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GEOLOGY AND CHROMITE DEPOSITS OF THE CAMAGÜEY DISTRICT CAMAGÜEY PROVINCE, CUBA

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Contents

Illustrations

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ABSTRACT

The Camagüey chromite district, near the city of Camagüey, Cuba, has supplied a substantial part of the refractory-grade chromite used in this country during the war. The ore occurs in a complex that consists mainly of serpentinized peridotite and dunite with minor amounts of gabbro, troctolite, and anorthosite. The complex was intruded into metamorphic rocks, and is unconformably overlain by Upper Cretaceous volcanic rocks with interbedded limestone and radiolarian cherts. Severe compressive stresses, initiated in late Cretaceous or early Eocene time, deformed both the sedimentary rocks and the underlying ultramafic complex and culminated in extensive thrust faulting, probably in the late middle Eocene. Uplift and erosion have removed the overlying rocks from the serpentine except in synclinal areas, the largest of which extends from Central Lugareño to Loma Yucatán.

Gabbroic rocks flank the tuffs along the limbs of the synclines, and their relative scarcity elsewhere in the district suggests that they formed the upper part of a roughly stratiform intrusion that remained essentially horizontal until the Cretaceous rocks were deposited. An overwhelming proportion (94 percent) of the known ore of the district has been found within one-half mile of the gabbro belts, which indicates that the chromite was localized in the upper part of the ultramafic zone. The larger bodies of chromite are believed to have been segregated before final emplacement of the magma, for their massive texture and irregular areal distribution do not seem compatible with segregation in place. However, small layered bodies of disseminated ore that occur near the base of layered troctolite masses may have differentiated after intrusion.

Geophysical prospecting by gravity methods has been successful in finding new deposits in the district, and the present studies have brought out new information on the localization and attitudes of the known deposits that may be of assistance in planning future geophysical work.

INTRODUCTION

LOCATION AND SURFACE FEATURES

The Camagüey chromite district, situated in the north-central portion of the province of Camagüey, Cuba (see fig. 1), has supplied refractory-grade chromite for about 20 years. The output averaged about 40,000 long tons per year prior to 1941, but under the stimulus of war needs was increased to more than 150,000 tons each for the years 1941 to 1943, inclusive. Total production has been slightly more than 1,000,000 tons. The district is roughly an elongate quadrilateral, trending east-west, with

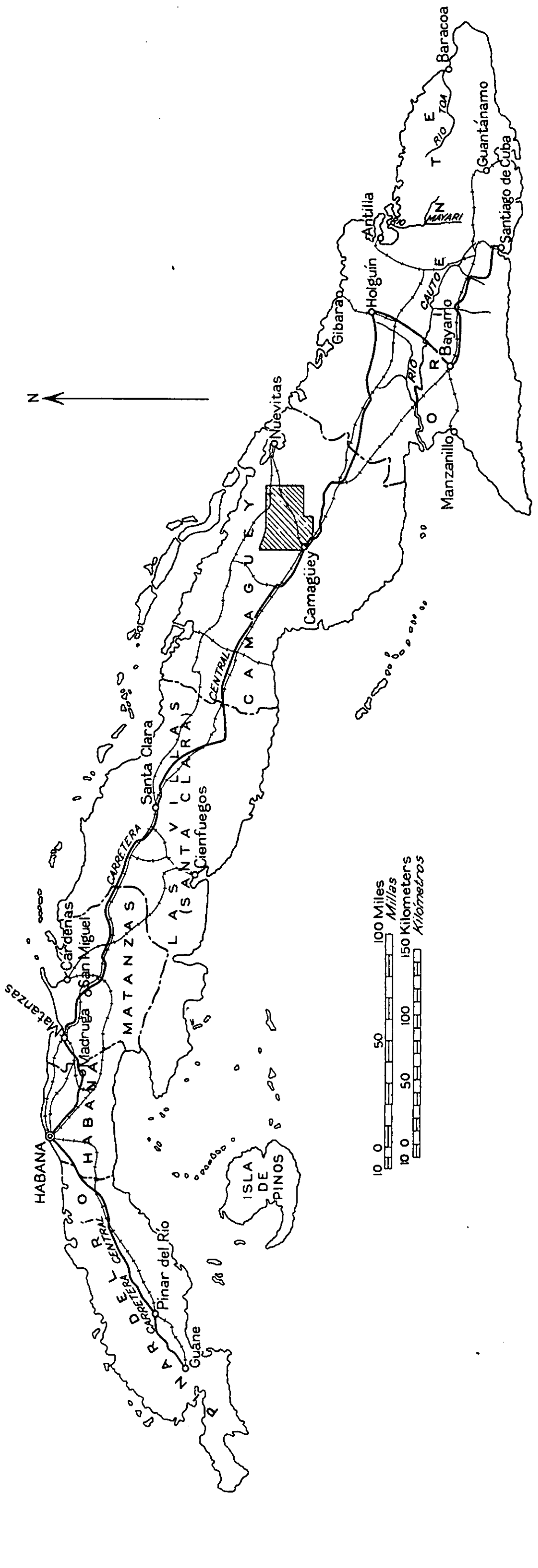

FIGURE 1.—Index map of Cuba showing location of the Camagüey chromite district.

the city of Camagüey in the southwestern corner. The part mapped by the Geological Survey covers approximately 475 square miles (1,240 square kilometers), of which about 200 square miles (520 square kilometers) is underlain by serpentine, the host rock of the chromite deposits. On the north the district is bounded by the Sierra de Cubitas, a low range of limestone hills, and on the northwest by the laterite-capped Mesa San Felipe. The other sides of the district lack topographic definition and roughly follow the outer limit of the ultramafic rocks.

Both the Camagüey-Nuevitas branch and the Norte line of the Consolidated Railroads of Cuba cross the district and connect with the sugar railroads of Central Lugareño and Senado, which give access to some of the more remote eastern portions of the district. The main line of the railroad, from Havana to Santiago, runs along the southwestern edge of the mapped area. The Carretera Central and the Camagüey-Nuevitas highways are the principal roads and connect with numerous secondary roads that reach into every part of the district. During the dry winter months it is possible to go almost anywhere by automobile, but in the wet summer season all the roads deteriorate and the poorer ones become impassable.

An open plain or savannah covered with bunchy grass, a few palms, and sparse brush extends over most of the district. A few scattered hills rise above the general level, however, and those parts of the area not underlain by serpentine support a luxuriant vegetation. The most prominent feature of the district is the Sierra de Cubitas, an arcuate northwest-trending limestone range 25 to 30 miles long, which culminates in Loma Tuabaquey, 980 feet in altitude. The south face is a continuous steep scarp crossed by only three passes west of Loma Tuabaquey; east of that peak it breaks up into a number of irregular spurs. The Sierra de Camaján, north of Minas, is an outlier of the Sierra de Cubitas, from which it is separated by the broad valley of the Río Máximo. The district is drained by the Río Máximo and Río Saramaguacán to the east, the Río Jigüey to the northwest, and by tributaries of the Río San Pedro to the southwest.

