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## THRUST FAULTS AND RELATED STRUCTURES IN EASTERN CUBA

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**Abstract**--Detailed areal mapping in central Camagüey Province and reconnaissance mapping in northern and eastern Oriente Province, Cuba, have revealed two major structural zones: (1) A zone of intense deformation, including thrust faulting, which lies north of the geographic axis of the island; and (2) a belt of domical mountains bounded on the north by Nipe Bay and the coast, and on the south by the Cauto trough and Guantánamo basin.

In Camagüey, extensive masses of serpentine and overlying tuffs have been complexly folded and overridden from the north by a block, at least 25 miles long, of limestones that form the Sierra de Cubitas and Sierra de Camaján. The overthrust carried a northern facies of Cretaceous and Eocene limestones over a southern facies of tuffaceous rocks of similar age, and had a displacement of at least six miles. In places serpentine was thrust over younger formations, and most of the shearing in the serpentine is attributed to diastrophism. A thrust zone exposed in Loma La Vigía, 15 miles north of Holguín, suggests a similar tectonic history for northern Oriente Province. Chaotic giant breccias that include waterlaid debris indicate that the overthrusts moved across the ancient land surface in both Camagüey and Oriente districts. The folding apparently began in the Cretaceous and culminated in overthrusting during early middle Eocene time. Post-Eocene deformation appears to be limited to warping or doming to maximum angles of about 20 degrees.

The zone of domical mountains is somewhat more than 100 miles long from east to west by 25 to 30 miles wide, and comprises three main units: (1) the Sierra de Nipe and (2) Sierra del Cristal domes, principally of serpentine; and (3) the Cuchillas uplift, which includes the Cuchillas de Toar and Sierra de Purial, composed of serpentine and pre-serpentine rocks. These uplifts are overlapped progressively on all sides by sediments ranging in age from Upper Cretaceous to Oligocene and Miocene, the older beds in places being highly folded. The mountains owe their present relief of 2000 to 4000 feet to the doming of an extensive erosion surface in the late Pliocene or early Pleistocene. The north and east flanks of the Cuchillas uplift extend below sea level, and drowned streams and elevated coral reefs show regional instability since the last major doming.

## Introduction

The serpentized peridotite which extends almost the entire length of Cuba has been generally recognized as an important element in the structure of the island, and much discussion has centered around its age and relations to the other rocks. Numerous investigators, beginning with HAYES, VAUGHAN, and SPENCER [see "References" at end of paper, 1901], have described the serpentine as occurring along axes of anticlinal folds, but estimates of its age have ranged from Cretaceous to middle Tertiary. Interest in the lateritic iron-ores led to rather detailed investigations of some limited areas of serpentine, particularly with regard to the formation of the laterites, by KEMP [1915], LEITH and MEAD [1911], CUMINGS and MILLER [1911], and others. The principal published contributions to the geology of the northeastern part of the island in recent years are by a group from the University of Utrecht, and are mainly of a reconnaissance nature [MAC GILLAVRY, 1937; KEIJZER, 1945]. The first extensive detailed study of the serpentines themselves was made between 1940 and 1945 by geologists of the United States Geological Survey as part of its wartime chromite investigations, the work being carried out under the auspices of the Interdepartmental Committee on Scientific and Cultural Cooperation with funds provided by the Department of State and the Foreign Economic Administration. The Camagüey district was mapped on a scale of 1:48,000 by FLINT, DE ALBEAR, and GUILD (in press), and parts of Oriente Province were reconnoitered by Guild and Thayer with the aid of aerial photographs taken by the United States Navy and the United States Army Air Forces. At the same time, the manganese deposits of Cuba were investigated and a large part of southern Oriente Province was mapped by PARK, [1942]; PARK and COX, [1944]; WOODRING and DAVLESS, [1944]; Straczek, Simons, and Lewis. The manganese investigations in the area south of the Sierra de Nipe contributed much information on the relations of the serpentine there.



Two major structural zones related to the serpentine were recognized: (1) A zone of strong deformation, including thrust faulting, which lies north of the geographic axis of the island and goes out to sea north of Nipe Bay; and (2) a zone of domical mountains bounded on the north by Nipe Bay and the coast, and on the south by the Cauto trough and Guantánamo Basin (see Fig. 1).

#### Zone of strong deformation

Camagüey district--The Camaguey and Holguín districts lie entirely within the zone of strong deformation, and although they occupy only a small part of it are believed to be representative of the zone as a whole. The major structural relations in the Camagüey district (see Fig. 2) appear to be relatively simple. An ultramafic complex, of which serpentinized peridotite is the dominant part, is intrusive into old metamorphic rocks, and is overlain unconformably by Cretaceous and younger rocks. Two volcanic rock units were recognized by MAC GILLAVRY [1937]: the "Tuff Series," mostly Upper Cretaceous in age, though the base is probably early Cretaceous; and an upper unit which is unconformable on the "Tuff Series" and is correlated with the Habana formation [PALMER, 1934] of Maestrichtian (latest Cretaceous) age.

Detrital fragments of quartz diorite from a stock that intruded and metamorphosed the lower rock unit in the vicinity of the city of Camagüey have been found in the Maestrichtian rocks. Serpentine fragments also were identified in these rocks, and the areal distribution of the formations indicates that the ultramafic complex antedates the "Tuff Series" as well. In the area mapped the Cretaceous and younger rocks overlap the margins of the complex on all sides except the northwest, and occupy an arcuate synclinal belt that crosses the center of the district. This syncline appears deep and is probably very complex, for although bedding in the tuffs dips steeply in many places, small masses of gabbro and serpentine crop out in the center of the structure.

The serpentine is bounded on the north by an overthrust fault which has been traced about 25 miles along the southern margin of the Sierra de Cubitas and is believed to underlie the Sierra de Camaján. These mountains are composed of limestones, more or less contemporaneous with the volcanic rocks, which represent a northern, marine facies of deposition. Although the thrust fault was not seen, its position is revealed by the relations along the front of the Sierra de Cubitas and within the Sierra de Camaján, and extensive exposures of fault breccias.

