CIRCULAR 47

HIGH-PURITY DOLOMITE DEPOSITS OF SOUTH-CENTRAL NEW MEXICO

By
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NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY

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STATE BUREAU OF MINES AND MINERAL RESOURCES

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ABSTRACT

Almost unlimited deposits of high-purity bedded dolomite, which could be utilized for the production of metallic magnesium and magnesium compounds, occur in south-central New Mexico, in the area from the Sacramento Mountains west to Deming, and from the northern tip of the San Andres Mountains south to Mexico. Iron-ore and silica sands, which could be used to make the ferrosilicon necessary to silicothermic production of magnesium metal, are present in large amounts in the same area. Large amounts of natural gas are available as a source of power, there is an adequate pool of inexpensive labor, and the warm climate would allow continuous operations.

The Ordovician Upham dolomite and the Silurian Fusselman dolomite are high-purity beds in most of the area. The Upham dolomite, 50-120 feet thick, contains an average of more than 21.3 percent magnesium oxide and less than 1.4 percent insoluble residues. The Fusselman dolomite thickens southward from a knife edge, in the northern San Andres Mountains, to more than 850 feet in thickness, in the southern Franklin and Florida Mountains. Although some outcrops show as much as 5-10 percent large-size chert, the dolomite has an average content of 21.5 percent magnesium oxide and 0.7 percent small-size insoluble residues.

The Ordovician Cutter and Aleman formations, which range from 50 to 500 feet in combined thickness, are mostly dolomite. The Cutter dolomite, however, includes argillaceous and limy beds that would need to be rejected selectively in the mining of high-purity dolomite. The Aleman dolomite contains 5-60 percent chert, which would have to be removed by flotation to produce high-purity dolomite. Some of the Permian carbonate beds in southern New Mexico are of high-purity dolomite, but are in relatively inaccessible localities.

INTRODUCTION

The object of this preliminary estimate of high-purity dolomite deposits in New Mexico is to bring to the attention of producers and consumers of magnesium and magnesium compounds the large reserves of high-purity dolomite within the State. The dolomite deposits of New Mexico are hundreds of miles closer to the consuming centers of the East than many western dolomite deposits utilized during World War II and during the Korean emergency, and they are near extensive gas and oil fields which can provide large quantities of inexpensive power. Although current freight rates are too high to make the transportation of New Mexico dolomite to eastern processers feasible, the location of New Mexico, almost 1,000 miles from any shoreline, is of obvious strategic advantage in wartime, and suggests that magnesium plants constructed near the dolomite deposits of New Mexico would be far less vulnerable to attack than the magnesium plants of the east and west coasts.

The processing of dolomite in New Mexico would require use of the silicothermic production method, which is relatively more expensive than the electrolytic method utilizing sea water and has been employed only during times of national emergency when support by Federal subsidy was possible. Canada, however, with almost unlimited resources of hydroelectric power, has two magnesium plants, and the larger of those is a silicothermic plant having an integrated ferrosilicon supply (Comstock, 1954).

This report gives quantitative and qualitative estimates of the high-purity dolomite deposits in New Mexico and is especially concerned with the Lower Paleozoic dolomites in the south-central part of the State. Dolomites at 12 localities were sampled and analyzed as a spot check of the bedded deposits; together with previous studies such a check provided an indication of the extent, the stratigraphic location, and the purity of the dolomites. Dolomite outcrops occur in the narrow north-south or northwest-southeast mountain ranges typical of the Mexican Highlands section of the Basin and Range physiographic province. Economic deposits of high-purity dolomite lie chiefly within a north-south elongated rectangle extending northward from the Mexico-Texas border to the north tip of the San Andres Mountains. The western edge of the area is near Deming, and its eastern boundary is formed by the Sacramento Mountains. High-purity dolomites also crop out west of Carlsbad, in the Guadalupe Mountains area.

South-central New Mexico is served by the Atchison, Topeka & Santa Fe Railway and by the Southern Pacific Railroad, and is crossed by U. S. Interstate Highways 54, 70, 80, and 85. Las Cruces, Deming, Alamogordo, Truth or Consequences, Silver City, and El Paso (Texas) are the chief cities in or near the region. Almost all of the San Andres and Organ Mountains and parts of the Sacramento and northern Hueco Mountains are within military reservations and are closed at present to the general public, as well as to mining and industrial users.

Definitions

As used by most geologists, the term dolomite describes a rock composed chiefly of magnesium and calcium carbonate, which will not effervesce (give off carbon dioxide) when treated with cold dilute hydrochloric acid. Whereas dolomitic limestone effervesces slowly, I limestone effervesces freely in reaction to dilute hydrochloric acid. When chemical analyses are available, the limestone-to-dolomite isomorphous system is divided into dolomite rock, or dolostone, which contains 90 percent or more of the mineral dolomite, and 40.77 to 45.73 percent magnesium carbonate; calcic-dolomite, which contains 90 to 50 percent of the mineral dolomite (19.5 - 10.8 MgO); dolomitic limestone which contains 50 to 10 percent of dolomite mineral (10.8 - 2.1 percent MgO); and limestone with less than 10 percent of the mineral dolomite. Tests with dilute hydrochloric acid show that dolomitic beds, loosely called "dolomite" in the field, may be dolomite in fact, or they may be calcic-dolomite or, depending upon crystal size and arrangements of calcite and dolomite mineral crystals, they may be chemically classified as dolomitic limestone. For economic purposes a high-purity or high-grade dolomite is one that contains 97 percent or more of carbonates and 41 percent or more of magnesium carbonate (19.6 percent or more of magnesia). Most of the high-purity dolomites are 98 percent or more soluble in hydrochloric acid.

The mineral dolomite, although a member of the calcite isomorphous group, is not an isomorphous mixture of calcium carbonate and magnesium carbonate, but is, rather, a definite combination of the two carbonates in equal molecular parts. Small amounts of calcium ions may substitute for the smaller magnesium ions, and the reverse; but dolomitic rocks containing an appreciable excess of calcium carbonate are a mixture of calcite and the mineral dolomite, and those containing an appreciable excess of magnesium carbonate are a mixture of magnesite and dolomite minerals. Kulp et al. (1951) have shown that there can be a complete gradational substitution of ferrous ions for magnesium ions and a gradation from dolomite into ankerite ($2CaCO_3MgCO_3FeCO_3$). Actual mineral dolomite and rock dolomite, therefore, approach, but only in a few cases contain, the theoretical composition of 45.73 percent magnesium carbonate and 54.27 percent calcium carbonate, or 21.86 percent magnesia, 30.41 percent lime, and 47.73 percent carbon dioxide weight percentages. Pure dolomite contains 13.2 percent magnesium, 21.7 percent calcium, 13.0 percent carbon, and 52.1 percent oxygen. The ratio of calcium carbonated to magnesium carbonate is 1.187 to 1. The amount of magnesia (MgO) was multiplied by 2.08C to obtain a percentage of magnesium carbonate, and the percent of lime (CaO) was multiplied by 1.785 to calculate a percentage of calcium carbonate. The magnesia to magnesium carbonate conversion factor ranges from 2.087 to 2.092, depending upon the significant places of the chemical analysis; i.e., 45.727 percent divided by 21.863 percent is 2.092, whereas 45.7 percent divided by 21.9 percent is 2.087.

Many chemical analyses of dolomites, including most of those listed in this report, are based on determinations of magnesia and lime only; magnesium carbonate and calcium carbonate are calculated from the oxides without determination of carbon dioxide. In some cases (Willman, 1943) this method of analysis indicates a slightly higher content of carbonates than actually occurs. Small amounts of magnesium may be combined with silica and alumina in day deposited as an impurity with the dolomite. Some of the calcium may be in calcium sulfate, either anhydrite or gypsum, or in calcium phosphate as apatite, or collophane. On the other hand, small amounts of carbon dioxide may be in other carbonates, principally the ferrous carbonates siderite and ankerite. The methods of sampling and analysis for this study indicate an error of plus or minus 1 percent. Within this limit the magnesium carbonate can be estimated from the amount of magnesia.

Insoluble residues of the dolomites were not studied in detail, but were estimated qualitatively by binocular examination of materials left after the samples had been dissolved in hot perchloric and dilute hydrochloric acids. Clay, quartz silt, quartz sand, chert, and carbonaceous matter were observed. To be considered high-purity dolomite, the samples must contain less than 1 percent silica and less than 1.5 percent iron oxides and alumina.

Procedure and Acknowledgments

Samples representing every five feet of the stratigraphic section in the San Andres Mountains had been collected in the course of another project (Kottlowski et al., 1956) and other samples from the Robledo Mountains, near Las Cruces, were available. Dolomite samples were collected from the Mud Springs Mountains and southern Caballo Mountains with the aid of Frank C. Kottlowski. Roy W. Foster cooperated in the sampling of Lower Paleozoic dolomites from the Sacramento, Florida, Victorio, and central Caballo Mountains, Snake Hills, and Bishop Cap (fig. 1). Representative chip samples were collected along a continuous vertical line from the various formations and were grouped into units typical of 25-, 50-, and/or 100-foot bedded units.

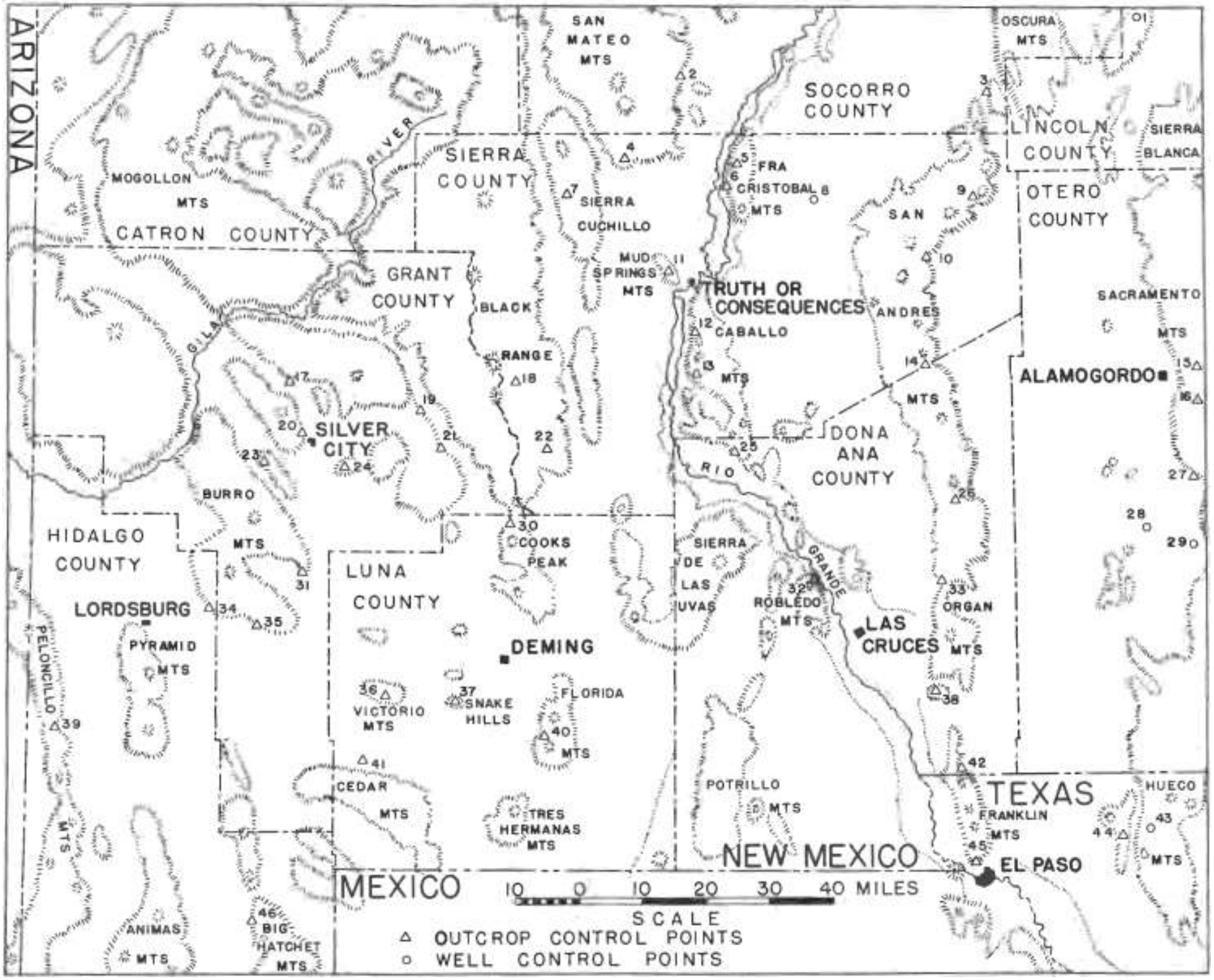


FIGURE 1. INDEX MAP OF DOLOMITE DEPOSITS IN SOUTHWESTERN NEW MEXICO

TABLE 1. Location of Control Points Numbered on Index Map, Figure 1.

Number	Location
1	Standard of Texas, No. 1 Heard oil test; sec. 33, T. 6 S., R. 9 E.
2	Eastern foothills of San Mateo Mountains near Eaton ranch; sec. 17, T. 8 S., R. 4 W.
3	Mockingbird Gap, northern San Andres Mountains; sec. 34, T. 8 S., R. 5 E.
4	Southern foothills of San Mateo Mountains; sec. 25, T. 10 S., R. 6 W.
5	Central Fra Cristobal Mountains; sec. 26, T. 10 S., R. 3 W. (Kelley & Silver, 1952).
6	Southern Fra Cristobal Mountains; sec. 11, T. 11 S., R. 3 W. (Kelley & Silver, 1952).
7	Sierra Cuchillo; sec. 18, T. 11 S., R. 7 W. (Jahns, 1955).
8	Sun Oil Company, No. 1 Victorio L. & C. Company oil test; sec. 25, T. 10 S., R. 1 W.
9	South side of Sheep Mountain, San Andres Mountains; sec. 25, A. 11 S., R. 5 A.
10	Rhodes Canyon, San Andres Mountains; sect. 8, T. 12 S., R. 4 E.
11	Mud Springs Mountains; sec. 24, T. 13 S., R. 5 W.
12	South Ridge, Caballo Mountains; sec. 10, T. 15 S., R. 4 W0 (Kelley & Silver, 1952).
13	Cable Canyon, central Caballo Mountains; sec. 10, T. 16 S., R. 4 W.
14	Hembrillo Canyon, central San Andres Mountains; sec. 11, T. 16 S., R. 3 E.
15	Pig Canyon, Sacramento Mountains; sec. 7, T. 16 S., R. 11 E0 (Pray, 1952).
16	Alamo Canyon, Sacramento Mountains; sec. 34, T. 16 S., R. 10 E.
17	Bear Creek Canyon, 11 miles north-northwest of Silver City; sec. 14, T. 16 S., R0 15 W.
18	Black Range near Kingston; sec. 24, T0 16 S., R. 9 W. (Kuellmer, 1954).
19	Near Georgetown, west side of Mimbres Valley; sec. 8, T. 17 S., R. 11 W.
20	Boston Hill, near Silver City; sec. 9, T. 18 S., R. 14 W. (Entwistle, 1944
21	West side of Mimbres Valley, west of San Juan; sect. 7, T. 18 S., R. 10 A. (Elston, 1957).
22	Lake Valley area; sec. 17, T. 18 S., R. 7 W. (Jicha, 1954
23	Little Burro Mountains; sec. 27, T. 18 S., R. 15 W. (Paige, 1916).
24	Lone Mountain; sec. 28, T. 18 S., R. 13 W.
25	West side of Red House Mountain, southern Caballo Mountains; sect. 10, T. 18 S., R. 3 W.
26	Ash Canyon, southern San Andres Mountains; sec. 28, T. 19 A., R. 4 E.
27	Southern Sacramento Mountains, sec. 1, T. 19 S., R. 11 E0 (Pray, 1952).
28	Plymouth Oil Company, No. 1 Evans oil test; sec. 15, T. 20 A., R. 9 E.
29	Sun Oil Company, No. 1 Pearson oil test; sect. 35, T. 20 S., R. 10 E.
30	Cooks Peak section; sec. 11, T. 20 S., R. 9 W. (Jicha, 1954
31	Eastern Burro Mountains; sec. 8, T. 21 S., R. 14 W.
32	Lookout Peak, Robledo Mountains; sect. 26, To 21 S., R. 1 W.
33	San Augustin Pass, northern Organ Mountains; sec. 29, T. 21 S., R$_0$ 4 E. (Dunham, 1935
34	Southwestern Little Burro Mountains; sec. 24, T. 22 S., R. 17 W.
35	Southern Little Burro Mountains; sec. 31, T. 22 S., R. 15 W0
36	Victorio Mountains; sec. 30, T. 24 S., R. 12 W.
37	Snake Hills; sec. 5, T. 25 S., R. 10 W.
38	Bishop Cap; sec. 25, T. 24 S., R. 3 E.
39	Central Peloncillo Mountains; sec. 26, T. 25 So, R. 21 W.
40	The Park, western Florida Mountains, sec. 35, T. 25 S., R. 8 W0
41	Klondike Hills; sec. 13, T. 26 S., R. 13 W. (Darton, 1928
42	Northern Franklin Mountains, near Texas-New Mexico line (Lloyd Pray, personal communication).
43	California Company No. 1 University-Theissen oil test; Hudspeth County, Texas.
44	Hueco Mountains outcrops; generalized section (King & King, 1945).
45	Southern Franklin Mountains, north of El Paso, Texas.
46	Northwest end of Big Hatchet Mountains; sect. 36, T. 30 S., R. 16 W. (Robert Zeller, personal communication).

