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EXPLORATION FOR CHROMITE DEPOSITS IN THE CAMAGÜEY DISTRICT, CAMAGÜEY, PROVINCE, CUBA

By

W. E. Davis, W. H. Jackson, and D. H. Richter

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CONTENTS

CONTENTS

CONTENTS

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

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Camagüey District, Camagüey Province, Cuba

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Abstract

During the period July 1, 1954, to April 5, 1956, the U.S. Geological Survey, on behalf of the Emergency Procurement Service, General Services Administration, conducted an exploration program in Camagüey Province, Cuba, to locate reserves of refractory-grade chromite. A regional gravity survey was made of part of the Camagüey chromite district and detailed gravimetric and geologic investigations, followed by exploration drilling, were conducted in nine areas totaling about 12 square miles.

The chromite deposits occur in an ultramafic complex that consists principally of a lower serpentinized peridotite and dunite member and an upper feldspathic member. The complex, which was intruded into a series of metamorphic rocks as a nearly stratiform mass, is unconformably overlain by Upper Cretaceous volcanic rocks interbedded with limestone and chert. Folding, probably concurrent with overthrusting from the north during early Tertiary time, has formed a number of long arcuate structures. Subsequent uplift and erosion has removed most of the overlying volcanic and feldspathic rocks, except in deeply folded synclinal areas. Most of the deposits occur as irregular tabular bodies, usually concentrated in clusters, in the upper part of the serpentinized rocks within half a mile of the feldspathic member. Consequently, the exploration was restricted to parts of narrow belts parallel to this member.

The density contrast between chromite and the serpentinized rocks is about 1.5 grams per cubic centimeter. This contrast is sufficient for chromite deposits lying at commercially exploitable depths to cause positive gravity anomalies of more than 0.5 gravity unit (0.05 milligal). However, parts of the serpentinized masses and some of the feldspathic rocks that occur in the serpentinized country rock are dense enough to cause anomalies of much the same lateral extent and magnitude as the chromite.

As more than two-thirds of the ore mined in the district come from deposits 45 to 60 meters long, containing 90,000 tons or more, the exploration was planned to search for deposits of this size. Gravimeters having scale constants of 0.7172 and 0.7856 gravity unit per scale division were used in making reconnaissance measurements over 20 x 40- and 30 x 60-meter grids to detect anomalies associated with masses of high-density material. The anomalous areas were mapped in detail by measurements made along grids ranging in size from 10 x 20 to 15 x 30 meters. Gravity differences were determined by making single observations at individual stations, observing base stations hourly, and re-observing a few stations to check drift and accuracy of measurement. About 11 percent of the stations established had to be rerun because of errors in closure, seismic disturbances, and instrument trouble. The probable error of a single observation based on 3,136 re-observed stations was about 0.08 gravity unit.

A large number of gravity anomalies were found and evaluated according to geology, areal extent, and gravity relief. Those not obviously associated with feldspathic rock were selected for drilling. To guide the drilling, depths to the top and center of hypothetical bodies that would cause anomalies of similar magnitude were computed in terms of chromite and feldspathic rock. Test holes were drilled on 106 positive gravity anomalies, which constituted probably less than a third of the total number found. These holes revealed that 10 anomalies were caused by chromite and 89 by other high-density materials; seven anomalies could not be explained by density data obtained from core samples. Drilling on five of the chromite deposits revealed about 236,000 tons of chromite. An additional estimated 12,000 tons are contained in three deposits that were not blocked out. No estimate was made of the tonnage in two small deposits.

A considerable tonnage of chromite may be discovered by drilling small anomalies occurring over the serpentinized rocks and some of the untested gravity features along the major geologic contact shown on the residual gravity maps. Exploration in adjoining areas may also reveal additional chromite reserves.

Introduction

Scope and previous work

An exploration program for refractory-grade chromite was conducted in the Camagüey chromite district, Cuba, by the U.S. Geological Survey on behalf of the Emergency Procurement Service, General Services Administration. A regional gravity survey was made of part of the district and detailed gravimetric and geologic investigations were conducted in nine areas totaling about 12 square miles. The results of this work were used as a guide for drilling in a search for large deposits of chromite and in estimating the reserves.

The feasibility of using the gravity method in prospecting for chromite deposits was tested in development work by the Bethlehem Steel Co. in 1942. In this work, exploratory drilling was done over positive anomalies found in detailed gravity surveys conducted by the Gulf Research and Development Co. (Hammer and others, 1945, p. 34-49; 1945, p. 60-62). The investigation showed that some of the anomalies were caused by chromite deposits; however, most of the features were associated with masses of feldspathic rock or dense partly serpentinized peridotite, and with changes in soil thickness. In general, the investigation proved that the gravity method would serve to delineate areas underlain by dense material and, therefore, could be used successfully to locate the areas most favorable for drilling.

Results of geologic mapping and studies of individual deposits, conducted previously in the district by the Geological Survey (Thayer, 1942; Flint and others, 1948) show that most of the known deposits lie within a belt about half a mile wide extending along the contact between serpentinized peridotite and feldspathic or volcanic rocks. Most of the deposits have been found by investigating surface indications, for which the entire district has been thoroughly prospected; only a very small part of the productive contact zone has been explored by subsurface methods. Therefore, it was reasonable to expect that a systematic exploration program would discover additional reserves.

The areas investigated and the plan of exploration were suggested by Flint and others (1948, p. 61-62) in view of results obtained in field work done in 1942-45 under the auspices of the Interdepartmental Committee for Scientific and Cultural Cooperation, Department of State, and the Foreign Economic Administration.

Location and access

The Camagüey chromite district (fig. 1) is in the north-central

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Figure 1. Index map showing location of areas investigated in the Camagüey chromite district, Cuba.

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part of the province of Camagüey, Cuba. It includes the small towns of Minas, Altagracia, and Cromo, which are on the Camagüey-Nuevitas highway northeast of Camagüey city. The parts investigated (fig. 1) lie along the edges of a savannah that surrounds most of the farming land in the district. They are referred to as the Aventura, Camagüey, Caridad, Estelnita, La Nona, Lolita, Ofelia, Oriente, and Victoria areas, after prominent mines.

Parts of all the areas, with the exception of the Ofelia and La Nona, are accessible by car via all-weather secondary roads connecting with the Camagüey-Nuevitas highway. The Ofelia and La Nona and parts of the others can be reached by traveling ungraded rough roads that are passable by car only during winter and early spring. The Camagüey-Nuevitas branch of the Consolidated Railroads of Cuba roughly parallels the Camagüey-Nuevitas highway across the district and gives access to the towns of Altagracia, Cromo, and Minas.

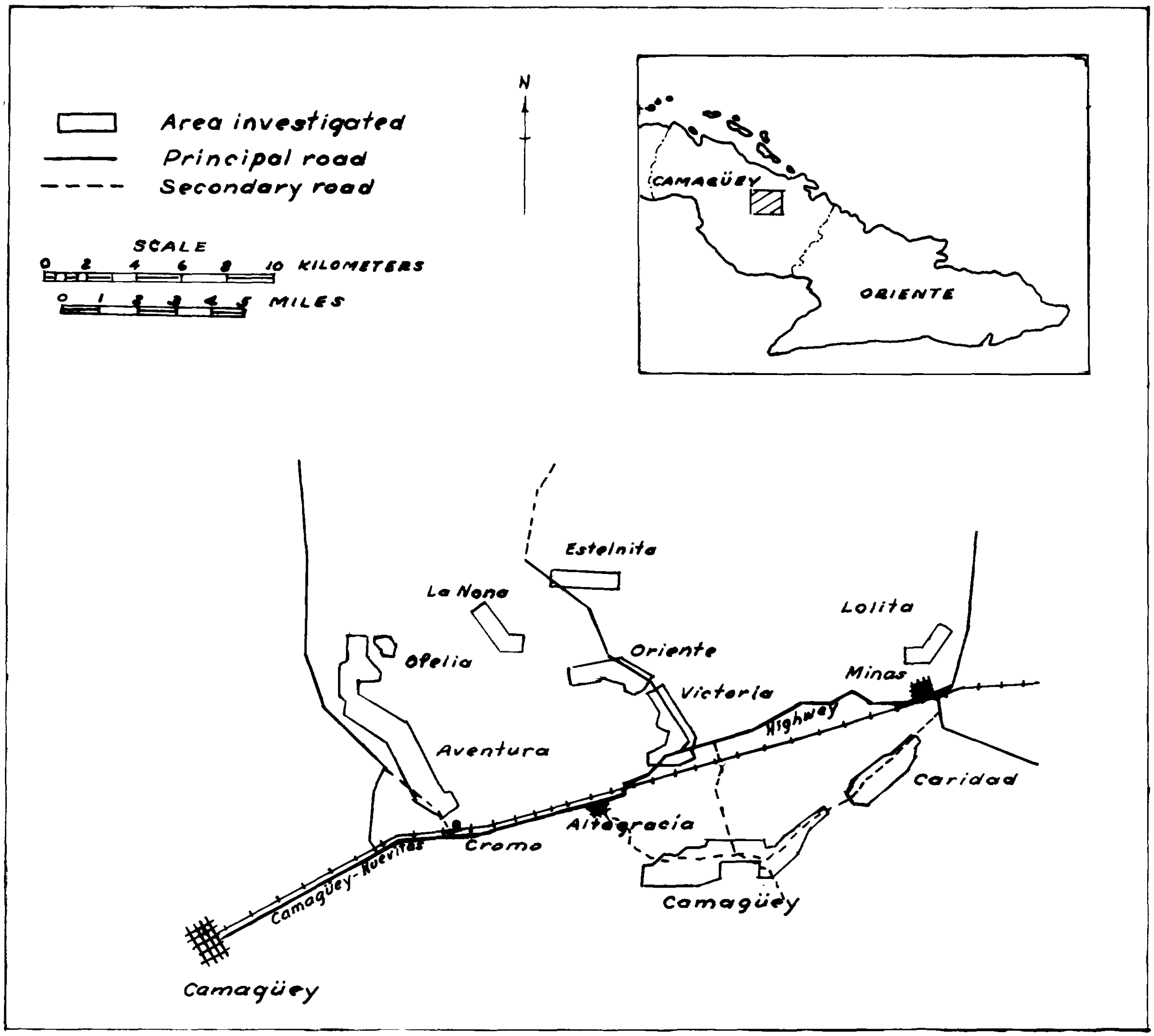

FIGURE 1. Index map showing location of areas investigated in the Camagüey chromite district, Camagüey Province, Cuba.

Surface features

A broad open plain, or savannah, covered with sparse vegetation extends over the major part of the investigated areas. The surface has an approximate mean elevation of 350 feet above sea level and is relatively flat except for a few scattered hills, ridges, and mine workings, few of which have a relief greater than 50 feet. Relief of most of the features is between 5 and 20 feet. Notable exceptions to this general low relief occur in the Camagüey, La Nona, and Oriente areas. In the La Nona and part of the Oriente long steep-sided ridges that rise 100 feet above the surrounding savannah border one side of the mapped areas. In the Camagüey area, a maximum relief of 150 feet occurs in the western section where mapping was done part way up the northern slope of Loma La Entrada.

The Estelnita, La Nona, Oriente, Ofelia, and the major portions of the Aventura and Victoria areas are drained to the north and east by the Río Máximo and its tributaries. The other areas are drained to the south and east by tributaries of the Río Saramaguacán.

Vegetation and climate

Soil on the savannah is derived mainly from the weathering of serpentinized peridotite and in most places is thin and infertile. Small deposits of laterite occur locally and transported soils are found in the larger intermittent stream valleys. The vegetation on the savannah consists of short coarse grasses and the ubiquitous scrub palms, of which guano hediondo and guano jata (gen. Copernicia) and yuranguana (gen. Coccothrinax) are the most abundant. Also common is a low thorny bush, espino de sabana (Brya ebenus), that usually grows in impenetrable clumps. Where the soil is thick and more fertile, a common toxic plant, guao (gen. Comocladia), and the nonindigenous thorny marabú (Cailliea glomerata) grow abundantly.

Another small shrub that grows in the savannah is locally called peralejo (Byrsonima crassifolia ?). This shrub, which seldom grows more than ten feet in height, has been used very successfully as a geologic indicator. Apparently, the peralejo grows only on feldspathic rocks, cherty silica rocks, and in residual and transported soil derived from these rocks. It is not unusual to find one or more peralejo growing on very small exposed pods and dikes of feldspathic rocks in the serpentinized country rock. The relatively bright yellow-green foliage makes this shrub a conspicuous marker in the field.

Off the savannah, in areas not underlain by serpentinized peridotite, the land generally supports a luxuriant vegetation. Here, besides lush grasses and a large number of Cuban hardwood trees, grow numerous large palms, guano cana (gen. Sabal) and palma real (Roystonea regia). The fronds of the guano cana and the fruit of the palma real are utilized for native roofing material and livestock feed.

The province has a warm humid climate. Showers occur almost daily during the late spring and summer months, but the rainfall diminishes during autumn, and the country becomes very dry during winter and early spring. The showers usually are more frequent during June and July but the heaviest rains are during the hurricane season, which normally extends from August 15 to October 15. Daily temperatures range from 70° to 97°F during the summer months and average about 70°F in winter. The hottest and most uncomfortable weather is in July and August. During these months ground temperatures in the savannah areas frequently rise above 115°F.

Field work and acknowledgments

Field work began on July 1, 1954, with the arrival of the geophysical party in Habana. Headquarters were stablished in Camagüey during that month, but owing to the late arrival of equipment, gravimeter measurements did not begin until August 4, 1954. Field mapping continued thereafter without any major interruption until the work was completed March 22, 1956. Exploratory drilling was started June 6, 1955, with two drill rigs. On October 27, 1955, drilling operations were reduced to one rig and continued until the project was terminated April 5, 1956.

Richard R. McDonald, Willie T. Kinoshita, and Thomas N. Hopper made most of the gravimeter measurements. They were assisted during a few months by Martin F. Kane, Jorge M. Hernandez, and Alfredo Pulido. Dionisio A. Bueno established most of the horizontal and vertical control. Roy M. Shuler, Raul Celestino Miranda, Pablo A. Calvan, and Evelyn G. Langford reduced the data and assisted in preparing the gravity maps.

W. E. Davis was in charge of the project and supervised the geophysical work. W. H. Jackson assisted in overseeing the gravity measurements and supervised the computing staff. The geologic mapping was done by D. H. Richter, who also directed the drilling. He was assisted part of the time by Martin S. Tischler. Interpretation of data, selection of drilling sites, and preparation of this report were done jointly by the authors.

The authors are indebted to Delos E. Flint, who was instrumental in getting the project under way and selecting the areas investigated; and to L. C. Pakiser for assistance in planning the program and periodically inspecting the gravity data. Grateful acknowledgment also is made to T. P. Thayer and P. W. Guild for their advice and assistance in studying the distribution of the chromite deposits.

We are pleased to acknowledge the assistance of members of the American Embassy and Foreign Operations Mission to Cuba, in making the necessary arrangements with the Cuban Government for undertaking the investigation. We wish especially to acknowledge the help of Mr. Paul A. Tate, U. S. Consular Agent, Camagüey, in securing local personnel, supplies, and quarters for the project. Also, we are grateful to the numerous land owners for their cooperation in granting permission to conduct investigations on their properties. Finally, the authors wish to express their gratitude for courtesies and assistance from the people of Camagüey, whose generous hospitality made the work more enjoyable.

Method of exploration

Applicability of the gravity method

Application of the gravity method in prospecting for chromite deposits in the Camagüey chromite district depends fundamentally upon the density contrast between the chromite and the surrounding country rock. The difference in density between the chromite contained in commercial deposits of the district and the country rock, which is serpentinized peridotite and dunite, is about 1.5 grams per cubic centimeter. This density contrast is sufficient for chromite masses lying at commercially exploitable depths to cause positive gravity anomalies of magnitudes more than 0.5 gravity unit (0.05 milligal). The feldspathic rocks in the serpentinized peridotite and dunite have an average density of about 2.7 grams per cubic centimeter, which provides a sufficient density contrast with respect to the serpentinized rocks to cause anomalies of much the same size and magnitude as the chromite. Similar anomalies also are created by density contrasts between parts of the serpentinized masses which range in density from 2.2 to 2.8 grams per cubic centimeter. Therefore, gravimeter measurements can be expected to delineate areas underlain by dense materials, but the areas must be test drilled to determine if the materials are chromite.

Control surveys

As more than two-thirds of the ore mined in the district came from deposits 45 to 60 meters long, and containing 90,000 tons or more (Flint and others, 1948, p. 61), the exploration was planned to search for deposits of this size. The station density of a 20x40-meter grid was considered to be of sufficient detail to detect most of the anomalies associated with these deposits. However, it would be necessary to check anomalous measurements and map the gravity features more in detail before undertaking exploratory drilling. As the gravity work progressed, a 30x60 meter grid was found to be satisfactory for reconnaissance purposes and was used to obtain greater areal coverage.

The grid pattern was laid out by means of a transit and tape survey, which provided accurate control for locating claim corners and drill holes. In the Victoria, Aventura, Ofelia, and Camagüey areas, and most of the Lolita area, gravity stations were staked at intervals of 20 meters along traverses spaced 40 meters apart, located at right angles to a base line parallel to the general trend of the serpentinized rock contact. In the other areas, gravity stations were staked 30 meters apart along traverses at intervals of 60 meters oriented in the same manner with respect to the contact.

Additional gravity stations were laid out for detailed work where anomalous conditions were found in the reconnaissance gravity mapping. In areas where the 20x40 meter grid was used, intermediate traverses were laid out with stations at 20-meter intervals forming 20x20 meter grids over the gravity features; over the center of a few anomalies, stations were located at intervals of 10 meters. In areas investigated on a 30x60-meter grid basis, detailed stations were staked, forming a 15x15-meter grid over the gravity anomalies. The elevations of stations, referred to an arbitrary base, were determined to less than 1/10 of a foot by leveling. The horizontal and vertical control was established by a surveyor and five assistants hired locally.

Concrete monuments were placed along the base lines at terminal stations, a few intermediate stations, and where the base lines change direction. These markers are 4 inches square, extend above the ground about 6 inches, and bear the respective station numbers. Where possible the monuments were tied to permanent reference points by magnetic bearing and distance.

Reconnaissance geologic investigations were made in advance of the control survey to determine the location of the base line and length of the gravity traverses. Following the layout work, the geology was mapped in detail, using the grid as a base. The contact between rock types was located as accurately as possible along each traverse and interpolated between the traverses. Small isolated rock exposures not crossed by the traverse lines were also mapped.

Gravity measurements

Two Worden gravimeters, having scale constants of 0.7172 and 0.7856 gravity unit per scale division, were used in making the gravity surveys. These instruments have a reading dial range of about 80 divisions and can be read to 1/10 of a dial division. The scale constants of the meters were checked periodically by observing the gravity difference between two survey stations that differed by about 36.5 gravity units. No appreciable change in the scale constants was noted during the course of the work.

