

ULTRAMAFIC ROCKS IN THRUST ZONES OF NORTHWESTERN ORIENTE PROVINCE, CUBA¹

MYRON T. KOZARY²

Hannover, German Federal Republic

ABSTRACT

Ultramafic rocks in northwestern Oriente Province, Cuba, are in narrow arcuate, parallel bands within a Cretaceous eugeosynclinal area. The structural relations between the ultramafic rocks and the "country rock" are seen best in the Silla Gibara hill mass 5 km southeast of Gibara. Here, 1-m to several hundred-meter-wide slivers of isoclinally folded and subsequently imbricated thrust plates appear to be "engulfed" in ultramafic rocks. These slivers, except for undated marble and Eocene conglomerate, are elements of a Cretaceous geosynclinal prism. Cretaceous radiolarian chert, middle Cretaceous pillow lava and reefal limestone, Campanian graywacke and pelagic limestone, and Maestrichtian fore reef limestone are present. The slivers are separated from each other by ultramafic rocks along consistently northeast-striking and steeply southeastward-dipping contacts.

The petrographic and structural appearances of the ultramafic rocks in the area indicate that several types of these rocks are present: "magmatic," "cold diapir," "tectonic," "basement," and even "sedimentary." This sequence suggests that the following series of events may have resulted in emplacement of the ultramafic rocks into their present site.

A geosynclinal depression originated in Early Cretaceous time as a result of tension along the zone of contact between the Caribbean "oceanic" crust on the south and a "continental" crust on the north. Serpentinization of the subcrustal peridotite of the oceanic segment raised the overlying thin gabbro crust. "Digestion" of the gabbro crust by volcanism began in middle Cretaceous time and a "trench" formed, by crustal failure, north of the volcanic zone. Oversteepening and subsequent collapse of the southern trench wall caused the formation of a series of northward-directed, high-angle "crustal" thrusts in Maestrichtian time. These "thrusts" involved the partly intact gabbro crust and the serpentinized ultramafic rocks below. Later the "crustal" thrust wedges were transformed into low-angle, northward-directed gravity thrusts. Increased mobility of the serpentinized ultramafic rocks along the sole of the thrusts facilitated the basinward sliding of the plates, throwing some into a series of recumbent folds. Continued hydration under differential stress increased the mobility of the serpentine fluidlike flow. Subsequently, in middle Eocene time, the serpentines in the cores of the folded thrust plates pierced the confining structures, tearing the strata into slivers, yet stringing them out in structurally coherent order as "flow" thrusts.

INTRODUCTION

The age and mode of the emplacement of ultramafic rocks in orogenic belts have become nearly as controversial as the origin of granite, although the discussion has not reached the magmatist-transformist level, and most ultramafic rocks are thought to have been derived from the subcrustal peridotite layer. It also generally is agreed

that ultramafic rocks appear in the early phase of the orogenic cycle (Hess, 1954, 1955), but there seems to be far less agreement regarding their mode of emplacement. Field relations commonly are difficult to interpret, because the ultramafic rocks are either in the metamorphosed roots of the old orogenic belts or in the most intensively deformed parts of the younger ones.

One of these younger orogenic belts, the Caribbean Island arc with abundant ultramafic rocks, represents what appears to be an ideal association of the various manifestations of an orogeny: active volcanism, high seismicity, large negative and positive gravity anomalies, foredeeps, and a great thickness of deformed sedimentary strata. Along the Greater Antillean part of this arc are segments in several stages of development; these become younger eastward, and various levels of the tectonic frame are exposed. The island of Cuba, nearly 1,100 km long and parallel with the orogenic belt, shows these stages, and consequently, the timing and method of emplacement of the ultramafic rocks can be determined.

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² Exploration manager, American International Oil Co. Deceased, October 20, 1966.

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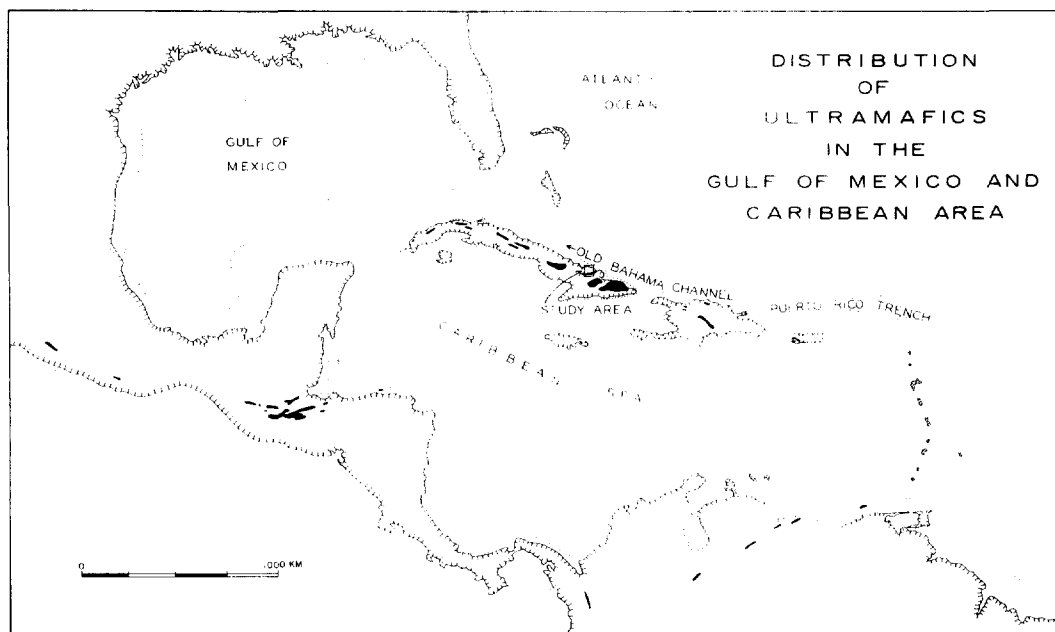


FIG. 1.—Distribution of ultramafic rocks (shown in black), Caribbean and Gulf of Mexico area. Study area shown by black box.

The ultramafic rocks in Cuba have been dated variously as Paleozoic (Schuchert, 1935), pre-Late Jurassic (L. M. R. Rutten, 1923), middle Cretaceous (MacGillivray, 1937), and Oligocene (Palmer, 1945), and several periods of intrusions also have been suggested (Schürmann, 1935; Palmer, 1945). However, except for the work by the U.S. Geological Survey in Cuba (Flint *et al.*, 1948), ultramafic areas have not been mapped in adequate detail to resolve this controversy. A structural study by the writer of a relatively small area (20 by 30 km) in northwestern Oriente Province, eastern Cuba, contains observations which may bear on the ultramafic problem.

DISTRIBUTION OF ULTRAMAFIC ROCKS

The ultramafic belt in the Caribbean orogenic belt can be traced from southern Mexico through Guatemala and through the entire Greater Antilles for a distance of more than 4,000 km to Puerto Rico. East of Puerto Rico it is interrupted by an active volcanic zone of the Leeward and Windward Islands, but the ultramafic rocks continue in northern Venezuela and strike into the Colombian Andes (Fig. 1).

In the entire arc of more than 8,000 km, the

island of Cuba contains the most extensive areas of ultramafic outcrops (Fig. 2), which extend 900 km along nearly the entire length of the island. They are found as bands in pre-late Eocene inliers within the Tertiary cover, 20–40 km wide, and are restricted to the north-central part of the island; almost none are present in the southern half. From west to east, there is a marked increase in both the linear extent and total mass of the individual ultramafic bodies. The ultramafic rocks persist beneath the Tertiary cover in about the same pattern; thus, about 15 percent of the island area or 15,000 sq km may be underlain by ultramafic rocks.

The individual ultramafic bodies range in size from slivers less than 1 m wide to massive bodies of more than 1,000 sq km, but the average body is 10–15 km long and 2–3 km wide, with an elongate, slightly sinuous outline. Within any specified zone, the largest bodies are along the southern edge of the ultramafic zone and the smallest and narrowest units are along the northern margins.

The areal distribution and structural setting of the ultramafic rocks seem to be about the same from Pinar del Río, the western end of the island, to northwestern Oriente Province, the east-

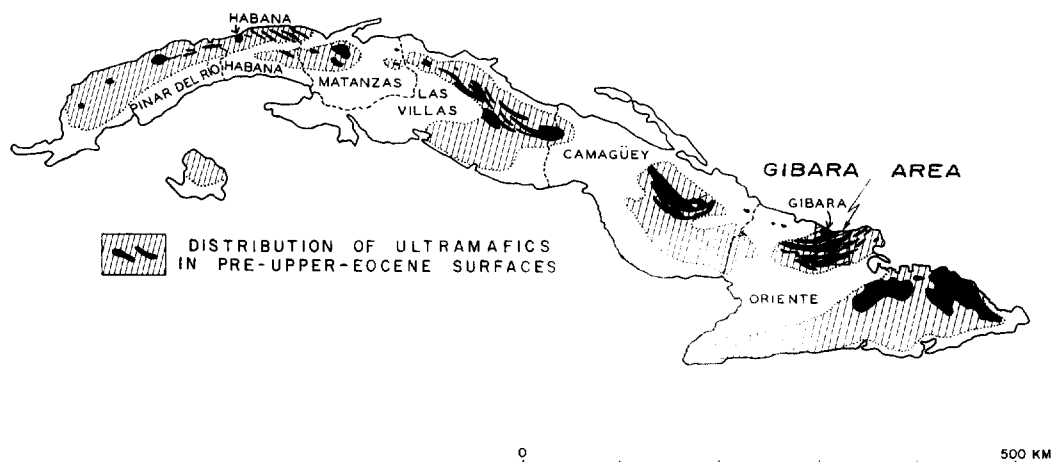


FIG. 2.—Distribution of ultramafic rocks (shown in black), Cuba. Study area shown by black box.

ernmost province (Fig. 2). However, in the eastern part of Oriente Province, the ultramafic rocks are more coherent and cover a much larger area. They are separated from the ultramafic rocks in northwestern Oriente by a major structural and topographic depression, which separates eastern Oriente from the rest of Cuba. This depression, on a regional scale, also represents a hinge between the now orogenically active eastern part and the more stable western part of the Greater Antillean part of the Caribbean Island arc.