The chip samples were crushed in a Chipmunk crusher. Vein material and fragments with weathered surfaces were removed; then the chips were ground to about 50 mesh in a Braun pulverizer. After washing, drying, and thorough remixing, a quartered and requartered part of the sample was dissolved in perchloric acid and evaporated to dryness. The dried Perchlorate salts were redissolved in dilute hydrochloric acid, and the solution was filtered. The calcium and magnesium chloride solution then was titrated with standardized Versenate, the disodium salt of tetraacetic acid. Murexide was used as the indicator for calcium; Eriochrome Black T was the indicator for magnesium. The insoluble residues were dried in an electric oven, at about 300°C, to burn the filter paper, and the residues were weighed after cooling. The insoluble residues then were examined under binocular and petrographic microscopes.

Ming-Shan Sun aided in setting up and standardizing the titrations. D. H. Reynolds, of Chapman and Wood, employed the normal gravimetric precipitation method to analyze 4 of the 77 samples previously analyzed by the Versenate method. The report has been reviewed critically by Roy W. Foster and Mrs. Helen Comstock (U. S. Bureau of Mines); it profited from discussions with members of the Bureau staff. William E. Arnold collaborated in the preparation of the maps, and Edmund H. Kase, Jr. and Howard E. Sylvester prepared the manuscript for final publication. Eugene Callaghan and Alvin J. Thompson initiated and directed the study.

PREVIOUS INVESTIGATIONS

Richardson (1909, p. 4) named the Montoya and Fusselman "limestones" from outcrops in the Franklin Mountains, and listed partial analyses, determined by W. T. Schaller, as follows (carbonates calculated from oxides):

Formation	CaO	MgO	$CaCO_3$ (In percent)	$MgCO_3$	Undet.
Fusselman, Hueco Mountains, 7 miles south of Hueco Tanks	28.63	18.69	51.12	39.02	9.86
Fusselman, Franklin Mountains	28.94	18.44	51.66	38.50	9.84
Montoya, Hueco Mountains, 8 miles south of Hueco Tanks	30.42	19.47	54.30	40.65	5.05
Montoya, Franklin Mountains, 3 miles north of El Paso	31.22	16.55	55.73	34.56	9.71
El Paso limestone, Franklin Mountains, 8 miles north of El Paso	32.12	16.00	57.33	33.41	9.26

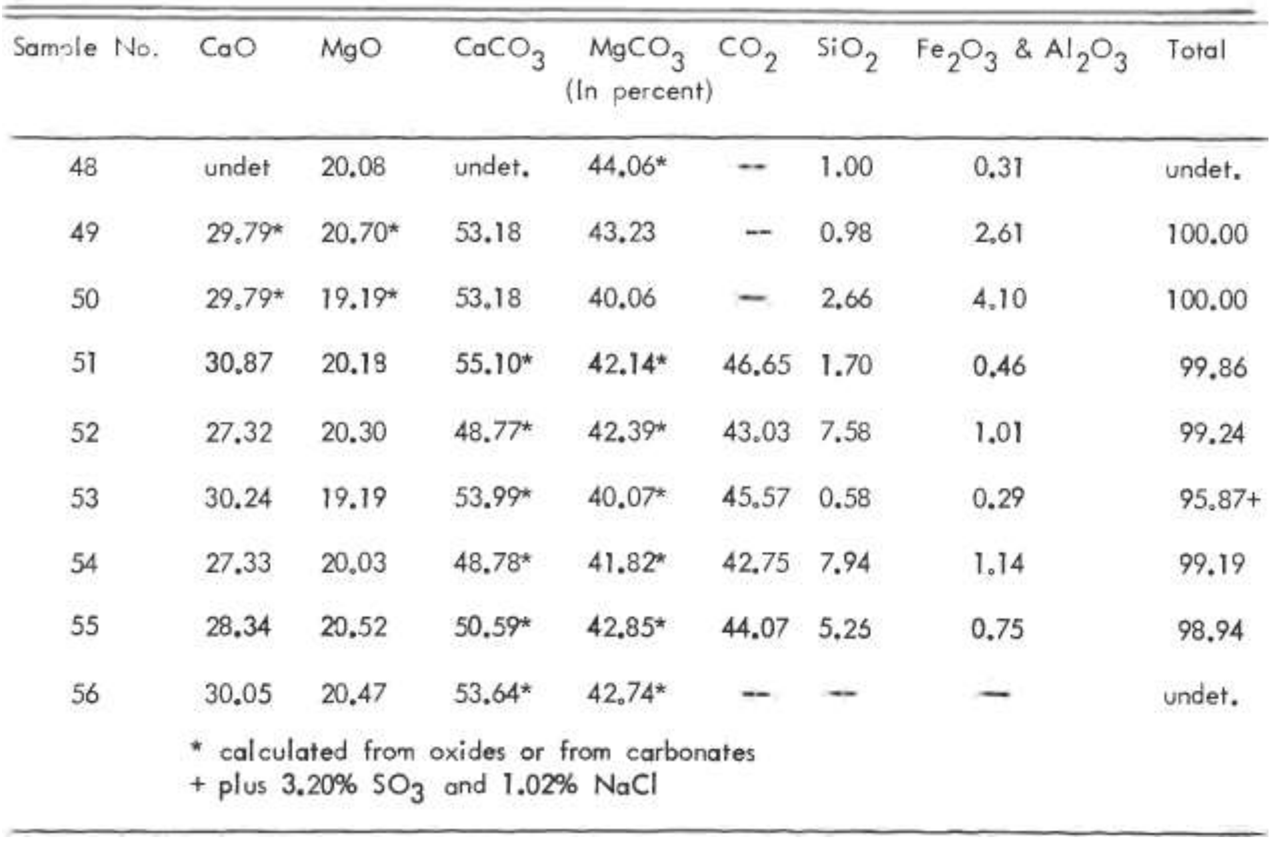
No indication was given as to whether the Schaller analyses are of channel samples, chip samples, or grab samples. The Montoya limestone of Richardson in the Franklin and Hueco Mountains is equivalent to the Upham and Aleman dolomites of the Montoya group, as defined by Kelley and Silver (1952. p. 56-66), and, as such, is of two distinctly different lithologic and chemical units. The Fusselman limestone of Richardson is equivalent to the Cutter-Valmont dolomite of the Montoya group and the restricted Fusselman dolomite. The samples analyzed by Schaller probably came from the lower part of Richardson's Fusselman limestone, now called the Cutter dolomite, and should not be compared with analyses of the Fusselman dolomite as it is now restricted.

Entwistle (1944, A. 16-20) and A. B. Romney analyzed samples of the El Paso, Montoya, and Fusselman dolomites from the Silver City area, and listed partial analyses as follows:

Formation	CaO	MgO	$CaCO_3$	$MgCO_3$	Insoluble	Total
			(In percent)			
Fusselman dolomite	32.07	17.78	57.25	37.12	0.64	95.01
Raven member, Montoya dolomite	29.89	17.77	53.36	37.10	2.6	93.06
Par Value member, Montoya dolomite	19.15	11.82	34.18	24.68	34.0	92.86
Basal sandy bed, Second Value member, Montoya dolomite	22.99	8.60	41.04	17.96	40.53	99.53
Upper part of El Paso dolomite	28.31	19.82	50.53	41.39	4.21	96.13
Basal sandy beds of El Paso dolomite	22.77	12.45	40.65	26.00	26.63	93.28

The Fusselman dolomite is thin (75 feet or less) in the Silver City area. The Raven member of Entwistle's Montoya dolomite is equivalent to the Cutter dolomite; the Par Value member is correlatable with the Aleman dolomite; and the Second Value member is equivalent to the Cable Canyon sandstone and Upham dolomite. The sample analyzed from the Second Value-Upham dolomite was from the basal sandy bed which contains a high percent of insoluble residues; similarly the sample from the basal El Paso dolomite is of a clastic rock containing much quartz sand and silt.

Darton (1928, p. 186) listed an analysis made by Chase Palmer of the Fusselman limestone collected from San Andres Canyon in the southern San Andres Mountains. The analysis showed 51.8 percent calcium carbonate, 38 percent magnesium carbonate, and 10.2 percent insoluble matter. An analysis of the lower part of the San Andres formation is also given (Darton, 1928, A. 70) from outcrops near Mesa del Yeso, T. 1 S., R. 2 E. Palmer's analysis is 52.80 percent calcium carbonate, 38.22 percent magnesium carbonate, and 8.98 percent insoluble residue, Weitz (1942, p. 76-82) listed analyses of scattered dolomite samples from Permian formations near Carlsbad, but dismissed the dolomites in south-central New Mexico with the comment, "There may also be some high-grade material (dolomite) in the El Paso-Las Cruces region, but no analyses showing a high enough magnesia content have been reported," The statement is apparently based on the 5 analyses published by Richardson and the analysis listed by Dorton. Poor sampling and a lack of understanding of the lithology and stratigraphy apparently condemned the entire south-central New Mexico dolomite deposits. The analyses listed by Weitz (1942, p. 78-79) are as follows:

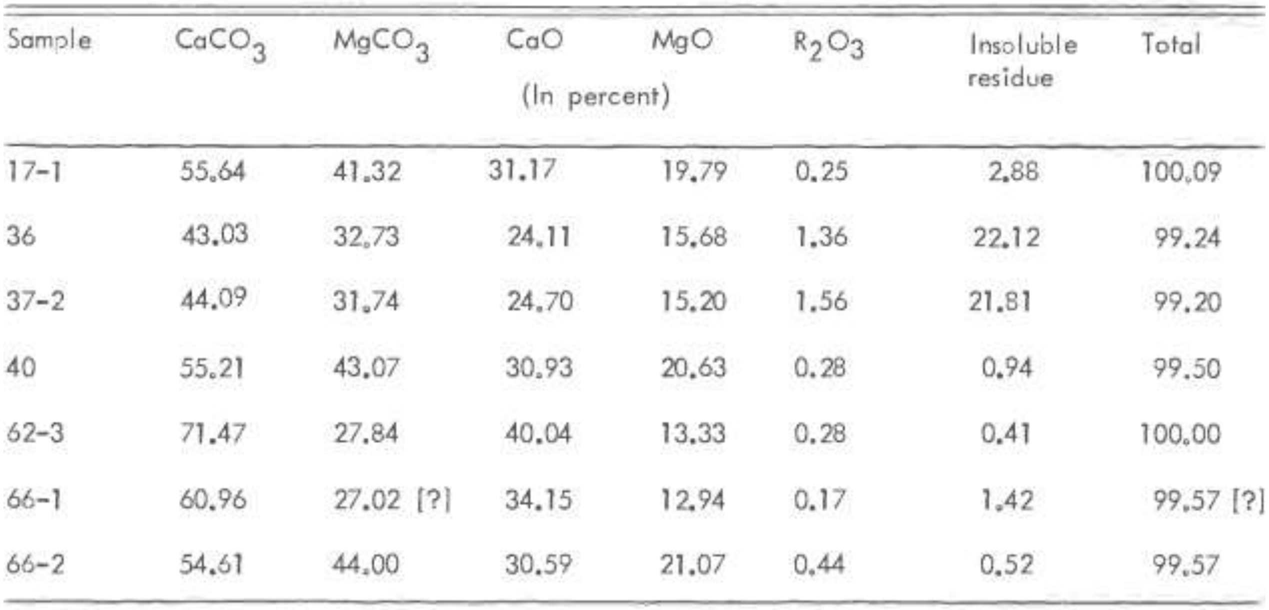


Sample No.	CaO	MgO	$CaCO_3$	$MgCO_3$ (In percent)	CO_2	SiO_2	Fe_2O_3 & Al_2O_3	Total
48	undet	20.08	undet.	44.06*	--	1.00	0.31	undet.
49	29.79*	20.70*	53.18	43.23	--	0.98	2.61	100.00
50	29.79*	19.19*	53.18	40.06	—	2.66	4.10	100.00
51	30.87	20.18	55.10*	42.14*	46.65	1.70	0.46	99.86
52	27.32	20.30	48.77*	42.39*	43.03	7.58	1.01	99.24
53	30.24	19.19	53.99*	40.07*	45.57	0.58	0.29	95.87+
54	27.33	20.03	48.78*	41.82*	42.75	7.94	1.14	99.19
55	28.34	20.52	50.59*	42.85*	44.07	5.26	0.75	98.94
56	30.05	20.47	53.64*	42.74*	--	--	—	undet.

* calculated from oxides or from carbonates
\+ plus 3.20% SO_3 and 1.02% NaCl

Sample 48 is from El Capitan Peak in Culberson County, Texas, a few miles south of the New Mexico border, and is apparently a sample of the Capitan limestone, although Newell et al., (1953, p. 178) noted that the Capitan reef rock contains very little dolomite. Sample 49 is listed as being from a 15-foot bed at top of Rocky Arroyo, 18 miles northwest of Carlsbad. The dolomite is either the bed capping the hills on the north side of Rocky Arroyo or the massive dolomite exposed in the arroyo bed; both are believed to be in the Seven Rivers formation, Permian age. This is the locality where the bedded dolomites of the Seven Rivers formation grade laterally into red shales and evaporite beds. Sample 50 is reported to represent a 7-foot bed in sec. 2, T. 21 S., R. 25 E., about 13 miles northwest of Carlsbad; this bed is also probably in the Seven Rivers formation. Samples 51-55 are listed from government test hole no. 13 of the Carlsbad formation in Eddy County. These samples were collected by W. B. Lang (Wells, 1937, p. 57) from depths of 1,180 feet (no. 55), 1,160 feet (no. 54), 1,136 feet (no. 53), 177 feet (no. 52), and near the surface (no. 51). Sample 56 is from "dolomitic Permian limestone 20 miles west of Carlsbad"; it is probably from the Seven Rivers formation. Except for samples 48-50, the magnesium carbonate and calcium carbonate were calculated from their oxides. Carbon dioxide was determined by chemical analysis for samples 51-55, which permitted a check to see whether the carbon dioxide balanced with the calcium and magnesium oxides to form carbonates. The actual carbon dioxide, as compared with the calculated amount necessary to form calcium and magnesium carbonates, ranges from an excess of 0.51 percent (no. 51) to a deficiency of 0.51 percent (nos. 52 & 55), and averages only 0.02 percent deficiency.

