acta geologica polonica

Vol. 28, No. 1 Warszawa 1978

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Nappe structures in the Sierra de Los Organos, western Cuba

ABSTRACT: Sierra de los Organos, western part of the Cordillera de Guaniguanico, Cuba, have been formed at Middle Eocene time, the nappes being transported northwards. Their tectonic style can be characterized by differential displacement of the rock masses forming ultimately partial nappes; subsequent structural inversion of the tectonic units relative to their original position; and zonation of tectonic deformations. Three lineation types have been recognized, representing different deformation phases. The oldest lineation type occurs within metamorphosed units. It may be related to metamorphic processes acting previously to the nappe overthrusting toward the north. The main lineation occurs in all tectonic units and resulted from the main overthrusting phase. The youngest lineation has originated after the main orogenic phase. Among small folds, the northerly displacements occur most commonly although southerly ones prevail in the Alturas de Pizarras del Norte. Nappe-scale units of the Sierra de los Organos reveal features of gravitation structures. Serpentinites and ultrabasic rocks present within the melange zones slid gravitationally down at the final stage of wildflysch sedimentation. They came from another facies-structural zone. Sedimentary basin of the Sierra de los Organos represented the southern part of Cuban orthogeosyncline, south to Zaza eugeosynclinal zone. During the main orogenic phase, tectonic units of the Sierra de los Organos were thrust over Zaza zone which may have been already folded during the Late Cretaceous or at the Cretaceous-Paleogene boundary. A subduction zone occurred probably in the southern part of leptogeosyncline and the northern part of Cuban eugeosyncline. Rotations and displacements along the Caribbean faults have resulted from differential displacements of the North and South American continents toward the west.

INTRODUCTION

Since 1971 to 1975, the present author participated in geological mapping (scale 1 : 250,000) of Pinar del Río Province, Cuba. Actually, she has mapped the central part of Sierra de los Organos, western Cordillera de Guaniguanico (*cf*. Fig. 1). By the way, tectonic mesostructures were also investigated. These data are analysed in the present paper.

The study has been accomplished due to a cooperation of the Polish Academy of Sciences and the Cuban Academy of Sciences.

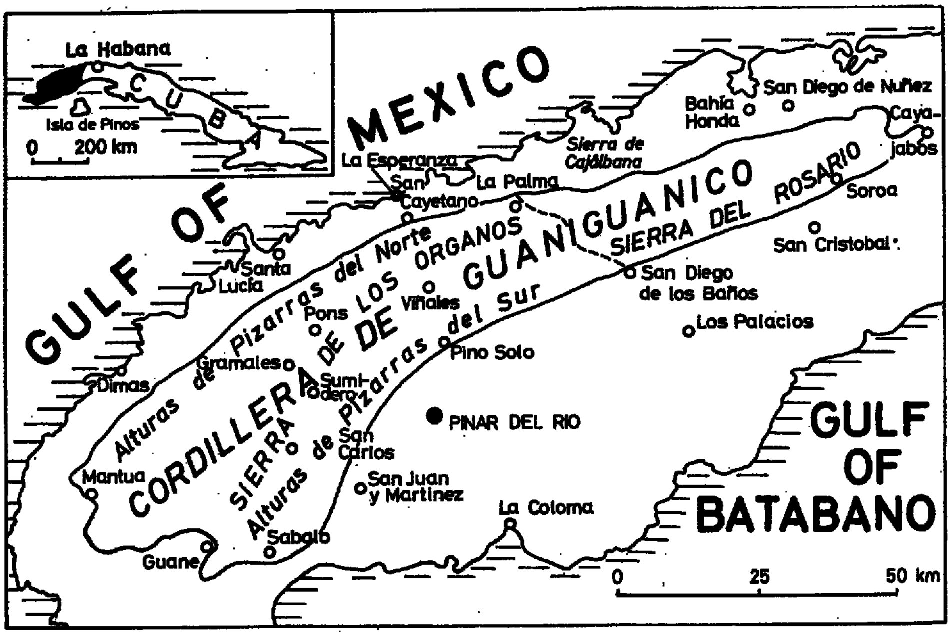


Fig. 1. Geographic setting of the Cordillera de Guaniguanico in Pinar del Rio Province (marked black within the inset)

OUTLINE TECTONICS OF PINAR DEL RÍO PROVINCE

GENERAL REMARKS

Tectonic units of Pinar de Río Province make part of the Greater Antillean orogenic system formed during the Tertiary. The main orogenic phase took place at Middle Eocene time (Khudoley 1967) although early orogenic movements started at Middle Cretaceous time in the Cuban geosyncline.

Four facies-structural zones (Fig. 2) have been distinguished in Pinar del Río Province (Pszczółkowski & *al.* 1975); *viz.* Guaniguanico, San Diego de los Baños, Bahía Honda, and La Esperanza zones.

The southern border of Guaniguanico zone (up to 45 km wide, up to 160 km long) coincides with a major dislocation of the fault of Pinar seen clearly in the area topography. The northern border appears more complex. In the west, tectonic units of Guaniguanico zone are thrust over La Esperanza zone (Piotrowska 1972, 1974, 1975; Haczewski 1975). In places, steep, vertical faults occur along the contact, making the tectonics very complex. In the east, there are both overthrusts of Guaniguanico units onto Bahía Honda zone and the reverse ones (Pszczółkowski & Skupiński *in:* Pszczółkowski & *al.* 1975). No deep fault has been found at this boundary (Pszczółkowski 1974) as claimed previously (Furrazola-Bermúdez & *al.* 1964, Judoley & Furrazola-Bermúdez 1971). East to the Sierra de Cajalbana, dislocation Consolacion del Norte (*cf.* Furrazola-Bermúdez & *al.* 1964) does not separate the Guaniguanico from Bahía Honda zone but runs within the latter zone

(Pszczółkowski & Skupiński *in:* Pszczółkowski & *al.* 1975). It is unclear whether this dislocation does represent a regional deep fault or but a local disjunction. In the west, it passes into a horizontal overthrust of gabbro-serpentinitic rocks onto Felicidades Formation (Skupiński *in:* Pszczółkowski & *al.* 1975). Structural units of Guaniguanico zone dip eastwards under Capdevila Formation (Pszczółkowski *in:* Pszczółkowski & *al.* 1975). To the west, they are transgressively covered by the Neogene sediments. They have, however, been recognized in boreholes situated at Guanahacabibes peninsula.

San Diego de los Baños facies-structural zone occurs southeast to Guaniguanico zone, with the boundary marked by Pinar fault (Figs 2—3). Its southeastern extent is unknown. One may but claim that its formations occur also in Batabanó Bay (Furrazola-Bermúdez & *al.* 1964). La Esperanza zone constitutes a narrow belt along the northwestern Cuba coast, bordering upon Bahía Honda zone along a tectonic contact north to La Palma. Bahía Honda facies-structural zone stretches along the northern coast of the island up to the eastern boundary of Pinar del Río Province (Figs 2—3).

San Diego de los Baños, Bahía Honda and La Esperanza zones resemble one another in both the facies and stratigraphy, while Guaniguanico zone appears quite different (Pszczółkowski & *al.* 1975).

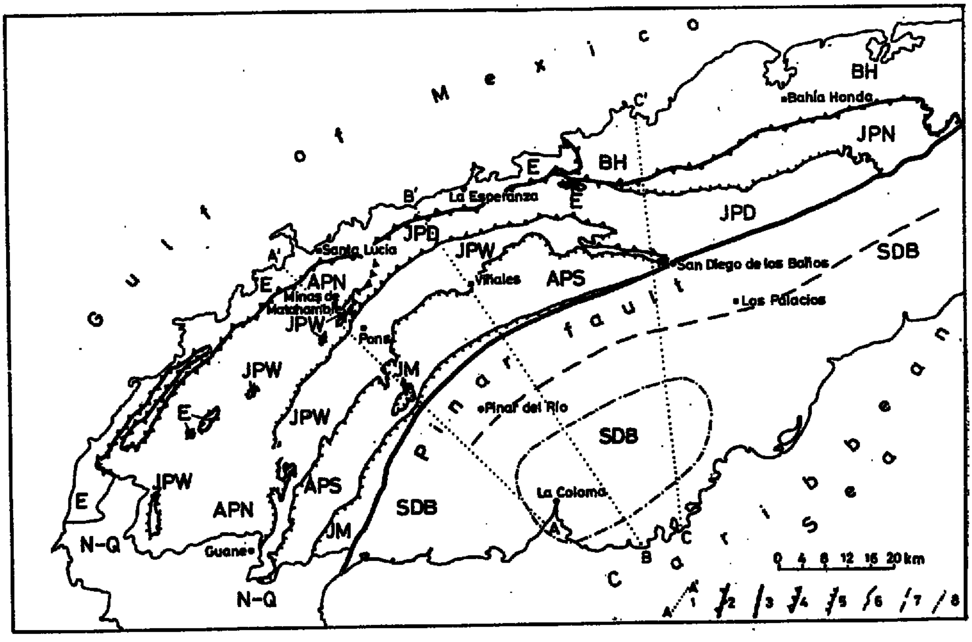


Fig. 2. Facies-tectonic zones in the Pinar del Rio Province

Guaniguanico facies-tectonic zone, *Sierra de los Organos region: JPW* calcareous units of the mogote belt, *APN* Alturas de Pizarras del Norte units, *APS* Alturas de Pizarras del Sur units, *JM* metamorphic units; *Sierra del Rosario region: JPD* southern units, *JPN* northern units, *E* La Esperanza facies-tectonic zone, *BH* Bahía Honda facies-tectonic zone, *SDB* San Diego de los Baños facies-tectonic zone; *N—Q* Neogene-Quaternary

1 cross-section lines as in Text-fig. 6

2 — boundaries of the facies-tectonic zone, *3* Pinar fault, *4* boundary of the regions Sierra de los Organos and Sierra del Rosario, *5* boundaries between the groups of units, *6* boundary between the Neogene-Quaternary and older formations, *7* Los Palacios basin axis, *8* inferred range of La Coloma elevation (at depth of about 900 m b.s.l.)

