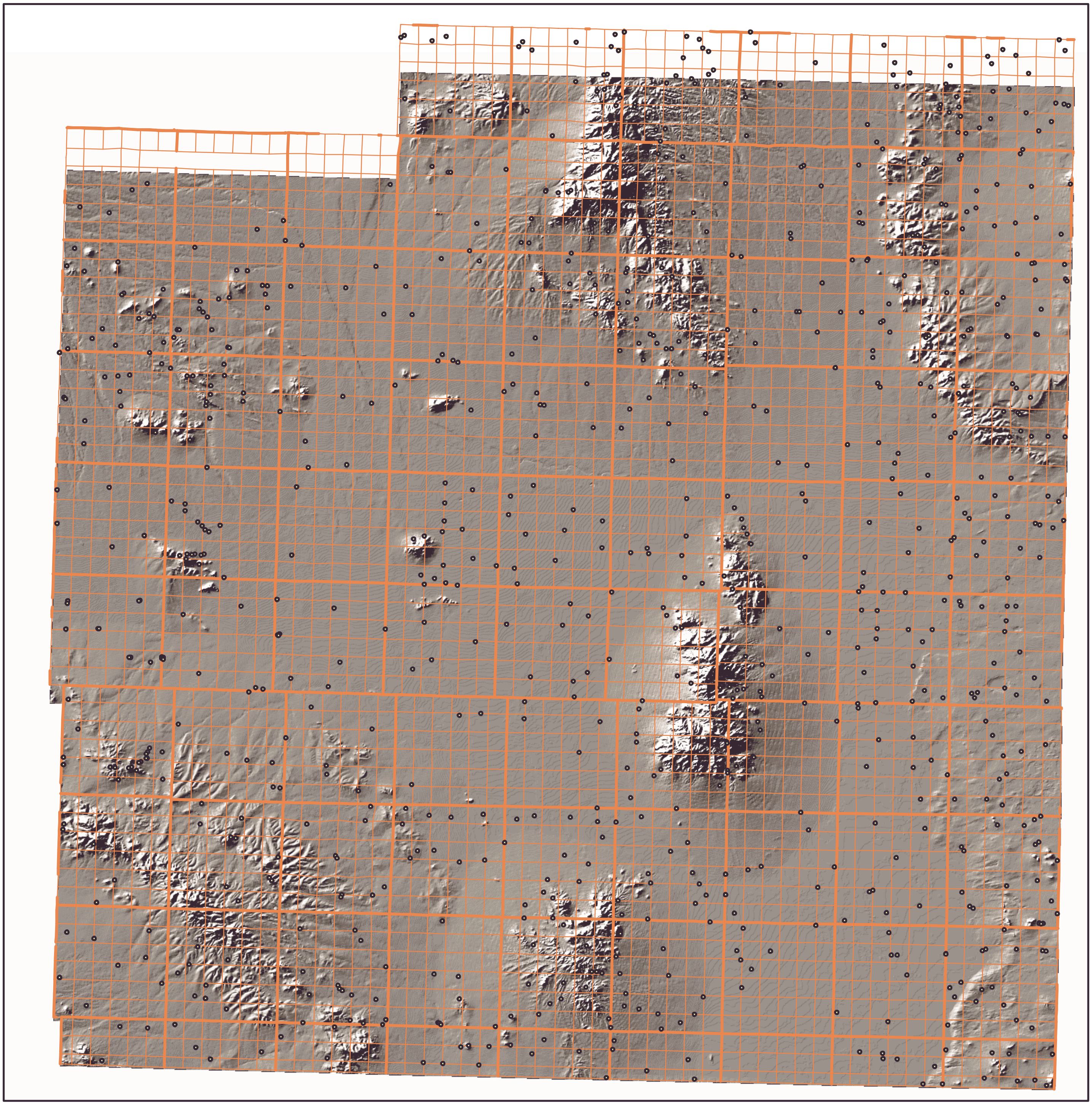
Porphyry copper deposits, New Mexico (blue diamonds are Santa Rita, purple triangles are Tyrone, red circles are Lordsburg).



Luna County granitic rocks (see Figure 8 for key).

Figure 10 continued next page.

FIGURE 10. A scatter plot of ANK ($Al_2O_3/(Na_2O + K_2O)$) verses ACNK ($Al_2O_3/(CaO + Na_2O + K_2O)$) and SiO_2 verses $Na_2O + K_2O$ of granitic rocks from Luna County. Analyses of Luna County granitic rocks are in Appendix 4. Analyses of porphyry copper deposits from McLemore (unpublished data) and McLemore et al. (1999b, 2000c). The line between alkaline and subalkaline is from Irvine and Baragar (1971).



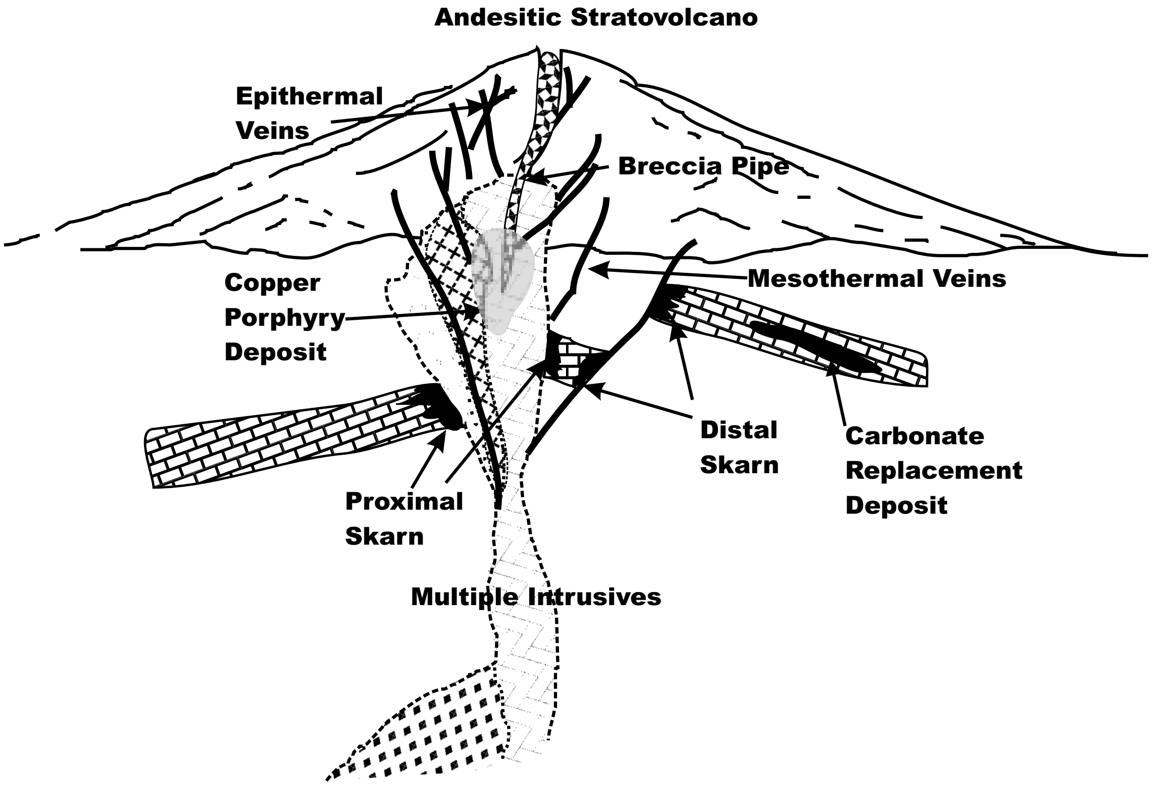


FIGURE 12. Simplified porphyry system (from McLemore and Lueth, in press).

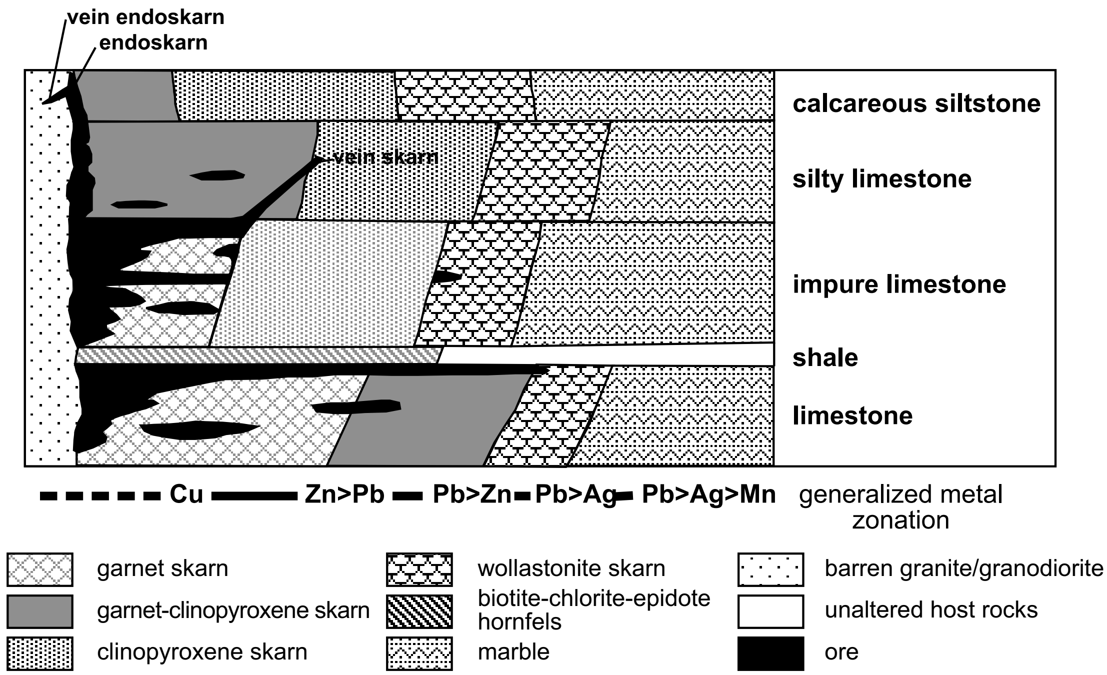


FIGURE 13. Diagrammatic sketch showing mineralization and alteration patterns in Laramide skarns in southern New Mexico (modified from Lueth, 1984; McLemore and Lueth, 1996; McLemore and Lueth, in press). Garnet forms nearest the stock in the purer limestone of the Lake Valley Limestone and Oswaldo Formation. Garnet-pyroxene forms adjacent to the stock in the argillaceous carbonate rocks. A hornfels typically forms at the parting shale in the Oswaldo Formation. Wollastonite and marble form the outer zones. Chalcopyrite occurs in the garnet zone and sphalerite occurs in the clinopyroxene zone and at the contact between the skarn and marble.

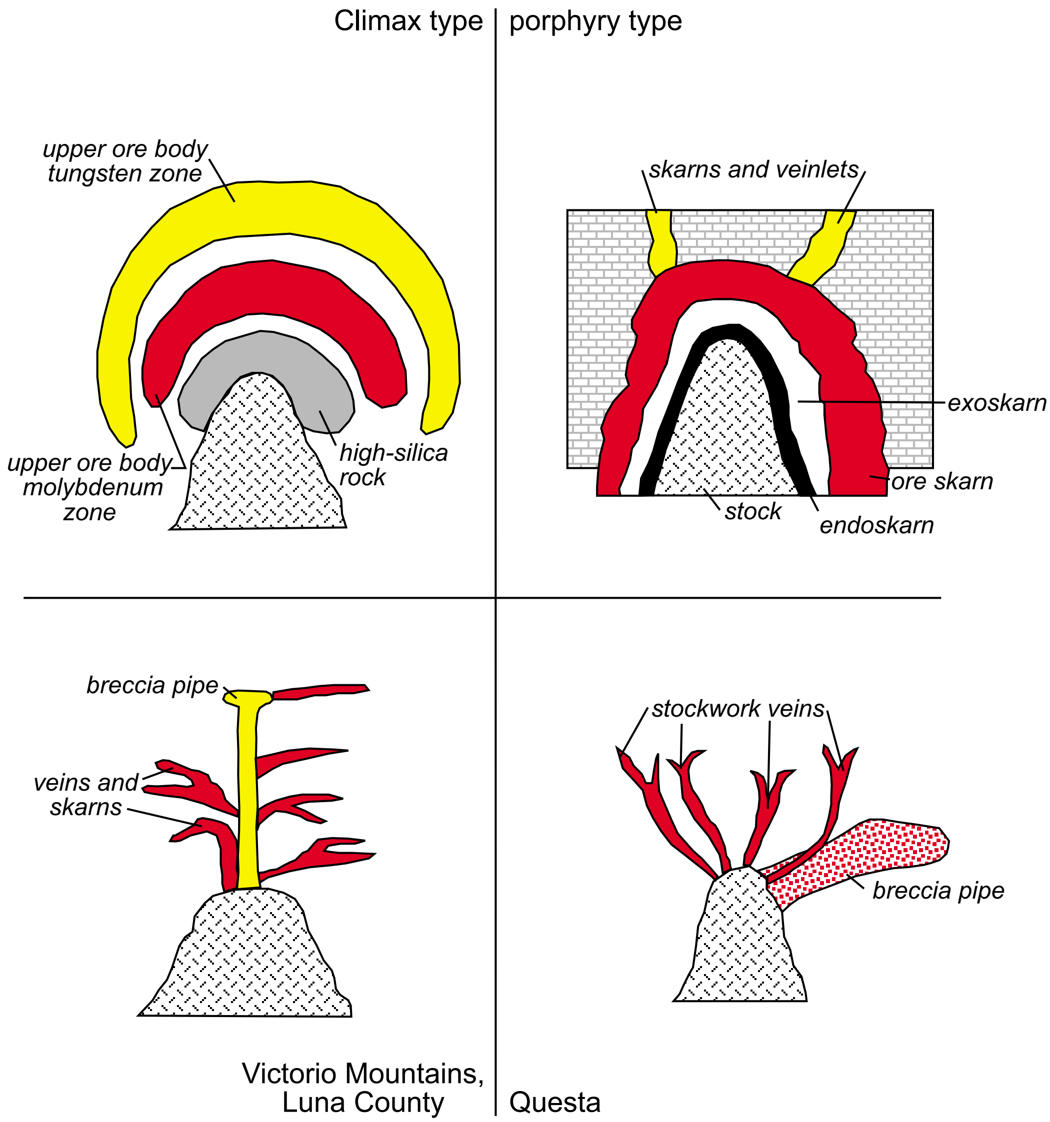


FIGURE 14. Schematic sketch of forms of porphyry molybdenum depoists that are dependent upon the amount of fluid in the source magma, overpressures, host rock permeability, and other physical/chemical characteristics (modified in part from P. S. Ross, personal communication, 6/01 and Guilbert and Park, 1986).

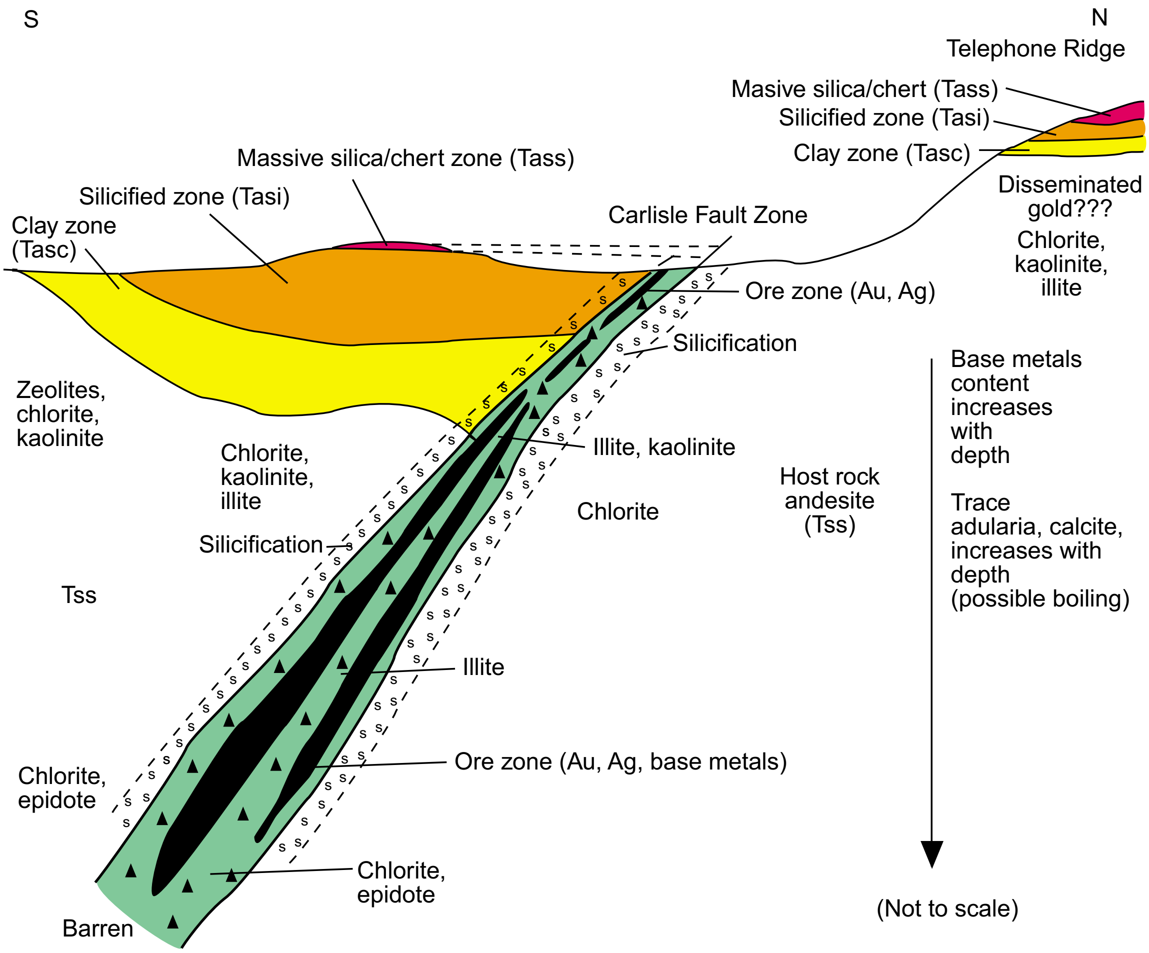


FIGURE 15. Relationship between alteration and vein deposits along the Carlisle fault (from McLemore, 1993 and modified in part from Weaco drill data).

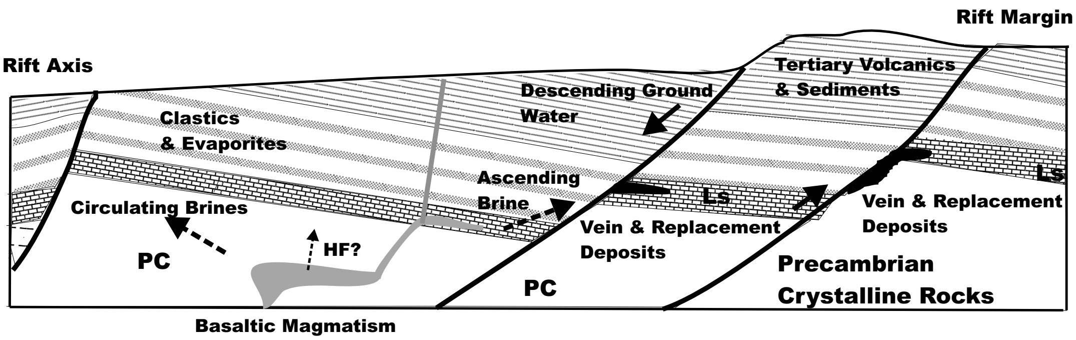


FIGURE 16. Rio Grande Rift deposits (from McLemore and Lueth, in press).

FIGURE 17. Travertine, southern Tres Hermanas Mountains (V. T. McLemore photo).