From Loma Tuabaquey (two miles east of Cuatro Caminos) westward, the south front of the Sierra de Cubitas trends about N 50° W; in places it rises abruptly as a scarp from the serpentine savannah, elsewhere low parallel ridges lie at the foot of the main escarpment, which attains a maximum height of about 700 feet. The limestones dip southward, rather gently within the range and steeply along the front; northwest of Banao the beds at the base of the scarp are overturned and dip 75° northeastward. The outermost ridges that extend southeastward from Banao consist of vertical lower and middle Eocene limestones which overlie the Cretaceous rocks making up the bulk of the range. Southeast of Loma Tuabaquey the front of the sierra swings east and breaks up into a series of irregular spurs which appear to correspond to fault blocks.

The structure of the Sierra de Camaján is more complex. Remnants of two thrust blocks, not distinguished on the map, rest on downfolded volcanic rocks of the southern facies, which in turn lie on serpentine. The lower block, which forms the southern and eastern part of the range, is composed of Upper Jurassic [IMLAY, 1942] and Lower Cretaceous [MAC GILLAVRY, 1937] thin-bedded fossiliferous limestones. A Fenster in this block exposes the underlying tuffs. Thick-bedded Upper Cretaceous limestones, very similar to those of the Sierra de Cubitas, are exposed in the northern and western part of the range, and form numerous isolated outliers on the older limestones in the southern part. They dip nearly vertically, although in most places the underlying thin-bedded rocks dip at moderate or low angles. The two blocks together are believed to be a klippe, or outlier, which has been separated from the main Cubitas thrust block by erosion.

Direct evidence of faulting along the base of the Sierra de Cubitas is shown by extensive brecciation of the serpentine. Northwest of Banao the serpentine just south of the limestone contact is thoroughly brecciated, and consists of recemented angular fragments; cherty material is also common. Marked angularity of the fragments indicates crushing that was very different from the "pasty" shearing usually found in serpentine. The serpentine breccia is best exposed in a 15-acre area about 3.5 miles east of Cuatro Caminos. There a broad reentrant in the foothills of the range, nearly surrounded by structureless limestones, is floored with unstratified serpentine breccia that superficially resembles glacial till. The fragments range in size from blocks a foot or two in diameter down to fine sand, and consist mainly of serpentinized peridotite, with an admixture of gabbroic rocks and scattered small pieces of white limestone. The contact between the breccia and limestone is very sinuous, appears to be nearly horizontal, and is marked by a



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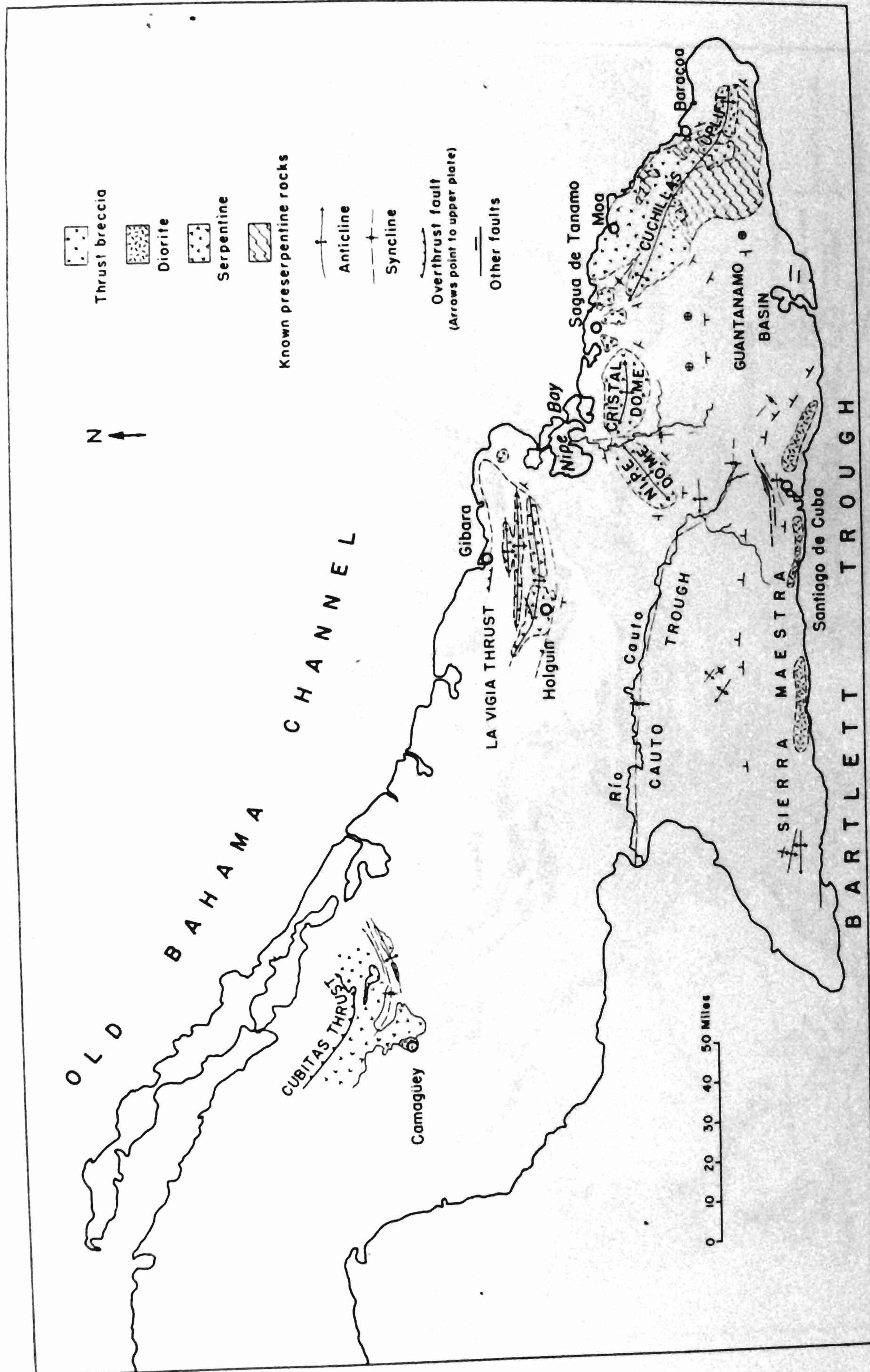