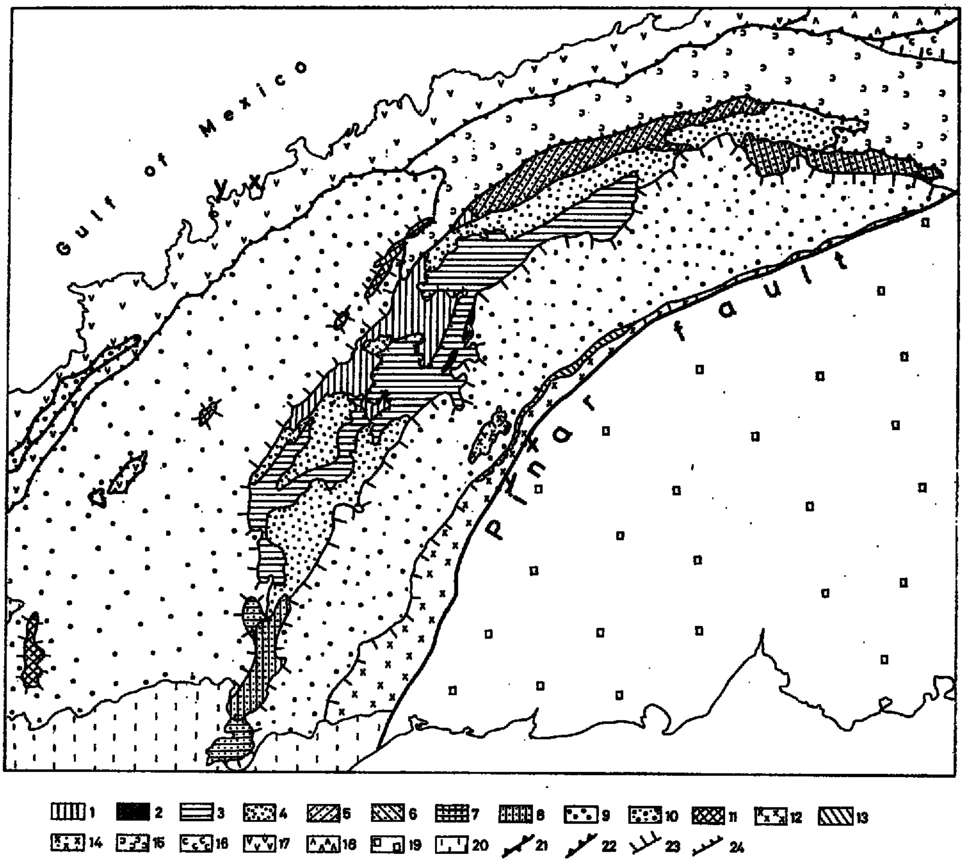


Fig. 3. Sketch-map of the structural units in the Pinar del Rio Province
Guaniguanico facies-tectonic zone:
Sierra de los Organos region: 1 Valle de Pons unit, *2* Quemado unit, *3* Infierno unit, *4* Vinales unit, *5* Ancón unit, *6* La Güira unit, *7* Paso Real unit, *8* Sierra de Guane unit, *9* Alturas de Pizarras del Norte units, *10* Alturas de Pizarras del Sur units, *11* Limonar — La Manaja tectonic window, *12* Pino Solo unit, *13* Mestanza unit, *14* Cerro Cabras unit
Sierra del Rosario region: 15 southern units, *16* northern units
17 La Esperanza facies-tectonic zone, *18* Bahia Honda facies-tectonic zone, *19* San Diego de los Banos facies-tectonic zone
20 Neogene-Quaternary, *21* boundaries of the facies-tectonic zones, *22* boundaries between Sierra del Rosario and Sierra de los Organos regions, *23* boundaries between the groups of units, *24* boundaries between units
Lines of sections (x—x and y—y) in Text-fig. 5 are indicated

The term "Guaniguanico facies-structural zone" has been recently introduced to designate the structures of Cordillera de Guaniguanico (Pszczółkowski & *al.* 1975). It is to replace such older terms as "Pinar del Río zone" (Furrazola-Bermúdez & *al.* 1964), "Pinar del Río tectonic unit" (Judoley & Furrazola-Bermúdez 1971), "northern Pinar del Río" (Khudoley & Meyerhoff 1971), or "meganticlinorium of Pinar del Río" (Pushcharovski & *al.* 1967, 1970).

La Esperanza zone has been recognized as a dictinct facies-structural zone by Danilewski, Haczewski, Piotrowska & Pszczółkowski (*in:* Pszczółkowski & *al.* 1975). Thus far, the formations occurring to the north of Guaniguanico zone were put into "Pinar del Río tectonic unit" (Judoley & Furrazola-Bermúdez 1971), "northern Pinar del Río" (Khudoley & Meyerhoff 1971), or "meganticlinorium of Pinar del Río" (Pushcharovski & *al.* 1967).

San Diego de los Baños and Bahía Honda facies-structural zones can be treated as counterparts of the Zaza zone, Central Cuba (*cf.* Hatten & *al.* 1958). The latter zone represented an eugeosyncline within the Cuban orthogeosyncline (Khudoley & Meyerhoff 1971). There is Las Villas facies-structural zone north to Zaza zone; it represented a marginal elevation (Khudoley 1967). Its northern part called Camajuaní zone (Ducloz & Vuagnat 1962, Meyerhoff & Hatten 1968) made part of a miogeosyncline within the Cuban geosyncline.

GUANIGUANICO FACIES-STRUCTURAL ZONE

Guaniguanico facies-structural zone exhibits considerable overthrusts. The nappe-scale units involve formations ranging in age from the Early or Middle Jurassic to Early Eocene. These formations constitute the lower structural stage. The post-orogenic stage consists of the Neogene formations. This stage starts with Paso Real Formation (Miocene) transgressive relative to Guaniguanico units. The Neogene strata are exposed in Guane area, eastern Pinar del Río.

Furrazola-Bermúdez & *al.* (1964) claimed that the Cordillera de Guaniguanico constituted an intrageanticline within the Cuban geosyncline. Some other authors claimed that an "oceanic trough" occurred in this area at Cretaceous to Early Paleogene time (Iturralde-Vinent 1975). The area occupied today by the Cordillera was also treated in terms of an anticlinorium cut by several deep faults (Vologdin & *al.* 1963, Abakumov & *al.* 1968, Judoley & Furrazola-Bermúdez 1971, Khudoley *in*: Khudoley & Meyerhoff 1971). Such an interpretation has, however, not been confirmed by more recent investigations (Piotrowska *in*: Pszczółkowski & *al.* 1975).

The section of Guaniguanico facies-structural zone starts with clastics of San Cayetano Formation (?Lower Jurassic to Oxfordian). In fact, these are the oldest sediments in Cuba. They are exposed in allochthonous tectonic units detached probably from their root zones. Similar but metamorphosed sediments occur also in Isla de Pinos and Trinidad units, Las Villas Province (Millán 1972, Somin & Millán 1972, 1974; Somin 1976). The presence of San Cayetano Formation in Guaniguanico zone is among its distinctive characteristics. At Oxfordian time, a carbonate deposition started in Guaniguanico zone. It continued throughout the Late Jurassic and Early Cretaceous and persisted in places up to Late Cretaceous and Paleocene time (Pons and Ancón Formations). Traces of tectonic and volcanic activity appear in the Upper Cretaceous strata thus, marking the onset of the main orogenic phase. Shaly-arenaceous sediments intercalated with breccias are typical of the strata of that age. Melange, that is the wild-flysch of Hatten (1957), has originated during the increasing orogenic movements. It comprises considerable amounts of alien rocks such as serpentinites, ultrabasic rocks, and sporadically acid igneous rocks (Piotrowski 1973, Myczyński & Pszczółkowski *in*: Pszczółkowski & *al.* 1975). The presence of extrusive rocks in the metamorphosed units of Pino Solo and Mestanza (Piotrowski 1973, *in*: Pszczółkowski & *al.* 1975) has an important bearing on the characteristics of Guaniguanico zone.