Philip King, in his monographic study (1948) of the southern Guadalupe Mountains just south of the New Mexico-Texas border, listed numerous analyses of Permian dolomites and dolomitic limestones that extend northward into New Mexico and crop out in the northern and central Guadalupe Mountains. In almost every case the dolomitic rocks are within predominantly limestone or even sandstone-shale units, and occur as relatively thin beds. King (1948, p. 17, 36, 37, 40, 62, 66) lists the following analyses:



Sample	$CaCO_3$	$MgCO_3$	CaO	MgO	R_2O_3	Insoluble residue	Total
			(In percent)				
17-1	55.64	41.32	31.17	19.79	0.25	2.88	100.09
36	43.03	32.73	24.11	15.68	1.36	22.12	99.24
37-2	44.09	31.74	24.70	15.20	1.56	21.81	99.20
40	55.21	43.07	30.93	20.63	0.28	0.94	99.50
62-3	71.47	27.84	40.04	13.33	0.28	0.41	100.00
66-1	60.96	27.02 [?]	34.15	12.94	0.17	1.42	99.57 [?]
66-2	54.61	44.00	30.59	21.07	0.44	0.52	99.57

The lime and magnesia was calculated from the carbonates; calcium phosphate is included with the calcium carbonate; and manganese carbonate is included with the magnesium carbonate. All rocks analyzed are of Permian age. Sample 17-1 is of the lower division, Victorio Peak member, Bone Springs limestone, collected on the west side of Guadalupe Peak. Sample 36 is of the South Wells member of the Cherry Canyon formation, collected at south base of Rader Ridge. Sample 37-2 is of the Manzanita member of the Cherry Canyon formation, collected from the south base of Rader Ridge. Sample 40 is from the lower part of the Goat Seep limestone, collected 21 miles northwest of Bone Canyon. Sample 62-3 is of the Capitan limestone, collected from the south wall at the mouth of McKittrick Canyon. Samples 66-1 and 66-2 are from the Carlsbad limestone; sample 66-1 was collected on the north side of Pine Spring Canyon; sample 66-2 was collected on the northeast side of Lost Peak.

Wells (1937, p. 57) listed several analyses of Permian beds made by Chase Palmer, apparently not published elsewhere. A sample identified as being from the Chupadera formation, northwest of Queen (Eddy County), contained 54.25 percent calcium carbonate, 38.70 percent magnesium carbonate, and about 7 percent insoluble residue. Another sample listed as occurring between gypsum beds 10 miles southwest of Hope (in Eddy County) is probably from the Chalk Bluff formation or Grayburg formation and consists of 54.41 percent calcium carbonate, 36.12 magnesium carbonate, and about 9 1/2 percent insoluble residue.

Newell et al. (1953, p. 46, 62, 69, 110) studied the Permian reef complex in the Guadalupe Mountains and listed the following analyses of Permian dolomites and dolomitic I limestones:

Sample	CaO*	MgO*	$CaCO_3$	$MgCO_3$	Fe_2O_3	Al_2O_3	SiO_2	Total
			(In percent)					
597	29.5	22.0	52.7	45.9	0.6	0.1	0.7	100.0
555	26.8	19.1	47.9	39.8	1.4	1.9	9.1	100.1
517	27.6	20.1	49.3	41.9	0.4	0.9	7.5	100.0
706	43.3	10.7	77.3	22.4	0.1	0.1	0.2	100.1
688	31.0	21.2	55.4	44.3	-	-	0.3	100.0

* Calculated from carbonates

Sample 597 is of the Azotea dolomite tongue of the Seven Rivers formation, and was collected from the Rocky Arroyo area west-northwest of Carlsbad. Sample 555 is of the Manzanita member of the Cherry Canyon limestone, and was collected one-quarter of a mile east of D ranch headquarters, about 6 miles east of Pine Springs, Texas. Sample 517 is of the Upper Getaway member of the Cherry Canyon limestone, and was collected along U. S. Highway 62 in Guadalupe Canyon. Sample 706 is a nontypical specimen of the Capitan reef limestone. Sample 688 is of the Goat Seep reef dolomite, and was collected in North McKittrick Canyon. In some areas the Seven Rivers formations consists of light-colored, thin-bedded, fine-crystalline dolomite, such as sample 597, and is about 500 feet thick. This dolomite facies of the formation, however, grades abruptly into red shales and gypsum The calcic-dolomites and dolomites of the Cherry Canyon limestone are local lenses interbedded with dark-colored limestones and sandstones, in only a few places exceeding 25 feet in thickness. The Goat Seep reef dolomite, such as sample 688, attains thicknesses of 1,200 feet for a belt about a mile wide, but grades sharply into interbedded limestones, dolomites, and arenaceous classic rocks.

Boyd (1956, p. 39, 51) listed 14 spectrographic analyses of two Permian formations in the Brokeoff Mountains on the west edge of the Guadalupe Mountains. The San Andres formation (2 samples) was listed as containing 53.1-58.8 percent calcium carbonate; 40.6-45.7 percent magnesium carbonate; 0.53-1.1 percent silica; 0.09-0o10 percent ferric oxide;:end 0.06-0.08 percent alumnia. The overlying Queen-Grayburg formations are listed as showing a range of 48.7-61.1 percent calcium carbonate; 33.5-46o9 percent magnesium carbonate; 0.52-6.35 percent silica; 0.20-0.56 percent ferric oxide; and 0.03-182 percent alumina. An average of the 12 Queen-Graysburg samples is 54.5 percent calcium carbonate; 41.9 percent magnesium carbonate; 2.8 percent silica; 0.38 percent ferric oxide; and 0.44 percent alumina. As 5 of the 12 analyses show magnesium carbonate in excess of the amount present in pure mineral dolomite, part of the magnesium probably occurs with silica and alumina as clay or as a substitute for calcium in calcium carbonate.

Most qualitative reports of the San Andres formation in southeastern and south-central New Mexico indicate the beds range from calcic-dolomite to limestone and contain much insoluble carbonaceous residue. Thick persistent beds of high-purity dolomite have been reported to date only on the west side of the Guadalupe Mountains, about 65 miles from Carlsbad.

MAGNESIUM DEPOSITS IN NEW MEXICO

Only relatively small deposits of brucite, magnesite, and olivine occur in New Mexico, and most of the deposits of brucite and magnesite are within restricted military reservations. The Permian saline deposits of southeastern New Mexico are extensively mined, chiefly for potash, although langbeinite (potassium magnesium sulfate) is produced by some of the mines. Other magnesium salts present are polyhalite (hydrous calcium magnesium potassium sulfate); kieserite (hydrous magnesium sulfate); carnallite (hydrous potassium magnesium chloride); kainite (hydrous potassium chloride magnesium sulfate); and leonite (hydrous potassium chloride magnesium sulfate). Most of the magnesium available in New Mexico, however, occurs in bedded, high-purity dolomites.

Dolomite Deposits

There are two types of dolomite deposits in New Mexico, bedded dolomite and replacement dolomite. Almost all of the Paleozoic formations contain at least thin beds of dolomite or dolomitic limestone, and in places limestone beds are replaced by irregular lenses and odd-shaped masses of dolomite. The Bliss sandstone of Cambro-Ordovician age contains some dolomitic sandstones, but no appreciable amounts of dolomite. The El Paso group is predominantly limestone, but in many areas thick beds and large irregular masses have been dolomitized, and in some localities, such as the San Andres Mountains, most of the beds of the group are dolomite, calcic-dolomite, and dolomitic limestone. The Montoya group is almost entirely dolomite, and even the basal Cable Canyon sandstone is cemented by dolomite. The Upham dolomite of the Montoya group is a dark-gray massive-bedded crinoidal high-purity dolomite which contains a considerable amount of arenaceous material in basal beds and some chert nodules near the top, but is relatively free of noncarbonate materials. The Aleman dolomite is very cherty, and includes as much as 60 percent of chert in thin beds, lenses, nodules, and silicified fossils. The uppermost formation of the Montoya group, which was included in the Fusselman dolomite by Darton (1928), is the Cutter or Valmont dolomite. The Cutter dolomite is relatively chert free, but is silty and argillaceous and includes many thin beds of calcic-dolomite and dolomitic limestone.

The Silurian Fusselman dolomite is massive bedded and ranges from light gray to dark gray, weathering brownish gray. The dolomite is almost pure, and only in a few localities contains appreciable amounts of small-sized insoluble residues, chiefly chert and some quartzose sand. The amount of large-sized chert within the Fusselman dolomite varies greatly from place to place. In the Robledo Mountains, for example, the Fusselman dolomite is about 250 feet thick, but only the lower 20 feet is relatively chert free; in contrast, in the Florida Mountains, Kelley and Bogart (1952) reported more than 1,350 feet of Fusselman dolomite, with only the lower 100-150 feet containing appreciable amounts of chert.

The Devonian formations consist chiefly of argillaceous rocks and contain no significant amounts of dolomitic beds. Mississippian and Pennsylvanian sedimentary rocks are dominantly fossiliferous limestones, and include only thin dolomitic beds. There are thin lenses of calcic-dolomite in the Permian Hueco, Yeso, and San Andres formations in southwestern and south-central New Mexico, but these dolomitic beds are interbedded with much thicker units of limestone, gypsum, and clastic rocks. As noted in the resume of previous investigations, there are high-purity dolomites in the Permian strata of southeastern New Mexico. Some of these dolomites, such as those of the Seven Rivers formation, are interbedded with, and grade laterally into, gypsum and red bed clastic deposits; others, such as the Goat Seep reef dolomite, are of limited lateral extent; and the San Andres formation high-purity dolomites are on the west side of the Guadalupe Mountains. The upper part of the thick Permian carbonate sequence in the Big Hatchet Mountains includes several 50- to 100-foot thick units of dolomite; these beds crop out in a rugged remote area and have not been analyzed. Post-Paleozoic sedimentary rocks are not known to contain any thick or persistent dolomite beds.

The most favorable formations in south-central and southwestern New Mexico that might include large deposits of high-purity commercial dolomite are the Upham and Cutter/Valmont dolomites of the Montoya group and the Fusselman dolomite. In most localities the Upham and Fusselman dolomites crop out as massive vertical cliffs, whereas the Cutter dolomite forms a steep ledgy slope below the Fusselman dolomite and above the cherty Aleman dolomite. In some places the nonresistant Devonian shales have been eroded to produce a wide shelf on top of the Fusselman dolomite, or, in localities where the Fusselman is absent, on upper beds of the Montoya group. Most of the outcrops of the Fusselman and Montoya dolomites are on frontal escarpments of the fault-block mountains typical of southwestern New Mexico. The beds dip 10-45 degrees into the range away from the scarp to become more deeply buried beneath younger rocks within the mountains. Large scale mining operations could begin with quarrying, but in most areas operations would probably have to go underground.

Upham Dolomite

The Upham dolomite overlies the Cable Canyon sandstone, which is the basal unit of the Montoya group in New Mexico. In many areas the Cable Canyon sandstone is a basal arenaceous phase of the Upham dolomite, and there is complete gradation from typical brown-weathering dolomitic sandstone, called Cable Canyon, up into dark-gray-weathering arenaceous dolomite of the lower Upham. In some sections dolomitic sandstones and arenaceous dolomites occur as thin lenses throughout the lower part of the Upham dolomite. This lower arenaceous facies may contain an average of 2-3 percent quartz sand (averaged for 25-75 feet of section), and in some localities, such as Bishop Cap and Cable Canyon, the quartz sand averages as much as 10 percent.

Most of the Upham dolomite is medium dark gray, fine to coarse crystalline, massive bedded, and crinoidal. Scattered thin lenses, stringers, and some large nodules of chert occur locally. The Upham dolomite crops out as a vertical dark-gray cliff, whose basal part is the brown-weathering Cable Canyon sandstone and whose upper part is within the overlying cherty Aleman dolomite. The Aleman dolomite is thin to massive bedded, and would form an excellent roof for underground mining operations. Insoluble residues of the seventeen Upham dolomite samples analyzed range from 0.2-9.7 percent; insolubles are 1.5 percent or less in 13 of the samples, and in only two samples exceed 3 percent. The residues are chiefly quartz, occurring as sand and silt-sized grains along with some microscopic chert. Carbonaceous material occurring as extremely fine-grained solid particles comprises 0.2-0.6 percent of the residue and forms an oily film on the surface of dissolving solutions. Vanderpool's studies (Kottlowski et al., 1956, p. 83) of insoluble residues from the Upham dolomite in the San Andres Mountains show 1-2 percent of drusy chert flakes and quartz sand.

None of the samples analyzed showed as much as 0.5 percent iron oxide, and qualitative examination of the residues suggests the Upham dolomite contains only traces of compounds other than calcium carbonate, magnesium carbonate, silica, and carbonaceous matter. The magnesium oxide content ranges from 19.3 to 21.7 percent, and only two samples (SC1 and BC2) contain less than 21.2 percent. However, these two samples, although they contain quantities of magnesium oxide approximating the 19.6 percent content necessary for a high-purity dolomite, contain, at the same time, too large a percent of impurities. There is not much vertical variation within the Upham, except for the larger amount of residues in lower beds. In the Alamo Canyon section of the Sacramento Mountains, for example, the four vertical units sampled vary only 0.2 percent in magnesium oxide content and only 0.4 percent of insoluble residues, with the upper three units varying only 0.1 percent of residues. Locally, however, there are scattered chert nodules that may raise the silica percentage of individual beds to as much as 10 percent.

The Upham dolomite is 75-120 feet thick in the mountain ranges east and southeast of the Caballo Mountains and in the region encompassed by the Snake Hills, central Peloncillo Mountains, and Big Hatchet Mountains. The dolomite is 40-75 feet thick in the rest of southwestern New Mexico, except where it has been removed by early Devonian erosion. The zero line follows a sinuous course (fig. 2) northeast from the central Peloncillo Mountains to Monticello, then eastward to the northern tip of the San Andres Mountains. Surface outcrops in the central Sacramento Mountains and records of the few scattered oil tests suggest the zero line trends southeast from the northern San Andres Mountains to the vicinity of Tuarosa, and then east and southeast toward southeastern New Mexico, where the pre-Permian Paleozoic rocks are buried beneath younger strata.