The geology in northwestern Oriente, therefore, represents the easternmost extension of the structures which predominate in central and western Cuba, where narrow, parallel, arcuate belts of abruptly alternating zones of ultramafic, volcanic, carbonate, and detrital sequences prevail.

GEOLOGY OF GIBARA AREA³

A structural high in northwestern Oriente, about 90 km long and 30 km wide, and centered around the cities of Holguín and Gibara, consists of an Early Cretaceous to middle Eocene miogeosynclinal carbonate belt on the northwest and a time-equivalent eugeosynclinal ultramafic, basic igneous, and sedimentary belt on the south. It is overlapped on the south by late Eocene and on the north by Miocene sedimentary strata (Fig. 3).

³ Editor's note: a recent publication by Knipper and Puig (1967) used Kozary's work as a basis for a more detailed study of this area. Knipper and Puig's work corroborates Kozary's in full.

NORTHWESTERN CARBONATE BELT (MIOGEOSYNCLINAL SEDIMENTS)

The northwestern carbonate belt west of Gibara Bay consists of a sequence of Cretaceous and lower to middle Eocene dolomite, backreef, reef, forereef, and open-sea deposits (labeled "Cretaceous miogeosynclinal sediments," Fig. 3). The structural trends are predominantly east-west and most outcrops have steep, nearly vertical dips. Within this belt are several northward-directed Eocene low-angle thrusts involving elements of only this belt, with younger normal-fault displacements. The carbonate belt ends abruptly at the western shore of Gibara Bay, and it is not found farther east on the island.

SOUTHERN EUGEOSYNCLINAL BELT

South of the carbonate belt, more than 50 percent of the area is made of ultramafic rocks. They are aligned in narrow (1–4-km-wide), parallel, and, locally, anastomosing bands. The entire belt is arcuate, being concave toward the north-northwest (Fig. 3).

The other rock types between the ultramafic rocks are mostly volcanic-derived detrital siltstone, sandstone, and conglomerate, with only minor primary volcanic and pyroclastic rocks, flows, and dikes. Limestone, chert, heterogeneous conglomerate, and metamorphic rocks are found in even lesser amounts. On the average these non-ultramafic sequences are in units less than 100 m wide. Although they do not persist as continuous outcrops, they can be traced intermittently with a

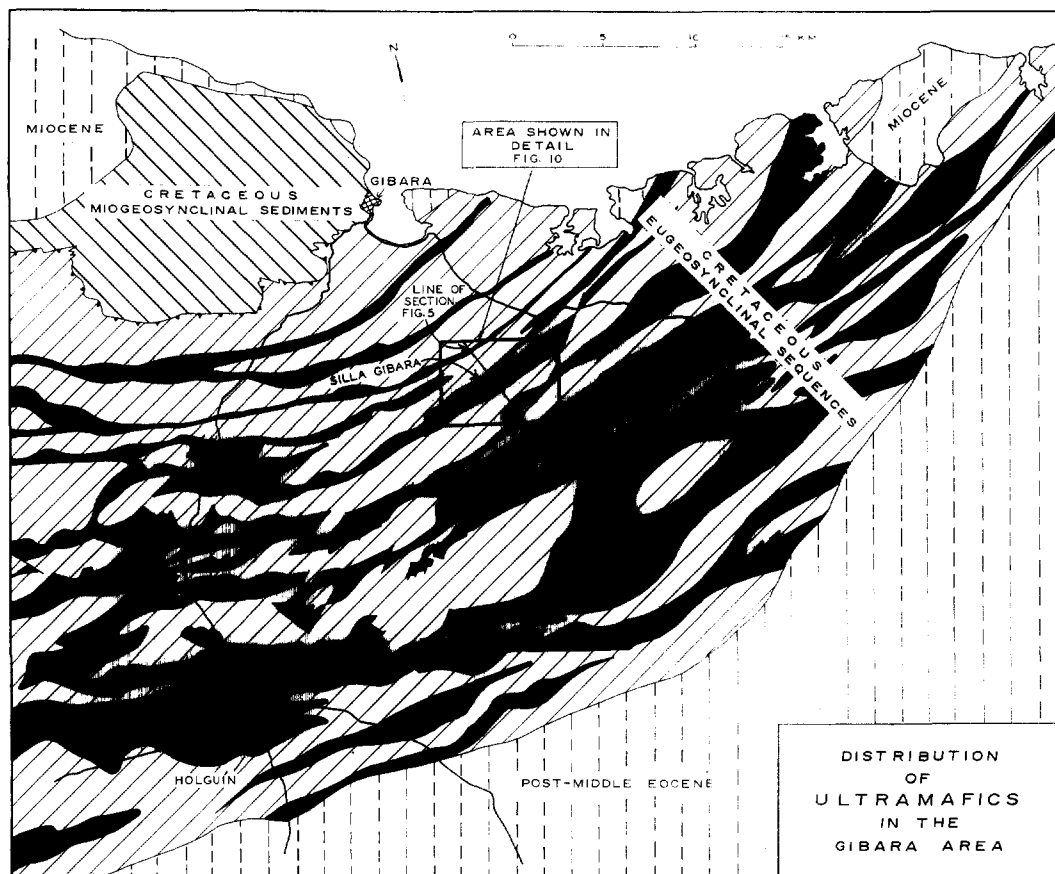


FIG. 3.—Distribution of the ultramafic rocks (shown in black), Gibara area, northwestern Oriente Province, Cuba. Locations of Figure 5 and Silla Gibara (Figs. 5, 7, 10) shown.

steep southward dip for long distances; they parallel the ultramafic trends.

Within the areas which appear to be exclusively ultramafic, small, 1–2-m-wide slivers of nonultramafic rock may be present, and nonultramafic zones contain slivers of tectonically conformable rock up to 20–30 m wide.

Most of the nonultramafic rock sequences are in low depressions between undulating hilly bands of ultramafic rocks, except for massive white limestone bodies which, because of their greater resistance to erosion, tower above both the ultramafic and nonultramafic terranes. In plan view, some of them are about 200–300 m long, and they have an average relief of 100 m. They are separated from each other by gaps of several kilometers, and are aligned in garlandlike rows, parallel with the regional structural trend (Fig. 4).

In volume the limestone is a negligible fraction compared with the other rock types; however, its topographic dominance influenced structural interpretations of the area, and it was considered, together with the ultramafic rock, as the main stratigraphic-tectonic element in the region. In

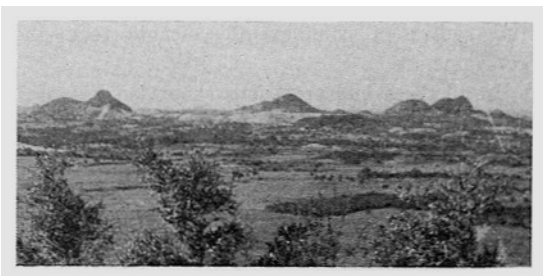


FIG. 4.—Landscape in eugeosynclinal area, Gibara river valley, showing "limestone" mogotes.

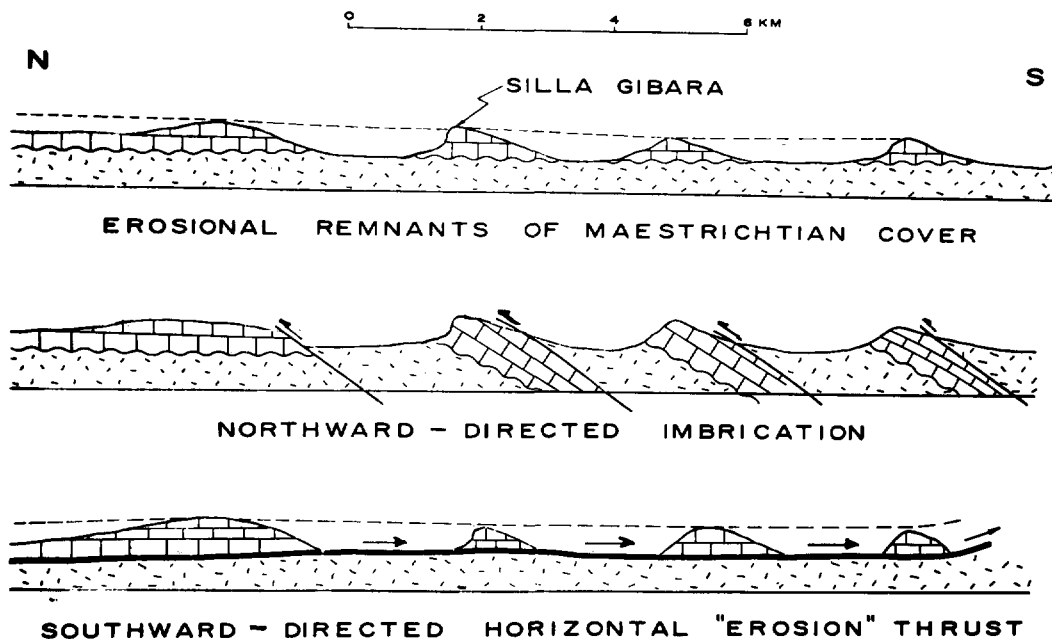


FIG. 5.—North-south cross sections showing previous interpretations of Silla Gibara area. Location of section shown on Figure 3.

the oldest interpretations, the limestone bodies were considered to be erosional outliers of a formerly extensive Upper Cretaceous cover, lying unconformably on an ultramafic and volcanic basement (Hayes *et al.*, 1901) (Fig. 5). Later, these same limestone hills were interpreted as fault blocks in a northward-directed imbrication of what appeared to be a normal sequence of Maestrichtian limestone beds (Fig. 6) overlying unconformably a pre-Maestrichtian sedimentary and igneous complex (Keijzer, 1945; de Vletter, 1946). Subsequently (Thayer and Guild, 1947), the same limestone masses were interpreted to be klippen of a southward-directed horizontal erosion thrust, with a latest Cretaceous limestone plate riding southward over what was thought to be a time-equivalent complex of volcanic rock and conglomerate.