One gravimeter was used mainly in making reconnaissance measurements and the other was used in detailing anomalies and making re-runs of misclosures. Occasionally both meters were used in the same phase of work for short periods of time. The meter crews consisted of an operator, recorder, and one assistant. The meters were transported between stations by hand and, during readings, were shaded by umbrellas that also served as wind shields. For ease and rapidity in making measurements, two tripods having legs 14 inches long were used with each instrument. While one tripod was in use at a station in making an observation, the other was set at the advance station by the recorder. The tripods were set with the base plates at a uniform height of 11 inches above the ground, as gaged by a marked key chain suspended from the center of the base plates. A small padded box 6 inches in height was used by the meter operator to sit on while making observations. This position of observing proved to be as rapid and much less fatiguing than kneeling.

Gravity base stations were established as the work progressed using the standard looping method. The gravity value of each base was determined from an average of five measurements differing by no more than 0.3 gravity unit. Gravity differences between grid stations were determined by making single observations at individual stations and observing a base station at intervals of one hour. During the initial run of stations from a base in the morning and after lunch, a repeat observation was made at the base station within 45 minutes. As an additional check on the drift of the meter, and the accuracy of the meter operator's reading, a repeat reading was made of at least one station of each previous run from the base. The initial and repeat readings of re-observed stations were corrected for drift. Where the corresponding corrected readings differed by 0.5 scale division or more, the line of stations involving the misclosure was re-run.

Repeat observations at base stations indicated that the instrumental drift (fig. 2) including tidal effects was generally

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Figure 2. Drift curves of Worden gravimeter No. 177.

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a minimum during mid-day and was greater in the morning than in the afternoon. During these periods the drift was fairly uniform, except during the first hour of operation after the meters had not been in use for periods of an hour or more. In the morning the drift averaged about one scale division per hour and occasionally reached a maximum of 1.5 to 1.8 scale divisions per hour. During the afternoon it was usually less than a scale division per hour.

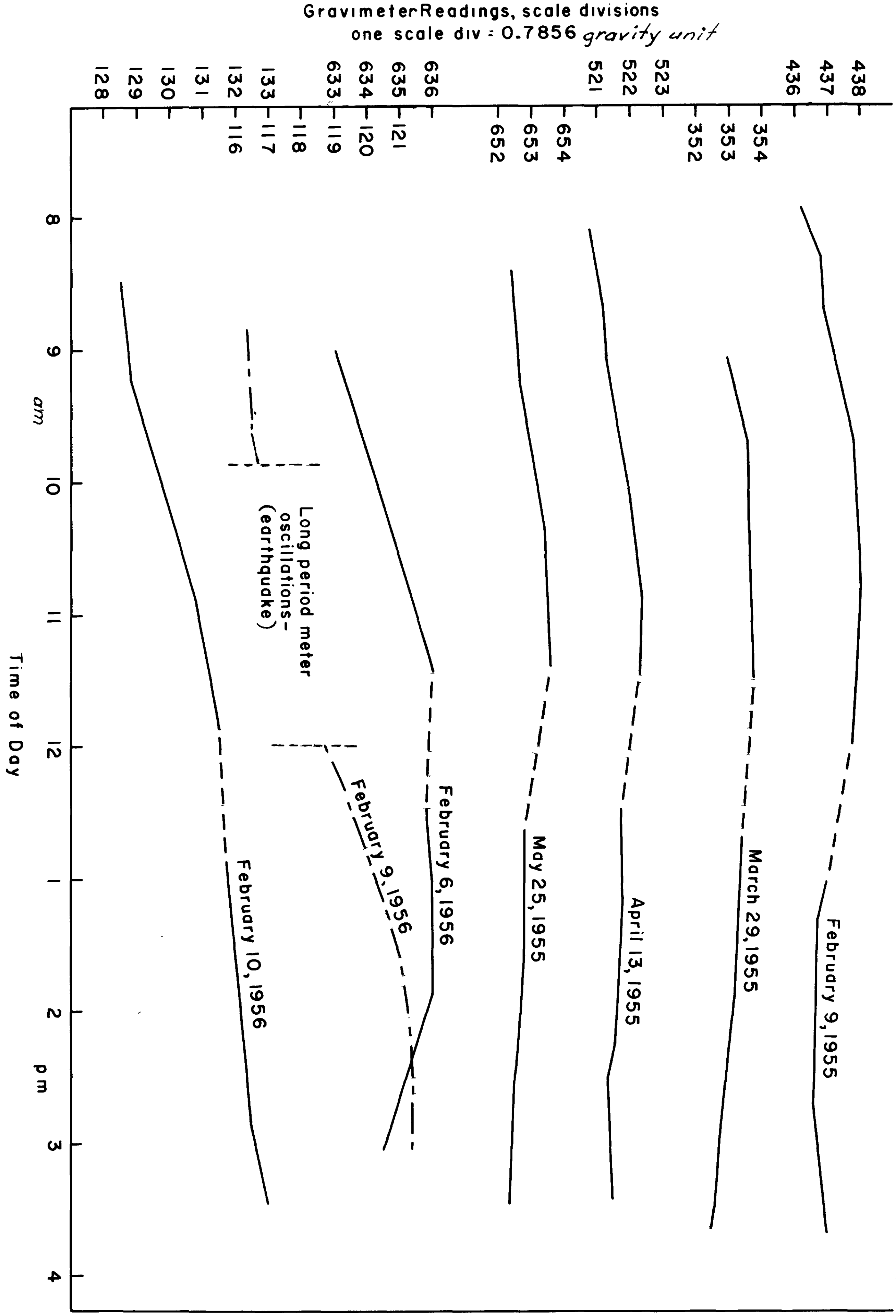


Figure 2.- Drift curves of Worden gravimeter No. 177

Treatment of data

After adjusting the gravimeter readings for drift, standard methods were used in reducing the data to obtain Bouguer and residual gravity values. A correction of 5.54 gravity units per kilometer was applied to compensate for the change in gravity with latitude. A combined elevation correction of 0.62 gravity unit per foot, based on an experimentally determined average rock density of 2.5 grams per cubic centimeter, was used in reducing the measurements to a common datum. Terrain corrections were not applied to the data because of the flat topography. Residual gravity values were determined by means of the nine-point second-derivative method (Henderson and Zietz, 1949, p. 508-516), using 80- and 120-meter squares for the 20x40 and 30x60 meter grids, respectively. In some of the anomalous areas, the residuals were smoothed graphically.

The Bouguer gravity values were plotted in profile form immediately after reduction to locate errors caused by erroneous elevations and meter readings at individual stations. The profiles also were used for control in removing regional effects graphically and in studying and interpreting the gravity features, most of which were not completely isolated by the nine-point residual method. Bouguer and residual gravity maps were prepared on a geologic base to determine the relationship of the gravity features with known geologic conditions. These maps were used in connection with the profiles to evaluate and select anomalies for detailed mapping and test drilling.

Progress of field work

The field work progressed rapidly with only a few intermittent delays of not more than two days caused by stormy weather and abnormal brushing conditions. Approximately 0.28 square mile was mapped with the gravimeter during the first two months of field work, which consisted mainly of establishing horizontal control well in advance of the gravity measurements. After this preliminary period the gravity mapping progressed at an average rate of about 0.55 square mile per month until November 15, 1955, when measurements were undertaken on a 30x60 meter grid basis. Thereafter, an average of 1.06 square miles were mapped per month. The schedule of gravity mapping is given in table 1.

Table 1. Schedule of reconnaissance gravity mapping

Period		Area	Reconnaissance grid (meters)	Square miles mapped
From	To			
Aug. 9, 1954	Dec. 9, 1954	Victoria	20 x 40	1.09
Dec. 10, 1954	May 31, 1955	Aventura	20 x 40	3.30
June 2, 1955	June 7, 1955	Ofelia	20 x 40	.10
June 8, 1955	Oct. 28, 1955	Camagüey	20 x 40	2.94
Oct. 31, 1955	Nov. 16, 1955	Lolita	20 x 40, 30 x 60	.31
Nov. 17, 1955	Dec. 21, 1955	Caridad	30 x 60	.94
Dec. 21, 1955	Jan. 27, 1956	La Nona	30 x 60	1.20
Jan. 31, 1956	Feb. 23, 1956	Oriente	30 x 60	1.28
Feb. 27, 1956	Mar. 9, 1956	Estelnita	30 x 60	.60

During the course of the investigation 41,921 stations were established with the gravimeters: 24,699 20x40-meter grid stations and 6,047 30x60-meter grid stations were established in the reconnaissance mapping; and 11,175 new and old stations were observed in the detailed work. The number of reconnaissance stations established per month increased during the first five months, and thereafter averaged 1,889 and 1,591 stations during the periods that measurements were made over the 20x40 and 30x60 meter grids, respectively. Checking and detailed mapping of anomalies was begun February 4, 1955, and after seven months this operation was currently following the reconnaissance mapping. The number of stations observed monthly in the detailed work varied according to working conditions and the amount of control work involved; an average of 828 stations were observed per month. About 11 percent of the total number of stations established during the investigation were re-observed because of misclosures.

The number of stations re-run monthly after the project was well under way corresponded to weather conditions as they affected the accuracy of meter readings: ideal reading conditions occurred during the winter months; intermittent strong winds affected measurements during the months of March to May; rains occurred frequently during the summer months and were especially troublesome during July; and the effects of tropical storms that occurred during September and October caused very unfavorable reading conditions.

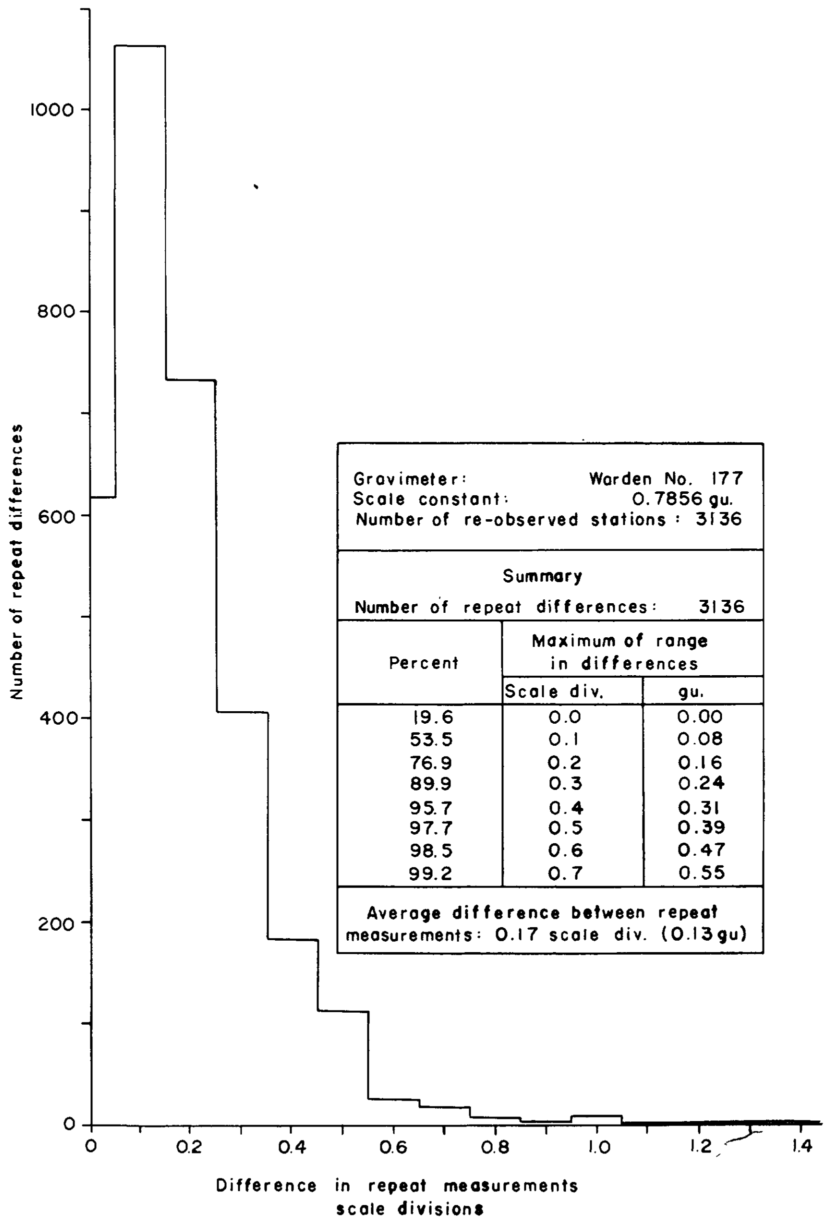
Troublesome seismic disturbances occurred frequently during the course of the field work. Some of these disturbances, apparently created by earthquakes, caused long period meter oscillations ranging from 10 to 50 scale divisions that continued for one to three hours (fig. 2). Others caused short period oscillations of one to five scale divisions that continued for one to three days and seemed to be associated with tropical storms.

Accuracy of gravimeter measurements

The precision attained in making gravimeter measurements was determined periodically during the investigation. After completing gravity measurements in an area, the differences in drift-corrected readings at re-observed stations were compiled and the apparent accuracy of observations made in that area was determined (fig. 3). The repeat data from individual areas

Figure 3. Frequency-difference curve of repeat gravimeter measurements.

revealed that the measurement accuracy varied but little from one area to another and increased slightly as the work progressed. The average difference between repeat readings ranged from 0.15 to 0.18 scale division (0.12 to 0.14 gravity unit) and the probable error of a single observation was between 0.10 and 0.12 scale division (0.08 and 0.09 gravity unit).



Percent	Maximum of range in differences	
	Scale div.	gu.
19.6	0.0	0.00
53.5	0.1	0.08
76.9	0.2	0.16
89.9	0.3	0.24
95.7	0.4	0.31
97.7	0.5	0.39
98.5	0.6	0.47
99.2	0.7	0.55

FIGURE 3- Frequency-difference curve of repeat gravimeter measurements

Upon completion of the gravity investigation, the reading difference data from all areas were combined and analyzed to obtain an indication of the accuracy of measurements for the survey as a whole. The precision attained in readings is indicated by the difference in measurements found at 3,136 re-observed stations (fig. 3): the average difference between the repeat measurements is 0.17 scale division (0.13 gravity unit); 53.5 percent of the repeat readings differ by 0.1 scale division (0.08 gravity unit) or less; 89.9 percent differ by 0.3 scale division (0.24 gravity unit) or less; and only 2.3 percent of the measurements differ by more than 0.5 scale division (0.39 gravity unit). These data indicate that the probable error of a single observation is about 0.10 scale division (0.08 gravity unit).

The errors made in observing the gravity stations are attributed mainly to erratic fluctuations in instrument drift and inaccuracies in reading the gravimeter. The magnitude of these errors, though small, must be given due consideration in evaluating anomalies of low gravity relief. Errors of a few tenths of a gravity unit may cause the selection of improper locations for test drill holes and considerable error in computing depths to sources of the anomalies. Therefore, in detailed mapping close-spaced gravity measurements should be made along several traverses across a gravity anomaly in order to delimit the feature accurately. To minimize errors caused by non-linear instrument drift, the detailed measurements should be referenced to a base station within, or near, the anomaly, and base readings made at intervals of less than one hour.

Classification of anomalies

The positive gravity anomalies were classified for investigation according to their relationship to outcrops of feldspathic rocks. Most of the anomalies were grouped in three classes in decreasing order of favorability: (1) anomalies apparently not related to feldspathic rocks; (2) anomalies overlying serpentinized peridotite but in line with or along the strike of feldspathic outcrops, indicating possible subsurface continuations of the feldspathic bodies; and (3) anomalies occurring partly over feldspathic outcrops and partly over serpentinized peridotite. Anomalies that could not be evaluated because of thick soil and disturbed ground were designated class 4. The anomalies that occurred entirely over feldspathic outcrops were considered definitely unfavorable and were not mapped in detail.

The anomalies also were studied and classified according to areal extent, gravity relief, and the theoretical amount of chromite indicated. The features were grouped in three major classes in order of decreasing importance: (A) prominent anomalies of more than 0.5 gravity unit magnitude that were shown on more than one traverse profile; this group of anomalies was classified further according to the quantity of chromite indicated, (1) more than 90,000 tons, (2) 50,000 to 90,000 tons, and (3) less than 50,000 tons; (B) anomalies of about 0.5 gravity unit that were not depicted prominently by the nine-point residual reduction, and were indicative of deep chromite bodies or disseminated chromite deposits, or possibly caused by variations in the degree of serpentinization or changes in soil thickness; and (C) anomalies of small areal extent and of magnitudes less than 0.5 gravity unit that could be caused by small deposits of chromite or by density contrasts in near-surface materials, dump materials around mines, or that could be the result of the manner in which the residual reduction was made.

Exploratory drilling

Most of the anomalies classified 1A to 3B inclusive and 4 were mapped in detail by close-spaced gravimeter measurements and were tested by drilling. After reducing the detailed field data, residual gravity maps of the individual anomalies contoured on intervals of 0.2 gravity unit, were prepared to determine the locations of test holes. Depths to the top and center of hypothetical disturbing bodies (Nettleton, 1940, p. 122-125) that would cause similar anomalies were computed in terms of chromite and feldspathic rock to guide drilling. Usually one test hole was drilled at a gravity station near the crest of each anomaly. Cores were taken in test drilling where dense materials were cut, and at the respective computed center depths, and (or) near the bottom of the holes. Bulk densities of the cored samples were determined to ascertain the source of the anomalies. The test holes were bottomed when a sufficient thickness of dense material was found to indicate that the dense masses were large enough to account for the anomalies. Where no dense materials were found in drilling, the holes were bottomed at depths about one and one-half to twice the computed center depths of the assumed disturbing masses.

The chromite deposits found were core drilled to determine the tonnage and to obtain samples of the chromite. Generally, the holes were drilled on 20-meter centers along the strike, or long direction of the deposits and on 10-meter centers normal to the strike. Some additional holes at 10-meter intervals along the strike were drilled near the extremities of the deposits to obtain adequate information for calculating reserves. Upon completion of drilling all holes were plugged with concrete and drill-hole numbers were marked on the top of the plugs. The discovery holes were tied to the nearest claim post by magnetic bearing and distance. Chromite reserves were calculated using a weighted volume estimate (Forrester, 1947, p. 560-563) based on the lateral distances between drill-hole sites in a uniform triangular block and the average vertical thickness of the chromite mass. A factor of 8.9 cu ft of chromite per ton was used in the calculations.

Regional gravity survey

Gravimeter measurements were made along roads connecting the mapped areas and crossing the district to obtain information regarding regional geologic structural features. Measurements were made at stations 0.2 kilometer apart along 13 traverses ranging in length from 1.8 to 19.8 kilometers. Distance between stations was determined from speedometer trip indicator readings that were checked at identifiable points shown on a map of the district. Elevations of the stations were established by leveling along loops about 30 kilometers in length. The error of closure was less than 4 feet.

The gravimeter was transported between stations by car and base stations were observed at intervals of about 1½ hours. Observed gravity values of the stations were reduced to Bouguer gravity referred to the arbitrary datum of the Aventura area. These data and values of stations along base lines of the areal surveys were incorporated in a Bouguer gravity map of the district.

Magnetometer measurements

Magnetometer measurements were made periodically during the investigation to determine if these data would be helpful in interpreting gravity features. In the Victoria area measurements were made at gravity stations along 12 traverses across the area and along parts of traverses across most of the prominent gravity maxima. Measurements also were made along a few traverses in the Aventura, Camagüey, and Oriente areas but owing to discouraging results, no large-scale investigations were undertaken. A Ruska magnetometer having a scale constant of 24.9 gammas per scale division was used in making the observations.