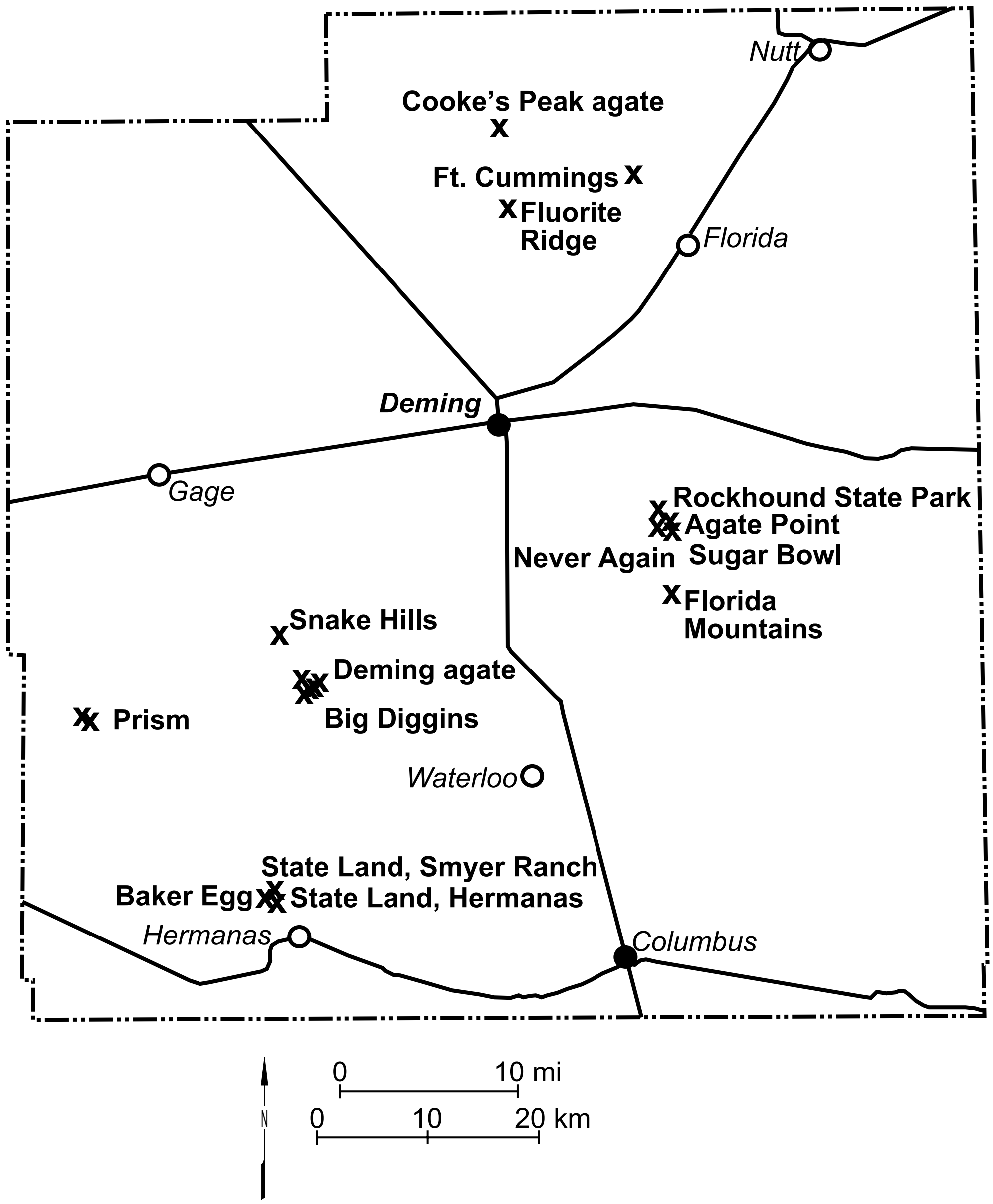


FIGURE 18. Geodes and agate in Luna County.

FIGURE 19. A cut and polished face of a thunderegg from the Baker Egg mine showing two amethyst quartz-plugged fill-tubes (from Colburn, 1999).

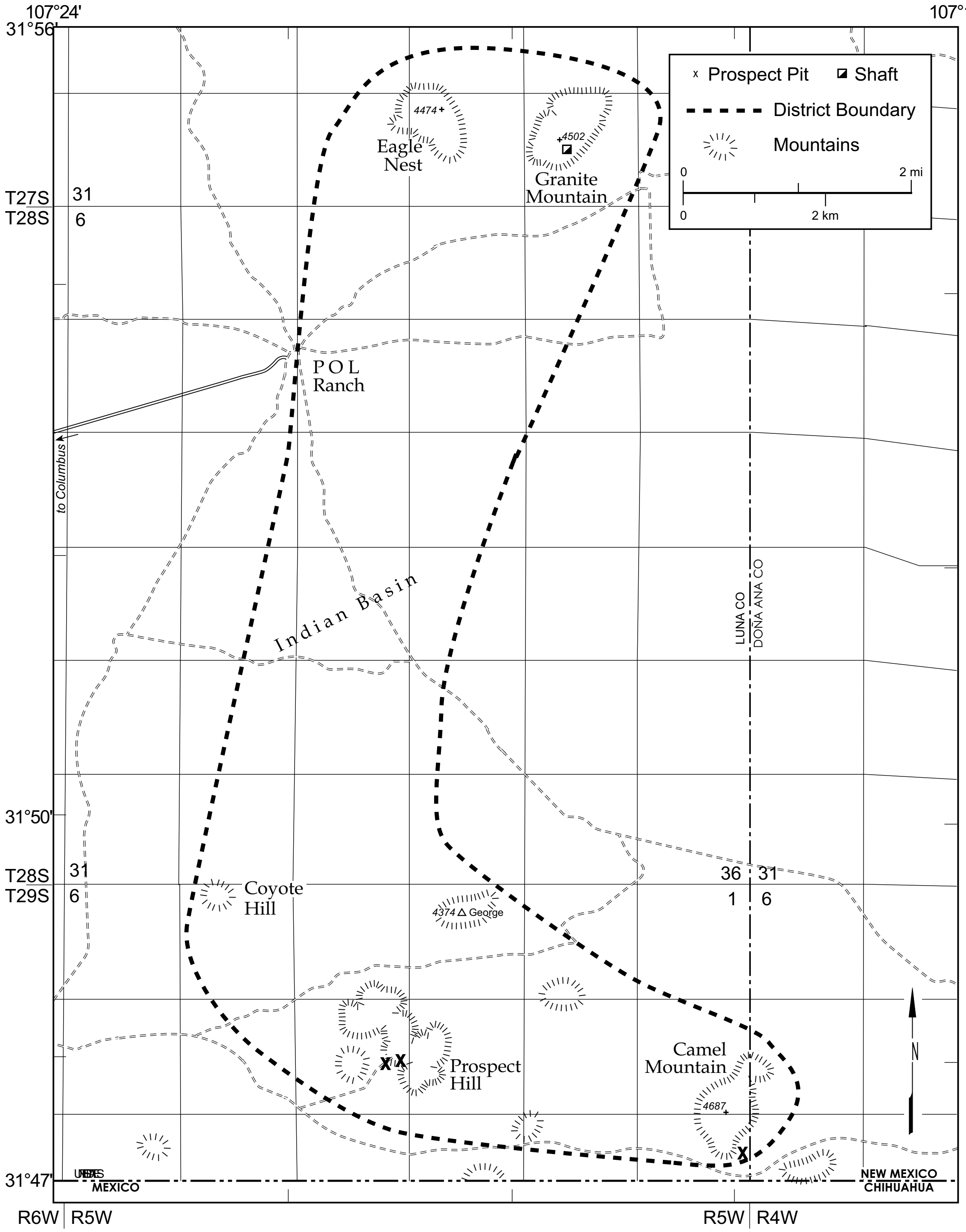


FIGURE 20. Mines and prospects in the Camel Mountain-Eagle Nest district, Luna County, New Mexico.

FIGURE 21. Camel Mountain, looking north. A prospect pit is on the top of the east ridge which is formed by a rhyolite dike (V. T. McLemore photo).

FIGURE 22. Eagle Nest Hill, looking north. A prospect pit is near the western crest (V. T. McLemore photo).

FIGURE 23. Vein containing calcite, quartz, siderite, galena, and pyrite striking east-west at Eagle Nest Hill (V. T. McLemore photo).

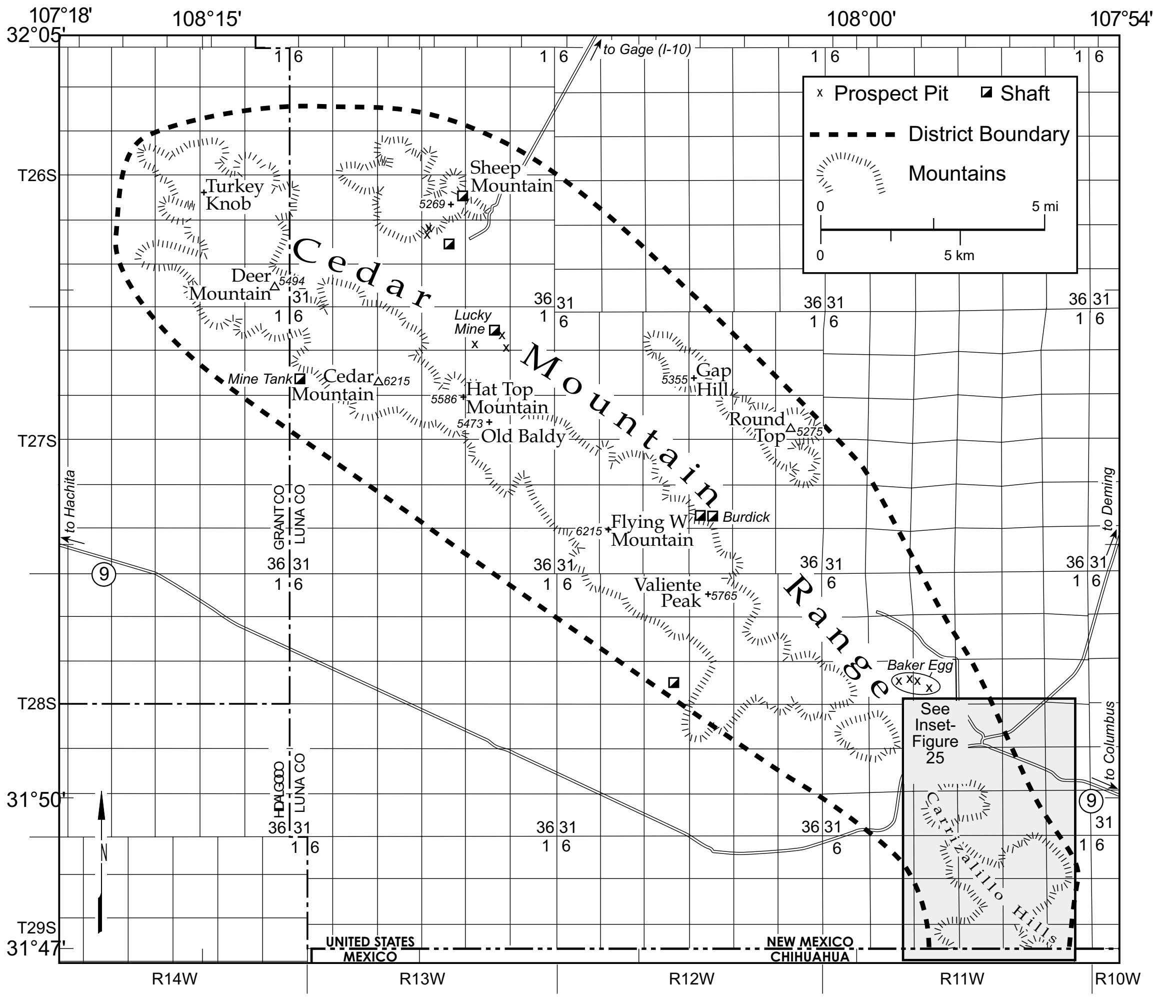


FIGURE 24. Mines and prospects in the Carrizalillo mining district, Luna County, New Mexico.

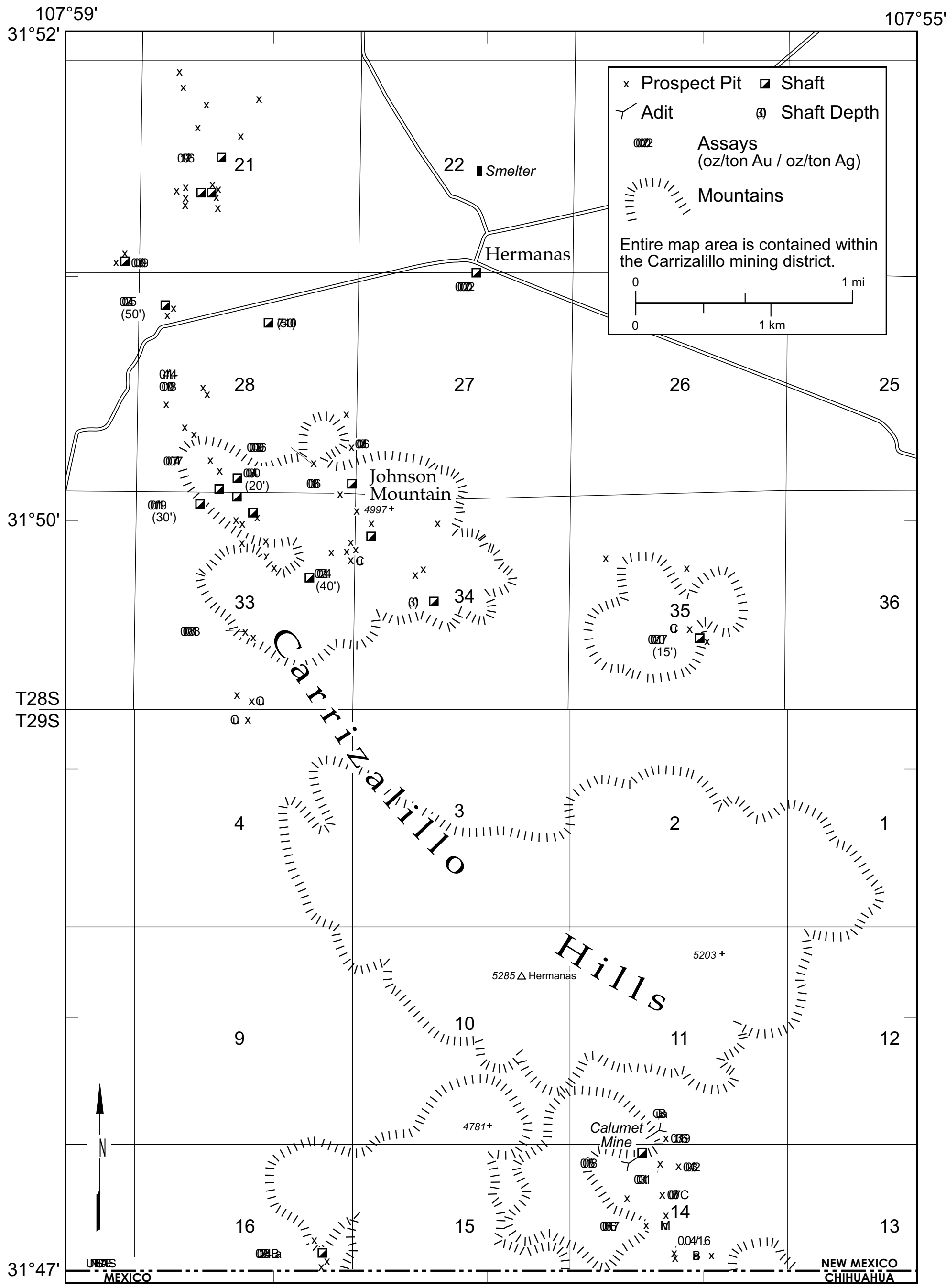


FIGURE 25. Mines, prospects, and assay values in the Carrizalillo Hills, southern Carrizalillo mining district, Luna County, New Mexico (chemical analyses from Gates, 1985).

FIGURE 26. Baker Egg No. 1 geode quarry, Carrizalillo Hills (V. T. McLemore, photo).

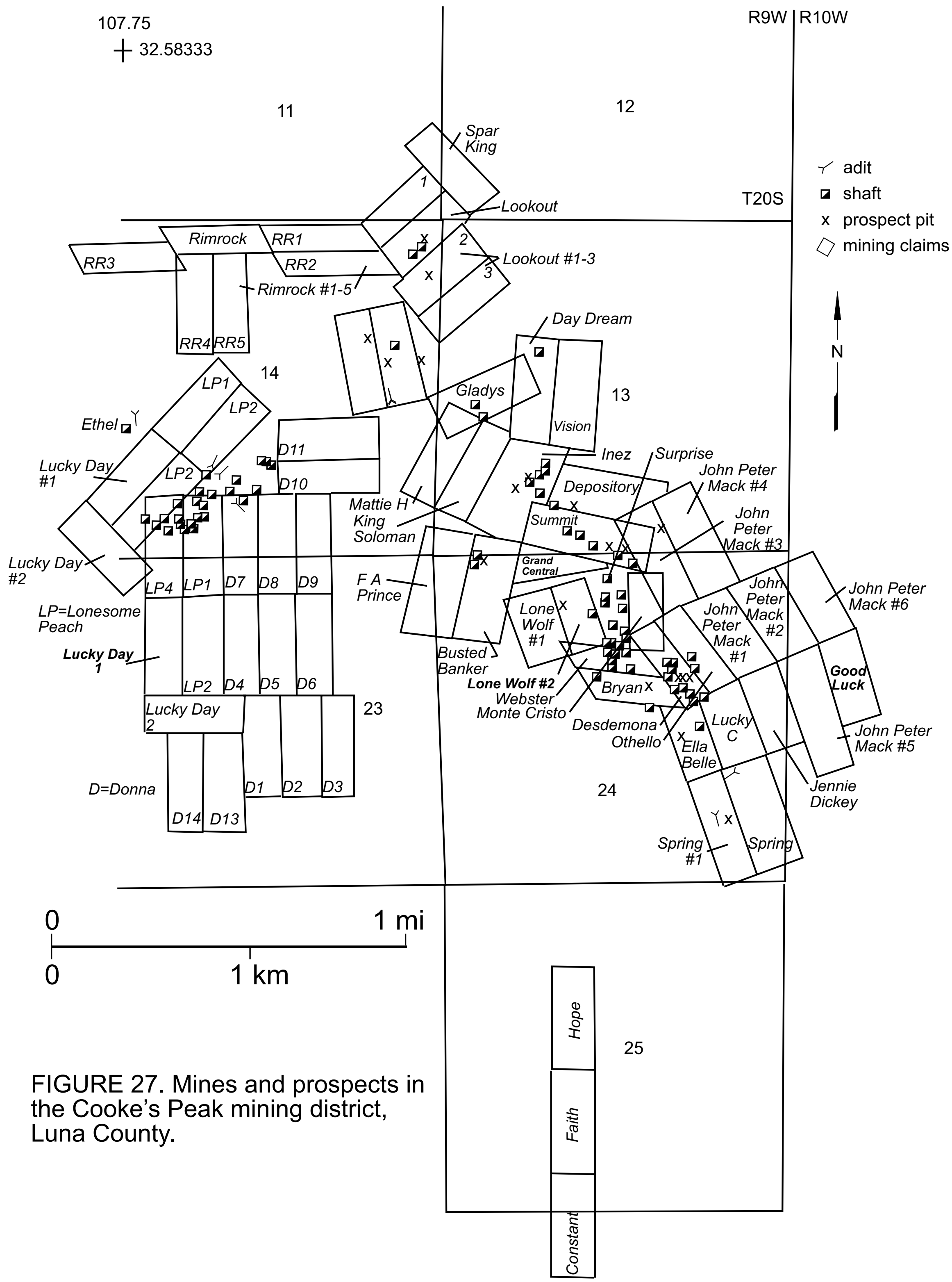


FIGURE 27. Mines and prospects in the Cooke's Peak mining district, Luna County.

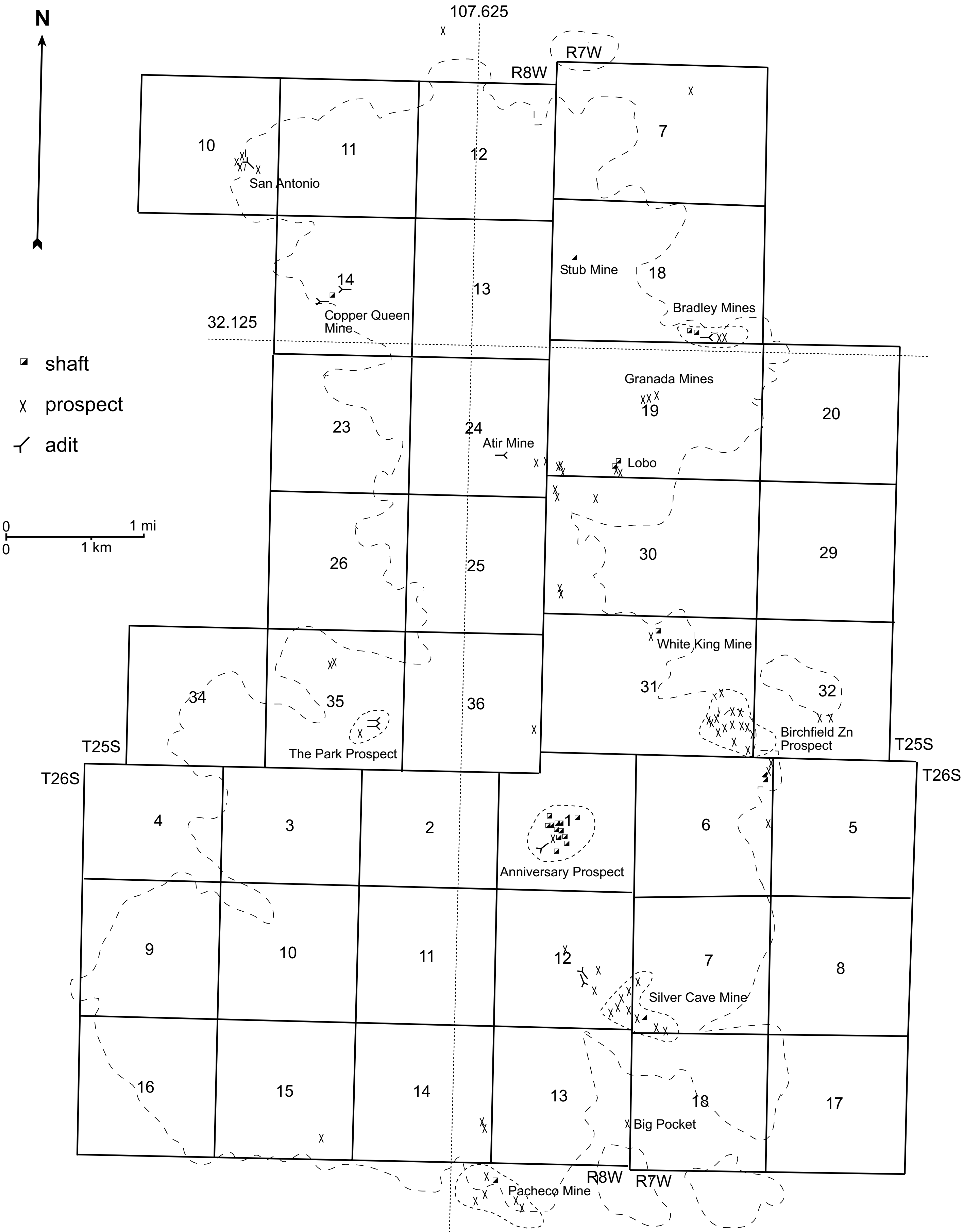


Figure 28. Mines and prospects in the Florida Mountains District, Luna County.