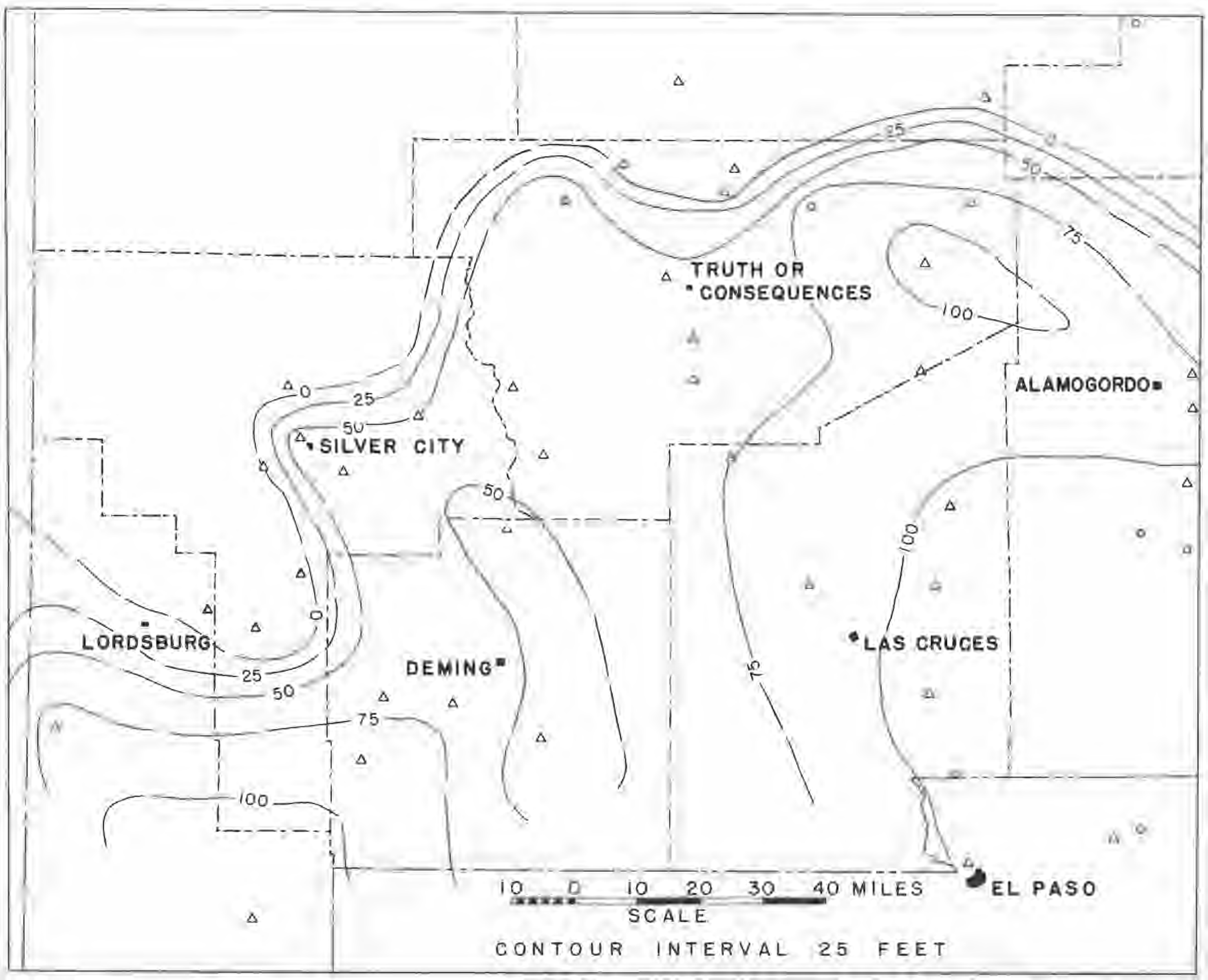


FIGURE 2. UPHAM DOLOMITE ISOPACH MAP

Aleman Dolomite

The Aleman dolomite includes thin bands, lenses, nodules, and stringers of chert, which make up as much as 60 percent of some beds. Typically, the Aleman is a hard, medium dark- to dark-gray, aphanitic to medium-crystalline, medium- to massive-bedded dolomite. The numerous chert lenses impart a thin-bedded or laminated appearance to the formation, but the lower beds form the upper part of a vertical cliff with the underlying Upham dolomite, and even the upper beds crop out as broken cliffs or thick ledges beneath the ledgy slope developed by the overlying Cutter dolomite outcrops.

Exclusive of megascopic chert, the Aleman beds are dolomite or calcic-dolomite that contain 0,9-4.1 percent small-sized insoluble residues, averaging about 2.0 percent for the 9 samples analyzed. Magnesium oxide percent of the noncherty rock is more than 21 percent for 7 of the 9 samples. The Mud Springs Mountains and southern Caballo Mountains samples contain 14.1-19.3 percent magnesium oxide. If the bulk percentage of the rock is calculated to include large-scale chert, the magnesium oxide content of the total rock ranges from 17.2 to 20.5 percent, except for the sample from the southern Caballo Mountains, which contains only about 10 percent magnesia.

The Aleman dolomite appears relatively free of clay and contains less than 0.5 percent iron oxide. The 8-30 percent of chert probably could be removed by flotation, and this chert could be a source of silica for the ferrosilicon used in the silicothermic process. The Aleman dolomite in most areas is 85-190 feet thick and comprises a very appreciable tonnage of high-silica dolomite.

Cutter Dolomite

The Cutter dolomite, in reports by Darton (1928) and others prior to 1952, was placed in the lower part of the Fusselman dolomite; the Cutter is correlative with the Valmont dolomite of Pray (1954) in the Sacramento Mountains, and with the Raven member of the Montoya dolomite in the Silver City area (Entwistle, 1944). The Cutter consists of medium-gray to dark-gray, aphanitic, thin- to medium-bedded dolomite that weathers light gray and crops out as smooth angular ledges. The dolomite in most places forms a light-gray-weathering steep slope, broken by thin angular ledges that contrast with the darker-weathering cherty Aleman dolomite below and the dark-gray Fusselman dolomite cliff above.

Some beds of the Cutter dolomite contain scattered small light-brown nodules of chert and locally a few thin lenses of Aleman-like chert. Vugs lined with tiny quartz, calcite, and dolomite crystals are common. Angular quartz silt, irregular wavy laminae of clay, and dispersed carbonaceous material are microscopic impurities. Studies by Vanderpool of the insoluble residues from the sections in the San Andres Mountains (Kottlowski et al., p. 84) show that the Cutter dolomite in that area contains as much as 35 percent of small-size sandy to granular dolomoldic chert in some of the lower beds, and, near the middle of the formation, shaty beds that have as much as 25 percent sandy silty shale. Most of the Cutter dolomite beds, however, contain only 1-4 percent insoluble residues.

The 19 analyses of the Cutter dolomite show a range of 4.2 to 11.4 percent insoluble residues which are chiefly clay and quartz silt. The vertical variation shown in the Alamo Canyon

Section of the Sacramento Mountains indicates, however, that much of the Cutter is high-purity dolomite and that most of the insoluble residue in a sample of the total formation is from an argillaceous soft zone commonly present near the middle of the unit, In Alamo Canyon the lower 40 feet has an approximate residue of 1.2 percent; the 40-foot soft zone contains 8.8 percent residue; and the upper 90 feet of dolomite averages about 2,7 percent residue, Even the soft zone in this section contains 19.9 percent magnesium oxide, and the overlying and underlying dolomites have more than 21 percent magnesium oxide, In several of the San Andres Mountains sections the argillaceous zone contains as much as 35 percent clay and quartz silt, whereas the rest of the Cutter dolomite averages only 2 percent, The overall average for the total formation is about 10 percent, Although the percent of magnesium oxide for the 19 samples analyzed ranges from 18.6 to 21.5, most of the rocks involved are almost pure mineral dolomite, diluted only by clay and some quartz silt. Selective quarrying of the beds below and above the soft zone would, in most areas, produce high purity dolomite,

The Cutter dolomite thins abruptly near the northern and western extent of Upper Ordovician outcrops as a result of erosion during early Devonian time. In the areas where the Cutter dolomite is overlain by the Fusselman dolomite, the Cutter dolomite is 150 or more feet thick, except between Silver City and Cooks Peak, where the Cutter is 50-120 feet thick (fig. 3). In the. Florida Mountains the Cutter dolomite may be as much as 400 feet thick.

Fusselman Dolomite

The Silurian Fusselman dolomite, as restricted by Kelley and Silver (1952), Pray (1953), and Kottlowski, et al. (1956), is in most areas equivalent to the upper part of the Fusselman dolomite as defined by Richardson (1909), and as used by Darton (1928) and others prior to 1952. The Fusselman is a relatively pure, medium- to medium dark-gray, aphanitic to coarse-crystalline, massive-bedded dolomite that forms a prominent dark-brown-weathering cliff, above and below slopes cut into the Cutter dolomite and Devonian shaly beds respectively. The amount of chert in the dolomite varies from place to place and occurs as small nodules, thin lenses, and silicified fossiliferous laminae. Some beds contain numerous vugs filled with quartz, dolomite, and/or calcite crystals, In several localities, such as the Sacramento and Florida Mountains and Bishop Cap, the Fusselman includes beds of relatively coarse-grained whitish dolomite, In the Florida Mountains these light-colored beds are interbedded and interlaminated with black aphanitic dolomites.

Only one sample of the 25 Fusselman samples analyzed has less than 21 percent magnesium oxide, and that sample (AC3, Ash Canyon, San Andres Mountains) contains 19.7 percent magnesium oxide, even though including 8.7 percent insoluble residue, Insoluble residues are less than 1,0 percent for 19 samples and less than 1.8 percent for 23 samples. The small-size residues are chiefly chert and some quartzose sandy silt, Large-size chert and silicified fossils form as much as 20 percent of some beds, but are absent from most of the Fusselman dolomite or form only one-half to five percent of it.

At every observed outcrop the Fusselman dolomite is erosionally unconformable or disconformable beneath Devonian beds; in many areas the upper few feet of the Fusselman is silicified and iron-stained, The Fusselman dolomite thins beneath the early Devonian erosion surface northward and westward from thick sections in the Florida and Franklin Mountains, The thin edge of the dolomite occurs six miles south of Rhodes Canyon in the San Andres Mountains; northeast of Alamogordo in the Sacramento Mountains; in the northern Caballo Mountains; and

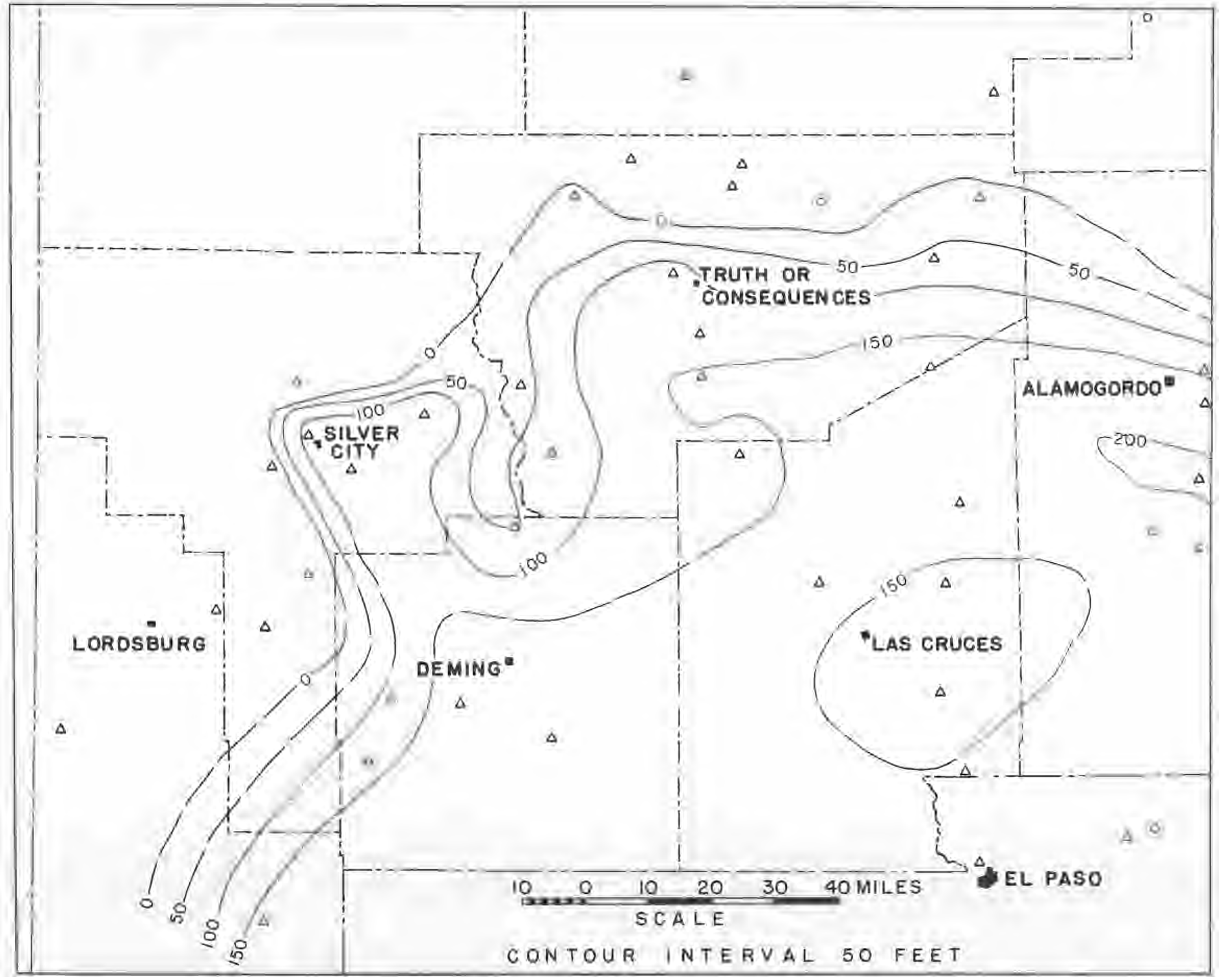
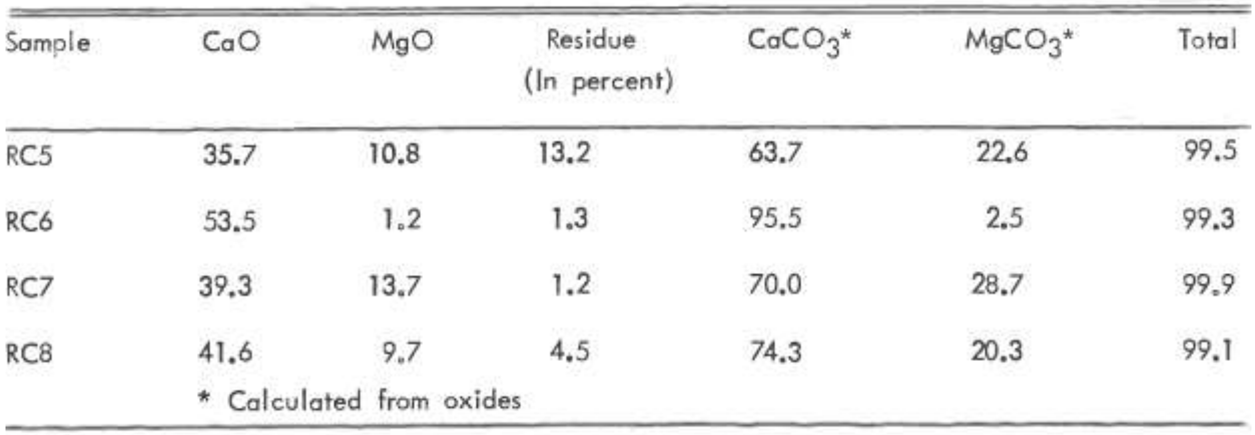


FIGURE 3. CUTTER DOLOMITE ISOPACH MAP

west of Silver City. The Fusselman dolomite is at least 200 feet thick in the area from Lake Valley southeastward and south-southwestward; is almost 850 feet thick in the southern Franklin Mountains; and may be more than a thousand feet thick in the Florida Mountains (fig. 4). Thick high-purity dolomite deposits of the Fusselman occur in many of the mountain ranges of south-central New Mexico.

