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THE MINERAL RESOURCES OF THE SIERRA NEVADA de SANTA MARTA, COLOMBIA (ZONE I)

by

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THE MINERAL RESOURCES OF THE SIERRA NEVADA de SANTA MARTA, COLOMBIA (ZONE I)

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ABSTRACT

The Sierra Nevada de Santa Marta on the north coast of Colombia is an isolated triangular mountain area that reaches altitudes of almost 19,000 feet. The exceedingly complex geology is shown on the 1:200,000 geologic map.

Despite five major periods of granitic intrusion, three major periods of metamorphism, and extensive volcanic eruptions, metallic deposits are small and widely scattered. Sulfide deposits of significant economic value appear to be absent. Many small copper deposits of chalcocite, cuprite, malachite, and azurite are found in epidotized rock in Mesozoic redbeds and intercalated volcanic rocks, but their economic potential is very small. Deposits of other common base metals appear to be absent. The most important metallic deposits may prove to be unusual bimineralic apatite-ilmenite deposits associated with gneissic anorthosite. The known magnetite deposits are too small to be exploited commercially. Primary gold deposits have not been identified and the placer deposits are uneconomic and very small.

The largest and most important deposits are nonmetallic. Enormous reserves of limestone are suitable for cement manufacture and some high-purity limestone is suitable for the most exacting chemical uses. Small deposits of talc-tremolite could be exploited locally for ceramic

use. The important noncoking bituminous coal deposits in the Cerrejón area are excluded from this study. Other nonmetallic resources include igneous dimension stone in a variety of colors and textures, and agricultural dolomite. There probably are important undeveloped ground water resources on the slopes of the wide Ranchería and Cesár valleys, which separate the Sierra Nevada from the Serranía de Perijá.

INTRODUCTION

The present study is one of four Colombian areas or zones whose mineral resources were evaluated by the Inventario Minero Nacional, Ministry of Mines and Petroleum, Republic of Colombia, in cooperation with geological consultants of the U. S. Geological Survey. The four-year program was established by the Ministry and was partly financed from a loan granted to the Colombian government by the Agency for International Development, U. S. Department of State. The Inventario Minero Nacional was closely affiliated with the Servicio Geologico Nacional through the project, and both are now part of the Instituto Nacional de Investigaciones Geologico-Mineras.

Nearly all the geological field work was done by Colombian geologists as shown on the index map on plate 1, but this report is the sole responsibility of the authors. Credit to the individual Colombian geologists is given where appropriate in the text and on the illustrations.

The area covered by this report, which includes the Sierra Nevada de Santa Marta, consists of 22,500 square kilometers on the north coast of Colombia and has been identified as Zone 1 by the Inventario Minero Nacional. The Sierra Nevada is an isolated triangular mountain mass that lies on the projection of the Cordillera Central, but Zone 1 also includes the wide valley drained by the Ríos Cesár and Ranchería and a small part of the Serranía de Perijá east of it, which is the northern part of the Cordillera Oriental. A small index map of Colombia on the reverse side of plate 1 shows the approximate location of Zone I, but not the exact limits of the area.

The geology of Zone I is shown on plate 1, and the sample locations are shown on a map on the reverse side. Some samples are located on the large-scale geologic maps in the text.

The metallic mineral resources are small and widely scattered. Only one of the known deposits of copper minerals has significant economic potential, although many small deposits in the Serranía de Perijá and the southern part of the Sierra Nevada have been studied several times. The most promising metallic deposits for exploration are apatite-ilmenite or ilmenite deposits associated with anorthosite. Although abundant float and veins along Quebrada del Hierro and elsewhere indicate that economic deposits might be found in the surrounding regions, the economic potential remains unproven. Nevertheless these are the only metallic deposits of possible important economic value known in the Sierra Nevada. A limited amount of prospecting and geological study along a northeast-trending belt of anorthosites, which have favorable geological characteristics, is therefore recommended to obtain the geological information on which to base a possible exploration program. No other metallic deposits are sufficiently promising to induce major mining companies to undertake large exploration programs.

The major resources identified in this study are the very large limestone reserves in the Durania and Ranchería areas, and smaller exploitable deposits of marble, talc or tremolite, and perhaps dolomite. Many igneous and metamorphic rocks can be cut and polished to make attractive finished stone.

Coal is specifically excluded from study by Inventario Minero Nacional, but the noncoking coal reserves of the Cerrejón area constitute a major resource that has been partly evaluated in several unpublished previous studies.

NONMETALLIC MINERAL RESOURCES

Limestone

Limestone is the most important mineral resource in Zone I that is described in this report. Although limestones of Pennsylvanian, Permian, Cretaceous, and Paleocene(?) ages are potential resources, only the Cretaceous limestones were sampled. The two sampled sections near Durania (coordinates d-15, pl. 1) and near Chorrera (k-6) on the Río Ranchería on the west edge of the Ranchería-Cesár valley are shown by the letter symbol Ca on plate 1. These sampled sections are in the discontinuous outcrop belt of Cretaceous limestone that parallels both sides of the wide Ranchería-Cesár valley. The Paleozoic limestones within the mapped area, unlike the Cretaceous and Paleocene limestone, are not readily accessible by road.

Very large resources of limestone suitable for cement, agricultural limestone or lime, and many chemical uses are present in the Cogollo Group and the La Luna Formation just west of the Ranchería-Cesár valley. The potential reserves in these units are almost unlimited and so readily accessible that there was no need to sample the limestones east of the valley or the Paleozoic limestones.

The Cretaceous limestones near Durania were carefully sampled and the quality of the indicated limestone reserves there is thought to be typical of the entire stratigraphic interval at the southern end of the Sierra Nevada. Thus the potential limestone reserves are much greater than the indicated reserves near Durania.

The belt of Cretaceous limestones west of the Ranchería Valley on the northeast side of the Sierra Nevada contain virtually unlimited reserves of limestone of the quality shown by the sampled section near Chorrera, where the sampled thickness is a tiny fraction of the limestone section. Most of the limestones are probably suitable for cement. It is possible that a careful search will discover large deposits of natural cement rock in the Cretaceous or Paleocene sections. Such rocks already contain the proper portion (25 percent) of argillaceous material for portland cement. All the analyzed limestones, however, require addition of argillaceous material.

Smaller, but still large reserves of limestone are found in the Serranía de Perijá northeast of La Paz and near Codazzi (i-15, pl. 1). Marble beds in the Precambrian metamorphic rocks and in the schists of the Eocene Orogen in the northwest part of the Sierra Nevada might provide local sources of lime, and agricultural lime, but they are not adequate for production of cement. The marbles near Cienaga are described separately as potential sources of marble.

The Paleozoic limestones in the Cerrejón, Río Seco, and Manaure areas in the eastern part of Zone I probably are generally suitable for cement, but they were not evaluated because their location is much less favorable than that of the Cretaceous reserves, which are adequate for any forseeable needs.

Limestone near Durania

Geology.--Cretaceous limestones and interbedded shale of the Cogollo Group cover about 80 square kilometers near the southern end of the Sierra Nevada. These limestones were sampled at six places in an area of seven square kilometers near Hacienda Durania at the northwest edge of the outcrop area as shown in figure 1. Here the limestone escarpment was sampled over stratigraphic thicknesses ranging from 6.4 to 25.3 meters, and reserves were calculated for six blocks. The exposed Cretaceous rocks are estimated to have a total thickness of 250 meters. Thus the calculated indicated reserves cover about 10 percent of the total outcrop area. Less than 10 percent of the total thickness was sampled.

The part sampled is chiefly massive limestone containing a few thin beds of shaley and sandy limestone. These rocks overlie more than 30 meters of sandy limestone, which grades downward into sandstone or conglomeratic sandstone at the base. A prominent, relatively thick layer of black calcareous pyritic shale and shaley black limestone is in the middle of the section stratigraphically above the rocks that were sampled. The Cretaceous rocks have a gentle to moderate regional dip to the southeast.

Reserves.--The limestones near Durania (fig. 1) are believed to be typical of the same stratigraphic interval in the entire outcrop area. They were sampled near Durania because they were well exposed and readily accessible. About 144 samples were collected. The indicated reserves are summarized in table 1. The reserves and analyses for each block will be given in tables a little later. We are inclined to infer about

Table 1.--Summary of the limestone reserves near Durania.
(Total area: 6,996,250 square meters; Specific gravity: 2.3)

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

	Average analyses (percent by weight)									Average content of carbonates (percent)	
Block number	Indicated reserves (tons)	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	H_2O -105°C	Ignition loss	Insoluble residue	$CaCO_3$	$MgCO_3$
1	52,345,000	48.63	0.73	0.16	0.38	0.53	0.12	37.99	11.34	86.85	1.52
2	39,569,000	50.90	.44	.42	.48	.22	.10	39.54	7.86	88.79	.92
3	35,730,000	49.74	.98	.11	.30	.34	.08	39.43	8.80	88.82	2.03
4	26,018,000	33.65	.63	.12	.54	.40	.11	26.81	37.57	60.09	1.32
5	25,444,000	43.39	.30	.05	.40	.88	.09	34.23	20.18	77.95	.63
6	23,360,000	46.26	.90	.14	.43	.18	.06	36.48	15.33	82.45	1.87
Total	202,466,000										
Average composition		46.70	.68	.19	.40	.39	.10	36.88	14.21	83.64	1.42
Average composition without Block 4		48.87	.69	.19	.37	.38	.10	38.49	10.47	87.46	1.43
Indicated reserves excluding Block 4	176,456,000										

ten times the total indicated reserves of 202,466,000 tons in blocks 1 to 6 for the same interval in the entire outcrop area (pl. 1). These inferred reserves probably have nearly the same average chemical composition as the indicated reserves. The inferred reserves could be conservatively multiplied by a factor of 3 to 5 to reflect the amount of limestone in the unsampled 90 percent of the stratigraphic section, even allowing for the amount of unsuitable shale, sandstone, or sandy limestone. Although the composition of these potential reserves probably is generally similar to the analyses of the indicated reserves, the average composition is highly uncertain. Thus the inferred reserves for the sampled interval are around 2,000,000,000 tons. Additional potential reserves of uncertain grade for the rest of the section in the southern part of the Sierra Nevada would be between 6 and 10 billion tons.

The indicated reserves and the analytical data in tables 2 to 7 give a clear picture of the chemical variations in each block although the individual strata cannot be correlated from one block to another for lack of adequate exposures. The samples in each table are listed in descending stratigraphic order. The covered intervals shown by a horizontal line in the tables were not sampled.

Table 2.--Indicated reserves in Block 1, Durania.

Sample number	Thickness (meters)	Volume (1000 cubic meters)	Weight (1000 tons)	H_2O -105°C	Ignition loss	Insoluble residue	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
				Chemical analyses (percent by weight)								Carbonate content (percent)	
IMN 121	0.30	429	988	0.03	40.79	5.04	50.76	2.35	0.15	0.37	0.06	90.64	4.91
IMN 123	.60	859	1,975	.04	40.68	4.10	53.50	.00	.17	.30	.98	95.53	.00
IMN 124	.30	429	988	.10	28.86	32.05	36.27	.12	.17	1.12	1.11	64.76	.25
IMN 125	.20	286	658	.10	30.49	28.07	38.84	.04	.09	.79	1.37	69.35	.08
1. IMN 126	.20	286	658	.11	29.12	31.64	37.01	.05	.23	.87	.95	66.08	.10
IMN 127	.70	1,002	2,304	.08	30.22	28.74	38.65	.05	.03	.57	1.35	69.01	.10
IMN 129	1.00	1,431	3,292	.09	40.76	4.75	51.85	1.49	.00	.27	.68	92.58	3.11
IMN 131	.60	859	1,975	.06	37.61	12.01	48.85	.05	.00	.37	.98	87.23	.10
IMN 132	.30	429	988	.13	37.24	12.49	48.55	.61	.03	.33	.59	86.69	1.27
IMN 133	.30	429	988	.06	37.75	10.52	48.91	1.41	.00	.30	.80	87.33	2.94
IMN 135	.50	716	1,646	.05	39.14	6.92	52.40	.03	.00	.49	.96	93.57	.06
IMN 136	.60	859	1,975	.11	39.44	8.48	51.15	.01	.37	.37	.01	91.33	.02
IMN 137	1.00	1,431	3,292	.18	38.04	11.72	48.43	.84	.17	.32	.26	86.43	1.75
IMN 139	.75	1,073	2,469	.20	35.17	18.10	44.70	.90	.14	.35	.41	79.82	1.88
IMN 140	.50	716	1,646	.12	38.05	11.63	48.33	1.19	.17	.30	.18	86.30	2.48
IMN 141	.75	1,073	2,469	.17	38.21	11.57	48.28	1.07	.19	.31	.15	86.21	2.23
IMN 142	.30	429	988	.16	39.93	7.50	51.16	.13	.29	.30	.16	91.35	.27
IMN 143	.30	429	988	.11	38.99	8.42	50.48	.90	.31	.24	.50	90.14	1.88
IMN 144	.30	429	988	.17	37.26	14.48	47.27	.11	.11	.29	.36	84.41	.23
IMN 145	.30	429	988	.15	37.81	12.73	47.40	.88	.18	.19	.39	84.64	1.84
IMN 147	.30	429	988	.10	42.10	2.42	52.73	1.79	.12	.15	.58	94.16	3.74
IMN 149	.85	1,217	2,798	.15	40.48	5.79	51.87	1.06	.17	.24	.14	92.62	2.21
IMN 150	.75	1,073	2,469	.18	40.58	4.99	51.66	1.33	.28	.38	1.86	92.75	2.78
IMN 152	.70	1,002	2,304	.17	39.26	8.80	50.20	.61	.17	.40	.18	89.64	1.27
IMN 153	.30	429	988	.25	38.18	11.30	48.00	1.00	.28	.42	.10	85.71	2.09
IMN 154	.90	1,288	2,963	.16	41.59	3.12	52.40	1.98	.15	.22	.18	93.57	4.14
IMN 156	.70	1,002	2,304	.18	41.82	2.72	54.41	.30	.10	.31	.04	97.16	.62
IMN 157	.80	1,145	2,634	.10	42.03	2.35	54.59	.16	.15	.14	.06	97.48	.33
IMN 159	.80	1,145	2,634	.12	40.14	6.62	51.66	.61	.30	.42	.03	92.25	1.27
Totals and averages	15.90	22,753	52,345	.12	37.99	11.34	48.63	.73	.16	.38	.53	86.85	1.52

Area of Block 1 is 1,431,000 square meters.

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

1. Covered interval 2 meters thick.

Table 3.--Indicated reserves in Block 2, Durania.

Chemical analyses (percent by weight) — Carbonate content (percent)

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

	Sample number	Thickness (meters)	Volume (1000 cubic meters)	Weight (1000 tons)	H_2O -105°C	Ignition loss	Insoluble residue	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
	IMN 56	1.10	748	1,720	0.10	42.47	1.60	55.22	0.35	0.00	0.10	0.00	98.60	0.73
	IMN 55	1.40	952	2,190	.10	42.77	.77	55.60	.24	.00	.10	.01	99.28	.50
	IMN 54	1.00	680	1,564	.09	42.88	.36	55.70	.28	.09	.11	.04	99.46	.58
	IMN 53	1.40	952	2,190	.07	39.00	7.32	51.47	.41	.36	.42	.19	91.91	.85
	IMN 51	1.10	748	1,720	.07	38.13	8.97	50.04	.10	1.57	.57	.21	89.35	.21
1	IMN 50	.50	340	782	.09	41.25	2.48	54.08	.22	.95	.40	.02	96.57	.46
	IMN 48	.60	408	938	.06	42.71	.98	53.79	.84	.18	.28	.99	96.05	1.75
	IMN 47	.80	544	1,251	.10	42.20	1.72	54.08	.55	.73	.45	.02	95.57	1.05
	IMN 46	1.20	816	1,877	.08	42.23	1.46	53.27	1.82	.52	.40	.03	95.12	3.80
	IMN 45	.90	612	1,408	.08	42.41	1.03	54.16	.80	.18	.41	.33	96.71	1.67
	IMN 44	.50	340	782	.08	42.09	1.28	55.15	.56	.18	.32	.10	98.48	1.17
	IMN 43	1.00	680	1,564	.13	42.62	1.99	53.81	.44	.36	.42	.02	96.08	.92
2	IMN 42	1.00	680	1,564	.10	42.14	1.73	54.16	.94	.36	.31	.15	96.71	1.96
	IMN 41	.60	408	938	.11	40.09	6.25	51.47	.64	.52	.28	.12	91.91	1.33
	IMN 40	.90	612	1,408	.10	42.75	1.71	53.63	.37	.95	.42	.02	95.76	.77
	IMN 39	1.40	952	2,190	.07	40.51	2.61	53.09	.37	1.81	.21	1.10	94.80	.77
	IMN 38	1.10	748	1,720	.09	39.74	8.62	49.68	.47	.09	.38	.50	88.71	.98
	IMN 37	1.00	680	1,564	.08	41.16	2.63	53.81	.18	.95	.31	.49	96.08	.37
3	IMN 36	1.00	680	1,564	.06	42.20	2.67	53.10	.44	.14	.67	.11	54.82	.92
	IMN 35	.50	340	782	.12	40.27	6.48	51.19	.05	.29	.57	.11	91.41	.10
	IMN 34	1.00	680	1,564	.07	38.36	11.05	48.72	.28	.14	.88	.08	87.00	.58
	IMN 33	.60	408	938	.10	32.72	24.15	41.18	.33	.46	.74	.12	73.53	.69
	IMN 32	.90	612	1,408	.06	41.78	3.95	52.79	.18	.03	.67	.05	94.26	.60
	IMN 30	.70	476	1,095	.16	30.78	27.85	39.02	.04	.46	.81	.48	69.67	.08
	IMN 29	.80	544	1,251	.16	31.50	26.60	39.92	.13	.14	.88	.08	71.28	.27
	IMN 28	.30	204	469	.10	36.83	14.73	46.43	.32	.06	.74	.42	82.91	.67
	IMN 27	1.00	680	1,564	.13	36.38	15.39	45.63	.49	.29	.81	.32	81.48	1.02
	IMN 26	1.00	680	1,564	.15	29.13	33.79	35.12	.45	.06	.80	.09	62.71	.94
	Totals and averages	25.30	17,204	39,569	.10	39.54	7.86	50.55	.44	.42	.48	.22	88.79	.92

1. Covered interval 3 meters thick.
2. Covered interval 1.5 meters thick.
3. Covered interval 5 meters thick.
Area of Block 2 is 680,000 square meters.