In all three interpretations shown on Figure 5, the ultramafic rocks were believed to be part of a local basement and no definite commitment was made as to their age or mode of emplacement, although each hypothesis implied a pre-Maestrichtian age. A study of the Gibara-Holguín area by the writer suggests that the assumed relations in the previous interpretations may not be valid be-

cause the ultramafic rocks appear to have much more complex relations with the massive limestone bodies.

One of the largest of the hills in the area is in the northernmost tier of limestone hills, about 5 km southwest of the town of Gibara. This is the "Silla Gibara" (Fig. 7), which consists of several isolated limestone masses 150–200 m high, strung out northeastward across an area of 2,000 by 4,000 m. Within the hill mass, representatives of

SYS- TEM	SERIES		EUROPEAN STAGE NAMES USED	
CRETACEOUS	UPPER	GULFIAN	MAESTRICHTIAN	
			SENONIAN	CAMPANIAN
				SANTONIAN
				CONIACIAN
			TURONIAN	
	LOWER	COMAN- CHIAN HUI- LAN	CENOMANIAN	
			ALBIAN	
			APTIAN	
			NEOCOMIAN	
			KLM	

FIG. 6.—European stage names, Cretaceous System, used in this paper.

most other nonultramafic rock types characteristic of the eugeosynclinal belt are found, but about 60 percent of the surface is made up of ultramafic rock.

TYPES OF ULTRAMAFIC OCCURRENCE

In this study no detailed petrographic analysis of the ultramafic bodies is presented, but some of the field relations concerning them are stated briefly.

CRYSTALLINE ULTRAMAFIC ROCKS

Most of the ultramafic rocks in the Silla Gibara area consist of slightly serpentinized peridotite and harzburgite, and very small amounts of anorthosite. The minerals are in the coarse size range, many of them being more than 0.5 cm in diameter; a few amphibole crystals more than 7 cm in diameter are observed. These crystalline ultramafic rocks pass through nearly every grade of serpentinization, particularly along the contact zones and internally sheared areas. Lithologically coherent units are about 40–50 m wide, and can be traced intermittently along the structural alignments for several hundred meters. The internal lineations of each band and contacts between the various types of ultramafic rock are aligned with the main regional structural trend.

The lineations strike northeastward and their dip is steeply southeastward. Generally the degree of serpentinization seems to be inversely proportional to the size of the coherent ultramafic body. The large bands of ultramafic bodies around the Holguín area consist almost entirely of unserpentinized ultramafic rock, whereas the small slivers

of ultramafic rock along the contact zones of the carbonate belt in the north consist completely of serpentine.

Within each of the bodies which appear to be southward-dipping wedges, serpentinization is most pronounced along the "bottom" part of the section, where there is a high degree of shearing, particularly in the smaller serpentine bodies along the northern carbonate belt.

GABBRO

Very hard unweathered gabbro has been found within the confines of the ultramafic rocks. Petrographically it seems to be a differentiate from the ultramafic masses, and numerous zones of gradation between the ultramafic rocks and the gabbro are observed. Where the internal lineation of the ultramafic rocks is pronounced, the conformity of the gabbro is clear and no cross-cutting gabbro can be observed. In larger persistent ultramafic bands, the gabbro is found along the southern flanks of the band. On the basis of the southward-dipping internal lineations, it can be assumed that the gabbro lies on "top" of the ultramafic rocks.

The gabbro is found only in association with ultramafic rock and nowhere has it been observed to intrude either concordantly or discordantly the nonultramafic sections. The gabbro, therefore, must be considered as part of the ultramafic-rock complex. Although a proper term should be established, such as "gabbro-ultramafic group," only the term "ultramafic rocks" is used herein.

MAGMATIC EXTRUSIVE SERPENTINE

Along the northern flank of the Silla Gibara are serpentine beds several meters wide which contain faint traces of pillowlike structures with variolitic cavities, suggestive of the presence of a highly basic or ultrabasic submarine lava flow. In Habana Province, east of Habana Bay (Fig. 2), more well-defined variolitic serpentine bodies have been found (Charles Ducloz, personal commun., 1956) in association with spilite and siliceous masses; Ducloz's observations seem to support the possible origin of ultramafic rocks as hot extrusive flows.

COLD INTRUSIVE SERPENTINE

Zones of brecciated ultramafic rocks of angular pebble- and cobble-size fragments embedded in a

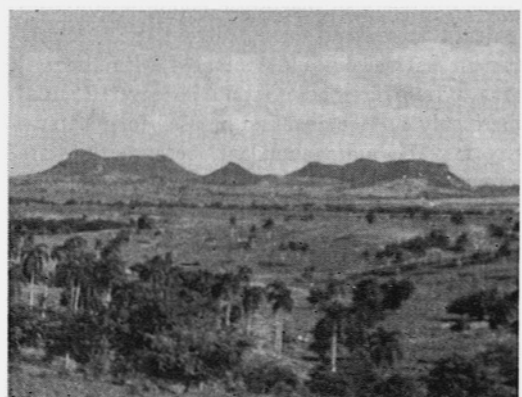


FIG. 7.—View of Silla Gibara. Location shown in Figures 3 and 10.

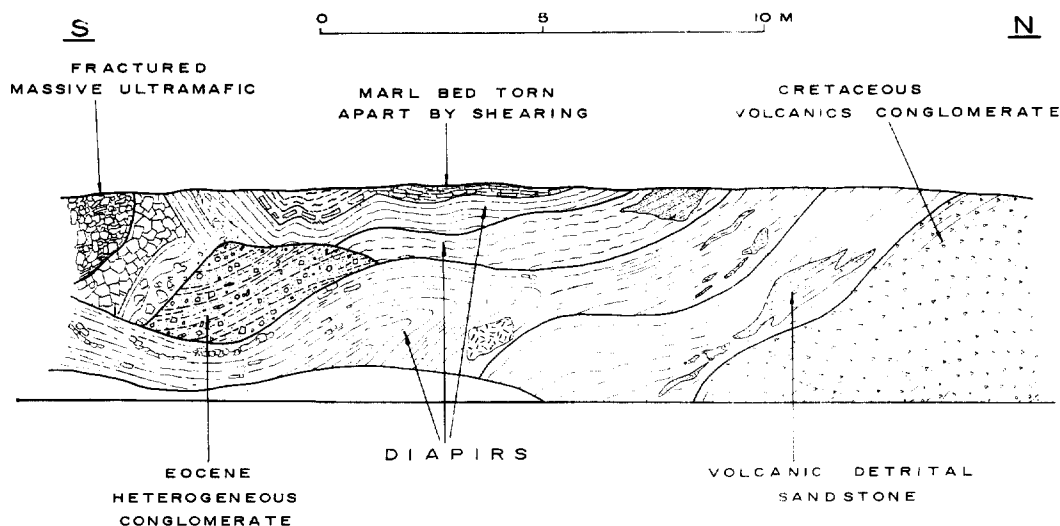


FIG. 8.—Serpentine diapirs, intrusive or extrusive. South-north section from road cut at Km 29, Holguín-Gibara highway, south of Gibara, Oriente Province, Cuba.

pasty serpentine groundmass have been observed along the western flanks of the Silla Gibara; they show the effects of a high degree of shearing. Repeatedly sheared and rebrecciated cobbles within the pasty serpentine mass indicate continued and prolonged movements which may be attributed to recurrent movements along fault zones.

However, within the Eocene conglomerate bodies along the northern and central part of the Silla Gibara, there are several small lenticular ultramafic bodies 0.5–3 m in diameter, which appear to be intruding compacted marl and heterogeneous roundstone and sharpstone conglomerates. The ultramafic bodies consist of a clayey sheared serpentine matrix enclosing fine-grain-size granules of fresh ultramafic minerals. In similar bodies found in roadcuts between the Silla Gibara and the town of Gibara, similar brecciated serpentine crosscuts similar marl and conglomerate and the bodies appear to be vertical diapirs of cold remobilized serpentine (Fig. 8).

COLD EXTRUSIVE SERPENTINE FLOWS

It seems likely that the diapirs could break in places to the surface, possibly along submarine fault scarps, and assume the shape of a mudflow. Such a body is present along the Holguín-Gibara highway, at km 5, where highly sheared serpentine with cobble aggregates of less serpentinized ultramafic rocks contains a few fragments of marl, and the entire layer of serpentine shows

evidence of slumping and surface creep and flow as shown in Figure 9.

SEDIMENTARY ULTRAMAFIC BODIES

Not within the Silla Gibara area, but 3,500 m southeast, conglomerate consisting of ultramafic fragments has been found. The constituents are pebble-cobble-boulder size. The degree of consolidation and diagenetic change is so advanced that without the presence of a few limestone pebbles the sedimentary origin of the rock would not be recognizable (Fig. 9). The beds of ultramafic conglomerate strike parallel with the primary ultramafic masses; their recognition therefore depends on the discovery of diagnostic nonultramafic constituents. In volume these sedimentary rocks appear to be insignificant compared with the primary ultramafic bodies. But in covered areas where only surface float can be used for mapping, they may be more abundant, because they are present in wedges with less erosion-resistant volcanic and volcanic-derived sedimentary rocks.