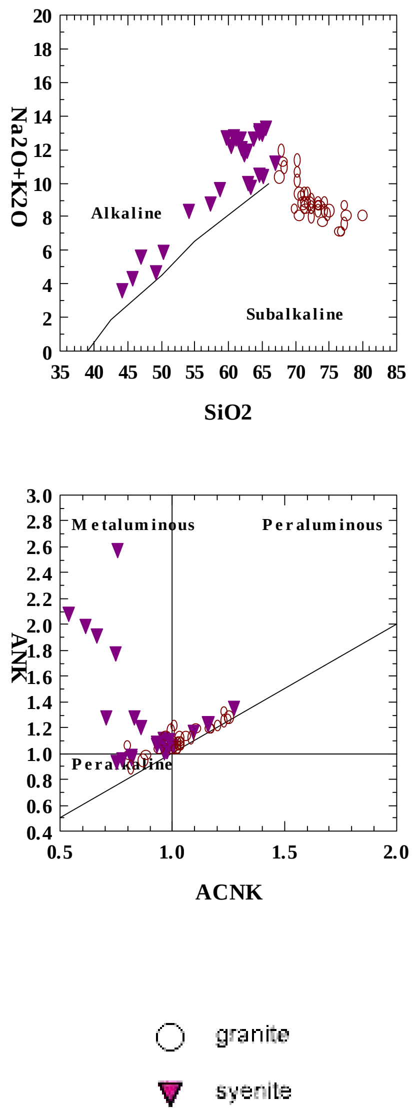


FIGURE 29. A scatter plot of Na_2O+K_2O verses SiO_2 and ANK (Al_2O_3/(Na_2O + K_2O)) verses ACNK (Al_2O_3/(CaO + Na_2O + K_2O)) of the Florida syenite-granites.

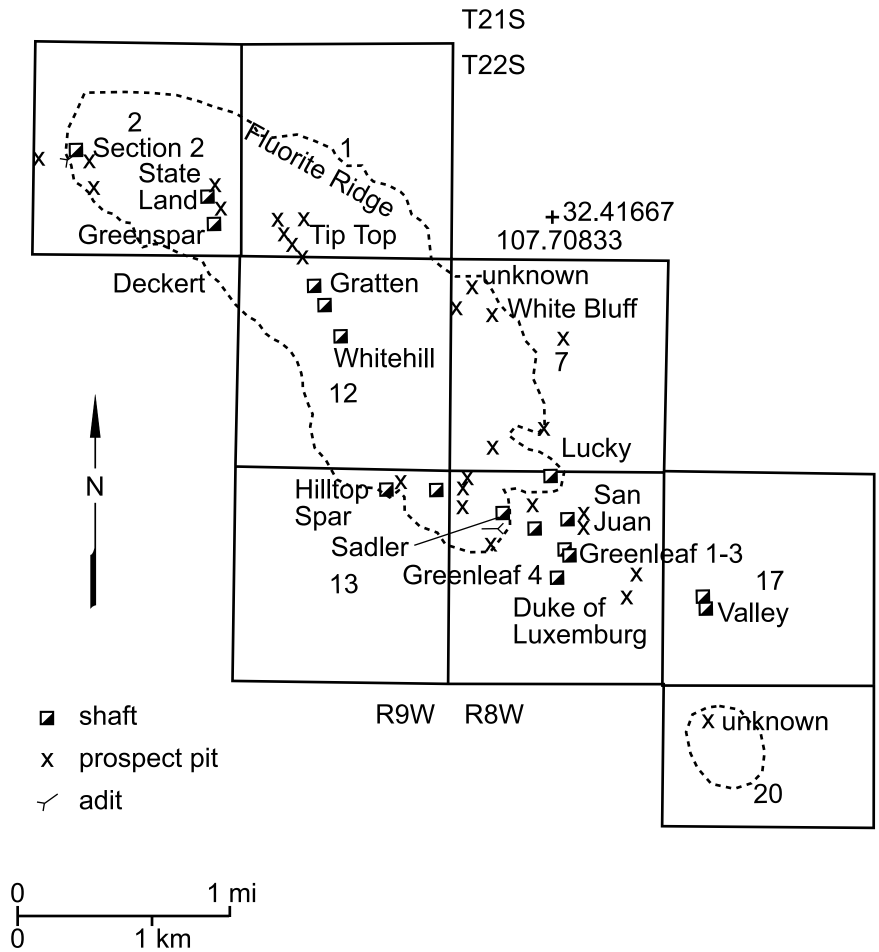


FIGURE 30. Mines and prospects in the Fluorite Ridge mining district, Luna County.

FIGURE 31. Lucky mine, south end of Fluorite Ridge. Jasperoid capped hill is in skyline (V. T. McLemore, photo).

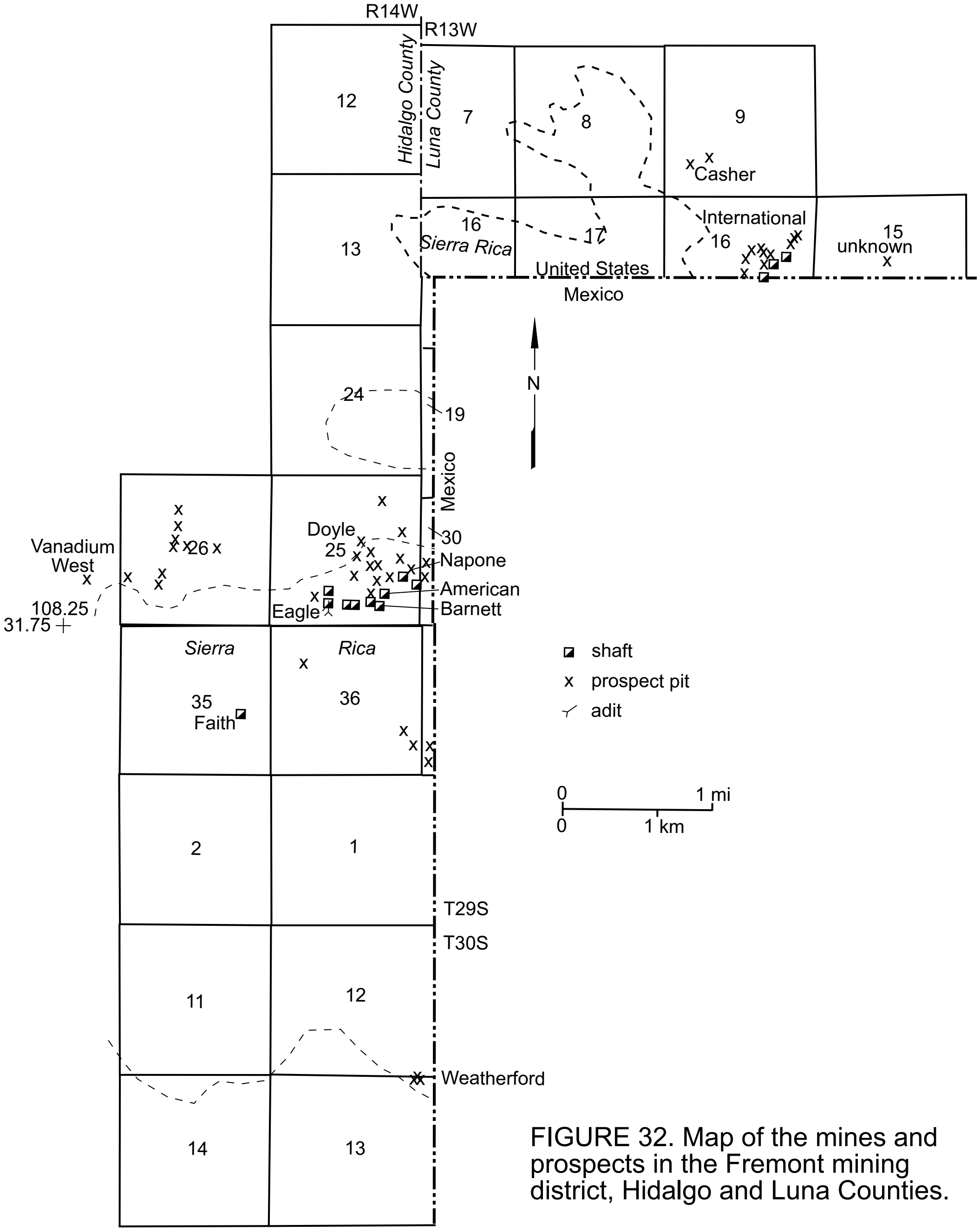


FIGURE 32. Map of the mines and prospects in the Fremont mining district, Hidalgo and Luna Counties.

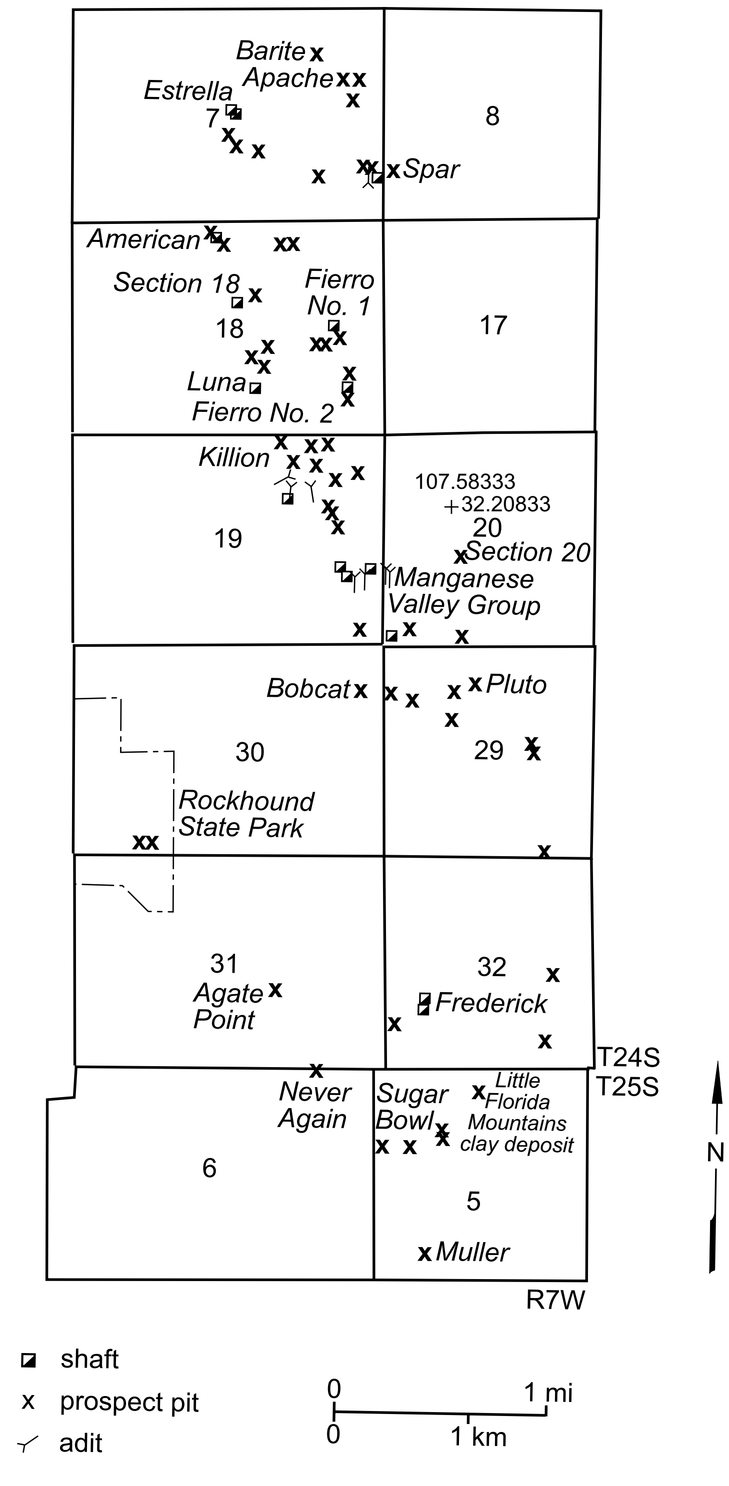


FIGURE 33. Mines and prospects in the Little Florida Mountains mining district, Luna County.

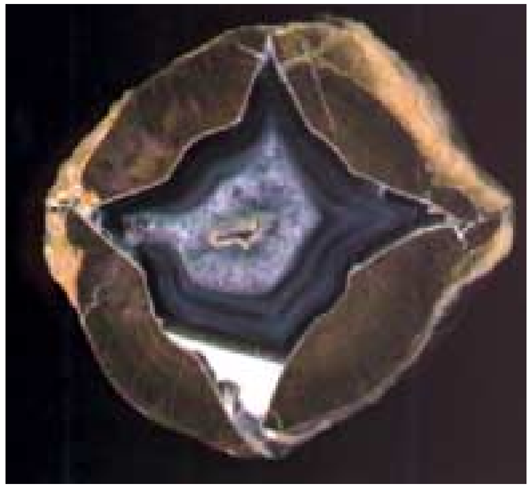


FIGURE 34. A thunderegg from the Never Again mining claim one mile southeast of Rockhound State Park,Deming, New Mexico (from Colburn, 1999).

FIGURE 35. A pair of star geodes (hollow thundereggs) with smokey quartz crystals from the Sugar Bowl mine, Little Florida Mountains district (from Colburn, 1999).

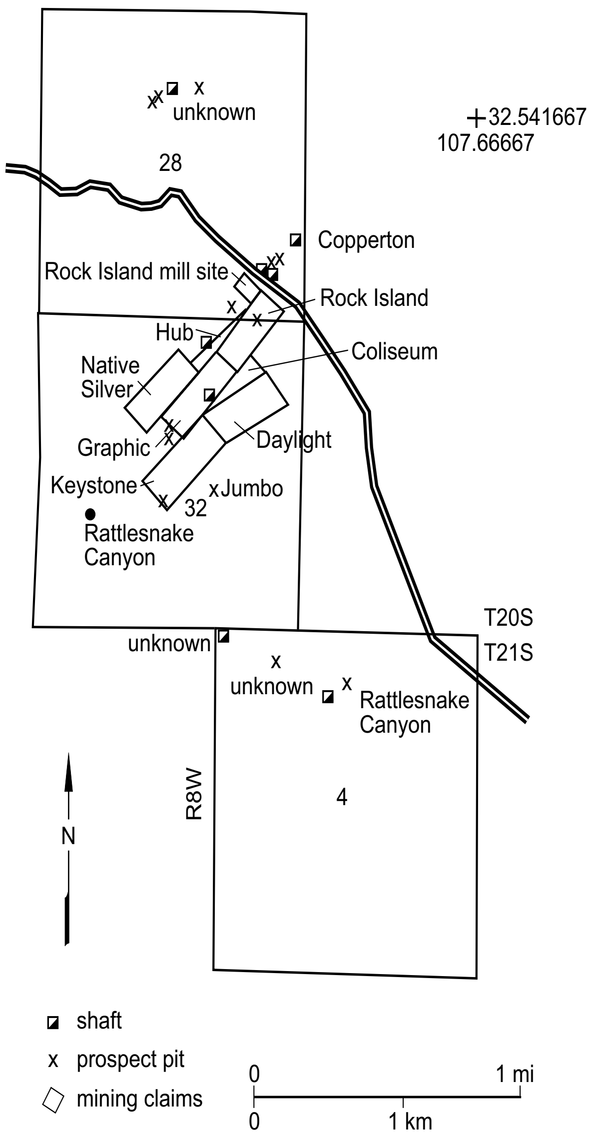


FIGURE 36. Mines and prospects in the Old Hadley mining district, Luna County.

FIGURE 37. Lucretia clay pit, Taylor Mountain (V. T. McLemore, photo).

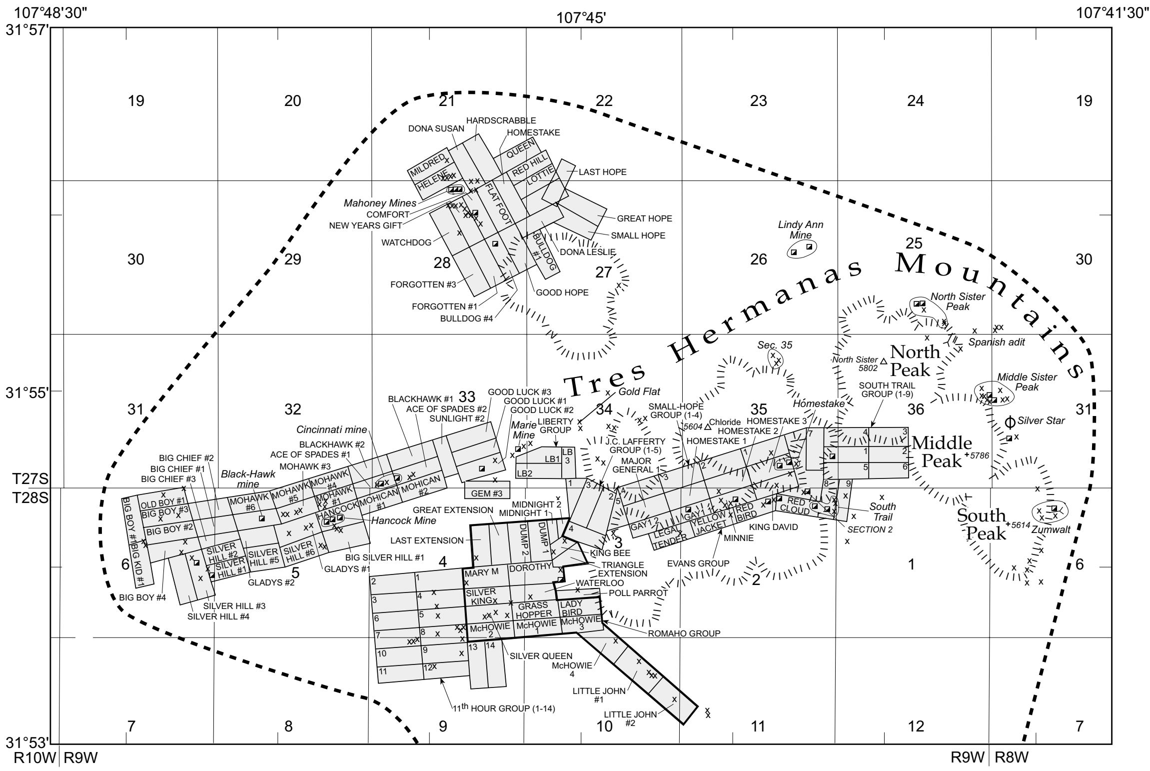


FIGURE 38. MInes and prospects in the Tres Hermanas mining district, Luna County.