Table 4. Indicated reserves in Block 3, Durania.

Sample number	Thickness (meters)	Volume (1000 cubic meters)	Weight (1000 tons)	H_2O $-105^\circ C$	Ignition loss	Insoluble residue	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
				Chemical analyses (percent by weight)								Carbonate content (percent)	
IMN 171	0.30	347	797	0.08	40.23	6.05	51.66	0.85	0.28	0.37	0.10	92.25	1.77
IMN 172	.40	462	1,063	.03	41.65	3.92	52.80	.63	.00	.31	.59	94.28	1.31
IMN 173	.30	347	797	.11	41.47	3.55	52.76	1.24	.12	.17	.21	94.21	2.59
IMN 174	.30	347	797	.11	38.67	10.48	48.66	1.25	.07	.31	.32	86.89	2.61
IMN 175	.40	462	1,063	.03	39.80	8.68	50.00	.46	.00	.35	.60	89.28	.96
IMN 176	.30	347	797	.09	36.22	15.22	46.86	.73	.15	.30	.10	83.67	1.52
IMN 177	.20	231	531	.05	40.24	6.04	50.60	.87	.16	.52	1.32	90.35	1.81
IMN 178	.30	347	797	.08	36.53	15.08	46.14	1.02	.23	.28	.19	82.39	1.75
IMN 179	.30	347	797	.05	39.40	9.04	49.80	.23	.16	.40	.74	88.92	.48
IMN 180	.30	347	797	.09	37.59	12.24	47.94	1.15	.15	.38	.37	85.60	2.40
IMN 181	.20	231	531	.14	36.59	13.96	46.30	.88	.03	.38	1.59	82.67	1.84
IMN 182	.30	347	797	.14	36.59	13.96	46.30	.88	.03	.38	1.59	82.67	1.84
IMN 183	.30	347	797	.06	39.27	9.38	49.02	1.44	.23	.30	.07	87.53	3.01
IMN 184	.20	231	531	.03	42.00	3.14	53.40	.56	.16	.17	.32	95.35	1.17
IMN 185	.25	289	664	.05	40.12	7.31	50.47	1.31	.03	.21	.16	90.12	2.73
IMN 186	.30	347	797	.06	38.84	10.08	49.38	.95	.23	.25	.02	88.17	1.98
IMN 187	.35	404	930	.11	34.07	20.24	42.62	.64	.00	.45	1.85	76.10	1.33
IMN 188	.35	404	930	.05	33.35	23.97	40.87	1.09	.07	.35	.13	72.98	2.27
IMN 190	.30	347	797	.09	42.50	2.78	54.10	.06	.00	.30	.55	96.60	.12
IMN 191	.30	347	797	.08	41.49	3.00	52.99	1.31	.00	.45	.35	94.62	2.73
IMN 192	.30	347	797	.14	40.81	5.71	51.80	.74	.00	.38	.17	92.50	1.54
IMN 193	.30	347	797	.05	41.12	4.58	51.91	1.40	.00	.22	.53	92.69	2.92
IMN 194	.30	347	797	.10	40.83	6.01	50.83	1.27	.23	.35	.12	90.76	2.65
IMN 195	.30	347	797	.09	40.48	7.33	50.64	.68	.04	.47	.24	92.42	1.42
IMN 196	.25	289	664	.09	40.48	7.33	50.64	.68	.04	.47	.24	90.42	1.42
IMN 197	.25	289	664	.06	40.56	6.98	50.44	1.38	.00	.25	.10	90.07	2.88
IMN 198	.25	289	664	.09	38.19	11.95	48.45	.39	.25	.40	.05	86.51	.81
IMN 199	.25	289	664	.05	38.00	13.35	46.50	1.44	.23	.25	.02	83.03	3.01
IMN 200	.35	404	930	.05	38.00	13.35	46.50	1.44	.23	.25	.02	83.03	3.01
IMN 201	.40	462	1,063	.05	38.00	13.35	46.50	1.44	.23	.25	.02	83.03	3.01
IMN 202	.40	462	1,063	.08	41.97	2.65	53.35	1.27	.15	.22	.03	95.26	2.65
IMN 203	.35	404	930	.06	41.06	3.84	53.17	1.40	.00	.14	.31	94.94	2.92
IMN 204	.20	231	531	.10	39.19	8.83	50.55	.64	.04	.38	.23	90.26	1.33
IMN 205	.30	347	797	.12	37.20	13.68	47.10	.70	.04	.47	.24	84.10	1.46
IMN 206	.30	347	797	.11	37.10	13.94	47.00	.99	.15	.35	.15	83.92	2.07
IMN 207	.50	577	1,328	.03	39.79	8.98	49.18	1.06	.08	.31	.16	87.82	2.21
IMN 208	.50	577	1,328	.09	40.75	5.34	51.91	1.18	.23	.22	.00	92.69	2.46
IMN 209	.50	577	1,328	.07	41.68	4.39	52.40	.67	.08	.31	.11	93.57	1.40
IMN 210	.50	577	1,328	.06	42.10	2.08	53.35	1.72	.15	.25	.15	95.26	3.59
IMN 211	.55	635	1,461	.08	41.26	5.72	51.30	.87	.25	.20	.05	91.60	1.81
IMN 212	.45	520	1,195	.09	41.60	3.12	53.35	1.27	.15	.14	.01	95.26	2.65
Totals and averages	13.45	15,542	35,730	.08	39.43	8.80	49.74	.98	.11	.30	.34	88.82	2.03

Area of Block 3 is 1,155,000 square meters.

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

Table 5.--Indicated reserves in Block 4, Durania.

Sample number	Thickness (meters)	Volume (1000 cubic meters)	Weight (1000 tons)	H_2O -105°C	Ignition loss	Insoluble residue	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
				Chemical analyses (percent by weight)								Carbonate content (percent)	
IMN 73	0.50	453	1,041	0.07	30.85	27.39	40.06	0.44	0.17	0.31	0.39	71.53	0.92
IMN 74	.50	453	1,041	.15	28.62	33.99	35.43	.66	.08	.50	.81	63.26	1.38
IMN 75	1.00	905	2,081	.07	29.36	30.47	38.25	.58	.04	.63	.53	68.30	1.21
IMN 76	1.00	905	2,081	.05	36.09	16.65	45.50	.86	.04	.50	.26	81.25	1.79
IMN 77	1.25	1,131	2,602	.14	19.65	54.12	24.65	.53	.02	.38	.32	44.01	1.10
IMN 78	1.25	1,131	2,602	.17	19.29	54.96	24.49	.21	.04	.30	.33	43.73	.44
IMN 79	1.50	1,357	3,122	.07	29.26	32.09	36.47	.85	.34	.45	.18	65.12	1.77
IMN 80	1.50	1,357	3,122	.09	25.99	38.82	33.05	.71	.08	.63	.46	59.01	1.48
IMN 81	2.00	1,810	4,163	.18	22.52	49.00	26.10	.65	.34	.67	.39	46.60	1.36
IMN 82	2.00	1,810	4,163	.15	26.46	38.25	32.54	.82	.08	1.00	.37	58.10	1.71
Totals and averages	12.50	11,312	26,018	.11	26.81	37.57	33.35	.63	.12	.54	.40	60.09	1.32

Area of Block 4 is 905,000 square meters.

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

Table 6.--Indicated reserves in Block 5, Durania.

Sample number	Thickness (meters)	Volume (1000 cubic meters)	Weight (1000 tons)	H_2O -105°C	Igni-tion loss	Insoluble residue	Chemical analyses (percent by weight) CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	Carbonate content (percent) $CaCO_3$	$MgCO_3$
IMN 72	0.30	375	862	0.05	42.08	3.44	53.38	0.17	0.00	0.17	0.33	95.32	0.35
IMN 71	.70	875	2,013	.08	20.07	53.42	24.66	.84	.00	.40	1.40	44.03	1.75
IMN 70	.40	500	1,150	.10	19.68	52.11	24.30	.64	.00	.35	2.65	43.39	1.33
IMN 69	.30	375	862	.11	41.55	3.05	51.58	.79	.15	.18	2.42	92.10	1.65
IMN 68	.25	312	719	.10	41.44	2.80	54.12	.26	.00	.18	.97	96.64	.54
IMN 67	1.35	1,688	3,881	.07	41.83	2.58	54.30	.24	.00	.15	.40	96.96	.50
IMN 66	1.35	1,688	3,881	.08	41.91	2.54	54.49	.00	.00	.17	.28	97.30	.00
IMN 65	.35	438	1,006	.04	42.00	2.57	54.50	.10	.00	.21	.29	97.32	.21
IMN 64	.15	188	431	.07	40.68	5.24	52.65	.19	.14	.31	.45	94.01	.39
IMN 63	.85	1,062	2,444	.06	40.69	5.53	52.03	.08	.15	.44	.76	92.91	.16
IMN 62	1.25	1,562	3,594	.09	40.34	5.57	52.60	.23	.00	.40	.55	93.92	.48
IMN 61	.90	1,125	2,588	.08	34.99	18.66	44.92	.08	.18	.61	.31	80.21	.16
IMN 60	.25	312	719	.13	22.78	46.50	28.71	.19	.00	.68	.79	51.26	.39
IMN 59	.25	312	719	.20	22.55	46.94	28.35	.22	.00	.83	.72	50.62	.46
IMN 58	.20	250	575	.16	21.17	51.76	24.30	.53	.18	1.00	.87	43.30	1.10
Totals and averages	8.85	11,062	25,444	.09	34.23	20.18	43.39	.30	.05	.40	.88	77.95	.63

Area of Block 5 is 1,250,000 square meters.

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

Table 7.--Indicated reserves in Block 6, Durania.

Chemical analyses (percent by weight)

	Sample number	Thickness (meters)	Volume	Weight (tons)	H_2O -105°C	Ignition loss	Insoluble residue	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
	IMN 87	0.30	472	1,085	0.04	41.84	2.45	54.04	1.06	0.01	0.14	0.22	96.50	2.21
	IMN 88	.35	551	1,268	.08	41.19	4.44	52.57	.92	.34	.24	.02	93.87	1.92
	IMN 89	.30	472	1,085	.07	41.27	3.81	53.30	.90	.08	.21	.16	95.17	1.88
	IMN 90	.35	551	1,268	.06	40.90	4.68	52.80	.79	.08	.38	.16	94.28	1.65
	IMN 91	.25	394	906	.09	35.61	17.30	45.20	.76	.34	.57	.01	80.71	1.58
	IMN 92	.25	394	906	.06	33.34	21.94	42.42	.97	.02	.71	.44	75.75	2.02
	IMN 93	.20	315	724	.07	40.26	6.43	51.57	.87	.34	.28	.03	92.08	1.81
	IMN 94	.25	394	906	.06	40.06	6.45	50.94	1.16	.17	.42	.46	90.96	2.42
	IMN 95	.25	394	906	.06	38.16	11.53	47.84	1.14	.34	.28	.45	85.42	2.38
	IMN 97	.30	472	1,085	.05	38.95	10.80	48.04	1.26	.34	.28	.15	85.78	2.63
	IMN 98	.35	551	1,268	.06	37.17	12.71	48.22	1.12	.05	.39	.05	86.10	2.34
	IMN 99	.40	630	1,449	.09	32.32	24.26	41.33	.70	.10	.74	.21	73.80	1.46
	IMN 100	.40	630	1,449	.06	32.33	25.40	40.22	.79	.10	.61	.09	71.82	1.65
1	IMN 101	.40	630	1,449	.03	35.90	16.60	45.68	.85	.10	.54	.06	81.57	1.77
2	IMN 102	.25	394	906	.04	31.17	28.25	38.79	.42	.30	.74	.05	69.26	.87
	IMN 103	.25	394	906	.01	37.42	13.22	47.50	.95	.05	.52	.03	84.82	1.98
3	IMN 104	.25	394	906	.07	36.51	14.72	47.13	.74	.02	.31	.12	84.16	1.54
	IMN 105	.40	630	1,449	.10	34.33	20.53	42.78	1.30	.15	.51	.03	76.39	2.71
	IMN 106	.40	630	1,449	.05	37.94	13.00	47.86	.23	.00	.28	.52	85.46	.48
4	IMN 107	.30	472	1,085	.08	29.18	33.43	34.62	1.90	.05	.52	.03	61.82	3.97
	IMN 96	.25	394	905	.06	30.30	29.99	38.66	.00	.00	.38	.57	69.03	.00
	Totals and averages	6.45	10,158	23,360	.06	36.48	15.33	46.26	.90	.14	.43	.18	82.61	1.87

Area of Block 6 is 1,575,000 square meters.

1. Covered interval 1 meter thick.
2. Covered interval 1 meter thick.
3. Covered interval 1 meter thick.
4. Covered interval 3 meters thick.

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

Chemical composition.--The indicated reserves have the following approximate weighted average composition in percent: 48.8 CaO, 38.5 ignition loss, 10.5 insoluble matter, 0.7 MgO, 0.2 P_2O_5, 0.4 Fe_2O_3, and 0.4 percent Al_2O_3. The ignition loss is chiefly CO_2 because crystallographically bound water would be nearly absent. The insoluble matter is chiefly quartz, which occurs as sand or silt-sized grains.

The analyses of scattered samples collected east of the reserve blocks whose stratigraphic position is uncertain, are shown in table 8. These few analyses support the contention that the chemical composition of the limestones is similar throughout the southern end of the Sierra Nevada.

The overall average grade can be improved by omitting Block 4, which has a much higher content of clastic impurities. Omitting this block would increase the CaO content about 2 percent and would reduce the content of insoluble matter about 3.8 percent, while reducing the total indicated reserve to 176,000,000 tons as shown in table 1. The fact that the insoluble content is chiefly quartz is clearly indicated by the relatively uniform average content of alumina and iron.

Minable thicknesses of very pure limestones for almost any use could be mined by open pit as shown by the analyses of the upper 3.5 meters in Block 2 (table 3). Almost certainly exploration would discover minable thicknesses of limestones of comparable high purity in the adjacent blocks and elsewhere in the same approximate stratigraphic interval.

Table 8.--Analyses of limestones east of reserve blocks, Durania.[1/]
(In percent)

Sample number	H_2O -105°C	Ignition loss	Insoluble residue	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
IMN 715	0.12	42.25	3.44	52.73	0.75	0.16	0.34	0.00	94.16	1.56
IMN 716	.05	42.67	2.26	53.87	.35	.28	.25	.07	96.19	.73
IMN 717	.09	42.00	3.48	53.30	.29	.22	.32	.01	95.17	.60
IMN 718	.06	42.50	1.87	54.21	.02	.37	.28	.39	96.80	.04
IMN 719	.06	42.80	1.79	53.68	.50	.47	.32	.15	95.85	1.04
IMN 720	.03	42.99	1.25	54.50	.10	.39	.23	.38	97.32	.21

[1/] No SO_3 detected.