FIELD WORK AND ACKNOWLEDGMENTS

The first comprehensive investigation of the chromite mines of Cuba was begun in 1940–41 by T. P. Thayer,[1] and since that time the study of the Camagüey district has continued more or less steadily. The field mapping was done on aerial photographs taken by the United States Navy. D. C. Cox, assisted by Jesús Francisco de Albear, surveyed the district by triangulation and compiled the base map. H. E. Hawkes, Jr., began aerial mapping in 1942, but was principally occupied with detailed

[1]Thayer, T. P., Chrome resources of Cuba: U. S. Geol. Survey Bull. 935–A, 1942.

mapping of individual deposits and with geophysical investigations. The geologic map that accompanies this report is the work of Flint and Albear, under the general supervision of Guild, but inasmuch as the senior author was inducted into the armed forces before completion of the report and Albear was engaged in paleontologic investigations in Cuba, much of the responsibility for preparation of the text fell upon Guild. Thayer first planned the project and has contributed greatly to the work both during his stay in Cuba and while in Washington, making preliminary studies of the petrography and mineralogy and critically reviewing and revising the map and text. J. W. Peoples and C. F. Park, Jr., visited the project and helped to focus attention on critical points. The work was under the general direction of D. F. Hewett and J. V. N. Dorr 2d.

The field work on which this report is based was carried on under the auspices of the Interdepartmental Committee for Scientific and Cultural Cooperation, Department of State, with funds provided by that Committee and by the Foreign Economic Administration. The Ministerio de Agricultura, through the Dirección de Montes, Minas y Aguas, José I. Corral, Director, rendered valuable assistance in the prosecution of the work. The authors wish at this time to express their gratitude to the personnel of these organizations and to all the companies, miners, and residents of the district for their splendid cooperation, without which the work could not have been brought to a successful conclusion.

GEOLOGY

A complex of partly altered peridotitic and associated gabbroic rocks, which are collectively referred to as serpentine in this report, forms the geologic environment of the chromite deposits. (See pl. 18.) This complex was intruded prior to Upper Cretaceous time into a series of schistose and crystalline rocks of unknown age, exposed at the present time mainly in the southwestern part of the district but also as small isolated inclusions elsewhere. Cretaceous volcanic rocks, with interbedded limestones, and Tertiary limestones and marls unconformably overlie the complex on the west, south, and east and occupy an arcuate belt extending westward from Central Lugareño past Minas and Altagracia to Loma Yucatán. Limestones of Mesozoic and early Tertiary age in the Sierras de Cubitas and Camaján have been pushed southward over this basement on a low-angle fault, which will be referred to as the Cubitas overthrust. Magmas of dioritic composition intruded the Upper Cretaceous volcanic rocks, altering them extensively in the vicinity of Camagüey.

METAMORPHIC AND SEDIMENTARY ROCKS

PRESERPENTINE ROCKS

The oldest rocks exposed in the area are phyllites, hornfels, tactites, and gneiss, all of them preserpentine, but otherwise of unknown age. In the mapped area these basement rocks, with the exception of small exposures south of the Carretera Central, occur only as masses surrounded by serpentine. The most extensive exposures are east and southeast of Camagüey city along the roads to Las Clavellinas and Maraguán. The phyllites range from light greenish gray to black on fresh surfaces and weather red brown to almost purple. Bedding commonly is obscured by the development of a strong flow cleavage, which is transected in some places by a fracture cleavage. The hornfels and tactite form small isolated inclusions in the serpentine, chiefly in the northwestern corner of the district. The tactite is a dense, light-colored rock containing a number of lime-silicate minerals; the hornfels is a dark rock similar in appearance to the phyllites, but without the prominent cleavage. The tactite and hornfels represent limestone and shale, respectively, that were metamorphosed by igneous rocks of intermediate to acid composition before they were intruded by the ultramafic rocks in which they are now found. A gray gneissic hornblende diorite exposed in a creek crossing the Carretera Central about a mile west of Santayana probably represents the type of intrusive that metamorphosed these rocks.

JURASSIC AND CRETACEOUS(?) ROCKS

The oldest known fossiliferous rocks in the area are a series of thin-bedded, fine-grained, white to buff or reddish-yellow limestones with which some thin cherts, tuffs, and limy bituminous shales are interbedded. They underlie most of the southern and eastern portions of the Sierra de Camaján. Complicated structure and relatively poor exposures obscure the detailed relations and prevent accurate measurement of the section, but the thickness is believed to be perhaps 1,000 to 1,500 feet. What appears to be the lower part of the series is characterized by small to medium-sized, tightly coiled ammonites, which have been determined by Imlay[2] to be of Portlandian (Upper Jurassic) age. A stratigraphically higher zone, separated from the lower one by unfossiliferous limestones, contains aptychi, or opercula of ammonites, and small loosely coiled ammonites that are poorly preserved. The general relations seem to be analogous to those described by Palmer[3] in the western part of the island, the lower zone equivalent to the Quemado formation

[2]Imlay, R. W., Late Jurassic fossils from Cuba and their economic significance: Geol. Soc. America Bull. 53, pp. 1417–1478, 1942.

[3]Palmer, R. H., Outline of the geology of Cuba: Jour. Geology, vol. 53, pp. 6–9, 1945.

(Portlandian) and the upper zone correlative to the aptychus-bearing beds, tentatively dated as Lower Cretaceous (Neocomian?). It was impossible, however, to map these formations as units in the field.

Cretaceous Rocks

A series of volcanic rocks with interbedded limestones and radiolarian cherts lies unconformably on the serpentine. The volcanic sequence is composed primarily of water-laid andesitic tuffs, associated with lesser amounts of amygdaloidal lava, felsite, andesite porphyry, diabase, and basalt. The sediments range from very fine grained ash to medium-coarse tuffs, which are in part well lithified and in part almost unconsolidated. Most of the flow and dike rocks were seen only as float but in concentrations that indicate rock in place under the soil cover.

Thin-bedded chert is exposed in pits and in shallow shafts sunk in search of manganese in the low range of hills southeast of Altagracia. Under the microscope, specimens of this chert seem to be composed of very fine grained chalcedony containing radiolarian tests and spicules. The manganese occurs only as superficial stains.

The limestones interbedded with the volcanic rocks seem to be mainly of reef origin. For the most part they form small masses from a foot to a few dozen feet thick and a few hundred to 2,000 feet long; the largest mass, which forms Loma Yucatán, is several thousand feet long and appears to be several hundred feet thick. Many of the lenses are composed of gray to white, massive, crystalline limestone devoid of fossils or detrital material. Others are conglomeratic and contain fragments of tuff, chert, limestone, and serpentine, the last demonstrating clearly that this sequence of rocks is postserpentine.

The fossils characteristic of the reef limestones are rudistids, determined by MacGillavry[4] and Palmer[5] to be of Upper Cretaceous age. For lack of better evidence the entire volcanic sequence is tentatively assigned to this age, although the lower part may be Lower Cretaceous.

White, crystalline to porcellanous, medium- to thick-bedded limestones, the Jaronú limestone of Palmer,[6] form the bulk of the Sierra de Cubitas. Palmer estimates the thickness of the formation at about 27,000 feet, but the writers believe that this apparent thickness may be due to repetition of a thinner section by faulting. Poorly preserved rudistid and foraminiferal remains indicate that the formation is Upper Cretaceous and contemporaneous with the volcanic series in the rest of the district. This indicates a great difference in environment between the northern and southern basins of sedimentation; probably the distance between them originally was considerably greater than it is now. (See p. 51.)