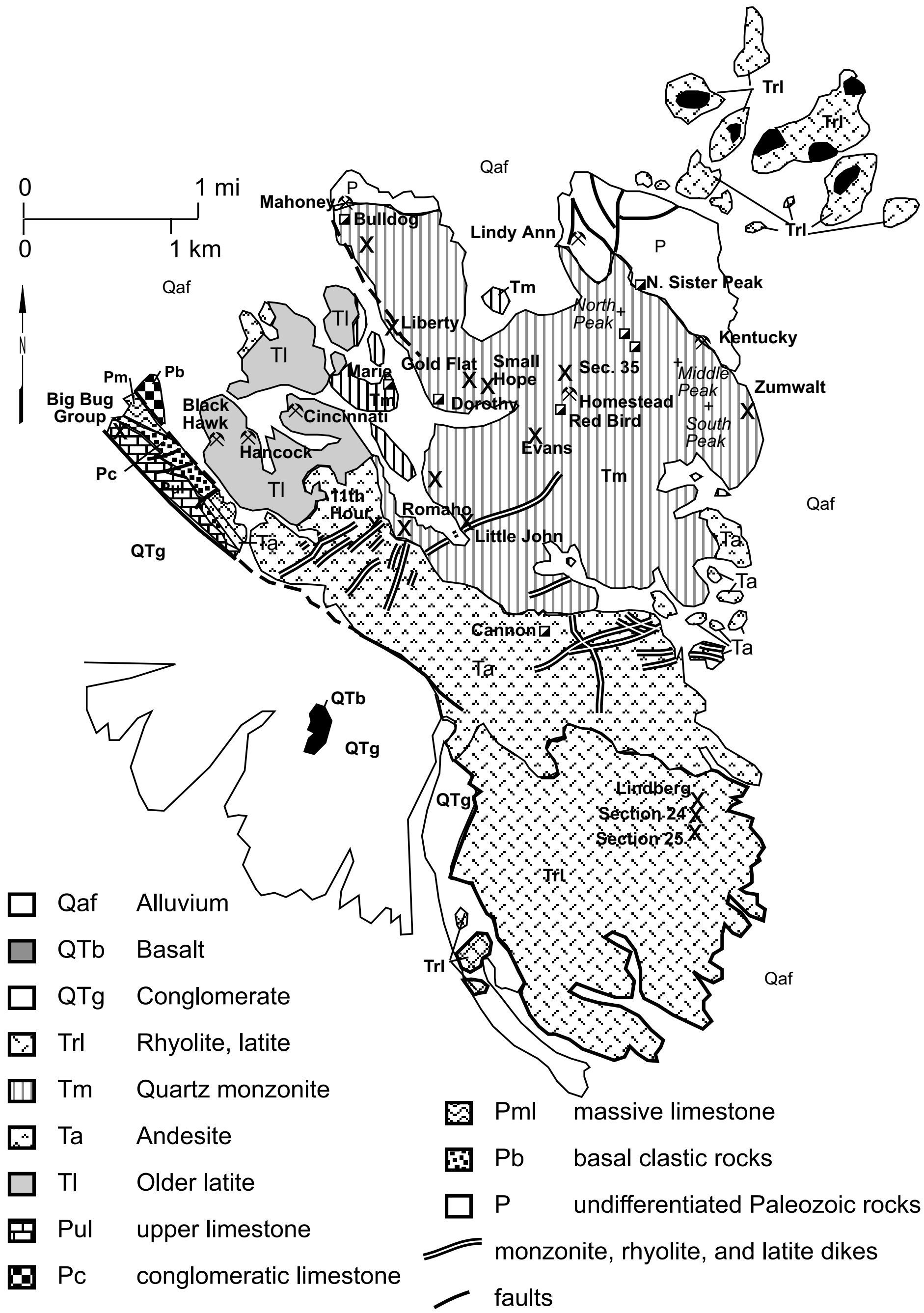


FIGURE 39. Geologic map of Tres Hermanas Mountains (modified from Balk, 1962 and Lucas and Estep, 2000).

FIGURE 40. Leach tanks at the Canon mine, Tres Hermanas district (V. T. McLemore, photo).

FIGURE 41. Fracture disseminated and stockwork veins at the Canon mine (V. T. McLemore, photo).

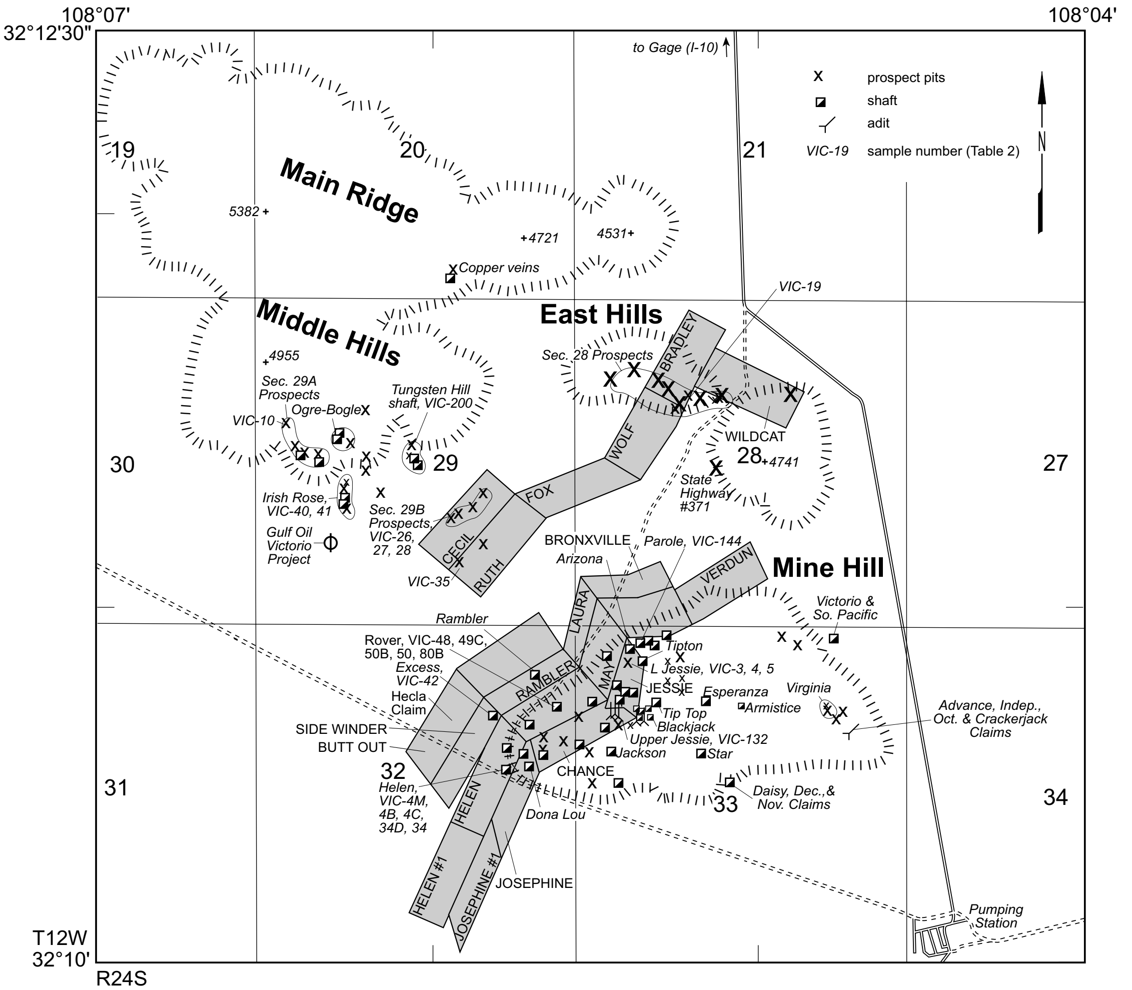


FIGURE 42. Mines and prospects in the Victorio mining district, Luna County.

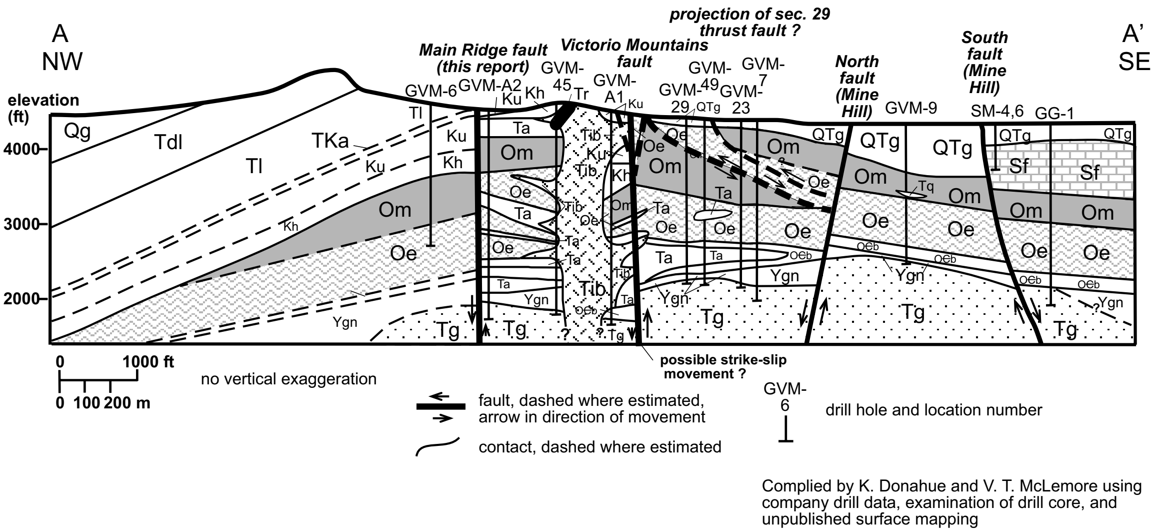


FIGURE 43. Simplified cross section of the Victorio Mountains.

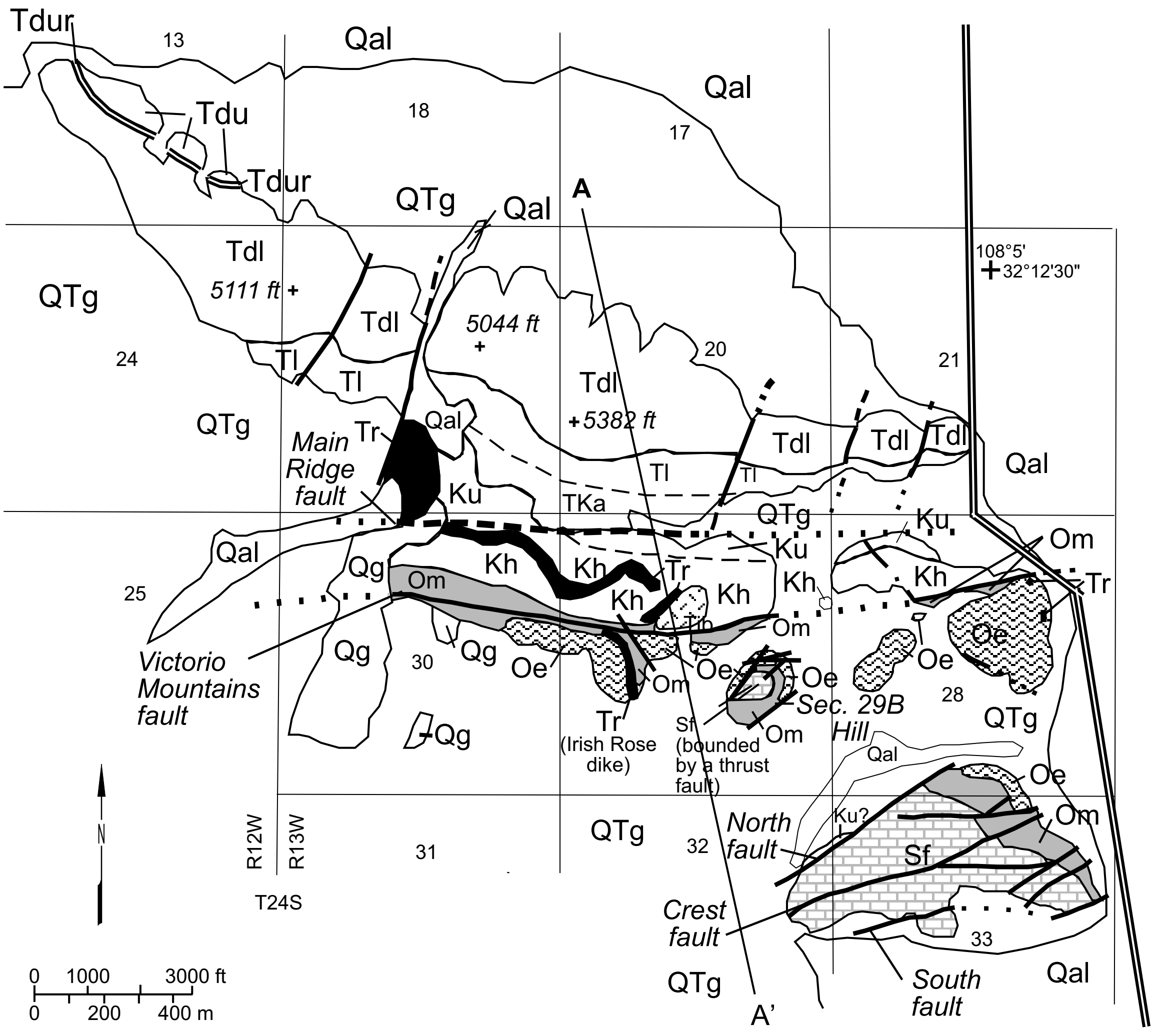


FIGURE 44. Simplified geologic map of the Victorio Mountains.

FIGURE 45. Closeup view of a 3-ft wide vein in limestone at Mine Hill, Victorio mining district. Center of vein consists of calcite, smithsonite, anglesite, cerussite, and iron oxides (V. T. McLemore photo).

FIGURE 46. Fissure vein in limestone at the Parole mine, Mine Hill, Victorio mining district. Limestone to the left of the vein is relatively unaltered, whereas the limestone to the right of the vein is replaced by iron and manganese oxides (V. T. McLemore photo).

FIGURE 47. Limestone quarry in Victorio Mountains (V. T. McLemore, photo).

DEFINITIONS OF LEVEL OF RESOURCE POTENTIAL

N **No mineral resource potential** is a category reserved for a specific type of resource in a well defined area.

L **Low mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicated geologic environment where the existence of mineral resources is unlikely and is assigned to areas of no or dispersed mineralized rocks.

M **Moderate mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence.

H **High mineral-resource potential** is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence. Assignment of high mineral-resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

DEFINITIONS OF LEVEL OF CERTAINTY

A Available information is not adequate for the determination of the level of mineral resource potential.

B Available information suggests the level of mineral-resource potential.

C Available information gives a good indication of the level of mineral-resource potential.

D Available information clearly defines the level of mineral-resource potential.

↑ *INCREASING LEVEL OF RESOURCE POTENTIAL*	U/A Unknown Potential	H/B High Potential	H/C High Potential	H/D High Potential
		M/B Moderate Potential	M/C Moderate Potential	M/D Moderate Potential
		L/B Low Potential	L/C Low Potential	L/D Low Potential
				N/D No Potential
INCREASING LEVEL OF CERTAINTY →				

FIGURE 48. Classification of mineral-resource potential and certainty of assurance (modified from Goudarzi, 1984).

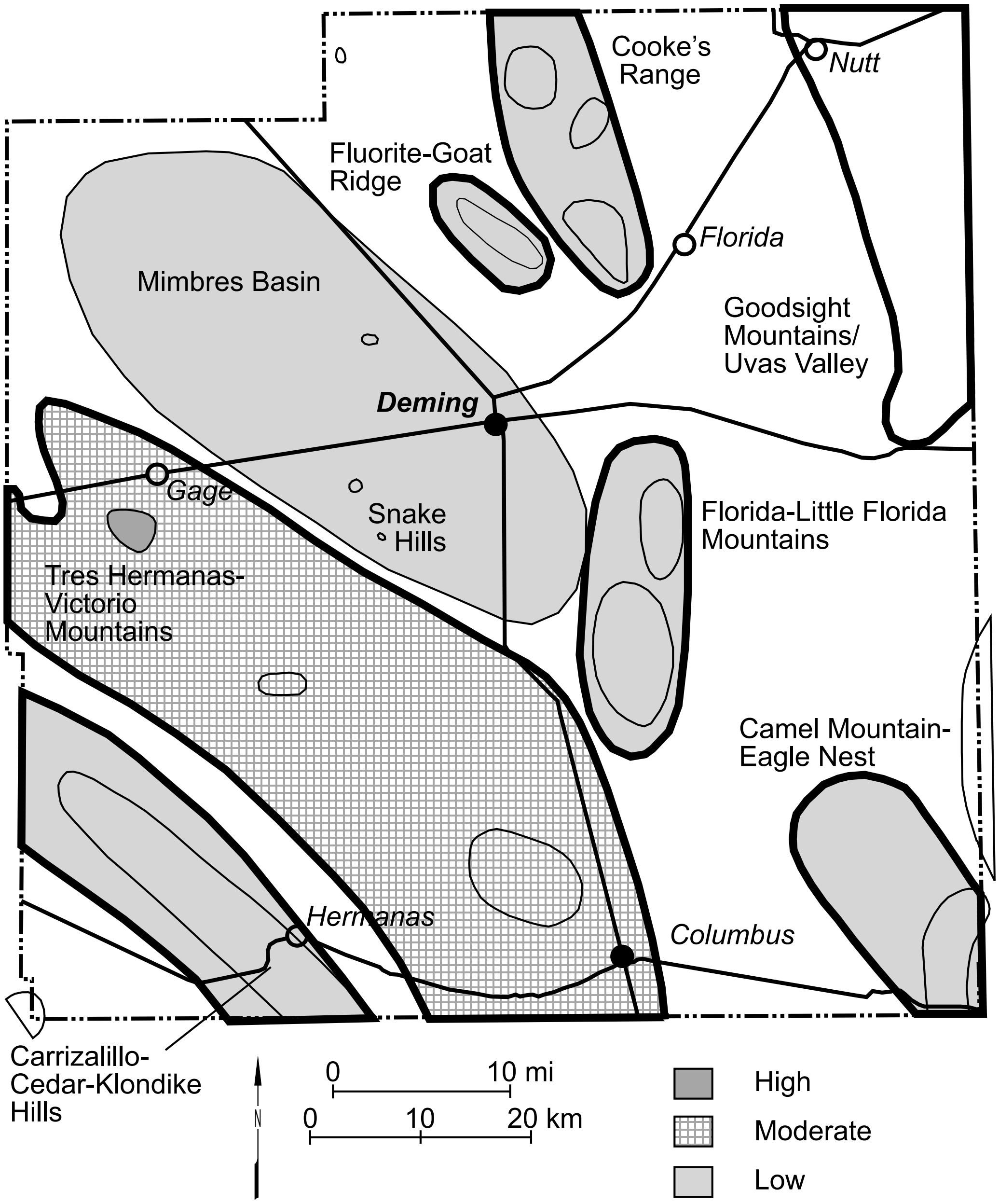


FIGURE 49. Beryllium mineral-resource potential in Luna County.

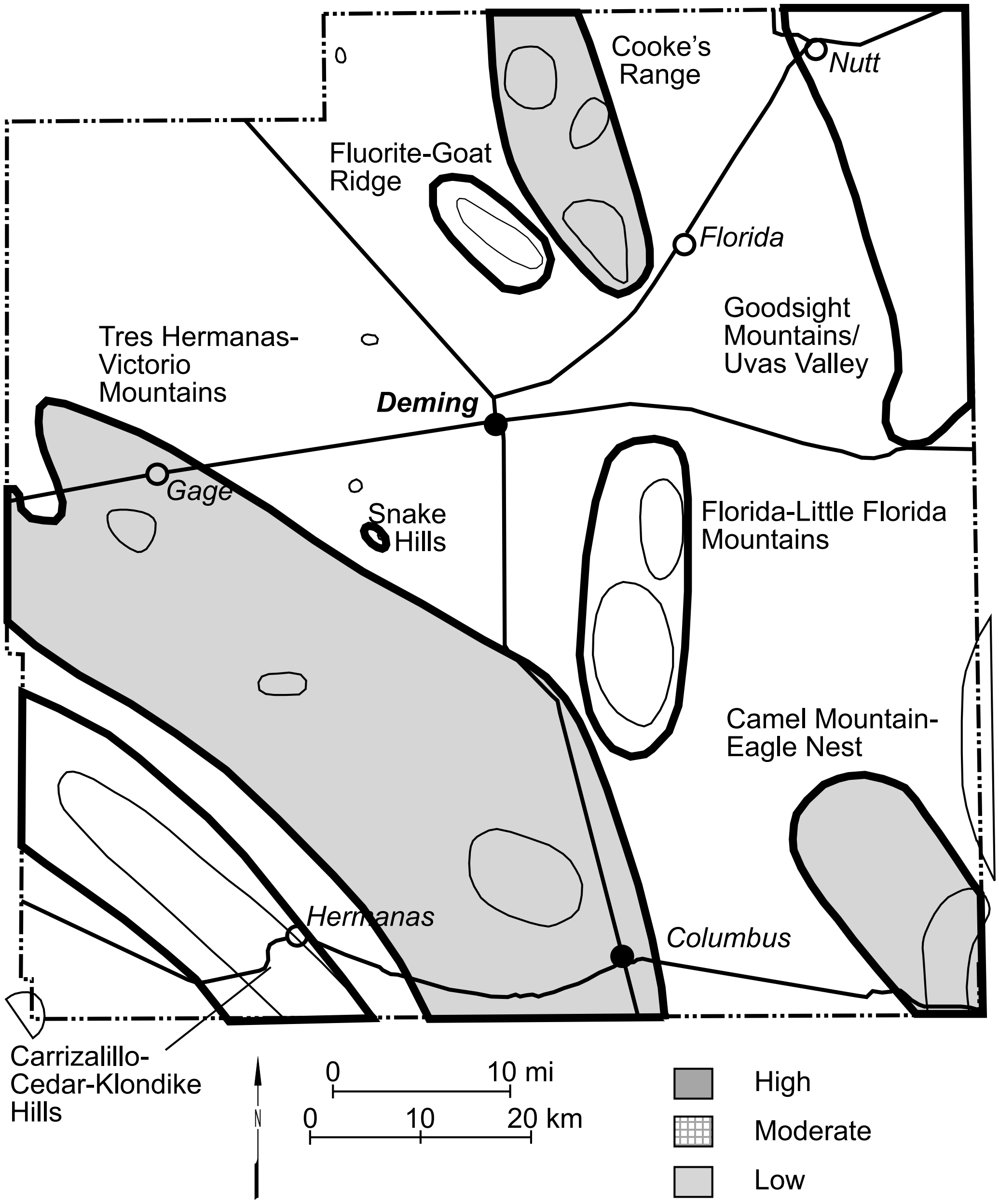
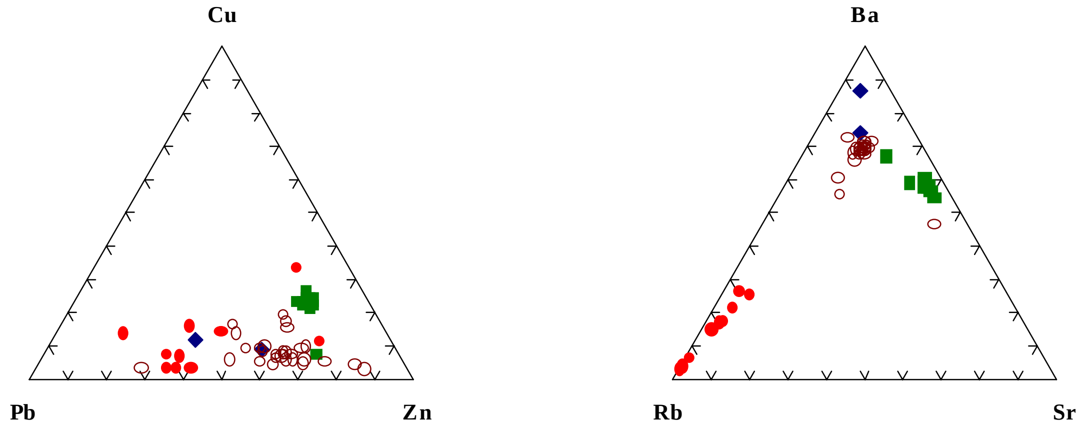
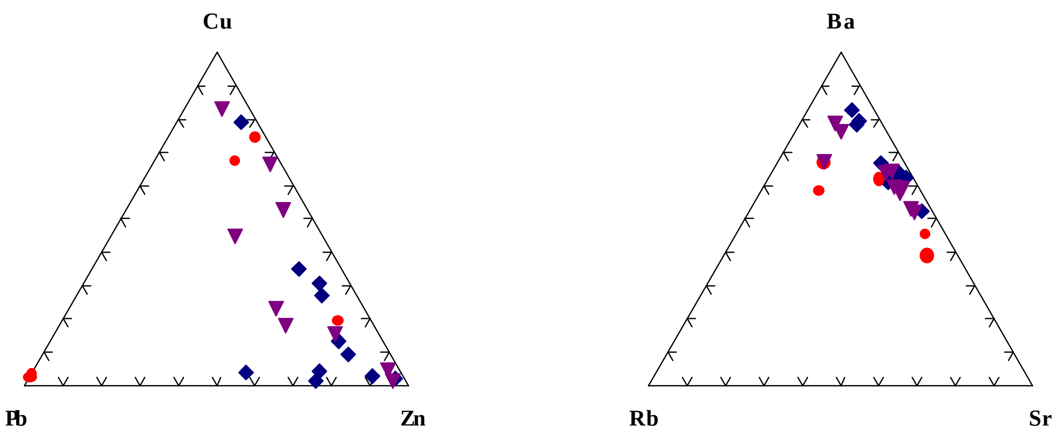


FIGURE 50. Bismuth mineral-resource potential in Luna County.