Geologic setting

General statement

The geology of the Camagüey district and origin of the chromite deposits have been described in previous publications (Thayer, 1942; Flint and others, 1948) and are reviewed here briefly. The general geologic map of a part of the district (fig. 4) accompanying this report

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Figure 4. Geologic map of part of the Camagüey chromite district, Camagüey Province, Cuba.

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has been modified from Flint's map by the addition of data from detailed studies and general observations.

Consolidated rocks in those parts of the Camagüey district that were investigated consist of a Cretaceous or older ultramafic igneous complex overlain by tuffs and flows interbedded with limestone and chert of Late Cretaceous age and limestone, chalk, and marl of Eocene age. Locally, these rocks were covered by relatively thin deposits of laterite, cherty silica, and other unconsolidated material.

The ultramafic complex is composed essentially of a lower serpentinized peridotite and dunite member and an upper feldspathic member consisting chiefly of gabbro, troctolite, and anorthosite. The complex is believed to have intruded a series of metasediments of unknown age as a nearly stratiform mass. These basement rocks are exposed only in the southwestern corner of the district. Following the erosion of the roof rocks and probably of some of the feldspathic member of the complex, the Upper Cretaceous volcanic rocks were deposited on the feldspathic portions of the complex, probably while it was still essentially horizontal.

Folding and concurrent large-scale overthrusting from the north has formed a number of long arcuate structures in the Camagüey district. Subsequent uplift and erosion has uncovered a large portion of the serpentinized peridotite, leaving the feldspathic rocks and overlying volcanic sequence only in structural troughs and lows. One of the major structural features is the Lugareño-Yucatán syncline, an arcuate trough more than 25 miles long, which crosses the center of the district.

Flat-lying Eocene limestone, chalk, and marl that were deposited after the regional deformation overlie the ultramafic and volcanic rocks throughout the southern part of the Camagüey district. Deposits of ferruginous cherty silica, probably developed during a number of erosional periods, cap many of the higher serpentine hills throughout the district.

Petrography

Ultramafic igneous complex

In this report, the ultramafic complex has been divided into two parts: (1) a thick serpentine unit consisting of serpentinized peridotite and dunite; and (2) a thin feldspathic unit consisting largely of gabbro, troctolite, and anorthosite. Although the contact between these units is covered by soil in most places, exposures in the Aventura, La Nona, Oriente, and Victoria areas, as well as the sequence indicated by geologic mapping, show that the serpentine unit underlies the feldspathic unit. Further evidence of this is revealed in rocks immediately below the contact where as much as 10 percent feldspar was observed in the serpentinized peridotite. Here these feldspar-bearing rocks grade downward into feldspar-free serpentinized peridotite or dunite, which suggests that gravity stratification was incomplete when the complex finally solidified. Alternatively, this interstitial feldspar may be the result of late movement of feldspathic material from a superjacent, still partially liquid feldspathic layer and filter pressing into a peridotite crystal mush prior to complete crystallization.

Serpentinized peridotite and dunite

As serpentinized peridotite forms the great mass of the ultramafic member of the complex, this term, for brevity and consistency, is used to denote both the serpentinized peridotites and dunites when referred to as a group. The term serpentine is reserved for those rocks that consist of nearly 100 percent serpentine mineral, and have had all primary mineralogic and textural features obliterated by either chemical weathering, physical stress, or both.

Serpentinized peridotite, a massive dark-green rock, is the predominant rock of the ultramafic complex. The original peridotite probably consisted of 75 to 95 percent olivine and 25 to 5 percent pyroxene. Of this, most of the olivine and some of the pyroxene has been altered to serpentine. The pyroxene crystals, which are less susceptible to weathering than olivine, stand out in relief on weathered surfaces and are easily detected on fresh surfaces by their pronounced cleavage. The weathered rock is dull gray, green, or brown.

Serpentinized dunite commonly occurs as relatively small lenticular bodies or zones, in general irregularly mixed in the serpentinized peridotite. In two of the areas studied, however, the La Nona and Oriente, a distinct dunite zone occurs between underlying serpentinized peridotite and overlying troctolite of the main feldspathic member. The serpentinized dunite, which contains no more than 5 percent pyroxene, is more highly altered (serpentinized) than the peridotite. It is a massive dark-green rock on fresh surface and light brown where weathered.

The bulk densities of serpentinized peridotite samples taken from surface exposures and drill holes range from 2.19 to 2.83 grams per cubic centimeter. Densities of the more highly serpentinized rocks are in the lower part of this range. An average bulk density of 2.5 grams per cubic centimeter, which is considered as representative of "normal" serpentinized peridotite, was determined from measurements of surface material, cores from holes drilled in locations having no associated gravity anomalies, and cores from holes where easy drilling conditions were found. An average value of 2.7 grams per cubic centimeter was postulated for the bulk density of the denser serpentinized peridotites that were cored. The densities of a few serpentine samples collected during the investigation range from 2.19 to 2.50 grams per cubic centimeter.

Feldspathic rocks

Medium- to coarse-grained gabbro, troctolite, and anorthosite comprise the uppermost rocks in the ultramafic complex. These rocks are found only in the centers and along the flanks of structural lows and are believed to be remnants of an essentially continuous feldspar-rich horizon. Small fine-grained gabbro and troctolite bodies and thin pegmatitic gabbro dikes also occur in serpentinized peridotite, but these are attributed to late stage, or residual, magmatic injections, whereas the main feldspathic unit is considered to have crystallized contemporaneously with the peridotite and dunite. Interstitial feldspathic material, which is fairly common in the serpentinized peridotite directly below the main feldspathic unit, has not been observed around these smaller feldspar-rich pods and dikes. Although no contact between any large masses of the three rock types in the upper feldspathic horizon was observed, the predominance of one type over another is thought to be due to compositional layering and/or mineral facies changes. With the exception of those containing chromite, the feldspathic rocks are the heaviest found in the detailed mapping. Their average bulk density is about 2.7 grams per cubic centimeter as determined from measurements of field and drill core samples, which ranged in density from 2.42 to 3.04 grams per cubic centimeter.

Gabbro is more abundant than the other rocks of this group and is more variable in mineral composition. A typical specimen, dark brownish gray on a fresh surface and having an equigranular texture, is composed of gray feldspar, dark-green to black pyroxene, and green serpentinized olivine. Gabbro usually weathers to a light-brown granular rock that disintegrates easily and is eroded readily.

The troctolite is composed of olivine and calcic plagioclase in varying portions. Banding due to alternate layers of olivine and feldspar is common. Removal of the olivine by weathering produces a pitted surface, but the rock as a unit is very resistant and forms many of the higher hills in the district.

Anorthosite consisting of 95 percent or more of calcic plagioclase usually occurs as small lenses, layers or segregations in the troctolite, and is by far the most resistant rock in the district.

Cretaceous volcanic and interbedded sedimentary rocks

A series of volcanic and interbedded sedimentary rocks of Cretaceous age unconformably overlies the feldspathic rocks, or where these are absent, serpentinized peridotite. Rocks of this series underlie most of the more fertile land in the district and are poorly exposed around the borders of many of the areas. Where observed, the volcanic rocks consist of buff to light-green tuffs, green to gray agglomerates, and dark-green fine-grained rocks referred to as felsite. Many of the tuffaceous rocks are brecciated and some of the waterlaid strata are highly calcareous.

A lens of gray crystalline limestone occurs in the volcanic rocks exposed in the western end of the Camagüey area. Other limestone masses, the largest of which forms Loma Yucatán, are scattered throughout the volcanic rocks in parts of the district not included in this investigation. According to Flint (Flint and others, 1948, p. 44), the limestones interbedded with the volcanic rocks are probably mainly of reef origin. Flint also points out that serpentine fragmental material found in some conglomeratic lenses strongly indicates that this sequence of rocks is post-serpentine.

Eocene sedimentary rocks

Eocene rocks, consisting principally of limestones and semiconsolidated sediments, unconformably overlie the ultramafic complex along the south border of the eastern part of the Camagüey area. Although thick soil covers most of the area underlain by these rocks, several small outcrops of soft buff-colored limestones were observed southwest of the Porvenir mine. In two drill holes, approximately 200 feet from the assumed contact of serpentinized peridotite and Eocene rocks, 14 feet of semiconsolidated yellow to buff marls were found above the serpentinized peridotite.

Cherty silica and laterite

Cherty silica, in part highly ferruginous, caps many of the higher serpentine hills in the Camagüey district. This material, formed by decomposition of serpentinized peridotite and subsequent concentration of the iron and silica, is well exposed on Loma La Entrada to the south of the Camagüey area and on Mesa San Felipe north of Camagüey city. Loma La Entrada is capped by more than 30 feet of chalcedony, jasper, and other varieties of cryptocrystalline quartz containing small vugs and vein-like networks lined with drusy quartz. Mesa San Felipe, on the other hand, is capped with a thick deposit of lateritic iron oxide of potential ore grade. These deposits and another of cherty silica that caps Loma Bayatabo southeast of Minas are remnants of an extensive erosion surface probably developed during late Tertiary time. Thinner and topographically lower deposits, such as the cherty silica on hills in the Camagüey and Caridad areas and the ferruginous silica cappings in the Aventura area are probably the result of later silica-concentrating processes following uplift and partial removal of the old higher surface.

Where observed, the contact between the residual deposits and underlying serpentinized peridotite is sharp. However, small unsilicified fragments of serpentine, as well as grains of chromite, are often observed in the silica and some siliceous vein material is usually present in the serpentinized peridotite directly under the cap.

Thin deposits of red lateritic soil ranging in thickness from a few inches to 1 or 2 feet are scattered throughout most of the investigated areas; some of the largest soil-covered areas are in the northern Aventura area, westward from the Camagüey mines in the Camagüey area, and in the central part of the Oriente area.

Alluvium

The largest stream valleys and local topographic lows throughout the savannah are usually filled with a few feet of alluvium. In the valley of the Río Máximo in the Aventura and La Nona areas as much as 10 to 15 feet of soil has accumulated. Alluvial material and possibly some eluvium derived from the Sierra de Camaján covers most of the serpentinized rocks in the Lolita area. Along the north side of the area, close to the base of the Sierra, the alluvium probably exceeds 20 feet in thickness. Thin talus deposits are present on the slopes of the hills in the La Nona area and on the northern slopes of Loma La Entrada in the Camagüey area. Thick black residual soils are common over large bodies of feldspathic and volcanic rocks and in many places conceal all contacts between these rocks and the serpentinized peridotite.

Structure and regional gravity features

The geologic structure of the Camagüey district is very complex. Only large regional features can be inferred from the occurrence and attitudes of the various rocks.

A series of folds that have downwarped the feldspathic member of the ultramafic complex and overlying volcanic rocks are prominent structural features. They are arcuate, trending from southwest in the eastern part around to northwest in the western part of the district. The Lugareño-Yucatán syncline, largest and most prominent of these folds, extends approximately 25 miles westward from the vicinity of Central Lugareño (9 miles east of Minas) to Loma Yucatán. The upward succession of serpentinized peridotite, feldspathic rocks, and volcanic rocks and associated limestones is well displayed along the flanks of the syncline. Two smaller folds parallel this syncline on the north. One extends southwest from the Lolita area and terminates near the south end of the Victoria area. The other, which borders the north side of the Estelnita area, probably continues beneath the Sierra de Camaján.

The large Lugareño-Yucatán syncline, with its dense infolded feldspathic and volcanic rocks, is indicated by a major gravity high (fig. 5)

Figure 5. Bouguer gravity and geologic map of part of the Camagüey chromite district, Camagüey Province, Cuba

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that extends from Loma El Pastil through Altagracia to beyond Minas. Prominent maxima over deep parts of the syncline, or possibly denser masses in the volcanics or feldspathics, occur on this feature near Loma El Pastil and east of Cromo. An area of low gravity, representing a fold on the northern flank, lies northeast of Altagracia. Here the gravity contours imply that the dip of the flank is gentle and that the feldspathic rocks are thin or absent. Minor anticlinal folds, evidenced by exposed serpentinized peridotite, also occur along this flank and are manifested by contour undulations that trend northwest from the low. Over the eastern part of the syncline, between Altagracia and Minas, the gravity relief is less, which indicates that the felspathic zone in this part of the fold is relatively thin. This is also indicated by the wide distribution of a large number of small serpentinized peridotite outcrops.

Remnants of the fold extending southwest from the Lolita area are manifested by two gravity maxima. These occur over the deeper parts of the fold where volcanic rocks are exposed. Between the maxima, the gravity data indicate that there is a general thinning of the feldspathic rocks toward the highway where it crosses the structural trend.

(followed by p. 40a)

Northwest of the southern maximum is a series of feldspathic rock outcrops that may be remnants of another fold paralleling the Lugareño-Yucatán syncline. These lie along the flank of a major gravity high containing two maxima. The northern maximum is centered near a large feldspathic outcrop and probably is caused by feldspathic rock lying at shallow depths. The southern maximum occurs over hills of dense serpentinized peridotite and indicates that a large part of the major gravity high is caused by a density contrast in the serpentinized peridotite. Another positive anomaly that is attributed to dense serpentinized peridotite lies a short distance west from the north end of the gravity high.

Two other prominent regional features are the Sierra de Cubitas (not shown on the accompanying maps) and the Sierra de Camaján. These are Cretaceous and Jurassic limestone masses that are believed to have been thrust over the ultramafic complex and volcanic rocks from the north (Flint and others, 1948, p. 45-52). This overthrusting probably represents the culmination of the strong forces which initially caused the folding observed in the older ultramafics and volcanics. A gravity high that begins west of the Estelnita area probably is associated with a fold that extends under the Sierra de Camaján.

Other faults, as shown by offset chromite bodies and intense shearing in the peridotite, are undoubtedly common, but the magnitude cannot be determined because of the uniformity of the rocks and the high degree of serpentinization.

Two prominent gravity lows are indicated by contours as developing along the western and southeastern edges of the mapped area. The low on the western edge is due in part to feldspathic and volcanic rocks that occur along the north side of the anomaly and a general thinning concomitant with increased serpentinization of peridotites and dunites in the ultramafic complex to the southwest. The gravity low in the southeastern part of the area overlies Eocene sedimentary rocks consisting mainly of low-density limestones and semi-consolidated marls.

Chromite deposits

Chromite, a hard, black mineral of the spinel group with the general formula of (Mg, Fe) $(Cr,Al,Fe)_2O_4$, is the ore mineral of the Camagüey deposits. Although the composition of chromite from different places varies widely, the samples from the Camagüey district that have been analyzed show a marked similarity. Mine-run ore usually contains about 31 percent Cr_2O_3 and 5 percent SiO_2. The ore mineral itself, cleaned of silicate gangue, has an average composition of about 36 percent Cr_2O_3, 30 percent Al_2O_3, 17 percent MgO, 13 percent FeO, and 4 percent Fe_2O_3. The bulk density is approximately 4.0 grams per cubic centimeter.

The Camagüey chromite occurs as grains up to one-eighth inch in diameter disseminated in a dunitic, peridotitic or feldspathic host rock, and as masses of practically pure chromite of much coarser grain size, with only minor interstitial silicate material. Individual deposits in the serpentinized peridotite form irregular, lenticular and tabular masses that range in size from small pods to masses several hundred feet long containing 200,000 tons or more. The tabular bodies are usually oriented parallel to the strike of the nearest contact between serpentinized peridotite and feldspathic or volcanic rocks, and dip from a few degrees to vertical, with the majority dipping steeply. Most contacts between the chromite masses and serpentinized peridotite country rock are faulted or sheared, the zone of movement being represented by a thin zone of serpentine. Where not sheared, the contacts are usually gradational. Many deposits are cut and offset by faults. Dikes of fine- to very coarse-grained gabbro, troctolite, and serpentine are common in the chromite bodies.

An unusual type of chromite in the Camagüey district, and one which may not conform mineralogically or genetically to the rest is the disseminated material that occurs as small deposits along parts of the feldspathic rock-serpentinized peridotite contact. These deposits, rarely more than a few feet thick, are very abundant in the La Nona, Oriente, and Victoria areas and are found either in the feldspathic rocks just above the contact or in serpentinized dunite immediately below it. The material in these deposits is magnetic, which indicates that magnetite is associated with the chromite. Although these chromite deposits have never been commercially exploited owing to their probable limited size and disseminated nature, a scarcity of refractory-grade chromite may in the future warrant investigation.

In all the areas studied the chromite bodies tend to be grouped in definite clusters near the top of the serpentine unit. Many of these clusters have undoubtedly resulted from the horizontal offsetting of large chromite bodies along late faults. Others, however, appear to have broken loose from large chromite masses, which had not yet attained their ultimate position, and moved prior to complete crystallization of the complex rock.

The origin of the Camagüey chromite deposits cannot be fully explained at the present time. Flint (Flint and others, 1948, p. 57-59) suggests two general possibilities: (1) differentiation and segregation of a homogeneous magma after intrusion into its present position; and (2) differentiation at depth prior to intrusion into the earth's upper crust. The first hypothesis seems untenable in light of evidence to date because it does not satisfactorily explain the structures of the chromite bodies or their localization underneath the feldspathic rocks. The second hypothesis, which is quoted below, appears to account for many of the features of the Camagüey district.

"According to this hypothesis long-continued differentiation by crystal settling deep within the earth resulted in the separation of a mafic magma into feldspathic and peridotitic components, with one or more chromite-rich bands somewhere near the base of the complex. Downward buckling of the crust during a period of orogeny, perhaps with accompanying slow heating of the ultramafic rocks by radioactive elements, caused partial melting of this substratum, followed by intrusion into the upper crust along a number of feeders. The intruded material was not entirely liquid, but included crystals and masses of unfused rock in a medium of molten magma, the whole constituting a crystal mush that spread out from the feeders in the form of a thick sill or lopolith. The feldspathic fraction floated to the top of the chamber while the heavier olivine-pyroxene mush was compacted on the floor. Relief of pressure caused progressive fusion lower and lower in the substratum until the chromiferous horizon was tapped, but as the chromite itself melts at an even higher temperature than the surrounding silicate minerals, most of the chromite was brought up in the form of irregular tabular blocks torn from the original layer and carried up in the viscous medium. By the time the chromite arrived at the intrusion chamber, compaction of the olivine and pyroxene had built up a fairly solid floor, leaving only the upper part of the chamber available to receive the additional material, which spread out more or less horizontally for short distances from the feeders, and solidified."

Investigations of areas

Victoria area

The Victoria area (fig. 4), 2 1/2 miles northeast of Altagracia, forms a narrow "J"-shaped belt that extends from the Río Santa Cruz southward along the edge of the savannah to the old La Victoria mine, a distance of approximately 3 miles. The area covers about 1.1 square miles and is accessible by the Camagüey-Nuevitas highway and a connecting all-weather road. Two large abandoned mines, the La Victoria and Victoria, each of which produced over 100,000 tons of chromite, are located in the area. The former, one of the oldest mines in the Camagüey chromite district, occupies a broad hill that dominates the southern part of the area.