Analyses by Laboratorio Químicó Nacional, Ministry of Mines and Petroleum

The indicated reserve of pure limestone in Block 2 is 5,470,000 tons. The average analysis of the 3.5 meter thickness in percent is 55.5 CaO; 42.7 ignition loss, 0.9 insoluble matter, 0.3 MgO, 0.11 Fe_2O_3, and only 0.03 P_2O_5. This limestone could be used for almost any chemical use. It meets all but the strictest chemical specifications, but limestone of even higher purity could be mined from the lower 2.4 meters of this interval. This interval contains only 0.56 percent insoluble matter, which is well below the strictest specifications, even if the insoluble matter is entirely silica.

The high-purity limestone could be used for calcium carbide, cyanamide, soda ash, and for any less exacting requirements. Undoubtedly a careful search would discover many times this tonnage of limestone of similar purity in the Cretaceous rocks if a large market should develop.

Unsampled covered intervals in three sections (Blocks 1, 2 and 6) introduce some uncertainty in the average composition, but we have no reason to believe that these consist of deleterious material. For cement it would even be helpful to have shale beds of appropriate composition in the limestones. However, the covered intervals are probably also limestone, although it may be thin bedded and somewhat argillaceous.

The covered intervals and the thickness of each are indicated in the tables by a line and a note. A lithologic description of each sampled section can be consulted in the files of the Instituto de Investigaciones Geologica-Mineras in Bogotá, but the correlation of the chemical analyses and the field descriptions is not very good.

Factors affecting exploitation.--The location of the limestone near Durania is very favorable. Roads, railroads, oil pipelines, clay deposits, and water are all found within a few kilometers (pl. 1). The El Difícil oil and gas field is only 30 kilometers to the southwest. Argillaceous rock, which is apparently suitable for making the appropriate mixture for portland cement, is present in the Cretaceous and Tertiary rocks and could be easily mined. About one quarter as much argillaceous material as pure limestone is needed. We have not investigated the composition of the argillaceous rocks. Gypsum could be shipped by river barge, rail or truck from a new mine near Bucaramanga. Large quantities of water are available in Rio Ariguaní or Rio Ariguanicito between 5 and 8 kilometers from the deposit.

A new cement plant near Durania could supply the region between Santa Marta and the Cesar valley as well as the existing plant in Barranquilla. This would free present consumption in the region for increasing exports with obvious earnings of foreign exchange in line with government policy.

Limestone near the Ranchería valley

Geology.--The Cretaceous limestones that form the east-dipping slope along the west side of the Rancheria valley extend 45 kilometers from near San Juan del Cesár to Cuestecita. They have an average width of about 7 or 8 kilometers. The total outcrop area is about 300 square kilometers and the average thickness is about 615 meters. In all this enormous volume we sampled only one section 48.4 meters thick on the escarpment at Los Hornitos just south of Río Ranchería near Chorrera (pl. 1). The sampled section is near the base of the unit. It represents only about 13 percent of the average thickness of the unit. The sampled section is believed to be typical of the same stratigraphic interval throughout the area. The sampled limestones are very uniform in hand specimen. The quality is good throughout, as shown by the uniform chemical analyses in table 9.

Reserves.--The Cretaceous limestones constitute a virtually unlimited reserve of high-quality limestone suitable for cement. Using only the sampled interval in the area of about 45 square kilometers south of the Rio Rancheria, the inferred reserve is about five billion tons. This is obviously only a small fraction of the potential reserves in the same unit, north of the river, but additional calculations would be a meaningless exercise in incomprehensibly large numbers.

There are also additional large potential reserves in other formations on both sides of the Ranchería valley. Limestones occur in the Hato Nuevo Formation of Paleocene-Cretaceous(?) age and in the Pennsylvanian and Permian rocks on Cerro Cerrejón and along the western border of the Serranía de Perijá. In 1956, Ronderos (1957, p. 81-99) apparently sampled the upper part of the Hato Nuevo Formation near Hato Nuevo and on the anticline near Papayal. He also sampled limestones on Cerro Cerrejón that we have included in the Cogollo Group and Pennsylvanian (Carboniferous)(?) limestone that we have tentatively included with the Devonian and Carboniferous rock unit. Ronderos considered all these rocks to be Cretaceous.

Table 9.--Chemical analyses of Cretaceous limestones west of the Rancheria Valley near Chorrera.

Sample number	Thickness (meters)	H_2O -105°C	Ignition loss 105-1000°C	Insoluble residue in HCl	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
	(Chemical analyses in percent)									Carbonate content in percent	
I.M.N.											
1211-1212	1.30	0.14	42.79	1.98	53.17	0.86	0	0.09	0.73	94.95	1.80
1210	.75	.11	42.55	2.50	53.10	.62	0	.14	.81	94.82	1.30
1209	.65	.13	42.38	2.63	52.88	.72	0	.13	.92	94.43	1.51
1208	.50	.20	42.72	2.16	52.77	1.11	0	.12	.68	94.23	2.32
1207	.50	.15	42.89	1.94	52.15	1.69	0	.07	.88	93.11	3.53
1205-1206	1.60	.11	42.93	1.89	52.94	1.15	0	.17	.60	94.63	2.41
1204	.65	.11	43.21	1.40	53.40	1.09	0	.09	.46	95.36	2.28
1203	.95	.13	43.08	2.05	52.00	1.92	0	.16	.54	92.86	4.02
1202	.40	.05	42.92	2.27	52.73	1.27	0	.08	.57	94.16	2.66
1201	.35	.12	42.85	1.91	53.85	.40	0	.13	.62	96.16	.84
1200	.60	.10	42.95	1.75	53.60	.70	0	.12	.58	95.71	1.46
1199	.50	.08	42.74	2.37	52.15	1.59	0	.19	.66	93.13	3.33
1198	1.20	.12	43.71	.87	52.69	2.02	0	.11	.34	94.09	4.22
1196-1197	1.40	.17	43.05	1.74	52.59	1.55	0	.15	.62	93.92	3.24
1195	.70	.13	43.35	1.22	53.27	1.33	.02	.10	.43	95.13	2.78
1193-1194	1.07	.14	43.20	1.55	52.79	1.51	.01	.08	.55	94.26	3.15
1191-1192	1.05	.08	43.37	1.30	52.98	1.55	0	.11	.43	94.61	3.24
1189-1190	.92	.16	43.12	1.33	53.27	1.12	.01	.12	.69	95.12	2.34
1187-1188	1.10	.10	43.14	1.56	52.31	1.88	.04	.14	.62	93.41	3.94
1186	.25	.19	43.30	1.41	52.31	2.00	.02	.10	.53	93.41	4.18
1185	.75	.14	42.63	1.88	53.85	.28	.02	.26	.72	96.16	.59
1183-1184	1.60	.13	42.94	1.40	54.23	.25	.03	.10	.68	96.83	.52
1182	.45	.14	43.10	1.55	53.85	.65	.02	.12	.46	96.16	1.36
1180-1181	1.05	.09	43.18	1.14	53.88	.76	0	.23	.72	96.21	1.60
1179	.16	.05	43.41	.95	53.49	1.26	0	.18	.52	95.52	2.63
1177-1178	1.00	.70	43.12	1.64	53.26	1.12	0	.09	.55	95.09	2.35
1176	.17	.10	43.28	2.20	50.77	3.02	0	.08	.42	90.66	6.31
1175	.23	.10	43.08	1.47	53.85	.65	0	.09	.66	95.16	1.36
1172-73-74	2.15	.11	43.08	1.53	53.37	.94	0	.10	.69	95.49	1.97
1171	.40	.16	43.13	1.24	53.31	1.01	.06	.15	.74	95.20	2.11
1169-1170	1.50	.09	43.12	1.54	53.07	1.24	.04	.09	.56	94.77	2.60
1168	.30	.03	43.02	2.12	52.54	1.56	0	.09	.46	93.82	3.26
1166-1167	1.30	.10	42.96	1.85	53.22	.96	.01	.10	.64	95.04	2.01
1165	.65	.03	42.69	2.46	52.31	1.45	0	.14	.81	93.41	3.03

Table 9.--Chemical analyses of Cretaceous limestones west of the Rancheria Valley near Chorrera (continued).

Sample number	Thickness (meters)	H_2O -105°C	Ignition loss 105-1000°C	Insoluble residue in HCL	CaO	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
	(Chemical analyses in percent)									Carbonate content in percent	
I.M.N.											
1164	.60	.13	43.28	1.66	52.00	2.06	0	.09	.61	92.86	4.31
1163	.60	.10	43.71	1.15	50.77	3.36	0	.11	.64	90.66	7.02
1161-1162	.95	.06	43.05	1.37	53.65	.78	0	.13	.76	95.81	1.64
1160	.35	.02	42.77	2.11	53.23	.87	.06	.13	.71	95.05	1.82
1159	.35	.04	42.78	2.22	52.69	1.23	0	.12	.73	94.09	2.57
1158	.80	.03	42.85	2.37	53.08	.96	.04	.06	.45	94.78	2.01
1157	.70	.02	43.60	.83	53.85	1.15	0	.04	.31	96.20	2.40
1156	.30	.03	43.45	1.44	52.46	2.03	0	.05	.40	93.68	4.25
1155	.60	.07	43.00	1.67	53.20	1.04	.07	.10	.68	95.00	2.17
1152-53-54	1.45	.11	43.01	1.70	53.92	.55	.01	.08	.43	96.62	1.15
1150-1151	1.30	.11	42.79	1.97	53.54	.63	.01	.10	.64	95.66	1.32
1149	.82	.06	43.46	.89	53.69	1.11	0	.07	.58	95.88	2.32
1147-1148	1.25	.07	43.23	.88	54.91	.02	.03	.05	.57	98.06	.05
1145	.55	.04	43.60	.33	55.23	.17	.05	.04	.46	98.63	.36
1144	.73	.05	43.44	.98	54.23	.75	0	.05	.35	96.84	1.57
1143	.21	.08	43.23	.97	54.62	.10	0	.05	.75	97.54	..21
1142	.15	.11	43.20	1.13	53.85	.80	0	.05	.75	96.16	1.67
1140-1141	1.00	.07	43.34	1.02	54.68	.28	.02	.04	.36	97.65	.59
1139	.50	.09	43.50	.54	55.00	.25	0	.03	.47	98.21	.52
1138	.40	.11	43.03	1.52	53.85	.60	0	.06	.74	96.16	1.25
1137	.80	.11	43.55	.43	55.00	.40	0	.05	.35	98.21	.84
1134-35-36	2.10	.25	43.34	.906	53.90	.79	.04	.07	.56	96.25	1.65
1130-31-32-33	3.25	.07	43.63	.59	54.78	.45	.04	.04	.30	97.83	.95
1127-28-29	2.20	.01	43.29	.92	54.58	.32	.10	.07	.62	97.38	.60
1125-1126	1.20	.02	43.32	.78	54.31	.13	.05	.06	.63	97.87	.26
1124	.55	.10	43.40	.83	54.62	.20	0	.06	.59	97.54	.21
1214	.60	.05	43.10	1.49	52.23	1.88	0	.34	.76	93.27	3.93
1213	.60	.08	42.87	1.81	53.29	.89	0	.12	.83	95.16	1.86
Arithmetic average		.11	43.12	1.50	53.34	1.05	.01	.21	.59	95.26	2.19

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All the samples collected by Ronderos are suitable for cement. However, the quality is generally poorer than that of the limestones at Chorrera. The erratic P_2O_5 content probably is too high for many other uses. In view of the unlimited reserves west of the valley, additional reserve calculations are unnecessary, and could not be carefully made because the exact locations of the samples and their stratigraphic positions were not given by Ronderos.

Chemical composition.--The chemical composition of the section near Los Hornitos is very uniform as shown by the analyses of 90 samples in table 9. The quality is very good for cement and many other uses as indicated by the very low content of insoluble matter and most minor constituents. The MgO content is higher near the top of the section, as shown by the generally higher analyses toward the top of the table. A few thin beds throughout the section exceed the allowable 3 percent maximum content of MgO for cement, but the overall average content is so much lower that it would cause no trouble.

In view of the uniform composition, we did not calculate a weighted overall average analyses. The arithmetric average in the table is very close to a true weighted average. The approximate average composition in percent is 53.3 CaO, 43.1 ignition loss, 1.5 insoluble matter, 1.05 MgO, 0.03 P_2O_5, 0.1 Fe_2O_3, and 0.6 Al_2O_3. The content of SO_3 was too low to be detected in any of the samples. Arithmetric averages in the table are given where several samples were collected from the same bed, instead of separate analyses of several samples from the same beds as shown by multiple sample numbers in table 9.

The analyses of three scattered samples collected just above the continuous section are about the same as the average analyses except for the notably higher, erratic content of P_2O_5, which ranges up to 1.97 percent in two samples. Phosphorus content this high is undesirable for some uses, but these beds could be stripped off if necessary in mining. We do not know whether the strata on the dip slope above the continuous section will prove to have a high average phosphorus content or whether only a few thin beds do.

Factors affecting exploitation.--The limestone deposits near Chorrera like those near Durania are favorably located near water, fuel, roads, and population centers. The Cerrejón coal field is nearby. Adequate water is available in the Rio Ranchería. A road passes next to the sampled section and the main highway is close. Abundant argillaceous material is found in the Cretaceous and Tertiary rocks near the deposit. There is an adequate labor supply in three sizeable towns within 10 kilometers.

The deposits could be mined by either open pit or by underground methods at several places close to the sampled section. The limestones in the lower part of the K_1 map unit could probably be mined anywhere along the western side of the dip slope as far north as Cuestecita, but these rocks are readily accessible only at the north and south ends.

Probably many other stratigraphic intervals of comparable thickness are suitable for cement in the higher part of the Cretaceous section. Possibly argillaceous cement rock could even be found that would not require a separate mining operation for the argillaceous matter.

Other deposits

There are probably minable reserves of limestone suitable for cement in any areas where limestones of Cretaceous, Paleocene, Pennsylvanian, and Permian ages crop out, but we have not sampled any other deposits because of the large reserves favorably located near Durania and Chorrera. Among these, the best possibilities are along the west front of the Serranía de Perijá, particularly near Manaure, near Codazzi, and in the thick section of Permian limestone beyond the east edge of plate 1 east of El Molino.

Two samples (IMN 1113-14) of Cretaceous(?) limestone from the circular isolated outcrop south of Rio Tapias (pl. 1) were analyzed. These are low-magnesium limestones containing only between 2.6 and 8.9 percent insoluble matter. The impure limestone has an exceptionally high content of P_2O_5 (2.52 percent) and Al_2O_3 (2.31 percent). Reserves are adequate for local use and perhaps enough for a cement plant if the three isolated outcrops are continuous beneath shallow unconsolidated terrace gravels, as inferred. The location, near Dibulla on the coast, which is 30 kilometers away, might make it feasible to export cement if port facilities are developed and adequate reserves are proved by drilling. Their immediate economic potential is very small.

Marble

Marble has been found in the Precambrian granulites (los Mangos), in the Gaira Schist, in the undivided schist, and in the Los Muchachitos Gneiss. The largest deposits in the Gaira Schist near Cienaga are mapped as a separate unit (pl. 1). Other layers of marble on Cuchilla Piedras

Blancas and in the undivided schists near Buritaca are in schists belonging to the Early Tertiary orogen. They are shown on plate 1 by a special line symbol. Many other thin beds of marble were seen in the Gaira Schist south of the Santa Marta batholith.

All the marbles in the Precambrian rocks contain metamorphic silicates, commonly pale green diopside. Some olivine, phlogophite, and mictocline may also be present. These marbles have no economic potential. The marble bed in the Los Muchachitos Gneiss that is shown by a line symbol on plate 1 also contains diopside, but the marbles in the schists do not contain visible metamorphic silicates. Many contain abundant detrital quartz, however, and many are too impure for use even for cement. Decorative marble is found only near Cienaga.

Marble near Cienaga

Geology.--Two small areas of marble, dolomitic marble, and sandy calcareous metasediments having a total area of 2.6 sq km were mapped near the southern tip of the Santa Marta Batholith at the western edge of the Sierra Nevada about 5 km east of Cienaga (pl. 1). These marbles form part of the partly foundered roof of the batholith, but they do not contain any metamorphic minerals. A map and cross section of the area (fig. 2) shows the geological relationship and the sample locations.