[4]MacGillavry, H. J., Geology of the province of Camagüey, Cuba with revisional studies in rudistid paleontology: Geog. geol. Mededeel, Physiog.-geol. Reeks 14, p. 20, 1937.

[5]Palmer, R. H., Personal communication.

[6]Palmer, R. H., Outline of the geology of Cuba: Jour. Geology, vol. 53, p. 13, 1945.

White crystalline limestones, commonly thick-bedded or massive but in places thin, wavy-bedded, or conglomeratic, form the northern part of the Sierra de Camaján and its westward extension in Lomas La América and Borges. They also underlie small areas in the southern half of the Sierra. The scanty rudistid and foraminiferal content of these beds dates them as Upper Cretaceous, and their lithology and structural relations to the underlying rocks indicate a correlation with the limestones of the Sierra de Cubitas.

Cretaceous or Paleocene Limestone

A dense white limestone crops out along the southeastern flank of the Sierra de Cubitas and is especially well exposed in the Cangilones (a shallow rocky gorge) of the Río Máximo and at Grúa Cangilones of Central Senado. The same limestone apparently crops out at Paso de Lesca and 9 miles northwest of Banao along the road to Central Jaronú. This limestone contains a microfauna considered by Bermúdez[7] to be uppermost Cretaceous or Paleocene because of affinities with similar faunas found farther west in Cuba.

Eocene Rocks

Middle and lower Eocene limestones, marls, and chalks containing well-preserved foraminifera occur in several widely separated areas around the periphery of the Camagüey district. Thin-bedded, buff to white crystalline limestones form a line of low hills about 6 miles in length along the front of the Sierra de Cubitas. These hills are separated from the main scarp by a narrow alluviated valley that extends from the vicinity of Banao to a point 2 miles east of Lesca. The same, or similar, beds are present in several narrow, southeast-treading belts in the foothills between Loma Tuabaquey and the Río Máximo. This limestone, in part at least, was deposited unconformably on the serpentine, for the basal zone contains fine-grained, unweathered serpentine detritus.

Two distinct units of the middle Eocene are present in the southern part of the district. One is an almost unconsolidated fossiliferous cream-yellow chalk or marl, which is well exposed on the Antón road about one-half mile south of Grúa Cuatro Caminos (south of Loma La Entrada). The other, probably higher stratigraphically, consists of the fine-grained, medium- to thin-bedded white limestone that forms Loma El Peñón, 7 miles east of Camagüey city. Both units lie unconformably across truncated Cretaceous volcanic rocks.

In the extreme northeastern corner of the mapped area marine limestones tentatively dated as uppermost middle Eocene uncomformably overlap Cretaceous volcanic rocks and serpentine. These sediments appear to be nearly undeformed, with only a slight seaward dip.

[7]Bermudez, P. J., Personal communication.

Undifferentiated Tertiary Rocks

A large area south of Minas and around Loma Bayatabo is underlain by white magnesian chalks, which overlie a basal conglomerate that contains lenses of unfossiliferous limestone and sandstone, and other sedimentary rocks. Exposures, except of the basal conglomerates, are poor, and the rocks have been mapped together as undifferentiated Tertiary. One boulder of limestone found south of Redención contains fossils that proved to be of Oligocene or Miocene age, but no outcrops were seen.

Residual Products of Weathering

A long period of erosion, probably during later Tertiary time, resulted in the development of a surface covered by extensive deposits of cherty silica and iron oxides, which deserve mention, although they are not strictly a stratigraphic unit. Remnants of the surface are preserved on Mesa San Felipe and Loma Bayatabo, which are prominent flat-topped hills, and perhaps on Loma La Entrada, although it is now a narrow ridge.

The lateritic iron oxides on Mesa San Felipe, which overlie a zone of cherty silica, were formed by decomposition of the underlying serpentine and concentration of the iron and silica. This deposit is iron ore, and it has been studied and described by Leith and Mead,[8] Cumings and Miller,[9] and others. The same weathering process probably produced the cherty capping of Loma Bayatabo from Cretaceous or Tertiary sediments, but as they are much poorer in iron than the serpentine no lateritic iron ore was formed. The lower part of the capping of this hill is white to light-yellow chalcedony with a horny to dull luster, and the upper part is a reddish jasper. Loma La Entrada, which is on serpentine, is capped with ocherous brown silica containing fragments of serpentine and grains of chromite. Any laterite that may have formed on this hill by solutions percolating downward from the zone of weathering has been removed, leaving only the chert.

The chert around Loma Bayatabo and elsewhere in the district is in part residual from the old surface, but the masses that cap scattered lower hills probably resulted from a renewal of the silica-concentrating process in a later epoch, after uplift and partial destruction of the old surface.

Alluvium

The larger valleys are filled with alluvium as much as 20 feet deep, and in addition many areas are so covered with such deep residual soil or alluvium that the bedrock is nearly or completely hidden. Float fragments

[8]Leith, C. K., and Mead, W. J., Origin of the iron ores of central and northeastern Cuba: Am. Inst. Min. Eng. Trans., vol. 42, pp. 90–102, 1912.

[9]Cumings, W. L., and Miller, B. J. , Characteristics and origin of the brown iron ores of Camagüey and Moa, Cuba: Am. Inst. Min. Eng. Trans., vol. 42, pp. 116–137, 1912.

in the soil are common, however, and these have been used as a guide in mapping the underlying bedrock wherever they seem to afford reliable clues.

IGNEOUS ROCKS

Ultramafic Complex or Serpentine

The rocks of the intrusive complex in which the chromite deposits occur may be divided into two main types: feldspar-free ultramafic rocks, including peridotite and dunite; and feldspathic rocks, which include gabbro, troctolite, and anorthosite. As these rocks intergrade and are the products of one primary magma, the term ultramafic, indicating the high content of magnesia and iron, has been applied to the entire complex, although the feldspathic members admittedly should not properly be called ultramafic. Measurement of the surface areas of the two types indicates that 10 to 12 percent of the total mass of the complex is feldspathic, but this estimate may be high inasmuch as the gabbroic rocks are more resistant to weathering than the peridotite, and their float masks large areas surrounding outcrops.

ULTRAMAFIC MEMBERS

The peridotite is a medium-grained, massive rock composed of olivine and a rhombic pyroxene near enstatite in composition; it is therefore of the variety known as harzburgite or saxonite. The pyroxene is subordinate in amount to the olivine, probably not exceeding 25 percent of the rock in most places, and with decreasing pyroxene content the peridotite grades into dunite. Most of the olivine and much of the pyroxene commonly is so serpentinized that only a small proportion of the primary minerals remains. Traces of the original minerals or characteristic pseudomorphs of them may usually be seen in serpentine that has not been greatly sheared. Fresh surfaces are normally dark green, and weathered surfaces are yellowish green to reddish brown. The cleavages of the pyroxene and its tendency to stand in slight relief on weathered surfaces helps to distinguish the peridotite from the dunite.