Geology

Geologically the Victoria area lies in a region of profound structural disconformity on the northern flank of the Lugareño-Yucatán trough. The disconformity is indicated by an abrupt change in trends of the elongated feldspathic bodies that occur in the serpentinized rocks (fig. 6). In the northern part of the area these masses strike

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Figure 6. Gravity features and geology in the Victoria area, Camagüey chromite district, Cuba

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roughly N.30° W. and in the middle of the area seem to butt against exposures striking N. 60° E. Further surface evidence, however, as to the nature of this disconformity along the main ultramafic-volcanic rock contact is obscured by soil cover.

Serpentinized peridotite and dunite constitute the main rock types in the Victoria area, but these could not be mapped as separate units at the scale of mapping used. Their heterogeneity is especially noticeable near the large structural break, where the rock type changes from outcrop to outcrop. An upward succession of peridotite, dunite, and troctolite, which is well shown in the Oriente area a few hundred meters to the north, was observed only in the extreme northern part of the Victoria area.

Feldspathic rocks of the uppermost member of the ultramafic complex are exposed in only a few localities around the synclinal border of the area. These rocks range from gabbro, troctolite, to anorthosite in composition and are consistently coarse grained. Large feldspathic masses occur in the serpentinized rocks away from the contact and, in general, are similar in composition and texture to the main feldspathic member; they are commonly surrounded by a narrow zone of feldspathized serpentine. Small fine-grained gabbro pods and dikes that do not appear to follow any structural trend are also common throughout the area.

Ore bodies in the La Victoria and Victoria mines were large tabular blocks of massive chromite which were oriented approximately parallel to the nearest serpentinized peridotite-feldspathic rock contact. The clustering of chromite deposits is well shown around the Victoria mine, where the main ore zone consisted of three separate large bodies and several smaller masses. A chromite deposit discovered by this investigation near the Victoria mine is probably an offset portion of the northernmost ore body, which, according to Flint (Flint and others, 1948, p. 54-55), was cut by a number of late cross faults that offset parts of the ore body to the west. A few small deposits occur at least 2,000 feet north of the main Victoria workings. Around the La Victoria mine, however, only two very small satellitic chromite masses were observed on the surface and no subsurface deposits were discovered by the exploration program.

Small disseminated chromite deposits, all less than 10 feet in diameter and not over 2 feet thick, crop out directly below the base of a troctolite mass exposed on a prominent hill in the northern part of the area and around troctolite masses in the central part of the area.

Gravity features

Indications of the structural disconformity are manifested by features of the contoured Bouguer gravity data. Contour undulations and closures, alined with outcrops and buried masses of dense material, reveal a marked change in structural trends in the central part of the area, and indicate that subsurface conditions are more irregular to the south. In the northern part of the area the gravity field is fairly uniform and the anomalies are relatively small in areal extent, which indicates that their sources are near the surface. To the south, the field becomes noticeably irregular and contains several broad features which indicate the occurrence of large masses of deeply buried dense material or clusters of small bodies of such material lying at shallow depths. Another prominent feature indicating structural disconformity is a contoured terrace effect that trends northward through the La Victoria mine and borders in part a general gravity high (fig. 6), which is associated with thin remnants of feldspathic rocks to the east.

High-gravity gradients and positive anomalies mark the main contact between serpentinized peridotite and feldspathic rocks along the western and southern sides of the area (fig. 6). Positive features occur over feldspathic rocks and in places extend over the adjacent serpentinized peridotite. Over the feldspathic zone, the gravity maxima apparently are caused by increases in thickness of the mass. Those extending over the peridotite probably represent subsurface continuations of the feldspathic rocks. Negative anomalies attributed to density contrasts in the peridotite also occur in a general area of low gravity over serpentinized peridotite near the contact. Two of the largest are centered near stations 38-16W and 108-16N and are probably caused by complete serpentinization of the peridotite or dunite.

Local and regional gravity features are shown in profiles of the gravity data (fig. 7). Bouguer gravity profiles reveal the general

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Figure 7. Magnetic, gravity, and geologic profiles along traverses 0, 1, 2, 62, and 88 in the Victoria area

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change in gravity values associated with the regional gradient that seems to be influenced greatly by denser rocks in the folds. In most profiles, a pronounced change in gradient occurs near the main contact between serpentinized peridotite and feldspathic rocks. Away from the contact outcrops of feldspathic rock, chromite bodies, and density changes in the serpentinized peridotite and dunite cause gravity highs and lows. The extent and amplitude of these features are revealed in nested profiles and most target anomalies are well-defined.

The contoured residual gravity data show more clearly the anomalies that are of primary interest in prospecting (fig. 6). These anomalies represent local or residual gravity effects that are isolated by removing the regional gradient from the Bouguer gravity station values. Prominent gravity highs and lows occur over parts of the major serpentinized peridotite or dunite-feldspathic contact. Some of the positive gravity features are over feldspathic rocks exposed along the contact, but others are attributed to the manner of removing the regional gravity gradient (fig. 7). This regional reduction effect also accounts in part for the prominence of the negative anomalies that occur over serpentinized rocks adjacent to the contact. Positive anomalies flanked by gravity lows are associated with outcrops of feldspathic rocks in other parts of the area. The positions of positive anomalies indicate that many of the feldspathic masses vary considerably in dip and thickness; in some cases the maximums of the anomalies occur to the side of the exposures. A few gravity lows apparently extend over the thinner portions of these bodies. Prominent negative anomalies also occur around open pits and large dumps in the vicinity of the mine workings. Other prominent gravity lows lie along streams where thick deposits of transported soil are found. Several positive anomalies, classified 1A to 2B, occur over serpentinized rocks near large feldspathic bodies and in other parts of the area where only small masses of dense rock were observed.

Results of drilling

Test holes ranging in depth from 32 to 266 feet were drilled on the crests of 18 positive anomalies (fig. 6) in this area. The drilling (table 2) showed that two anomalies occur over deposits of chromite; nine are related to feldspathic rocks; four are associated with dense serpentinized peridotite; and two are over serpentinized peridotite containing thin stringers of feldspathic rock. All these materials afforded harder and more difficult drilling conditions than the associated normal serpentinized country rock.

Table 2. Results of exploratory drilling in the Victoria area

Gravity Anomaly		Drill Hole		Apparent source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
W3-1N	1A3	32	171	Dense serpentinized peridotite containing feldspathic stringers	51-137
0-1N	1A3	1	66	Chromite	20-61
1.5-9.5W	3A3	31	32	Troctolite	1-32
4.5-8W	1B	30	200	Serpentinized peridotite containing stringers of feldspathic rock	80-200
15.5-11W	2A2	2	80	Chromite	28-69
15.5-0	1B	3	100	Feldspathic rock	52-100
41.5-4.5E	1A2	14	168	Alternating stringers of serpentinized peridotite and gabbro	0-168
41-22W	3A2	15	135	Gabbro	4-135
50.5-4E	1A2	16	165	Dense serpentinized peridotite	2-23
63-2W	1B	19	266	~~Dense~~ do. serpentinized peridotite	1-45
65-2W	1B	20	232	~~Dense~~ do. serpentinized peridotite	30-80
66-14W	Gravity low	20L	52	Serpentine	3-52
69B-14S	1B	23	105	Dense serpentinized peridotite with stringers of feldspathic rock	47-105
70-18S	1A3	23A	85	Gabbro	45-85

(continued)

Table 2. (continued)

Gravity Anomaly		Drill Hole		Apparent source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
79-16N	3A3	25	108	Troctolite	6-108
78-5S	1B	26	150	Feldspathic rock	20-70,95-104,140-150
78-4S	1B	26A	205	Serpentinized peridotite with numerous feldspathic stringers	3-205
81-5N	3A1	27	163	Gabbro	2-163
83.5-22S	1B	28	200	Dense serpentinized peridotite	20-150
85-22S	1B	28A	42	Feldspathic rock	2-39
87-6S	3A3	29	100	Troctolite	1-82, 84-100
90-12S	2B	29A	40	Troctolite	27-40

One of the chromite deposits is indicated by the anomaly centered near station 0-1N (fig. 8). Trenching and closely spaced

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Figure 8. Residual gravity anomaly over chromite deposit near 0-1N and drill hole sections through the chromite body, Victoria area

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drilling around discovery hole 1 proved 24,000 tons of refractory-grade chromite and revealed that the deposit extends from the surface to a depth of 197 feet, dips steeply to the south, and is probably cut by a fault between drill holes A and D. The anomaly lies over the main part of the deposit and indicates a possible extension to the south. This extension was investigated by hole H, which failed to cut chromite in drilling to a depth of 300 feet.

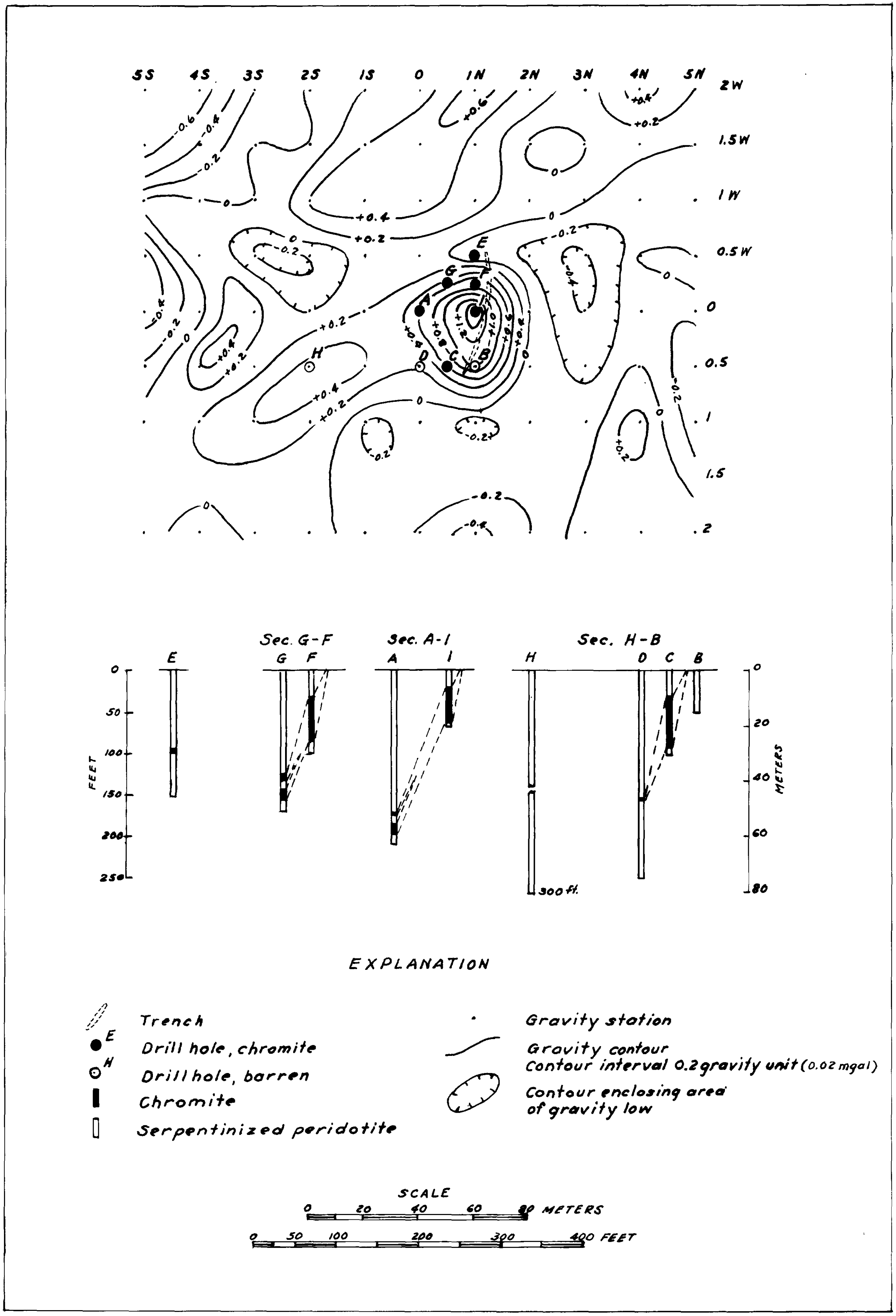

FIGURE 8. Residual gravity anomaly over chromite deposit near 0-1N and drill hole sections through the chromite body, Victoria area.

The other chromite deposit is indicated by the anomaly centered near station 15.5-11W (fig. 9). This deposit lies very close to an

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Figure 9. Residual gravity anomaly over chromite deposit near 15.5-11W and drill hole sections through the chromite body, Victoria area

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outcrop of troctolite near the northwest end of the Victoria mine. The chromite body contains approximately 115,000 tons, dips steeply toward the southwest, and comes within 10 feet of the surface. Most of the ore lies below 75 feet and the bottom is between 225 and 250 feet deep. The anomaly is prominent and regular in shape, involves 12 stations, and has a gravity relief of 1.6 gravity units. The position of the anomaly with respect to the troctolite indicated that the feature could be caused by a continuation of the troctolite at depth. However, in view of the absence of an anomaly over the outcrop, the source was considered to be other dense material.

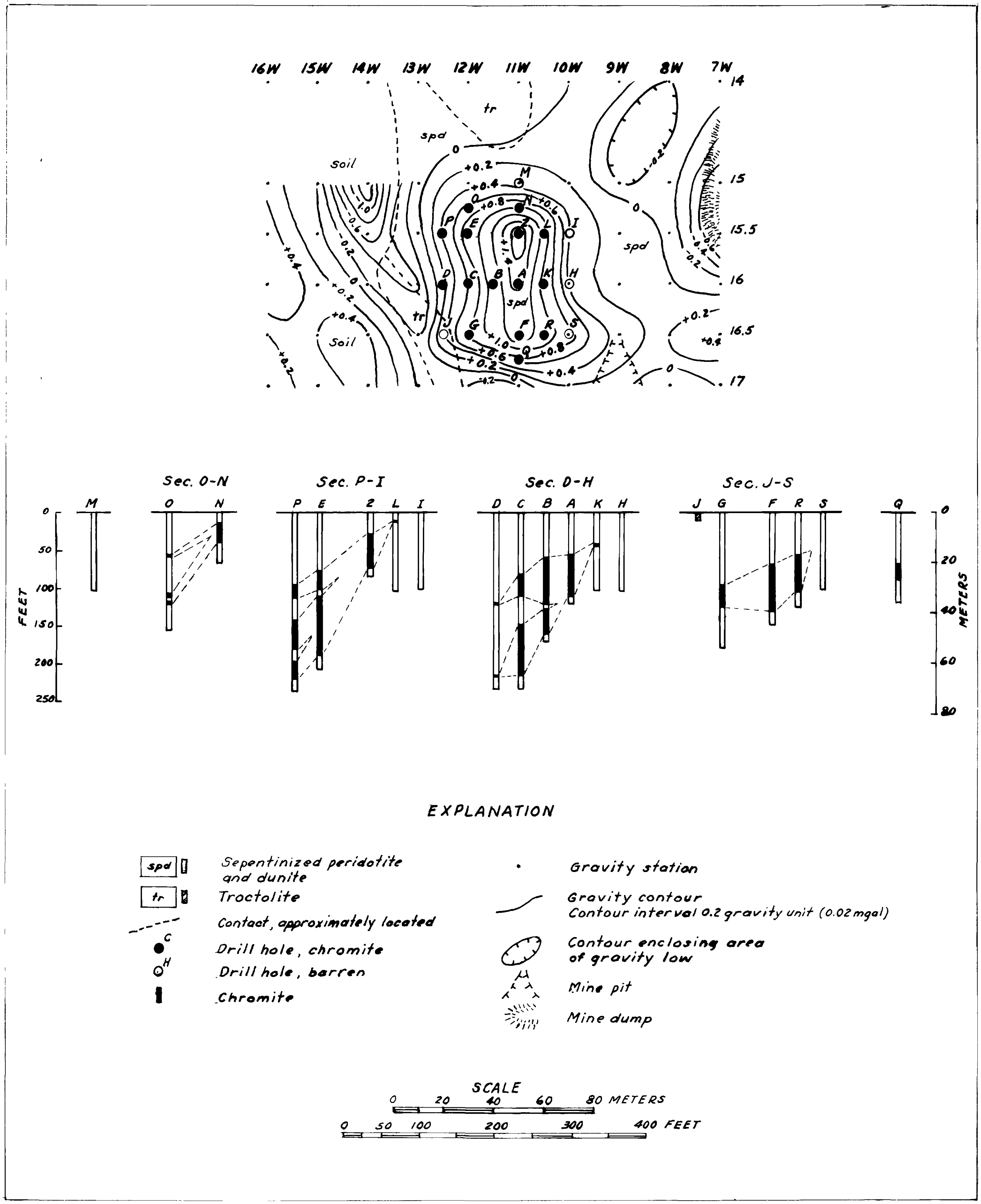

FIGURE 9. Residual gravity anomaly over chromite deposit near 15.5-11W and drill hole sections through the chromite body, Victoria area.

Two test holes were drilled on each of three anomalies. Hole 20 was drilled 120 meters south of drill hole 19, 63-2W (fig. 6), which did not find a sufficient amount of dense material to account for the anomaly. A body of dense black serpentinized peridotite that also was cut in hole 19 was found between 30 and 80 feet in hole 20 and was considered to be the apparent source of this anomaly. Hole 26A was drilled to investigate a small local high lying on the flank of an anomaly caused by feldspathic rock revealed in drill hole 26, 78-5S. Drilling showed that the small high was caused by lenses of feldspathic rock that apparently extend north from the main body. Another small high on an anomaly overlying feldspathic rock was tested by drill hole 28A, 85-22S. This feature probably was caused by thickening of the feldspathic mass that is the source of the major gravity anomaly.

In addition to test drilling for chromite, hole 20L was drilled at station 66-14S near the center of a gravity low for correlation purposes. This hole found claylike serpentine extending from a depth of 3 feet to the bottom of the hole 53 feet deep. The anomaly was probably caused by this rock, which is extremely soft and friable and could not be cored.

Discussion

The tested gravity anomalies do not have characteristic features that would serve to identify the materials with which they were found to be associated. Although the anomalies caused by chromite are comparatively small in areal extent and are fairly prominent and regular, the anomalies caused by other heavy materials are similar and cannot be differentiated from the chromite anomalies. Of interest is the close proximity of the chromite body at 15.5-11W and troctolite as revealed by drill holes G and 2J (fig. 9). This indicated that gravity anomalies partly associated with feldspathic rocks are potential prospects for chromite.

The magnetometer measurements along traverses crossing the area could not be used successfully in evaluating the gravity anomalies. These measurements indicate that the vertical magnetic intensity varies locally, depending upon the amount of magnetic material contained in the soil and rocks lying near the surface. The range of variation of the magnetic intensity is approximately 2,400 gammas, but over the major portion of the traverses, the range is between 500 and 1,000 gammas. Profiles of the data are very irregular (fig. 7) showing pronounced changes in the intensity from station to station that impart a "saw-tooth" character to the profiles. Low magnetic values were obtained over exposed feldspathic rocks and over shallow feldspathic bodies where the overburden apparently consists mainly of soil derived from these rocks. Low values also were obtained over the chromite deposits and parts of the area underlain by serpentinized peridotite. High magnetic values were observed over other parts of the serpentinized country rock and over feldspathic rocks near their contact with serpentinized peridotite. In general, the magnetic intensity appears to be slightly greater and the amount of variation is more over the serpentinized rocks than over the feldspathic rocks. However, the magnetic values are so erratic that the data cannot be interpreted successfully.