Permian Dolomites in South-Central New Mexico

Dolomitic limestones and some calcic-dolomites occur interbedded with limestones, gypsum, and clastic beds of the Yeso and San Andres formations, but do not form any extensive high-purity deposits in south-central New Mexico. Samples collected from the type section of the San Andres formation (Rhodes Canyon, San Andres Mountains) were analyzed, and show a range of 1.2-13.7 percent magnesium oxide and 1.2-13.2 percent insoluble residues. The analyses are as follows:



Sample	CaO	MgO	Residue (In percent)	$CaCO_3$*	$MgCO_3$*	Total
RC5	35.7	10.8	13.2	63.7	22.6	99.5
RC6	53.5	1.2	1.3	95.5	2.5	99.3
RC7	39.3	13.7	1.2	70.0	28.7	99.9
RC8	41.6	9.7	4.5	74.3	20.3	99.1

* Calculated from oxides

Sample RC5 is from the basal 93 feet of light-gray limestones, dolomitic limestones, calcarenites, and limy sandstones. Sample RC6 is from the overlying 221 feet of massive-bedded dark-gray limestone having some argillaceous and carbonaceous beds, Sample RC7 is from the next higher 114 feet of light-gray dolomitic limestones and calcic-dolomites, Sample RC8 is from the upper 142 feet of light-gray dolomitic limestones having basal argillaceous beds. None of these groups of beds are high-purity dolomite, although individual beds may be.

The section of San Andres dolomite exposed on the east side of the pit at Gallinas Station (sec. 11, T. 2 S,, R. 12 E,) was sampled by Vincent C. Kelley, University of New Mexico, and yielded the following analysis: magnesia, 20,02 percent; lime, 32.20 percent; ignition loss (mostly CO_2?), 44.31 percent; silica, 3.26 percent; alumina, 0,56 percent; ferric iron oxide, 0,14 percent; soda, 0,05 percent; potash, 0.11 percent; sulfur trioxide, absent. These beds are high in magnesium oxide but also contain more than 3 percent silica.

The San Andres formation crops out extensively in southeastern New Mexico and caps many of the mountain ranges of south-central New Mexico, It extends on the surface as far northwest as the Zuni Mountains and appears as isolated outcrops as far west as Horse Mountain in Catron County. Any intensive exploration of dolomites in areas favorable for economic development should, therefore, include a check of the dolomitic beds in the San Andres formation,

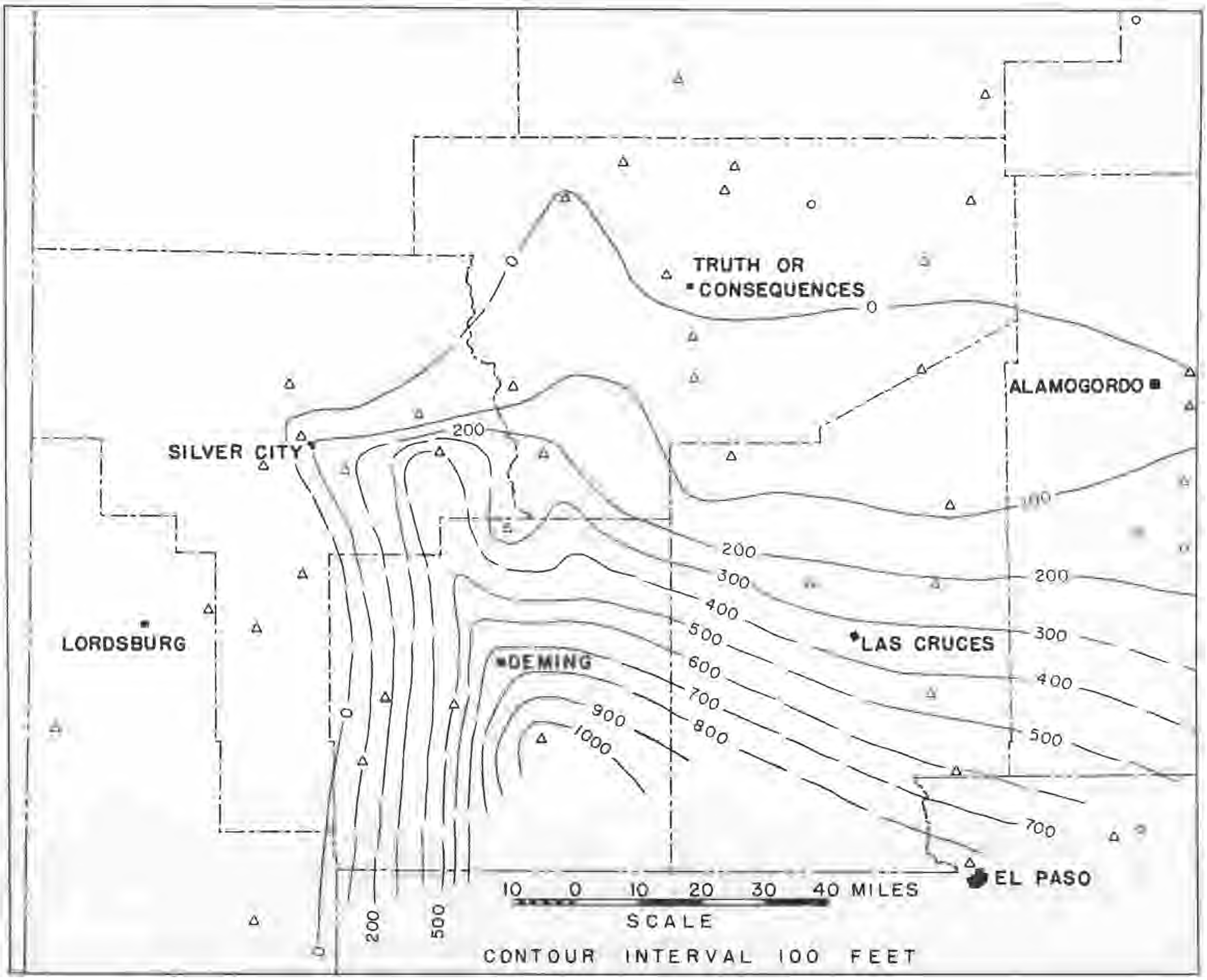


FIGURE 4. FUSSELMAN DOLOMITE ISOPACH MAP

Occurrence of Dolomite Deposits in South-Central New Mexico

Lower Paleozoic dolomites crop out in the following places: in the Sacramento, San Andres, Organ, Robledo, Caballo, Mud Springs, Florida, Victorio, Big Hatchet, Peloncillo, and northern Franklin Mountains; at Bishop Cap, Sierra Cuchillo, Black Range, Cooks Peak, Snake and Klondike Hills; near Lake Valley; on the west side of the Mimbres River Valley; and near Silver City (fig. 1). Most of these outcrops were visited. The more favorable and thicker deposits were sampled and analyzed.

Sacramento Mountains

The Sacramento Mountains are an eastward tilted fault-block, with a steep west-facing escarpment overlooking the Tularosa Valley and a gentle slope dipping eastward toward the Pecos Valley, The Ordovician and Silurian dolomites crop out at the foot of the escarpment from the latitude of Alamogordo (T. 16 S.) southward to T. 19 S, Pray (1954, p. 94-97) described the El Paso group, about 420 feet thick, as largely of dolomites, but with much quartz sand in lower beds and considerable silt in upper strata. The Upham dolomite is 80-100 feet thick, with basal sandy beds; the Aleman dolomite is 100-120 feet thick, cherty, and its top is marked by a bed of chert, 1-4 feet thick. The Valmont/Cutter dolomite (Pray, 1953), 150-225 feet thick, is a light-gray sublithographic dolomite with sparse chert laminae and nodules. The zone of soft argillaceous dolomite is 40-70 feet above the base of the Valmont, The Fusselman dolomite is 70-100 feet thick, except at the northern outcrops, where the Fusselman is thin or absent owing to early Devonian erosion. Chert is abundantly but erratically distributed in the Fusselman dolomite and occurs as relatively large-size nodules sharply separated from the dolomite matrix. The section was sampled at the mouth of Alamo Canyon and in the small canyon north of Alamo Canyon. Units and analyses are as follows:

Fusselman dolomite, overlain unconformably by dolomitic silty sandstones of the Devonian Onate formation:

Unit No.	Description	Thickness (in feet)
SA22	medium dark-gray crystalline cherty dolomite; chert, 5 percent	4½
SA21	brown-weathering medium dark-gray crystalline cherty dolomite	19
SA20	brown-weathering medium dark-gray crystalline dolomite; chert, 2-20 percent, as flakes, nodules, and thin lenses	19
SA19	brown-weathering dark-gray cherty dolomite; chert, 5 percent	19
SA18	medium dark-gray cherty dolomite; chert, 5 percent as nodules	19
SA17	light-gray whitish-weathering crystalline dolomite	19
	Total Fusselman dolomite	99½

Valmont dolomite:

SA16	light-gray aphanitic medium-bedded dolomite	18
SA15	light-gray aphanitic thin- to medium-bedded dolomite	25
SA14	medium-gray dolomite with some 1-4 inch thick chert lenses	25
SA13	medium-gray aphanitic dolomite; basal 5 feet argillaceous	25
SA12	light-gray argillaceous dolomite and calcic-dolomite; nodular beds; form ledgy slope (soft zone)	25
SA11	gray aphanitic dolomite with one 4-inch chert bed; top 8 feet is of argillaceous dolomite in soft zone	25
SA10	medium- to medium dark-gray aphanitic dolomite	25
	Total Valmont dolomite	168

Aleman dolomite:

SA9	dark-gray dolomite; visible chert, 15 percent; with 1-2 foot thick chert bed at top	25
SA8	dark-gray dolomite; visible chert, 8-20 percent	25
SA7	dark-gray dolomite weathers light-gray; 5 percent visible chert	25
SA6	light-gray-weathering dark-gray dolomite, with 5 percent visible chert in nodules, thin lenses, and stringers	25
SA5	dark-gray aphanitic to medium-crystalline dolomite; 8 percent visible chert	25
	Total Aleman dolomite	125

Upham dolomite:

SA4	dark-gray fossiliferous crystalline massive dolomite, with some chert nodules	7½
SA3	dark-gray crinoidal crystalline dolomite; upper half contains scattered chert nodules	25
SA2	dark-gray crinoidal crystalline massive-bedded hard dolomite	25
SA1	dark-gray dolomite, with basal 2-12 feet arenaceous	25
	Total Upham dolomite	82½

Beneath the Upham dolomite is 4 feet of brown-weathering dolomitic sandstone and sandy dolomite called the Cable Canyon sandstone; the Cable Canyon sandstone is disconformable on the El Paso group dolomites.

Analyses of units SA1-SA22, excluding the visible chert, which was not collected, follows:

Sample	CaO	MgO	Residue (In percent)	$CaCO_3$*	$MgCO_3$*	Total
SA22	30.7	21.3	0.3	54.8	44.5	99.6
SA21	30.0	21.4	0.5	53.6	44.7	98.8
SA20	30.4	21.4	0.3	54.3	44.7	99.3
SA19	30.4	21.8	0.4	54.3	45.5	100.2
SA18	30.2	21.7	1.3	53.9	45.2	100.4
SA17	30.4	21.6	0.3	54.2	45.1	99.6
SA16	29.7	21.5	2.2	53.0	44.5	99.7
SA15	29.6	21.2	2.7	52.8	44.2	99.7
SA14	29.4	21.2	3.2	52.5	44.2	99.9
SA13	28.8	20.7	5.1	51.4	43.2	99.7
SA12	27.7	19.9	8.8	49.4	41.6	99.8
SA11	28.5	20.6	6.0	50.9	43.0	99.9
SA10	30.0	21.9	1.2	53.5	45.7	100.4
SA9	30.6	21.2	1.2	54.6	44.2	100.0
SA8	30.1	21.5	1.3	53.7	44.9	99.9
SA7	30.0	21.6	1.4	53.6	45.1	100.1
SA6	29.7	21.2	2.4	53.0	44.3	99.7
SA5	30.0	21.5	0.9	53.6	44.9	99.4
SA4	30.1	21.7	0.9	53.7	45.3	99.9
SA3	30.0	21.6	1.0	53.6	45.1	99.7

SA1-5A22 (con't)

Sample	CaO	MgO	Residue (In percent)	$CaCO_3$*	$MgCO_3$*	Total
SA2	30.1	21.6	0.9	53.7	45.1	99.7
SA1	30.1	21.5	1.3	53.7	44.9	99.9

* Calculated from oxides

The Fusselman dolomite contains an average of 21.6 percent magnesium oxide and 0,5 percent insoluble residues, excluding the visible large-size chert, which may average as high as 5 percent. The Valmont dolomite contains an average of 20.9 percent magnesium oxide and 4.2 percent insoluble residues. The basal 42 feet averages 21.5 percent magnesium oxide and 1.2 percent insoluble residues; the 38-foot soft zone averages 19.9 percent magnesium oxide and almost 9 percent residues; and the upper 88 feet averages 21.2 percent magnesium oxide and 2.7 percent insoluble residues. The Aleman dolomite averages 21.4 percent magnesium oxide and 1.4 percent insoluble residues, excluding the visible large-size chert, which averages about ten percent. The Upham dolomite averages 21.6 percent magnesium oxide and 1,0 percent insoluble residues.

Tonnages of high-purity dolomite within 100 feet of the edge of the outcrop exposed for almost 20 miles along the west side of the Sacramento Mountains are the following: Upham dolomite, average 90 feet thick, about 85 million tons; basal Valmont dolomite, average 40 feet thick, about 38 million tons; Fusselman dolomite, average 85 feet thick, about 80 million tons. These outcrops are 2-6 miles east of the Southern Pacific Railroad, which has sidings or yards at Alamogordo, Omlee, Valmont, and Escondida Siding. Natural gas is available from the El Paso Natural Gas Company pipeline which supplies Alamogordo from El Paso.

San Andres Mountains

The San Andres Mountains are a long narrow fault-block range, tilted westward so that sedimentary beds dip westward into the Jornada del Muerto syncline, and are bounded on the east by a high bold fault-zone escarpment which overlooks the Tularosa Valley The range is about 80 miles long from San Augustin Pass at the south to Mockingbird Gap at the north; the Montoya and Fusselman dolomites crop out on the east-facing escarpment and are erosionally thinned near the north end of the range beneath Devonian beds.

The El Paso group consists chiefly of dolomite in the San Andres Mountains, but dolomitization is erratic, and there are abrupt changes, vertically and laterally, from limestone to dolomite. The upper 141 feet of the El Paso group in Rhodes Canyon (RC1) contains 276 percent calcium oxide, 19.8 percent magnesium oxide, and 9.0 percent insoluble residues. The large amount of residues is typical of the El Paso strata in the range. The Upham dolomite is 77-115 feet thick, except at the north end of the range, where it was thinned by early Devonian erosion. The Upham (RC2, HC1, AC1) averages 21.5 percent magnesium oxide and 1.1 percent insoluble residues, which range from the 1.5 percent in Hembrillo Canyon (HC1) to the C.7

percent in Ash Canyon (AC1). The Aleman dolomite is 68-116 feet thick where not thinned by erosion, and in Rhodes Canyon (RC3) it contains more than 21 percent magnesium oxide and 2o8 percent insoluble residues, excluding the 2-50 percent of visible chert. The Cutter dolomite (R4, H2, A2) is 168-182 feet thick where not thinned by erosion, and contains an average of 193-2O.6 percent magnesium oxide and 5.1-11.4 percent insoluble residues. The argillaceous zones in the Cutter dolomite which contain as much as 35 percent insoluble residues, chiefly silica and clay, are not economically valuable; but the argillaceous zones could be avoided by selective quarrying or mining. The Fusselman dolomite thins to a knife edge 6 miles south of Rhodes Canyon, but thickens southward to 95 feet in Ash Canyon. In Hembrillo Canyon the Fusselman dolomite (HC3) averages 21.4 percent magnesium oxide and 1.2 percent small-sized insoluble residues, but the cherty section of the Fusselman dolomite in Ash Canyon (AC3) contains only 19.7 percent magnesium oxide and 8.7 percent small-sized insoluble residues, with some beds containing as much as 45 percent visible (megascopic) and microscopic silica.