SUMMARY OF ULTRAMAFIC TYPES

In and around the Silla Gibara area, five different types of ultramafic occurrence have been recognized. Although the primary units, whatever their origin, are greater in areal extent and volume by many orders of magnitude than the other types, the presence of the other groups increases the complexity of the geologic history of the area.

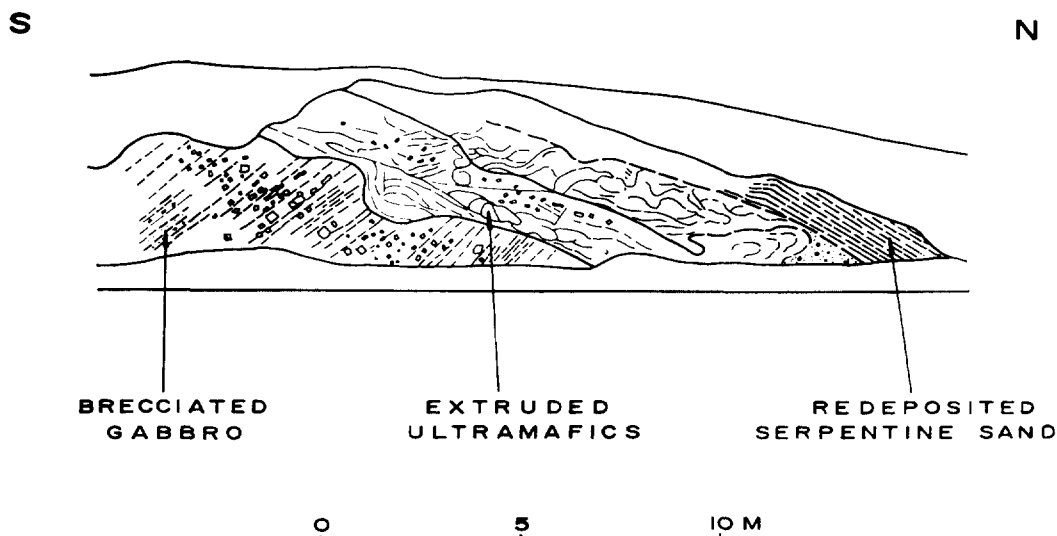


FIG. 9.—Exposures of nonmagmatic(?) emplacement of serpentine. South-north section from road cut at km 5, Holguín-Gibara highway, south of Gibara, Oriente Province, Cuba.

NONULTRAMAFIC ROCK SEQUENCES IN SILLA GIBARA AREA

The nonultramafic outcrops in the Silla Gibara range from meter-size units to bodies more than several hundred meters wide. They appear to either stand vertically or dip steeply southward. They are everywhere separated from each other by ultramafic rocks (Fig. 10). There are no normal sequences and the law of superposition cannot be used in the Silla Gibara area or elsewhere in the eugeosynclinal belt; the tops and bottoms of beds can be determined in very few places.

STRATIGRAPHY

The oldest rock units are thought to be white marble of possible pre-Cretaceous age (Fig. 11). The next unit is a multicolored, thin-bedded, laminated, black to gray calcilutite with abundant *Radiolaria* and primitive *Globigerina cretacea* s.l. of middle Cretaceous(?) age. It is overlain by red andesitic pillow lava with small contorted lenses of globigerinal limestone, possibly of middle or early Late Cretaceous age. Another volcanic agglomerate or pyroclastic unit has been identified tentatively as early or middle Late Cretaceous. Wedges of backreef limestone with an arenaceous foraminiferal fauna of abundant *Coskinolinoides* sp. are thought to be of Cenomanian to Turonian age. The next unit is a sequence of dense, thinly laminated, manganese-stained calcilutite with a pelagic Campanian fauna.

Of approximately the same age but ranging into the highest part of the Maestrichtian is a group of orbitoidal forereef calcarenites. On the basis of the presence of *Sulcorbitoides*, *Pseudorbitoides*, *Rhabdorbitoides*, and *Vaughanina*, four distinct units can be identified, which would date this group from the early Campanian to the late Maestrichtian. The limestone units form the characteristic steep-walled towering hills.

There are also two Eocene(?) conglomerate units—a fine heterogeneous sharpstone conglomerate of possibly post-Maestrichtian age, containing only elements from a nonvolcanic, pelagic, fauna-bearing late Campanian sequence; and a heterogeneous roundstone conglomerate, a detrital suite of ultramafic and basic igneous units, as well as orbitoid-bearing, cobble-size fragments of Campanian to Maestrichtian forereef calcarenite embedded in an undated marl matrix.

Thus, within a distance of less than 2,000 m, facies and age representatives of a geosynclinal sequence ranging in age from possibly late Early Cretaceous through early Eocene, and facies ranging from backreef, reef, forereef, open sea, to deep sea and volcanic, are present. Although there are only one or two representatives of any particular facies and the Cretaceous time span is incompletely represented, it is possible to reconstruct the outlines of a geosynclinal prism. Because the width of the geosyncline may have been at least 100 km, the slivers in the Silla Gibara

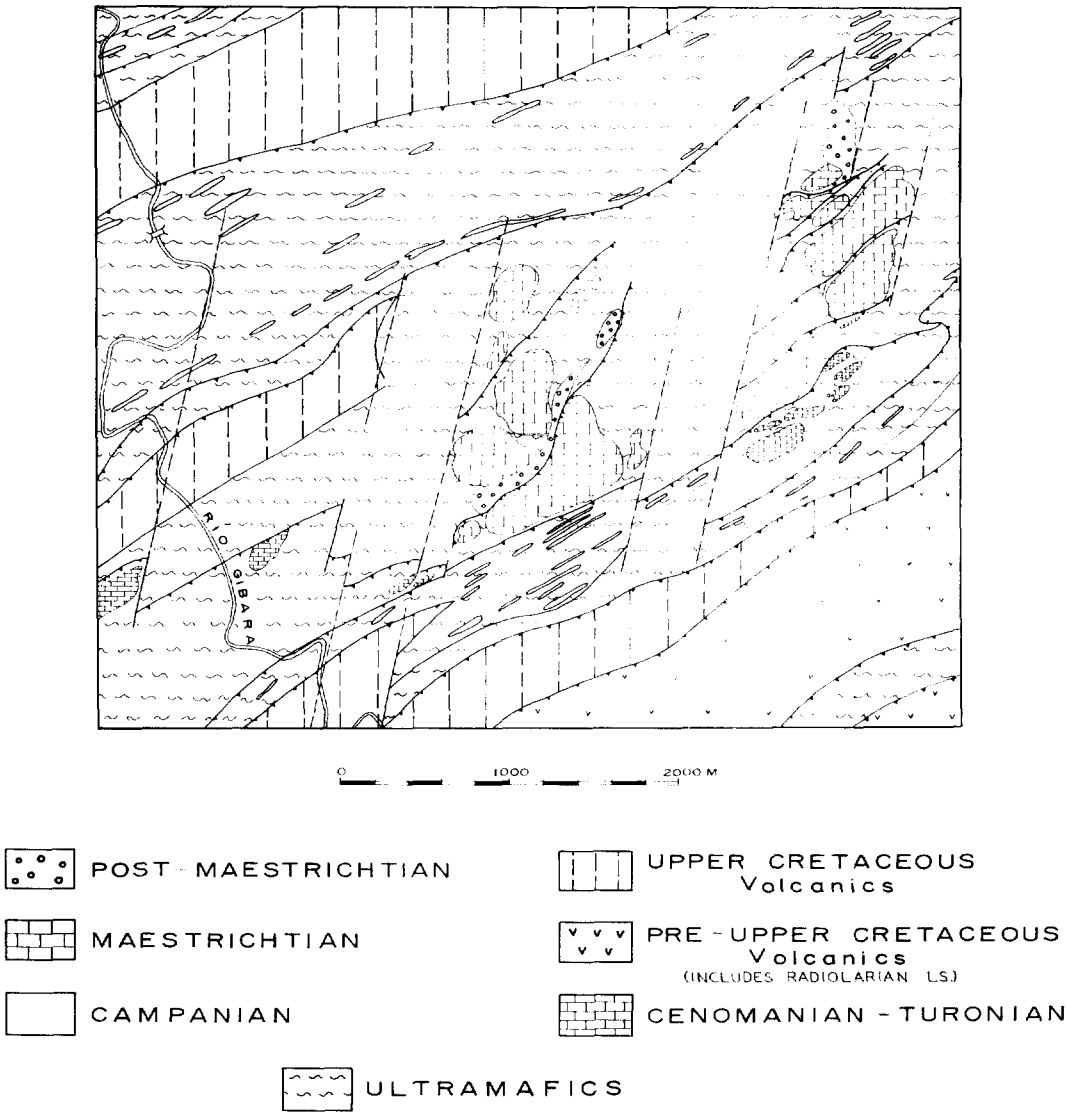


FIG. 10.—Geology of Silla Gibara, northwestern Oriente, Cuba. Location of map area shown on Figure 3.

area are an infinitely small sample of the geosynclinal sequence. The slivers are similar in size to the elements of Alpine *Wildflysch*, but their regional and local structural setting is sufficiently coherent geometrically to require a reasonable explanation of their final emplacement.

STRUCTURE

The nonultramafic rock units are separated from each other by ultramafic rocks in which they appear as a series of wedges, and the nature

of their contact with the ultramafic rocks is not self-evident. Wherever exposed, the contacts have a steep southeastward dip; therefore the nonultramafic rocks lie within the ultramafic rocks as wedges, and are not unconformable above them.

A generalized north-south cross section (Fig. 11) along the northeastern end of the Silla Gibara hill mass begins in the north with a sequence of pillow lava in vertical contact with the ultramafic rocks. With ultramafic rocks intervening, the pillow lava is followed by Campanian pelagic

limestone and Upper Cretaceous graywacke beds with layers of red andesite porphyry and massive, time-equivalent forereef limestone. Between the forereef units, separated by ultramafic rocks, is the post-Maestrichtian heterogeneous sharpstone conglomerate carrying pelagic Campanian constituents.