The peridotite greatly exceeds all other rock types in volume, making up probably 85 percent of the total mass of the complex.

The dunite is composed of 95 percent or more of olivine and not more than 5 percent of pyroxene; almost all of it contains minor amounts of chromite in small, distinct grains. As seen under the microscope, the texture is that of a medium-grained, equigranular rock; because of the essentially monomineralic composition, little can ordinarily be seen in a hand specimen. Occasionally, on freshly broken surfaces light may be reflected from indistinct cleavages in residual grains of olivine, but most specimens are a dense greenish black in which even the accessory chromite grains are seen with difficulty. The dunite weathers to a smooth light-brown or dun-colored surface.

The dunite has been observed most often as the wall rock of the ore bodies, also as irregular masses in the peridotite. The association of dunite with chromite is notable, and almost without exception it is the rock immediately enclosing the ore, if the original frozen contacts have been preserved. This dunite is in the nature of a sheath or envelope, which may range in thickness from less than a foot to several dozen feet. There is no correlation between the size of the ore deposit and the thickness of the envelope, however, and the presence of dunite does not necessarily indicate an ore body. Dunite also occurs as narrow dikes filling fractures in the chromite ore bodies.

FELDSPATHIC MEMBERS

The feldspathic members of the ultramafic complex occur as large irregular masses, as sheets, and as small dikes and pluglike bodies. The larger masses and sheets seem to be essentially contemporaneous with the peridotite, for they show similar structural features and grade into it, in places across zones tens of feet wide. Many of the smaller masses show crosscutting relations and are slightly younger.

Of all the rocks the gabbros show most variation, both in composition and texture, for they grade into all the other associated types. In the larger masses the gabbro ordinarily is a medium-grained, equigranular, granitoid or gneissoid rock that is gray where fresh and gray to brown on weathered surfaces. Some of the olivine-bearing varieties are poikilitic, and contain large crystals of augite enclosing the olivine and feldspar. The texture in dikes ranges from pegmatitic, with interlocking anhedral crystals up to 6 inches across, to almost aphanitic diabasic, with grains indistinguishable except under the microscope. The pegmatitic dikes occur exclusively within ore bodies and are unusually well developed in the Aventura mine. The fine-grained dikes are commonly found in the peridotite, either as small sheared blocks or as long narrow masses. A number of parallel dikes in the low hills north of the highway between Minas and Redención appear to have been intruded into tension cracks developed in the peridotite after it was sufficiently rigid to hold open long fractures. Some of these fine-grained dikes may be related to post-serpentine vulcanism instead of to the ultramafic magma; however, in the absence of definite evidence to the contrary they are tentatively considered part of the ultramafic complex.

Although the gabbro locally forms prominent hills, as in the area north of the Ofelia mine, some large areas of it show few exposures, and float fragments in the soil are the principal indications of its presence.

The troctolite consists of olivine and bytownite-anorthite plagioclase in varying proportions. It is an equigranular, medium- to coarse-grained rock on which rapid weathering of the olivine produces a pitted surface. It occurs in large, layered masses, some of which appear to be gently dipping sheets, and in vertical tabular dikelike bodies. Layering is commonly prominent in dikes of troctolite cutting ore and peridotite.

The anorthosite is a white, equigranular, granitoid to gneissoid rock of medium-coarse grain, composed essentially of bytownite or anorthite plagioclase, with accessory chromite and in some places pyrite. It occurs as layers in troctolite and gabbro and also as fairly extensive bodies.

Quartz Diorite

An intrusive stock with the average composition of a quartz diorite underlies the city of Camagüey and its outskirts. Although natural outcrops of the diorite are rare, road cuts and small quarries afford numerous exposures. In general, the rock is a medium-grained subhedral quartz diorite composed of plagioclase, hornblende, and varying amounts of quartz. Some specimens contain substantial amounts or orthoclase, and one was found to have the composition of a quartz monzonite.

The stock intruded Cretaceous volcanic rocks, picking up numerous inclusions of tuff near the margins and metamorphosing a wide zone which is well exposed along the road to Acueducto north of the city. The volcanic rocks there have been bleached, devitrified, epidotized, and silicified by the hydrothermal action, and sodic oligoclase or albitic feldspars have been introduced into some of the tuffs.

Small bodies of soda-rich feldspathic rocks scattered both in the volcanic sequence and in the serpentine probably are related to the intrusive at Camagüey. The widespread but economically unimportant copper mineralization of the district is also ascribed to this source.

STRUCTURAL FEATURES

Regional Structure

The geologic structure of the Camagüey district as a whole is complex, in places exceedingly so; therefore, only a brief description of the salient features can be given here.

The oldest structural features are those in the preserpentine phyllites, which were formed from shaly sediments by intense dynamic metamorphism, with development of flow and fracture cleavages. The phyllite-serpentine contact parallels this cleavage in places, and the intrusion of the peridotitic magma may in part have been controlled by it.

The distribution of the ultramafic and younger rocks reflects an overall arcuate structure, convex to the south, which probably resulted from intense north-south compression and was superimposed on older structural features about which little is known. The principal known structural elements are: (1) the Lugareño-Yucatán syncline, (2) the

Cubitas overthrust; which involves the Sierra de Camaján as well as the Sierra de Cubitas, and (3) the quartz diorite stock near Camagüey.

The curved belt of Cretaceous rocks that extends from the vicinity of Central Lugareño to Loma Yucatán is due to postserpentine deformation, because detrital serpentine was found in the limestone lenses in the arc. It is believed to be a syncline, probably a very complex one, of tuffs folded down into the serpentine. Observed dips in the sediments are steep, and numerous small bodies of serpentine and gabbroic rocks within the tuffs indicate minor folds or complex faulting. Relatively small patches of tuffs surrounded by serpentine, such as that west of Loma Borges, are also believed to indicate synclinal features in which the younger rocks have been preserved.

A major low-angle fault, for which the name Cubitas overthrust is proposed, has been traced continuously almost 18 miles along the south front of the Sierra de Cubitas, and is believed to have originally extended eastward beyond Central Senado. Evidence of a similar fault has been observed around the base of the Sierra de Camaján. The rocks in the Sierra de Cubitas and Sierra de Camaján are therefore believed to have been thrust southward over the serpentine and infolded volcanic rocks.

The limestones in the Sierra de Cubitas strike about parallel to the front of the range and dip southward. North of the crest of the range the beds dip gently to moderately, but near the front they dip steeply and in places are overturned northward. From Loma Tuabaquey westward the outermost ridge along the front is made up of complexly faulted, nearly vertical limestones ranging in age from Cretaceous to middle Eocene. Southeast of Loma Tuabaquey the mountain front is irregular, and coarse fault breccia of serpentine and limestone is exposed over an area of several acres in a flat-floored reentrant valley cut through steeply dipping limestones. Float fragments of similar breccia are found at other points near the base of the scarp, and are numerous north of Banao, where the surface of the serpentine slopes downward toward the overturned limestones in the mountain front.