Aventura area

The Aventura area (fig. 4), which contains approximately 3.3 square miles, covers a narrow zone about half a mile wide and 6 miles long extending northward from the Rafael mine, near Cromo, to beyond the Teyde mine near Loma El Pastil. With the exception of the extreme northern part, the area is generally accessible by car throughout the year. Chromite production amounting to more than 300,000 tons was obtained from several mines of which the Aventura was the largest producer.

Geology

Serpentinized peridotite constitutes at least 95 percent of the serpentinized rocks in the Aventura area (fig. 10). Small zones or lenses

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Figure 10. Gravity features and geology in the Aventura area Camagüey chromite district, Cuba.

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of serpentinized dunite are scattered throughout the area but nowhere form a mappable unit.

The feldspathic member of the ultramafic complex changes in composition along the entire eastern side. However, in this part of the area most of the feldspathic rocks are covered by soil and nowhere was the contact between gabbro and troctolite observed. Small fine-grained gabbroic bodies are common throughout the entire Aventura area, with the heaviest concentration south of the Roma and Aventura mines. A large coarse-grained gabbroic body near the Carmela mine is probably a remanent of the feldspathic member exposed in a structural low.

Volcanic rocks were observed in a number of localities along the eastern edge of the area near the Aventura mine. In general, these rocks overlie serpentinized peridotite, but they were also found in places above the feldspathic rocks. South and east of the Aventura mine the volcanic rocks are predominantly light buff-colored calcareous tuffs, whereas, north of the mine small exposures of dark-green crystalline rocks were observed.

The contact between serpentinized peridotite and feldspathic or volcanic rocks along the eastern side of the area is very irregular, and some of the larger feldspathic masses which protrude into the serpentinized peridotite may be fault blocks. The best evidence of faulting along the main contact is in an area north of the Rafael mine, where a narrow band of troctolite, 2,000 feet long, appears to have moved northwest along a definite linear trend. Two other large feldspathic masses in the area may have been displaced by faulting. These masses, one located between the Roma and Aventura mines, and the other south of the Angelina mines, are in contact with serpentinized peridotite on their north side. The contacts are fairly straight and are oriented normal to the general trend of the serpentinized peridotite-feldspathic rock contact. Northwest of the contact of the feldspathic mass lying between the Roma and Aventura mines, and roughly paralleling it, are a series of small siliceous bodies that may have been formed hydrothermally along a shear or fault zone. The irregular general geologic pattern around the Aventura mine also indicates major structural divergence in this part of the area.

Two potential magnesite deposits were disclosed by drilling west of the Aventura mine. These bodies consist of white to pink crystalline magnesite intimately associated with talc, quartz, and a chlorite mineral in a dense highly sheared light-colored rock. They probably result from intense hydrothermal alteration and replacement of favorable zones in the serpentinized peridotite. The magnesite deposits and the area immediately surrounding them form low hills that are capped by deposits of ferruginous cherty silica, which probably are remnants of an earlier erosional period. Other hydrothermal features in the Aventura area are: (1) a molybdenite-bearing massive quartz body 2,000 feet west of the Aventura mine, (2) small chalcopyrite-bearing quartz veins in gabbro near the Carmela mine, and (3) abundant thin chloritized shear zones with minor copper minerals in serpentinized peridotite southwest of the Roma mines. The molybdenite-bearing quartz body is exposed in an irregular area covering approximately 25 square feet, and is associated with a small mass of magnesite-talc rock similar to the material described above.

The numerous chromite mines and prospects in the Aventura area described by Thayer (Thayer, 1942, p. 40-51) appear to be concentrated in six definite groups or clusters that constitute the Rafael, Roma, Aventura, Carmela, Angelina, and Teyde mines. The clusters are separated from each other by areas of barren serpentinized peridotite, and all contain a number of chromite bodies that may or may not belong to the same mine property. One cluster, the Carmela, extends northwest out of the mapped area and includes the chromite deposits of the Buck and Charles A. mines. The majority of chromite bodies in the Aventura area strike parallel to the nearest serpentinized peridotite-felspathic rock contact, which is commonly 300 to 1,200 feet away. A notable exception to this is the large Aventura deposit, which has a strike normal to the nearest contact.

Gravity features

Over most of this area the gravity field is fairly uniform except along the eastern side where high gradients mark the main contact between serpentinized peridotite and feldspathic or volcanic rocks (fig. 10). A general area of low gravity lies between the Aventura and Carmela mines. North and south of this "low" the gravity field increases northward and eastward, respectively. Along parts of the main contact local gradients of low magnitude indicate where the serpentinized peridotite is in direct contact with the volcanic rocks. A prominent gravity minimum is centered near station 63-24E over volcanic rock consisting mainly of light pyroclastic material. Other gravity "lows" are associated with the dumps and pits of mines. A gravity "high" over exposures of ferruginous silica is centered near station 95-18W. Another prominent gravity maximum near station 146-1W occurs over a large coarse-grained gabbro body. Prominent anomalies of less areal extent are scattered widely over the area, but appear to be associated mainly with dense rocks. In this group are several small positive anomalies that were test-drilled for chromite.

Feldspathic rock outcrops are noticeably absent in the general area of the major gravity "low" which implies that greater structural uplift and subsequent erosion occurred in this part of the Aventura area. Further evidence of structural divergence is revealed by pronounced changes in trend of gravity contours around the Aventura mine and near the Carmela mine. These changes are associated with the orientation of feldspathic rocks involved in the disconformity. The fault along the main contact north of the Rafael mine is indicated by a gravity "low," but there is no pronounced gravity evidence of faults expressed in the gradients over the serpentinized peridotite-feldspathic rock contact north of the Roma mine and south of the Angelina mine.

Results of drilling

Thirty positive gravity anomalies in this area were investigated by holes drilled to depths ranging from 34 to 350 feet (table 3). The investigation proved that two anomalies indicate deposits of chromite, ten are associated with feldspathic rocks, fourteen are over masses of dense serpentinized peridotite, and two occur over rock consisting mainly of magnesite, talc, and quartz. No dense materials that would account for gravity anomalies were found in drilling two of the features.

Table 3. Results of exploratory drilling in the Aventura area

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
S30-0	1A1	1	305	Dense serpentinized peridotite	180-305
S3-9W	1A3	15	148	Unexplained, serpentinized peridotite with feldspathic stringers	0-130
S5-7.5W	1B	15A	150	Unexplained, serpentinized peridotite with feldspathic stringers	30-150
S1.5-19W	1A1	16	184	Feldspathic rock	90-118
15-9W	2B	21	102	Dense serpentinized peridotite	50-102
12.5-13W	1A3	21A	34	Gabbro	4-34
32-12E	1B	25	65	Dense serpentinized peridotite	3-65
52-11W	1A3	31	238	Dense serpentinized peridotite	10-116 & 125-159
62.5-7W	1A1	33	254	Dense serpentinized peridotite	1-131
58-8E	2A2	35	85	Gabbro	3-85
74.5-17W	1A3	38	240	Dense serpentinized peridotite	10-240
80-6E	4A2	42	65	Gabbro	4-65
83.5-4E	4A1	43	105	Gabbro	8-105
84-16E	4B	43A	100	Feldspathic rock	57-85
89.5-5W	1A2	44	155	Feldspathic rock	3-62
96-19W	1A1	46	200	Magnesite, talc, and quartz rock	5-200

(continued)

Table 3. (continued)

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
96-10E	1A2	47	140	Dense serpentinized peridotite and gabbro	33-114 114-140
100.5-10W	1A2	50	55	Magnesite, talc, and quartz rock	3-55
106-15W	1B	52	140	Lenses of dense serpentinized peridotite	75-140
110-16W	1C	54	170	Unexplained, serpentinized peridotite	2-170
128.5-14W	1A1	56	281	Dense serpentinized peridotite and feldspathic rock	22-281
136-13W	2A2	58	97	Gabbro	73-97
173-3E	1B	63	200	Dense serpentinized peridotite	121-150
176-12.5W	1B	64	95	Gabbro	2-95
178-5E	1A1	65	248	Dense serpentinized peridotite	65-248
177-8E	1A1	65A	150	Dense serpentinized peridotite	1-150
178-3W	No anomaly	65B	102	Serpentinized peridotite	1-102
181-12E	1B	66	260	Chromite	198-219
195.5-28E	2A1	67	340	Gabbro	90-340
197.75-7.5E	1B	68	100	Dense serpentinized peridotite Feldspathic rock	38-89 90-100
200.5-5.5E	1B	69	110	Dense serpentinized peridotite and feldspathic rock	51-110
200-6E	1B	69A	100	Feldspathic rock	3-100
209.25-7E	1A3	70	101	Chromite	60-81
214-3E	1B	72	350	Dense serpentinized peridotite with feldspathic stringers	150-350

The chromite deposits appear to be small extensions of ore bodies mined from pits of the Teyde and Angelina mines (fig. 10). The largest deposit, containing about 5,000 tons, was found in testing the anomaly centered near station 209.25-7E (fig. 11). Development drilling around

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Figure 11. Residual gravity anomaly over chromite deposit near 209.25-7E and drill hole sections through the chromite body, Aventura area.

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discovery hole 70 showed that the chromite body is narrow, lies between depths of 22 and 102 feet, dips steeply eastward, and is close to a mass of feldspathic rock cut in drill hole I. The other deposit was found in testing the anomaly near station 181-12E. Chromite was cut between depths of 198 and 219 feet in drill hole 66, but an offset hole drilled 20 meters north of the discovery hole was barren. In view of the size of this anomaly and depth to the chromite, the deposit was considered too small to justify the expense of delimiting the body by drilling.

Near another pit of the Teyde mine, a thin stringer of chromite in dense serpentinized peridotite was found between 38 and 39 feet in drill hole 68 (197.75-7.5E). Offset drilling was not done because holes 69 and 69A drilled over a neary maximum (200.5-5.5E) failed to intersect chromite and indicated that dense serpentinized peridotite and felds-pathic rocks are the probable source of the gravity anomalies.

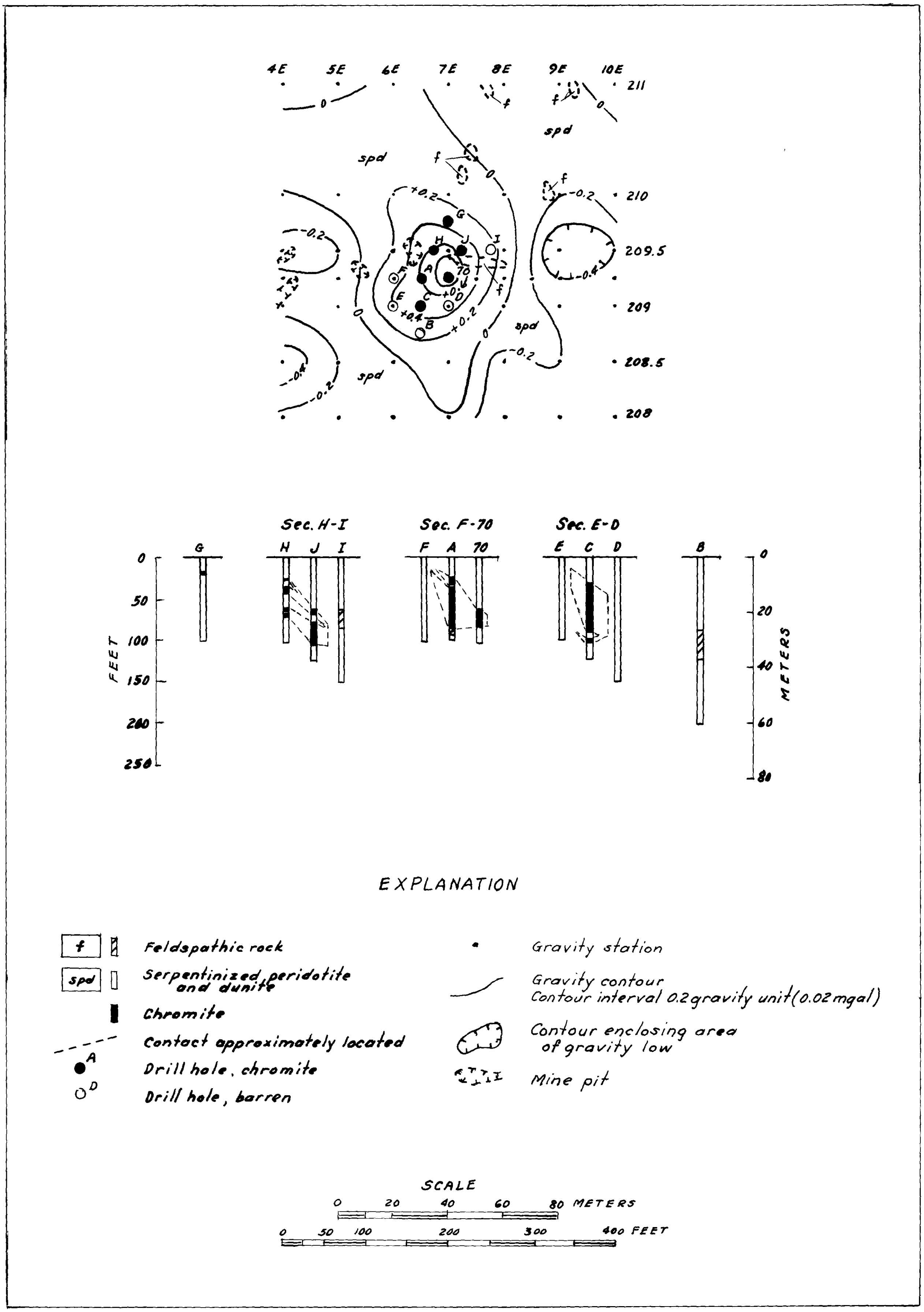

FIGURE 11. Residual gravity anomaly over chromite deposit near 209.25 - 7E and drill hole sections through the chromite body, Aventura area.

One of the most prominent anomalies found in the mapping is centered near station 83.5-4E in a dump area west of the Aventura mine. It has a Bouguer gravity relief of about 4.3 gravity units and involves more than 113 reconnaissance stations. Near the center of the anomaly test hole 43, which was drilled to a depth of 105 feet, disclosed gabbro between depths of 8 and 105 feet. A cored sample of the gabbro taken near the bottom of the hole had a bulk density of 2.66 grams per cubic centimeter. The anomaly is probably caused by a large body of gabbro.

Another large anomaly that was found and tested during the investigation is over exposures of ferruginous silica near station 96-19W. This anomaly embraces more than 100 reconnaissance stations and has a Bouguer gravity relief of 3.6 gravity units. A hole drilled at the center of the anomaly disclosed rock composed predominantly of a mixture of the minerals magnesite, talc, and quartz, lying between depths of 5 and 200 feet. According to a partial chemical analysis of core samples taken at a depth of 75 feet in drill hole 46 (96-19W), the rock contains about 29 percent MgO, 1 percent CaO, and 34 percent SiO_2. The samples had an average density of 2.87 grams per cubic centimeter. Very likely the outcrops of ferruginous silica represent the highly weathered surface exposure of this body.

The anomalies that were not explained by materials found in test drilling are centered near stations S3-9W and 110-16W. Holes 15 and 15A, drilled on maxima of anomaly S3-9W, found serpentinized peridotite containing only a small amount of feldspathic material. It is believed that this anomaly is caused by concentrations of feldspathic material in the serpentinized peridotite, or possibly by small masses of disseminated chromite that were missed by the drill holes. The anomaly 110-16W was tested by drill hole 54, which found serpentinized peridotite extending from a depth of 2 feet to the bottom of the hole 170 feet deep. An additional hole was not drilled because the anomaly was considered to be too small to represent a large deposit of chromite. This anomaly is probably caused by materials less dense than chromite, lying at shallow depths in the serpentinized peridotite.

Because a large number of anomalies were found to be associated with dense serpentinized peridotite, as indicated by zones of difficult drilling and bulk densities of cored samples, a drilling test was made in the serpentinized peridotite near anomaly 178-5E. Serpentinized peridotite that was hard to drill was found in test holes 65 and 65A, located on the maxima of this anomaly. Hole 65 cut hard peridotite lying between depths 65 and 248 feet, and samples taken at depths of 115 and 151 feet had a bulk density of 2.73 grams per cubic centimeter. Hole 65A went through hard peridotite extending from a depth of 2 feet to the bottom of the hole 150 feet deep. A sample taken between depths of 43 and 45 feet in this hole had a density of 2.62 grams per cubic centimeter. Hole 65B was drilled 100 meters west of the anomaly to determine drilling conditions and the bulk density of the serpentinized country rock. Easily drilled serpentinized peridotite was found to a bottom depth of 102 feet; a sample taken at depth of 100 feet had a density of 2.52 grams per cubic centimeter. The test hole revealed that there is a sufficient density contrast between the "normal" serpentinized peridotite and the dense serpentinized peridotite to cause these gravity anomalies, and indicates that the dense masses can probably be detected by difficult drilling conditions.

Discussion

The results of exploration indicate that there are no large reserves of chromite in this area, unless they are associated with untested anomalies that appear to be caused by feldspathic or volcanic rocks, or lie at depths below 200 feet. Four anomalies, however, may possibly be caused by chromite, but these could not be tested because they occur in areas under cultivation. Three of these are centered near stations S17.5-13E, S20-5E, and S22.5-5E, east of the Rafael mine. Although they are not expressed as prominent residual features, these anomalies do have considerable Bouguer gravity relief. The fourth anomaly, which is very prominent, occurs at station 60.5-26E. This feature is particularly interesting because it lies close to the major contact where there is a pronounced change in trend of the feldspathic rocks. Also, it is similar in size and shape to those anomalies that indicate chromite in the Victoria area.

Ofelia area

The Ofelia area, smallest studied in this investigation (fig. 4), occupies a small, flat savannah 0.3 mile east of the northern end of the Aventura area. It is approximately 0.2 mile long, covers about 0.1 square mile, and is accessible by car only during the dry season. The Ofelia mine, which has produced more than 10,000 tons of massive chromite from at least three separate bodies, was the sole producer.

Geology

Scanty rock outcrops owing to thick soil cover are characteristic of the area and vegetation was heavily relied upon as a guide in mapping (fig. 12). The few exposures observed, however, indicated

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Figure 12. Residual gravity and geologic map of the Ofelia area.

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that the serpentinized rocks are predominantly peridotites and that the felspathic rocks along the border consist mainly of coarse- to medium-grained gabbro. Only a few small fine-grained gabbro dikes and pods were found in the serpentinized peridotite. Structurally the area appears to be on a small subsidiary anticline on the southern flank of the Lugareño-Yucatán trough. The Ofelia mine, whose workings and chromite bodies have been described by Thayer (1942, p. 46-47), covers 4 to 5 acres in the northeast part of the area. Low-grade disseminated chromite is abundant on the surface around the two central workings and a disseminated-chromite zone dipping to the east is exposed in the bottom of the easternmost pit.