The Late Cretaceous forereef limestone is followed by slivers of middle Cretaceous *Globigerina*-bearing and radiolarian limestone, and next by slivers of marble. The section continues with late Late Cretaceous forereef units and Cenomanian to Turonian reef and backreef elements. Late Campanian pelagic limestone units are found next at the foot of the southern slopes of the Silla Gibara hill mass, followed by the *Globigerina*-limestone-bearing pillow lava.

Nearly all of the units persist intermittently along the strike. The late Campanian pelagic calcilutite, in particular, can be traced along very clearly defined intermittent bands which are sufficiently persistent to suggest the presence of well-defined, coherent tectonic units.

The juxtaposition of very different facies along narrow linear belts suggests an imbrication of a very thin geosynclinal prism. Subsequent imbrication of the superimposed thrust plates may explain the facies distribution found in a distance of less than 2,000 m. The structural coherence of the Campanian pelagic limestone bodies south and north of the main hill mass of Silla Gibara suggests the presence of a folded thrust plate. The size of the fold of the thrust plate would be only 1,500 m, a size which suggests folding caused by sliding or slumping rather than major alpine horizontal displacements.

Within the Silla Gibara area structural control is not adequate to pursue this type of speculation. However, the setting of the nonultramafic rock sequence within the complex suggests a generally northward-directed imbrication, with contemporaneous facies types in close proximity to each other, and orderly enough to obviate such terms as chaotic, *mélange*, or *Wildflysch*.

CONTACT RELATIONS OF ULTRAMAFIC ROCKS

The nature of the contacts between the ultramafic rocks and the nonultramafic rocks, even in freshly excavated road cuts or quarries, is difficult to evaluate; the nature of contacts traced in weathered rocks and soil is even more question-

able. Besides these uncertain field observations, the unusual characteristics of serpentized ultramafic rocks must be taken into account, such as (1) their excessive mobility under slight stresses, (2) their postulated low intrusive temperatures which do not leave metamorphosed contacts, and (3) their low resistance to abrasion which prevents, except in the most unusual circumstances, preservation of serpentine conglomerate.

The lack of large discordant ultramafic bodies showing a marked crosscutting relation with the country rock leads to the conclusion that most contacts observed are fault contacts.

MAGMATIC CONTACTS

The possibility of a magmatic intrusion of serpentine at the present site in the Silla Gibara area cannot be ruled out on the basis of only contact relations, because several examples have been cited of relatively low-temperature intrusive ultramafic magma (Hiessleitner, 1952; Kündig, 1956) which leaves no contact-metamorphosed boundaries. A discordant intrusion *in situ* is not likely, because no crosscutting contact has been observed. In the case of a discordant intrusion, the entire nonultramafic rock sequence would be a roof pendant in the ultramafic mass, and this does not explain the prevailing structural conformity between the intrusive mass and the country rock.

The possibility of a concordant *lit par lit* injection *in situ* cannot be accepted, because the strata involved range from soft marl to hard marble and are very different in competence. Moreover, most of the ultramafic masses do not suggest a concordant intrusion *in situ*.

In both the discordant- and concordant-intrusion *in situ* hypotheses, the tectonic complications should take place before the intrusion, and thus the time of the intrusion would be Eocene. The reported serpentine detrital rock in Maestrichtian rocks (MacGillavry, 1937) could not be explained unless ultramafic intrusions of two ages were assumed, as suggested but not proved by Schürmann (1935).

The possibility also exists that intrusion was not at the present site of the Silla Gibara area. The lack of evidence of crosscutting contacts in exposed sections rules out a discordant intrusion, but not a concordant intrusion prior to the deformation or the beginning stages of geosynclinal de-

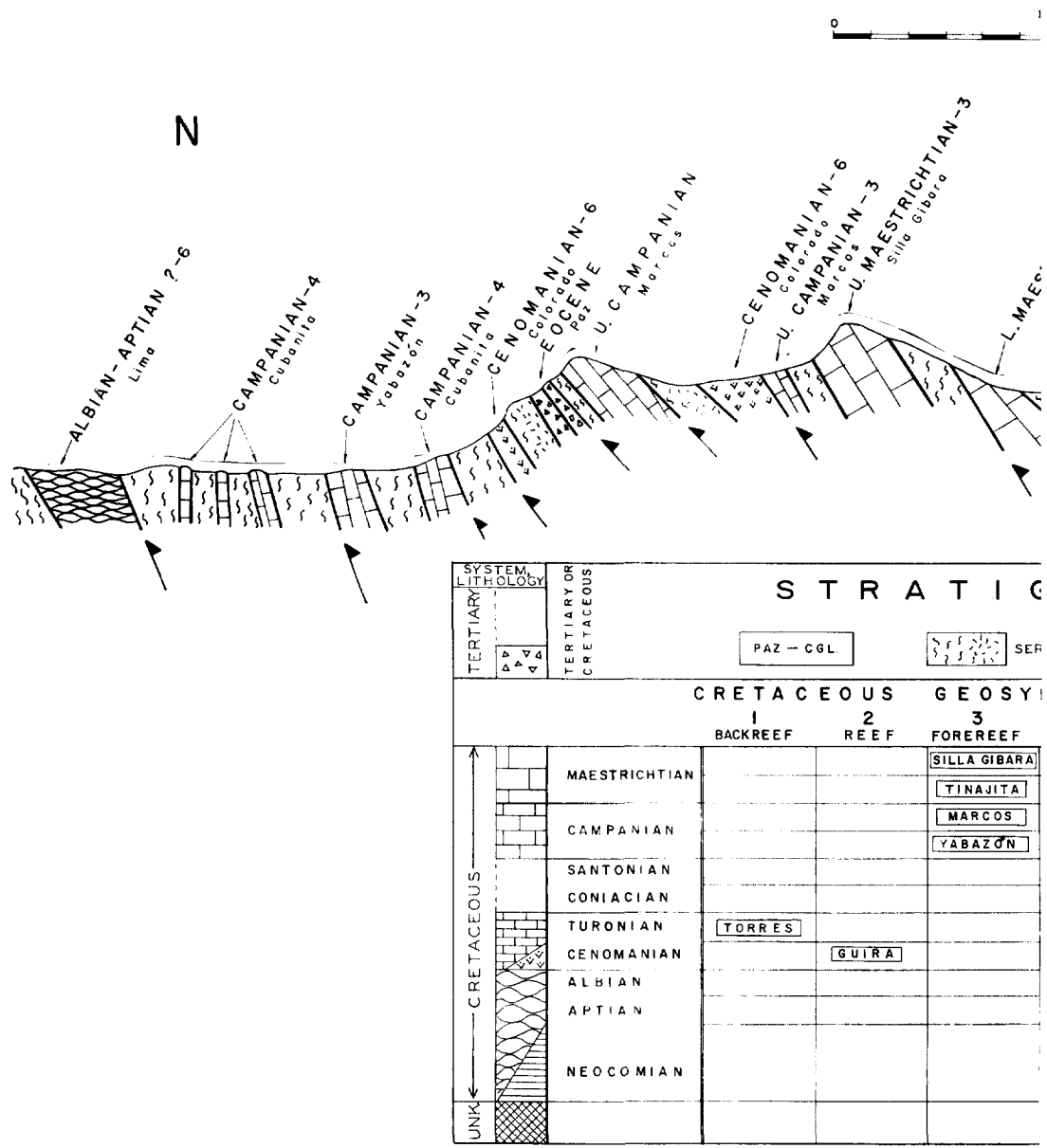


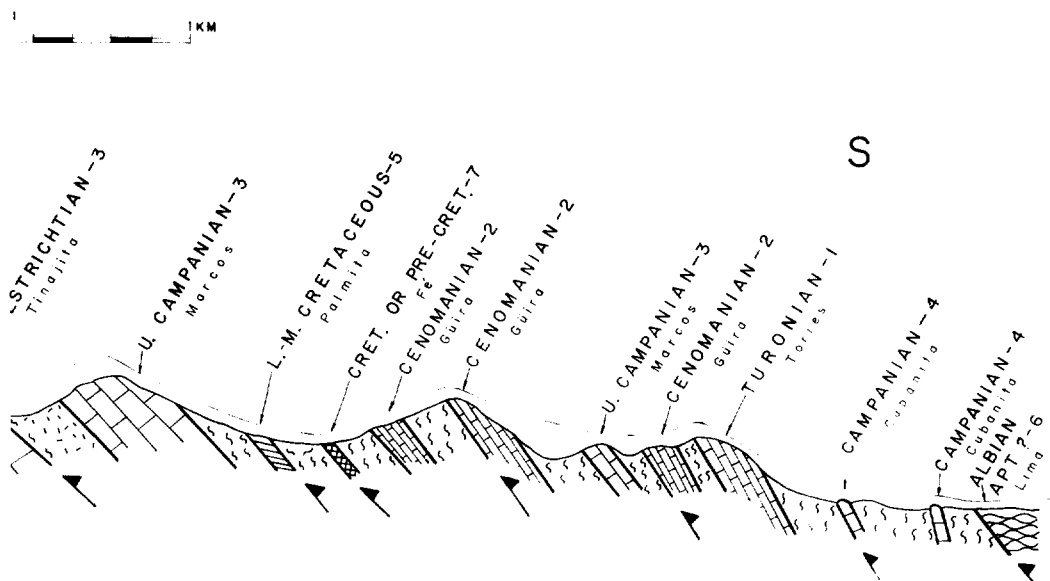
FIG. 11.—North-south cross section and general stratigraphy of Silla Gíbara area.

velopment. Concordant sill-type bodies also require discordant feeders; these, however, may have been faulted out before the deformation of the section, and their absence does not disprove this hypothesis.