The geology in figure 2 was mapped by Dr. Cesár Duque on an enlarged part of quadrangle 18 III D of Institute Geografico Agustín Codazzi. We have added the sample locations of Dr. Roberto Wokittel (1958, unpubl. report 1286, 24 p.) to those of Dr. Duque. Dr. Wokittel and Dr. Jesus A. Bueno (1957, unpubl. report, 1225, 10 p.) made brief studies of the area for the Servicio Geologico Nacional. These reports though unpublished are in files open to the public.

The relationships of the marbles to the schists are puzzling. The marble overlies biotite schists. The schists are part of the Gaira Schist, which was metamorphosed to the amphibolite facies shortly before the intrusion of the batholith about 50 m.y. ago. However the lack of metamorphism, beyond recrystallization which has coarsened the grain of the marble near the contact, contrasts with the high grade of metamorphism of the schists. Conceivably the marbles, many of which contain constituent oxides to form abundant metamorphic silicates but lack them, are younger, and may overlie the schists unconformably. If so, the contact with the schists to the southeast, which apparently overlie the marble, would have to be a reverse fault throwing upper schists over the marble sequence. Instead we have interpreted the marble as a member of the Gaira Schist that is interbedded with the schists, as shown in the cross section. The marbles are clearly intruded by the batholith.

The marble sequence consists of two members; a lower member of relatively pure low-magnesium marble and an upper member of impure sandy marble, calcareous metasediment, metasiltstone, quartzite, and possibly dolomitic marble (fig. 2). The rocks on Cerro La Pedrera are believed to correlate with the upper member.

The principal noncalcareous constituent is quartz sand, which forms disseminated clastic grains or stringers along the bedding planes. The sedimentary structures generally are still clearly evident except in the massive coarse white marble near the contact. Many of the marbles are mottled gray and white. Much of the upper member is gray to dark gray and it apparently was little recrystallized. There obviously has been very little shearing within the marble sequence, in marked contrast to the incompetent thin-bedded schists above and below.

The lower member apparently is repeated by a northeast-striking normal fault along Quebrada Honda. The dip slip was approximately 280 meters. The upper member has been eroded from the western block. Some erratic dips near the north end of this block suggest that there are unexplained local structural complexities, but the larger structures are clear.

The apparent thickness of the marble sequence is 460 meters as measured from the cross section. The lower member is between 230 and 250 meters thick and the upper member is about 230 meters thick.

Exploitation.--The marble deposits have been exploited for many years in as many as nine places as shown on the map. The location of seven primitive small kilns or ovens, which burned wood, are shown in figure 2. These kilns produced calcined lime, which was sold to paint manufacturers and others. The sites of two small crushing plants (mills) are also indicated. The crushed rock was used chiefly for artificial stone floor in Barranquilla, Santa Marta and nearby towns (Wokittel, 1958).

A small mill near the north end of the cross section is now inactive. It contains crushing and screening equipment that may still be usable. This was the most elaborate installation in the area. Sr. Hernandez Padilla has recently installed a Raymond mill to produce ground limestone for export, an operation that may be the beginning of larger scale, more technical exploitation of the marble. Some diamond drilling has been done along the south margin of the western block. The possibility of producing finished marble dimension stone is being investigated.

Economic potential.--The economic potential of the marble sequence is quite large, but it is largely restricted to the lower member. The upper member contains quartzites and generally is too impure for most uses. Its economic potential is limited to the dolomite or high-magnesian limestone on Cerro Pedrera. Some beds of relatively pure low-magnesian marble are also present in the upper member as indicated by Wokittel's samples of the material (table 10) used in the kilns near Cerro Pedrara (fig. 2).

There are many possible additional uses for the best material. Wokittel suggested possible use of lime and hydrated lime for insecticides and fungicides, emphasizing the now obsolescent use of "caldo bordoles" in combating the Sigatoca disease of the declining, but still large, commercial banana plantations. He also suggested possible use for calcium carbide, mortar and plaster, portland cement, finished marble, refractory dolomite, agricultural dolomite, bricks of calcareous sand (calicanto) and water treatment. Undoubtedly domestic markets will grow as economic development proceeds and population increases.

Reserves of low-magnesian marble.--The available data are not sufficient to calculate measured or indicated reserves or reliable quality because the chemical analyses are too variable and many impure beds might occur even in the lower member. The following reserve estimates of potential and inferred material are conservative to allow for the many unknown factors affecting both the volume and the quality

Table 10.--Chemical analyses of the marbles and dolomitic marbles near Ciénaga.

Chemical analyses (percent by weight)

Sample number	H_2O -105°C	Ignition loss	Insoluble residue	CaO	MgO	SO_3	P_2O_5	Fe_2O_3	Al_2O_3	Carbonate content (percent) $CaCO_3$	$MgCO_3$
Upper member											
IMN 985	0.00	27.80	37.34	33.34	0.46	0.00	0.07	0.45	0.33	59.69	0.96
IMN 986	.12	11.29	73.46	12.85	.30	.00	.00	1.07	.88	22.94	.62
IMN 987	.14	7.04	82.60	6.98	1.21	.00	.07	.85	.83	12.46	2.53
IMN 988	.04	14.63	66.20	15.54	1.13	.00	.00	.49	.86	29.54	2.36
IMN 989	.05	1.52	95.95	.38	1.01	.08	.04	.55	.31	.68	2.11
IMN 990	.02	31.93	26.29	40.38	.13	.00	.00	.13	.97	72.11	.27
IMN 991	.09	37.89	13.57	45.08	2.24	.00	.00	.19	.71	80.50	4.68
IMN 992	.05	35.50	18.70	44.11	.67	.00	.00	.10	.80	78.77	1.40
Upper(?) member, Cerro La Pedrera											
Wo 809	.07	39.62	8.91	36.56	11.18	.08		.48	.80		
Wo 810	.06	34.00	13.32	32.29	17.56	.07		.42	.66		
Wo 811	.05	44.38	.67	33.76	17.64	.08		.32	.32		
IMN 993	.10	44.78	3.56	35.13	15.60	.00	.00	.07	.48	62.73	32.62
IMN 994	.05	46.43	.83	33.06	18.69	.00	.00	.09	.71	59.07	39.09
Average, 5 dolomites		41.84	5.46	34.16	16.13			.28	.59		
Wo 812	.07	39.40	7.01	48.23	1.27	.22		.32	1.40		
Wo 813	.06	37.58	11.12	46.77	1.09	.22		.32	1.20		
Wo 814	.08	38.43	6.00	43.52	7.42	.22		.32	1.44		
Wo 815	.06	39.27	8.67	48.00	.60	.20		.48	1.00		
Wo 816	.09	36.52	13.79	39.93	5.62	.19		.16	1.40		
IMN 995	.05	28.27	35.63	33.05	2.09	.00	.00	.07	.73	59.02	4.37
Lower member											
IMN 996	.06	42.43	2.82	53.06	.61	.00	.00	.13	.82	94.75	1.27
IMN 997	.07	37.90	12.90	47.69	.11	.00	.00	.19	.91	85.16	.23
IMN 998	.02	36.87	14.67	46.15	.24	.00	.13	.17	1.45	82.41	.50
Wo 817	.07	39.22	6.20	49.24	.60	.16		.32	1.38		
Wo 818	.08	39.13	7.70	48.12	.64	.19		.32	1.72		
Wo 819	.06	41.84	.32	52.46	.30	.15		.32	.72		

Table 10--<u>Chemical analyses of the marbles and dolomitic marbles near Cienaga.</u> (con't.)

Sample number	H_2O -105°C	Ignition loss	Insoluble residue	CaO	MgO	SO_3	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$
	Chemical analyses (percent by weight)									Carbonate content (percent)	
Wo 820	.07	42.31	.22	52.04	.43	.14		.32	.56		
Wo 821	.06	42.55	.56	52.27	.27	.23		.32	.52		
Wo 822	.08	37.03	10.93	46.88	.43	.18		.48	1.72		
Wo 823	.39	39.55	5.03	48.56	.41	.20		.48	1.12		
Wo 824	.09	41.63	.88	52.27	.41	.25		.32	.96		
Wo 825	.07	40.40	3.45	50.58	.68	.19		.32	.60		
Wo 826	.07	34.65	14.38	44.35	1.49	.37		.32	1.48		
Wo 827	.07	39.72	3.91	50.36	.90	.41		.48	.68		
Wo 828	.07	40.38	2.93	51.14	.62	.31		.32	.68		
Wo 829	.10	39.00	5.63	47.89	2.03	.341		.48	1.00		
Average 16 low-magnesian limestones	.10	39.66	5.78	49.57	.64			.33	1.02		

Samples with Wo taken from Roberto Wokittel, 1957,
Calizas de Cienaga, Departamento del Magdalena, Informe No. 1286.

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

of usable marble. The principal uncertainty regarding volume is the unknown depth to the highly irregular upper contact of the batholith. The cross-section is diagrammatic and the true contact can only be determined by drilling or geophysical methods. The quality cannot be closely determined without much additional sampling on the surface and some drilling. The estimates of inferred reserves are limited to the lower member, specifically to that part that does not require stripping of the upper member and that lies above the level of Quebrada Honda.

The western block of the lower member has an average exposed stratigraphic thickness of about 200 meters; an average length of 800 meters, excluding the poor material at the north end; and a width down dip of 300 meters. Using a specific gravity of 2.3, this volume would contain a maximum potential reserve of 55,200,000 metric tons of which about one fourth might be readily minable. Thus the inferred reserve is about 13,800,000 tons of marble with the following approximate average percentage analyses: CaO 49.57, MgO 0.64, and insoluble matter 5.78. This very low average magnesia content of 16 samples compares with an average of 16.13 percent MgO in 5 dolomites on Cerro Pedrera.

The part of the lower member east of the fault that is not overlain by the upper member has an average exposed stratigraphic thickness of 100 meters, an average strike length of 1000 meters, and an estimated average extension down dip of 100 meters. The maximum potential tonnage would be about 11,500,000 tons, but only about one fifth lies above the level of the Quebrada and would be easily minable. The readily minable inferred reserve is thus 2,300,000 tons. The average grade of this marble is assumed to be the same as that of the western block.

The total maximum potential reserve without stripping the upper member is thus about 68,000,000 tons and the total readily minable inferred reserves is 16,000,000 tons. This compares to Wokittel's 1957 estimate of 10,000,000 tons, without geological mapping. Only a small fraction of this might be suitable for cut marble slabs, and selective mining might be necessary for most chemical uses, but the entire section should be usable for cement, agricultural limestone, or other low-grade uses.

The available chemical analyses are given in table 10 which includes Wokittel's analyses. The analyses from the lower member, the upper member, and the dolomites or high-magnesian limestones are given in separate groups. Many of Wokittel's samples were collected from the kiln sites, and their exact sources are unknown. The samples are located on the map.

Dolomite reserves.--Dolomite is apparently confined to the central fault block on Cerro La Pedrera as indicated on the map. Reserves can not be estimated for lack of sufficient information owing to heavy vegetation and rubble-covered slopes. The quality of the five analyses varies greatly because of the erratic content of insoluble material (table 10). Beds of unknown thickness of relatively pure dolomite are interbedded with sandy dolomite, sandy magnesian marbles, and calcareous metasedimentary rocks. The only bed of relatively pure dolomite that we saw was on top of the highest hill (IMN 993-994), but chest-high grass severely limited observations.

Dolomite is scarce in Colombia and we believe that limited exploration of the Cerro La Pedrera area is justified beginning with trenching in the long dry season when the brush and grass can be burned off. It is quite possible that beds of refractory dolomite of minable widths might be found if the laboratory tests of the best dolomite proves it to be satisfactory. Certainly large reserves of agricultural dolomite could be developed, probably enough for any domestic market within economic hauling radius.

At present, however, we can not say whether several beds of relatively pure dolomite are present and whether there are also several beds of relatively low-magnesian marble in the same section. The sandy rocks containing dolomite on Cerro Pedrera probably correlate with the sandy upper member farther north. The clear implication of this very tentative correlation is the probable occurrence of dolomite beds in this much larger area. If so, the economic possibilities are very greatly enhanced. If, however, the dolomites are hydrothermal, the possibilities are much reduced.

Marble on Cuchilla Piedras Blancas

Several beds of impure sandy marble crop out in the Gaira Schist on Cuchilla Piedras Blancas about 2 kilometers south of the El Carmen Fault. They are shown by a line symbol on plate 1. The area was mapped and sampled by geologist Alfonso Arias to the extent permitted by poor exposures and heavy vegetation.

Two beds of marble that strike N. 70° E. and dip about 70° SE. are separated by about 250 meters of schist or quartz diorite. The upper bed, which is 35 to 40 meters thick, can be traced continuously for a kilometer northeast of Río Piedras and the same bed, which is 15-20 meters thick, probably crops out near Quebrada Lisa another 1.6 kilometers northeast. The upper bed was sampled in three places within one kilometer. The lower bed was sampled in two places a kilometer apart. At Río Piedras a third marble between the other two is about 1 meter thick. Two other very thin marble layers are separated by a thin layer of schist. Three sills of quartz diorite separate these beds but, farther east, the intervening rocks are schists up to 250 meters thick.

The composition of these marbles resembles that of the much thicker upper member of the marble sequence east of Cienaga (fig. 2) and they might possibly be correlative. They might also correlate with the marble in the schist between Ríos Guachaca and Buritacá (pl. 1), but there is no real basis for these doubtful correlations.

The sections of the main (upper) layer at Río Piedras and on the trail a kilometer east are too impure to have commercial potential. Generally the lower part of the principal marble is thin bedded, dark colored, and it contains more impurities than the upper part, but only one of 11 samples from these two sections contains less than 10.9 percent insoluble matter. The arithmetic average analyses are given in table 11. The main layer 2.7 kilometer northeast of the river on the ridgetop trail is considerably purer. There the top bed (IMN 879) is coarse white marble that consists of 97 percent $CaCO_3$ and 1.9 percent $MgCO_3$. The samples from this section do not contain any detectable SO_3, P_2O_5, Fe_2O_3, or Al_2O_3. The quality of the light-gray coarse marble in the middle part is acceptable for some low-grade uses although it contains 7.5 percent insoluble material. The lower part contains too much quartz to be usable.

Table 11.--Average chemical analyses of marbles on Cuchilla Piedras Blancas.

	Chemical analyses in percent							Carbonate content		Remarks
Sample number	CaO	Ignition loss	Insoluble residue	MgO	P_2O_5	Fe_2O_3	Al_2O_3	$CaCO_3$	$MgCO_3$	
Upper layer										
IMN 895	50.7	44.16	0.47	3.98	0.01	0.06	0.58	90.53	8.32	Near Quebrada La Lisa
IMN 877-879	49.02	38.41	10.18	3.17	0	0	0	87.53	4.54	Trail, Cuchilla Piedras Blancas
IMN 880-883	46.50	34.47	17.38	0.66	0.01	0.13	0.43	83.04	1.37	200 meters northeast of Río Piedras
IMN 888-894	44.23	34.09	19.81	0.54	0.06	0.12	0.86	78.97	1.13	Río Piedras
Middle layer										
IMN 887	43.20	33.95	20.13	0.50	0	0.06	1.94	77.14	1.04	Río Piedras
Lower layer										
IMN 897	52.10	40.93	6.22	0	0	0.06	0.49	93.03	0	Trail, Cuchilla Piedras Blancas
IMN 885-886	45.85	35.30	16.42	0.33	0	0.08	1.76	81.87	0.68	Rio Piedras

Note: Samples in each section listed in descending stratigraphic order. Sections arranged in order along strike toward the southwest. The analyses are arithmetic averages where more than one sample was analyzed.

Analyses by Laboratorio Químico Nacional, Ministry of Mines and Petroleum

The lower layer on the trail is 3 meters thick (IMN 897) and it consists of 93 percent $CaCO_3$, 6.2 percent insoluble matter and 0.5 percent Al_2O_3. The lower layer at the river contains much more impurities.

The present economic value of these marbles is nil considering their poor location, which would require about 4 kilometers of steep new road up 600 meters from the present road head at El Carmen on Río Piedras near the contact of the Santa Marta batholith. For this reason, we did not give the analyses of each sample or calculate reserves. Instead arithmetic averages of each layer at each sample point are given.

Talc-tremolite

Talc and tremolite form small lenses that are concordant with the foliation of the enclosing metamorphic rocks and irregular masses that are closely associated with small intrusive(?) bodies of retrograded or altered ultramafic rocks, particularly with serpentinized ultramafic rocks. Talc schists or chlorite-talc schists are also present, as on Serranía de Nueva Granada (c-5, pl. 1), but they have no possible economic value because of the high iron content. They are not discussed here.