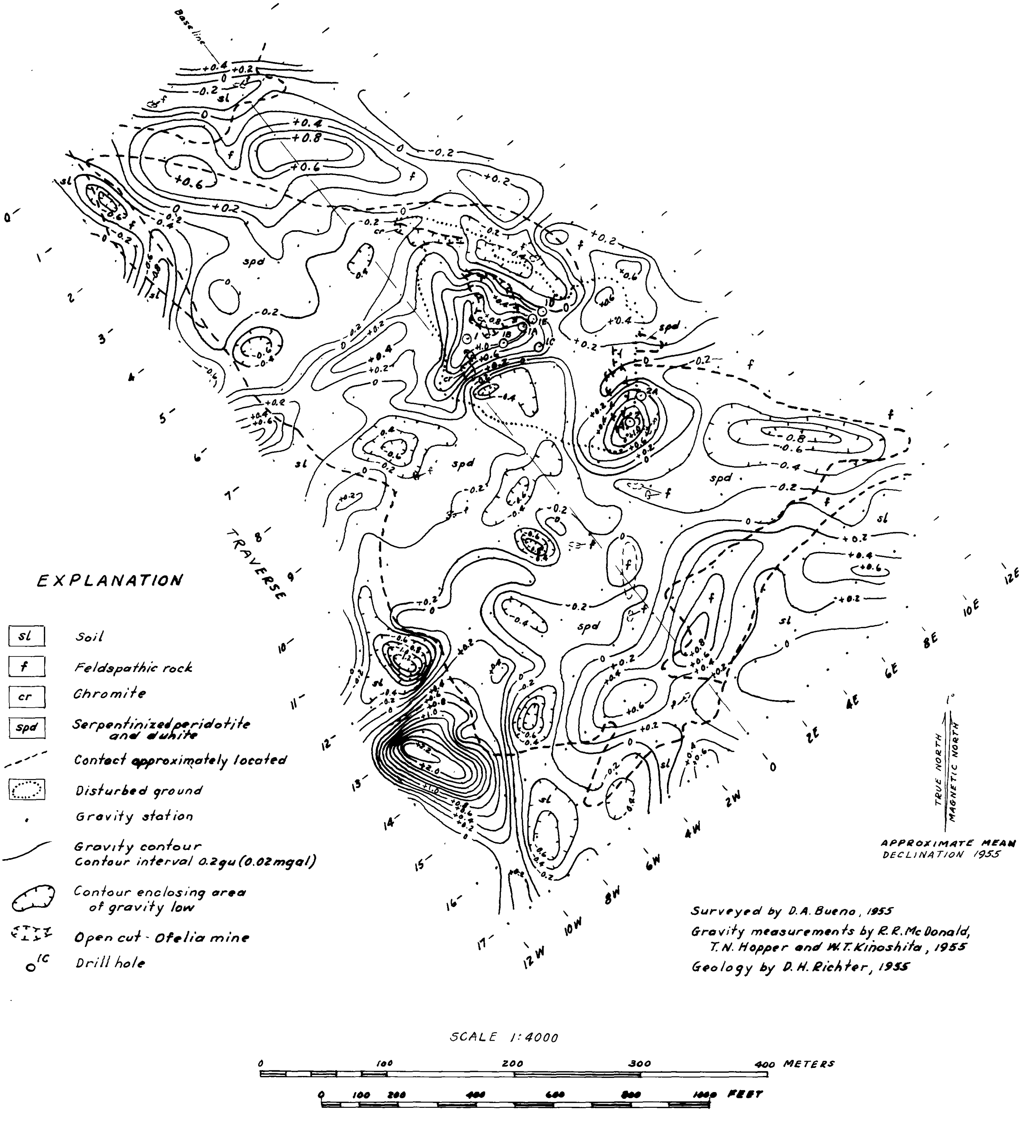

FIGURE 12. Residual gravity and geologic map of the Ofelia area, Camagüey chromite district, Cuba.

Gravity features

Prominent gravity features occur near the mines and along the border of the area. On the northern side a high gradient indicates the major contact between serpentinized peridotite and felspathic rock. A gravity "low" apparently associated with less dense felspathic rock, or volcanic material not evident at the surface, occurs along the southwestern side. Another gravity "low" attributed to the effects of bordering felspathic rocks lies over serpentinized peridotite along the northeast end of traverses 13 and 14. The most prominent residual feature (fig. 12) is a gravity maximum at the southwest end of these traverses, where the ground is under cultivation. Two smaller positive anomalies flanked by gravity "lows" occur near the largest mine pits.

Results of drilling

The positive gravity anomalies near the mines are the only features in this area that were investigated by drilling (table 4). Anomaly 8-3E (fig. 12), which occurs in part over an exposed body of disseminated chromite, was tested by six drill holes to determine if any massive chromite underlies or is interbedded with the disseminated material. In the course of drilling, no appreciable amount of massive chromite was disclosed; however, the disseminated chromite body was found to continue to a depth of 90 feet. It contains a minimum of 20,000 tons of chromite. The anomly 10.75-4E was tested by two holes, which found a small deposit of disseminated chromite between depths 17 and 59 feet. This deposit is undoubtedly the continuation of a disseminated chromite mass that is exposed in the wall of a mine pit nearby and dips toward the drill holes. On the basis of drilling and size of the anomaly, it is estimated that the deposit probably contains between 5,000 and 8,000 tons of disseminated chromite.

Table 4. Results of exploratory drilling in the Ofelia Area

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
7.5-1E	1A3	1	127	Serpentinized peridotite and blue clay	6-127
8-3E		1A	110	Chromite	0-87
8-2E		1B	59	Chromite	0-35
8.5-3E		1C	70	Chromite	1-44
8-4E		1D	130	Serpentinized peridotite	7-130
8-3.5E		1E	112	Chromite	22-54, 65-90
10.75-4E	1A3	2	100	Chromite	25-59
10.5-5E		2A	78	Chromite	17-39, 53-58

Discussion

Except for two untested gravity maxima, the residual gravity and geologic map (fig. 12) shows no other features that may be attributed to the occurrence of chromite. Gravity profiles show that the maximum at station 15-3W is associated with feldspathic rocks exposed near the center of the traverse. It is very doubtful, therefore, that this feature indicates chromite. The anomaly near 13-11W is very prominent and may be indicative of a large deposit of chromite. This anomaly undoubtedly is caused by a mass of dense material lying at shallow depths, but is typical of those features associated with the magnesite-talc-quartz rock and some of the gabbros. It could not be test-drilled because permission was not granted by the property owner.

Camagüey area

The Camagüey area (fig. 4) occupies a long and relatively narrow savannah on the south side of the Lugareño-Yucatán syncline. It begins 2½ miles southeast of Altagracia, extends about 5.6 miles in a general easterly to northeasterly direction, and includes approximately 2.9 square miles. A part of the area near the Camagüey mine was not studied during this investigation because it was prospected previously by the Gulf Research and Development Co. Roads from Altagracia, Colonia San Serapio, and Minas afford easy access to the area throughout the year. A large sugar company, with headquarters at Central Senado, north of Minas, controls most of the land and maintains a railroad that crosses the area south of San Serapio. Gently rolling land, dominated by high Loma La Entrada, is typical of the western part of the area. Toward the east, however, the terrain gradually flattens and the ultramafic rocks are exposed over a long, low domelike feature.

Geology

Serpentinized peridotite is the predominant rock type in the area (fig. 13). Serpentinized dunite occurs locally but was not mapped

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Figure 13. Gravity features and geology in the Camagüey area, Camagüey chromite district, Cuba.

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as a separate unit. A sheared contact between dark greenish-brown serpentinized peridotite and a mass of light bluish-green serpentine is well exposed in a railroad cut of the Central Senado line near the south-central part of the area. The serpentine is a highly sheared rock that lacks original textures, but which has probably resulted from complete serpentinization of original peridotite in a wide fault zone. These zones of serpentine, as indicated by the exposure in the railroad cut, are probably common, but owing to their high susceptibility to mechanical breakdown, their occurrence in soil-covered topographic lows is easily overlooked.

The feldspathic, volcanic, and Tertiary rocks that border the Camagüey area are generally covered by a thick mantle of soil. In many places, especially along the northern side of the area, the soil cover is extensive enough to mask entirely the nature of the rock contacts. Feldspathic rocks do not appear to be as abundant in the Camagüey area as in some of the others, but where observed, they range from gabbro to troctolite. The volcanic rocks are light-colored tuffs, in part highly brecciated, agglomerates, and dense dark-green felsites. At the western end of the area light-gray dense limestone occurs in the volcanic assemblage. Tertiary rocks, principally semiconsolidated marls and limestone, unconformably overlie serpentinized peridotite along the southern border in the western half of the area. Dikes and lenses of feldspathic rocks are scattered throughout the serpentinized peridotite. Between the Camagüey and Almendares mines these small masses trend parallel to the major structural features, but elsewhere they are not oriented along any particular trend.

Cherty silica and silicified serpentine cap the hills that extend eastward from Loma La Entrada. These cappings, rarely more than 5 feet thick and less than 2 feet where exposed in the railroad cut, grade downward through a narrow zone into normal serpentinized peridotite. A thick mantle of cherty silica float covers the flanks of Loma La Entrada and the hills to the north and west.

The larger chromite deposits of the Camagüey area, including both mined and unmined ore bodies, occur in three definite groups or clusters. From east to west these clusters are: the Porvenir, which includes the large Porvenir and Ferrolana mines and a 70,000-ton body discovered during the course of this investigation; the Virtudes, which includes the Virtudes, Almendares, and Casi Reina mines; and the Camagüey, which contains the large Camagüey mine and the Camagüey 2a, a large unmined chromite mass discovered by the Gulf Research and Development Company survey. A few small mines and prospects are also present in the far western part of the area, and two small mines occur between the Camagüey and Virtudes clusters. Although complete information is not available, total production from the area probably exceeded 300,000 tons, and potential reserves are probably in excess of 600,000 tons.

Gravity features

In the western part of the Camagüey area prominent gravity anomalies occur over parts of the peridotite-feldspathic or volcanic rock contact at the west end of the base line (fig. 13); a broad gravity high centered south of the base line includes a large part of traverses 4 to 22; another major high with maxima near the base line extends southward from the north side, between traverses 26 and 53. Most of the feldspathic rocks exposed in serpentinized peridotite in this part of the area lie within these large features and along their borders. Small positive anomalies are associated with several of the feldspathic rock outcrops. A high gravity gradient occurs near the soil contact and over feldspathic rocks along the north ends of traverses 46 to 59. This feature suggests that the feldspathic rocks extend under the soil to the northwest. Low gravity values, indicating the occurrence of rocks less dense than the serpentinized peridotite, lie along the south ends of traverses 44 to 73, where measurements were made over outcrops of cherty silica and along the northern slope of Loma La Entrada. Another high gradient which defines the serpentinized peridotite-feldspathic or volcanic rock contact along part of the north side occurs over rocks of high density between traverses 73 and 104.

Over the central and northeastern parts of the area, the gravity field increases to the northwest, and the Bouguer gravity contours are fairly regular showing minor undulations and a few prominent closures. Major anomalies are associated with feldspathic rocks near stations 109.5-21N, 117.5-13S, and 131-6S. Another prominent anomaly centered near station 152-19N occurs over soil near outcrops of feldspathic and volcanic rocks. Smaller gravity features over serpentinized peridotite lie near the Casi Reina, Virtudes, El Porvenir, and Ferrolana mines. A pronounced decrease in gravity is associated with the soil and silicified serpentine along the southern end of traverses 131 to 179. High gradients along the northwest side indicate the occurrence of feldspathic and volcanic rocks on the flank of the major structure. Numerous feldspathic rocks that crop out in the serpentinized peridotite in the northeast part of the area lie in a general area of low gravity gradient, which is expressed as a high on the profile of the regional gradient.

Results of drilling

In this area, 20 gravity anomalies were investigated by drilling (table 5). The test holes ranged in depth from 27 to 325 feet and revealed that two anomalies indicate deposits of chromite, ten occur over feldspathic rocks, and four are associated with dense serpentinized peridotite. No high-density materials were found in drilling four of the anomalies.

Table 5. Results of exploratory drilling in the Camaguey Area

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
224.5-0	4A2	4	230	Feldspathic rock	25-70
219.5-5N	1A2	1	141	Chromite	70-111, 118-120
208-4S	1A2	2	82	Gabbro	60-82
206.5-5N	1B	3	152	Unexplained, serpentinized dunite and gabbroic material	17-152
190-8S	1A2	6	153	Unexplained, serpentinized peridotite and dunite	7-153
191.5-7S	1A2	6A	200	Unexplained, serpentinized peridotite and dunite	45-200
178.5-17S	4A2	7	103	Unexplained, serpentinized peridotite	15-103
178-16S	4A2	7B	100	Serpentinized peridotite	12-100
177.5-16S	4A2	7A	200	Chromite Serpentinized peridotite	11-11.5 11.6-200
167-10N	1B	24	100	Feldspathic rock Dense serpentinized peridotite	27-41 41-93
162-20N	4A2	8	181	Gabbro	15-73, 172-181
161.5-25.5N	1A3	23	102	Feldspathic rock	12-32, 62-67, and 83-102
156.5-21.5N	4A2	9	27	Gabbro	4-27
152.25-25N	1A3	10	49	Chromite	10-29

(continued)

Table 5. (continued)

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
124-0.5N	1A2	11	148	Serpentinized peridotite with feldspathic stringers	1-100
124-0.5S	1A2	11A	95	Dense serpentinized peridotite	23-95
120-2S	1A2	22	250	Unexplained, serpentinized peridotite with feldspathic stringers	47-250
57-17N	1A2	13	250	Dense serpentinized peridotite	73-250
56-21N	1A2	13A	200	Dense serpentinized peridotite	91-200
41.5-20.5S	4A1	12	53	Feldspathic rock	2-7, 31-53
23.5-21N	1B	17	150	Gabbro	27-61
19-1N	1A2	14	210	Dense serpentinized peridotite with feldspathic stringers	37-61, 103-210
12-24S	1A2	16	230	Dense serpentinized peridotite Gabbro	78-117 203-230
11.5-4S	1B	15	325	Serpentinized peridotite with feldspathic stringers	23-187
9.5-2.5S	1B	15A	270	Unexplained, serpentinized peridotite with feldspathic stringers	97-161
11-15N	3B	21	200	Feldspathic rock	111-123

More than one test hole was drilled over each of five gravity features (fig. 13). The anomaly 190-8S containing two maxima was tested by holes 6 and 6A, which found no materials that would cause the increase in gravity. This anomaly is accentuated by a change in the gravity gradient, and may be due largely to the manner of removing the regional gravity effect. Evidently, it is not as prominent as shown on the residual map. Chromite was found between depths 11 and 11.5 feet in one of three holes drilled over anomaly 178.5-17S near the Virtudes 3A mine. The drilling results reveal that no large deposit of chromite is indicated by this anomaly and that the increase in gravity apparently is caused by differences in thickness of the Eocene marls, which overlie the serpentinized peridotite. Anomalies 124-0.5N and 57.17N were considered to be tested sufficiently after two holes that were drilled on maxima of each feature found dense serpentinized peridotite. An unexplained anomaly, 11.5-4S, containing two maxima, was tested by drill holes 15 and 15A, but as no chromite was found, the investigation of this anomaly was discontinued.

One of the two chromite deposits is indicated by anomaly 219.5-5N near the Ferrolana and El Porvenir mines. Closely spaced drilling (fig. 14) over the anomaly revealed that the deposit is an irregular,

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Figure 14. Residual gravity anomaly over chromite deposit near 219.5-5N and drill hole sections through the chromite body, Camagüey area.

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discontinuous, tabular mass containing about 72,000 tons of chromite. The associated gravity anomaly embraces 46 stations and has two gravity maxima of 1.4 and 1.5 gravity units, respectively. Near the maximum in the central part of the anomaly, chromite comes within 40 feet of the surface and extends to a depth of 140 feet. Near the other gravity maximum the ore lies between depths of 76 and 168 feet. A gap in the chromite body is indicated near the center of the anomaly by five holes that failed to cut ore. A small isolated mass of chromite, 28 feet thick, underlies the southwest end of the feature.

The second chromite deposit was discovered by drill hole 10, 152.25-25N, near the Ampliación de Almendares mine. This deposit is small and appears to be an extension of the ore body that was mined from small pits nearby. The thickness of the chromite lens cut in drilling and the size of the anomaly indicate that the deposit contains about 5,000 tons.

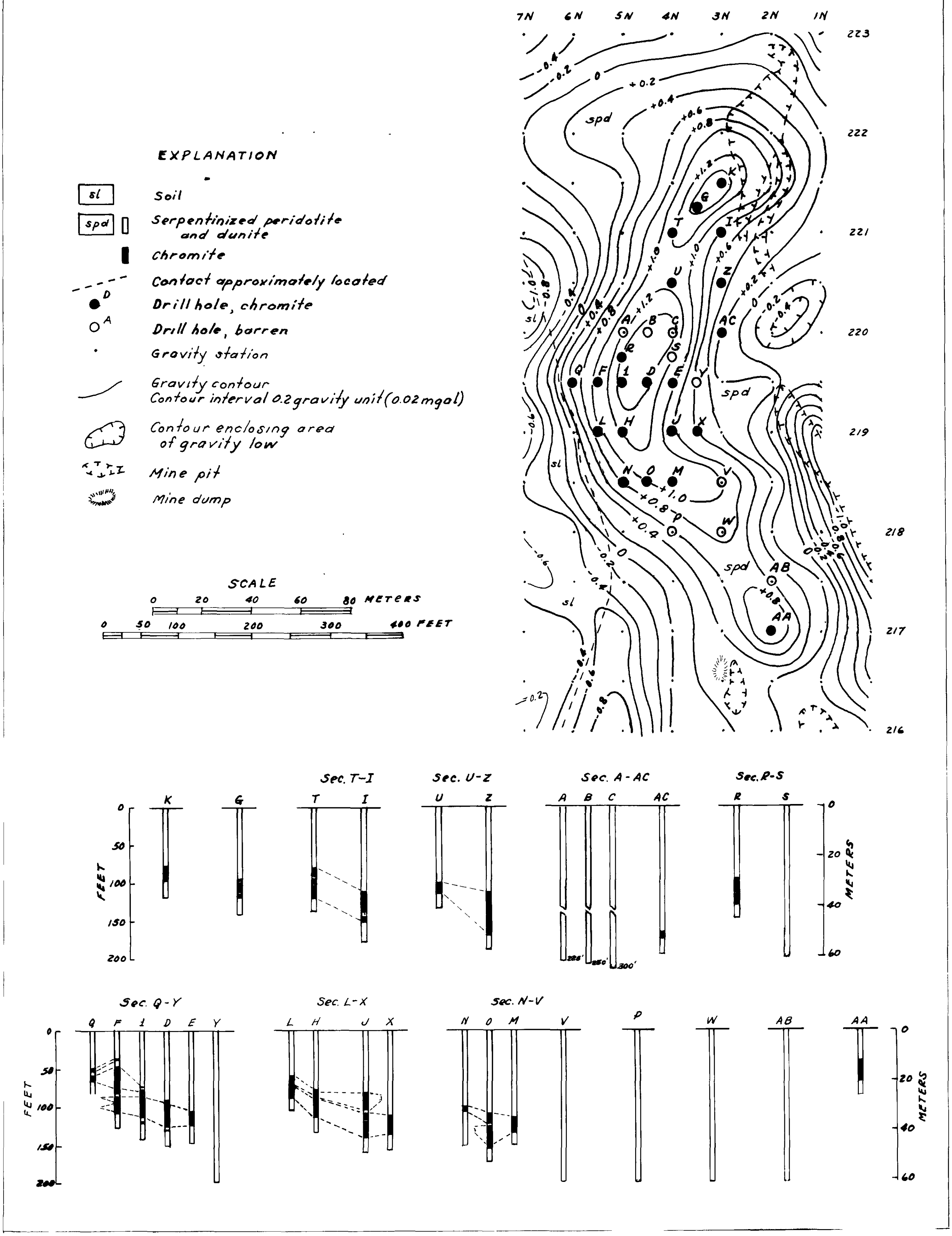

FIGURE 14. Residual gravity anomaly over chromite deposit near 219.5-5N and drill hole sections through the chromite body, Camagüey area.