Two main regions have insofar been distinguished in Guaniguanico zone, different in both the facies and tectonic style although displaying also some common features (Figs 2—3). The southwestern part of Cordillera de Guaniguanico is called the Sierra de los Organos (Nuñez-Jimenez 1965). The northeastern part is formed by the Sierra del Rosario. Both the regions show nappe structure. Guaniguanico nappe units are commonly claimed to have been thrust northwards (Hatten 1957, 1967; Rigassi-Studer 1963; Meyerhoff *in*: Khudoley & Meyerhoff 1971; Danilewski 1972; Piotrowska 1972, 1974, 1975; Pszczółkowski & *al.* 1975). In contrast, Palmer (1945) regarded the nappe units as thrust from the north. Simultaneous overthrusts from both the north and south toward the central zone, *i.e.* the mogote belt, were claimed by Guzik (*in:* Pszczółkowski 1971).

This subdivision of Guaniguanico zone into the regions of Sierra de los Organos and Sierra del Rosario can also be regarded as a structural subdivision. In fact, the units of Sierra del Rosario were previously claimed to be structurally lower (Hatten 1957) or even autochthonous when compared to the units of Sierra de los Organos (Rigassi-Studer 1963). However, validity of such interpretations has been questioned because of the superposition of Sierra del Rosario units (Pszczółkowski *in:* Pszczółkowski & *al.* 1975) .

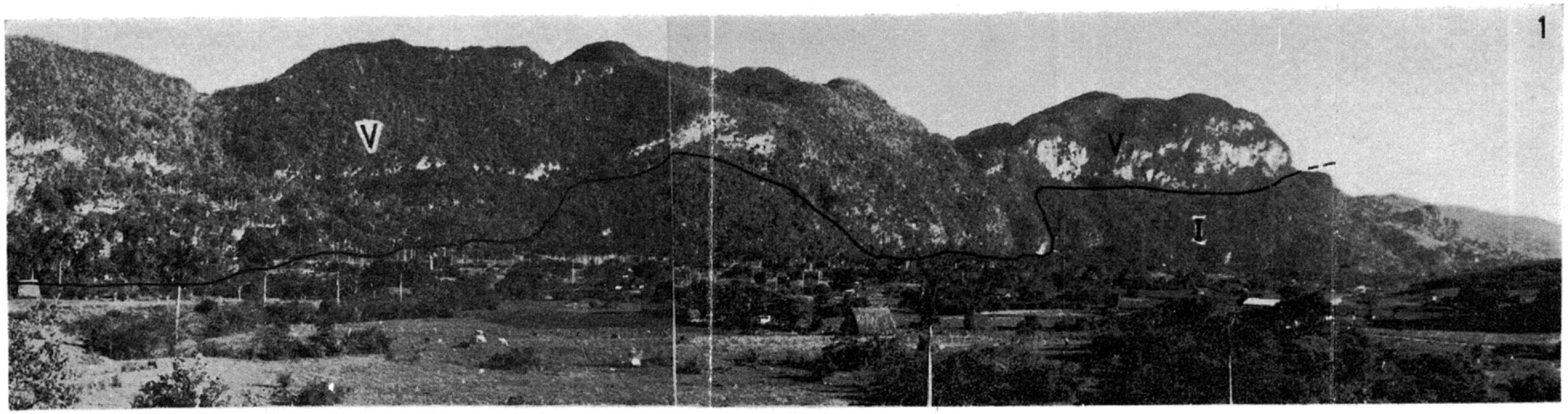
The structure of Sierra de los Organos has been much better studied than that of the Sierra del Rosario. In fact, the "Alpine style" of Sierra de los Oganos has already been recognized by Hatten (1957, 1967) who pointed out to such features as overfolded nappes and overturned folds, the latter being also sligthtly digitated in places. Some shears leading to scale formations were observed by Meyerhoff (*in:* Khudoley & Meyerhoff 1971). Most structures were interpreted by Rigassi-Studer (1963) as shear nappes. However, Piotrowska (1972, 1975, *in:* Pszczółkowski & *al.* 1975) proposed that the nappes have developed due to décollements and subsequent differential displacements; the latter being understood as diversified velocity of the moving of rock complexes along the slightly inclined surfaces of the sliding. Differential displacement velocity among particular structural units of the Sierra de los Organos has resulted in the observed "structural inversion" (diverticulation) of overthrust units. In its turn, a shear nature has been proposed by Pszczółkowski (*in:* Pszczółkowski & *al.* 1975) for the nappes of Sierra del Rosario.

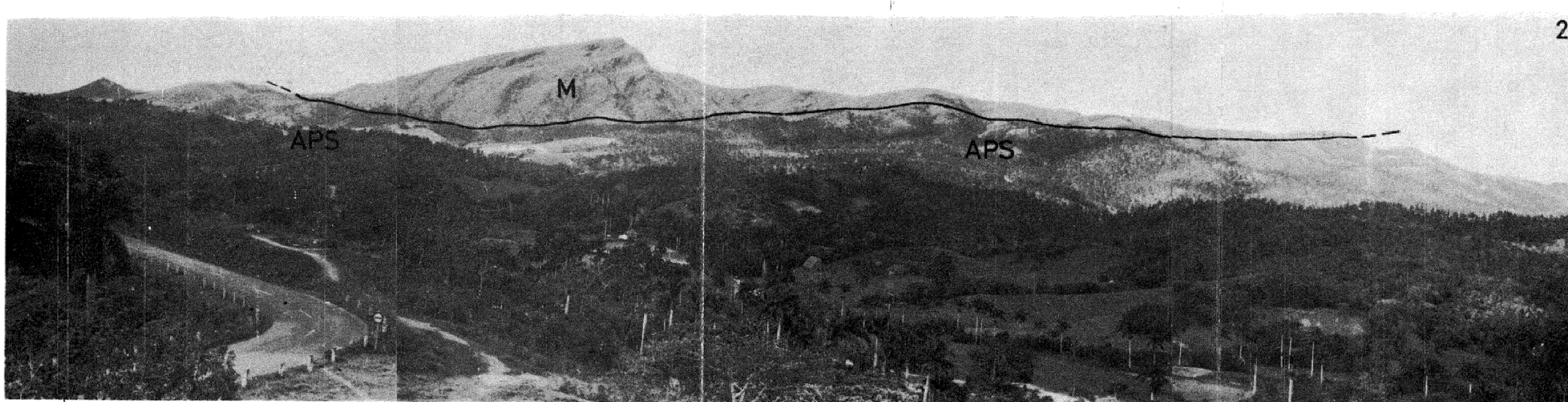
The Sierra de los Organos comprise four groups of structural units (Figs 3—5); each group may have represented a separate nappe at the time following the initial nappe development (Piotrowska *in:* Pszczółkowski & *al.* 1975; *cf.* also Piotrowska 1972, 1975).

Nappe-scale calcareous units of the mogote belt are the lowest tectonic units of Guaniguanico zone (Pl. 1, Fig. 1). Initially, they were transported along with the nappes of Alturas de Pizarras; however, a décollement at the top of San Cayetano Formation and differential displacements resulted in their subsequent separation. Thereafter, the calcareous nappe has become split into smaller nappe-scales. The nappe-scale units of the Alturas de Pizarras del Sur overlie the calcareous units of the mogote belt in the southern Sierra de los Organos. At the initial phases of tectonic transport, they were probably united with those of the Alturas de Pizarras del Norte. The latter ones are thrust over the calcareous units of the mogote belt in the northern Sierra de los Organos. Metamorphosed units occupy the highest structural position in the Sierra de los Organos (Pl. 1, Fig. 2).

In the Sierra del Rosario, Pszczółkowski (*in:* Pszczółkowski & *al.* 1975) has distinguished two groups of structural units (Fig. 6). Southern units are thrust over the nappe-scale units of Sierra de los Organos. They occur also in the north, by the localities La Palma and Río Malas Aguas (D. Danilewski, *pers. comm.*) where they cover partly the units of Alturas de Pizarras del Norte (Pszczółkowski & *al.* 1975). In deformation style, they resemble the units of Sierra de los Organos. They are overlaid by a group of northern units occupying the highest structural position in Guaniguanico zone.