The Cubitas range extends for about 25 miles, of which 18 miles is within the area mapped. Former extension of the thrust several miles east of the present range is indicated by exposures of the breccia that forms low hills in the vicinity of Central Senado. This breccia is best exposed in a long railroad cut 1¼ miles (2 kilometers) north of the sugar mill. There it consists of fragments of limestone, tuff, serpentine, gabbro, and troctolite ranging from grains the size of sand to structural units dozens and even hundreds of feet long, mixed with marl or finely crushed limestone. A few thin beds of sorted and water-laid debris, derived from and interlayered with the breccia members, were noted dipping steeply south, but most of the breccia lacks stratification other than original bedding within the individual blocks. In places a distinct sheeting is visible, and blocks of brittle limestone are usually broken into many small fragments. The presence of water-laid beds within the breccia suggests that the advancing front of the thrust rode over coarse debris being piled up ahead of it either on land or in shallow water, grinding the brittle components of the breccia to relatively small, usually rounded, fragments. The tuffs, and to some extent the serpentine, escaped much of the comminution because their comparative plasticity localized stresses at the edges of the blocks.

The Sierra de Camaján is believed to have been formed by two overlapping thrust plates, the lower one consisting of the ammonite- and aptychus-bearing strata and the upper one of Cubitas-type limestone; both appear to rest on tuffs downfolded into the serpentine. The southern and eastern parts of the sierra constitute a structural unit consisting of a dome of thin-bedded limestone flanked by irregular remnants of the upper plate. Scattered outcrops and float of volcanic rocks near the center of the dome indicate a window exposing the underlying rocks through the thrust plates. The northern and western parts, including Lomas La América and Borges, consist mostly of east-trending, steeply dipping, massive or thick-bedded limestones and are part of the upper plate. The trace of the fault between the plates is extremely sinuous, particularly in the northeastern corner of the area, and several windows and outliers have been mapped. All the faulting is believed to be related to the main Cubitas overthrust; the details have not been worked out, however, as several important factors, such as the source of the older limestones and their original relations to the serpentine, tuffs, and Cubitas-type limestones are not known.

Although the total displacement along the Cubitas overthrust is unknown, a minimum of about 6 miles is indicated by the distance from the south edge of the Sierra de Camaján to the base of the Sierra de Cubitas southeast of Loma Tuabaquey. The distribution of the Senado breccia to the south and east of the range also indicates that the overthrust sheet has been stripped back at least 8 miles by erosion. Corroboratory evidence for a considerable transport along the fault is furnished by the differences in lithology between the limestones of the upper plate and the predominantly tuffaceous nature of the contemporaneous sediments making up the lower stationary block.

The Cubitas overthrust is believed to have been the culmination of an orogeny that took place in early Eocene time. The lower and middle Eocene limestones involved in the thrusting along the front of the Sierra de Cubitas set a definite lower age limit, but the upper limit is not known with certainty. The presence of almost undeformed limestones of uppermost middle Eocene age near Grúa Gurugú, a few miles north of Central Lugareño, suggest that the thrusting had ceased by that time.

Folding prior to the thrusting is shown by the angular unconformity between Upper Cretaceous tuffs and middle Eocene limestone in the vicinity of Loma El Peñón. The divergence of the structural trends in the volcanic rocks of this area, which lie nearly at right angles to those prevailing over the rest of the district, is believed to be due to the influence of two diorite stocks, one to the northwest at Camagüey city and the other to the southeast, just outside the area mapped. The beds may have been folded by forces accompanying intrusion of the stocks or by later forces that crowded them against the stocks as buttresses. Thorough shattering and shearing of the diorite suggest that the latter hypothesis is more probable.

Structure and Distribution of the Ultramafic Rocks

The similarity in the distribution of the feldspathic rocks and the Cretaceous volcanic rocks, strikingly shown by the almost continuous strip of gabbro along both sides of the Lugareño-Yucatán syncline and seen in many other places in the district, is of great significance to an understanding of the structure of the ultramafic complex. No large bodies of feldspathic rocks were found far from the tuffs. This distribution suggests that the feldspathic rocks were concentrated mainly in the upper part of a nearly horizontal stratiform complex, and that the volcanic rocks were deposited on a surface formed by erosion that stopped just above the base of the feldspathic zone. The layering of the gabbro and troctolite originally may have been horizontal, which, if so, would imply that it should be parallel to bedding in the tuffs. Few exposures yield sufficient data on the attitudes of either layering or bedding to enable the degree of parallelism between them to be determined satisfactorily, but in general it may be said that the trends shown by the distribution of rock types in both the igneous and sedimentary rocks are roughly parallel. The volcanic rocks are known to have been severely deformed during the long period of folding that culminated in the Cubitas overthrust, and the underlying serpentine was necessarily involved in the same movements, although to some extent it may have yielded by internal shearing rather than by folding. The layering of the feldspathic rocks ranges in dip from nearly horizontal to vertical, and some of the high dips must be due to postvolcanic folding. Uplift and renewed erosion have removed the tuffs and the remnant of the feldspathic zone from the anticlinal areas and have left them in the synclines, thus producing the areal distribution of rock types shown on the map.

To summarize, the sequence of events after emplacement of the peridotite and gabbroic rocks seems to have been as follows: (1) removal of roof rocks from the complex and erosion nearly to the base of the feldspathic zone, (2) deposition of a thick series of volcanic rocks and associated limestones, (3) intrusion of the diorite stock near Camagüey and folding and erosion, (4) deposition of Eocene limestones, (5) folding culminating in the Cubitas overthrust, (6) erosion and minor vertical adjustments.

ORE DEPOSITS

GENERAL FEATURES

Chromite is a black hard moderately heavy mineral that varies widely in composition, as indicated[10] by the formula $(Mg, Fe)O \cdot (Cr,Al,Fe)_2O_3$. The chromites of Camagüey have an average composition, after eliminating silicate impurities, of approximately 36 percent Cr_2O_3, 30 percent Al_2O_3, 17 percent MgO, 13 percent FeO, and 4 percent Fe_2O_3. Because the alumina content is high, the ore is of good refractory grade in spite of its relatively low content of chromic oxide.

The chromite occurs as anhedral or occasionally subhedral grains, commonly a millimeter or less across, disseminated principally in dunite and less commonly in peridotite, troctolite, or anorthosite, and as larger masses which are all within the peridotite zone although surrounded by a dunite envelope. The texture ranges from that of a normal rock through increasing proportions of chromite and an increase in grain size to a massive, moderately coarse-grained aggregate consisting entirely of chromite. The simplest ore is an aggregate of individual grains usually having a banded appearance because of variations in the proportion of ore and silicate minerals from layer to layer, but the ore in nearly all the commercial deposits of the district is of the massive or coarse-grained type with only minor amounts of silicate gangue minerals, which usually do not exceed 10 to 12 percent by weight. These may be olivine or feldspar, or both and their alteration products. In some deposits the chromite forms spherical, flattened, or ellipsoidal nodules one-quarter to one-half inch across. Clusters of broken fragments clearly show that some disseminated ore was formed during emplacement by fracturing and pulling apart of already solidified nodules; Thayer[11] suggests that some disseminated chromite originated in the same manner from massive ore.