Some of the small bodies of ultramafic rocks are shown on plate 1. They occur in metamorphic rocks belonging to all three orogens, but those in the Buritacá Gneiss near Quebrada Rodríguez (b-6, pl. 1) are the most important. Similar deposits of talc and tremolite in ultramafic rocks were seen on the road near Cincinati (b-6, pl. 1) and in several places in the San Lorenzo and Gaira Schists, but they have no economic value because of their dark color and high iron content.

The ultramafic rocks and the talc and tremolite deposits are poorly mapped because of very poor outcrops, dense vegetation, and rubble-covered slopes. Eight pits were dug to partly outline the central deposits near Quebrada Rodríguez. Float blocks of resistant massive tremolite rock or pyroxenite on the slopes or in the quebradas are often the only visible sign of these rocks. Talc is much less conspicuous than massive resistant tremolite. Many small masses of ultramafic rocks, particularly of pyroxenite, are not altered to talc or tremolite, which are more closely associated with serpentine.

Deposits on Quebrada Rodríguez

Geology.--The only known deposits of possible economic value are in the Buritaca Gneiss near Quebrada Rodriguez. These were mapped by geologist Raul Durán (fig. 3). Five small bodies were found, two of which contain massive dark green serpentine, which may be more extensive than indicated on the map. The enclosing amphibolites give Jurassic radiometric ages (R. Marvin, 1968, written commun.) that were probably degraded from Permian or Triassic metamorphic ages during the Eocene orogeny. The serpentine is unfoliated and it probably was intruded after the Eocene orogeny, possibly before the pegmatitic stage of the Eocene quartz diorites. The serpentine is intruded by a thin granitic dike near the prospect pit (fig. 3). Talc and tremolite have apparently replaced the serpentine.

The largest body may be a discordant intrusive mass of altered serpentine, but the three smaller ones appear to be concordant lenses in the amphibolites. The fourth also appears to be discordant and contains some serpentine (IMN 676). This body is poorly exposed along an abandoned and overgrown road that crosses the southwest corner of figure 3. Reconstruction of this road has begun. Exposures will be much better in the new road cuts.

Two small concordant lenses at the northeast end of the group of deposits consist largely of fibrous and radial crystals of pale green tremolite. These lenses may be metamorphosed dolomitic rocks, but we are inclined to relate them to magnesian fluids that are directly or indirectly derived from the serpentines. No serpentine was seen in these lenses.

In the prospect pit (fig. 3) pale low-iron chlorite(?) and phlogopite mica occur with the talc and tremolite. The tremolite is pale green and commonly forms large crystals and fibrous cross-fiber asbestos-like masses or veinlets. The talc is less abundant and it may be derived from the tremolite. Chlorite may be an alteration product of mica. Talc and chlorite and possibly tremolite are retrograde minerals that are not consistent with the higher metamorphic grade of the enclosing amphibolites. These minerals obviously formed after the regional metamorphism and later than the serpentine. As much as 7 percent of an opaque black oxide is present in the serpentine and in some of the talc-tremolite rock derived from it. This could cause trouble for ceramic use unless it can be separated. Tremolite is generally at least twice as abundant as talc.

Economic potential.--The economic potential is doubtful for the following reasons: (1) conflicting laboratory reports on the color of the baked ceramic; (2) the variable mineralogy and iron content; (3) the common presence of unknown amounts of serpentine; and (4) poor exposures.

Therefore we did not attempt to calculate reserves. The deposit has attracted the interest of a ceramics firm in Florida, which applied for a concession in 1966 to exploit the deposit. The firm contracted a consultant geologist to examine the largest deposit.

The quality is apparently marginal. The best material near the prospect on the largest body burned to a satisfactory pale cream ceramic, according to preliminary tests made by the ceramics firm in Barranquilla. However four samples (IMN 665-668, fig. 3) burned to an unsatisfactory dark color, according to tests made for us by Locería Colombiana in their well-equipped laboratory in Medellín. This laboratory concluded that the tested material has little economic value. These samples are not from the same body as the satisfactory material. Even if some material has commercial value, selective mining and hand sorting would be required. Trenching, careful sampling, and additional laboratory tests under the supervision of experienced specialists is clearly required to evaluate the deposit.

All the material is tremolitic talc, which is almost as satisfactory as steatite talc for ceramic use, provided the iron content is low enough to form a white ceramic. Any other color is only suitable for colored glazed tile or bathroom fixtures because the public expects white ceramic ware. We are not able to judge how much iron is tolerable in the Colombian market nor can we judge the color of the resulting ceramic from the color and mineralogy of hand specimens. If tan and brown ceramics are acceptable, there is undoubtedly a large amount of suitable material. The available test data suggest that none of the material will burn dead white. The lenses of tremolite rock like that in the northern two bodies would probably provide more uniform material than the larger bodies associated with serpentine.

Feldspar

The feldspar of commerce is potassium or sodium feldspar or felspathoidal syenites which are sold on the basis of combined K_2O, Na_2O, and Al_2O_3. Unfortunately the anorthositic gneisses consist of plagioclase, which is much too calcic to have any commercial value. The known pegmatites are much too small to be commercial sources of potassium or sodium feldspars.

It is technically, but not economically feasible to produce mixed potassium-sodium feldspar (perthite) concentrates from coarse-grained pink granites and the quartz-perthite granulites. A quartz concentrate could be produced as a byproduct. These rocks, which contain 50 to 60 percent useful feldspar, are very common in the Precambrian sequence and in the Patillal and Pueblo Bello batholiths. Probably the costs of crushing and flotation would be uneconomically high. Relatively fine grinding would probably be necessary to produce quartz-free feldspar concentrates. Because the pink color probably is hematite that is too fine to resolve with an optical microscope, perhaps the iron content is too high to give white ceramics. Tests are necessary to determine this.

Geologists Luis Jaramillo and César Duque studied the elongated body of anorthosite near Rio Frio and submitted 20 samples for chemical analyses which show the average CaO content to be about 10 percent and the CaO/Na_2O ratio to range widely from 2.8 to 7.8 percent; the feldspar was too calcic to have any conceivable commercial value.

Clay

None of the clay deposits within the mountain areas of the Sierra Nevada have significant economic potential so far as we have been able to determine. However, the Cretaceous, Tertiary, and possibly also the Quaternary rocks in many lowland areas may be suitable for such uses as cement and local manufacture of brick. The brick produced near Valledupar and generally in the region is low in quality, but we can not say whether this results from poor raw material, from low firing temperatures, or from primitive firing techniques. Many lateritic soils should be suitable for brick for local use.

Kaolinites in three areas all appear to be too rich in iron to yield white ceramics, although the rocks are white. We are unable to evaluate their suitability for other uses, but their economic potential is small.

The swelling clays in the older Miocene rocks west of the Sierra Nevada may be bentonites rich in montmorillonite. They might be used to line irrigation canals and reservoirs. The most likely use, however, is for cement additives.

Kaolinite deposits near San Pedro de la Sierra

Apparently little kaolin has been produced in the Sierra Nevada. Wokittel (1960, p. 297), reports unspecified deposits somewhere between Cienaga and Sevilla. These deposits probably are those studied by the West German geological mission (Fricke, 1960, p. 106-111) and by ourselves.

The German mission studied deeply weathered kaolinized granite and granite pegmatite dikes between Cuadro Caminos and San Pedro de La Sierra (c-6, pl. 1), a distance of a few hundred meters. The feldspar is kaolinized but the coarse quartz and the fine flakes of muscovite are unaltered.

X-ray investigations (Fricke, 1960) indicate that the kaolinite content ranges from 15 to 20 percent in the fraction coarser than 60 microns to 40 percent in the fraction less than 6 microns. The content of muscovite and illite decrease from 30 to 20 percent in the finer fractions. The chlorite content is less than 10 percent and feldspar varies from 15 to 30 percent. Most of the quartz in the sample from Cuatro Caminos is coarser than 60 microns, but the quartz in the San Pedro samples was much finer grained, dropping from 20 to less than 5 percent. The minus 60 micron fraction of the rock varies from 29 percent at Cuatro Caminos to 75 percent at San Pedro.

Photographs made in 1960 of the fresh bulldozer cuts which are now completely overgrown, indicate that the road cut was in hard granite about 25 feet high, but only three narrow kaolinized seams or dikes are visible.

Kaolinite deposits near El Platanal

Many small tabular masses of kaolinized rock are present in the Platanal region from El Mico along the road to San Pedro de la Sierra (pl. 1). Most of these were probably granite or aplite dikes. These highly kaolinized rocks were sampled at 24 places between El Limon and Cuatro Caminos near San Pedro. They range from 0.50 to 3 meters thick and can be traced only a few meters along strike because of heavy vegetation.

Two complete and two partial analyses show that the parent rocks are granitic rocks that are similar to the one near San Pedro whose analysis was reported by Fricke and others (1960). This similarity strongly suggests that these dikes also have similar mineralogical compositions, and contain 30 to 40 percent kaolinite.

Five samples (IMN 669-673) of the most kaolinized igneous rocks from along the road to San Pedro de la Sierra were submitted to the laboratory of Locería Colombiana in Medellín for tests. All five samples burn to dark-colored ceramics, which have no commercial value (Hernán Vasquez, 1967, written commun.). Obviously none of the material in the region can be used to produce white ceramics because the iron content is too high. It is unlikely that the iron content could be economically reduced sufficiently by beneficiation, and therefore the kaolinite deposits near El Platanal and in the Cuatro Caminos-San Pedro area have no commercial potential.

Twelve samples from near the road between El Limón and San Pedro had a surprisingly high burn variable sulfur content. The sulfur probably is derived from oxidized pyrite. If pyrite remains, it would destroy any possibility of exploitation for ceramics because the pyrite would form brown mottling. The SO_3 content ranges from 0.10 to 3.75 percent. The SO_3 content of four samples is more than 0.90 percent. This is very deleterious for most uses.

Three samples (IMN 738, 740, and 744) contained less than 0.18 percent SO_3, but two of these had low Al_2O_3 content, between 18.7 and 19.3 percent, which indicates incomplete alteration to kaolinite. The highest alumina contents are between 24.5 and 32.8 percent.

The lime (CaO) content of these 12 samples ranged from 0.9 to 7.5 percent. Eight samples contained less than 3.1 percent and four contained less than 1.9 percent.

The analytical data, the firing tests, and the small size all indicate the deposits have no commercial value so it was not necessary to present the analyses of all 12 samples.

Kaolinite deposits near El Secreto (El Congo)

A body of white, intensely kaolinized anorthosite(?) occurs on the slope 500 meters east of Quebrada El Secreto at an altitude between 650 and 800 meters (c-4, pl. 1). This body is 500 meters long and 200 to 400 meters wide, according to Luis Jaramillo. This is the largest of many areas of kaolinized rock within the Rio Frío anorthositic gneiss, but it is in a region 3 km north of the deep canyon of Rio Frío that is accessible only by mule trail. About 300,000 cubic meters of kaolinite is present, assuming a depth of only 2 meters. The reserves are therefore large enough to justify testing to ascertain if a suitable product can be prepared by beneficiation. There seems to be little possibility that the material can be exploited without beneficiation. The economic potential cannot be evaluated directly without analyses, but analyses of clay from the southern part of the parent(?) anorthosite body 3 to 5 kilometers farther south make important economic potential highly unlikely.

The parent anorthosite contains abundant chlorite, which forms the foliation, and some sericite. The Al_2O_3 content ranges from 27.5 to 33 percent in relatively fresh rock. The Fe_2O_3 content ranges from 3 to 4.4 percent.

Relatively fresh parent(?) rock contains 27.5 to 31 percent Al_2O_3 and 3 to 4.4 percent Fe_2O_3. Kaolinized rock contains 32.5 to 33 percent Al_2O_3 content and 1.5 to 3.8 percent SO_3. The iron and SO_3 content are probably too high for ceramic use because firing tests on other kaolinized rocks with less iron and sulfur burned dark brown. Therefore, the detailed analytical data for the anorthosite or the clays derived from it are not given.

The kaolinite content can be assumed to range up to 30 or 40 percent, judging from the kaolinites in the Cuatro Caminos-San Pedro area. Pyrite was not seen but it may have been present as indicated by the SO_3 content. Part of the iron was in chlorite and magnetite(?). Ferric iron oxides that were partly derived from pyrite or chlorite, and residual magnetite(?) probably are the principal iron minerals in the clay.

Bentonite deposits

Pure bentonite is unknown in the Sierra Nevada and in the surrounding regions, but many of the gypsiferous Miocene shales appear to be rich in swelling montmorillonite judging from the very wide shrinkage cracks that develop in the dry season. The cracks can reach widths of 10 cm. The shales are very slick when wet and apparently swell greatly. These characteristics were noted in the Tertiary strata along the road from Bosconia toward Campo El Difícil on the west bank of the Río Ariguaní (c-16).

These clays are certainly suitable for such uses as impermeable lining of canals, reservoirs, and stock tanks. They might even be suitable for drilling muds where relatively low quality would be acceptable.

Graphite

Two types of graphite have formed in the metamorphic rocks of the Sierra Nevada. The most common form is carbonaceous material, probably chiefly amorphous or semicrystalline graphite, in certain beds within the schists of the Early Tertiary orogen.

Locally layers of schist as much as 2 meters thick are estimated to contain 10 to 15 percent graphitic material. These beds are most abundant in the Gaira and San Lorenzo Schists, particularly along the road between Minca and the microwave relay station on Cerro San Lorenzo (c-3) and along the road to Colonia Militar (c-4). The graphite could be separated by flotation, but the required mining, crushing and other costs would be prohibitive. The graphite concentrate would be suitable only for the lowest grade uses such as paint and lubricants, which are now supplied by imported synthetic graphite, which is very cheap.

Locally the graphite has been recrystallized and concentrated into seams, particularly along the contacts of quartz veins and pegmatite dikes, but even these deposits lack commercial interest.

The second type of deposit contains well crystallized flake graphite, which is abundant in some layers of Precambrian granulites. These deposits have greater commercial potential, but not in the foreseeable future.

Well crystallized flake graphite is abundant in some layers in the Precambrian granulites of the Guamachito area where the graphitic rocks are associated with other granulites of unusual composition, including rocks rich in garnet or magnetite In hand specimens the brillant graphite flakes are readily confused with hexagonal flakes of biotite. The flakes are 2 to 3 or 4 mm in diameter.

The graphite occurs chiefly in layers which contain abundant garnet, quartz, perthite, and little or no plagioclase. Graphite makes up several percent of these rocks.

Well crystallized flake graphite that is suitable for electrical equipment is very expensive, particularly in larger sizes. Possibly commercial flake graphite could be produced from some layers in the Guamachíto area, but prolonged and expensive concentration tests by specialists in graphite beneficiation would be required in addition to exploration. It is unlikely that an export market could be developed, and no domestic market exists. Therefore, although similar deposits have been exploited, no exploration is recommended.

Graphite-rich beds are known in the undivided metamorphic rocks of the Sevilla Arch about half way between the Latal pluton and San Pedro de la Sierra (c-6, pl. 1). The graphite-rich gneisses crop out in several places between the headwaters of Quebradas La Cruz and Orihueca. The graphite in this area has been mistaken for molybdenite.

Mica

Phlogopite, biotite, and muscovite occur in the Sierra Nevada, but there are no known deposits from which cut or flake mica could be produced commercially.

The muscovite occurs in small books up to 1 or 2 inches (2-5 cm) across in many small pegmatite dikes in the Santa Marta batholith and in the enclosing metamorphic rocks for about 6 kilometers from the contact. Similar dikes are common on the western slope below an altitude of 1500 meters. All the known pegmatites are too small to mine, even if scrap mica could be a byproduct of feldspar mining operations. These simple pegmatites contain no other valuable minerals.

Biotite schist up to a few meters thick forms layers in the Precambrian granulites near the confluence of Río Los Mangos and Río Guatapurí and near Corral de Piedras. Some of these rocks are extremely rich in biotite or altered biotite that might be partly expandible (vermiculite). It is remotely possible that biotite or vermiculite could be produced as a soil additive to improve texture and slowly supply potassium, as has been done in Brazil (Agency for International Development, agricultural expert, oral commun.). A more likely use would be as a cover on thin asphalt-paper roofing material.

Phlogopite has formed only in calc-silicate marbles within the granulite sequence. It is nowhere abundant.

Silica

The glass factory of Peldar in Barranquilla wants a closer supply of glass sand, but we have not seen any deposits that could be exploited on the western or northern slope.