If the ultramafic rocks were emplaced as a sill, such an intrusive body had to be sufficiently thick to permit the gravity differentiation of the ultra-

mafic rock from the gabbro (which together have the dimension of a laccolith at least 4,000 m thick as determined by the thickness of the ultramafic gabbro bodies around the city of Holguín).

The intrusions must have taken place before the Maestrichtian and after the Neocomian, on the basis of the first appearance of datable volcanic rocks in possibly Aptian-Albian time or, more



3 R A P H Y

RPENTINE AND GABBRO

NCLINAL ECOLOGIES

4 SLOPE	5 TRENCH	6 VOLCANIC	7 METAMOR.
CUBANITA			
		COLORADO	
		LIMA	
	PALMITA		
			METAMORPHIC FE

Ultramafic rocks shown as gray areas marked by wavy lines.

likely, Cenomanian time. Although the thickness of the pre-Campanian sedimentary sequence in the southern part of the geosynclinal prism cannot be estimated properly, it is not likely to be more than 3,000 m. Because the time of the ultramafic intrusion generally is considered to be middle Cretaceous (Rutten, 1936; MacGillavry, 1937), an even thinner sedimentary or volcanic

column would have been available for the emplacement of a sill whose thickness is greater than that of the host rocks. The thickness of the nonultramafic rocks very likely was much too small for concordant relations to be maintained. An ultramafic sill at least 4,000 m thick, even if injected along the lower boundary of the geosynclinal prism, would have caused considerable de-

formation, particularly because most of the sedimentary strata consist of thin-bedded chert and platy limestone. If the site of the emplacement of the ultramafic sill were the center of the volcanic belt, no "bedding planes" would be likely to be present and the sill would have had to cut pipes, dikes, and feeders of the volcanoes; a relatively cold viscous intrusion hardly would be able to do so. As a very hot melt, it would have incorporated the various rock types encountered along its path, but the chemical composition of the melt would have been changed completely and the confining boundaries would be even less distinct.

It can be argued that the ultramafic rocks have been emplaced into the metamorphic rocks below the geosynclinal sedimentary strata; however, in that case the sill-like emplacement would have had to occur in a sequence of very contorted metamorphic rocks.

In summary, the emplacement of the ultramafic rocks as a large discordant or concordant intrusive body in the present structural setting cannot be proved, and the hypothesis that they were emplaced in the undeformed geosynclinal prism also involves several unresolved problems.

ULTRAMAFIC SUBMARINE LAVA FLOWS

Because the intrusive hypothesis does not seem to account for the present distribution of the ultramafic rocks, and because variolitic serpentine has been observed in the Silla Gibara area, they might be regarded as ultramafic submarine lava flows. For the same reasons as put forth for the intrusive hypothesis, the extrusion could not have taken place at the present site.

The ultramafic rocks must have been formed before Campanian-Maestrichtian time, and in the "volcanic" facies of the geosynclinal area, associated with spilite and radiolarian chert. Both spilite and radiolarian rocks have been found in the Silla Gibara area, but the ultramafic rocks are not found exclusively with them. There is an excessive amount of ultramafic rock compared with spilite—a fact which is curious but which does not necessarily rule out the submarine-flow origin. However, the ultramafic flows must have been sufficiently thick to permit gravity separation of the peridotite from the gabbro and also to cool for a long enough time to allow formation of the extremely coarse crystals. The coarsely crystalline igneous bodies may be explained as later intrusions into the submarine lava, but coarse-grained

units are everywhere structurally conformable and gradational with the fine-grained units.

ULTRAMAFIC ROCKS AS BASEMENT

Several of the contacts could be interpreted easily as erosional contacts if one assumes that the ultramafic rocks and gabbro were exposed as basement during different times within the Cretaceous geosynclinal areas. Within the Silla Gibara hills, the existence of erosional contacts cannot be proved, but their presence cannot be ruled out. It is very likely, for example, that the Senonian to Maestrichtian limestone beds were deposited on ultramafic structural highs, because Maestrichtian strata are known to carry ultramafic detrital constituents. Admittedly some of the contacts are erosional, but this does not establish the mode and age of the emplacement of ultramafic rocks in pre-Maestrichtian sections. The ultramafic rocks have been considered (Flint *et al.*, 1948) to be an intrusion in an old metamorphic sequence on the basis of the presence of metamorphic xenoliths in the ultramafic rocks. This would date the emplacement of the ultramafic rocks before the formation of the Cretaceous geosyncline, and they would then be part of an old basement complex. However, if the ultramafic rocks were part of an old basement, ultramafic detrital material should appear in the Jurassic-Cretaceous column before it does in the Maestrichtian, particularly because several unconformities are known to be present below the Maestrichtian. Perhaps the ultramafic basement became exposed only in Late Cretaceous time; this would explain the late appearance of the ultramafic detrital material.

However, the absence of crosscutting volcanic feeders, necks, sills, and dikes of the middle to Upper Cretaceous volcanic sequences in this ultramafic and metamorphic "basement" is evidence against a pre-Cretaceous age for the ultramafic rocks. Furthermore, if ultramafic intrusives *are* absent in the Cuban segment of the Cretaceous eugeosyncline—which otherwise seems to have all prerequisite elements of a "classic" example—this eugeosyncline would then be exceptional because ultramafic intrusives are characteristic of most of the world's eugeosynclines.

TECTONIC CONTACTS

Faulting.—Most contacts in the Silla Gibara area can be attributed to faults—some late normal faults which offset structures toward the

northeast, and others high-angle reverse faults which are part of a regional northward-directed imbrication. However, faulting cannot account for the original emplacement of the ultramafic rocks. Nor can faulting explain the engulfment of the nonultramafic rocks with the retention of a certain degree of structural unity as shown on the maps (Figs. 2, 3). The nonultramafic rocks appear to "float" in the ultramafic rocks like attenuated sand or cobble beds in mudflows and strung-out rock fragments in salt diapirs.

Intrusive serpentine diapirs.—Because small bodies, 1-20 m wide, of serpentine diapirs can be seen in several exposures in road cuts and quarries in the Silla Gibara area, it may be possible to extend the mechanism to a larger scale, to units 100-1,000 m wide. In these units, bodies of un-serpentinized ultramafic rock may be carried along, as well as slivers of limestone 10-100 m in diameter, just as the cobbles and boulders are carried in the smaller scale serpentine diapirs. Several of the contacts in the Silla Gibara area show that the ultramafic rocks are highly brecciated and that they have the characteristics of flow structures.

Hydration and a small amount of stress may begin the flow of the serpentine surrounding the un-serpentinized ultramafic fragments. The mobility of the entire mass may be nearly that of gypsum or salt, or that of sedimentary rocks under very high confining pressure, as seen from some of the small-scale examples, or "models," in the field. The intense brecciation of the ultramafic rocks may be partly the result of the volume change during the initial process of serpentinization, and also of brecciation during the flow and deformation of the serpentine body.

The differential mobility of the serpentinized ultramafic rocks is a result of the extreme contrast in competence between crystalline ultramafic rocks and massive limestone bodies. In disturbed layers of interbedded sand and soft clay, clay "diapirs" will pierce the sand layers; similarly, in imbricate structures of serpentinized ultramafic rock and hard limestone, the serpentine will be squeezed out and, with added compression, may even tear the confining tabular limestone and other rock sequences to pieces.

Diapiric ultramafic rocks which may have extruded from the ultramafic soles of thrust plates would explain the engulfing of various units and account for the small-scale imbrication of the

many varied rock units in the Silla Gibara area, but not for the mode and age of emplacement of the primary ultramafic rocks.

SUMMARY OF CONTACT RELATIONS

In summary, the relations between the ultramafic and the nonultramafic rock sequences in the Silla Gibara area and in the entire eugeosynclinal belt in northwestern Oriente cannot be explained by one mechanism. A combination of several mechanisms may yield a more probable explanation, but without a review of the history of the regional tectonic setting, such speculation cannot be carried far.

SUGGESTED MODES OF EMPLACEMENT OF ULTRAMAFIC ROCKS

The predominance of "primary" ultramafic rocks in northwestern Oriente requires an extensive magmatic source, which may be the subcrustal peridotite layer (Hess, 1954). Their emplacement into the Cretaceous geosyncline without an intrusive mechanism gives rise to a paradox.

The space problem in this paradox, however, is not as formidable as it might first appear. Recent studies have shown that the peridotite layer is only 12 km below sea level in the Caribbean Sea and 9 km in the Atlantic (Worzel and Shurbet, 1954). Therefore, in a deformed part of the oceanic crust, such as a trench, the subcrustal layer may be exposed along fault scarps, as in the Mid-Atlantic Ridge (Shand, 1949; Hess, 1954), or at least may become involved relatively easily and exposed along the deformed flanks of a trench during successive disturbances.

In the Puerto Rico Trench (Fig. 1), north of Puerto Rico, where water is 8 km deep and sediments are 6 km thick (Worzel and Shurbet, 1954), the bottom of the trench must be 2 km below the Mohorovicic discontinuity in the Caribbean Sea and 5 km below in the Atlantic Ocean. Because the deformation of the trench involved large-scale faulting (explained by tension and not by downbuckling [Worzel and Shurbet, 1954] of the crust), the peridotite layer may be adjacent to the sedimentary column of the trench. It is known to crop out along the north wall of the trench (Hersey and Chase, 1965).

The Puerto Rico Trench extends east-west and strikes toward the Old Bahama Channel (Fig. 1) westward between Cuba and the Bahama Banks. The large negative gravity anomaly which is cen-

tered along the Puerto Rico Trench can be traced westward and is found, greatly reduced in magnitude, in northwestern Oriente Province and north-central Camagüey Province along the contact between the northern carbonate and southern volcanic belts.