At the Guillermina mine coarse octahedra and nodules of chromite with cores of feldspar are set in a matrix that is troctolitic in the center of the deposit but more dunitic toward the edge. At the periphery the interstitial material is feldspar-free dunite, although the feldspathic cores remain. This is believed by Thayer[12] to be the result of crystallization in a feldspathic environment with a later shift to an olivinitic environment.

Near or at the base of several prominent layered troctolitic masses, zones of chromite-rich rock a foot or so thick may be traced for considerable distances. The chromite may be in layers or arranged in stringers of feldspar that enclose or surround olivine grains in a manner suggesting a fish net.

[10] Stevens, Rollin, E: Composition of some chromites of the Western Hemisphere: Am. Mineralogist, vol. 29, pp. 1–34, 1944.

[11] Thayer, T. P., Chrome resources of Cuba: U. S. Geol. Survey Bull. 935–A, pp. 21–22, pl. 5.

[12] Thayer, T. P., op. cit., pp. 42–43, pls. 3*B* and 4.

The ore deposits range in size from small knots of chromite to masses containing 200,000 tons or more. They are commonly lenticular, but may be tabular, roughly equidimensional, or very irregular. The contacts with the enclosing rock, which nearly everywhere is dunite, are for the most part sharply gradational if unsheared, or are "frozen". Most of the deposits are probably bounded by faults. Apparently the ore bodies, being considerably stronger than the surrounding rock, reacted to shearing stresses more or less as hard kernels, and movements were localized along their margins. The result has usually been to smooth off irregularities and provide good walls from which the ore breaks cleanly. The envelope of dunite, present along practically all frozen contacts, is commonly removed by the shearing.

Dikes appear to be more abundant in and near the ore than elsewhere in the peridotite and are common features of the deposits. As the best exposures are in the mines, and as chromite affords maximum contrast for the dikes, this abundance may be more apparent than real, although

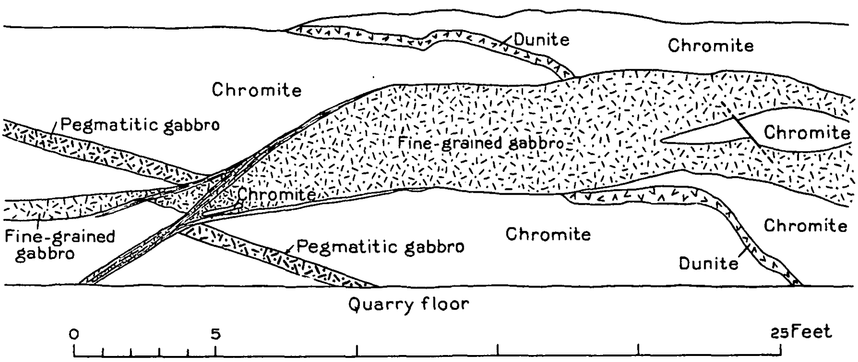

FIGURE 2.—Sketch of face at Lolita mine, Camagüey district.

in the Moa-Baracoa district of Oriente Province there can be no doubt of the close association of dikes with ore. The dikes were intruded in the order (1) dunite, troctolite, and anorthosite, probably essentially contemporaneous; (2) pegmatitic gabbro; (3) fine-grained gabbro. Fragments of chromite are commonly enclosed within the dikes, and the dike material in many places contains cemented breccias of angular ore fragments. The age relations formerly were well exposed at the Lolita mine (see fig. 2), where fine-grained gabbro cuts dikes of both dunite and pegmatitic gabbro.

The Victoria mine shows many features typical of the larger deposits of the district. (See pl. 19.) The deposit is now virtually exhausted although some ore remained when it was mapped in April 1943. The total known length of the ore zone is 950 feet, including isolated bodies at either end, and the main deposit is approximately 600 feet long and 25 feet thick and extends 100 to 150 feet down the dip. The width of the deposit varies throughout its length, and the ore tends to pinch or finger out at the ends and downward, but the over-all shape is fairly simple. The ore body strikes N. 10° to 35° W. and dips moderately to steeply southwest. In general the envelope of dunite around the deposit is thin, although the few exposures northwest of the main pit indicate a zone of dunite up to 70 feet in width, extending to the prospect 150 feet away. This area is regarded as favorable for further drilling.

Shearing along faults about parallel to the contacts has removed much of the dunite or transformed it to a green sheared serpentine in which the original rock type cannot be identified with certainty. The most prominent structural feature of the deposit is the horizontal offset, along several cross faults, of the north end of the body to the west. This movement seems to have been one of the last that affected the deposit, as these faults cut and offset most of the others. The small southeastern body may very well be a portion of the main mass, offset along a fault that forms the lower boundary of the south body and the upper boundary of the main body. Minor faulting, however, obscures the picture.

Dikes are not so numerous in this mine as in some others, but a number of gabbroic and troctolitic dikes cut the ore and the serpentine wall rock. In general they strike parallel to the deposit and dip in the same direction.

DISTRIBUTION

Relation to the Serpentine-Gabbro Contacts

The most significant results of the detailed mapping of the Camagüey district has been to show that, although all the economic deposits in the district occur in the ultramafic rocks, there is a general areal relationship between the ore deposits and the feldspathic rocks and overlying volcanic rocks. A statistical study of their distribution reveals that 94 percent of the known ore of the district, including both mined ore and reserves, lies within half a mile of the belts of feldspathic rocks that extend along the contacts with the tuff series, or, where gabbroic rock is absent and the tuff directly overlies the serpentine, within half a mile of the tuffs. Of this ore 82 percent lies along the limbs of the synclinal arc extending eastward from Loma Yucatán, and 12 percent lies near the gabbro rimming the structural depression on which the Sierra de Camaján rests. Only a very few small deposits have been found along the eastern third of the arc, from Minas to Lugareño. The combined production and known reserves average about 80,000 tons per square mile in the Loma Yucatán-Minas area and about 17,000 tons per square mile around the Sierra de Camaján. In contrast to this, the total known ore in the remainder of the area underlain by serpentine averages only 750 tons per square mile. The average for the district as a whole is 10,000 tons per square mile.

The distribution of chromite within these zones, however, is by no means uniform. The richest area is that extending from the Camagüey mine to the Ferrolana, where more than one-third of the known ore is concentrated within less than one percent of the district. Other notable concentrations are at the Lolita mine north of Minas, in the vicinity of the Victoria and La Victoria mines, east and northeast of Altagracia, and in the area northward from Cromo to Loma El Pastil.

The conclusion seems inescapable that the distribution of the ore deposits is in some way related to the localization of the feldspathic rocks, which seem to be near the top of what was once a more or less stratiform complex. During the deformation of the area, the ore bodies, which originally underlay the feldspathic zone, came to their present positions around the flanks of the synclinal areas. In the structurally high areas the gabbroic rocks and the chromite have been removed by erosion, leaving only the deeper nearly barren serpentine.