The metamorphosed units of Sierra de los Organos border upon San Diego de los Baños zone along Pinar fault; while from the north, they overlie the nappe--scale units of Alturas de Pizarras del Sur. One may suppose that they have been thrust over the units of both Alturas de Pizarras del Sur and del Norte (Piotrowska 1972, 1975, *in:* Pszczółkowski & *al.* 1975). However, they could also represent the highest nappe of Guaniguanico zone. This would imply either an incomplete





1 — Panoramic view of Sierra Quemado from the Pons Valley; visible is the overthrust of Viñales unis (*V*) upon Infierno unit (*I*)
2 — Panoramic view of Cerro Cabras: metamorphic unit (*M*), preserved as nappic cap, rests upon the units of Alturas de Pizarras del Sur (*APS*)

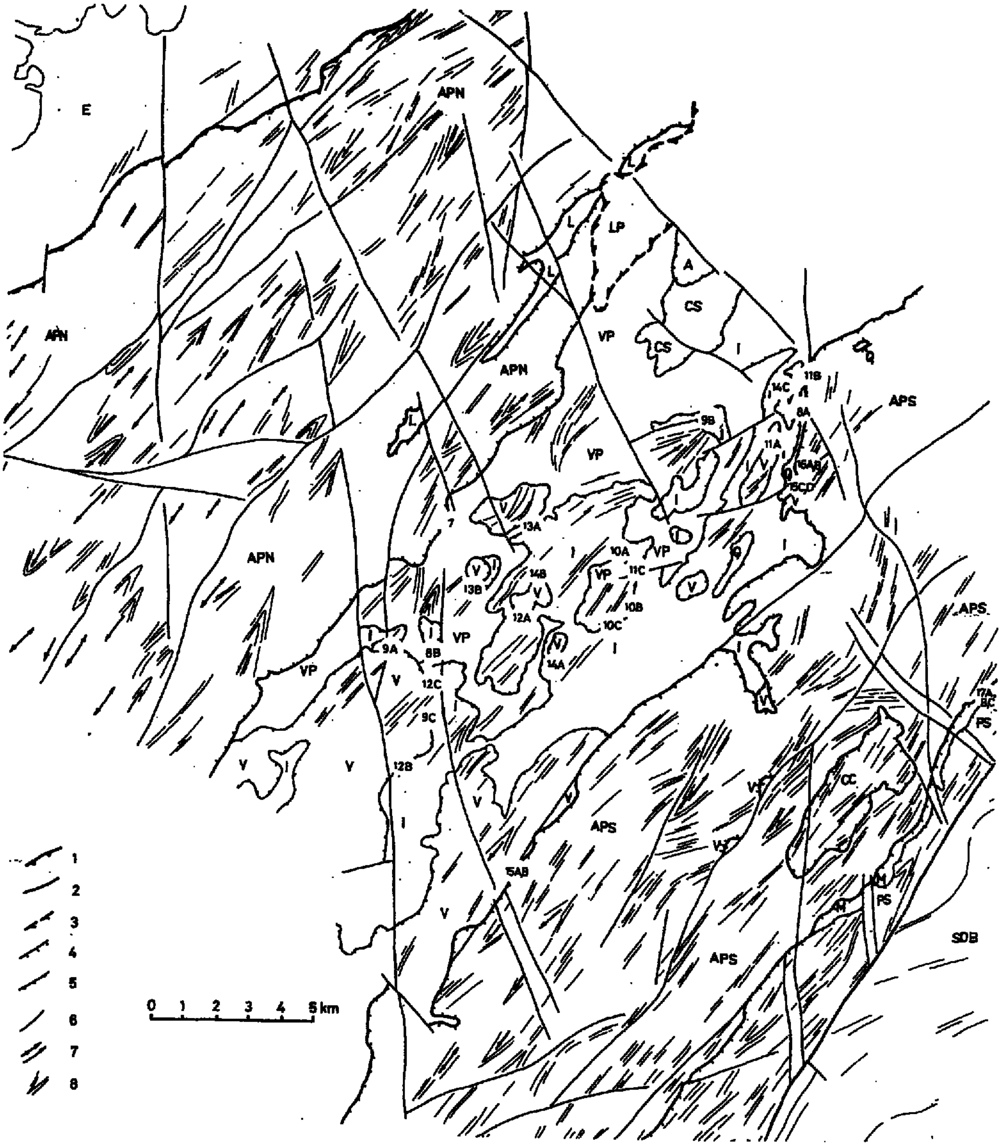


Fig. 4. Tectonic sketch-map of the central part of Sierra de los Organos
E La Esperanza facies-tectonic zone; *SDP* San Diego de los Banos facies-tectonic zone
Guaniguanico facies-tectonic zone, Sierra de los Organos region:
Calcareous units of the mogote belt: *VP* Valle de Pons unit, *Q* Quemado unit, *I* Infierno unit
CS Celadas unit, *V* Vinales unit, *A* Ancón unit, *L* Limonar zone, *APS* Alturas de Pizarras del Sur units, *APN* Alturas de Pizarras del Norte units, *LP* La Paloma unit of Sierra del Rosario region
Metamorphic units: *M* Mestanza, *PS* Pino Solo, *CC* Cerro Cabras
1 boundaries of the facies-tectonic zones, *2* Pinar fault, *3* boundary between Sierra del Rosario and Sierra de los Organos regions, *4* boundaries between the groups of units in Sierra de los Organos, *5* boundaries between the units in Sierra de los Organos, *6* faults, *7* fold axes read from aerial photographs, *8* strikes of beds read from aerial photographs
Location of sections presented in Text-figs 7—18 is indicated in circles

coverage of Alturas de Pizarras del Sur units by the units of Sierra del Rosario, or a shear of the former by the latter ones.

Most structures of the area between La Palma and Río Malas Aguas have usually been attributed to the Sierra de los Organos (Hatten 1957; Rigassi-Studer 1963; Danilewski 1972; Piotrowska 1972, 1974, 1975), except of La Paloma unit assigned to the Sierra del Rosario (Pszczółkowski & *al.* 1975). However, two different interpretations seem plausible at the moment. Firstly, the units of Sierra del Rosario may cover those of the Sierra de los Organos, their southwestern extent being difficult to trace due to post-orogenic erosion (Pszczółkowski & *al.* 1975). Secondly, a group of tectonic units may occur in that area comprising both the nappe-scale units of Alturas de Pizarras del Norte and the southern units of Sierra del Rosario; this group of units may have formed a structural assemblage stemming from a transitory facies zone between the facies of Sierra de los Organos and Sierra del Rosario types (Piotrowska *in*: Pszczółkowski & *al.* 1975).

Were the second interpretation accepted, a threefold subdivision of Guaniguanico facies-structural zone would appear adequate. Then, the nappe-scale units of Sierra de los Organos represent the lowermost structural assemblage. This assemblage comprises the calcareous, Alturas de Pizarras del Sur, and metamorphosed units. Another assemblage is composed of the units of Alturas de Pizarras del Norte and some southern units of the Sierra del Rosario. The northern units of Sierra del Rosario represent still another structural assemblage.

In fact, the tectonic style appears quite different between the southern and northern units of Sierra del Rosario (Pszczółkowski & *al.* 1975), whereas the southern units of Sierra del Rosario appear to be largely analogous to those of the Sierra de los Organos. Nevertheless, more investigations are needed to solve ultimately this problem.

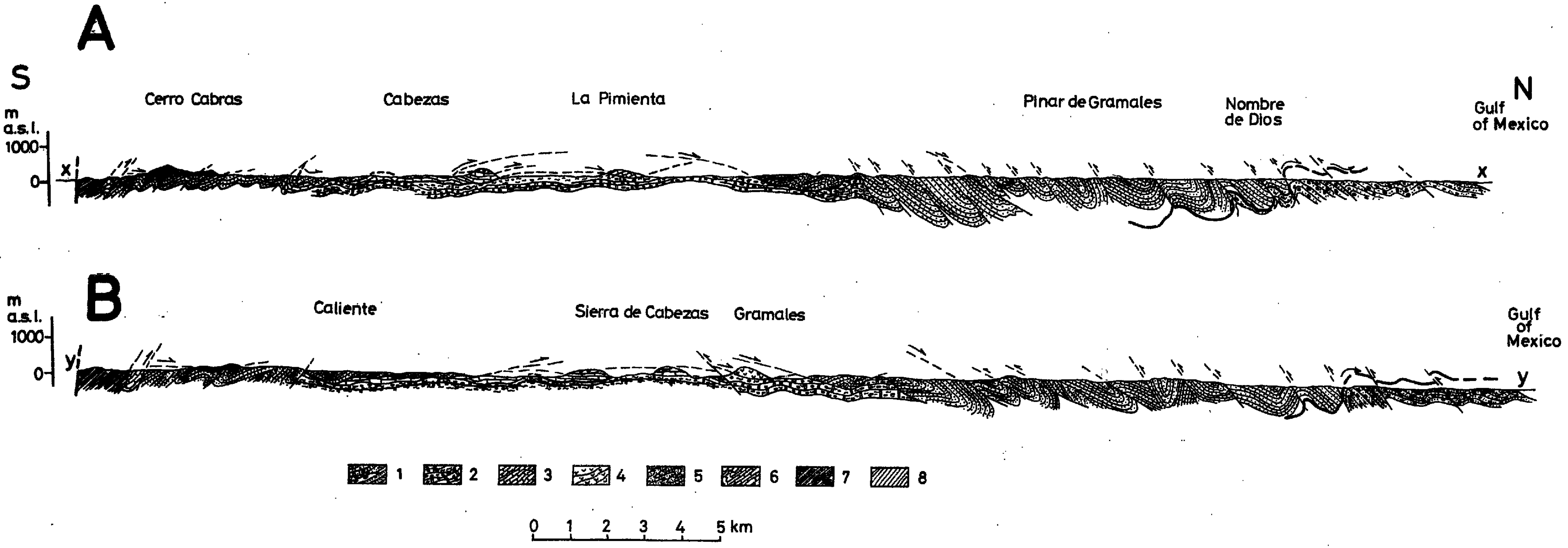
The initial nappes of Guaniguanico zone have probably stemmed from either the area of present-day Batabanó Bay, or an area situated further to the west (with a dextral displacement along Pinar fault taken into account). By the way, the metamorphosed units resemble metamorphic formations of Isla de Pinos (Millán 1972, Somin & Millán 1974) which may suggest that the initial nappe was originally related to the latter island. One may claim that the metamorphosed units have been derived from the southernmost part of Cuban geosyncline, when compared to the rest of Cordillera de Guaniguanico. North to their root zone, the units of Sierra de los Organos, mogote belt, and Alturas de Pizarras del Sur occurred originally. To the east, there was the root zone of the units of Alturas de Pizarras del Norte and southern Sierra del Rosario. The northern units of Sierra del Rosario occupied probably the easternmost position.