The quartz veins near Santa Marta, like the one on Hacienda La Carmela, 9 kilometers from Santa Marta are too small to exploit commercially unless arrangements could be made to use the old abandoned crushing plant near the Cienaga marble deposits. It is doubtful whether the Peldar factory would be interested in such a small source even if the crushing and mining costs were not large. It might be easier to produce a glass sand from the beach sand by means of flotation combined with electromagnetic separation and Humphrey Spiral Concentraters, but this would be feasible only as a byproduct of operations to recover magnetite and ilmenite or other heavy minerals.

Gypsum

The gypsum deposit on the offshore bar near Pueblo Viejo just west of Cienaga (Wokittel, 1960, p. 256) consists of hardly more than a few scattered selenite crystals and seams less than a few centimeters thick. Many of the Miocene strata around the west and south edges of the mountains are gypsiferous shales, but nothing of economic interest has been found that can be produced from the surface even at bare subsistence wages.

The gypsum in the Aguas Blancas Formation of Eocene age in the Cerrejon area does not appear to have any economic potential. Possibly a small amount might be hand picked from seams a few centimeters thick if a cement plant were established nearby; however, most of the gypsum required for cement would have to be transported from Santander where a good deposit is now in production. This new mine should rapidly displace most of the hand-picked gypsum produced in the Guajira Peninsula because river transportation to the large cement plant in Barranquilla is feasible. Most of the gypsum produced in Colombia has been used as an additive to control the setting time of cement. For this purpose crude gypsum is added during final grinding of the calcined clinker.

Salt

Salt is a state monopoly, and it is no longer produced at Pozos Colorados since the oil pipe line and marine terminal offshore were built there. Salt was formerly exploited at Pozos Colorados south of Gaira (a-3) by allowing salt water to intermittently flood the salinas behind the beach. Trade winds during the extreme dry season causes rapid evaporation to dryness.

Wokittel (1960, p. 231) reports that 3000 tons were produced at Pozos Colorados between 1954 and 1958. We did not seek more complete production data.

Asbestos

A few tiny veinlets of cross-fiber tremolite "asbestos" are associated with talc-tremolite deposits in serpentine near Quebrada Rodriguez. This mineral is too brittle for spinning, but might be used in asbestos-cement manufacture (eternite). Significant discoveries of fibrous tremolite are very unlikely.

Magnesite

A small uneconomic magnesite deposit reported near Santa Marta by Wokittel (1960, p. 263) was not confirmed. If it exists it may be a calcareous bed in the Taganga Phyllite northwest of the Santa Marta batholith, but it is more likely that small amounts of magnesite were found in the talc-tremolite deposits or in altered ultramafic rocks. Some of these rocks contain a carbonate that might be magnesite, but nothing of commercial value can be expected.

METALLIC MINERAL RESOURCES

Iron and titanium minerals and apatite

In the Sierra Nevada, there are several small deposits of magnetite, titaniferous magnetite, banded apatite-ilmenite rocks, and some thin layers of metamorphic rocks that are rich in magnetite or ilmenite and commonly apatite. Although none of these deposits has proved to be of immediate economic value, some may become economic resources in the future. The following descriptions may provide guides for exploration when accessibility improves and larger domestic markets develop.

The most promising deposits are in Precambrian anorthositic gneisses or are closely associated with these rocks. Three varieties of anorthositic gneisses are distinguished on the geologic map (pl. 1). They form a poorly defined, discontinuous northeast-trending belt. Perhaps other anorthositic gneisses are present between the known occurrences because the intervening area is inaccessible and is still poorly known.

Apatite-ilmenite deposits on Quebrada del Hierro

Geology.--Veins, dikes, and float of banded apatite-ilmenite rock have been found in the drainage of Quebrada del Hierro (e-3, pl. 1) south of Río Don Diego Chiquito, which is the principal tributary of Río Don Diego. The deposits are in and near a gneissic anorthosite just south of the Buritaca pluton of quartz diorite as shown on figure 4.

Veins of nearly pure ilmenite, or of ilmenite and apatite, and dikes of mafic rocks rich in these minerals intrude the anorthosite mass, which contains coarse interstitial accessory magnetite. The known ilmenite veins are less than two meters wide and have limited economic potential. The mafic dikes are also unusually rich in apatite and ilmenite or magnetite, but they are not economically interesting. The dikes and veins are probably related to the unusual banded bimineralic apatite-ilmenite rock described below. Only the banded ore can be considered an important potential economic resource.

The banded rock consists of many alternating parallel layers a few centimeters thick of apatite-rich and ilmenite-rich rocks. This rock is chiefly from float, except for one possible outcrop. The largest boulders, which are about 2 meters thick, contain about 40 parallel alternating layers of apatite and ilmenite that must have formed by gravitative separation in a stratiform mass of ore magma. The texture indicates that an ilmenite liquid crystallized as large intergrown grains that enclose subhedral to anhedral apatite grains.

The one possible outcrop of banded apatite-ilmenite rock was a large half-buried block about 4 meters thick near a vein (IMN 1271, fig. 5), but it may be a huge slump block that has ridden down the slope from a higher level. A vein of ilmenite 1 to 2 meters wide nearby may possibly have been a feeder for the adjacent banded ore, if the latter is truly an outcrop.

A white, medium-grained intrusive(?) plagioclase rock (oligoclasite?) crops out a hundred meters upstream, but its shape, size, and age are unknown. The banded ore may possibly be genetically related to this oligoclasite.

Analytical data.--The banded rock contains 30.9 to 33.9 percent total iron as Fe_2O_3, 19.7 to 20.9 percent P_2O_5, and 19.2 to 19.7 percent TiO_2. The dark and light bands appear equal in total thickness. Only apatite and ilmenite are present. These minerals may occur in any proportion in individual layers, but overall they are present in about equal amounts by volume.

Semiquantitative spectrographic analysis of the crushed banded ore by Nancy M. Conklin (U. S. Geol. Survey, 1967, written commun.) showed 0.1 to 0.7 percent of magnesium, silicon, aluminum, manganese, and cerium, and smaller amounts of other rare earths listed in order of decreasing abundance. An apatite concentrate contained about 0.2 percent Fe and Mg. Nearly all rare earths are contained in apatite.

Two samples from dikes cutting the anorthosite were studied in thin section. Both contain about 20 percent oligoclase; the percentage range of composition is 10-25 percent pyroxene, 10-25 percent uralitic amphibole, and 10-20 percent apatite. One sample (IMN 1269) contains about 3 percent magnetite(?), 3 percent sphene, and about 5 percent sulfides; another sample from the same dike contained 14.65 percent Fe_2O_3, 2.01 percent P_2O_5, and 1.03 percent TiO_2. The other sample (IMN 2170) contain 15 percent ilmenite, 2 percent sulfides, a little orthopyroxene and biotite, and much less amphibole.

One vein (IMN 1271) contained 33.2 percent Fe_2O_3, about the same as the banded ore, 11 percent TiO_2, and 6 percent P_2O_5. The titania content and especially the phosphoric oxide content are considerable less than in the banded ore.

Economic potential.--In large enough amounts the banded ore would be a valuable resource because it is technically feasible to produce two commercial concentrates, one of apatite and another of ilmenite. The inferred stratiform shape would make exploration relatively easy if the banded ore could be found in outcrop. Thicknesses between 2 and 4 meters can be inferred from float blocks or possible outcrops and if the deposit is stratiform, there would be possible reserves of 8,200,000 to 16,400,000 metric tons per square kilometer of area, using a specific gravity of 4.1. The potential size of the target thus justified exploration, but of course no reserves can be estimated at present. The heavy vegetation and lack of access trails would make exploration difficult and the high costs of road construction would require large reserves before exploitation would be feasible. Aeromagnetic surveys probably would not be successful because the high magnetite content of many layers of metamorphic rocks would produce anomalies comparable to the ilmenite deposits.

A possible distant source for part(?) of the banded apatite-ilmenite rock is indicated by its presence in an unconsolidated gravel 0.7 kilometer south of Quebrada del Hierro. This gravel is present on dissected remnants of an ancient erosion surface on both sides of a small quebrada that cuts the underlying metamorphic rocks. The gravel contains well rounded cobbles and boulders of banded rock as much as 20 cm thick. The elevation of the gravel (370 to 400 meters) is well above the top of the anorthosite.

If the banded apatite-ilmenite rock is derived from gravels that were deposited during an earlier erosion cycle, no economic evaluation would be possible until the source was found. A possible distant source may be the Precambrian granulites in the central part of the Sierra Nevada where unbanded metamorphic rocks very rich in apatite and magnetite were found by Gansser (1955). However a genetic relationship between the banded ore and the anorthosite, the veins, the dikes, and the intrusive(?) oligoclasite is more likely. All these can serve as guides for exploration.

Quite possibly other deposits will be found in areas of metamorphic rocks in the surrounding region, particularly near anorthosites which might be more widely distributed than is indicated on the map. A number of rock units were not identified on the aerial photographs, including one possible vein or dike that is shown in blank near the south edge of figure 4. There are unconfirmed reports of iron(?) deposits different from the banded ore in the Central batholith about 30 kilometers from the coast and also east of figure 4. At least 12 applications for iron concessions have been submitted. Further exploration is justified and economic deposits may yet be found.

Metamorphic rocks rich in ilmenite, magnetite, or apatite

Layers of Precambrian gneisses that are exceptionally rich in ilmenite, magnetite, or apatite have been found in four areas in the Sierra Nevada. Two localities were reported by Gansser (1955) in the high glaciated central part of the Sierra Nevada. Magnetite-rich granulites were found in the Guamachito area on the western edge of the mountain mass. Gneisses rich in magnetite or ilmenite and apatite were found by MacDonald (1969, written commun.) near the Niyula anorthosite body west of Río Don Diego (e-4).

These rocks have no economic value at present, but it is possible that thicker or richer deposits may be found. Therefore a brief description is given.

Thin layers of ultramafic granulites that are very rich in magnetite (or ilmenite?) and apatite were found by Gansser in mafic granulites on the west-northwest side of El Guardián, a peak about 5285 meters high south of Río Donachui, and also west of the Paleozoic outcrops in the Chundua region. One rock in the El Guardián area contains 65 percent magnetite (or ilmenite), 20-25 percent apatite, and a little hornblende, olivine, and accessory sphene epidote, and biotite. Some rocks also contain plagioclase. The apatite-ilmenite rock near El Guardian is very similar to the apatite-ilmenite rocks on Quebrada de Hierro except for the lack of banding.

In the Chundua region some pyroxenite layers in the Precambrian metamorphic sequence are rich in magnetite or ilmenite but apatite is almost absent. Gansser's sketch of a thin section indicates about 30 percent opaque oxides plus another 15 percent of sphene, which envelopes the ilmenite(?).

Sample 292 of MacDonald (1967, p. 44) was described as a quartz(?)-ilmenite-hornblende granulite that contains 40 percent hornblende, 25 percent ilmenite(?), and 30 percent quartz. Feldspar or mica are absent. We wondered if the quartz might not be apatite instead, considering the nearby anorthosite and the remarkable absence of feldspar. This was confirmed by MacDonald in a letter dated May 16, 1969.

The magnetite-or ilmenite-rich granulites in the Guamachito area are associated with garnet-rich granulites. Some of these rocks contain as much as 20 or 30 percent magnetite.

Mocoa (Espiritu Santo) magnetite deposit

The Mocoa colluvial magnetite deposit is on the ridge between Quebradas Mollete and Espiritú Santo near the headwaters of Quebrada Seca along a road at an altitude of about 400 meters. It is within the anorthositic gneiss one kilometer south of Río Sevilla. The location is indicated on the geological map (pl. 1) by the iron prospect near coordinates 1,000,000 W. and 1,680,000 N.

The deposit consists of loose angular blocks of magnetite enclosed in a bright red clay. The largest blocks are about one meter in diameter. The primary deposit does not crop out, nor was it discovered in trenches and pits dug in 1943. However, the size and angularity of the magnetite blocks indicate that there must be a hidden deposit of unknown size and shape _in situ_ nearby.

The deposit consists entirely of coarsely crystalline magnetite that contains fine-grained spinel and ilmenite(?) exsolved along the octahedral (111) crystallographic planes which causes a pronounced octahedral cleavage. Beautiful octahedral crystals and cleavage fragments are common. The deposit is probably a high-temperature magmatic deposit.

Microscope study by Fricke and others (1960, p. 100-105) showed that the magnetite was partly transformed to hematite (martite) along the octahedral partings. The ilmenite plates contain very fine grains of aluminum spinel and hematite flakes. The spinel is very abundant, judging from the high alumina content in the analyses.

The iron content varies from 59.3 to 61.7 percent in three analyses. The alumina content was reported to be 13.0 percent (Fricke, 1960), and 11.7 percent insoluble was reported by Mutis (1945). The titania content is 1.4 to 1.5 percent. The magnesia content is 1.3 percent; MgO is 0.19 percent, and SiO_2 is only 0.23 percent. Phosphorus is very low (0.016 percent P_2O_5). Traces of chromium, nickel, lead, vanadium, cobalt, gallium, copper, zirconium, germanium, molybdenum, and antimony were detected spectrographically (Fricke, 1960).

The deposit was explored in 1943 by Eng. Vincente Mutis (1945, p. 414-432). Trenches and pits were dug on a 25-meter grid and sampled. The part of the deposit that contains over 100 kg per cubic meter measures 250 by 275 meters. This irregular area contains seven smaller concentrations, which contain more than 500 kg per cubic meter.

The area with magnetite float has an irregular equidimensional shape which suggests a stock work or breccia pipe rather than a single vein. The red clay that encloses the magnetite may indicate alteration of the mineralized rock because the anorthosite host rock normally weathers white.

The total exploitable reserve is small, because the primary deposit was not discovered. Mutis estimated that 8,000 tons of magnetite could be recovered from material having an average grade of 270 kg per cubic meter. The deposit has little apparent economic value because of its small size and relatively high titanium content. It is said to be owned by Acería Paz del Río (integrated government steel mill) who shipped several truckloads of hand-sorted ore, possibly for test purposes.

Similar but much smaller alluvial or colluvial deposits and sparse magnetite or ilmenite float are widely distributed between this deposit and Río Tucurinca but no outcrops are known. The economic possibilities of the known deposits are small, but small economic deposits might yet be found. Magnetite (or ilmenite) has been found in small quantities in Quebradas Hobo, Cristo, Patagonia, Flojera, and Hierro (Reymond, 1945, p. 411) and in Quebrada Mollete. Reymond (1942, unpub. report No. 294) reported that magnetite from "Torrente de Cristo" contained 54 percent Fe and 0.33 percent Ti. Wokittel (1960, p. 162) reports ilmenite containing over 25 percent TiO_2 somewhere south of Sevilla.

La Reina magnetite deposits

Gansser (1955) reported magnetite deposits on the west-northwest side of Pico La Reina on the south edge of the glacier. We did not visit these deposits, which are shown by two prospect symbols labelled Fe on pl. 1 near coordinates f-7.

The largest magnetite deposit is at an elevation of 5,100 meters on the contact between the batholith near Pico Ojeda and the porphyry on Pico La Reina. It consists of massive magnetite, which appears to have replaced original scales of hematite. A large part of the deposit is covered by glaciers. These deposits might be economically exploitable if they were in an accessible place, but their location rules out any foreseeable commercial value.

Some deposits are related to dikes that are intruded along the contact between granite porphyry and granite gneiss. Magnetite with a little quartz and pyrite occurs on the contact of dikes of granophyric granite porphyry and veinlets of magnetite occur within the dikes. The magnetite in dikes of hornblende diabase appear to come from the porphyry.

La Socola magnetite deposit

A small vein of no commercial value is probably present in the altered volcanic rocks near the west contact of the granitic outcrop near the road north of La Socola (i-9, pl. 1). This deposit is indicated by angular float up to 50 cm in diameter of pure magnetite.

Black beach sands

Wokittel (1960, p. 162) reports ilmenite-bearing sands in the Municipio de Cienaga where there were five concessions. The first occurrence may be near Río Tucurinca where float magnetite (or ilmenite) was reported during the geological mapping. The other ilmenite-bearing sands probably are on the coast.

Beach sands rich in ilmenite or magnetite are common from Cienaga west past Barranquilla through Puerto Colombia as far as Galerazamba. The commercial potential of the beach sands between Barranquilla and Cienaga is slight unless higher grade layers are present beneath the surface.

The beach sands of the north coast, particularly those near Puerto Colombia west of Barranquilla, deserve further evaluation including drilling if preliminary sampling and concentration tests indicate the possibility of producing salable concentrates of magnetite, ilmenite, and possibly apatite. Layers of black sand containing up to 50 percent heavy minerals form seasonally on the wide beaches between Puerto Colombia and Barranquilla by wave action during the breezy season. These seasonal layers are as much as 25 cm thick. The black minerals are presumably magnetite because they are strongly magnetic, but the titanium content might be too high for use as iron ore.