Fig. 1--Some major structural features of eastern Cuba



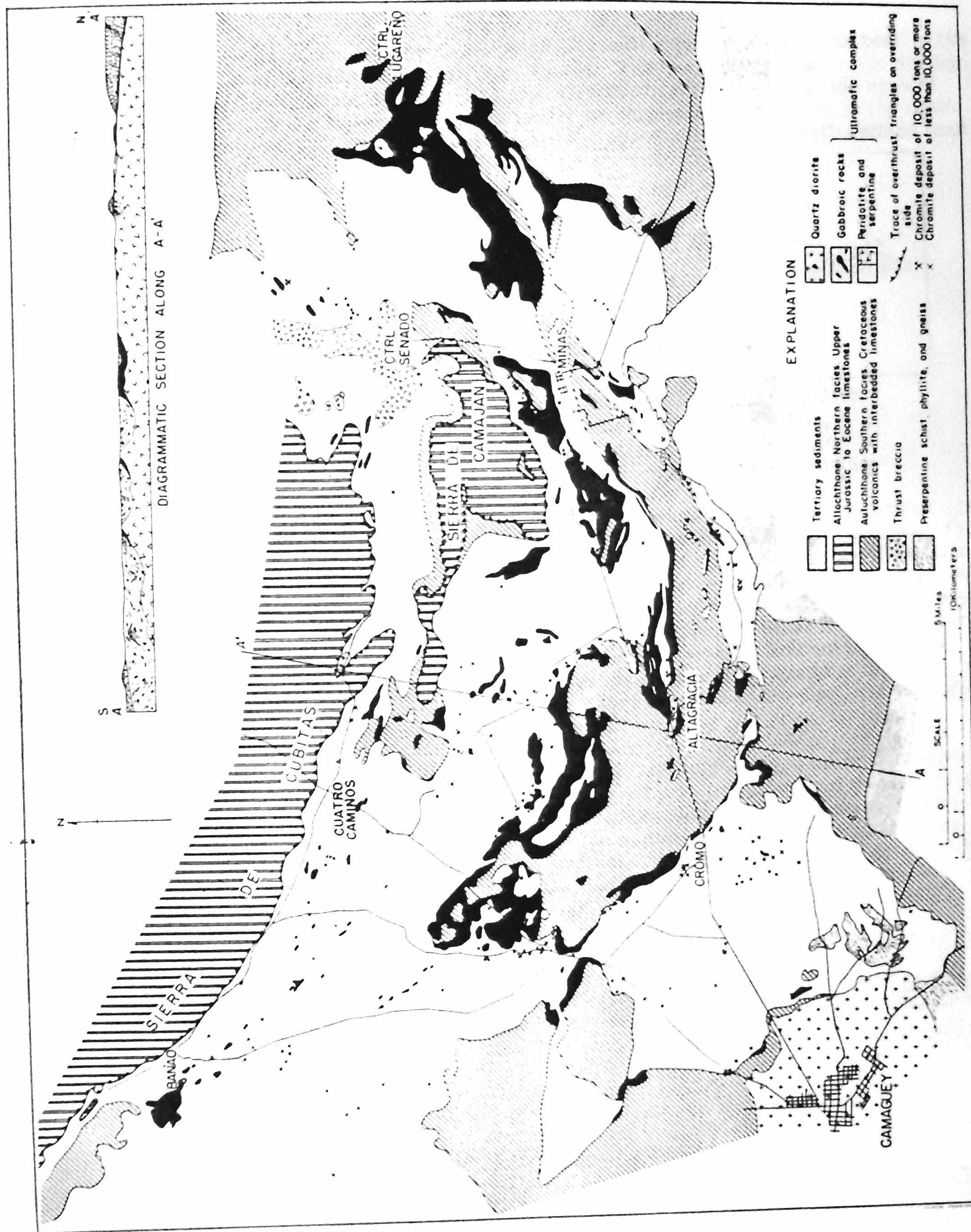


Fig. 2--Geologic map of the Camagüey chromite district, Cuba



notable concentration of cherty silica. Exposures of massive serpentine less than half a mile to the southeast and the apparent low dip of the contact suggest that the breccia is between 20 and 50 feet thick.

Serpentine thrust over younger limestone and shales is well exposed in the north bank of the Río Máximo, six miles east of Cuatro Caminos (see Fig. 3). The basal beds lying on the serpentine consist of subangular fragments of serpentine in a matrix of carbonate and grade upward through sandstone into shale and limestone. A few pieces of serpentine were found in the limestone. The beds dip 35 to 65° SW under serpentine, and the upper contact is a well-defined fault

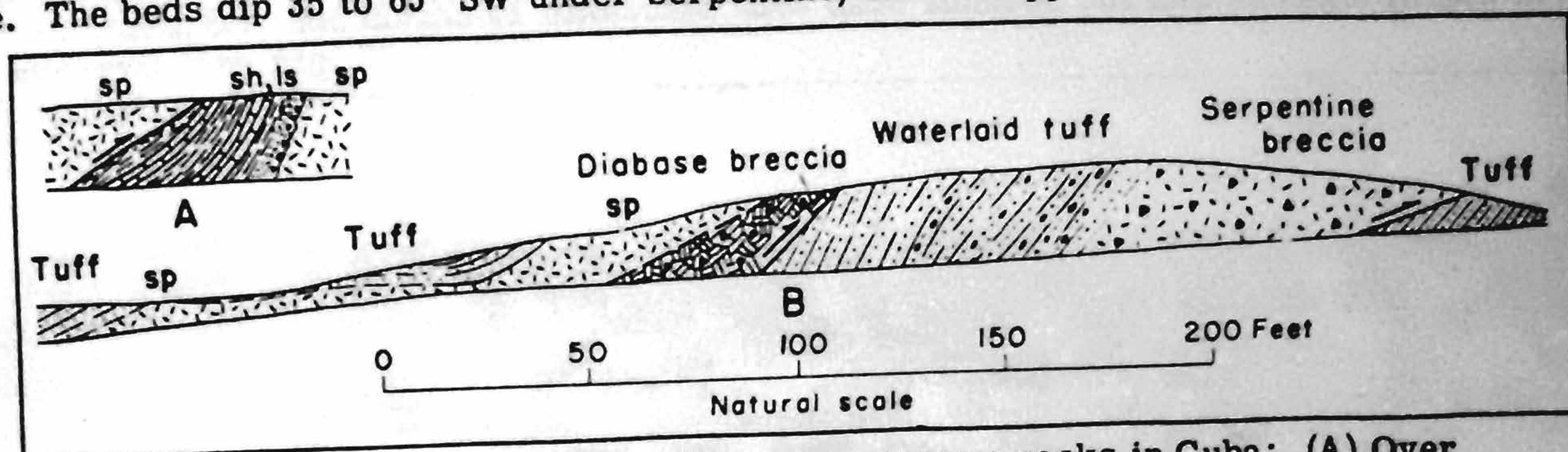


Fig. 3--Thrusting of serpentine over younger rocks in Cuba: (A) Over unconformable marine shales and limestones, Río Máximo, Camagüey; (B) over tuffs containing serpentine boulders, in cut on Gibara road 3.5 miles north of Holguín, Oriente Province