SAN DIEGO DE LOS BANOS FACIES-STRUCTURAL ZONE

San Diego de los Baños facies-structural zone comprises the Upper Cretaceous to Neogene sediments. An unconformity occurs between the Upper Cretaceous San Juan and Paleogene Capdevila Formations. The Middle Eocene Loma Candela Formation, the first one deposited after the main orogenic phase, covers transgressively the older formations with an unconformity of about 12°. The Miocene Paso Real Formation is again transgressive relative to the older formations.

According to Meyerhoff (*in*: Khudoley & Meyerhoff 1971), the Cuban orthogeosyncline was formed at Tithonian time. However, Pszczółkowski (*in*: Pszczółkowski & *al.* 1975) assessed that the early phase of geosyncline formation took already place during the Middle Jurassic. At Cretaceous time, calcareous sediments were

Sections in the central part of Sierra de los Organos (for location see Text-fig. 3)



1 La Esperanza facies-tectonic zone
2—8 Guaniguanico facies-tectonic zone: *2—4* calcareous units of the mogote belt (*2* Valle de Pons, *3* Infierno, *4* Viñales), *5* Alturas de Pizarras units, *6—8* metamorphic units (*6* Mestanza, *7* Cerro Cabras, *8* Pino Solo)

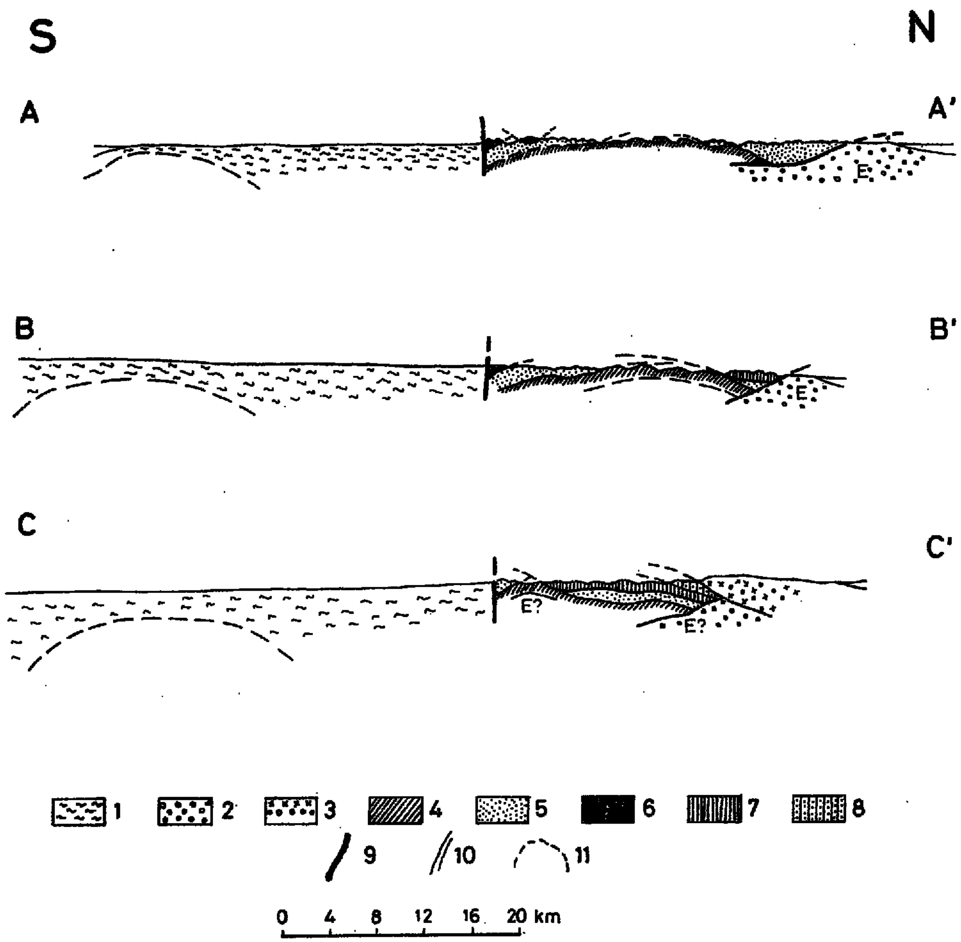


Fig. 6. Sections through the Pinar del Rio Province (*cf.* Text-fig. 2)
1 San Diego de los Banos facies-tectonic zone, 2 La Esperanza facies-tectonic zone, 3 Bahía Honda facies-tectonic zone
4—8 Guaniguanico facies-tectonic zone in Sierra de los Organos region (4—6): 4 calcareous units of the mogote belt, 5 Alturas de Pizarras units, 6 metamorphic units, and in Sierra del Rosario region (7—8): 7 southern units, 8 northern units, 9 Pinar fault, 10 overthrusts, 11 La Coloma elevation

deposited in Guaniguanico zone; whereas in Zaza zone, ultramaphic and maphic rocks, aplitic intrusions, breccias, and tuffs were formed (Khudoley & Meyerhoff 1971). In fact, the sediments of San Diego de los Baños zone are quite different from the coeval sediment of Guaniguanico zone. The depocenters were probably rather distant. The present-day neighborhood of these zones can, however, be easily explained by a possible horizontal displacement of some 160—180 km along the fault of Pinar (Piotrowska & Pszczółkowski *in*: Pszczółkowski & *al.* 1975).

San Diego de los Baños facies-structural zone is but poorly known because of the Neogene cover and small number of boreholes. The accessible data do not allow to recognize in detail its tectonics. According to Furrazola-Bermúdez & *al.* (1964), the zone represents a weakly disturbed structure dipping monoclinally southwards, that is toward Los Palacios basin filled with the Tertiary sediments of considerable thickness (Khudoley & Meyerhoff 1971), and elongate along the NE—SW axis.

The borehole data indicate that the top surface of the Lower Eocene and/or Cretaceous strata declines rapidly down. This trend is paralleled by a rapid increase in thickness of the Upper Eocene to Miocene strata. The thickness distribution shows clearly a considerable synsedimentary subsidence of Los Palacios basin (Piotrowska *in:* Pszczółkowski & *al.* 1975). Two structural stages have been distinguished therein, *viz.* the pre-orogenic one (the term refers here to the main orogenic phase) consisting of San Juan, Capdevila, and Universidad Formations, and the post-orogenic one represented by Loma Candela and Paso Real Formations and the younger strata. As judged from rather constant thickness of the Lower Eocene deposits all over San Diego de los Baños zone, Los Palacios basin developed probably during the main orogenic phase and adapted its shape to the older structural trends; hence, it may be conceived as post-orogenic one (Piotrowska *in:* Pszczółkowski & *al.* 1975).

A dome has been ascertained at La Coloma by means of boreholes and geophysical investigation (*cf.* Ducloz 1956). There are basalts and diabases at the top of the dome. Both their age and origin has remained thus far unknown. They can be tentatively related to the Upper Cretaceous rocks; then, their origin would be related to the main orogenic phase. The basalts and diabases are overlaid by the Oligocene and Miocene rocks.

Both the facies distribution (Myczyński & Piotrowski *in:* Pszczółkowski & *al.* 1975) and tectonic structure of San Diego de los Baños zone reflect the geologic history quite different from that of the Guaniguanico. The facies of the Upper Cretaceous San Juan Formation (Myczyński & Piotrowski *in:* Pszczółkowski & *al.* 1975) suggest an unstable sedimentation during increasing orogenic activity. Transgressive contacts and unconformities occurring commonly in the Paleogene strata indicate even more considerable vertical movements. Thereafter, the Middle Eocene transgression (Loma Candela Formation) covered a system of broad folds of small amplitude.

San Diego de los Baños zone may exhibit a nappe structure. Then, the lack of strong tectonic disturbances would indicate that the supposed nappe was a great slab transported under the form of a "board" (Piotrowska *in:* Pszczółkowski & *al.* 1975).

BAHÍA HONDA FACIES-STRUCTURAL ZONE

Bahía Honda zone comprises the Upper Cretaceous to Paleogene strata beginning with Felicidades Formation of the Cenomanian to Campanian age. Felicidades Formation is composed of limestones, shales, cherts, tuffites, andesitic porphyrites, and sandstones; the total thickness is about 1400 m. It is overlaid transgressively by San Juan Formation, just as in San Diego de los Baños facies-structural zone. The Paleogene is represented by Capdevila (Upper Paleocene to Lower Eocene) and Universidad Formations (Lower to Middle Eocene) comprising sandstones, greywacke calcarenites, conglomerates, marls, and marly limestones. The main disconformity occurs at the boundary between the Upper Cretaceous strata and Capdevila Formation. Gabbros and serpentinites of unknown age seem to be the oldest rocks in the area, when assumed to be pre-tectonic as suggested by the lack of thermal contacts. Their present-day position in Bahía Honda zone is probably due to the orogenic processes (Pszczółkowski & Skupiński *in:* Pszczółkowski & *al.* 1975).