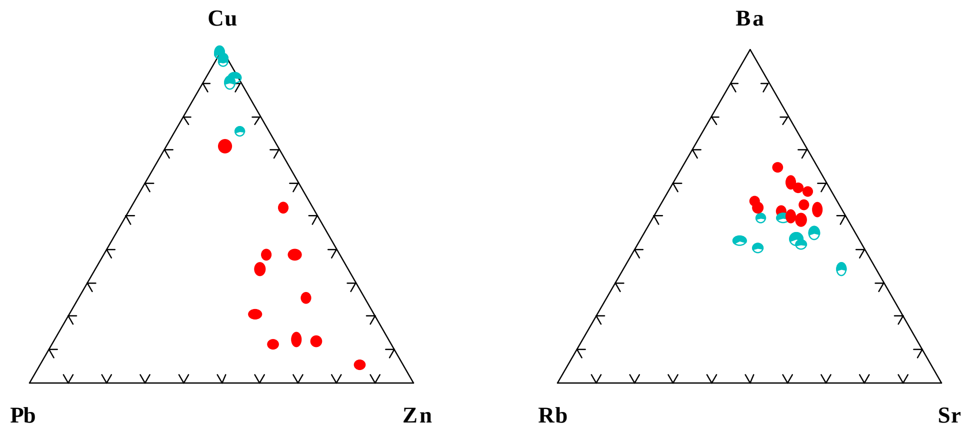


Granitic rocks from Luna County (see Figure 8 for key).



Porphyry copper deposits in southwestern New Mexico (blue diamonds are Santa Rita, purple triangles are Tyrone, red circles are Lordsburg).

Figure 51 continued on next page.



Copper Flat porphyry, Sierra County (red circles are unmineralized monzonite, green half-filled circles are mineralized monzonite).

FIGURE 51. Cu-Pb-Zn and Ba-Rb-Sr plots of granitic rocks from Luna County compared with porphyry copper deposits in southwestern New Mexico.

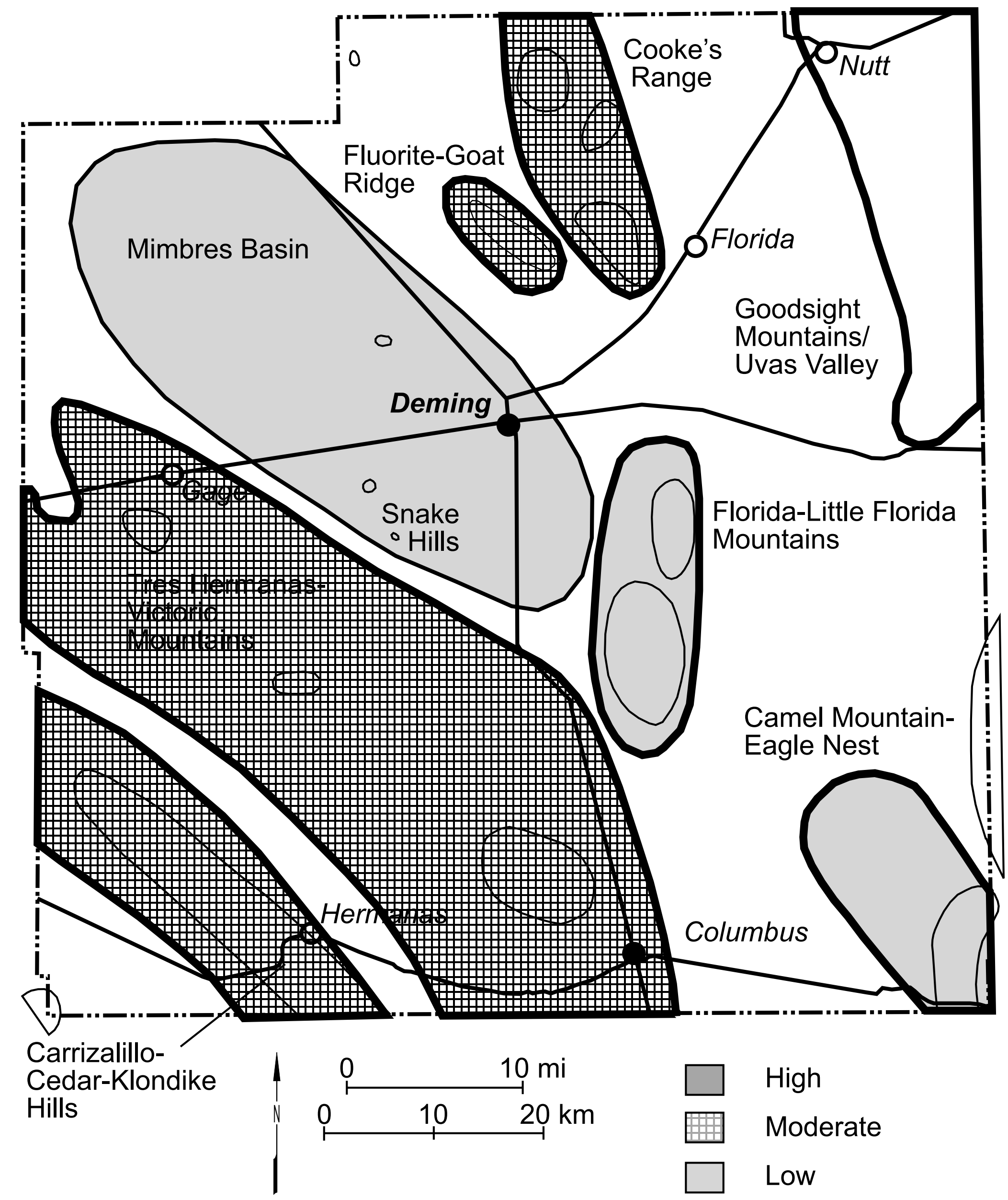


FIGURE 52. Copper mineral-resource potential in Luna County.

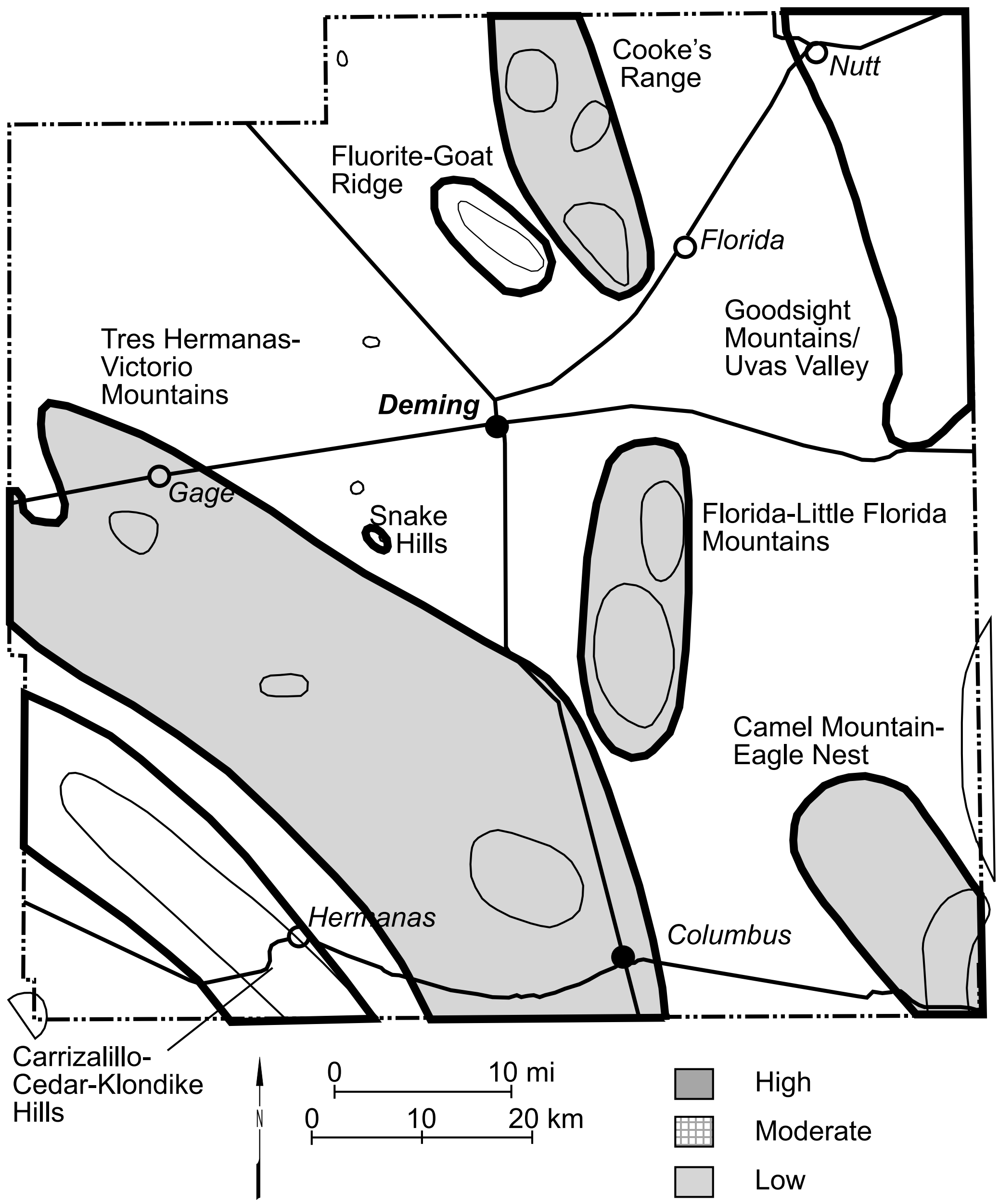


FIGURE 53. Germanium mineral-resource potential in Luna County.

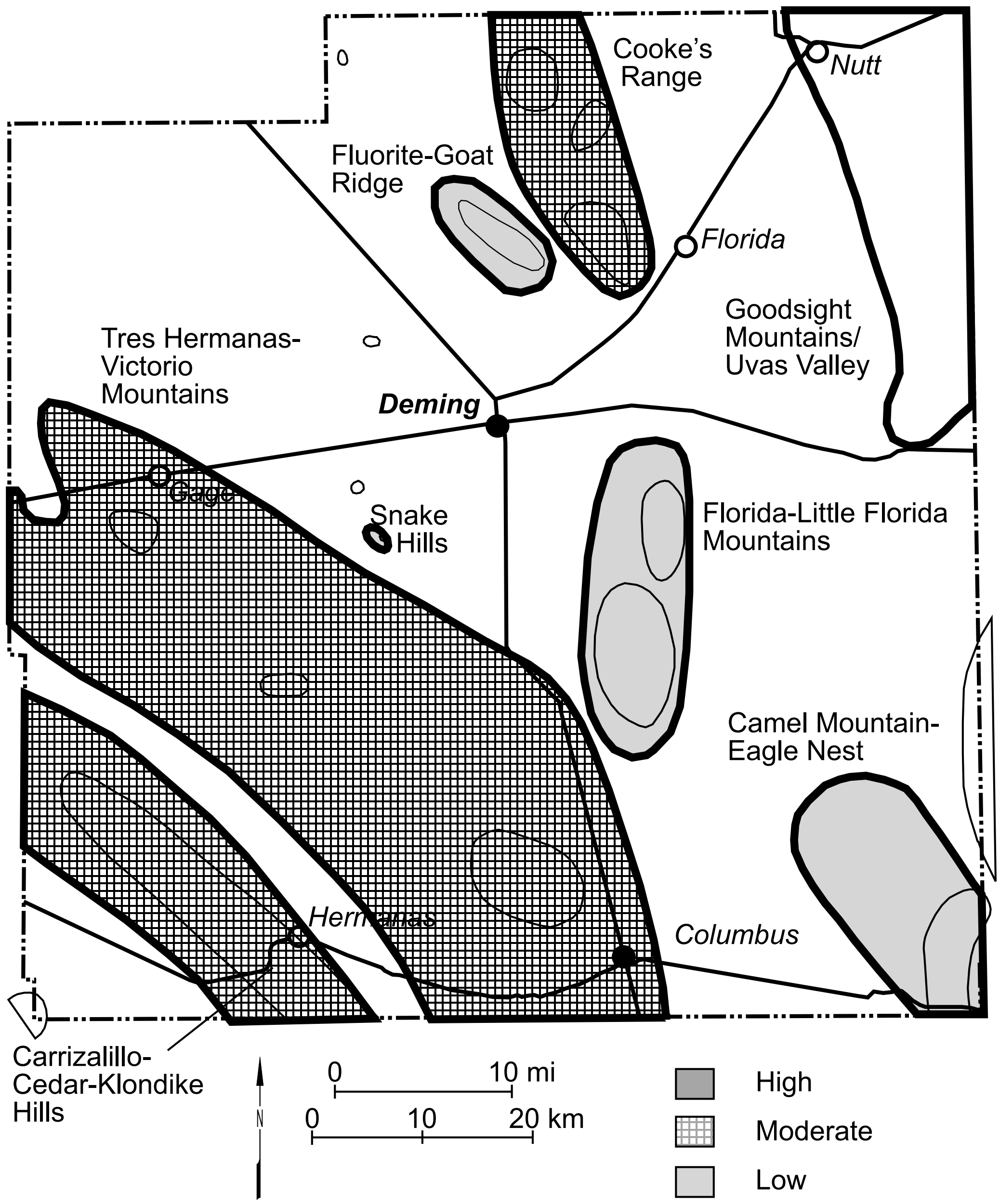


FIGURE 54. Gold mineral-resource potential in Luna County.

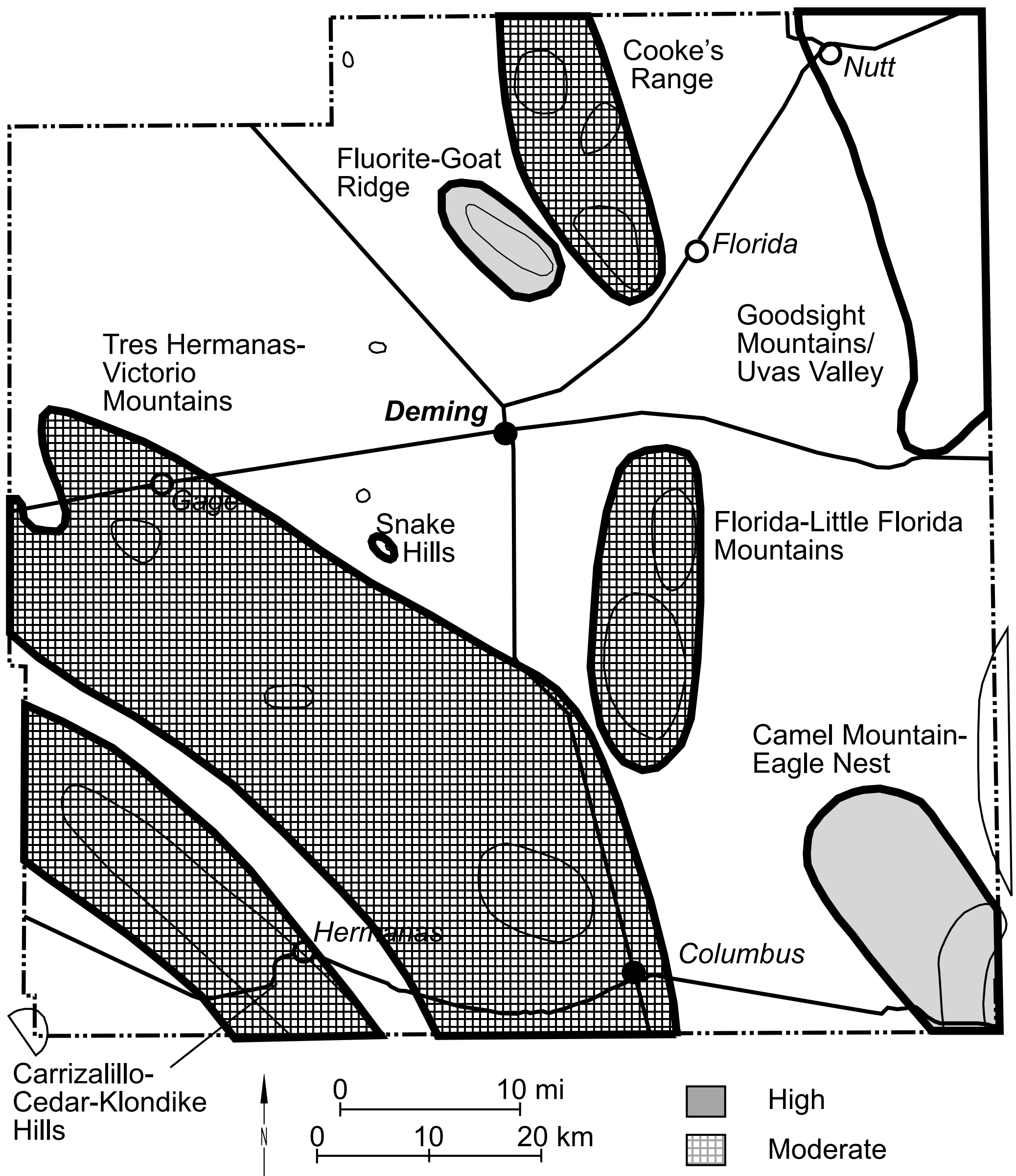


FIGURE 55. Iron mineral-resource potential in Luna County.