that dips about 40° SW. About two miles to the northwest, in a side road, similar relations are indicated by fine-grained sandstones and mudstones interlayered with sheared serpentine. The sandstone was traced by float about 1000 feet northwest of the road along the strike; it is about six feet in greatest thickness and dips about 45° SW, parallel to the shearing in the serpentine. Thin sections show that the bedded material consists of well-rounded and well-sorted unweathered serpentine grains cemented by calcite without appreciable replacement. Float fragments of similar bedded material were found a few hundred feet southeast of the main breccia exposures. The limestones involved in these reverse faults have not been dated, but they resemble the Paleocene (?) Cangilones limestone which covers an extensive area a short distance to the east, and tentatively are regarded as similar in age [see DE LABEAR, in press].

An area of ten to twelve square miles in the vicinity of Central Senado, east of the Sierra de Cubitas and northeast of the Sierra de Camaján, is underlain by an extraordinary mixture of serpentine and gabbro, tuff, and limestone. A 2000-foot cut on the Senado railroad about 1 1/2 miles north of the sugar mill shows that the rocks are divided into distinct units or blocks that are more or less homogeneous and are bounded by faults (see Fig. 4). The units consist of tuff, of brecciated

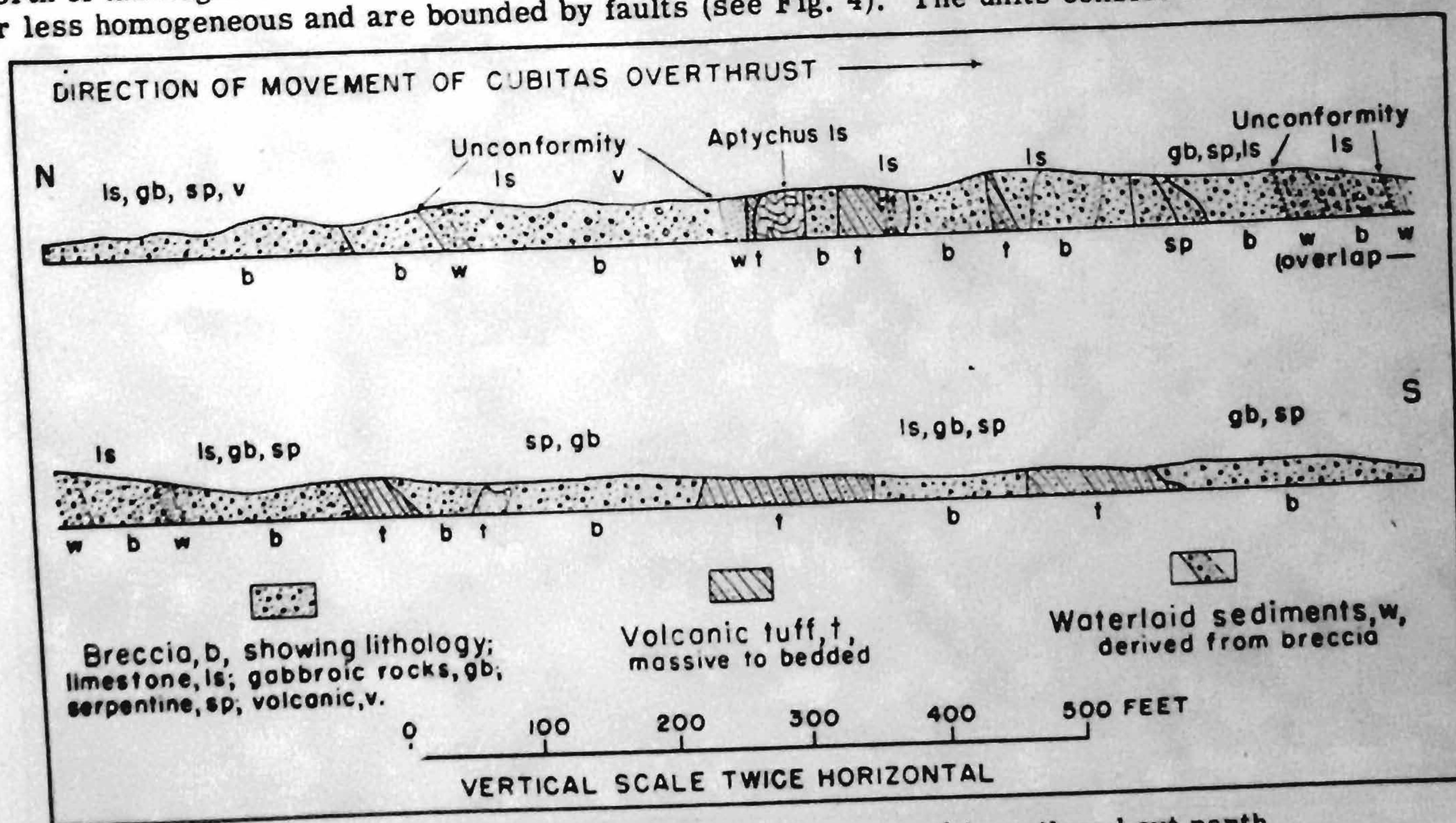


Fig. 4--Generalized section of breccias exposed in railroad cut north of Central Senado, Camagüey, Cuba



limestone or serpentine, and of mixtures of serpentine, gabbro, and limestone in any proportions. Viewed on a large scale, these units form a giant breccia. The bedding in the blocks of volcanic tuff dips uniformly southward at angles ranging up to  $80^\circ$  and in general it is only slightly folded, indicating relatively mild internal deformation. Blocks of tuff occupy about 20 per cent of the total area exposed in the walls of the cut. A 30-foot unit of highly contorted thin-bedded aptychus limestone, and a 50-foot unit of brecciated serpentine are exposed in the east wall of the cut. Most of the breccia, as shown in Figure 5, consists of an unsorted or rudely stratified mixture of large blocks ranging up to four feet in diameter in a matrix of fine-grained serpentinous, clayey or limy material, and resembles glacial till (see Fig. 6). In places the breccia approaches fault gouge in character, and blocks of limestone have been sheared out into elongate lenses of granular material (see Fig. 7).