There are three independent structural units in Bahía Honda zone (Skupiński *in:* Pszczółkowski & *al.* 1975), roughly coincident with the lithostratigraphic formations. Thus, Felicidades unit borders directly upon Quiñones unit of the Sierra del Rosario, Guaniguanico zone; Capdevila unit overlies the Upper Cretaceous sediments; and Sierra de Cajalbana serpentinite-gabbro group stretches eastwards between Felicidades and Capdevila units. The boundaries separating these structural units are of tectonic nature; namely, they represent faults or overthrusts dipping generally to the north (Skupiński *in*: Pszczółkowski & *al.* 1975). Locally, sediments of Capdevila unit may be disturbed due to the serpentinites and gabbros piercing through the sedimentary mantle (Pszczółkowski *in*: Pszczółkowski & *al.* 1975).

Tectonic deformations are much stronger in Bahía Honda zone than in the facies equivalent strata of San Diego de los Baños zone. They attain their maximum intensity by the contact of Sierra del Rosario units with Bahía Honda zone (Pszczółkowski & *al.* 1975).

The units of Guaniguanico zone are distinctly superposed over Bahía Honda ones (Pszczółkowski *in*: Pszczółkowski & *al.* 1975). According to Hatten (1957), the rocks of Sierra de Cajalbana represent the highest nappe in the area, transported from the south. However, there are no data to support this hypothesis. Pszczółkowski & Skupiński (*in*: Pszczółkowski & *al.* 1975) claimed that Bahía Honda deposits had initially occurred north to the root zone of Guaniguanico nappes. In fact, the characteristics of the contact between Bahía Honda and Guaniguanico zones may suggest that the former zone acted as a check mass for Guaniguanico units being transported northwards.

According to Pszczółkowski (*in*: Pszczółkowski & *al.* 1975), the serpentinites and gabbros continued also to pierce through the sedimentary mantle after the Early Eocene time. This process and a possible uplift of the whole structure may have lead to considerable deformations, especially along the contact of the igneous rocks with sedimentary and volcanic-sedimentary formations.

LA ESPERANZA FACIES-STRUCTURAL ZONE

In the south, Guaniguanico units are usually superposed over La Esperanza zone. However, small overthrusts of La Esperanza units onto Guaniguanico ones have also been observed (D. Danilewski, *pers. comm.*). Apart from these overthrusts, there are also several faults displaying steep southwards-inclined or vertical slip surfaces (*e.g.* west to Santa Lucia). One may also claim that in places, Guaniguanico and La Esperanza zones have been jointly folded or scaled (Piotrowska 1972, 1975, *in*: Pszczółkowski & *al.* 1975).

As judged from the lithological sequence, such paleontologically barren formations of La Esperanza zone as Santa Lucia, Panchita, and Arroyo Rico (Pszczółkowski & Danilewski *in*: Pszczółkowski & *al.* 1975) may represent the Lower(?) and Upper Cretaceous. The sedimentary conditions at the latest Cretaceous and Paleogene time (San Juan and Capdevila Formations) appear to have resembled those prevailing in Bahía Honda and San Diego de los Baños zones.

Considerable fold and disjunctive deformations occur in strata of Santa Lucia, Panchita, and Arroyo Rico Formations. Diagram of *b* lineation (Fig. 40, diagram *I*) demonstrates two distinct lineation directions; *viz.* one of azimuth 50—60° and axes dipping gently southwestwards at some 10°, the other of azimuth 160° and axes dipping northwards at 0—50°. A small field in the diagram center represents vertical lineations. The former direction agrees well with the structural direction typical of Pinar del Rio Province; the latter one indicates an approximate direction of the tectonic transport. This problem will be dealt with further on in the text.

Concentric folds with disharmonically deformed central parts prevail in La Esperanza zone. They are particularly common in siliceous rocks of Panchita Formation. They display both the northerly and southerly vergencies (Piotrowska *in*: Pszczółkowski & *al.* 1975). There are both the northerly and southerly displacements, as demonstrated by the abundance of reverse faults and shears.

TECTONICS OF THE SIERRA DE LOS ORGANOS

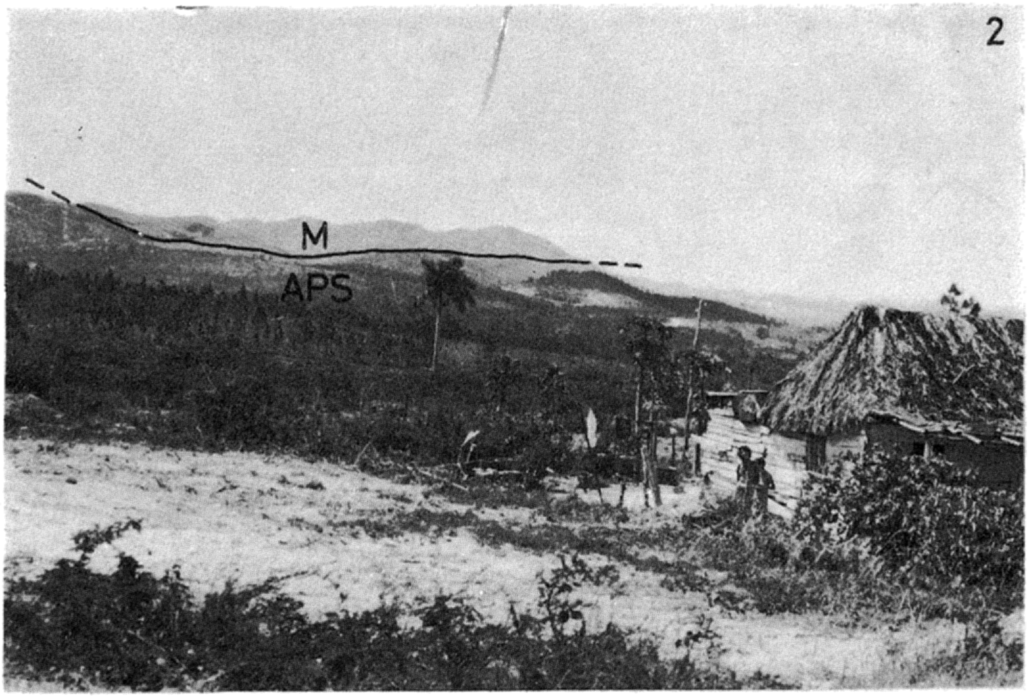
The region of Sierra de los Organos is here meant to comprise the hills of Alturas de Pizarras del Sur and, in part, del Norte and the mogote belt. There are several overthrust tectonic units in this area, forming jointly a belt 30 to 40 km wide and 100 km long.

The structural units of Sierra de los Organos (*cf.* Fig. 3) are generally parallel to the whole Cordillera de Guaniguanico. West to San Diego de los Baños, they follow the ESE—WNW axis over a short distance. The structural directions are almost parallel to latitude further to the west, up to Viñales. West to Viñales, the directions become more and more close to the NE—SW axis. By the localities Santo Tomás and Isabel Maria, Sierra Quemado, the units of mogote belt may locally show SSW—NNE directions (Fig. 4) due to some peculiarities of the overthrusting process (vertical and strike-slip faults parallel to the transport direction, and substrate morphology controlling the overthrust velocity) as well as to some subsequent displacements of rotational character. In general, the tectonic units display NE—SW direction between Viñales and Valle Luis Lazo. West to Mogote San Carlos, the structural directions are still more and more close to meridional. Thus, the units of Sierra de los Organos mark an arc to be delineated from a point somewhere in Batabanó Bay; however, the radii may be quite different for particular unit groups.