Discussion

Several prominent maximums that were not drilled are shown on the gravity and geologic map (fig. 13), but these are attributed to sources other than chromite. The maximum 221-3S is part of an anomaly tested by drill hole 4, 224.5-0, which revealed that the gravity feature is caused by feldpathic rock. Maximum 211-5S was not drilled because it is part of an anomaly over gabbro found in drill hole 2, 208-4S. The anomalies near stations 198.5-1S and 196-3N are comparatively small and appear to be associated with changes in density of the surface material. Untested anomalies near the soil contact along the southeast end of traverses 179 and 167 occur where there is a pronounced change in the regional gravity gradient. These anomalies are attributed to the manner of removing the regional gravity effects. Maximums near stations 159-13S, 157-21S, and 154-17S are also attributed to the regional reduction and the topographic effect of a ridge that crosses the south end of these traverses. Variation in surface materials, changes in gradient, and topographic effects account for the untested anomalies occurring along the southeast end of traverses 153 to 121. The maximums 113-31N and 109-31N were not drilled because the gravity profiles indicate that these features are associated with a mass of feldspathic rock, which is exposed along the north end of traverses 108 and 105 to 98, and probably extends east beneath the surface along the soil contact.

Caridad area

The Caridad area (fig. 4) lies northeast of the Camagüey area, on a secondary Altagracia-Minas road, about 2 miles southwest of Minas. The area is approximately 0.5 mile wide, 1.7 miles long, and covers 0.9 square mile. Most of the area is gently rolling savannah that increases in elevation to the south, along the base of a large flat-topped hill just beyond the limits of the mapped area. Chromite production of the Caridad area, which was principally from the Caridad mine, greatly exceeded 100,000 tons.

Geology

The serpentinized rocks in the Caridad area are predominantly peridotites (fig. 15). No large or continuous bodies of serpentinized

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Figure 15. Residual gravity and geologic map of the Caridad area, Camagüey chromite district, Cuba.

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dunite were observed. A common feature, not observed in the other areas, are long irregular zones containing abundant small gabbro bodies, feldspathized peridotite, and normal serpentinized peridotite that trend roughly parallel to the major serpentinized peridotite-feldspathic rock contact.

The main contact between feldspathic or volcanic rock and serpentinized peridotite, along the northwestern side and northeastern end of the area, is covered by soil and is inferred mostly from float and vegetation. Large feldspathic bodies, both gabbro and troctolite, are common in the serpentinized peridotite in the northeastern part of the area.

Cherty silica and silicified peridotite cap the higher ground around the Caridad mine and a low broad hill in the northeast-central part of the area. Associated with the cherty silica on the hill are several long narrow carbonate bodies resembling dense, fine-grained limestone. These masses strike across the regional trend in the manner of dikes or fracture fillings, and their relationship to the other rocks is not evident. A thick cap of cherty silica is also present on a large, flat-topped hill south of the area and large deposits of silica float cover the serpentinized peridotite on the northern slopes of this hill.

The large chromite body of the Caridad mine in the southwestern part of the area was discovered by means of a torsion-balance survey. This discovery was made just before mining operations, which had exhausted the small surface bodies, were to be abandoned. According to Thayer (1942, p. 44-45), the chromite body occurred as a flat tabular mass 70 feet below the surface. Chromite was also produced from small deposits of the Olga mine near the center of the northwest side, and the Boquina mine in the northeastern part of the area. Three small chromite deposits are exposed in the central part of the area. These do not appear to have been investigated by trenching or other surface methods of prospecting.

Gravity features

The gravity values increase northward over most of the Caridad area. In the northeastern part, high gravity gradients form the eastern side of a "low" lying northwest of the base line. Pronounced gravity highs occur over feldspathic rocks along this side and in the northern end of the "low". The high gravity gradients are caused by masses of feldspathic rock bordering the eastern end of the area. Along the northwest end of traverses 23 to 31, there is a high gravity gradient that apparently is associated with volcanic rocks and soil-covered feldspathic rocks. Prominent gravity highs occur over the soil contact at stations 23.5-11N and 29-11N near the base of this gradient. The gravity contours along the southeast part of traverses 10 to 24 show a pronounced decrease in gravity to the south, which is probably caused by masses of cherty silica and volcanic rocks that border this part of the area. A similar decrease in gravity occurs over cherty silica and silicified serpentine southeast of the Caridad mine.

The low broad hill, capped with cherty silica and carbonate rocks, in the northeast-central part of the area may be associated with a structural discontinuity. Gravity contours in this part of the area show a pronounced change in direction, which cuts across the trend of the feldspathized peridotite zones and follows the strike of the cherty silica and carbonate rocks. A change in the gravity gradient crossing the trend of the carbonate rocks indicates that the hill lies on a small fold.

The density of small prominent residual gravity anomalies (fig. 15) appears to be less in the Caridad area than in the areas discussed previously. This is due mainly to the larger 30x60-meter grid station spacing used in making the reconnaissance gravity survey, and the larger square employed in correcting for regional gravity effects. Anomalies delineated by the wider spaced gravimeter measurements are relatively broad and are depicted as having low gravity relief.

Prominent residual features occur over feldspathic, volcanic, and carbonate rocks and over parts of the zones of feldspathized and silicified peridotite. The largest gravity maxima are associated with feldspathic rock outcrops. A few, probably caused by buried masses of feldspathic rock, also occur in soil-covered parts of the area. Less prominent gravity highs occur over serpentinized peridotite near the soil contacts and over parts of the feldspathized peridotite zones. Gravity "lows" also occur near and in parts of these zones. More prominent gravity minima are over the volcanic rocks exposed near the center of the northwest side of the area, the hill capped by cherty silica and carbonate rocks, and the disturbed ground near the Caridad mine. A pronounced gravity high also occurs over silicified peridotite southeast of this mine. No gravity anomalies are associated with the three small chromite exposures in the central part of the area.

Results of drilling

Test holes ranging from 39 to 345 feet in depth were drilled over nine anomalies in this area (table 6). The logs of these holes show that one anomaly occurs over a deposit of chromite, six are over masses of gabbro, and two are associated with dense serpentinized peridotite. All of these rocks, except one gabbro mass lying below 103 feet, were found at depths less than 91 feet. Most of the rock masses extend below the bottoms of the drill holes. The deeper test holes, which bottomed at depths of 235, 305, and 345 feet, were drilled over anomalies attributed to dense serpentinized peridotite.

Table 6. Results of exploratory drilling in the Caridad Area

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
3-15S	4A1	2	235	Dense serpentinized peridotite	90-235
5.2-8.3S	4A3	1	150	Chromite	4-7
5-8.4S	4A3	1A	150	Dense serpentinized peridotite and breccia + (probable fault zone)	42-65
5.2-8S	4A3	1B	90	Chromite	3-5
9-1N	1A1	10	80	Gabbro Dense serpentinized peridotite	19-38 77-80
9.8-0.5N	1B	10A	345	Dense serpentinized peridotite	22-345
16-11N	1A1	3	305	~~Dense serpentinized~~ do peridotite	74-305
23.5-10N	1A1	4	90	Gabbro	43-90
29-10.5N	1A2	7	83	~~Gabbro~~ do.	53-83
30-5S	3A1	5	200	~~Gabbro~~ d.	103-200
38.3-4.3S	1A2	6	52	Gabbro	18-52
38.3-4.7S	1A2	6A	39	~~Gabbro~~ do	34-39
42.5-6.5N	3A2	9	52	Gabbro	27-52

The chromite deposit is indicated by the anomaly 5.2-8.3S (fig. 15) north of the Caridad mine. Two of three holes drilled on this feature cut chromite between depths of 3 and 7 feet. The third hole, 1A, cut dense serpentinized peridotite and zones of brecciated material that indicated faulting. This deposit is estimated to contain about 500 tons, which was considered too small to justify additional drilling.

Two test holes were drilled on anomaly 38.3-4.3S, which is partly over a pit of the Boquina mines. Although the source of the anomaly was discovered to be gabbro in drill hole 6, an additional hole 6A was drilled nearby to investigate the possibility of chromite occurring in line with the mine. No chromite was discovered in drilling this hole, which also bottomed in gabbro cut at a depth of 34 feet.

Anomaly 9-1N also was investigated by two test holes. Drill hole 10, 9-1N, found gabbro lying between depths 19 and 38 feet and bottomed in dense serpentinized peridotite. The gabbro accounted for a small local high near the crest of the anomaly, but was considered to be too small in areal extent to cause the main anomaly. Drill hole 10A, 9.8-0.5N, found dense serpentinized peridotite extending from a depth of 22 feet to the bottom of the hole 345 feet deep. Therefore, in view of the dense peridotite also found in hole 10, the source of this anomaly is attributed to a buried mass of dense serpentinized peridotite.

Discussion

In addition to the untested anomalies that occur over major feldspathic outcrops, there are a few gravity maximums that were not drilled (fig. 15). The maximums 3-10N and 5-11N were not tested because they are in a part of the area that is under cultivation and the property owner would not permit drilling. Gravity profiles show that the maximum 18-9N is part of an anomaly tested by hole 3, and indicate that the maximum is probably underlain by dense serpentinized peridotite cut in drilling that hole. The positive anomaly near 26-2N was considered too small to be investigated by drilling. Gravity profiles also indicate that the maximum 27-6S is underlain by dense feldspathized peridotite, which comes to the surface under the anomaly near 25-6S. The gravity maximums 30-9N and 31-8S were not drilled because they are parts of anomalies associated with gabbro as revealed in test holes 7 and 5, respectively. Positive anomalies near 46-5N and 47-3S occur over soil, but are attributed to feldspathic rocks that underlie this part of the area as indicated by the gravity gradient.

Examination of the gravity data shows that the area has been prospected in sufficient detail to detect large deposits of chromite. Except the two gravity maximums that could not be tested, all the positive anomalies of sufficient magnitude to be caused by chromite have been investigated adequately by drilling or studied sufficiently to determine the kind of material with which they are associated. It is doubtful that any large chromite deposits are present that have not been detected by gravity measurements or have been overlooked in the drilling investigation.

Lolita area

The Lolita area (fig. 4) covers a small narrow band of serpentinized peridotite at the base of the Sierra de Camaján, approximately one mile north of the town of Minas. This area, which is 1.1 miles long, covers about 0.3 square mile and includes the immediate environs of the Lolita mine, one of the largest producers in the Camagüey district. A good secondary road from the Minas-Sola highway affords easy access to the area.

Geology

The entire area is covered by soil (fig. 16) which, in those parts

Figure 16. Residual gravity and geologic map of the Lolita area, Camagüey chromite district, Cuba.

not disturbed by mining operations, supports a heavy growth of grass and other vegetation. This alluvium or possibly eluvium derived from the limestones and volcanic rocks of the Sierra de Camaján covers the extreme north and northwest parts of the area. Serpentinized peridotite is exposed only around the edges of the mine workings but is believed to underlie most of the soil and unconsolidated material. Coarse-grained gabbro is exposed in several places on a long low hill in the western part of the area, and a small troctolite outcrop occurs over a large inferred feldspathic mass that borders the area on the south and southeast.

The structural environment of the Lolita chromite deposits is apparently similar to that of the other large deposits in the Camagüey district. However, for the Lolita area, the structure to which the deposits appear to be related is not the large Lugareño-Yucatán syncline, but rather a smaller syncline to the north, whose axis parallels the major structure.

The clustering or grouping of chromite deposits is well shown by the ore bodies that constitute the Lolita mine. This cluster occupied a narrow northeast-trending zone 400 feet wide and 3,500 feet long and contained at least five separate chromite bodies. Production of more than 100,000 tons came principally from a large centrally located body. Although considerable reserves reportedly remain, very little chromite could be observed in the water-filled workings. A small deposit of massive chromite, exposed about 800 feet northwest of the main Lolita pit, is the only other occurrence observed in the area.

Gravity features

Bouguer gravity values in the Lolita area increase eastward at a rate of approximately 18 gravity units per kilometer, and show minor variations near the mines and near small feldspathic outcrops in the western part of the area. The largest variation occurs in a disturbed area near the southwest end of the Lolita mine. Another fairly prominent feature is a high-gravity gradient along the southeast end of traverses B to 7. This gradient is attributed to feldspathic rocks that are exposed to the south and probably underlie the edge of the area.

Most of the residual gravity features (fig. 16) have low gravity relief and are comparatively small. Gravity maxima and minima that appear to be associated mainly with small dumps and pits occur in the vicinities of the mines. A prominent gravity "low" crosses the southeastern parts of traverses 0W to 9 near the base of the high-gravity gradient. Two large positive anomalies occur over parts of the traverses west of 2W. The maximum of one of these anomalies occurs near an outcrop of feldspathic rock, which probably causes the anomaly. There is no gravity expression of the chromite body that crops out northwest of the main Lolita pit. The significance of most of the residual features in this area is not evident in the surface geologic mapping because of the soil cover and disturbed conditions due to mining operations.

Results of drilling

Five anomalies in the Lolita area were tested by holes drilled to depths ranging from 85 to 375 feet. The results (table 7) show that one anomaly occurs over dense serpentinized peridotite and chromite, two are over masses of dense serpentinized peridotite, and another is associated with feldspathic rock. One anomaly could not be explained by the density of material found in drilling.

The chromite was discovered in testing anomaly 15-4S (fig. 16) near the Lolita mine. Drill hole 4 went through four lenses of chromite totaling 20 feet in thickness between depths of 103 and 199 feet. Two offset holes, 4A and 4B, cut lenses of chromite totaling 21 feet and 9 feet, respectively. Hole 4B was drilled to a depth of 375 feet to determine whether the anomaly is caused by a large body of chromite lying at great depth. Owing to thick overburden and the fact that these holes did not cut a massive chromite body, the investigation of this anomaly was discontinued.

Table 7. Results of exploratory drilling in the Lolita Area

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
4W-1N	4A3	7	180	Dense serpentinized peridotite	12-180
9.5-1S	4B	3	250	Unexplained, serpentinized peridotite	3-250
15-4S	4B	4	230	Dense serpentinized peridotite	29-44
				Chromite	103-111, 176-181, 185-189, 196,199
15.5-5S	4B	4A	250	Dense serpentinized peridotite	37-84, 92-97
				Chromite	84-92, 97-110
14.5-4S	4B	4B	375	Dense serpentinized peridotite	83-109
				Chromite	235-238, 337-343
16-7S	4C	6	85	Dense serpentinized peridotite	53-85
20-1N	4B	5	155	Feldspathic rock	27-43

Serpentinized peridotite without lenses of denser material was found in hole 3, which was drilled to a depth of 250 feet to test a small maximum near station 9.5-1S. This anomaly occurs along a road in a part of the area where materials from mine workings and a crushing plant have been dumped. The variation in gravity probably is caused by changes in density of the surface material. No additional holes were drilled over the anomaly because the test hole indicated that the gravity feature is not associated with a large deposit of chromite.

Discussion

The results of the investigation indicate that there are no major deposits of chromite in this area, unless they occur at depths too great to be detected by the gravimeter. Three gravity maximums were not tested, but these do not appear to be indicative of large chromite deposits. The anomaly 3-9N (fig. 16) was mapped in detail gravimetrically, but was found to be too small to justify the expense of exploratory drilling. Gravity maximums near stations 4W-5S and 6W-5S also were mapped in detail. The maximum 4W-5S was not drilled because it is obviously caused by feldspathic rock. Gravity profiles and geology indicate that the other maximum, 6W-5S, probably occurs over an extension of the feldspathic mass. This maximum was not drilled because permission was not granted by the property owner.

La Nona area

The La Nona area (fig. 4), approximately 4 miles north of Altagracia, trends west and northwest along the northern flanks of the Lugareño-Yucatán syncline. This area is about 2.2 miles long, averages half a mile wide, and covers approximately 1.2 square miles. The southern and southwestern border lies along the crest of a series of steep-sided troctolite-capped ridges. These ridges, which are broken by several erosional gaps, have a maximum relief of 110 feet. Two very poor roads, one running east from the Aventura mine and the other west from the Oriente area, give access to the La Nona area only during the dry winter season. The area includes several small mines and prospects, the biggest of which is the La Nona mine.

Geology

This area is one of the few investigated where serpentinized dunite occurs along a definite horizon in the ultramafic complex. In fact, an upward succession of serpentinized peridotite, serpentinized dunite, and troctolite was observed throughout the entire area (fig. 17).

Figure 17. Residual gravity and geologic map of the La Nona area, Camagüey chromite district, Cuba.

In the northwestern part, serpentinized dunite is exposed in a band between 200 and 300 feet wide directly under the troctolite. Toward the southeast the band gradually widens, becoming 700 to 800 feet wide in the south-eastern end of the area. This apparent widening does not reflect an increase in thickness of the dunite, but is merely attributable to a change in the attitude of the members of the complex. In other words, the layers dip steeply to vertical in the northeastern part of the area and are more nearly flat lying in the southeastern part, giving rise to a larger areal outcrop. The contact between serpentinized dunite and serpentinized peridotite, although not actually observed, is apparently sharp. The upper contact of the serpentinized dunite with the troctolite is also sharp but of a different nature. Several tens of feet below the troctolite, interstitial feldspathic material appears in the dunite and increases in abundance upward. Directly beneath the troctolite, feldspathic material amounts to approximately 10 percent of the rock by volume.

The troctolite caps the ridges along the south and southwest border of the area and is without much doubt the lower part of the main feldspathic member. Westward from the northern part of the area, approaching the center of the Lugareño-Yucatán syncline and higher up in the feldspathic member, the troctolite grades into coarse-grained gabbro. To the south a small anticline apparently separates the troctolite bordering the area from its complement exposed in the major structure lying a quarter of a mile to the southwest.

Small fine-grained gabbro bodies are very common throughout the La Nona area, but unlike similar bodies in other areas show a pronounced distribution pattern. The bodies, which vary in size from elongated masses 300 feet long and 60 feet wide to small lenses a few feet in diameter, occur predominantly along linear trends that swing eastward from the general trend of the syncline. The longest linear trend observed has a minimum length of 3,500 feet.

Chromite production from the La Nona area probably did not exceed 15,000 tons. The mined ore deposits, from north to south, are the Leocadia, La Nona, and Mabel 2a, with the bulk of the production coming from four small ore bodies in the La Nona mine . Small noncommercial disseminated deposits are abundant in the serpentinized dunite directly below the troctolite contact. Garnierite and secondary copper minerals are present in fractures in most of these disseminated deposits.