Similar ilmenite-bearing(?) sands occur locally on the small beaches in the protected coves east of Santa Marta and along the north side of the Sierra Nevada, but the content of black minerals appears to be lower than near Puerto Colombia.

The source of the ilmenite in the black sands near the Sierra Nevada is the metamorphic rocks judging by the relatively high amounts of titanium shown by semiquantitative spectrographic analyses of 8 to 19 samples. Four samples (IMN 777, 778, 786, and 780) contained between 1 and 3 percent titanium and 4 others contain about 0.7 percent according to semiquantitative spectrographic analyses. The samples with the greatest amount of titanium also were generally rich in iron, which exceeded the titanium by a factor between 2.5 and 10, usually between 5 and 7.

Titanium occurs chiefly in opaque iron-titanium oxides and in sphene, but much of the iron in these rocks is in silicates and sulfides as shown by the samples rich in iron but poor in titanium. These latter samples include a mineralized quartz diorite with sulfides (IMN 701); a peridotite (IMN 781) with about 10 percent iron, 0.7 percent chromium and 0.3 percent nickel and virtually no titanium; and a quartz-garnet granulite (IMN 785) with over 10 percent iron and manganese, chiefly in the garnet.

Some metamorphic rocks much richer in titanium discussed in the preceeding section have also contributed to the beach sands.

Copper

The local concentrations of copper minerals noted in three units of red beds of Mesozoic age during the geological mapping did not warrant detailed study. Most of the known deposits have already received considerable attention because of erroneous comparisons with porphyry copper deposits and suggestions of significant supergene enrichment despite the lack of any gossan or limonite boxworks that might indicate a leached zone of copper sulfides. Past unrealistic economic evaluations were based on these ideas. Therefore the description of the deposits is limited to a brief summary of those in the map area, compiled chiefly from the reports listed below. Copper minerals were seen in about 22 places, which are shown by prospect symbols and the symbol Cu on plate 1.

The reader is referred to the reports of Wokittel (1957, p. 60-67) and later investigators for more detailed descriptions, sketch maps, and analytical data. Wokittel's pioneer study was followed by more detailed studies by a German government mission (Fricke and others, 1960 unpub. open file report), by the Servicio Geologico (Campetier and others, 1963) and a Japanese government mission (Horikoshi and others, 1965 and 1966, unpub. open file reports). Pagnacco (1962, p. 5-13) published a brief description of the copper mineralogy, which appears to supplement the report of Champetier and others. A part of the latter report was published in 1962 by Radelli in Geologia Colombiana.

Deposits in redbeds

Description.--Minor concentrations of largely oxidized copper minerals are scattered along the west border of the Serranía de Perijá for 140 kilometers from near San Diego almost to the Oca Fault, but most of this belt lies beyond the area mapped. Within the mapped area, these deposits are clustered (1) between San Diego and Media Luna, and (2) between Urumita and Los Portales, on the east-central margin of plate 1. Similar deposits occur in the southern edge of the Sierra Nevada. Many of these deposits are shown on plate 1 by prospect symbols and the symbol Cu.

The deposits are in red beds that range in age from Triassic (Guatapurí Formation) to Early Cretaceous (Los Portales Formation), in intercalated spilitic, basaltic, or andesitic volcanic rocks, or in small hypabyssal intrusive bodies, and are of three types: (1) lenses and veinlets of quartz-epidote rock with copper minerals; (2) disseminated deposits of oxidized copper minerals in red beds; and (3) oxidized copper minerals in brecciated hydrothermal quartz veins (El Rincón).

Most of the copper deposits in the San Diego area are lenticular veins of quartz-epidote rocks in spilitic, andesitic, or gabbroic rocks or in the enclosing red beds near the contacts. Deposits between

Urumita and Los Portales are similar quartz-epidote veins or disseminated deposits in red beds. The geological map (pl. 1) does not show all the deposits because of the small scale. The location of 8 prospects in the Urumita area is given on a map by Horikoshi and others (1966).

The mineralogy is simple and varies chiefly in the proportion of oxidized copper minerals and sulfides. Among the sulfides chalcocite replaces a little bornite and covellite replaces chalcocite. Sulfides decrease in abundance northward and are generally rare in the region north of Urumita. The predominant minerals are malachite, azurite, chrysocolla, cuprite, and native copper.

All the named deposits shown on the geologic map consist of quartz-epidote rock except that at El Rincon. The veins and lenses are commonly very small and are in both igneous and sedimentary rocks. The veins were apparently formed in minor fractures by residual or deuteric fluids from the igneous rocks. This is most clearly shown by the stratiform concordant mineralized zone in red sandstone below an andesitic volcanic flow(?) at the Ovejo prospect (Horikoshi and others, 1966, p. 28). The mineralized zone is about 20 meters thick and as much as 400 meters long, but it is very low grade (less than 0.05 percent copper) because it consists of widely spaced steep lenticular veinlets or lenses of quartz-epidote rock that are less than several meters long and less than 20 or 30 centimeters wide. Elsewhere these veinlets seldom contain more than 1 percent copper, but the grade is as high as 4 or 5 percent locally. The veinlets seldom constitute more than 5 percent of the mineralized zone.

Clearly the quartz-epidote veins, and the copper minerals in them, formed at relatively high temperatures. It is logical to relate the veins to the deuteric or late magmatic alteration of the volcanic and hypabyssal rocks. Many of the volcanic rocks and some of the hypabyssal intrusive rocks are reddish spilites in which the primary mafic minerals have been replaced by secondary minerals. This alteration may have freed the copper that was contained in the primary mafic minerals, allowing it to be redeposited in veins filling the cooling cracks.

It hardly matters whether the magma was sufficiently hydrous to be thoroughly altered at a late stage of crystallization, or whether the mafic rocks were extruded or intruded into water, or into water-saturated sediments. The relative scarcity of sulfides, especially sulfides rich in sulfur, and the abundance of hematite instead of pyrite is consistent with this mode of origin, which explains the very small size. The mineralizing fluids were relatively oxidizing as shown by the abundance of hematite and oxidized copper minerals. Part of the residual mineralizing fluid escaped into the enclosing sedimentary rock and into the minor fractures.

The quartz-epidote copper veins thus represent a peculiar type of late magmatic or hydrothermal deposit. Accordingly the sulfides are primary, not supergene, although chalcocite is often supergene in deposits in other regions.

The mineralizing fluids were too poor in sulfur to form sulfides rich in sulfur, such as pyrite and chalcopyrite, and the environment was too oxidizing to allow iron sulfides or mixed iron-copper sulfides to form except for a little bornite. The iron was deposited as epidote and hematite before the sulfides formed. The depletion of iron and sulfur caused the copper to be precipitated first as bornite, then chalcocite, then covellite. Finally primary(?) native copper and cuprite may have formed. Azurite and malachite in the veins are probably secondary.

Clearly there has been considerable local solution and migration of copper during erosion and weathering. Migration may also have occurred through aquifers after folding or faulting. Some deposits of very low grade disseminated malachite or azurite may have been formed by copper that was precipitated from migrating dilute fluids by calcite in the red beds or in the altered igneous rocks. However we do not believe supergene enrichment has occurred in the veins, because copper is rarely greatly leached in the absence of abundant iron sulfides, which oxidize to form sulfuric and sufurous acids and ferric sulfate, all strong solvents. This leaching process is invariably marked by precipitation of iron and the formation of voids, except in deposits that are unusually rich in pyrite.

Economic potential.--The only deposit of any economic potential is the El Rincón deposit, which was discovered by the Japanese team in 1966. None of the other deposits have any economic potential even during periods of high copper prices and further exploration is not justified. This unfavorable evaluation does not exclude the possibility of economic copper deposits in the interior of the Serranía de Perijá, which is little known geologically. There is no reason to expect that commercial deposits will be found in Mesozoic red beds. Although insignificant concentrations of secondary copper minerals are widely distributed in red beds, they seldom contain important deposits.

No large intrusive complex, such as those in which prophyry copper deposits occur elsewhere, are known in the Serranía de Perijá and the intrusive rocks in the Sierra Nevada appear to be barren.

El Rincón copper prospect

The El Rincón vein deposit was described by Horikoshi and others (1966). About ten veins between 0.15 and 3.0 meters wide form a mineralized zone about 400 meters long near the San José Fault (pl. 1). The veins form four en echelon groups, each about 100 to 150 meters long. The veins strike N. 45°-80° W. and dip 70°-80° SW., and contain brecciated quartz impregnated by malachite and chrysocolla. No sulfides are present.

The widest veins contain between 1.15 and 1.39 percent copper and 36 to 49 g/t silver over widths of 2 to 3 meters. The grade increases slightly downward. The Japanese estimated an average grade of 1.40 percent Cu of which 1.30 percent is acid soluble, and 40 g/t silver.

The reserves of oxide ore was estimated to be 42,687 tons to a depth of 30 meters, but the Japanese expect that primary sulfide ore is probably present at depth, partly because of the high silver content. They concluded that possibly 150,000 tons of reserves might be present above a depth of 100 meters and suggested exploration to test this possibility.

The veins were discovered accidentally by the Japanese in 1966 and apparently were not previously known. We have not seen the deposit, and therefore cannot judge the probability of hypogene sulfide ore at depth. This possibility must be considered questionable in view of the complete lack of sulfide. No mention was made of a gossan, voids or a leached outcrop. Therefore all the copper possibly was deposited from ground waters moving along the brecciated quartz veins. The high silver content does not necessarily indicate a hypogene deposit as shown by the fact that silver deposits in sandstone near Leeds, Utah, may be deposited from ground water.

Gold

There are very few specific data, and no reliable production data, on the gold deposits in the Sierra Nevada. Gold taken from the Tairona Indians or from graves ("guacas") in the form of artifacts, which may not have been mined in the region, probably accounted for most of the production. We do not know of a single deposit, either lode or alluvial, that could be mined under foreseeable conditions. The following is a brief summary based chiefly on two published reports by Restrepo (1937) and Reymond (1942). Many unconfirmed references to gold in the Sierra Nevada in historical documents do not give specific data suitable for inclusion in this report.

Gold has been mined in the Sierra Nevada largely if not entirely from alluvial deposits, if gold artifacts are excluded. Gold has been reported from the drainages of the Ríos Buritacá, Cordoba, Sevilla, Tucurinca, Dibulla, Don Diego, and Palomino (pl. 1) and from quebradas Palencio and Achiote whose locations are not known. These reports are based on colonial documents quoted by Restrepo (1937, p. 201-202) and others. It is not clear how much gold was mined and how much was excavated from graves.

The occurrence of alluvial gold in the drainages of the rivers along the western slope was confirmed by panning by 750 people who were unemployed because of disruption of the banana industry by World War II. Reymond (1942, p. 424-425) reported that the average amount recovered in a day's panning was only 0.8 g of 900-fine gold, but some rich pockets yielded as much as 1 kilogram of gold. He reported that all the rivers on the western slope of the Sierra Nevada, particularly between Río Frío and Río Fundación, contain gold.

Some layers at the base of consolidated conglomeratic beds were rich enough locally to justify primitive attempts to mine a short distance under ground. It is not known whether these layers were in the Tertiary or Quaternary rocks, but probably some gold is present in the Tertiary conglomerates, particularly in those that directly overlie the bedrock. The Tertiary rocks, however, are not definitely known to contain gold.

Restrepo and Reymond agree that gold was mined near the town of Sevilla. Restrepo described gold artifacts that weighed between 4 and 9.5 pounds that were found near where fine gold was panned. He estimated that the total gold production of Magdalena (including Cesár) was about 1,000,000 pesos up to 1890, but we are unable to convert this into modern money or weights. Presumably most of this gold was Indian artifacts, which suggests that it was imported because the Taironas were famous goldsmiths and dominated the north coastal region.

We could not confirm the occurrence of gold on the north slope of the Sierra Nevada. Raul Durán met a campesino, who claimed to have found a little gold near the surface. Gold panned from Río Buritacá by another campesino proved to be altered, bronze-colored biotite.

Gold was mined from shallow narrow alluvial ribbons along several quebradas draining the west side of the low hills of Precambrian granulite in the Guamachito area (b-8, pl. 1). These short quebradas between Río Sevilla and Río Tucurinca were thoroughly panned during World War II, judging by the number and spacing of the pits. The remaining volume of alluvial material is too small to have any further economical value. Undoubtedly this is part of the productive area referred to by both Restrepo and Reymond.

The source of the gold in the Guamachito area is an interesting problem. Probably it is derived from Precambrian granulites or from veins or dikes intruding them, because the quebradas do not drain other rocks. The unlikely alternatives require the gold to be derived from either the main part of the Sierra Nevada along a former drainage system that is unrelated to the present one, or from Tertiary sedimentary rocks that once might have overlain these low hills.

Gold and silver were not detected in two semiquantitative spectrographic analyses of the granulites from the Guamachito area (IMN 698, 785). More than 1 ppm silver and 20 ppm gold are normally detected by this method. Fire assays of two other samples from Quebrada Manantial did not detect either gold and silver, but these samples did contain traces of common metals as shown by the following chemical analyses by the Medellín Laboratory of the Ministerio de Minas y Petroleo:

		Percent					
Sample number	Rock type	Copper	Lead	Zinc	Iron	Manganese	Sulfur
IMN 697	Garnet-quartz-perthite granulite	0.14	0.65	0.21	1.54	0.72	3.09
IMN 701	Quartz-perthite-granulite	.15	.06	.26	3.12	.28	3.89

These metals are contained in the disseminated sulfides that are commonly present in the metamorphic rocks of the area. Pyrite and chalcopyrite(?) were identified in hand specimens of both samples.

Eleven samples from other areas, that contained relatively abundant sulfides or which were altered, were fire assayed for gold and silver, but traces of gold and silver were detected in only two of them. These negative results included the most promising samples encountered in the course of the geological mapping. Most of these samples came from the area between Pueblo Bello and Valledupar. No mineralized veins wider than a few centimeters were seen in the whole Sierra Nevada, although barren quartz veins are relatively abundant on the western slope.

One mine(?), presumably a lode mine, was reported to have been worked briefly about 15 years ago. This mine is supposed to be a few kilometers south of the Río Aracataca near the outer part of the Aracataca Batholith. The operation was carried on in secrecy and perhaps it was a treasure instead of an actual lode mining operation. The area was mapped in 1965 during the early stages of the project and we do not have any more data.

Other metallic minerals

Manganese deposits first reported by Reymond (1942) and published again in the compilation of Wokittel (1960, p. 141) have no economic significance. Their very existence is doubtful because graphite might have been confused with pyrolusite.

Molybdenum near the Aracataca area reported by Wokittel, probably was graphite. A few grains of molybdenite were seen in a pink granite (IMN 432) from Quebrada San Pedrito (f-12, pl. 1) at the headwaters of Quebrada Santa Tirsa. Chemical analysis showed that the rock contained 0.06 percent molybdenum, but it has no commercial value. A few parts per million (ppm) of molybdenum were detected in 2 of 17 samples by semiquantitative spectrographic analyses. One of these, an amphibolite which contains about 30 ppm Mo, was the only sample with detectable silver (5 ppb).

Tungsten is not known to occur in the Sierra Nevada, although many igneous rocks and calc-silicate rocks were checked for scheelite with an ultraviolet lamp. A few almost microscopic specks in some calc-silicate rocks gave the typical fluorescence of scheelite and other tiny grains gave the typical fluorescence of uranium, but neither element was detected by semiquantitative spectrographic analyses of 17 samples.

A peridotite partly altered to talc and tremolite contained about 0.7 percent chromium and 0.3 percent nickel. This is normal for rocks so rich in magnesium and iron and it has no economic significance.

Uranium and thorium minerals are absent in the Sierra Nevada except the trace amounts normally occuring in igneous and metamorphic rocks. A radiometric reconnaissance made in 1956 by Dr. Jaime López (Servicio Geologico Nacional, unpub. open file report 1158) between Valledupar, San Sebastian, and Pueblo Bello did not reveal any unusual radiation that was not consistent with the local lithology. The potassium-rich quartz-perthite granulite layers intercalated with biotite schist along Rio Los Mangos had radiation levels 6 to 8 times the normal background, that is up to 0.1 mr/hour but chemical analyses did not reveal uranium. Such high backgrounds are normal for potassium-rich granitic rocks that have very low contents of calcium and magnesium. Equally high background was found locally in similar rocks during scintillator traverses during this program but no economic significance can be attached to such readings. High radiation is particularly typical of the pink granite, and especially of the fine-grained granophyric granites in the Patillal Batholith.