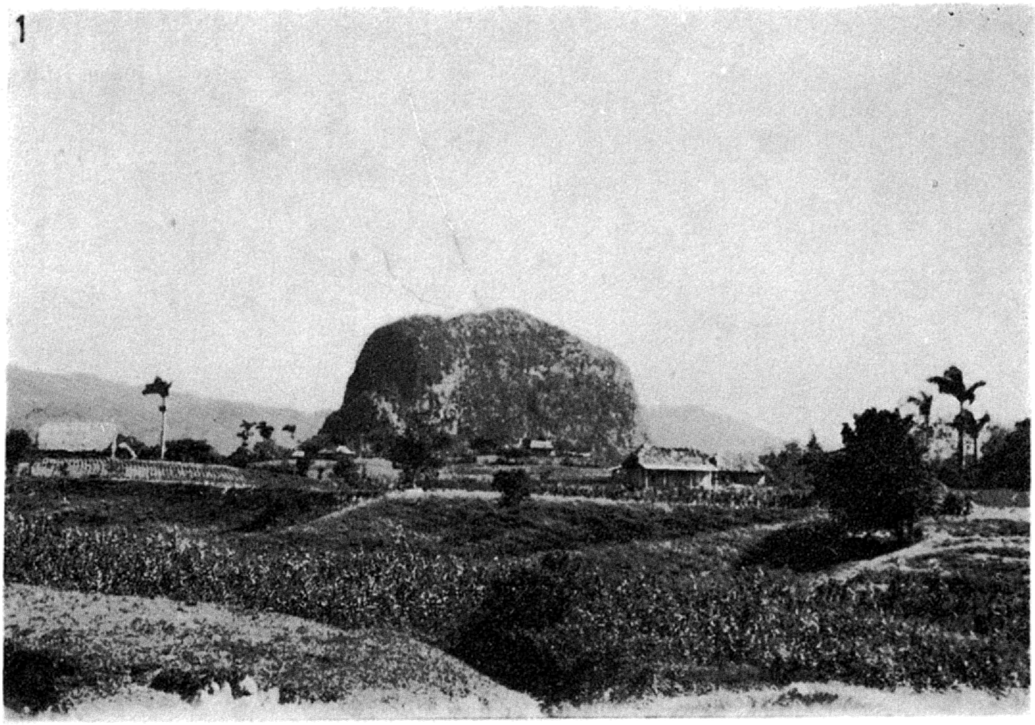
This outline course of Sierra de los Organos tectonic units is obviously highly generalized. In fact, there are also several deviations, sometimes quite significant ones (*e.g.* in the Sierra Quemado). These discrepancies result from slightly different local transport directions or subsequent deformations (Pls 2—3).

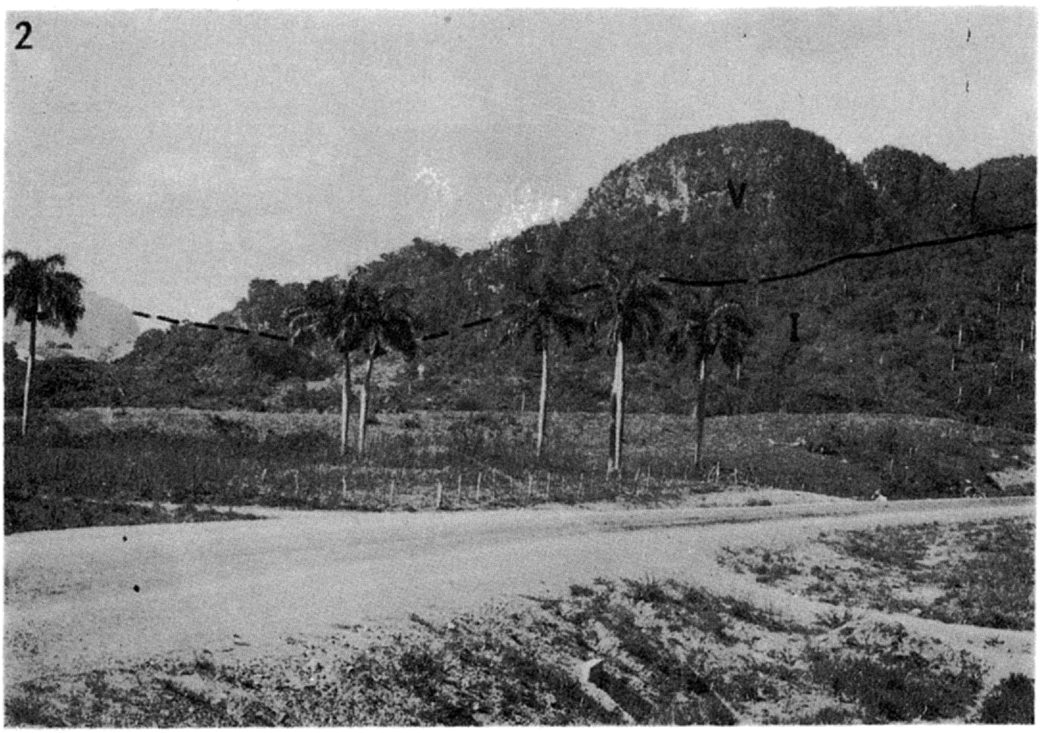
Aside of the change in the course of Sierra de los Organos structural units, the width of outcrop belt does also change continuously (Fig. 3). The belt is rather narrow in the east due to the coverage by Sierra del Rosario units and the structures truncation by Pinar fault. It gradually widens westwards to become finally by Guane three or even more times as wide as in the eastern part of the area.

Four distinct groups of nappe-scale units have been recognized in Sierra de los Organos region (Piotrowska *in*: Pszczółkowski & *al.* 1975). The first one, *viz.* calcareous units of the mogote belt, includes Valle de Pons, Sierra Quemado, Infierno, Celadas, Sierra de Guane, Paso Real, Viñales, Sierra de la Güira, and Ancón units (Figs 3—4). This unit group represents the lowest structural element of Sierra de los Organos. Alturas de Pizarras del Sur units (= "nappe inferior de San Cayetano" of Piotrowska 1972, and "nappe units of the Alturas de Pizarras" of Piotrowska 1975) occur south to the mogote belt. This unit group comprises mostly strata of San Cayetano Formation. Alturas de Pizarras del Norte units are situated north to the mogote belt. The prevalence of San Caye-



1 — Western part of Cerro Cabras: metamorphic unit (*M*) overthrust upon the units of Alturas de Pizarras del Sur (*APS*)
2 — Overthrust of Viñales unit (*V*) upon Infierno unit (*I*) near Santo Tomás





1 — Mogote "El Elefante" in the Luis Lazo Valley
2 — Mogote Las Tunas in the Pons Valley; visible is the overthrust of Viñales unit (*V*) upon Infierno unit (*I*)

tano Formation deposits is characteristic of this unit group. There is also a group of metamorphosed units including the units of Mestanza, Pino Solo, and Cerro Cabras.

The area of Sierra de los Organos shows a distinct linear pattern of the structural units. Most units can be traced over large distances (Figs 3—4). In places, the intersection boundaries present somewhat complex pattern due to the complexity of nappe geometry. Nevertheless, one may try to determine the spatial orientation of the whole structure of Sierra de los Organos. The central mogote belt appears to coincide with the present-day axial zone (Piotrowska 1972, 1975), as along its strike the lowest tectonic units are exposed. Then, the mogote belt is a distinct, longitudinal elevation. There are longitudinal depressions both north and south to the central zone. The depression of Alturas de Pizarras del Sur is relatively shallow. The occurrence of small tectonic windows by San Felipe and Calientes may be explained by a local elevation of the structures, resulting from both the main or subsequent orogenic processes and disjunctive displacement. The longitudinal depression of Alturas de Pizarras del Norte is deeper than the southern one. It displays also some linear elevations (Limonar-La Manaja zone) reflected by tectonic windows related to processes coeval or subsequent to the main phase of tectonic transport.

Aside of these main longitudinal elements, there are also some local transversal undulations. The most important one is the elevation of Pons Valley (Hatten 1957, Rigassi-Studer 1963), called Pons elevation (Piotrowska *in:* Pszczółkowski & *al.* 1975). It culminates by Pons but it extends also westwards, all over Pica Pica Valley. As the matter of fact, the lowermost tectonic unit of Sierra de los Organos area, *viz.* Valle de Pons unit, crops out in both Pons and Pica Pica Valleys over a large area.

There is a distinct transversial depression by Minas de Matahambre, Alturas de Pizarras del Norte (Piotrowska 1972, 1974, 1975). The overthrust base of the units of Alturas de Pizarras del Norte has not been reached at the depth of 1400 m therein (Fig. 5). In fact, this is a very deep depression vanishing quickly towards both the southeast and northwest, the southwestern slope being the steepest one. The northeastern and southeastern extents of this depression are hardly determined.

Another transversal depression is supposed to exist within the mogote belt east to and by Viñales (Pszczółkowski 1971). Tectonic units exposed in that area are thrust one over another and dip steeply northwards. There are exposed most calcareous units of the mogote belt, while Valle de Pons unit may be supposed to occur at a great depth. Presumably, the depression axis can be traced between Mogote Pancho Luis and Pico Simon. In the east, the depression borders upon tectonic units of the Sierra del Rosario; whereas it contacts with Pons elevation in the west.

To the southwest of Pons elevation, tectonic units dip gradually up to Valle Luis Lazo where San Carlos transversal depression of the mogote belt may begin.

Still further toward the southwest, the whole structure of Sierra de los Organos tends to dip. However, a small elevation may occur by Guane. In fact, Grodzicki (*in*: Pszczółkowski & *al.* 1975) claimed that there are two other units cropping out from underneath San Carlos unit (= Viñales unit), *viz.* Paso Real and Sierra de Guane units.

CALCAREOUS NAPPE-SCALE UNITS OF THE MOGOTE BELT

VALLE DE PONS UNIT

The term "Valle de Pons unit" has recently been introduced (Piotrowska *in*: Pszczółkowski & *al.* 1975) for the unit called previously "unidad parautóctono (Piotrowska 1972) or "bottom unit" (Piotrowska 1975).