Gravity features

The Bouguer gravity data reveal several prominent regional gravity effects. A high gravity gradient, terminating in a reversal between traverses 47 and 48, occurs over the troctolite ridges and serves to define the contact between serpentinized dunite and troctolite along the southwest side of the area. Continuation of the gradient between traverses 21 and 33 indicates that feldspathic rocks underlie the serpentinized peridotite bordering this part of the area. East of traverse 48, low gravity values along the serpentinized dunite-troctolite contact indicate that the troctolite capping of the ridges is either very thin or less dense than in other places along the south side. A gravity "low" that originates to the north lies in the northern part of the area. Major undulations in the contours of this feature show the low gravity effect caused by soil along the Río Máximo. Several gravity anomalies that are associated with exposures of gabbroic rocks occur in a broad area of high gravity between traverses 11 and 36. This general "high" is part of an anomaly centered about a mile east of the area (fig. 5), which is alined with the trend of the troctolite ridge to the south. The large number of gabbroic rock outcrops and their diverging easterly trend implies that this gravity feature is associated with an arcuate fold that parallels the northern flank of the major syncline. Southeast of this high the gravity field decreases and the gravity contours, as well as the trend of feldspathic outcrops near the baseline, reflect the eastward change in trend of the structure.

Prominent positive and negative residual anomalies (fig. 17) occur near the serpentinized dunite-troctolite contact and over several of the gabbroic rock outcrops. Major gravity "lows" cross the southwestern and northeastern parts of traverses 24 to 35. Prominent negative anomalies also occur over soil along the Río Máximo. Most of the positive anomalies in this area appear to be associated with the feldspathic rocks. However, the maxima of some of these are far enough from the outcrops to suggest that the features are caused by the occurrence of other high-density materials.

Results of drilling

No deposits of chromite were found by the drilling in this area. Nine gravity features were tested by holes drilled to depths ranging from 45 to 340 feet (table 8). The results show that five anomalies occur over masses of dense serpentinized peridotite and four are associated with feldspathic rocks. Bulk densities of the cored samples taken in drilling indicate that these materials are sufficiently dense to account for the anomalies.

Table 8. Results of exploratory drilling in the La Nona Area

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
4-9.5S	2A2	1	121	Gabbro	49-52,64-69,80,88-121
11.25-8.5N	1A1	2	325	Dense serpentinized peridotite with feldspathic stringers	12-200
31.5-6S	1A3	4	235	Dense serpentinized peridotite	43-81,103-132
35.5-9S	1A1	5	340	Dense serpentinized peridotite with feldspathic stringers	18-43, 89-101
34.5-7.5N	1A1	6	262	Dense serpentinized peridotite	50-221
45-6.5S	1A1	7	262	Dense serpentinized peridotite with feldspathic stringers	24-262
46-9S	3A2	8	45	Troctolite	1-45
46-3.5N	3A1	9	45	Gabbro	2-45
59-8S	1A1	10	45	Troctolite	1-45

Discussion

Examination of the residual gravity and geologic map (fig. 17) shows that most of the prominent positive anomalies not obviously associated with feldspathic rocks were drilled. Except for anomalies of very low gravity relief, there are no untested maximums that are considered to be caused by chromite. Test holes 1 (4-9.5S) and 9 (46.3.5N) were drilled over small gravity "highs" on the flanks of anomalies partly associated with feldspathic rocks. Further testing of these features was not done because the drilling revealed that the anomalies are caused by feldspathic rocks. The anomaly near 17-13N was mapped in detail but proved to be of low magnitude and was considered too small to represent a chromite deposit worthy of drilling. Anomalies 19-12N and 51-8S were not drilled because the gravity data and geology indicate that feldspathic rocks cause these features. The anomaly near 54-10N is a broad feature that is attributed to the manner of removing the regional gravity effects.

Oriente area

The Oriente area (fig. 4) lies along the edge of the savannah between the La Nona and Victoria areas. It extends northwestward from the Río Santa Cruz to the Altagracia mine and contains about 1.3 square miles. The western end is on the south side of the troctolite-capped ridge that forms the southern border of the La Nona area. An all-weather road that crosses the Victoria area also gives access to the Oriente area. Small mines and prospects are common throughout the area, but total chromite production has been very small.

Geology

In general, the geology (fig. 18) is very similar to that of

Figure 18. Residual gravity and geologic map of the Oriente area, Camagüey chromite district, Cuba.

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the neighboring La Nona area. The serpentinized rocks are easily separable into distinct dunite and peridotite units that trend parallel to the major structure. Minor folding, however, which is apparently absent in the La Nona area, complicates the interpretation of rock relationships.

The feldspathic member of the ultramafic complex along the southern border is, for the most part, covered by thick soil. Where observed, either as small individual outcrops or as float, the member ranges between troctolite and gabbro in composition, with the former being more abundant. Several large troctolite and gabbro masses are present in the area and are separated from the main feldspathic member by serpentinized peridotite. These rocks probably represent basal portions of the feldspathic member preserved in one or more small northwest-trending synclines. Small dikes and pods of fine-grained gabbro, showing no apparent orientation, are scattered throughout the area.

The chromite bodies in this area are small and apparently all are of the disseminated type. They are either closely associated with outcrops of feldspathic rock or occur in zones between feldspathic masses, where erosion has removed the overlying feldspathic rocks. Apparently most of the chromite was obtained from clusters of small deposits of the rather widely scattered Oriente mines.

Gravity features

Over most of this area the gravity values increase to the north and northeast at a rate of approximately 32 gravity units per kilometer. This gradient, which is attributed to an increase in density of the ultramafic rocks to the northeast, becomes noticeably less near the south side of the area. On this border west of traverse 27, a reversal in the gradient indicates the occurrence of feldspathic rocks along the major contact. Elsewhere near the border, low gravity values reveal the absence of high-density material. Here, owing to thick soil cover, the contact could not be mapped accurately. Apparently the feldspathic rocks come to the surface farther to the south than indicated by surface mapping, or volcanic rocks of low density are in direct contact with the serpentinized peridotite along this side of the area. Other major variations in the gravity gradient occur over feldspathic rocks exposed along the northern part of traverses 33 to 35 and 43 to 52. A less prominent anomaly is associated with the feldspathic rocks exposed between traverses 2 and 9. In general, the direction of Bouguer gravity contours parallels the serpentinized peridotite-feldspathic or volcanic rock contact and reveals no structural divergence. Several small anomalies indicated by flexures in the gravity contours occur over the general area underlain by serpentinized peridotite. Some of these are over small exposures of feldspathic rocks, but others appear to be caused by high-density materials lying at shallow depths in the serpentinized rocks.

Several positive and negative residual anomalies of large magnitude occur along the south side of the area (fig. 18). Most of the positive features are near the major contact and appear to be associated with feldspathic rocks. Some of these, however, are over parts of the border where soil covers the contact and their source is not evident. West of traverse 27, the negative anomalies coincide with a pronounced change in the gravity gradient. Therefore, these features probably are not caused by low density materials in the serpentinized peridotite, but are due to the manner of removing the regional gravity effects. Other prominent positive anomalies flanked by gravity "lows" lie over the larger masses of feldspathic rocks exposed in the western and southeastern parts of the area. Small gravity maximums occur in the vicinity of borrow pits near station 18-10N and small mine pits exposing disseminated chromite near station 31-13N. Only a few positive anomalies that do not appear to be caused by the occurrence of feldspathic rocks occur over the serpentinized rocks and in soil-covered parts of the area. Chromite is exposed in a few places, but only one, near station 10-2S, appears to be indicated by a gravity anomaly.

Results of drilling

Holes ranging in depth from 50 to 290 feet were drilled over ten anomalies in the Oriente area (table 9). The drill logs show that seven anomalies are over feldspathic rocks and three are associated with dense serpentinized peridotite. A small lens of chromite occurring above feldspathic rock was found in hole 5, 19.75-12.5S (fig. 18). After drilling an offset hole at station 19.25-12.5S that cut only feldspathic rock and serpentinized peridotite, the chromite deposit was considered too small to justify the expense of drilling additional exploratory holes.

Table 9. Results of exploratory drilling in the Oriente Area

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
9-18.5S	3A1	3	262	Troctolite	41-72
10.25-2S	2A3	1	50	Troctolite	1-50
17.75-6S	2A1	4	247	Dense serpentinized peridotite with feldspathic stringers	11-247
19.75-12.5S	1A3	5	98	Chromite Feldspathic rock	4-6 32-53
19.25-12.5S		5A	52	Feldspathic rock	1-19
22.5-6N	1B	7	290	Dense serpentinized peridotite with feldspathic stringers	24-93
31.25-14.5N	1A1	8	271	Dense serpentinized peridotite	33-271
42.5-6.7S	1B	6	200	Feldspathic rock	31-119
47.5-3S	2A1	10	67	Feldspathic rock	2-67
52-11N	3A3	9	153	Troctolite	1-51
54-12S	1A2	11	80	Dense serpentinized peridotite Feldspathic rock	2-46 46-80

Discussion

The residual gravity and geologic map (fig. 18) shows a few untested prominent anomalies, but the cause of these was revealed during the investigation. The anomaly at station 14-5S is part of a broad gravity high extending from 10-2S to 18-6S, as revealed by the gravity profiles. Owing to the fact that holes 1 and 4 found high-density rocks under parts of this feature, the anomaly was considered to be caused by similar material and, therefore, was not drilled. Another untested gravity maximum lies close to a contact between serpentinized peridotite and serpentinized dunite near station 16-7N. Relatively low gravity values were observed over the adjacent serpentinized dunite and indicate that this anomaly is associated with the change in density of the serpentinized rocks. Similar conditions cause a long narrow anomaly extending from 11-5N to 13-6N. The anomaly 24-9S may be caused by a small deposit of chromite. This feature was mapped on a 15-meter grid, but was found to be too small in areal extent to warrant test drilling. Gravity maximums near 43-12S were not drilled because the Bouguer gravity gradient indicates that the main anomaly is over feldspathic rocks. The anomaly near 45-9N is also suspected of being caused by feldspathic rock. Gravity profiles show that this maximum is part of a gravity "high" embracing major exposures of feldspathic rocks and indicate that they are continuous at depth.

In this area, closer spaced gravity measurements may detect more small deposits of chromite, but it is doubtful if any large deposits would be found. Considering past production in the area, it may be expected that the aggregate tonnage revealed by such a survey probably would not justify the cost of a detailed investigation.

Estelnita area

The Estelnita area (fig. 4), 0.4 mile wide and 1.5 miles long, covers a portion of a large savannah around the Estelnita and Pedro mines, which are about 6 miles due north of Altagracia. It is easily accessible by the road that runs north from the Camagüey-Nuevitas highway and passes through the Victoria and Oriente areas. This area is apparently on the south flank of a large, poorly defined synclinal structure that plunges eastward under the Sierra de Camaján. The dominant physiographic feature in the area is a pronounced terrace extending along the entire northern side of the area. This terrace forms the border between a higher flat savannah, underlain by serpentinized peridotite, and a low-lying soil-covered area to the north.

Geology

The predominant rock type in the Estelnita area is serpentinized peridotite (fig. 19). Small areas of serpentinized dunite were

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Figure 19. Residual gravity and geologic map of the Estelnita area, Camagüey chromite district, Cuba.

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observed, but are not shown as separate units on the geologic base map. Along the northern side the contact between serpentinized peridotite and the feldspathic or volcanic rocks is covered by thick soil. Small, fine-grained gabbro bodies occur throughout the area, and small troctolite masses are relatively abundant in the eastern part; but in general, fewer feldspathic rocks were observed in the Estelnita area than in other areas investigated.

Several springs occur along the terrace edge in the northern part of the area, draining the higher serpentine savannah northward onto the lower soil-covered land. Thin siliceous travertine deposits, probably representative of older spring deposits, are scattered over the terrace.

The ore bodies that comprised the Estelnita and Pedro mines probably were small deposits containing massive chromite. Although complete information is not available concerning these mines, the total production is estimated to be about 15,000 tons.

Gravity features

The occurrence of large feldspathic rock masses along the north side of the area is indicated by a high gravity gradient that begins near the soil contact. The thickest of these masses are revealed by major Bouguer gravity highs centered near stations 5-10N and 27-9N. Apparently the feldspathic rocks lie near the surface and in places extend beneath the serpentinized peridotite into the savannah. A prominent gravity high, expressed by the Bouguer contours as a nose trending eastward along the base line between traverses 31 and 39, embraces several small outcrops of feldspathic rock. This feature probably is associated with a large buried mass of similar high-density material. A large gravity anomaly that was not explained by the geologic mapping occurs over the south end of traverses W2 to 2. Also unexplained are several minor features occurring in other parts of the area, as indicated by small closures and undulations in the Bouguer gravity contours. Most of these are caused by density contrasts in materials lying at shallow depths.

Several positive and negative residual gravity anomalies (fig. 19) are associated with changes in the gravity gradient along the north side of the area. The positive anomalies probably indicate the less deeply buried parts of the feldspathic rock masses or density contrasts in these rocks. The negative anomalies, however, appear to be associated with a pronounced change in the gravity gradient and are not considered as being caused by low-density materials in the serpentinized peridotite. They are attributed to the manner of removing the regional gravity effects. The most impressive anomalies of interest in prospecting are centered near stations 0-10S and 17-3N. Others of low gravity relief occur near the base line east of traverse 22. Some of these, however, are over small exposures of feldspathic rocks that may cause the anomalies. Prominent negative anomalies also occur near mine workings and south of the base line between traverses 7 and 18 and traverses 25 and 33. Except for dump material around the mines, the cause of these anomalies was not revealed by the geologic mapping.

Results of drilling

Four anomalies in the Estelnita area were tested by holes drilled to depths ranging from 87 to 192 feet (table 10). The results of drilling show that two anomalies are associated with dense serpentinized peridotite and two occur over dense serpentinized peridotite containing stringers of feldspathic rock. Bulk densities of core samples taken from these materials ranged from 2.67 to 2.86 grams per cubic centimeter, which indicates that the rocks are sufficiently dense to cause the anomalies.

Discussion

The gravity anomalies in this area (fig. 19) were studied carefully and it is evident that no large chromite deposits occur at moderate depths. Closely spaced gravity measurements were made over ten gravity maximums. All but four of these proved to be too small in areal extent and magnitude to warrant test drilling. The gravity maximums near the soil contact along the north side of the area were not drilled because the gravity gradient indicates that these features are associated with feldspathic rocks. The maximums along the base line east of traverse 22 also were not tested. These are "weak" anomalies that are accentuated by long gravity "lows" lying north and south of the base line, and were not considered as being caused by material of high density in the serpentinized peridotite. The "low" north of the base line is caused by topography and the effect of feldspathic rocks bordering the area, but the cause of "lows" on the south side is not known.

Table 10. Results of exploratory drilling in the Estelnita Area

Gravity Anomaly		Drill Hole		Apparent Source of Anomaly	
Location	Classification	Number	Total depth (feet)	Material	Depth interval (feet)
W0.5-2.7N	1A1	2	167	Dense serpentinized peridotite	19-167
0-10S	1A1	1	192	Dense serpentinized peridotite	23-192
17-2.5N	3A2	3	112	Dense serpentinized peridotite containing feldspathic stringers	24-112
37.75-2.5S	2A2	4	87	Dense serpentinized peridotite containing feldspathic stringers	7-87

Summary and Conclusions

The gravity data indicate that under favorable terrain conditions detailed gravimeter surveys, of the precision required in searching for mineral deposits that give rise to small anomalies, can be carried out successfully using standard field techniques. The accuracy necessary in measuring the small gravity differences can be attained by using gravimeters having low scale constants, by exercising normal care in handling and reading the meters, and by frequently re-observing base stations and a few intermediate stations to check the instrument drift. Reconnaissance gravity measurements, adequately spaced to detect significant anomalies, followed by closely spaced measurements over anomalous parts will expedite the investigation of large areas.

During the investigation, 106 gravity anomalies that constituted probably less than a third of the total number found were test drilled. The results of drilling revealed that 10 anomalies indicate deposits of chromite, 89 are associated with rocks of high density, and seven occur over serpentinized rocks that do not seem to be sufficiently dense to cause noticeable variations in gravity. Drilling on five of the chromite deposits revealed about 236,000 tons of chromite, of which 19,000 tons is of the disseminated type. An additional estimated 6,000 tons of shipping grade chromite and 6,000 tons of disseminated chromite are contained in three of the deposits that were not blocked out. No tonnage estimate was made for two small chromite deposits.

The tested gravity anomalies do not have features characteristic of the materials with which they are associated. Although most of the anomalies caused by chromite are comparatively small and are fairly prominent and regular, many of the anomalies caused by other high density materials are similar. In general, however, anomalies associated with large masses of feldspathic rock are more prominent and much larger in areal extent than those caused by chromite. Anomalies over the denser parts of the serpentinized peridotite are usually broad features of low gravity relief that correlate with surface irregularities. The source of these broad anomalies cannot be identified easily because the anomalies vary considerably in magnitude which is caused mainly by the wide range of density contrast in the serpentinized rocks.

Deposits of chromite discovered by the exploration program lie within a quarter of a mile of the contact between serpentinized peridotite and feldspathic or volcanic rocks. They occur at shallow depths in close proximity to mines and prospects that consisted of several ore bodies. Only a few indications of chromite, which apparently represent small deposits, were found in the unexploited areas between large mines. It therefore, appears that most of the chromite reserves in the district occur in a few large bodies near exploited deposits, which are parts of widely separated groups or clusters that parallel the contact.

The importance of using integrated detailed gravimetric and geologic surveys in searching for chromite deposits in the Camagüey district is demonstrated by this investigation. Because of the wide distribution of deposits, exploratory drilling undertaken without guidance resulting from preliminary geophysical and geological investigations would be economically unsound. The gravity measurements serve to delineate areas in which chromite may be found, and provide data for locating and determining depths of drill holes. Detailed geologic mapping yields essential information for evaluating and interpreting the gravity anomalies. Evaluation of the anomalies on the basis of geology, areal extent, and gravity relief, is helpful in limiting drilling, but does not serve to differentiate anomalies caused by chromite from those associated with unexposed masses of high-density rocks.

The amount of chromite found did not greatly increase the known reserves of the district. However, there is a good possibility that drilling on some of the untested anomalies along the major contact may disclose a considerable tonnage of chromite. Considering the large number of small deposits that have been found in the district, it is also reasonable to expect that a fairly large aggregate tonnage of ore may be contained in small deposits which were not detected or delineated adequately by the widely spaced reconnaissance gravity measurements. These deposits may be found by doing a limited amount of detailed gravity mapping and test drilling around small anomalies shown on the residual gravity and geologic maps.

In several areas similar exploratory work may disclose deposits that would substantially increase the district reserves. These areas are: the northern flank of the Lugareño-Yucatán syncline between the Victoria area and Minas; a southward extension of the Aventura area; the area of serpentinized peridotite northeast of Central Senado; and the area between the small towns of Banao and Cuatro Caminos along the front of the Sierra de Cabitas. The two latter, which are not included in the district geologic map of this report, are shown on Flint's geologic map (Flint and others, 1948, pl. 18).

Other parts of the district that may warrant future exploration are those containing subsidiary folds indicated by the regional gravity survey. The most important of these are: the serpentine areas on the northeastern flank of the Lugareño-Yucatán syncline between the Victoria area and Loma El Pastil; and the areas of gravity maxima northeast of the La Nona and Oriente areas.

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