Fig. 5--Mixed breccia in west wall of railroad cut north of Central Senado, showing heterogeneity; small lens of waterlaid debris dipping steeply southward near center of view; height of exposure about 12 feet



Fig. 6--Close-up of breccia unit similar to that shown in Figure 5, showing angularity of fragments and lack of sorting



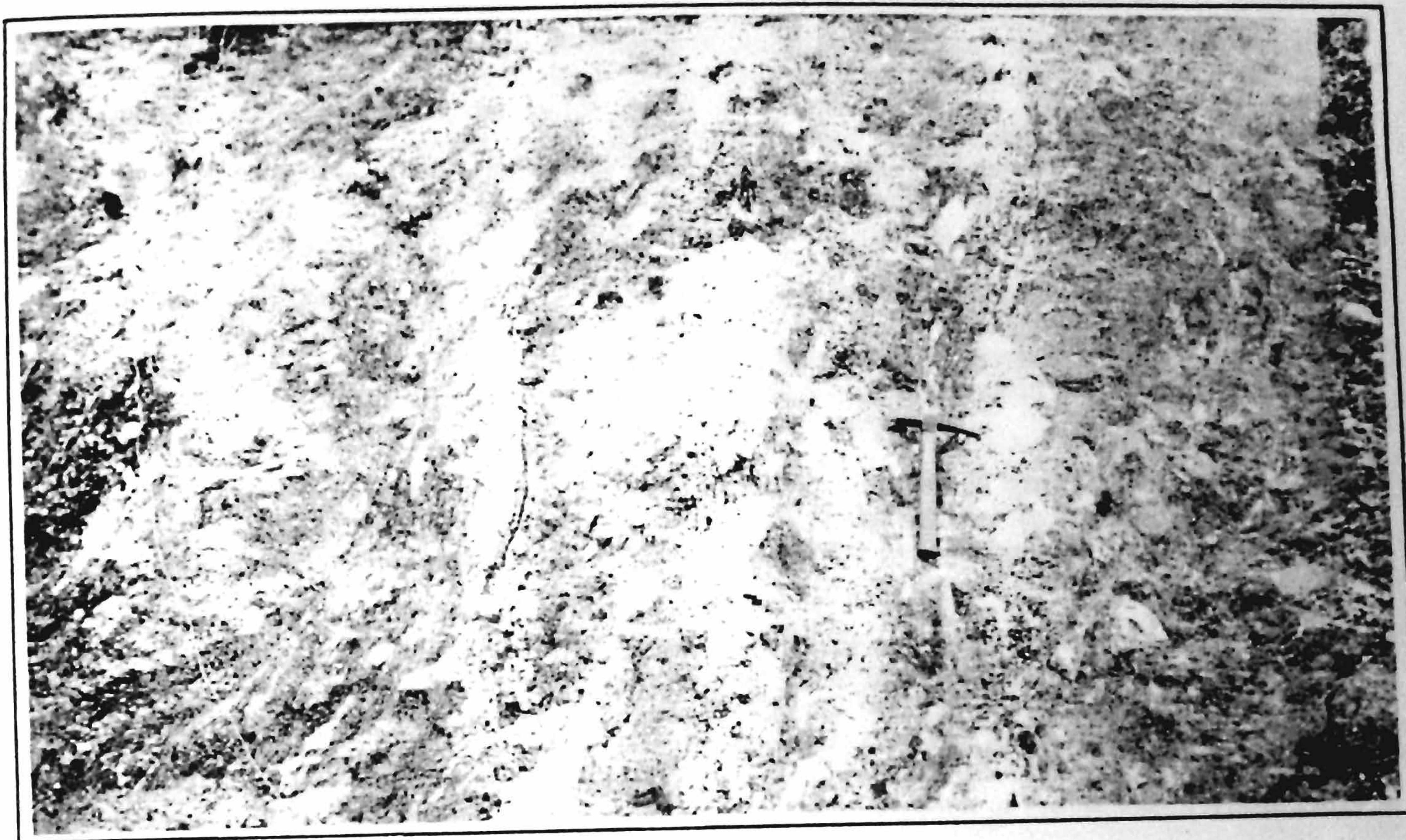


Fig. 7--Breccia resembling fault gouge, in which limestone fragments have been sheared out into lenses and streaks in serpentinous matrix; west wall of railroad cut north of Central Senado, Camagüey

A few thin lenses of waterlaid sandy to gravelly material are interlayered with the breccia. These sediments are in general analogous to the water-worked debris commonly found in morainal deposits; they grade into and obviously were derived from the underlying breccia, and have been disturbed to various degrees. The lenses range in thickness from a foot or two up to 20 feet, and lie approximately parallel to the stratification in the breccia.

The giant breccia lies along the extension of the Cubitas overthrust and at a corresponding altitude. The rocks composing the breccia include those involved in the thrusting and no others, namely, aptychus and other limestones, various facies of the ultramafic complex, and volcanic tuffs. They are regarded therefore as fault breccias similar to those exposed along the base of the Sierra de Cubitas, though developed on a grander scale. The interlayering of waterlaid debris shows that the breccias were exposed to erosion, presumably along the advancing edge of an erosion thrust, and were then overridden by the upper plate. These breccias have many features in common with the "chaos" described by NOBLE [1941] east of Death Valley, and appear to be similar in origin. Several low hills in the vicinity of the breccia exposures are covered with float derived from the ammonite- and aptychi-bearing limestones and are believed to be held up by large blocks from the lower part of the upper plate.

The dip of the overthrust apparently varies considerably from place to place. At the east end of the Sierra de Cubitas and under the Sierra de Camaján it appears to be horizontal. In the vicinity of Banao, however, the fault must dip more steeply than the surface of the serpentine, which slopes gently toward the mountain; it may dip  $15^\circ$  or more northeastward.