Exploration potential for sulfide deposits

The scarcity of significant metallic deposits, particularly of sulfides of the common base or precious metals, is surprising in view of the abundance of plutonic rocks of many different ages, some of which were relatively shallow as shown by the contemporaneous ignimbritic volcanic rocks. The complex structure, particularly the major lineaments, should have provided adequate channels for ascending solutions derived from three separate orogens or from the major plutons of five ages unless the major faulting was invariably pre-intrusive so that there was little or no faulting during the hydrothermal stage.

The absence of sulfide base metal deposits in the Precambrian granulites is hardly surprising because they were formed under very high pressures and temperatures in the deepest levels of the crust and may be polymetamorphic. Common sulfide-forming metals would long since have been expelled upward from them. However, the same is not true of the other lower-grade metamorphic rocks, which contain favorable reactive beds such as marble. Disseminated sulfides are common in the schists and gneisses of the Sevilla Arch and Eocene Orogens, but apparently this adequate supply of metals was never concentrated. The plutonic rocks are remarkably sterile and veins with sulfides are very rare.

The absence of disseminated sulfides and sulfide deposits related to the batholiths can only mean that the magmas, for some reason, were extremely poor in metals. Either the magmas were generated from metal-poor metamorphic rocks or the processes by which they formed did not allow them to take up the metals. Perhaps the region is a sterile metallogenetic province.

The scarcity of gold, silver, and base metals in the igneous and metamorphic massifs of Colombia that have been studied by this exploration program is the rule rather than the exception. Gold is commonly associated only with the Antioquian Batholith. Exploration programs therefore should be directed toward the unmetamorphosed geosynclinal rocks that crop out between the Sierra Nevada, Santander, and Antioquian massifs.

Igneous rocks of the types and ages found in the Sierra Nevada seem to be unfavorable for the discovery of significant deposits of the common sulfophile metals in northern Colombia. The igneous and metamorphic basement has been well mapped in the Guajira Peninsula, in the Sierra Nevada, in the southern part of the Santander massif, and in Antioquia. The Triassic, Jurassic, Lower Cretaceous, and Eocene plutons and the associated volcanic rocks are all apparently sterile and attention should be directed to other igneous rocks. Similarly the Precambrian granulites appear to be unfavorable, but perhaps it is too early to write off the younger metamorphic rocks outside the Sierra Nevada, where the sulfides might have been concentrated instead of remaining disseminated. This is not to say that economic deposits might not eventually be found in the two younger metamorphic series in the Sierra Nevada, but that the prospects are poor, considering the accessibility, difficult terrain, and prevalent heavy vegetation. Under these circumstances, search for small hidden massive sulfide lenses, the most likely deposits, is very difficult because airborne electromagnetic or magnetic methods are excluded by the terrain.

Suggestions for future exploration

We conclude that the Sierra Nevada is not favorable for the discovery of important sulfide deposits, and only a limited amount of exploration is justifiable when adequate laboratory facilities become available. No further work should be done without a geochemical laboratory and a spectrograph to analyze for traces of common metals. Once these facilities are available and more favorable areas have been studied, we recommend a limited geochemical prospecting program.

The first stage of the prospecting program should consist of systematic sampling of the water in the streams draining the Sierra Nevada during low water. Quick geochemical surveys for combined lead-zinc-copper should be made of the principal streams to establish regional background. Any significant anomalies should be followed upstream to their source in the drainage basin. Then the soils in the source area might be sampled if a careful search does not reveal evidence of a deposit. Sulfides do not last long near the surface in hot, humid climates and deposits formed by metamorphic segregation usually have few visible surface signs. Vein deposits are unlikely in the areas we mapped, but blind sulfide deposits might occur in the Sevilla Arch province and in areas of hydrothermal alteration southeast of the southeastern belt of batholiths, particularly west of Valledupar. For such deposits the best method is water sampling, particularly in heavily forested humid areas.

The batholiths are considered to be distinctly more favorable than the hypabyssal and volcanic rocks. The younger metamorphic rocks are more favorable than the Precambrian granulites, particularly in the Sevilla Arch. The red beds are distinctly unfavorable. The Cretaceous limestones are unfavorable only because they are younger than most of the igneous activity in the regions where they occur. The Paleozoic limestones are considered more favorable because they are older than all the igneous rocks. The Corual Formation and the highly altered hypabyssal rocks that intrude(?) them east of the Tierra Nueva Fault are relatively favorable, although limestones are absent.

Drilling should not be considered unless and until good geochemical anomalies or other evidence of sulfide mineralization are found.

WATER RESOURCES

Assessment of the ground water potential is important because of the large areas of undeveloped or underdeveloped fertile semiarid land around the margins of the Sierra Nevada, particularly in the Cesár and Ranchería Valleys, where new productive rice and cotton industries could be greatly expanded with adequate water for irrigation. Some specific areas are being or have been investigated by other agencies and ground water resources have already been partly developed in the Codazzi area for growing cotton and rice. An investigation of the ground water potential of the dry areas in the Ranchería Valley and in the lowlands near the Oca Fault near Cuestacita is being made now for the Corporación del Valle del Rio Magdalena or the Instituto Nacional de Cooperativas y Reforma Agraria by technicians from Israel.

Rancheria Valley

The water potential of the area between San Juan de Cesár and the Oca Fault appears to be good in regard to the Cretaceous and the Eocene rocks. The limestones of Cretaceous and Paleocene age offer artesian potential because the dip slopes along the west side of the valley would channel all the ground water on the east slope down under the arable valley areas. Very good soils can be expected in the limestone areas and the adjacent valley slopes.

The most promising artesian aquifers are the Cogollo Group, the La Luna Formation, and the Hato Nuevo Formation. The artesian potential of these rocks on the east side of the valley cannot yet be clearly defined because the structure is poorly understood. The quality of ground water from the Cretaceous and Paleocene rocks should be good.

The folds in the Paleocene and Eocene rocks suggest the possibility of local artesian water potential on the flanks of the anticlines in the Papayal area.

The coarser clastic beds in the Eocene section offer better potential than the finer grained rocks, but the quality may be poor to fair because fairly high saline content might be expected. The ground water potential of the Quaternary rocks is probably not very great on the west side of the valley, but may be much better along the Perijá front.

Cesár Valley

The artesian water potential is probably not very great along the west side of the valley because the source areas are too low to receive abundant rainfall and the catchment basins are small. This is particularly true of the Cretaceous rocks. Otherwise the artesian water potential would be quite good.

The most promising artesian aquifers are the La Luna Formation and the sandstone or conglomerate at the base of the Cogollo Group. The ground water potential of the Guatapurí Formation is probably small because of low porosity, but local conglomerates at the top may be good local aquifers.

The ground water potential of the west edge of the valley in the Los Venados area is sufficiently promising to deserve study along a belt 5 kilometers wide and parallel to the Cretaceous outcrop; further out to the southeast the potential aquifers are buried beneath too much Umir shale, which has virtually no ground water potential.

Even if ground-water movement may be interrupted by the Cesarito fault, the Cretaceous rocks northwest of it still might contain exploitable ground water along the projected northeast strike of the Cretaceous rocks.

The ground-water possibilities of the central part of the César Valley are not very great because the east-dipping favorable Cretaceous rocks are deeply buried. In these areas the only potential source is a few hundred feet of Pliocene or Quaternary unconsolidated sediments, which probably have been eroded all along Rio Cesar. Locally these rocks may have limited potential where they are thicker as on the downthrown side of such faults as the Cesarito, San Diego, and Media Luna Faults.

Potential artesian sources may exist on the southwest-plunging tip of the Verdesia anticline where Cretaceous rocks are exposed just south of the mapped area.

The very good ground-water potential of the Quaternary rocks east of the Media Luna Fault has already been studied (López, 1958, unpubl. open file report 1289) and in part developed. The depth to the water table in the Quaternary sediments is less than 18 meters. Commonly, the depth is less than half this. Four test walls were drilled by Servicio Geológico in 1958 (Unpubl. open file report 1311) and private development began shortly afterward.

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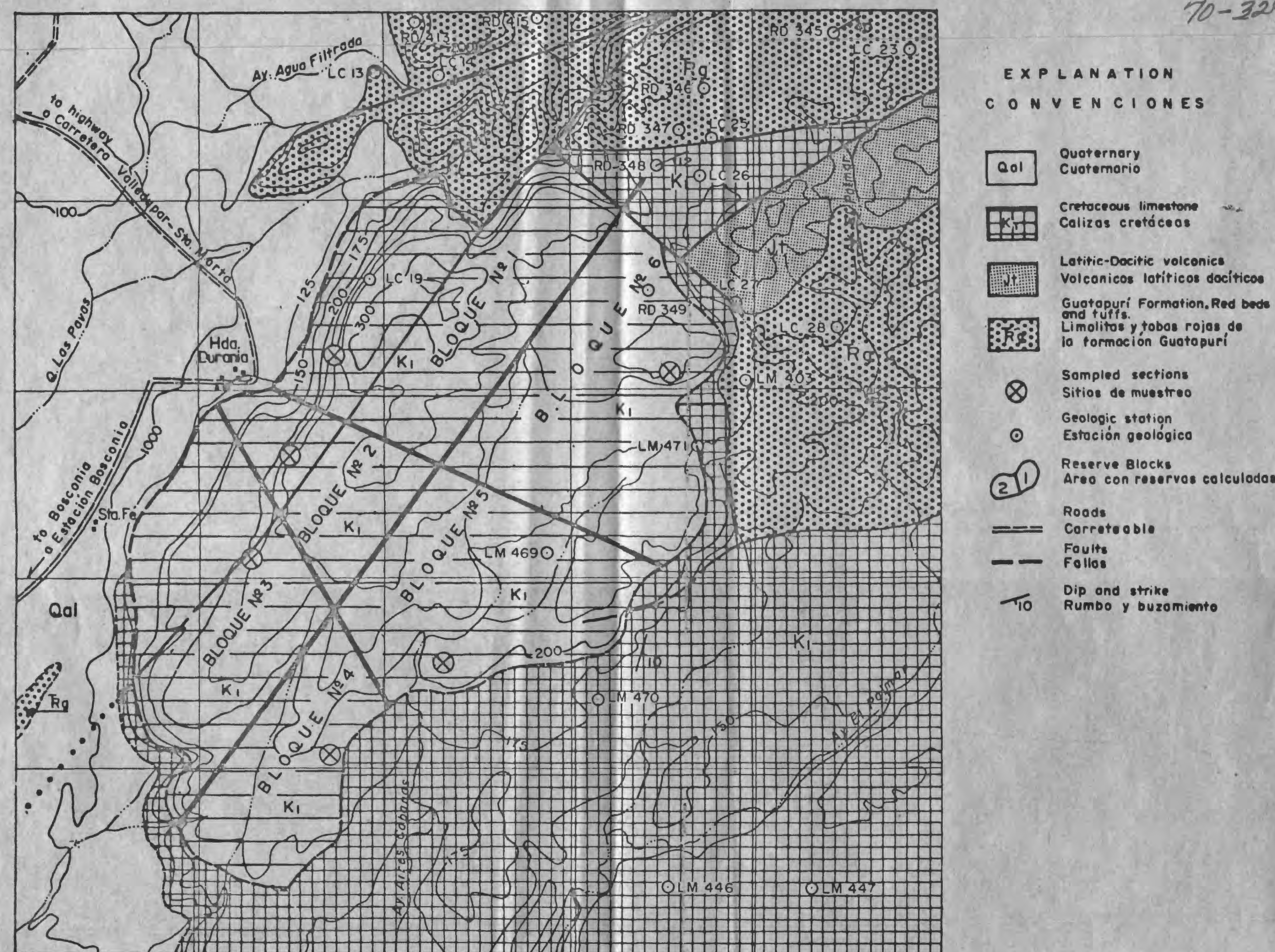

GEOLOGIC MAP OF THE LIMESTONE DEPOSITS NEAR DURANIA

MAPA GEOLOGICO DE LOS YACIMIENTOS DE CALIZA DE DURANIA

Scale 1: 25.000

0 0.5 1Km.

Escala

Figure 1 [redacted]

Geology mapped by Luis Medina, Luis Castillo, and Raúl Duran; Sampled by Luis Medina.

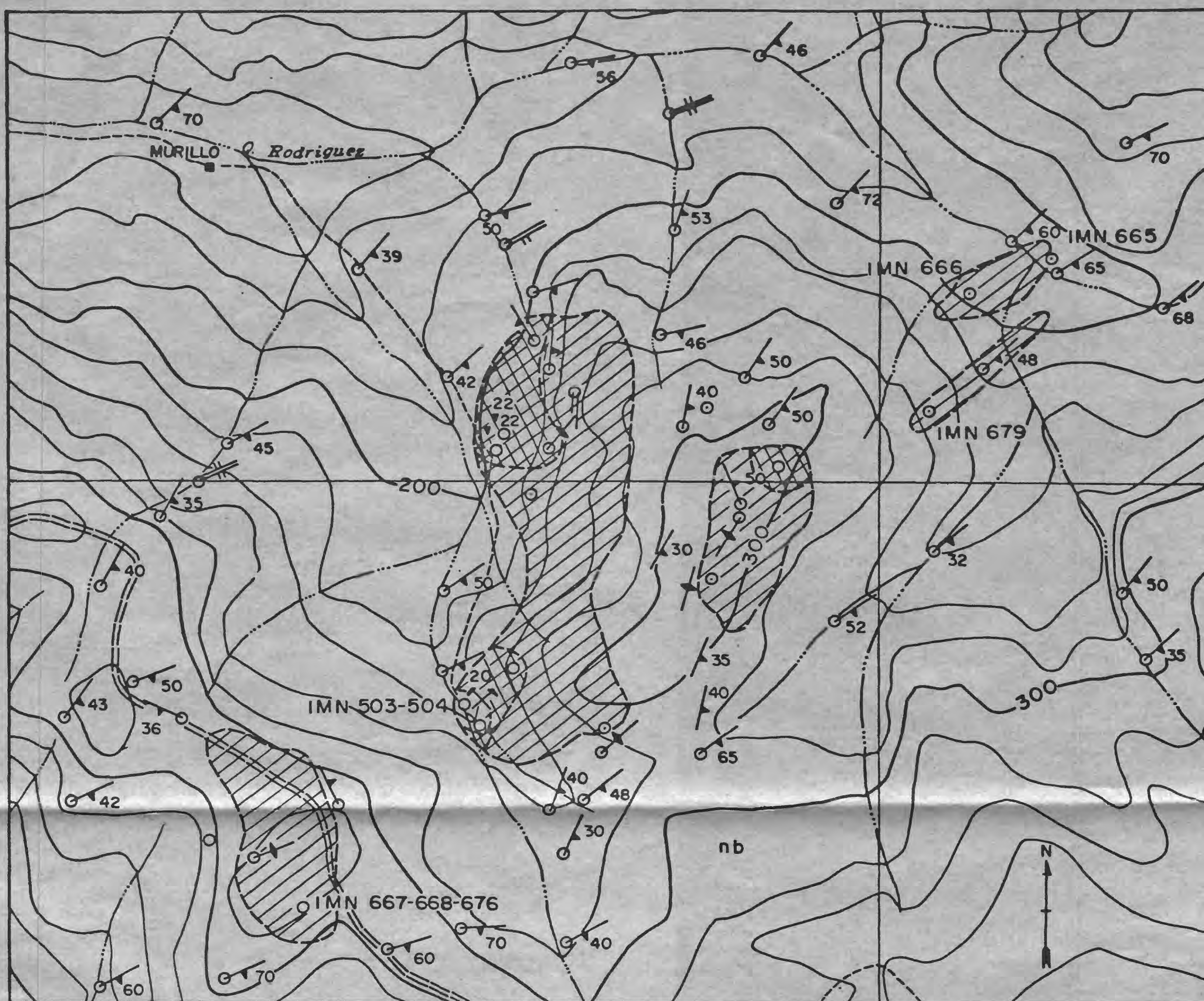

FIGURE 3 MAP SHOWING TALC AND TREMOLITE DEPOSITS DERIVED FROM SERPENTINE NEAR QUEBRADA RODRIGUEZ

70-329

Geology by Raúl Durán
Topography from quadrangle 18 IV D

nb Buritaca Gneiss

Tremolite and Talc

Serpentine

Approximate contacts

Strike and dip of foliation

Strike and dip of dike

⊙IMN665 Samples

Abandoned road

Trails

Prospect pit

D:I.C.O