The distribution of most of the other ore deposits and feldspathic masses may also be explained by the hypothesis outlined above. Between the vicinity of Banao, near the northwestern corner of the district, and Loma Borges, 12 miles to the southeast, there are many small chromite and gabbro bodies. The presence of Cretaceous volcanic rocks at both ends of the belt suggests that a synclinal axis, bowed slightly upward in the middle, extends from Banao to Loma Borges; probably the tuffs, feldspathic rocks, and the richer part of the ore zone have been eroded. The Guillermina deposit, which apparently has been shifted from a feldspathic to dunitic environment, perhaps by settling in the magma, is at the southern edge of this zone, as is also the La Perla, the other outstanding example of a deposit in which nodules of chromite enclose feldspar. The belt of deposits that extends northeastward from Central Senado is also associated with gabbro bodies, the largest exposed being half a mile long. This belt approximately follows the continuation of the northeasterly swing of the Sierra de Camaján and thus may be considered as the eastern extension of the Banao-Loma Borges belt emerging from under the cover of tuffs and limestones, although exposures are not sufficient to prove this relationship. It is interesting to note that the prospects in the small group 2 miles southeast of Minas are also alined parallel to the regional structure.

The group of deposits south of Cromo has no apparent relation to the tuff contact, but a low hill of flat-lying troctolite in the center of the area suggests that they lie in a shallow structural basin. The serpentine of the area appears to be less sheared than elsewhere, and a number of the deposits have unfaulted contacts. Most of them are small, and many are composed principally of disseminated ore.

Attitudes of the Deposits

The tabular or lenticular deposits, which include most of those in the district, show a pronounced tendency to strike parallel to the trend of the nearest contact between serpentine and gabbro. The Aventura ore body, the only major exception of this rule, lies near a reentrant in the gabbro contact, and though it strikes perpendicular to the nearest contact, it lies parallel to the contact to the south. In the area between Banao and Loma Borges the bodies of both ore and gabbro tend to lie with their longer axes parallel to the trend of the belt.

No corresponding correlation of the dips of deposits and contacts can be demonstrated, as the dips of the contacts are not known. A number of deposits, however, are known to dip steeply toward the contact, the most notable being the Victoria and the Camagüey, and no large deposits are definitely known to dip away from it. Most of the bodies are vertical, or nearly so.

ORIGIN

The distribution and mode of occurrence of the deposits suggest several possible explanations for their origin, which will be outlined briefly. No final conclusions are reached at this time as a more complete discussion of origin must await the completion of studies of the other chromite districts of Cuba and similar deposits in the western United States.

Two general possibilities suggest themselves: first, differentiation and segregation of an essentially homogeneous magma after intrusion into its present position; and, second, in differentiation in depth before the magma was intruded into the upper crust of the earth. The actual method of formation of the ore bodies is not clear, but the separation by gravity of early-formed crystals has been invoked to explain the origin of certain chromite ores, and may in part at least account for these. The crosscutting dikes of dunite, troctolite, and gabbro in the deposits indicate clearly that wherever they were formed the chromite masses separated from the magma at an early stage.

If the segregation occurred in place, some process of crystalization and segregation in or near the base of the feldspathic zone would appear to have resulted in the formation of irregularly distributed lenses and tabular masses of chromite which then settled, in most places not more than half a mile. Most of the deposits apparently were formed with their longer axes horizontal, or came to rest in that position in a medium solid enough to prevent further sinking.

This hypothesis does not satisfactorily explain the irregular distribution of the deposits within the zone beneath the feldspathic rocks. The ore bodies show the irregularities in form and distribution that are characteristic of the pod or sackform deposits in California, Oregon, and the eastern United States, rather than the stratiform regularity of the chromite horizons in the Stillwater and Bushveld complexes of Montana, that are generally recognized as having been formed essentially in place. The typical Camagüey ore is coarser-grained and more massive than the Bushveld or Stillwater ores, and much of the disseminated ore appears to have been formed by the disruption of massive ore rather than by the accumulation of individual crystals.

The sporadic localization and coarse grain might originate by a process of progressive irregular concentration of the chromium in the gabbroic fraction of the magma in the upper part of the magma chamber, and crystallization of chromite late in the magmatic sequence. By this hypothesis much of the olivine and pyroxene would have settled in the magma chamber before the chromite formed, thus preventing it from sinking far. Such a process, however, would require volatile constituents to keep the chromium in solution until late in the crystallization sequence, and even with their aid it is uncertain that chromite would not be deposited early, as in the normal sequence it crystallizes at the upper end of the olivine range. The brecciation of the deposits and injection of the dunite, troctolite, and gabbro dikes appears difficult if not impossible in the time afforded by this hypothesis.

The second hypothesis, that much or all of the differentiation occurred in depth, seems to account for many of the features of the Camagüey district. (See fig. 3.) 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.

The origin postulated is similar to that proposed for the Stillwater and Bushveld complexes, but carried one step further; that is, after differentiation the layered complex was re-fused and intruded into a higher level in the crust. The Camagüey district may therefore be a connecting link between the two principal types of chromite deposits, the layered and the sackform.

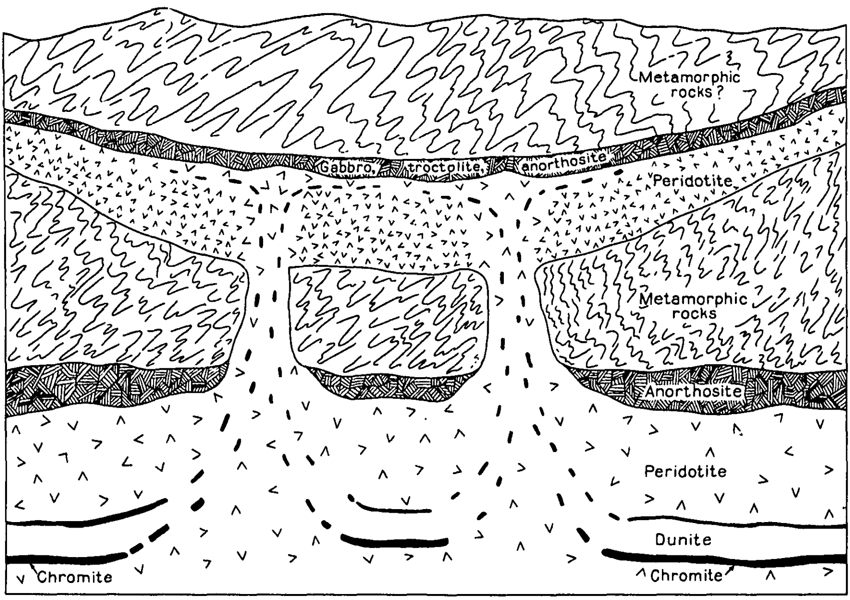

FIGURE 3.—Schematic section showing inferred origin of the Camagüey ultramafic complex.

Thayer[13] indicates that reactions occur between silicates and various components of the chromite molecule far below the fusion point of the chromite, and this mechanism may explain the constant association of the ore with olivine and feldspar. The presence of the spinel mineral chromite reduces the silica content of the system and brings it below the range in which pyroxene is stable. Reaction should occur with hypersthene to form olivine and with diopside to form olivine and calcic feldspar, thereby producing the dunitic or troctolitic environment in which the deposits are always found.

[13]Thayer, T. P., Preliminary chemical correlation of chromite with the containing rocks: Econ. Geology, vol. 41, pp. 202–217, 1946.