Like many overthrusts, the Cubitas fault appears to be arcuate. The front of the upper plate is convex to the south, and the major structures of the district as a whole are parallel to it. The central syncline is concave northward and is believed to have been formed by the forces that caused the overthrusting. Exposures in most of the chromite mines show that the serpentine is highly sheared, and segments of faulted gabbroic dikes indicate that displacements of many feet along shears are common. High-angle shearing is so intense in the serpentine in a zone one to two miles wide along the front of the Sierra de Cubitas that it shows clearly in aerial photographs. Some of the fresher gabbro bodies there have been reduced to mylonite and superficially resemble hornfels. Most of the dikes and irregular masses of gabbroic rock in this belt are oriented parallel to the shear planes, though whether by rotation during shearing or by earlier primary igneous control is not known.



The Cubitas overthrust probably developed in the middle Eocene, for it involves lower and middle Eocene limestones, and upper Eocene limestones lie nearly horizontal only six miles northeast of Central Senado, on the projection of the Sierra de Cubitas. The presence of serpentine sandstone in the fault breccia and as slices along minor thrusts suggests that in places the overthrust followed an unconformity which was in part a surface of marine planation, for such sandstones could have been formed only under marine conditions. Subaerial erosion, even in an area of relatively high relief, would have resulted in oxidation and formation of lateritic products.

The reverse fault in the Río Máximo and the related faults dip southwest, opposite to the Cubitas overthrust, and presumably they were sheared off by it. Though probably small, they are additional evidence of the intense compression to which the serpentine was subjected. The shearing in the serpentine throughout the Camagüey district therefore is believed to be due to diastrophic movements rather than late-stage magmatic processes.

The structure in the southern part of the district is complicated by two stock-like masses of quartz diorite, one which underlies the city of Camagüey, and another to the southeast, just outside the mapped area. These rocks and related dikes in the serpentine also show the effects of strong deformation.

Holguín district--The geology of the section between Holguín and the north coast is similar to that of the Camagüey district. Rocks known to be older than the serpentine were not found in place, but inclusions of altered diorite and tectite indicate that the original peridotite came up through a crystalline basement. Upper Cretaceous tuffs containing limestone lenses overlie the serpentine, and both they and the serpentine are cut by numerous dikes of uraltic diabase and andesitic to rhyolitic porphyries. The city of Holguín is on a stock of hornblende diorite, dikes of which have chilled margins against the serpentine. Oligocene and Miocene limestones wrap around the district and form picturesque steep-sided knobs and mesas within it.

All the pre-Oligocene rocks have been compressed into a number of east-west folds, and the serpentine is exposed principally along the crests of three main anticlines. Cuts along the Holguín-Gibara road show that the rocks are highly deformed, and in several places serpentine is faulted against tuff. Highly brecciated serpentine that contains blocks of diabase, probably from broken up dikes, is thrust southward over tuffs in a cut 3.5 miles north of Holguín (see Fig. 3B). Aerial photographs show many small domical folds involving serpentine northwest of Holguín and one of them is crossed by a prominent fault that strikes northwest.

Chaotic breccias similar to those near Senado are well exposed in a cut through Loma La Vigfa, 16 miles from Holguín on the Gibara road. The cut is about 750 feet long and nearly 40 feet in greatest depth (see Fig. 8). The exposed section differs from that north of Senado in that it shows no tuffs or ultramafic rocks (although a block of serpentine is exposed in the road bed just below the section), and waterlaid debris constitutes a large part of it. The breccia members are composed almost entirely of limestone, some blocks being as much as 20 feet long. Most of the fragments appear to be from Upper Cretaceous limestones, and some contain pieces of large rudistids. A few pieces of shaly limestone and chert were seen in the breccia.

The waterlaid materials range in size from angular gravel to marl, and include basal conglomerates derived from the underlying breccia. Contemporaneous deformation is shown by numerous angular unconformities involving variations in attitude of  $45^\circ$  or more. The beds all dip southward except in a few places where they are steeply overturned to the north, and in general the younger beds to the south dip less steeply than the others. Lensing of the breccias is shown by one member that is nearly 25 feet thick in the west side of the cut, and pinches out on the east side. The blocks near the center of the section (see Figs. 9 and 10) are in the thin edge of this member.

The deposits in Loma La Vigfa, like those in Camagüey, appear to have been laid down along the front of a thrust sheet advancing from the north. The overturning of beds toward the north, lower dips in the successively higher beds toward the south, and the north-dipping reverse faults farther south all indicate movements from the north toward the south. Much of the upper plate of the La Vigfa thrust appears to have been destroyed by erosion, for the area northeast of the road cut is occupied by a low coastal plain, but limestone hills that extend for several miles to the northwest probably are part of it. Exposures to the south indicate that the cut reveals only part of the section of thrust breccias. The large blocks of brecciated limestone should assist greatly in tracing the breccia zone even where exposures are poor.



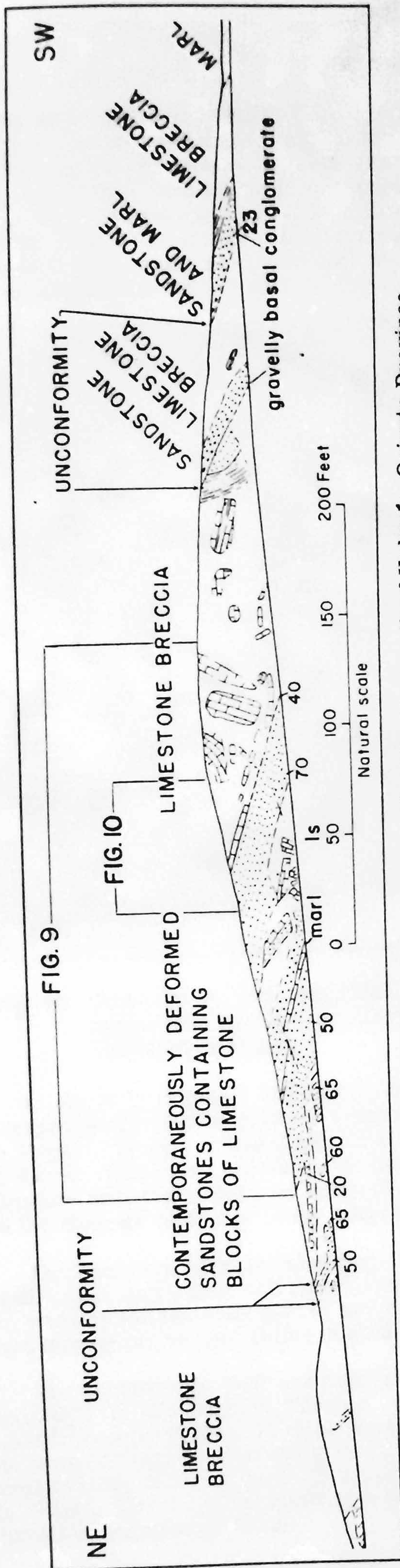


Fig. 8--Section in road cut through Loma La Vigfa, 16 miles north of Holguín, Oriente Province, Cuba; figures show true dip of beds; covered areas blank