In the same area in northwestern Oriente, the writer has mapped 1,200 m of heterogeneous Late Cretaceous to Eocene sharpstone conglomerate derived from the northern carbonate belt and more than 1,800 m of early to middle Eocene beds of alternating layers of red radiolarian ooze, *Globigerina* limestone, and interbedded coarse heterogeneous conglomerate similar to the deposits found in the Puerto Rico Trench (Ewing and Heezen, 1954).

Geophysical and structural evidence suggests the former presence of a trench just south of the northern carbonate belt in northwestern Oriente, at the present site of the Silla Gibara. This trench, designated here as the "Auras trench" (Fig. 12), in its initial stages may have been part of a broader geosyncline, developing as a result of tension along the contact zone between the southernmost extension of the thinning wedge of the sialic North American continental mass and the much thinner gabbroic layer (ocean crust) of the Caribbean basin (Ewing and Worzel, 1954). The initial deformation may have started during the Late Jurassic in western and central Cuba, and somewhat later in eastern Cuba, because the oldest rock in northwestern Oriente is Early Cretaceous. By middle Cretaceous time, the crust had been sheared along a series of fractures where the greatest stresses were concentrated along the contact zone between the oceanic and continental crust.

After shearing (Fig. 12, sec. 2), the northern sialic limb rose and the southern gabbro layer sank to establish a new equilibrium: a trench formed along the area of break. Along the shear zone, either seawater from above or juvenile water from below entered the peridotite layer and initiated serpentinization. The increase of volume of 25 percent (Hess, 1954) as a result of serpentinization raised the areas south of the southern margins of the broken gabbro layer to, or nearly to, sea level. The northern section of the break was not affected because the weight of the sialic-simatic crust prevented large-scale serpentinization and subsequent uplift. The lack of sedimen-

tary cover along the southern margin of the geosynclinal prism, the shallow water, and the fracturing caused by the downbending of the gabbro crust into the trench must have triggered the volcanic cycle by reduction of pressure and corollary increase in temperature. In the central part of the sheared geosynclinal prism, the 6–8-km column of water, the weight of the sediments and the downdropped segment of the thinning (but considerably thicker than it became subsequently) crustal segment maintained sufficient pressure to prevent the inception of the volcanic cycle in that area.

During the process of volcanism along the southern margin of the trench, large parts of the gabbroic crust must have been "digested" because it must have served as the source of volcanism. The volcanic materials then were redeposited into a deepening trench on the north and the more stable sections on the south; this process constantly reduced the total weight and thickness of the gabbroic crust until the contact area between the gabbro and the serpentinized peridotite was reached (Fig. 12, sec. 3).

At the same time, a state of disequilibrium was reached by (1) the oversteepening of the southern trench wall as a result of the steady deepening of the trench, (2) the uplift of the southern hinge line as a result of continued serpentinization of the subcrustal layer, and (3) the weakening of the crust by the partial digestion of the gabbro by volcanism, which led to a "collapse" of the wall of the trench in a manner similar to the closing of the sides of a deep groove drawn in fluid mud. In the Auras trench, only the southern side "collapsed" and the northern side, except perhaps for a series of normal faults, must have been stable (Fig. 12, sec. 4).

The "collapse" took place along a series of southward-dipping shear zones, cutting deep into the subcrustal layers. The pattern of the lines of failure may have resembled that observed in failing earth embankments. Movement along the shear zones developed into a series of high-angle northward-directed "crustal" thrusts which exposed the original Mohorovicic discontinuity at the gabbro-ultramafic contacts. Wedges of ultramafic rock with gabbro above overrode imbricated segments of the geosynclinal prism.

Because the weight of the "crustal" thrust wedges prevented them from emerging far above

E V O L U T I O N O F "A U R A S" T R E N C H

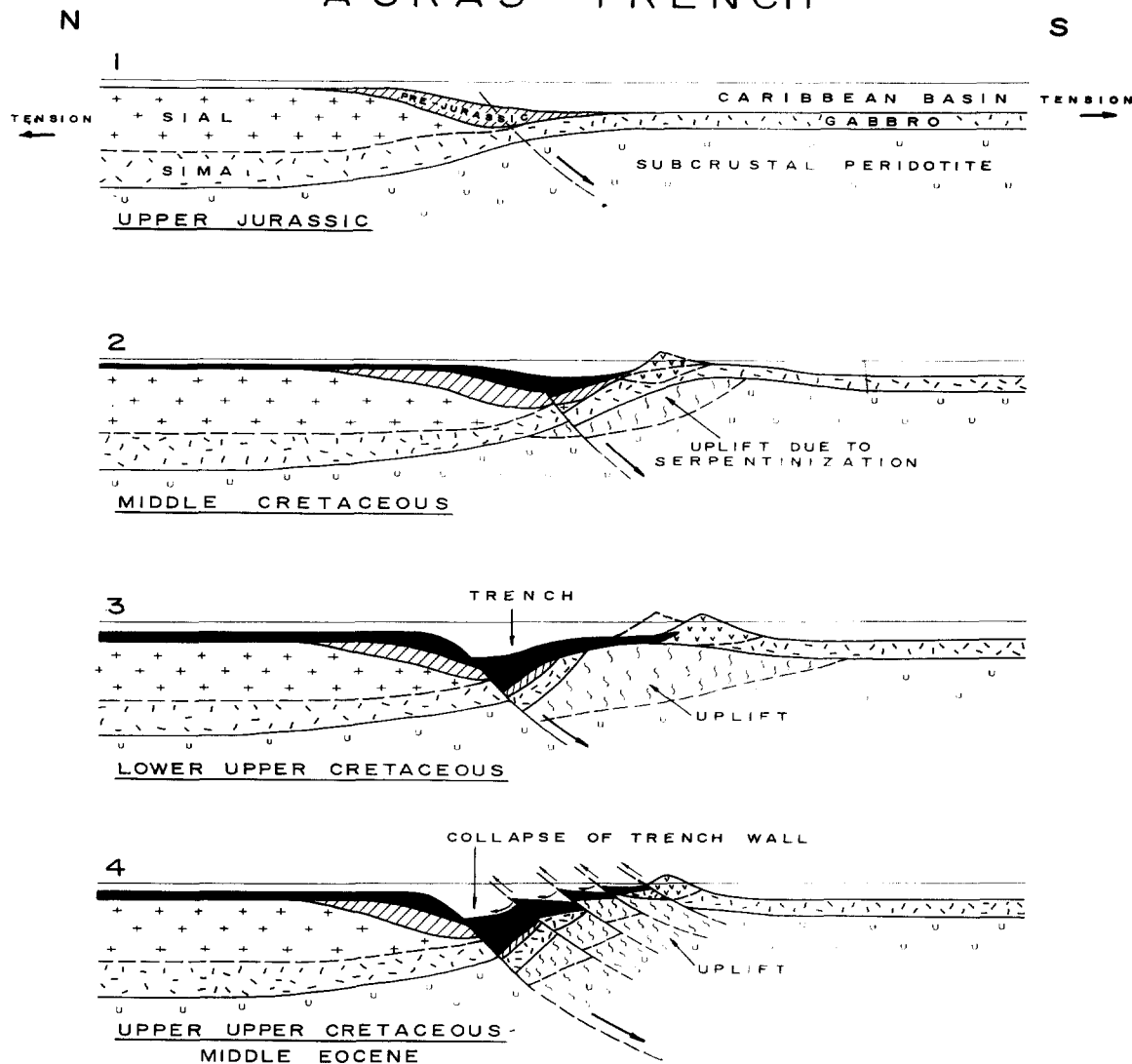


FIG. 12.—North-south sections postulated evolution of Auras trench. Cretaceous geosynclinal prism shown in black.

the sea bottom, they were transformed into a series of flat-lying thrust slices, in which the lower plates acted as temporary buttresses to the overriding higher plates. The steady deepening of the trench and the increased plasticity of the serpentinized ultramafic rocks which served as the soles of the "crustal" thrust wedges greatly facilitated

the piling of the plates along the southern slope of the trench (Fig. 13).

Within each thrust plate the structural coherence of the sedimentary sequences may have remained intact, but normal faulting of the slope of the trench may have led to partial disintegration of the higher plates along submarine fault scarps.

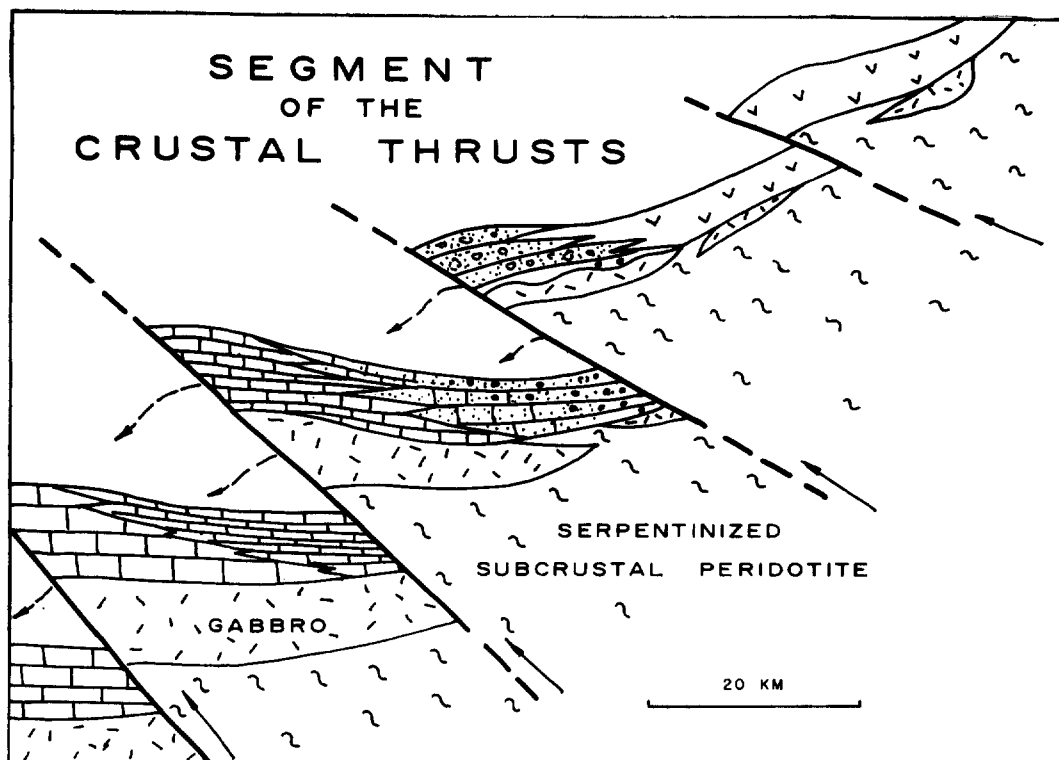


FIG. 13.—Segment of postulated “crustal” thrust wedges along southern slope of Auras trench.