GEOPHYSICAL PROSPECTING

The entire district was carefully prospected for surface indications of deposits more than a decade ago, and no important finds have been made for a number of years. The likelihood of finding more ore by ordinary methods is therefore extremely small, and the two companies that have the largest holdings in the district, the Juragúa Iron Co., a subsidiary of the Bethlehem Steel Corp., and the Compañía Cubana de Minas y Minerales, a subsidiary of E. J. Lavino & Co., have turned to subsurface methods of exploration.

The simplest method used has been drilling, ordinarily in the immediate vicinity of known deposits, in the hope of finding satellite bodies or faulted parts of known bodies. As the proportion of ore to the total mass of the serpentine is extremely small, even in the richer belts, the chances of finding appreciable quantities of ore by "wildcat" drilling in the absence of any surface indications are not good.

PREVIOUS WORK

It was recognized some years ago that geophysical methods of prospecting might be of value in the search for chromite. Magnetic surveys are of doubtful value for chromite ordinarily is not strongly magnetic, whereas the variable amounts of magnetite resulting from the serpentinization of olivine may give strong but meaningless anomalies. On the other hand, the difference in specific gravities between chromite, about 4, and serpentine, 2.5, should give gravity anomalies detectable by modern instruments. The first gravity investigation for chromite in Cuba, a survey made with a torsion balance, revealed an anomaly too large to be caused by the known ore body at the property; subsequently, drilling at the indicated spot located a deeper deposit.

W. D. Johnston, Jr., and T. P. Thayer, of the Geological Survey, were instrumental in arousing interest in further geophysical work. In 1942 a number of areas owned by the Bethlehem Steel Corp. were very precisely surveyed with a gravimeter by a party from the Gulf Research & Development Co.[14] Little was known at that time about the system of distribution of the deposits, and the surveys were not all made in the most favorable areas. In all about 0.8 square mile was covered, and one large deposit was discovered that constitutes a substantial addition to the chrome ore reserves of the district. Altogether, 113 anomalies were found, of which very few have been shown to be caused by ore. Most of them result either from the presence of feldspathic rocks appreciably heavier than serpentine; from variations in the depth of the soil cover, which is lighter than serpentine; or from causes not yet understood.

[14]Hammer, Sigmund, Estimating ore masses in gravity prospecting: Geophysics, vol. 10, pp. 60–62, 1945. Hammer, Sigmund, Nettleton, L. L., and Hastings, W. K., Gravimeter prospecting for chromite in Cuba: Geophysics, vol. 10, pp. 34–49, 1945.

SUGGESTIONS FOR FUTURE WORK

The results of the detailed geologic mapping should be of assistance in planning further work of this nature. For lack of better information, the Gulf Research & Development Co. assumed that the typical deposit was spherical, and a square grid of 20 meters was used for the instrument stations. As more than two thirds of the ore in the district is concentrated in deposits containing 90,000 tons or more, it probably would be more profitable to cover larger areas more rapidly in search of additional bodies of this size than to concentrate on very detailed examinations of limited areas. Most deposits in this district are tabular and the average ore body of 100,000 tons will have a length of at least 200 feet; furthermore, it will very probably be oriented parallel to the nearest serpentine-gabbro contact. Stations at 20-meter intervals on parallel lines perpendicular to this contact and 50 meters apart should give adequate gravity coverage and cut the work to only 40 percent of that necessary for a 20-meter net. A closer spacing of stations along traverse lines, possibly at intervals of 15 meters, should give superior results at little more than half the cost of the previous survey per square mile. Significant anomalies should be mapped in more detail by closely spaced stations.

Detailed geologic mapping should precede geophysical prospecting in any area, to refine, if possible, the mapping of the serpentine-gabbro contact so that traverses may be made as nearly as possible perpendicular to it. Magnetometer surveys probably would be helpful in locating the contact under shallow alluvium or residual soil by differences in the magnetic susceptibilities of the serpentine, gabbro, and tuffs. The dip of the contact probably could be approximated by geophysical methods if found to be related to the attitude of the deposit, or if it would aid in interpretation of gravity data. Regional gravity studies might disclose important clues to the shape of the entire serpentine mass and to the localization of bodies within it.

Although the economic aspects of the method are naturally not subject to an exact analysis because chance is certain to play a large part in any exploration program, a brief consideration of the factors involved will serve to give a hint as to the costs to be expected. Using the data given in the Gulf Research & Development Co.'s report,[15] which shows that the party covered 0.8 square mile in somewhat less than 6 months, it seems that with the proposed faster system a square mile could be covered in 3 months. The expenses of such a party are not precisely known, but are believed to be approximately $3,000 per month, making the cost of surveying approximately $9,000 per square mile. The cost of drilling to test promising anomalies is likewise uncertain, but with modern truck-mounted, high-speed equipment, shallow holes could be drilled for about 25 cents a foot, inasmuch as cores would not have to be

[15]Hammer, Sigmund, Nettleton, L. L., and Hastings, W. K., op. cit., p. 37.

taken in preliminary drilling for chromite. If all highs are drilled, two drills working two shifts would probably be necessary to keep up with the geophysical party; if each drill averages 100 feet per shift and works 25 days per month, the total drilling cost per month should be about $2,500, or for the 3-month period necessary for covering a square mile, $7,500. The basic exploration cost per square mile would thus be about $16,500, although additional expenses, such as detailed studies of anomalies found by the reconnaissance survey, might raise the cost to $20,000. The density of discovered chromite has been shown to be 80,000 tons per square mile in the most favorable part of the Loma Yucatán-Minas arc, and there is good geologic reason to suppose that many concealed deposits in this belt are at such shallow depths as to be detectable by the gravity method. If one-half the ore is assumed to be in deposits of 100,000 tons or more, an average of 40,000 tons of ore per square mile might be found at a cost of 50 cents per ton.

AREAS SUITABLE FOR GEOPHYSICAL PROSPECTING

The most favorable area in which to resume geophysical prospecting is that in the vicinity of the Camagüey and Ferrolana mines, where the concentration of ore is already known to be extraordinarily high. The pattern of outcrops suggests that this belt continues eastward to the serpentine area in which the La Caridad mine is situated. Isolated outcrops of serpentine, two of them containing small chromite bodies, lie east and north of the main serpentine lens and the possibility of finding ore under the sediments should be investigated eventually, although probably not until other more favorable areas have been thoroughly studied. Such areas should include the vicinity of the Lolita mine, the area between the Victoria and La Victoria mines, and the area northward along the contact from Cromo to Loma El Pastil.

Another area deserving of consideration lies northeast of Central Senado, where some 17,000 tons of ore per square mile is known, in spite of the fact that much of the area is covered by residual soil, which makes ordinary methods of prospecting extremely difficult. Work in this area consists first of searching for very shallow deposits concealed by the soil cover; the depth of this cover must then be accurately determined in order to make necessary corrections. The use of a soil auger to obtain samples for determination of specific gravity and to check the nature of the bedrock might be advisable.

In conclusion, prospecting for chromite by gravity methods in the Camagüey district has been shown to be scientifically sound and economically practicable, even with inadequate preliminary geological mapping. With improved techniques, including detailed geological studies, gravity prospecting for chromite has definite possibilities for commercial success in districts where the conditions are as favorable as in Camagüey.

INDEX