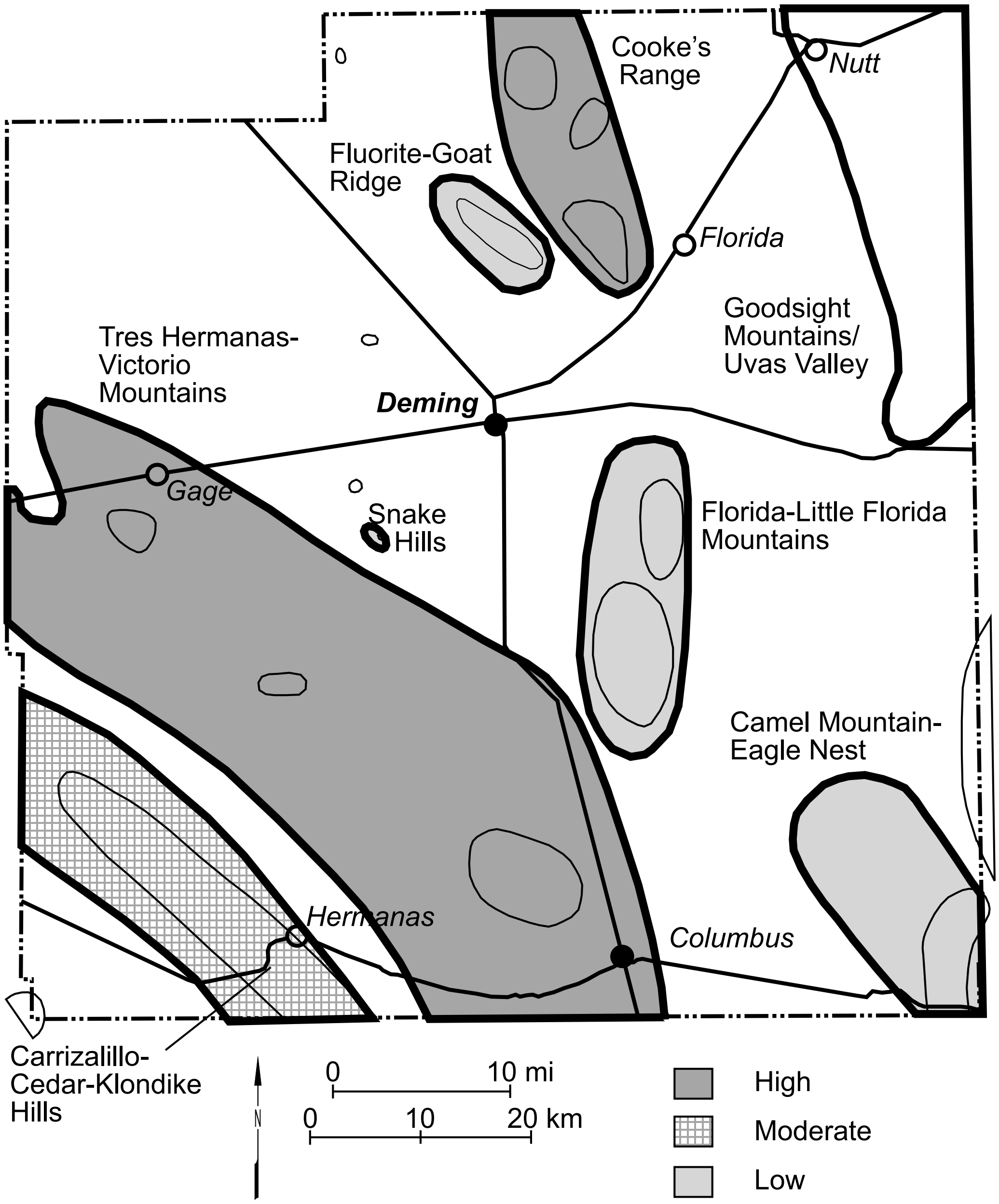


FIGURE 56. Lead-zinc mineral-resource potential in Luna County.

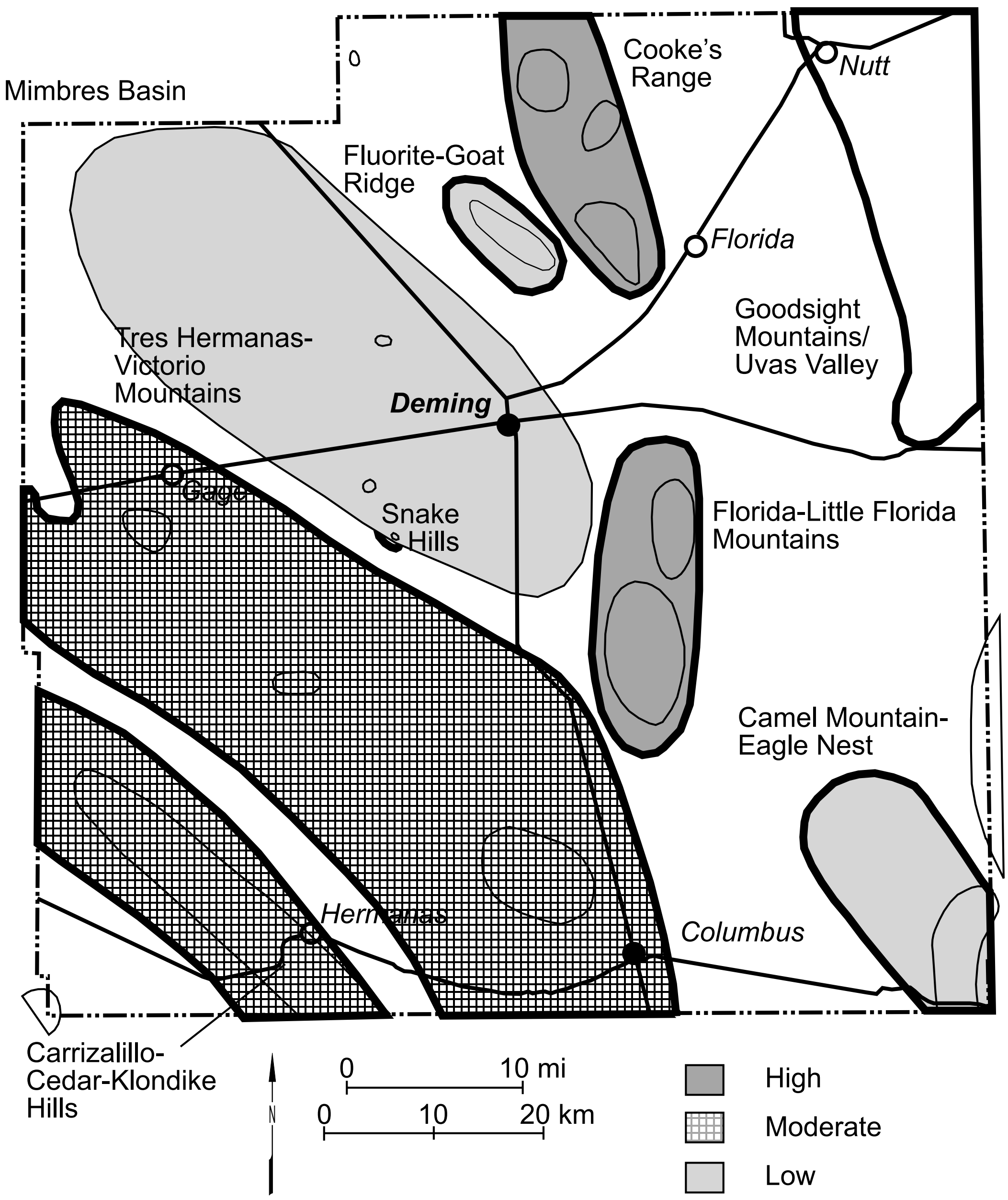


FIGURE 57. Manganese mineral-resource potential in Luna County.

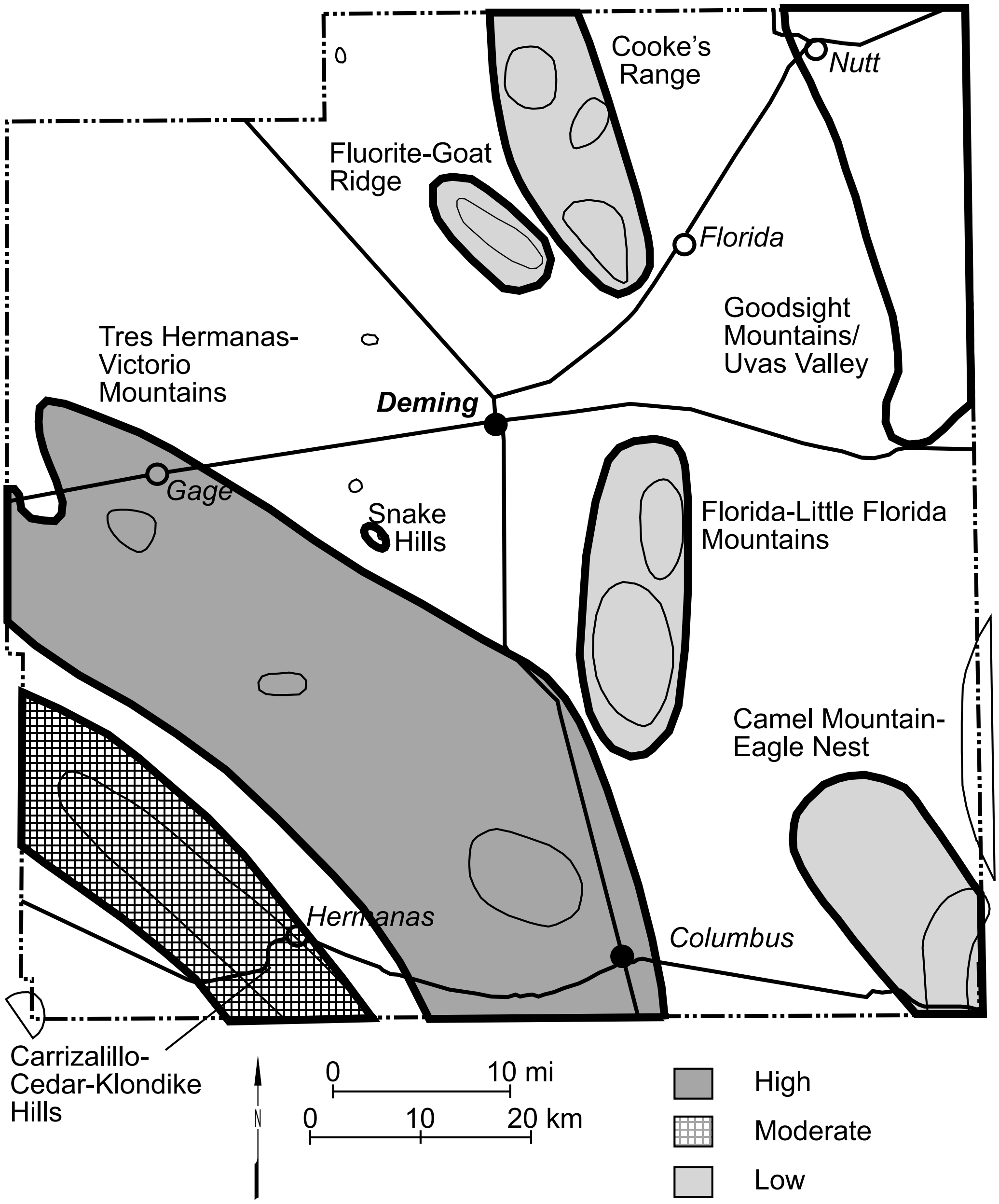


FIGURE 58. Molybdenum mineral-resource potential in Luna County.

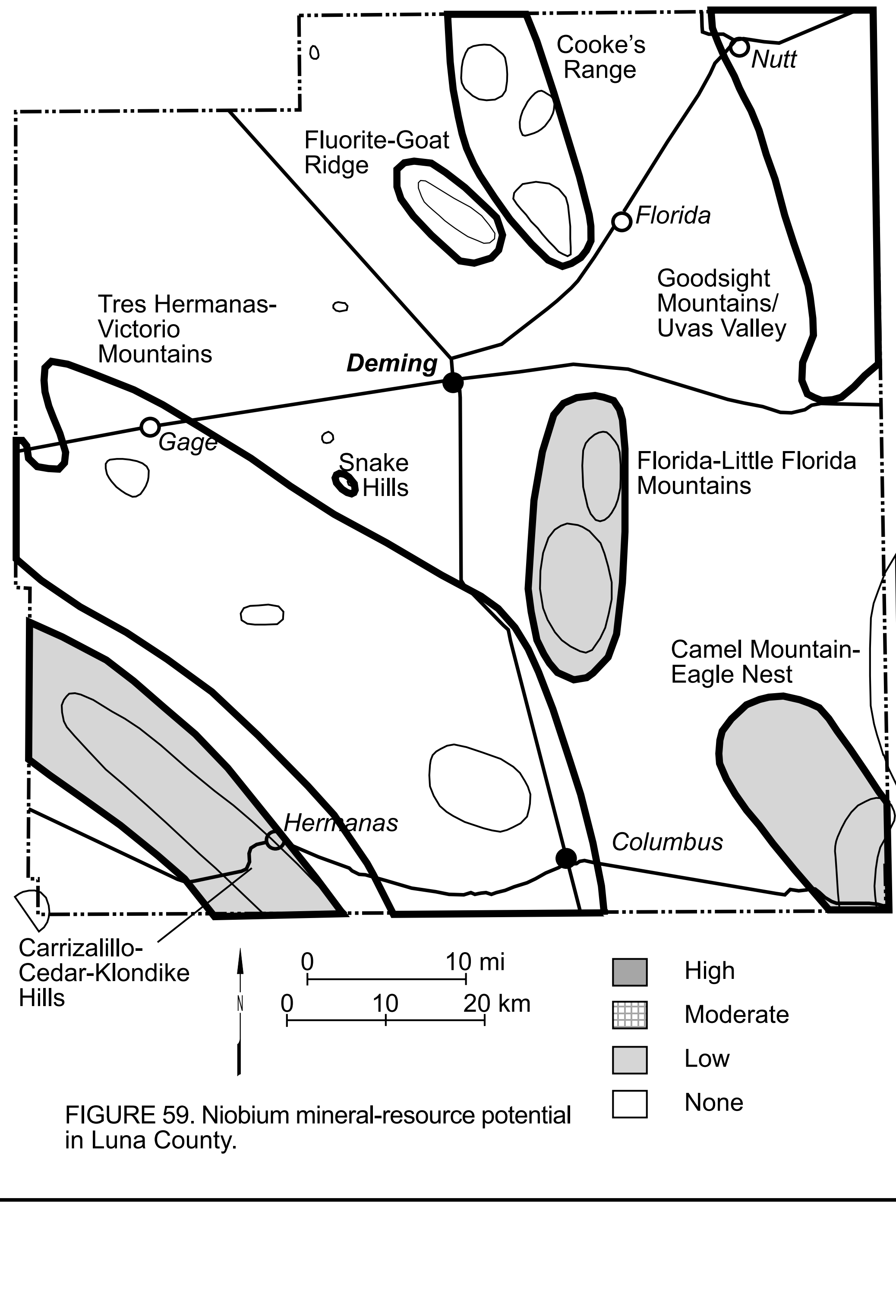


FIGURE 59. Niobium mineral-resource potential in Luna County.

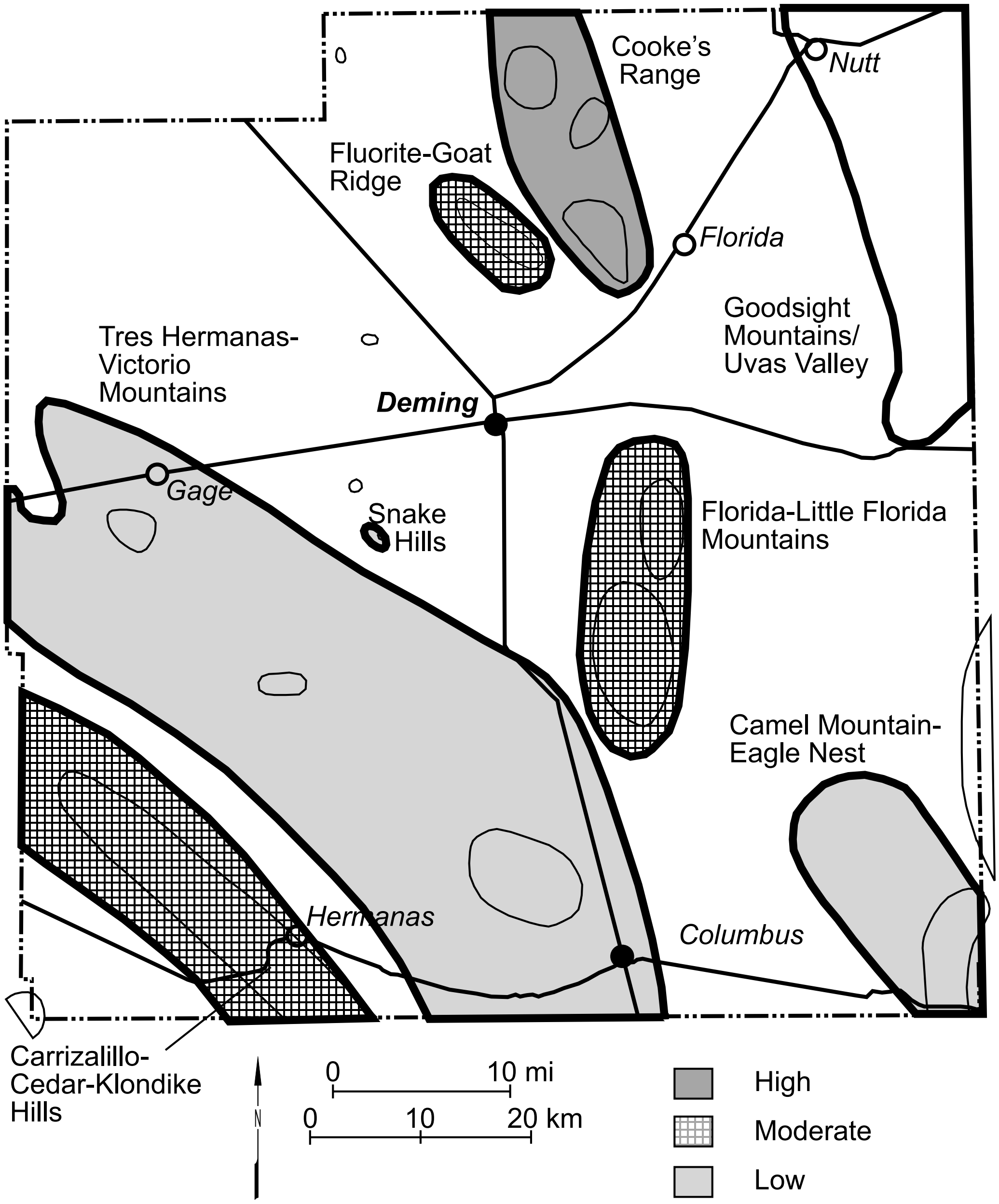


FIGURE 60. Silver mineral-resource potential in Luna County.

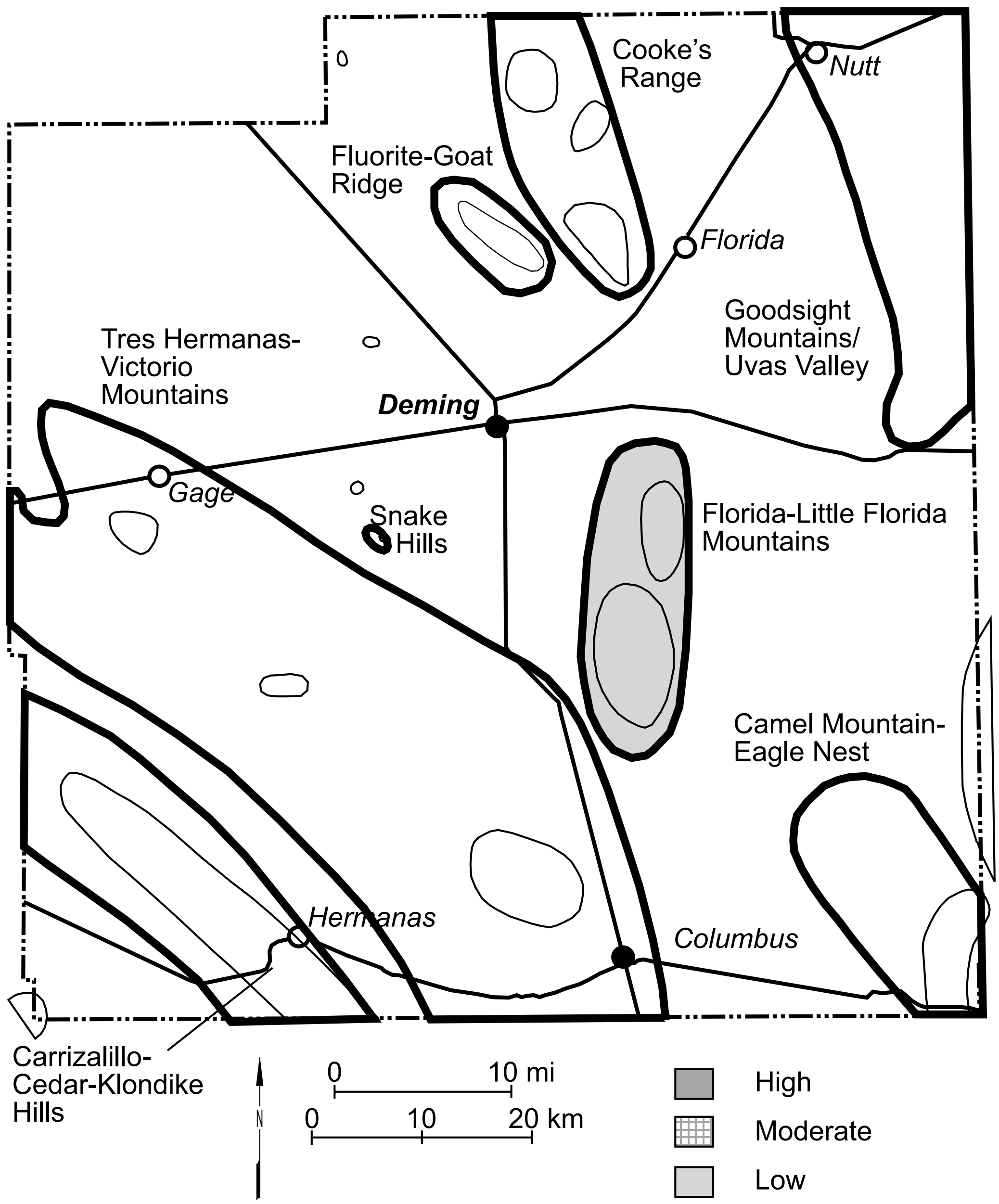


FIGURE 61. Thorium and rare-earth elements mineral-resource potential in Luna County.