The heterogeneous conglomerate and the conglomeratic ultramafic bodies, as well as the serpentine “mudflows,” may have been formed at that time.

“FLOW” THRUSTS

The lower, undissected thrust plates, however, became more mobile because of the successively more complete hydration of the serpentine along

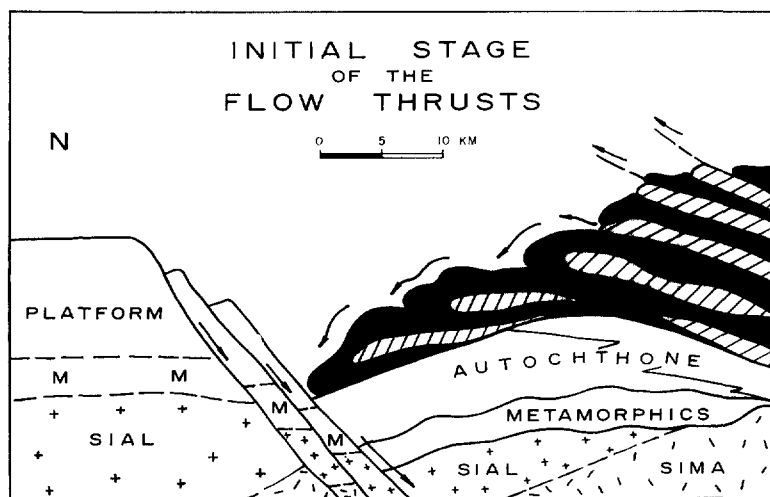


FIG. 14.—Postulated initial stage of “flow” thrusts after collapse of trench. Ultramafic rocks shown in black. M = metamorphic rocks.

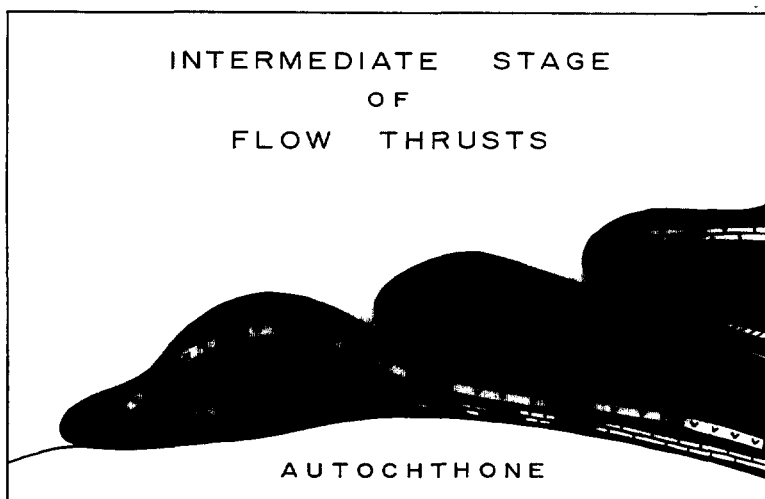


FIG. 15.—Postulated intermediate stage of "flow" thrusts after collapse of trench. Ultramafic rocks shown in black.

the soles and the confining weight of the higher plates (Fig. 14). During sliding, some of the plates were thrown into recumbent folds only 1 or 2 km in diameter. The serpentine within the folds, behaving nearly as a fluid, pierced the cores of the

isoclinally folded plates, tore and separated the strata into thin slivers, and strung them out in relative order (Fig. 15). The movement in the final state of the very mobile serpentine can be characterized as a "flow" thrusting similar to the types

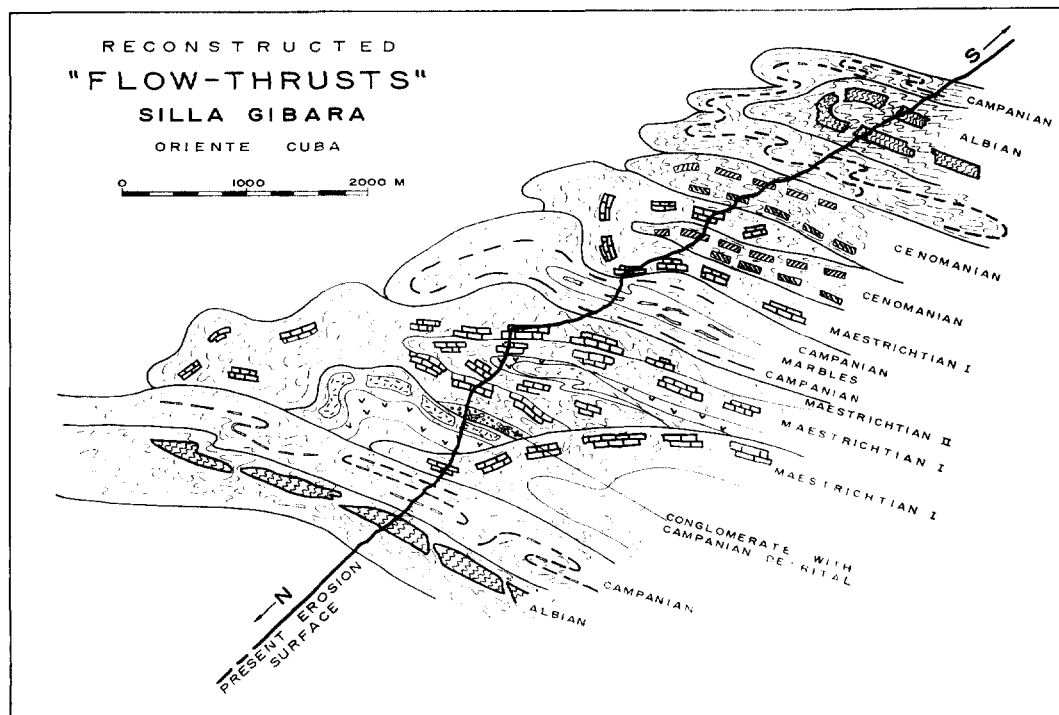


FIG. 16.—North-south reconstructed section of "flow" thrusts in Silla Gibara. Ultramafic rocks shown by wavy lines.

demonstrated in scale-model experiments by Bucher (1956). These "flow" thrust sheets were piled on top of each other at the bottom of the trench in approximately the manner shown in the reconstituted cross section of the Silla Gibara area (Fig. 16).

SUMMARY

Although the early phase of the postulated sequence of events cannot be documented adequately within the scope of this paper and therefore may be open to question, the intrusive origin of the ultramafic rocks has been set aside in favor of an amplified tectonic interpretation. The hypothesis presented relies on the "tensional" origin of oceanic trenches, as suggested by Worzel and Shurbet (1954), and on the early serpentinization of the subcrustal peridotite layer, as suggested by Hess (1954). The sequence of events otherwise is based on (1) the transformation of a geosynclinal depression into a trench, (2) the tectonic evolution of the trench, (3) the "digestion" of part of the gabbro crust by volcanism, and (4) the extreme structural mobility of serpentine under stress.

The tectonic interpretation of the ultramafic rocks does not rule out the possibility of *bona fide* magmatic ultramafic intrusions along "structurally" rather than "stratigraphically" concordant planes; however such bodies have not been observed in northwestern Oriente.

If the sequence of events is valid, the emplacement of the ultramafic rocks into the Cretaceous geosyncline in northwestern Oriente may have taken place as follows:

1. Tension at the contact zone between the oceanic and continental crust, and inception of a geosynclinal depression in Early Cretaceous time;
2. Failure of the crust and formation of a trench in middle Cretaceous time;
3. Concurrent serpentinization of the oceanic segment of the subcrustal layer and partial digestion of the gabbro of the crust by volcanism;
4. "Collapse" of the southern trench wall along a series of high-angle, northward-directed "crustal" thrusts involving the partly intact gabbro layer and underlying serpentinized ultramafic rock;
5. Transformation of the "crustal" thrust wedges into horizontal thrust slices and their partial disintegration along submarine fault scarps; and
6. Continued basinward sliding of the lower intact thrust plates and their final destruction by very plastic serpentine "flow" thrusting.

CONCLUSION

In conclusion, the unserpentinized ultramafic units in the Silla Gibara area and in northwestern

Oriente may be tectonic slivers of the original crust emplaced during a protracted orogenic process extending from the middle Cretaceous into the late Eocene. Most contacts observed in the Silla Gibara are "fault" contacts (*sensu latu*) of a complex sequence of "crustal" thrusts, "gravity-thrust" slices, and "flow" thrusts in a northerly direction, during the operation of which the ultramafic rocks had a paramount role. The ultramafic rocks, therefore, are not only an integral part of the Cretaceous orogenic cycle in northwestern Cuba, but also may have been one of the major factors in its development. At first, evolution of the ultramafic rock into serpentine supplied the stresses for the uplift of the confining gabbroic crustal layer and led to the destruction of the latter by volcanism; subsequently the serpentinized ultramafic rocks served also as carriers of thrust plates and finally contributed to the destruction of the plates by their nearly fluid-flow behavior even at low confining pressures.

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