Analyses of dolomites in the San Andres Mountains are as follows:

Sample	CaO	MgO	Residue (In percent)	$CaCO_3$*	$MgCO_3$*	Total
RC4	27.1	19.3	11.4	48.4	40.3	100.1
RC3	29.5	21.2	2.8	52.7	44.3	99.8
RC2	29.8	21.4	1.2	53.2	44.7	99.1
HC3	29.9	21.4	1.2	53.4	44.7	99.3
HC2	28.8	20.6	5.1	51.4	43.0	99.5
HC1	30.0	21.4	1.5	53.6	44.7	99.8
AC3	27.5	19.7	8.7	49.1	41.1	98.9
AC2	28.9	20.8	5.2	51.6	43.4	100.2
AC1	30.1	21.6	0.7	53.7	45.1	99.5

* Calculated from oxides

Outcrops of the Lower Paleozoic dolomites in the San Andres Mountains are within 'White Sands Proving Ground and are therefore unavailable for exploitation at present. The Upham dolomite alone provides reserves of about 350 million tons of high-purity dolomite, even if only a 100-foot-wide strip of outcrop, averaging 100 feet thick, were to be quarried.

Organ Mountains

The Organ Mountains are a narrow, high range composed chiefly of igneous rocks, with intruded and partly metamorphosed sedimentary beds on the west flank. The Lower Paleozoic dolomites have been altered to magnesite and brucite marble at the southern end of the range; but these magnesium-rich rocks are of limited extent and are amid large masses of quartz monzonite. Even where the dolomites are not metamorphosed to magnesite marble, they are mineralized, silicified, and broken by numerous faults, and do not form many large masses of high-purity dolomite uncontaminated by silica.

Dunham (1935) mapped the Organ Mountains, and measured sections of the sedimentary beds. The El Paso group is chiefly dolomite and is more than 800 feet thick. The basal Cable Canyon sandstone of the Montoya group is 10-12 feet thick and is a pebbly dolomitic quartz sandstone. The Upham dolomite is dark-gray massive-bedded crystalline dolomite more than 100 feet thick, overlain by 140-180 feet of cherty Aleman dolomite. The Cutter dolomite was included by Dunham (1935, p. 40) in the lower part of the Fusselman dolomite and appears to be 80-125 feet thick. The restricted Fusselman dolomite is a partly cherty, dark, massive dolomite about 125 feet thick in the northern part of the Organ Mountains. Dunham reported the Fusselman dolomite to be thinned by pre-Pennsylvanian erosion in the southern part of the Organ Mountains; but the contact is a fault, not an erosion surface, and the Fusselman is more than 400 feet thick on Bishop Cap just south of the Organ Mountains.

Most of the Organ Mountains is within White Sands Proving Ground and is a restricted area not accessible to the public . Further, although the magnesium-rich rocks in the area could provide an economical source of magnesium, their magnesium content varies and the pure deposits are few in number.

Bishop Cap

Bishop Cap is the highest peak of a series of short north-south ridges which are small westward tilted fault blocks amid alluvial fans south of the Organ Mountains, and are separated from the Franklin Mountains to the south by alluvial fans and remnants of an ancient high-level erosion surface. The sedimentary rocks that crop out in the Bishop Cap ridges range from the middle of the El Paso group up to middle Pennsylvanian beds. The beds are cut by a number of faults of small displacement which in most places are silicified and include barite-flourite veins. The largest areas of outcrop of the Lower Paleozoic dolomites are in the three eastern ridges. Samples were collected from a section measured on the middle ridge, in the northeast quarter of sec. 25, T. 24 S., R. 3 E., where the beds dip 11-36 degrees to the west. Units sampled are as follows:

Fusselman dolomite: top 140-200 feet covered in strike valley, overlain by Devonian cherty limestones and blackish shales:

Unit No.	Description	Thickness (in feet)
BC12	gray crystalline dolomite, granular, massive-bedded	60
BC11	gray tan-weathering fine-crystalline dolomite	50
BC10	light-gray, fine- to medium-crystalline dolomite	50
BC9	light- to medium-gray tan-weathering crystalline dolomite	50
BC8	light- to medium-gray, medium- to fine-crystalline dolomite	50
BC7	light-gray to tan, fine-crystalline granular porous dolomite	50
	Total Fusselman dolomite measured	310
	Cutter dolomite:	
BC6	gray aphanitic argillaceous dolomite; scattered chert nodules	41
BC5	gray to pink aphanitic argillaceous dolomite; weathers light-gray; up to 20 percent chert in some beds as scattered nodules and thin laminae; partly covered	50
	Total Cutter dolomite	91
	Aleman dolomite:	
BC4	dark-gray, aphanitic to fine-crystalline, cherty; in basal 100 feet chert is 10-50 percent; medial 50-60 feet chert is 5-10 percent; top 2-15 feet chert is 10-13 percent; total thickness is 166 feet.	
	Upham dolomite:	
BC3	dark-gray fine-crystalline fossiliferous massive-bedded dolomite with scattered silicified fossils	68

Upham dolomite: (con't)

BC2	medium dark-gray fine-crystalline fossiliferous dolomite; basal beds algal and with scattered arenaceous lenses	50
	Total Upham dolomite	118

El Paso group:

BC1	light-brown sugary dolomite; bedding nodular; upper uppermost 106 feet measured; the next section lower, as much as 100 feet of the dolomite, partly covered by talus; bedrock below completely obscured by alluvium and talus.

Analyses of the samples collected from the Bishop Cap section are as follows:

Sample	CaO	MgO	Residue (In percent)	$CaCO_3$*	$MgCO_3$*	Total
BC12	30.0	22.0	0.3	53.6	45.9	99.8
BC11	30.1	21.7	0.6	53.7	45.3	99.6
BC10	30.7	21.5	0.2	54.8	44.9	99.9
BC9	30.3	21.7	0.5	54.1	45.3	99.9
BC8	29.4	21.2	3.2	52.5	44.2	99.9
BC7	30.3	21.8	0.5	54.1	45.5	100.1
BC6	28.6	20.1	7.2	51.0	42.0	100.2
BC5	28.5	20.5	6.5	50.9	42.8	100.2
BC4	30.0	21.5	1.6	53.5	44.9	100.0
BC3	29.8	21.5	1.5	53.2	44.9	99.6
BC2	27.5	19.8	9.7	49.1	41.3	100.1
BC1	29.1	20.6	4.6	51.9	43.0	99.5

* Calculated from oxides

The dolomite outcrops are about 7 miles east of the Atchison, Topeka & Santa Fe Railway siding in the Rio Grande Valley at Mesquite. A plant could be serviced by the El Paso Natural Gas Company pipeline that parallels the Rio Grande from El Paso to Las Cruces. Within 100 feet of the edge of the outcrop, as much as 56 million tons of high-purity Fusselman dolomite (400 or more feet thick) and about 10 million tons of the upper 70 feet of the Upham dolomite are available. The Fusselman dolomite averages 21.7 percent magnesium oxide and about 0.9 percent insoluble residues. The upper one-half to two-thirds of the Upham dolomite averages 21.5 percent magnesium oxide and 1.5 percent insoluble residues.

Northern Franklin Mountains

The Franklin Mountains are a long narrow fault-block range with a high fault escarpment facing eastward over the Tularosa and Hueco Basins and with sedimentary beds dipping steeply to the west toward the Rio Grande Valley. The lower Paleozoic dolomites are exposed along the eastern escarpment from Anthony Gap, near the New Mexico-Texas border, to the north end of the range, a distance of about 6 miles. The northern part of the dolomite outcrops is inside of one of the numerous Fort Bliss target ranges, and the southern outcrops are easily accessible only by roads through restricted military lands.

Lloyd Pray (personal communication) measured a section near the state line and reported 104 feet of Upham dolomite, 166 feet of cherty Aleman dolomite, 159 feet of the Cutter/Valmont dolomite, and 608 feet of Fusselman dolomite. The Fusselman dolomite contains almost no megascopic chert. The Upham and Fusselman dolomites appear chemically similar to the Bishop Cap beds and probably include large deposits of high-purity dolomite.

Robledo Mountains

The Robledo Mountains are a wedge shaped fault block on the west side of the Rio Grande Valley, 10 miles northwest of Las Cruces. The Lower Paleozoic dolomites crop out on the northeast side of Lookout Peak, at the north end of the range, where the beds are broken by numerous small-scale faults and intruded by rhyolite sills. The dolomite deposits are about 3 miles from the Fort Belden siding of the Atchison, Topeka & Santa Fe Railway.

The Upham dolomite is 45-77 feet thick and is typical dark-gray medium-crystalline, hard, massive-bedded dolomite, with basal beds only slightly arenaceous. Chemical analysis of the Upham dolomite shows calcium oxide, 29,9 percent; magnesium oxide, 21.5 percent; insoluble residues, 1.4 percent; calculated calcium carbonate, 53.4 percent; calculated magnesium carbonate, 44.9 percent; total, 99.7 percent. The Apeman dolomite is about 90 feet thick and contains as much as 50 percent chert. The Cutter dolomite is shot through by rhyolite sills and is at least 155 feet thick; it is almost chert free and does not appear to be silicified or altered along intrusive contacts. Partial analysis of the Cutter dolomite shows calcium oxide, 29.0 percent; magnesium oxide, 20.8 percent; insoluble residues, 4.4 percent; calculated calcium carbonate, 51.8 percent; calculated magnesium carbonate, 43.4 percent; total, 99.6 percent. The Fusselman dolomite may be 250 feet thick, although the upper 20 feet is ferruginous cherty dolomitic limestone somewhat similar to Devonian cherty beds to the south. Only the basal 20 feet is relatively chert-free crystalline dolomite, with the medial 210 feet containing 2-15 percent chert as small nodules, stringers, laminae, and silicified fossils. Partial analysis of the Fusselman dolomite, excluding the visible chert, shows calcium oxide, 30.4 percent; magnesium oxide, 21.8 percent; insoluble residues, 0.2 percent; calculated calcium carbonate, 54,3 percent; calculated magnesium carbonate, 45.5 percent; total, 100.0 percent.

At least 4 1/2 million tons of high-purity Upham dolomite and more than 18 million tons of Fusselman dolomite, which, however, contains an average of at least 5 percent megascopic chert, occur within 100 feet of the outcrop edge on Lookout Peak.

Caballo Mountains

The Caballo Mountains are a north-trending range bordering the east side of the Rio Grande Valley from Hatch to Truth or Consequences. The main part of the range is a tilted fault block with steep western fault zone escarpment overlooking the Rio Grande Valley and with sedimentary beds dipping relatively gently eastward under the Jornada del Muerto. From Caballo Dam southward there are numerous complex fault block hills west of the main range. The chief outcrops of Lower Paleozoic dolomites are along the western escarpment of the main range. The stratigraphy of the dolomites has been described in detail by Kelley and Silver (1952), who designated Cable Canyon as the type locality of the Cable Canyon sandstone, and of the Upham, Aleman, and Cutter dolomites.

The Upham dolomite is 50-80 feet thick in the Caballo Mountains and contains a considerable scattering of quartz sand throughout the formation, although arenaceous beds are concentrated near its base. Insoluble residues of the two sections sampled (Cable Canyon and Red House Mountain) average 2,8 percent, while magnesium oxide averages 20.3 percent. Selective mining or quarrying of the upper less arenaceous dolomites would yield high-purity dolomite. The cherty Aleman dolomite is 120-170 feet thick and, where sampled on Red House Mountain, includes almost 30 percent visible chert. The sample contains only 14.1 percent magnesium oxide and 2.4 percent insoluble residues (excluding the visible chert) and is therefore a calcic-dolomite. The Cutter formation in the Caballo Mountains includes some limy claystone and dolomitic limestone, as well as dolomite, and varies from 50 to 146 feet in thickness; the thinner sections are attributed to pre-Fusselman erosion. The samples of the two sections examined contain an average of more than 8 percent insoluble residues and 19.6 percent magnesium oxide.

The Fusselman dolomite is irregularly thinned by post-Fusselman erosion and where present in the Caballo Mountains it is only 10-50 feet thick. In most localities the Fusselman is cherty, but the section on Red House Mountain contains less than 5 percent visible chert, 0.6 percent insoluble residue, and 21.6 percent magnesium oxide.

The Atchison, Topeka & Santa Fe Railway traverses the Jornada del Muerto plains east of the Caballo Mountains and joins the Rio Grande Valley at Rincon, but most of the dolomite deposits in the Caballo Mountains are at least 15 miles from the railroad, and the Lower Paleozoic dolomites in the Caballo range are relatively impure and probably do not include large deposits of high-purity dolomite.

Analyses of dolomite samples collected from the Caballo Mountains follow:

Sample	CaO	MgO	Residue (In percent)	$CaCO_3$*	$MgCO_3$*	Total
Ccc3	29.1	19.3	7.2	51.9	40.3	99.4
Ccc2	29.1	19.3	7.5	51.9	40.3	99.7
Ccc1	29.4	21.2	3.3	52.5	44.2	100.0
SC4	30.3	21.6	0.6	54.1	45.1	99.8
SC3	27.5	19.8	9.5	49.1	41.3	99.9
SC2	37.8	14.1	2.4	67.5	29.4	99.3
SC1	32.1	19.3	2.4	57.3	40.3	100.0

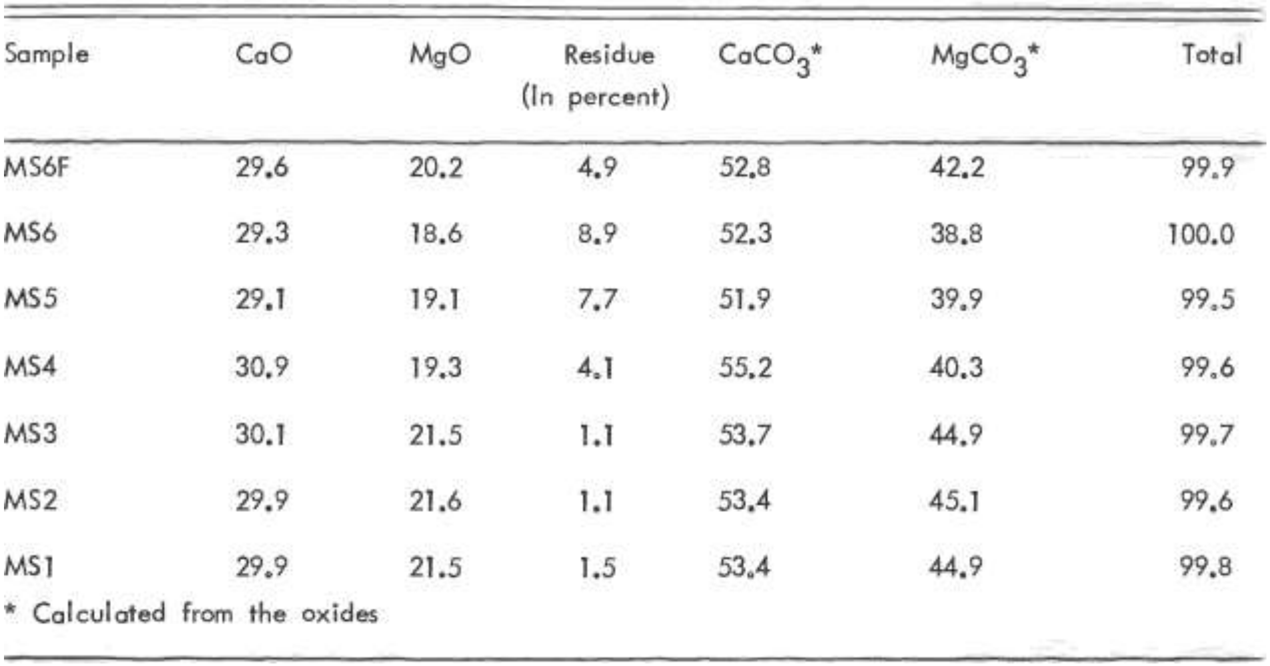
* Calculated from the oxides

Locality Ccc is the northeast side of Cable Canyon, SE 1/4 NE 1/4 sec. 10, T. 16 S., R. 4 W. Sample Ccc1 is from the 70 feet of Upham dolomite; sample Ccc2 is from the lower 50 feet of the Cutter dolomite; and sample Ccc3 is from the upper 105 feet of the Cutter. Locality SC is near the southern end of the Caballo Mountains on the southwest side of Red House Mountain, NW 1/4 sec. 10, T. 18 S., R. 3 W. 5C4 is of the Fusselman dolomite, more than 50 feet thick; SC3 is of the Cutter dolomite, about 145 feet thick; SC2 is of the Aleman dolomite, about 170 feet thick; and SC1 is of the Upham dolomite, about 75 feet thick.