Fig. 9--Interlayered breccia and waterlaid material in Loma La Vigfa portion of cut shown is indicated in Figure 8, above



## Zone of domical uplifts

The zone of domical uplifts begins on the west with the Sierra de Nipe and extends eastward to within a few miles of Cape Maisí at the eastern tip of Cuba, a distance of more than 100 miles. The main structural units in the zone are: (1) The Sierra de Nipe dome; (2) the Sierra del Cristal dome; and (3) the Cuchillas uplift, a complex unit that includes the Cuchillas de Toar and Sierra de Purial. The zone averages about 25 miles in width and parallels the north coast from Nipe Bay eastward. The Cauto trough and Guantánamo basin adjoin the zone on the south except along the Sierra de Purial, which slopes off into the Bartlett Trough. The mountains rise from near sea level to altitudes of 2000 to 4000 feet and comprise some of the most rugged terrain in Cuba.

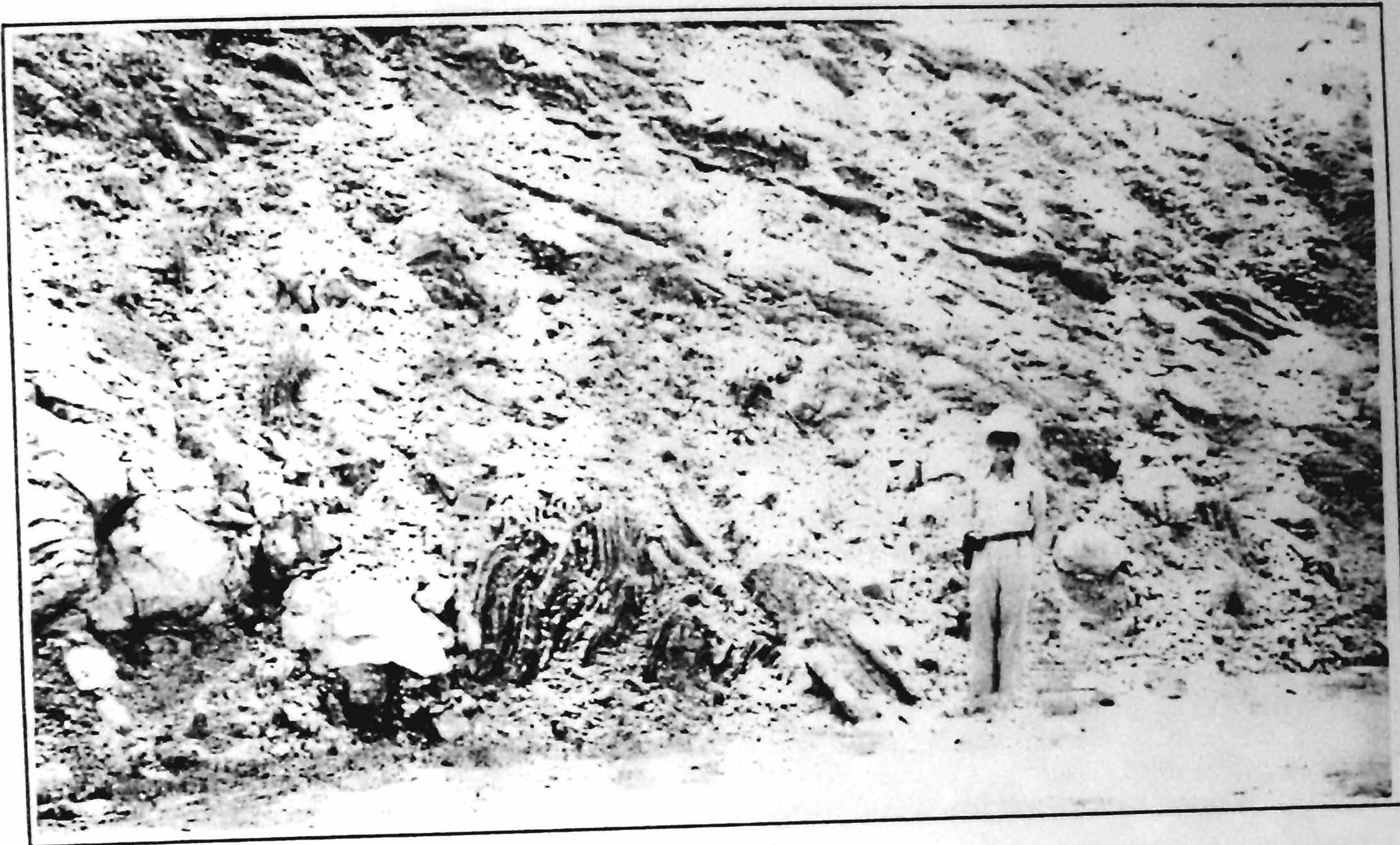


Fig. 10--Close-up showing character of breccia in Loma La Vigía, and overlying thin-bedded calcareous sandstones; note block of thin-bedded cherty shale; area covered by photo indicated in Figure 8

As shown in Figure 1, the Sierra de Nipe and Sierra del Cristal are elliptical domes with cores of serpentine flanked by younger sedimentary rocks, and separated by a synclinal fold along the Río Mayarí. Steeply folded Upper Cretaceous and Eocene beds that contain boulders of serpentine and diorite flank these domes on the south and southwest, and are overlain by upper Eocene and Oligocene beds that extend far up on all sides of the domes. The older beds are vertical in places, and the steepest dips seen in the Oligocene beds are about 20 degrees.