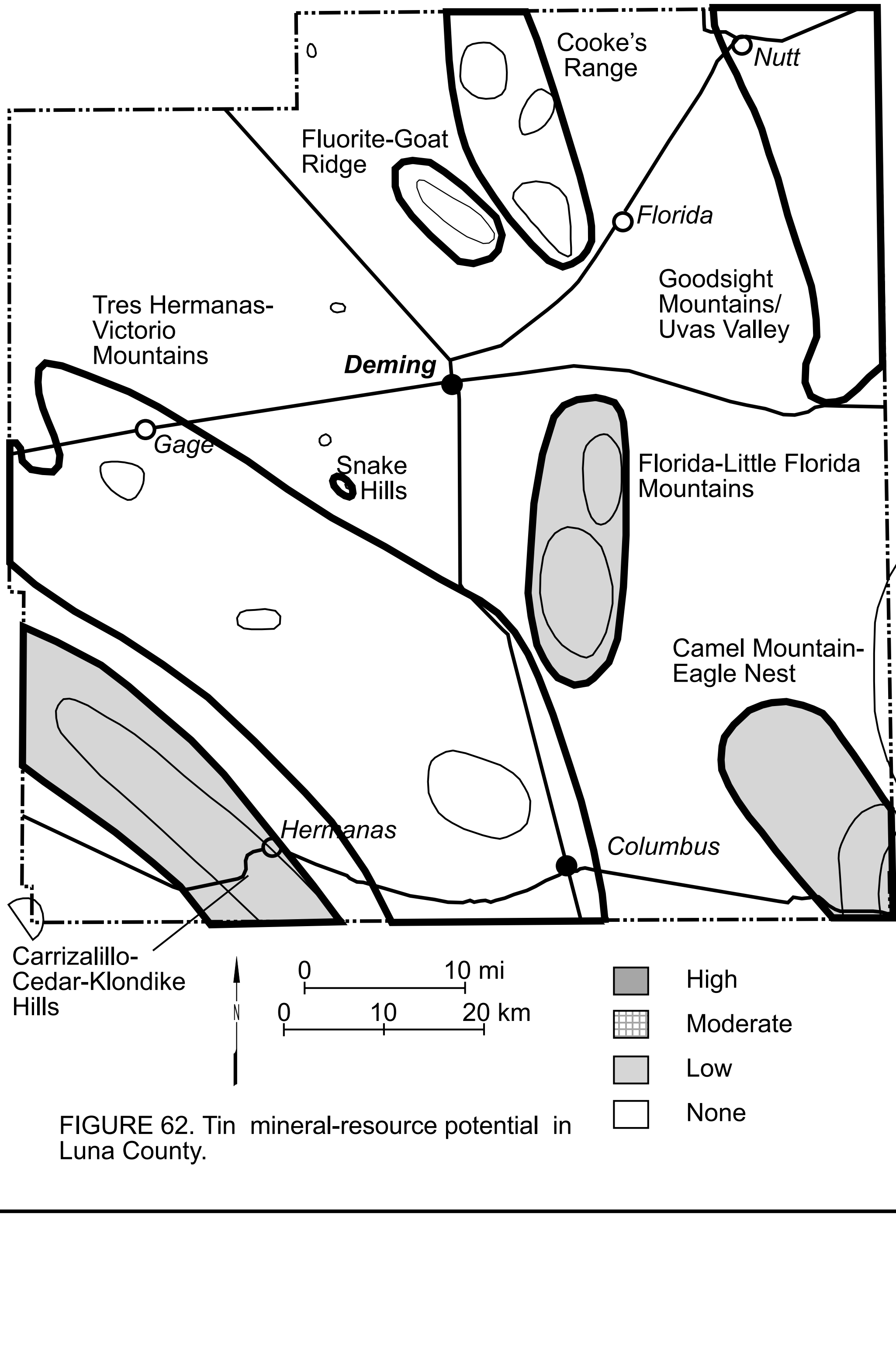


FIGURE 62. Tin mineral-resource potential in Luna County.

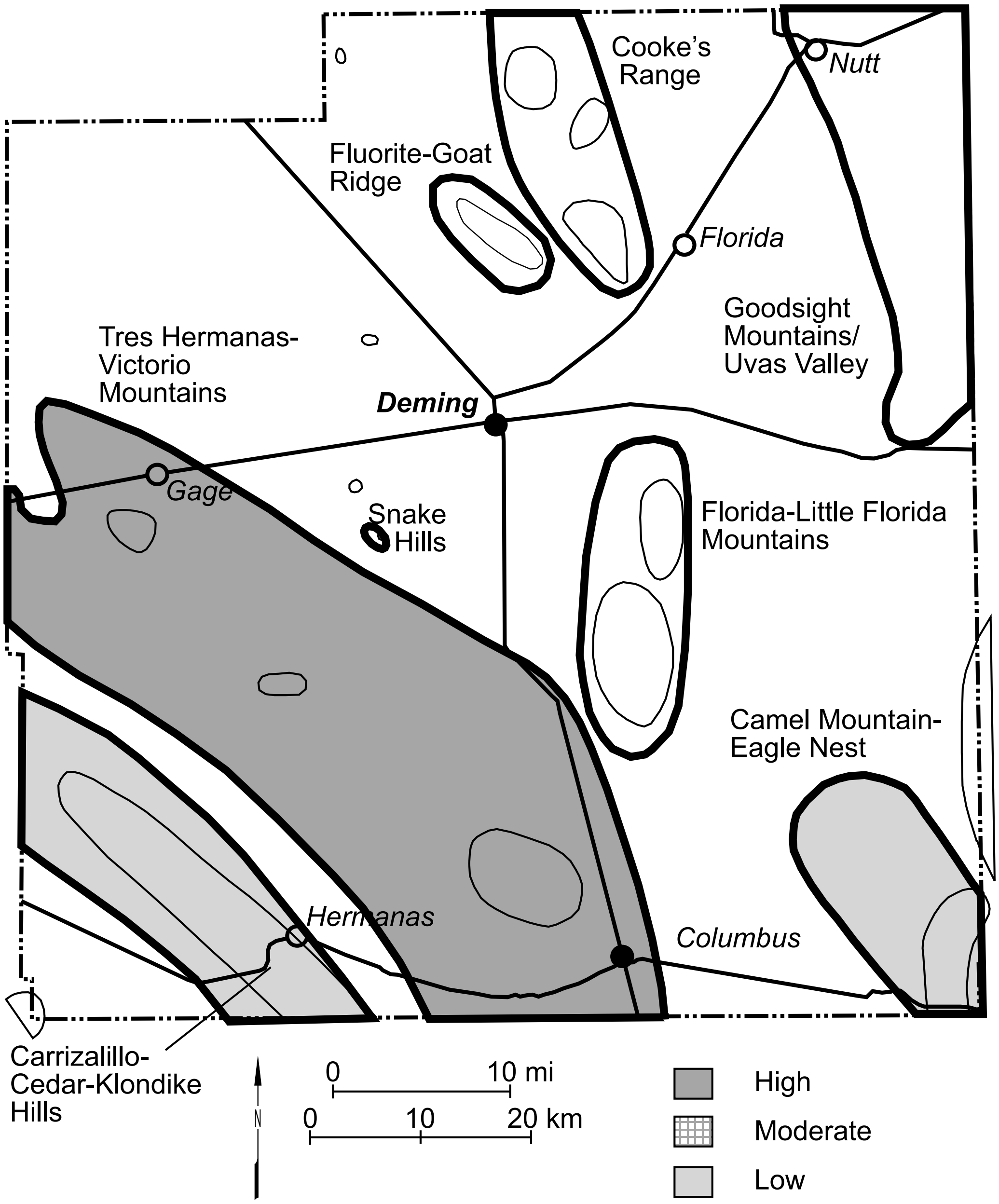


FIGURE 63. Tungsten mineral-resource potential in Luna County.

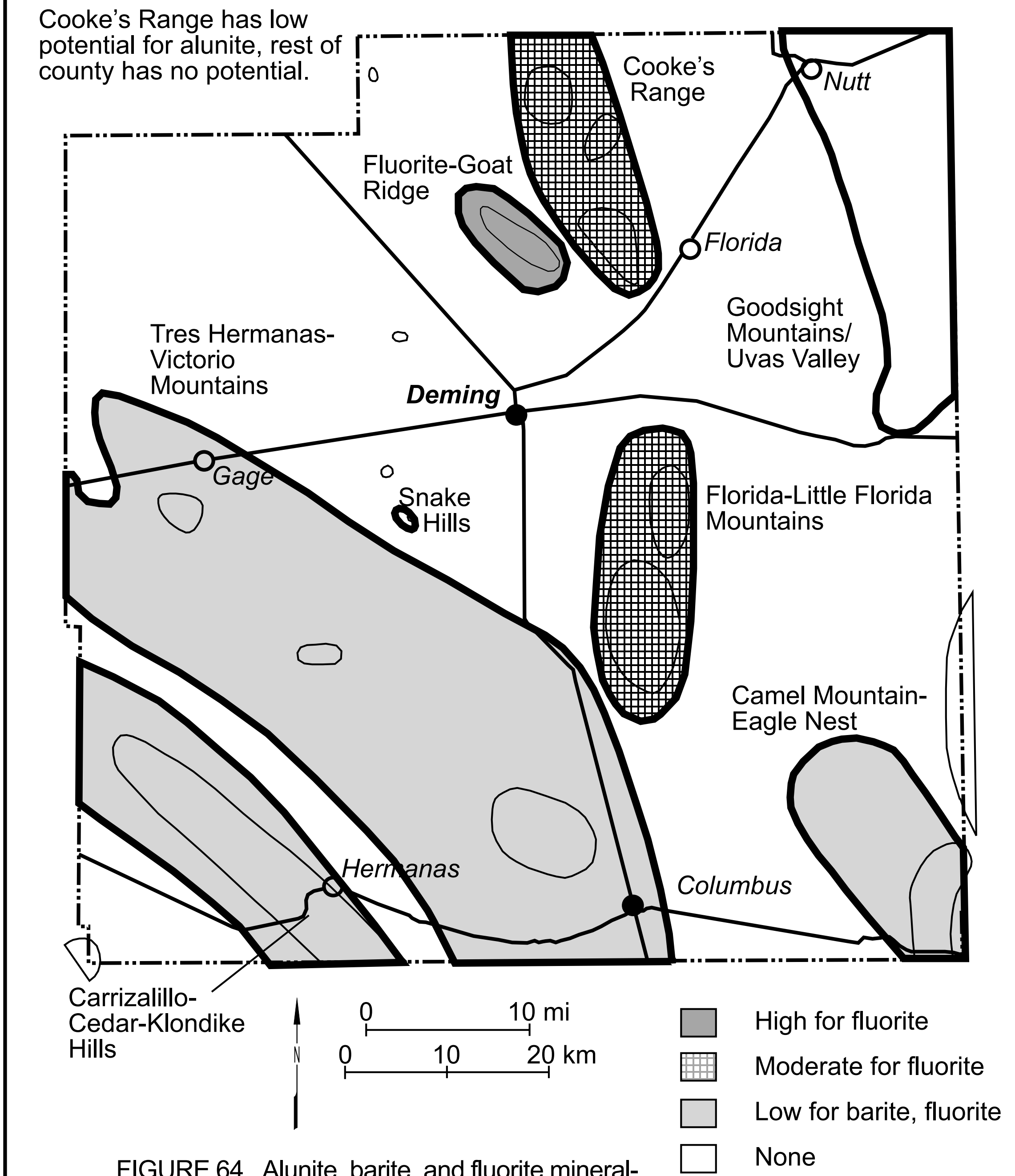


FIGURE 64. Alunite, barite, and fluorite mineral-resource potential in Luna County.

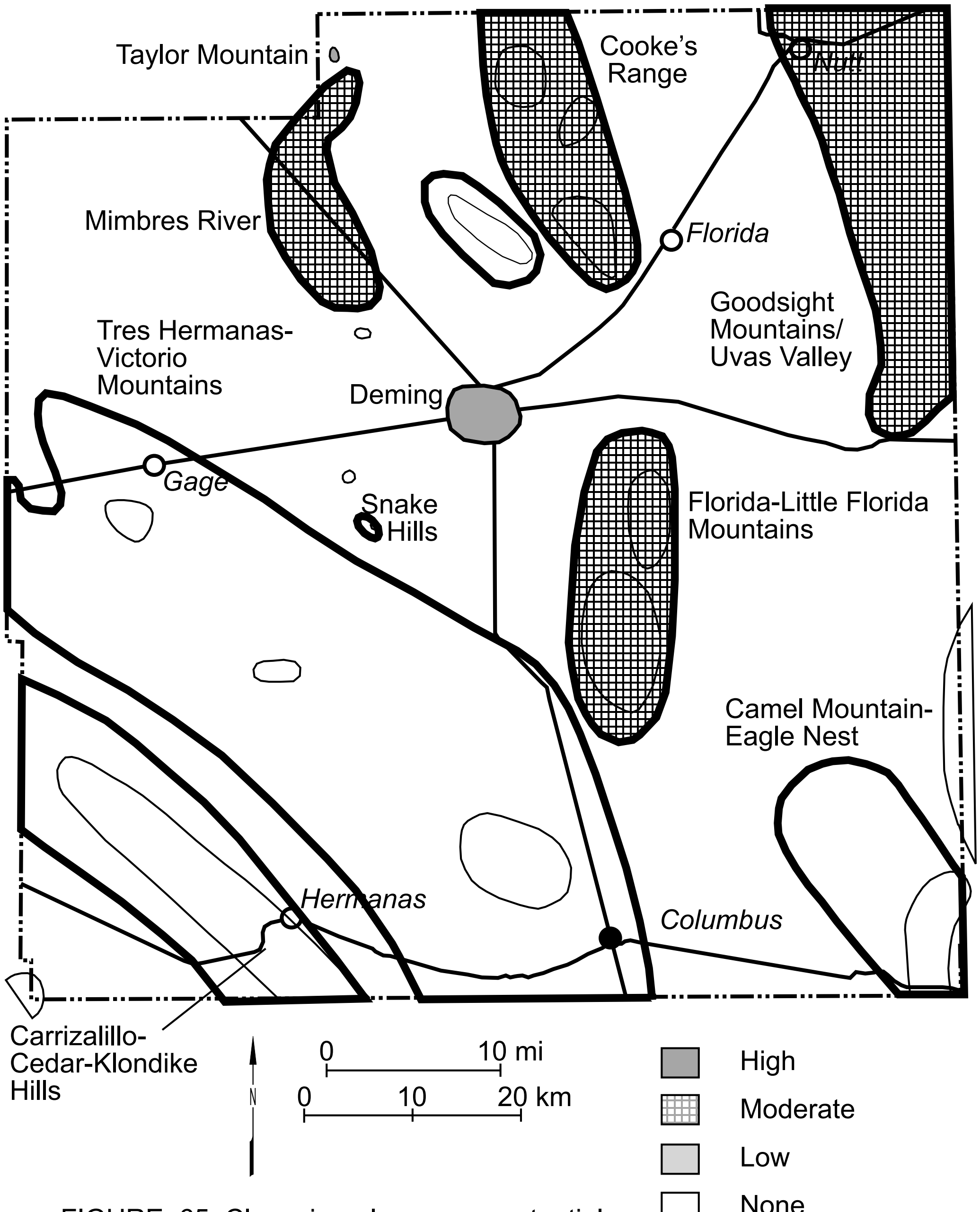


FIGURE 65. Clay mineral-resource potential in Luna County.

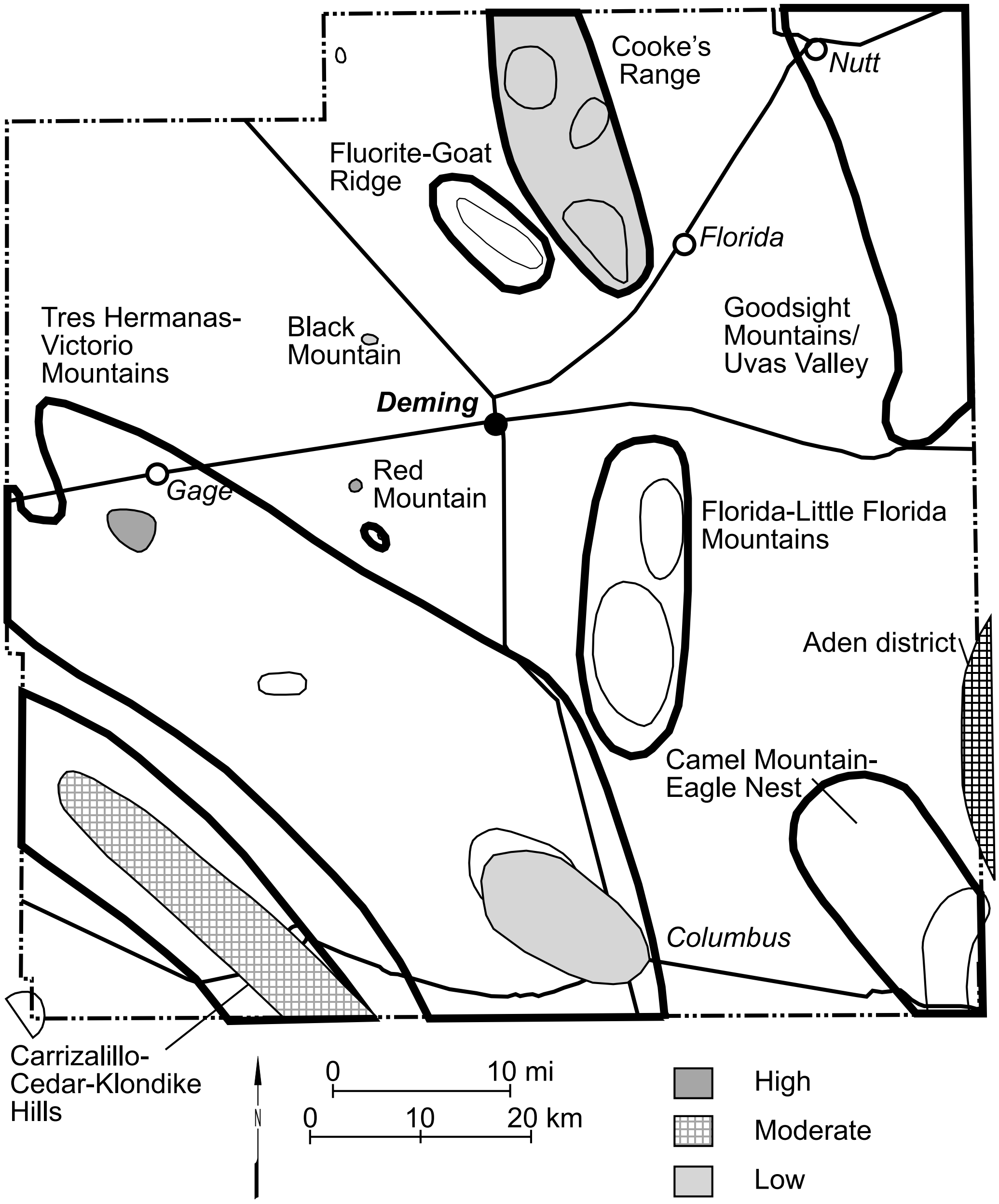


FIGURE 66. Crushed stone mineral-resource potential in Luna County.