Mud Springs Mountains

The Mud Springs Mountains are a small fault-block range a few miles northwest of Truth or Consequences, New Mexico. The range is bounded on the southwest and west by a steep fault-zone escarpment, with the sedimentary beds dipping east-northeast at 16-44 degrees. The highest peak is the uppermost edge of a dip slope cut on the Aleman and Cutter dolomites, and these Ordovician dolomites form a broad tilted terrace which would allow relatively inexpensive quarrying. The Upham dolomite is more than 50 feet thick, averages 1.2 percent insoluble residues and 21.5 percent magnesium oxide, and occurs as the lower part of the vertical cliff beneath the terrace. The Aleman dolomite is about 125 feet thick and contains a relatively small amount of chert (probably not over 5 percent), although individual beds contain as much as 20 percent visible chert. The Aleman dolomite, however, contains 4.1 percent insoluble residues in addition to the megascopic chert, and only 19.3 percent magnesium oxide. The Cutter formation ranges from 121 to 162 feet in thickness (Kelley and Silver, 1952, p. 62), and in part of the Mud Springs Mountains includes limy claystones and dolomitic limestones as well as argillaceous dolomite. Insoluble residues average more than 8 percent, and magnesium oxide under 19 percent. The Fusselman dolomite is absent, having been removed by post-Fusselman erosion.

Analyses of samples collected from south side of Cuchillo Negro Peak, NE 1/4 sec. 25, T. 13 S., R. 5 W., follow:



Sample	CaO	MgO	Residue (In percent)	$CaCO_3$*	$MgCO_3$*	Total
MS6F	29.6	20.2	4.9	52.8	42.2	99.9
MS6	29.3	18.6	8.9	52.3	38.8	100.0
MS5	29.1	19.1	7.7	51.9	39.9	99.5
MS4	30.9	19.3	4.1	55.2	40.3	99.6
MS3	30.1	21.5	1.1	53.7	44.9	99.7
MS2	29.9	21.6	1.1	53.4	45.1	99.6
MS1	29.9	21.5	1.5	53.4	44.9	99.8

* Calculated from the oxides

MS6 is from the upper 75 feet of the Cutter dolomite; MS5 is from the lower 50 feet of the Cutter; MS4 is from the Aleman dolomite; MS3 is from the upper 20 feet of the Upham dolomite; MS2 is from the medial 20 feet of the Upham; and MS1 is from the lower 15 feet of the Upham dolomite. MS6 is from unit MS6 and represents the fines between 20 and 48 mesh that resulted from crushing of the chip samples. This crude experiment suggests that almost half of the impurities of the Cutter dolomite break easily into particles less than 48 mesh (openings 0.0116 inch).

The Upham outcrops in the Mud Springs Mountains are about 5 miles from Truth or Consequences and almost 25 miles from Engle, the nearest shipping point on the Atchison, Topeka & Santa Fe Railway. As much as 7 million tons of high-purity Upham dolomite occur within 100 feet of the edge of the outcrop and a much wider belt could be quarried after removal of the lower Aleman dolomite. There are, however, numerous small faults and some silicified zones in the Upham dolomite which should be avoided because of their large silica content.

Sierra Cuchillo and Black Range

Most of the Black Range and a considerable part of Sierra Cuchillo consist of igneous rocks; the Lower Paleozoic dolomites are exposed in small fault blocks near Winston and near Chise in Sierra Cuchillo, and intermittently along the east side of the Black Range. In many places the dolomites are mineralized, silicified, and intimately broken by faults. Jahns (1955) reported a thickness of 70 feet Upham dolomite, 60 feet of Aleman dolomite, 10-35 feet of Cutter-Valmont dolomite, and 0-15 feet of the Fusselman dolomite in Sierra Cuchillo. Near Kingston, Kuellmer (1954) measured about 60 feet of Upham dolomite, as much as 40 feet of Cutter dolomite, and 85 feet of Fusselman dolomite. Near Lake Valley, Jicha (1954) found the Fusselman dolomite to be 212 feet thick; the Cutter dolomite, 77 feet thick; and the Upham dolomite, 55 feet thick. Near Lake Valley, the upper part of the Upham dolomite contains large scattered chert nodules, whereas the upper beds of the Fusselman dolomite are silicified and mineralized. Dolomite deposits in the Black Range and Sierra Cuchillo appear to be both too far from transportation facilities and too impure to be economical.

Cooks Peak

Cooks Peak is a short north-northwest-trending complex horst in which the sedimentary rocks were intruded by a large granodiorite porphyry stock, Lower Paleozoic dolomites crop out only on the northwest flank of the range, where they are silicified and mineralized. Jicha (1954) reported the Upham dolomite to be 47 feet thick; the Cutter dolomite, 50 feet thick; and the Fusselman dolomite, at least 225 feet thick. The impure dolomite outcrops are about 29 miles by rough roads from the nearest railroad loading stations at Deming and Spalding.

Mimbres Valley

The Lower Paleozoic dolomites form cliffs and ledges along the southwest side of the Mimbres Valley, from San Juan northwestward to Georgetown. Elston (1957) reported over 400 feet of Fusselman dolomite at the south end of this belt of Paleozoic rocks, but the Fusselman may be only 40 feet thick near Georgetown. Thickness is difficult to determine because the Fusselman crops out as ledges capping a dip slope and is overlain by nonresistant Devonian shales which slump down to fill the strike valley separating the Fusselman and Devonian outcrops. The Upham dolomite is about 50 feet thick, and the Cutter dolomite is as much as 120 feet thick. The area is isolated, although not many miles from the railhead at Santa Rita, and the dolomites (especially the Fusselman) contain rather large percentages of chert, are silicified along numerous small-scale faults, and in places are mineralized.

Silver City Range and Lone Mountain

The Montoya group dolomites and Fusselman dolomite crop out on the southwest side of Lone Mountain, 3 miles west of Hurley; on the northeast and west flanks of the Silver City Range; and near Bear Creek Canyon north-northwest of Silver City. Entwistle (1944) described and made analyses of the dolomites near Silver City. The Upham dolomite (Second Value member of the Montoya dolomite, according to Entwistle) is 90 feet thick, the Cutter dolomite (Raven member) is 120 feet thick, and the Fusselman dolomite is about 75 feet thick. In the Silver City region the Paleozoic beds were beveled by pre-Cretaceous erosion so that the basal Cretaceous sandstone overlaps all Paleozoic formations from the Permain beds down to Precambrian rocks. On Treasure Mountain, 6 miles west-northwest of Silver City, the basal Cretaceous Beartooth sandstone rests on an erosonally thinned Fusselman dolomite, and in the Little Burro Mountains, 8 miles southwest of Silver City, the Beartooth sandstone is unconformable on Precambrian rocks. The Lower Paleozoic dolomites are cut by numerous dikes and sills, are broken by faults, and in places are silicified and mineralized. Although Entwistle's analyses were of samples not representative of the total dolomite beds, they show relatively high insoluble residues and suggest the dolomite formations in the Silver City area may not qualify as high-purity dolomites.

As drawn on the isopach maps (figs. 2-4) the Upham, Cutter, and Fusselman dolomites are suggested as pinching out north of Bear Creek (no. 17, fig. 1). This is an implied but not proved pre-Devonian or early Devonian erosional thinning, which marks the northern extent of Ordovician and Silurian outcrops in south-central New Mexico but which may not occur as far south as Bear Creek in the region north of Silver City. Absence of the dolomites in the Burro Mountains and in the area north of Lordsburg is due chiefly to pre-Cretaceous or early Cretaceous erosion.

Peloncillo Mountains

The Peloncillo Mountains are a long narrow range along the Arizona-New Mexico border and are composed chiefly of igneous rocks, except for a central block of Paleozoic and Cretaceous sedimentary beds between Steins Pass and Granite Gap. The sedimentary rocks are partly metamorphosed, are broken by many faults, and are intruded by dikes and sills. Quaide (1953) reported about 85 feet of Upham dolomite overlain by Devonian shaly beds, with the Cutter, Aleman, and Fusselman dolomites absent. To the west, in the northern Chiricahua and Dos Cabezas Mountains of Arizona, shaly Devonian rocks erosionally overlie various parts of the lower El Paso group beds which are, in turn, absent further west. Appreciable tonnages of uncontaminated high-purity dolomite do not appear to be present in the central Peloncillo Mountains.

Big Hatchet Mountains

The Big Hatchet Mountains are a high rugged horst range composed almost entirely of Pennsylvanian and Permian sedimentary rocks, except for two small blocks of Lower Paleozoic strata near the north end of the range. Robert Zeller (personal communication) reported about 125 feet of Upham dolomite, perhaps as much as 155 feet of Cutter dolomite, containing appreciable amounts of white chert nodules, and no Fusselman dolomite, unless the upper 30 feet of the Cutter can be referred to the Fusselman. Scattered outcrops of these dolomites also occur across the Hachita Valley on the western edge of the Sierra Rica Mountains. Some of the Permian carbonate rocks are dolomites, but occur in relatively inaccessible parts of the ranged. The Montoya group dolomite outcrops are about 20 miles south of the Southern Pacific Railroad station at Hachita and are of relatively limited extent.

Snake Hills, Victorio Mountains, and Klondike Hills

The Snake Hills, 11 miles southwest of Deming, are a low east-west ridge of Lower Paleozoic beds amid extensive alluvial plains. The highest hill is capped by extremely cherty beds of the Aleman dolomite, with the easternmost ridges including strata as old as the lower rocks of the El Paso group. The basal 40 feet of the Montoya group is of brown arenaceous dolomite with lenses of quartz pebbles, probably attributable to the Cable Canyon sandstone. The Upham dolomite is about 70 feet thick, crops out for a length of about one-half mile, and contains an average (SH1) of 29.6 percent calcium oxide, 21.3 percent magnesium oxide, and 2.3 percent insoluble residue. Silicified zones are common.

The Victorio Mountains are an isolated group of hills south of the Southern

Pacific Railroad station of Gage, about 20 miles west of Deming. The Montoya and Fusselman dolomite crop out in the southern ridges, where they are much silicified, mineralized, and faulted. Chip samples representing the upper relatively unaltered beds of the Fusselman dolomite (V1) average 29.9 percent calcium oxide, 21.5 percent magnesium oxide, and 1.7 percent insoluble residues. The dolomite outcrops are about 4 miles south of the railroad and extend for 1 1/2 miles east-west. They are cut by numerous mineralized quartz veins, and thus appear to be too contaminated to be high-purity dolomite deposits.

The Klondike Hills, about 11 miles south of the Victorio Mountains, are low isolated ridges several miles north of the volcanic Cedar Mountains. The Aleman dolomite appears to be the highest member of the Montoya group exposed, with the units similar in thickness and Anthology to those in the Snake Hills. The dolomite outcrops are of limited extent and accessible only over seasonally passable ranch roads.

Florida Mountains

The Florida Mountains are a high rugged triangular-shaped range that rises abruptly from surrounding alluvial plains about 8 miles southeast of Deming. The structure of many parts of the range is complex, especially in the southern part, where thrust faults, high-angle reverse faults, and normal faults are numerous. The Montoya group and Fusselman dolomites near The Park (west-central side of the range) are cut by many reverse faults, some of which are quite inconspicuous. In places the faults are marked by zones of groundup and brecciated white-and-black dolomite, 60 feet wide; but in other places the breccia zones are only a few inches to a few feet wide. Although cemented by porous vuggy calcite mixed with pulverized dolomite dust, the breccia zones are relatively nonresistant to erosion and crop out in saddles or as covered slopes; therefore, when the breccias are thin, and covered by talus and slope wash, they may be easily overlooked.

The Lower Paleozoic formations crop out on the west side of Capitol Dome at the northwest tip of the range and in a belt of shattered fault blocks that crosses the south-central part of the range from the west side of The Park to the eastern slopes of Gym Peak. On the west side of Capitol Dome the Aleman cherty dolomite and lower beds are overlain with pronounced erosional unconformity by Permian rocks whose basal beds are limestone boulder-conglomerates in a reddish clay silt matrix (Christina Balk, personal communication), strikingly similar to the basal Powwow conglomerate of the Lower Permian Hueco formation in the southern Sacramento and Hueco Mountains. The two northwest-trending ridges northwest of The Park are composed mostly of Fusselman dolomite, with beds of the Montoya and El Paso groups on the lower western slopes. As pointed out by Kelley and Bogart (1952) the beds attributed to the "Gym limestone" by Darton (1917) are, in most areas of the Florida Mountains, actually the Fusselman dolomite. However, the Montoya and Fusselman dolomites west and northwest of The Park are cut by numerous brecciated fault zones and are so overridden by Precambrian granites from the south that it may be impossible to obtain true thicknesses of the formations. The Fusselman outcrops on the southwestern of the two ridges are interrupted by at least 5 breccia zones, and at several outcrops large wedge-shaped masses of Upham, Aleman, and Fusselman dolomites are jumbled together and bordered by only thin breccia zones. No continuous unfaulted section of the Fusselman dolomite was found on this ridge.

The Lower Paleozoic dolomites also crop out on the crest of the range east of The Park and on the east slope of Gym Peak. In both areas the dolomites are broken by many faults. Silicified and mineralized zones are common, and the outcrops are relatively inaccessible.