The Cuchillas uplift is somewhat longer than the Sierra de Nipe and Sierra del Cristal combined, and is much less well known than they. The Cuchillas de Toar lie north of the Río Toa and are made up for the most part of serpentine, but the Sierra de Purial, south of the Río Toa, consists largely of pre-serpentine metamorphic rocks of unknown age.

The Cuchillas de Toar are separated from the Sierra del Cristal by a broad synclinal lowland drained by the Río Sagua de Tánamo. The serpentine core of the uplift extends practically to the coast from a point about 15 miles east of the mouth of the Río Sagua de Tánamo to Baracoa, for the strip of Tertiary beds along the coast is very narrow and discontinuous. From Baracoa southward the Tertiary beds dip eastward away from, and wrap around, the eastern tip of the Sierra de Purial. The Cuchillas uplift as a whole is flanked on the southwest by the sedimentary rocks that form the Guantánamo basin.

The present relief of this mountainous belt is due to uplift along the axes of earlier folding, accentuated by erosion on the steep flanks and along irregular belts of relatively weak rocks. Remnants of an extensive erosion surface cover large areas in the higher parts of all the sierra. This



surface is best preserved in the vicinity of Moa, on the north slope of the Cuchillas uplift, and is referred to as the Moa surface. The lateritic iron-ores of eastern Cuba, including the famous Mayarí and Moa fields, are on this or a closely related surface. Near Moa the laterite-covered surface rises southward at an angle of about five degrees from sea level to more than 2000 feet, and the parts above the 500-foot contour are being rapidly dissected by stream erosion. The laterite extends seaward under Moa Bay, where the low dip has permitted the formation of a barrier reef. A few miles north of Baracoa the flank of the uplift, which appears to dip seaward about 15 degrees, has been stripped of laterite, and deep water is close to the shore. The Cuchillas uplift, therefore, extends below sea level, and the coastline from Baracoa westward for a distance of about 40 miles is essentially the sea-level contour on the Moa surface. Although erosion has stripped the laterite from the steeper parts of the Sierra de Nipe dome and accentuated the plateau-like aspects of the summit areas, the original domical form of the sierra is shown by the longitudinal profiles of the main ridges. The relief directly caused by doming is therefore on the order of 2000 to 3000 feet. The Moa surface cuts across all the rocks, although best preserved on the serpentine, and is believed to have been formed during Pliocene time, when similar surfaces were being developed in the Sierra Maestra [TABER, 1934]. It has been argued that the laterite might have been formed where it now is, rather than on a surface of low relief near sea level, and that the uplands accordingly do not necessarily indicate uplift of the magnitude and character indicated. Everywhere except on the lower slopes around Moa the streams are rapidly destroying the laterite-covered surface by cutting deep valleys into it. The intricate and deep dissection, with development of steep knife-like ridges (whence the name "Cuchillas"), that characterizes the present cycle is regarded by the authors as precluding formation of extensive laterite-covered surfaces except near sea level under climatic conditions similar to those of the present.

#### General relations

Although the structural zones have been described as distinct, with individual characteristics, they apparently were formed by the same crustal forces, as they have certain features in common. The principal differences appear to be of degree rather than kind, and indicate decreasing intensity of deformation southward. Small domical folds are as characteristic of the Holguín district as the reverse faults are, and there are many domes in the sedimentary rocks south of the Sierra de Nipe. The structure of the Sagua de Tánamo district in the northern edge of the zone of domes is very complex, and thrust faults are known to be present. On the road to the Talión mine, 2 1/2 miles west of Sagua de Tánamo, serpentine overlies tuffs on a nearly flat shear, and an erosional contact between the tuffs and serpentine is well exposed 100 yards nearer the mine. There is, therefore, no apparent definite boundary between the zone of thrust faults and the zone of domes.

The major structural axes in the Camagüey and Holguín districts obviously do not line up (see Fig. 1), and they appear more likely to be en echelon. The extensive area of younger Tertiary rocks west of the Camagüey district precludes close correlation with the Santa Clara region, but RUTTEN [1936, p. 28] indicates that the same general situation holds there also, for he describes a southern zone of gentle folding and a northern zone of tight folding and overthrusting. It is not known whether the main structural axes parallel the length of the island or cross it diagonally. If the thrusting is related to the development of a tectogene off the north coast of Cuba as postulated by HESS [1938], it would appear that the tectogene was formed mainly during the late Cretaceous and early Tertiary. If, however, the intrusion of the ultramafic rocks marked the first stage in its development, the tectogene must have been initiated in early Cretaceous time, and perhaps earlier.

The influence of the peridotite on the deformation is not clear. Very little is known about the form and extent of the peridotite masses in either the Camagüey or Oriente districts, as most of the margins are concealed by younger formations. The peridotites in the Oriente district appear to be either batholiths or very thick sheets, for although they formed topographic highs during much of late Cretaceous and Tertiary time, and must have been deeply eroded, no evidence of their floors has been found. The ultramafic complex in Camagüey Province shows some of the features of a lopolith and may be a relatively thin sheet [FLINT, DE ALBEAR and GUILD, in press]. The Camagüey complex and the serpentines in Holguín apparently failed to act as buttresses, and were folded and faulted as if they were thick sedimentary formations. The peridotites in the zone of domes retain most of their original structures, and although largely serpentinized, do not show the effects of strong shearing. Intense local deformation in the older beds around the edges of the domes would seem to indicate that the peridotites originally were competent and formed buttresses of a sort. The composition of the boulders in the Cretaceous and Eocene beds, however, indicates that serpentinization was far advanced early in the deformational history of the region, and it seems questionable whether serpentine, even in very large masses, would form effective buttresses. The serpentine in the domes therefore is presumed to have escaped internal deformation by virtue of weakness of the deforming forces rather than its own strength.



The late Tertiary deformation increases in magnitude from northwest to southeast, and is strongest in the Cuchillas uplift. The Camagüey district affords, at most, evidence of broad warping with a relief about equal to the height of Mesa San Felipe, or 200 to 300 feet. The Nipe dome stands about 2000 feet above the surrounding plains, and the Cuchillas uplift has a probable total relief of considerably more than 3000 feet. The amount of deformation appears to be roughly in inverse proportion to the distance from the Bartlett Trough, the nearer the trough, the more intense the deformation.

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