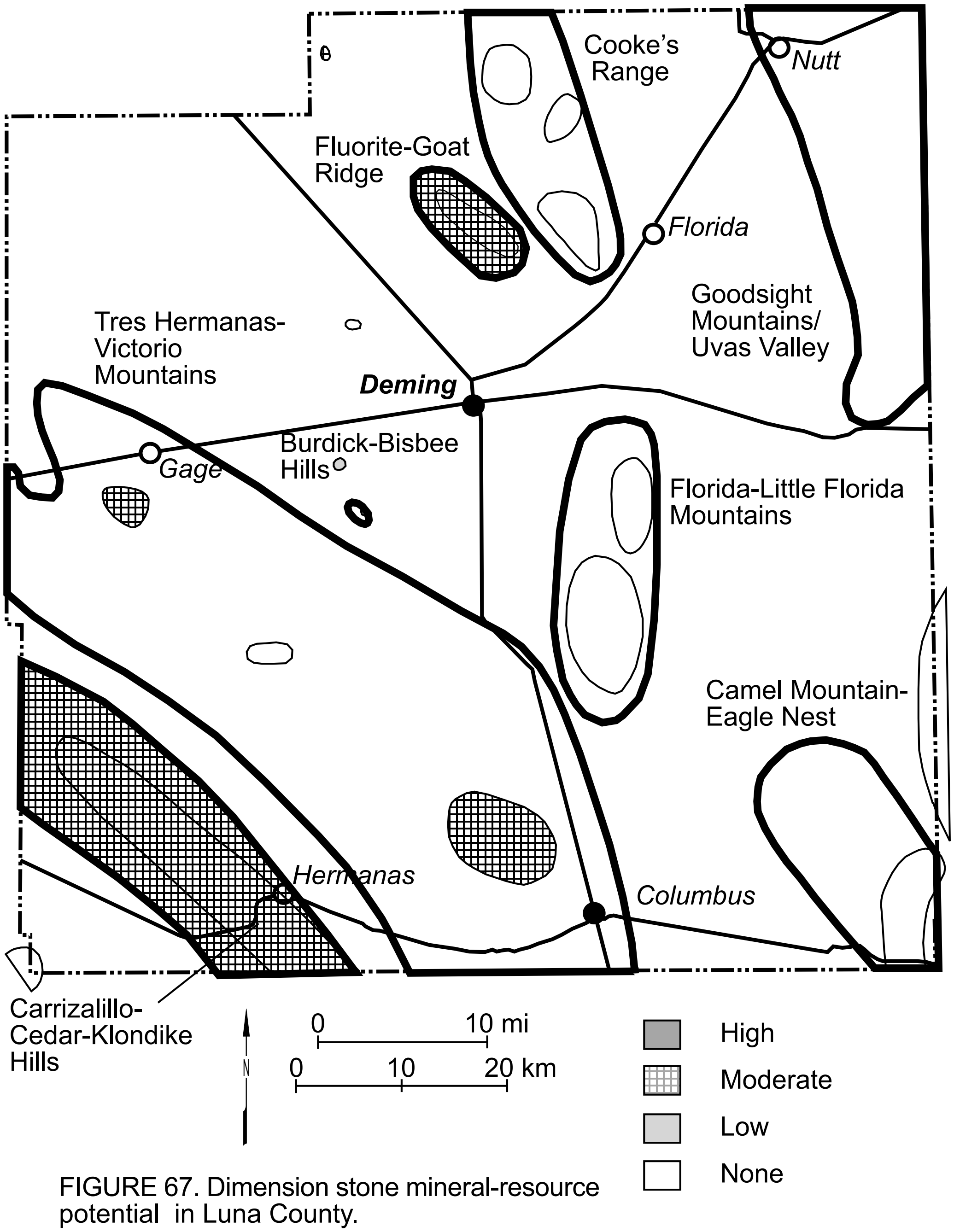


FIGURE 67. Dimension stone mineral-resource potential in Luna County.

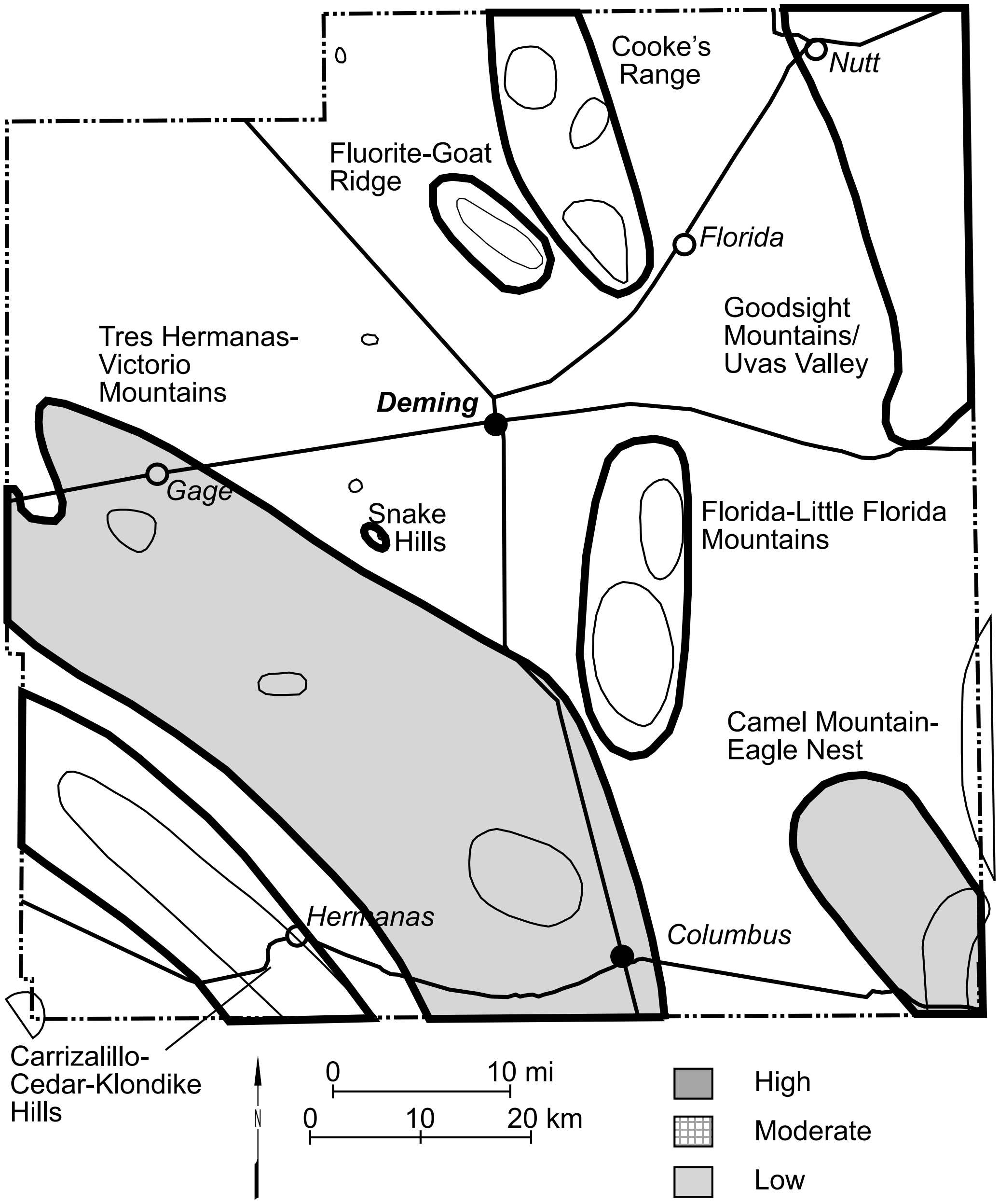


FIGURE 68. Garnet mineral-resource potential in Luna County.

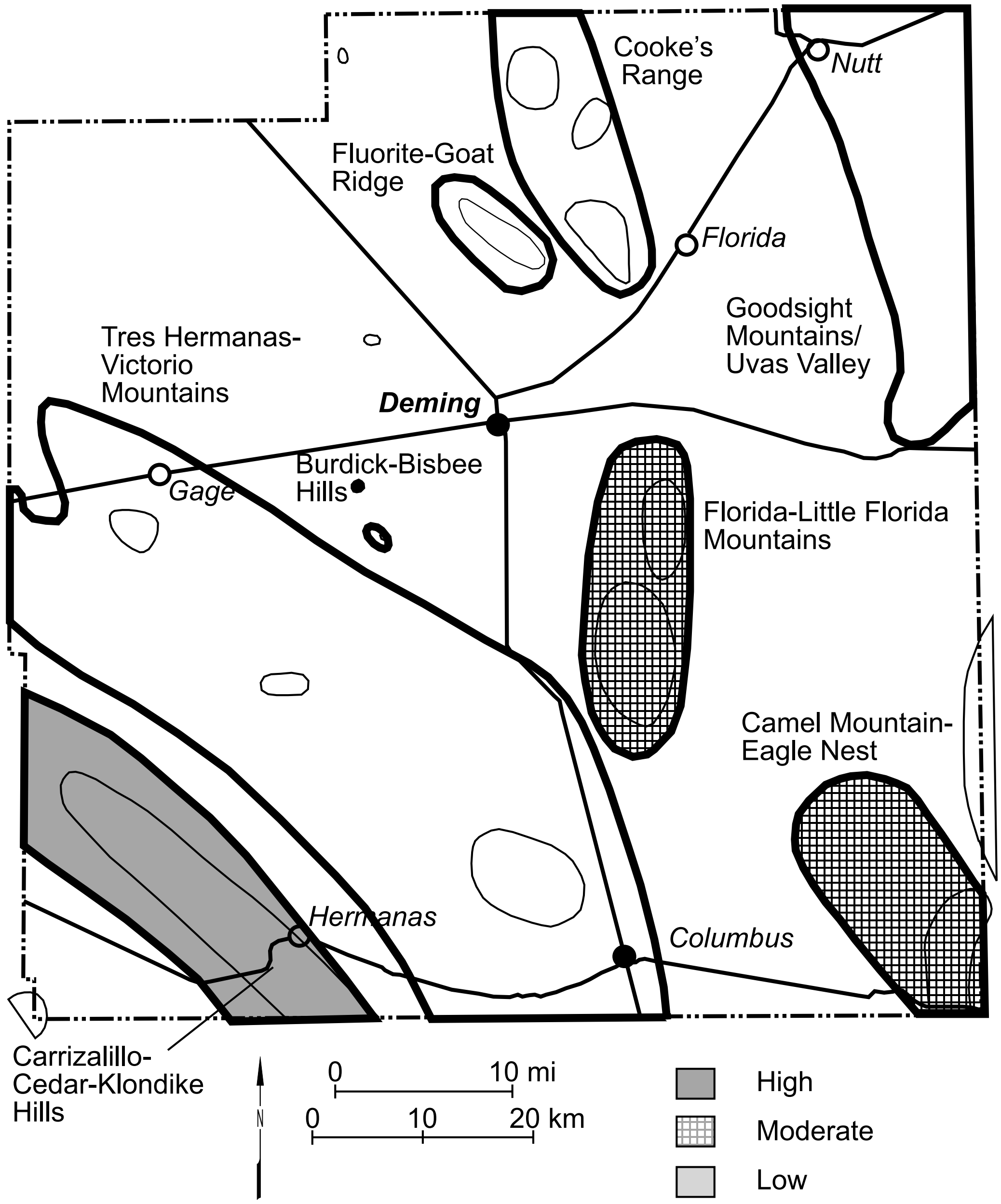


FIGURE 69. Gems, semiprecious stones. and mineral collecting mineral-resource potential in Luna County.

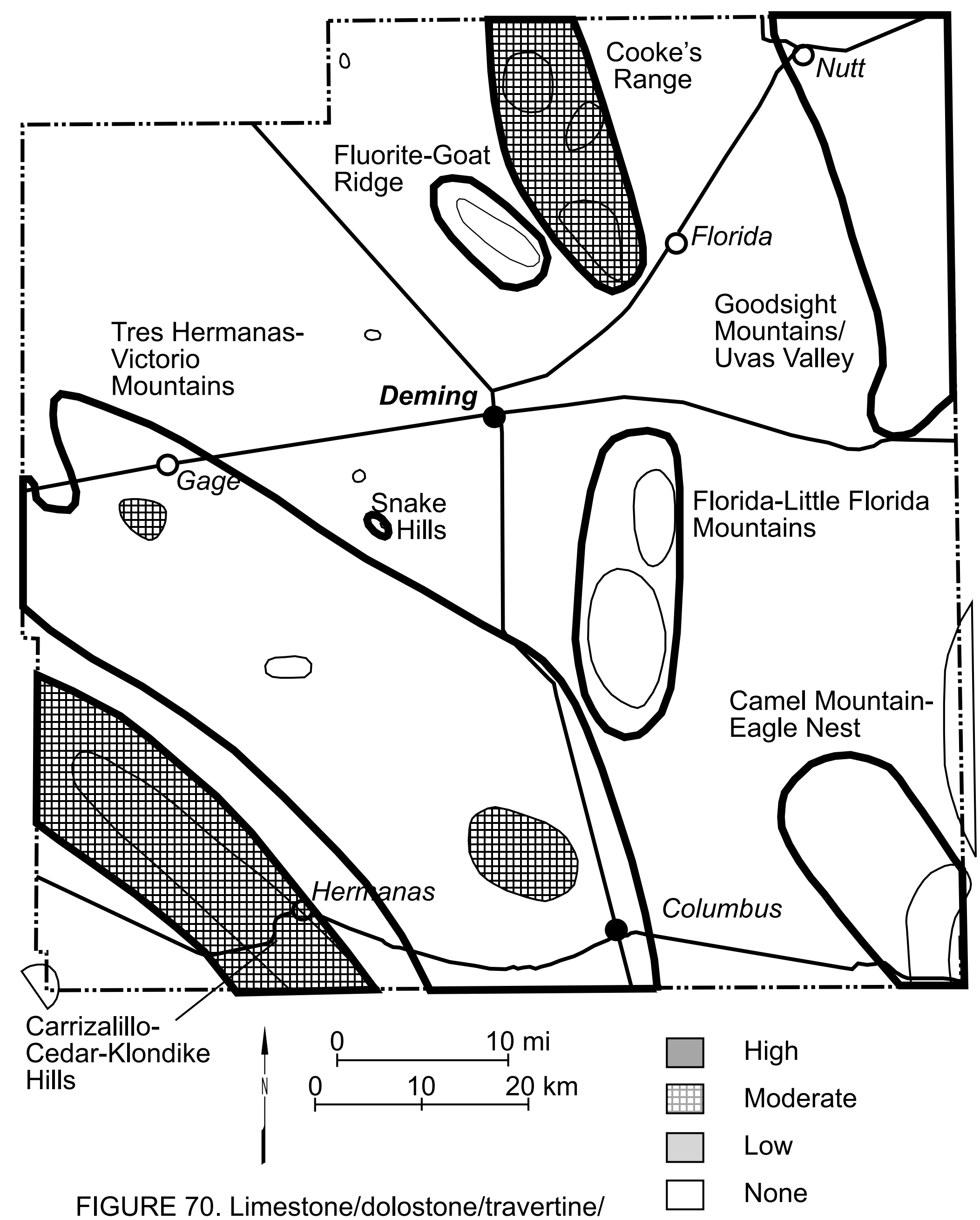


FIGURE 70. Limestone/dolostone/travertine/marble mineral-resource potential in Luna County.

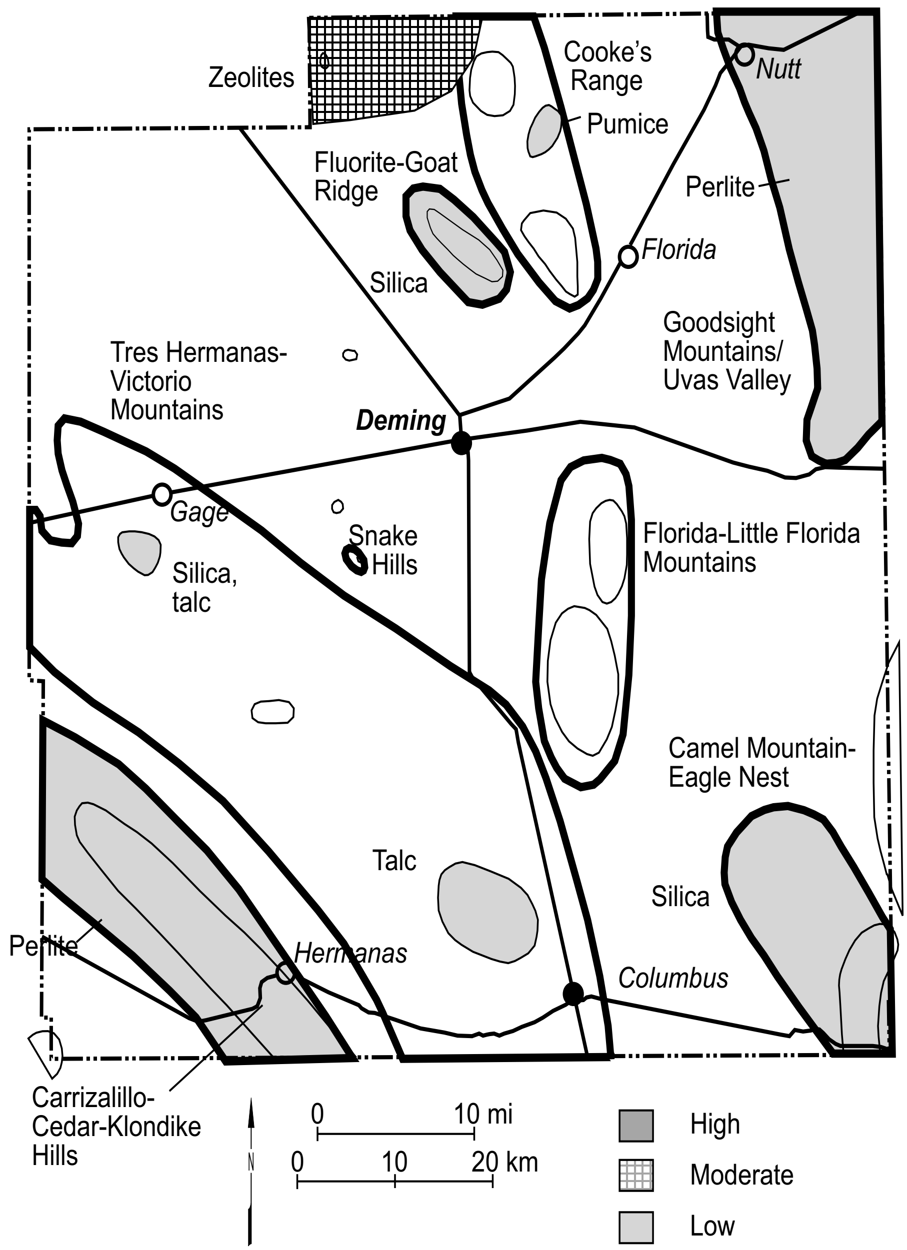


FIGURE 71. Perlite, pumice, silica, talc, and zeolites mineral-resource potential in Luna County.

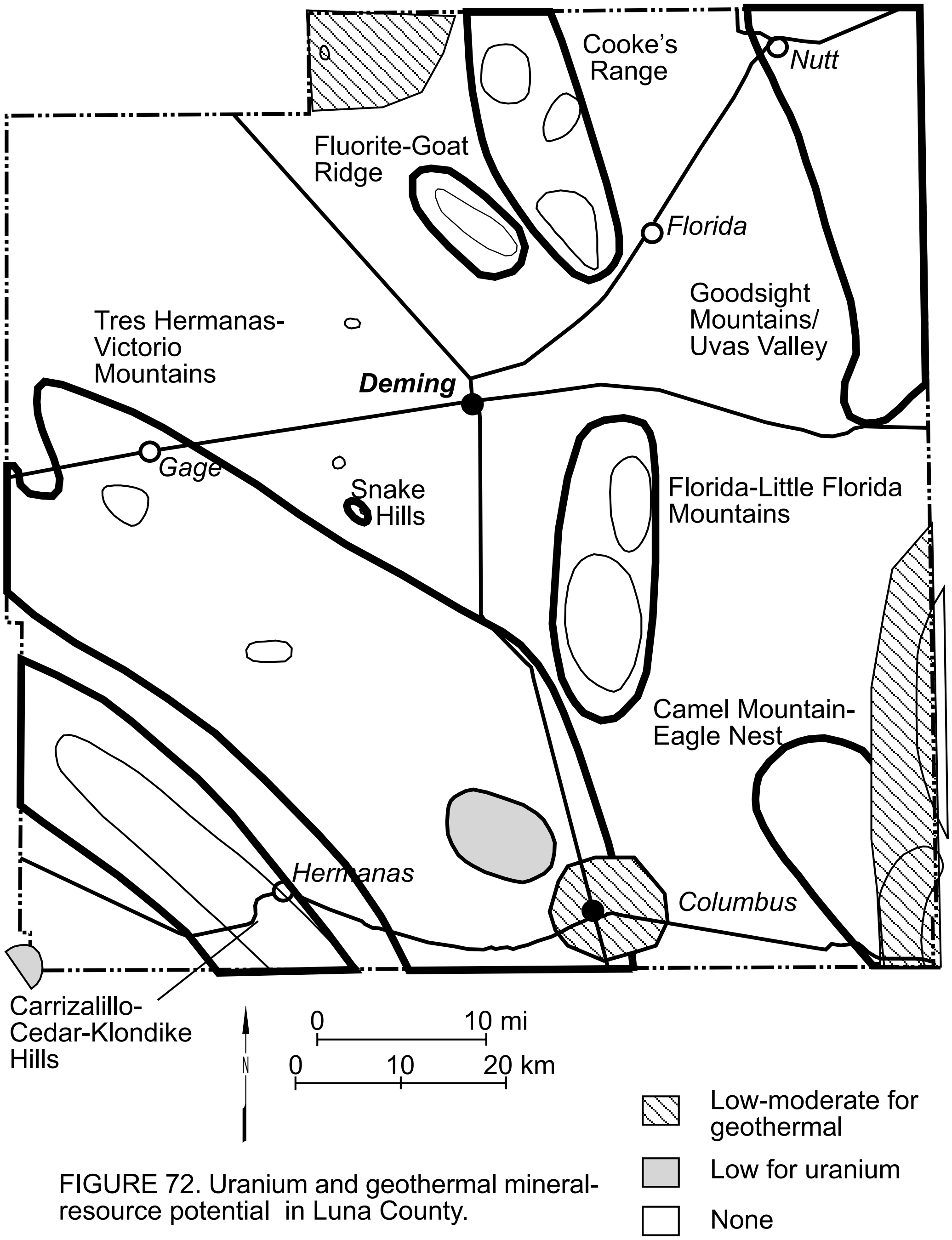


FIGURE 72. Uranium and geothermal mineral-resource potential in Luna County.