The dolomites that crop out on the ridge west of The Park in sec. 34, T. 25 S., R. 8 W., were sampled and analyzed. The ridge, cut by many brecciated fault zones, does represent a thick pile of relatively pure dolomite, although the beds cannot be assigned to a continuous stratigraphic section. The breccia zones are as much as 60 feet wide, and spot checking in the field indicated they consist principally of shattered dolomite fragments and dust with less than 10 percent calcite cement. There are a few lenses, 3-14 inches thick, of coarse-crystalline calcite, but no quartz veins or silicified zones were seen except near the base of the ridge. The chip samples were collected from units measured perpendicular to the bedding, which dips 10-20 degrees to the east-southeast. The "section" is as follows, from top down:

Unit No.	Description	Thickness (feet)
F8	light-gray fine-crystalline massive-bedded Fusselman dolomite with scattered tiny silicified, chain corals near top; breccia zone at top, above which is perhaps 75 feet of similar dolomite but which is shattered and veined below a thrust plate of Precambrian granite	65
F6 and F7	each 100 feet thick, of light- to medium-gray fine-crystalline massive-bedded Fusselman dolomite; a few thin interbeds of black aphanitic dolomite	200
F5	gray fine- to medium-crystalline Fusselman dolomite with scattered thin chert flakes; 35 feet thick; overlain by wedge-shaped breccia zone about 30 feet thick, composed chiefly of fragments of Upham and Aleman dolomites	65
F4	light-gray brownish-weathering fine-crystalline massive-bedded Fusselman dolomite with a few chert flakes; basal beds form sole-shaped plates above breccia zone	100
F3	gray fine-crystalline massive-bedded Fusselman dolomite with irregular breccia zone at top	100
F2	gray to dark-gray massive-bedded fine-crystalline Fusselman dolomite, 80 feet thick; overlain by 20 feet of crinoidal dark-gray medium-crystalline Upham dolomite, separated from Fusselman below by thin (1-4 inches) breccia zone.	100
F1	light-gray tan-weathering fine-crystalline Fusselman dolomite with scattered chert flakes and a few calcite veinlets. Overlain by thick breccia zone composed of large and small fragments of Fusselman and various Montoya group dolomites. Base is a fault zone along which the Fusselman dolomite is successively in contact with the formations of the Montoya group	100

Unit No.	Description	Thickness (feet)
F9	Upham dolomite, about 40 feet thick; dark-gray medium-crystalline massive-bedded crinoidal dolomite with lower arenaceous laminae; partly silicified and shattered	40
	Total measured dolomites	770

Analyses of the chip samples are as follows:

Sample	CaO	MgO	Residue	$CaCO_3$*	$MgCO_3$*	Total
			(In percent)			
F9	30.3	21.7	0.2	54.1	45.3	99.6
F8	30.3	21.7	0.3	54.1	45.3	99.7
F7	30.3	21.8	0.2	54.1	45.5	99.8
F6	30.3	21.7	0.6	54.1	45.3	100.0
F5	30.4	21.7	0.3	54.3	45.3	99.9
F4	30.3	21.7	0.3	54.1	45.3	99.7
F3	30.3	21.8	0.4	54.1	45.5	100.0
F2	30.0	21.5	1.6	53.5	44.9	100.0
F1	30.1	21.6	1.0	53.7	45.1	99.8

* Calculated from the oxides

The mass of dolomite fault blocks represented by the above analyses is more than 700 feet thick and occupies at least 0,6 square mile. It should contain more than a billion tons of dolomite averaging 21.7 percent magnesium oxide and 0.6 percent microscopic insoluble residues. The outcrops are 14 miles south-southwest of the Southern Pacific Railroad at Deming. Two east-west natural gas pipelines of the El Paso Natural Gas Company serve Deming and the surrounding area. Ample underground water is available, especially in the area east of Deming.

Pennsylvanian Carbonate Rocks in the Oscura Mountains

The Lower Paleozoic dolomites pinch out beneath Devonian beds at the south end of the Oscura Mountains. In the central and northern parts of the range, Pennsylvanian sedimentary rocks, chiefly limestones, overlie the Precambrian granites. Several of the limestones were analyzed for the following three reasons: (1) to find out if they were dolomitic; (2) to determine the amounts of impurities and magnesium oxide in the limestones, as a check on their suitability for making cement; and (3) to see if favorable ore-bearing horizons of the Hansonburg mining district are chemically different from adjacent barren beds.

Limestones from the Adobe formation, the Council Springs limestone, and the Burrego formation were sampled. All samples of these limestones show a magnesium oxide content of less than one percent, and differ from each other only in the amounts and types of insoluble residues each contain. The most favorable ore horizons, the Council Springs limestone and lower limestones of the Burrego formation, average 55.2 percent calcium oxide, 0.6 percent magnesium oxide, and only 0.3 percent insoluble residues. Some of the limestones above and below the Council Springs limestone contain large amounts of residues, chiefly clay and quartz silt, but others are almost identical in composition. The chief physical difference is that the Council Springs limestone, a massive 20-foot thick coquinoidal limestone, shattered into breccia masses in fault zones, whereas the adjacent thinner limestones broke along relatively sharp planes. Most of the limestones are very low in magnesium oxide, contain only small amounts of clay and quartz, and show high percentages of calcium oxide.

Method of Analysis

Percentages of calcium and magnesium, and rough estimates of iron, were obtained by titration with Versenate, as described by Cheng, Kurtz, and Bray (1952) and by Jodry (1955). Both papers provide details of the method. A gram sample was dissolved in perchloric acid, heated, and evaporated to dryness. After cooling, the dried salts were dissolved in dilute hydrochloric acid, the insoluble residue was filtered off, and the sample solution was titrated. Murexide, mixed with potassium sulfate and buffered by 20 percent potassium hydroxide was used as the indicator for calcium. The end point was reached when the solution changed from pink to violet. Eriochrome Black T, mixed with sodium borate and methanol and buffered by a mixture of ammonium chloride, ammonium hydroxide, and 10 percent potassium cyanide, was used as the indicator for magnesium. The end point occurred when the solution changed from wine red to pure blue. If more than one-half percent of iron were present the solution turned from blue to brown within 5 minutes after titration. The amount of insoluble residues was determined by burning the filter paper and weighing the burnt residue. The Versenate (ethylenedinitrilo - the disodium salt of tetraacetic acid) was standardized against a standard calcium solution.

Although this titration method of analysis of dolomite is less time-consuming than the precipitation and separation method of standard analyses, there are several sources of possible error. A single gram sample from the many pounds of chip samples collected may not be representative, especially of the insoluble residues. The tendency is to undertitrate for calcium (pink to violet color change) and to overtitrate for magnesium (wine red to blue color change). Some of the reagents age rapidly, and fresh mixtures should be prepared at almost daily intervals. While percentages of magnesium oxide, calcium oxide, and insoluble residues did not usually vary more than 0.5 percent between two consecutive analyses, there were samples which were run 5 times to obtain 3 analyses within a range of 0.5 percent of individual constituents.

The analyses calculated from titrations were checked by four standard analyses made by D. H. Reynolds of Chapman and Wood and were found to agree within 0-0.5 percent. Insoluble residues of many of the samples were checked by dissolving relatively large samples (roughly 100 grams), decanting the solutions, and drying the residues at low temperatures (approximately 100° C). Insoluble residues thus determined were sometimes as much as 0.6 percent greater than those obtained from the one-gram samples, the additional residues being carbonaceous material that was burned off below the approximate 800°C needed to remove filter paper used with the one-gram samples.

Standard solutions of dolomite having various percentages of iron chloride (0.2-1.5 percent) were titrated with Versenate in order to check the effect of iron on the titration of magnesium. No error was introduced into the magnesium determination. As noted by Cheng, Kurtz, and Bray (1952) the solution turns from blue to brown several minutes after titration for magnesium, if sufficient iron is present in the tested solution. Experiments suggested that 0.6 percent iron would turn the solution brown five minutes after titration, but that less than 0.6 percent iron would not cause an appreciable change in color.

Other Magnesium Compounds in New Mexico

The only known deposit of brucite (magnesium hydroxide) in New Mexico is in the southern part of the Organ Mountains, where small bodies of brucite marble occur locally (Dunham, 1935, p. 95) near the intrusive contact of quartz monzonite and the Lower Paleozoic dolomites. Somewhat larger deposits of magnesite (magnesium carbonate) occur as lenses within the metamorphosed dolomites near South Canyon and Target Range Canyon in the southern Organ Mountains and on the southwest edge of the San Andres Mountains north of San Augustin Pass (Dunham, 1935, p. 236). These deposits are within White Sands Proving Ground and are not accessible to the public.

Yale and Stone (1922, p. 234) reported a deposit of magnesite in Grant County about 30 miles north of Lordsburg on the west side of Ash Creek, 2 miles above its junction with the Gila River. The magnesite occurs as replacement of detached blocks of limestone (?) within granite (?); the largest body of magnesite reported is 7 feet thick and about 80 feet long. Its depth is unknown. The deposits are small and inaccessible.

The Permian saline deposits in southeastern New Mexico include numerous magnesium salts, but only langbeinite (magnesium and potassium sulfate) is mined. It is sold as Sul-Po-Mag, which contains 18.5 percent water-soluble magnesium oxide. During World War II the magnesium chloride waste produced from langbeinite ores by the International Minerals and Chemical Corporation's potash plant near Carlsbad was shipped to Austin, Texas, where it was used in the corporation's electrolytic plant. Dolomite from quarries near Burnett, Texas, was also used in the process at Austin. However, the sulfate content of the Carlsbad salts was troublesome, and during the later part of the war, this difficulty, together with various other reasons, led International to use the magnesium chloride produced by the Dow Plant at Freeport, Texas.

ECONOMIC FACTORS IN USE OF DOLOMITE

The chief products made from dolomite are dead-burned dolomite, refractory magnesia, basic magnesium carbonate (precipated magnesium carbonate), and magnesium metal. Dead-burned and raw dolomite are used chiefly for producing and repairing open-hearth furnace linings, and are comparatively low-priced products that must be quarried and calcined as close to consuming plants as possible. The average cost of dead-burned dolomite from 1950 to 1954 was only $12.35-$14.44 per ton. In bask furnace bottoms the raw dolomite should contain less than 1 percent silica, less than 1 1/2 percent combined iron oxide and alumina, and at least 35 percent of magnesium carbonate (Colby, 1941). Similarly, refractory magnesia, with average costs of more than $40 a ton, should be prepared near consuming plants, as freight rates from the southwest, for example, would increase the cost by more than 30 percent. Basic magnesium carbonate is used extensively to make asbestos fiber insulation, and plants are located near such large consuming areas as California, Illinois, and New York.

Dolomite is also used with sea water and magnesium-rich well brines to produce specified magnesias, magnesium hydroxide, refractory and caustic-calcined magnesia, magnesium chloride, basic magnesium carbonate, and epsom salt. Sea water is the source of magnesium chloride cell-feed for the two electrolytic plants now operating in the United States. Dolomite is the magnesium-bearing raw material utilized in silicothermic plants.

The silicothermic process was first used on a large scale during World War II, and again during the Korean emergency. During World War II, 13 plants were built to produce magnesium metal; in 12 of those plants, all owned by the Federal government, production was evenly divided between the electrolytic and silicothermic processes (Comstock, 1956; Surplus Property Adm., 1945). Costs per pound of metallic magnesium, with estimated charges of 8 percent on investment to allow for depreciation and interest, for the 3 least expensive electrolytic plants at Velasco, Texas; Painesville, Ohio; and Marysville, Michigan, were 18, 20, and 23 cents, respectively, up to 1945; for the 3 least expensive silicothermic plants at Spokane, Washington; Luckey, Ohio; and Canaan, Connecticut, the costs per pound were 22, 22, and 26 cents, respectively. Freight charges are a relatively small part of total costs in the production of metallic magnesium and make a difference only of about one cent a pound between the plant farthest from the consuming markets and the plant closest to the markets (Surplus Property Adm., 1945). The average cost during World War II for all 12 Government-owned plants, including an estimated 8 percent for capital investment, was about 32 cents per pound. Average comparable costs during the Korean emergency, when the plants were reactivated, was about 48 cents per pound, approximately a 50-percent increase from 1945 to 1953. The total costs of the most economical silicothermic plant were more than 4 cents a pound higher than those of the Dow Magnesium electrolytic plant at Velasco; raw materials used by the silicothermic plant were 2-8 cents more, labor 0.7 cents less to 1.3 cents more, power 1 cent less, repairs and other costs about the same, and capital charges (5 percent depreciation and 3 percent for interest on investment) 3 cents less.

The somewhat higher production costs at the 6 Government-sponsored silicothermic plants lay for the most part in the cost of raw materials. To compete successfully with an electrolytic plant, a silicothermic plant must have, in addition to sources of high-purity dolomite, nearby sources of silica and iron, as well as cheap fuel, an adequate labor supply, and a climate that encourages continuous capacity operation.

One important advantage offered by the silicothermic process is the high-purity (99.95 percent) metallic magnesium it produces. The electrolytic process produces a metallic magnesium, 99.8 percent pure, which must be refined to 99.95 percent purity before it can be used for certain products.

Evidence that the silicothermic process can compete with the electrolytic process is the scheduled opening, late in 1958, of the first commercial production in the United States of metallic magnesium by the silicothermic or ferrosilicon reduction process, at the Selma, Alabama, plant of the Alabama Metallurgical Corp., a joint undertaking of Brooks and Pekins, Inc. and Dominion Magnesium, Ltd. The Selma operation will use high-purity dolomite quarried at Montevallo, 70 miles from the plant. The dolomite will be calcined after shipment to Selma, mixed with ferrosilicon (FeSi), and briquetted. The briquettes are to be placed in retorts, the air evacuated, and the materials heated to about 2100°F. During the process, magnesium, reduced by the silicon and vaporized, distills from the retorts into removeable condensors and crystallizes. It is then melted by conventional methods. The residual material in the retort is a dicalcium silicate, with portions of iron and magnesium. Magnesium metal, analyzing 99,95 percent pure, is thus produced from the calcined dolomite in one operation. About 14 tons of high-purity dolomite and more than a ton of ferrosilicon is used to produce one ton of high-purity metallic magnesium (Comstock, 1954). The high-purity metallic magnesium is especially desirable as a reducing agent in the refinement of uranium, zirconium, hafnium, and titanium, as well as in the production of certain magnesium alloys.

South-central New Mexico has large deposits of high-purity dolomite, favorable year-round climate, and relatively large pools of reasonably priced labor in the areas of Las Cruces, Deming, Truth or Consequences, Alamogordo, Silver City, and El Paso (Texas). The areas are close to natural gas fields which could provide inexpensive power for production of ferrosilicon, and fuel suitable for heating silicothermic retorts. Large tonnages of iron ore are available in the Silver City and Fierro-Hanover areas, and considerable amounts are available in the Capitan district 50 miles north-northeast of Alamogordo. The Orogrande district, 35 miles south-southwest of Alamogordo (Kelley, 1949); the Iron Mountain district at the north end of Sierra Cuchillo; and the Iron Hill district on the west side of the Robledo Mountains also have deposits of iron ore. Large amounts of silica are available from the extensive dune sands in the Tularosa Valley northwest of Alamogordo; from the Jornada del Muerto northeast of Las Cruces; and from La Mesa plains west of the Rio Grande Valley.

In parts of south-central New Mexico, the basal beds of the Bliss sandstone are siliceous oolitic hematite, and at those localities a quarrying and beneficiating operation could possibly combine the production of ferrosilicon and magnesium metal at one plant located near the outcrop of high-purity dolomite and the iron-ore beds of the Bliss sandstone. The Bliss iron-ore beds are separated from the Upham dolomite by 50-150 feet of upper Bliss sandstones and by 300-900 feet of the El Paso group carbonate rocks, as well as by 2-25 feet of the Cable Canyon sandstone. The oolitic hematite beds are as much as 15 feet thick and are a persistent facies of the Bliss sandstone in an east-west belt from Rhodes Pass in the San Andres Mountains west to the Silver City area, where the facies occurs in the Black Range, the central and northern San Andres Mountains, and the Caballo Mountains. Analyses reported by Kelley (1951) show 21-39 percent iron, 27-62 percent silica, 1-3 percent lime, and 0.13-0.66 percent phosphorous. Numerous mines in southwestern New Mexico and southeastern Arizona (Robert Weber, personal communication) are increasing their use of ferrosilicon in forming heavy-media for sink-and-float concentration processes, and this increased use should provide a further market for ferrosilicon.

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