This unit crops out mainly in Pons and Pica Pica Valleys, central part of the Sierra de los Organos. Its base part is unknown and its lowest exposed members can be attributed to the Cretaceous Pons Formation (Hatten 1957, Myczyński *in*: Pszczółkowski & *al.* 1975). Pons Formation is overlaid by Ancón Formation, the latter one occurring exclusively in this particular tectonic unit. Higher in the section, there are sediments of Pica Pica Formation and melange rocks with large serpentinite bodies. The entire sequence can be fully observed rather rarely, as Ancón and Pica Pica Formations and the melange rocks are commonly reduced tectonically. The contact of Pica Pica Formation with the overlying melange is commonly tectonic in nature.

The beds dip usually gently southwards. In places, there are asymmetrical, tilted folds of a dozen of so meters in amplitude. Their vergency is to the north. There are preserved but the upper limbs of anticlines, while the inverted, shorter ones are usually squeezed along a vertical, fault surface concordant with the *B* axis of the structural coordinates. Apart from this set of faults, there is also another one more or less perpendicular to the former and concordant with the general direction of tectonic transport. This twofold pattern of fault systems results in peculiar "reticulation" of the whole unit, reflected by a complex image at the land surface. The most intense deformations occur at the top of Valle de Pons unit, that is within Pica Pica Formation and the melange rocks.

Valle de Pons unit is usually overlaid (Figs 3—5) by Infierno unit (Piotrowska 1975) or the related Celadas one (Danilewski *in*: Pszczółkowski & *al.* 1975). The overthrust of Infierno unit onto Valle de Pons one can be observed in the Sierra de Cabezas, southern part of Pons Valley, at Mogote El Toro, and in the central part of Pica Pica Valley. Well-bedded limestones of the upper part of Guasasa Formation are thrust over the melange or Pica Pica Formation of Valle de Pons unit. These limestones begin the section of Infierno unit in that area. As both Infierno and Celadas units are tectonically reduced in the northern and northeastern parts of Pons and Pica Pica Valleys, the members of Viñales unit are thrust over Valle de Pons unit in those areas. This is the case of the mogote of Gramales. At the northern extreme of both Pons and Pica Pica Valleys, Valle de Pons unit is overthrust by clastic sediments of San Cayetano Formation representing already the group of nappe units of Alturas de Pizarras del Norte (Fig. 7). The overthrust plane is well exposed in numerous creeks running off the hills of Alturas de Pizarras del Norte. Thus, Valle de Pons unit appears overthrust by Infierno, Celadas, Viñales, and Alturas de Pizarras del Norte units, from the south to the north, respectively.

Valle de Pons unit is the lowest one in the mogote belt and hence, its appearance in the tectonic windows of Pons and Pica Pica Valleys may demonstrate an

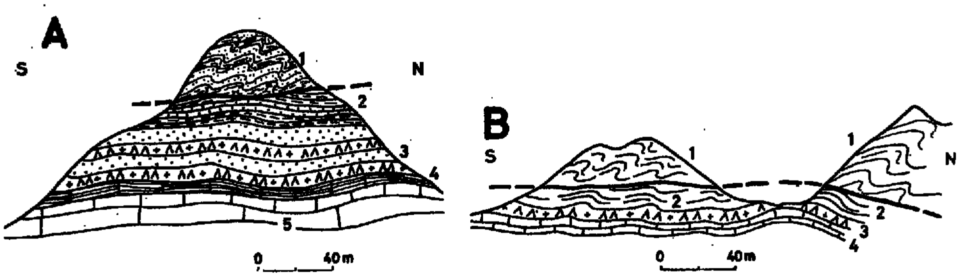


Fig. 7. Sections (*A*, *B*) across Alturas de Pizarras del Norte near Gramales
1 San Cayetano Formation; 2—3 Pica Pica Formation: 2 sandstones and shales, 3 cherts, sandstones and shales; 4 Ancón Formation; 5 Pons Formation

elevation of the whole structure axis. In fact, one might doubt whether there are any other exposures of this unit. However, Grodzicki (*in*: Pszczółkowski & *al.* 1975) has recognized by Guane, southwestern Sierra de los Organos, another group of tectonic windows, *viz.* Portales zone, and claimed its equivalence to Valle de Pons unit.

QUEMADO UNIT

This unit is exposed at the southern slopes of Sierra Quemado (Piotrowska 1975). Its outcrops form but a narrow belt stretching from Santo Tomás in the east to Isabel Maria in the west. The stratigraphic sequence is normal, the beds dipping gently to the northwest or southeast. The unit comprises exclusively some members of Jagua Formation. The lowest exposed strata are coquinitic limestones attributed to Pan de Azúcar Member of Jagua Formation. Higher in the section, there is commonly but not always Jagua Vieja Member represented by the "queso" level of concretions. At the top, these strata are overthrust by bedded limestones of the upper part of Guasasa Formation of Infierno unit (Fig. 8*A*). The base of Quemado unit is unknown. Nevertheless, one may suppose that it is thrust over Valle de Pons unit. Quemado unit does not occur in Pons Valley, while it is clearly

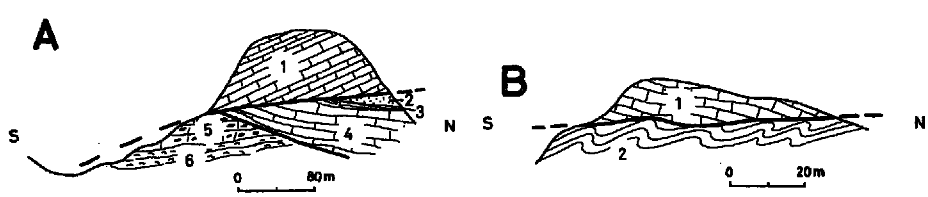


Fig. 8

A — Section across the mogote Quemado
1 Vinales unit; 2—4 Infierno unit: 2 Pica Pica Formation, 3 Ancón Formation; 4 Guasasa Formation; 5—6 Quemado unit, Jagua Formation: 5 bedded limestones with concretions, 6 coquinas

B — Section across Sierra Quemado near Santo Tomás
1 Infierno unit, 2 Pica Pica Formation of Valle de Pons unit

overthrust by Infierno unit in the Sierra Quemado. Hence, one may conclude that it is higher than Valle de Pons unit and lower than Infierno unit.

By Santo Tomás, Sierra Quemado, Infierno unit has been completely squeezed out and hence, Quemado unit is tectonically overlaid by massive limestones of the upper part of Guasasa Formation assigned to Viñales unit; the disconformity approximates 40°.

Quemado unit is but a narrow and small structure. It can be ascertained nowhere except of the Sierra Quemado. However, massive limestones of the lower part of Guasasa Formation are also exposed north to that area, along a belt about 0.5 km long and 15—20 m broad. In close analogy to the position of Jagua Formation strata in the Sierra Quemado, they are overlaid by Infierno unit. This may indicate that one deals here with a fragment of Quemado unit.

The structural thickness of Quemado unit is as small as its areal distribution. At the base of the overlying unit of Infierno, there are bedded limestones of the upper part of Guasasa Formation. Thus, both Jagua Formation and massive limestones of the lower part of Guasasa Formation are lacking. Hence, it appears quite possible that Jagua Formation forming today Quemado unit belonged initially to the base parts of Infierno unit. During the tectonic transport, a part of the rock mass could be detached resulting in the separation of Quemado unit. Then, Quemado unit may be recognized for a scale.

PASO REAL UNIT

This unit has been distinguished by Grodzicki (*in:* Pszczółkowski & *al.* 1975). It is exposed over a small area by Guane, western Sierra de los Organos. It runs approximately along a meridional, declining sligthly to the SSW. This unit is among the lower ones of the mogote belt and therefore, its occurrence may indicate a local elevation of the structure axis. The relation of Paso Real unit to such structures as Valle de Pons, Quemado, or Infierno units is unknown. One may but claim that it is lower than Infierno unit and higher than Valle de Pons one. Paso Real unit comprises Jagua Formation and massive limestones of the lower part of Guasasa Formation.

SIERRA DE GUANE UNIT

This unit has been also recognized by Grodzicki (*in:* Pszczółkowski & *al.* 1975). It is exposed by Guane and stretches northeastwards up to the mogote of San Carlos where it becomes covered with Viñales unit. It shows the NNE—SSW direction. It occurs within Guane elevation bordering upon San Carlos depression. Sierra de Guane unit comprises Jagua Formation and the lower part of Guasasa Formation. As judged from the general tectonic situation, Sierra de Guane unit may be either equivalent to or lower than Infierno unit.

INFIERNO UNIT

Infierno unit is among the most extensively exposed units of the mogote belt. Its outcrops occur over the area extending from Mogote Zacarías in the east to Sierra Pesquero in the west, especially between the localities of Viñales and Sumidero, *i.e.* within Pons elevation and at its slopes (mostly the southern ones). In fact, there are some mogotes built first of all of formations belonging to Infierno unit. Southwest to Viñales, Infierno unit plunges usually under higher units of the mogote belt and its outcrops are commonly associated with fault systems uplifting the structure; this is the case of the Sierra Pesquero. Apart from the mogote belt, some bedded limestones exposed in tectonic windows and halfwindows in the Alturas de Pizarras del Sur can also be interpreted as fragments of Infierno unit.

Infierno unit consists of remnants of San Cayetano, Jagua, Ancón, and Pica Pica Formations in the east, and Guasasa Formation in the west. The latter formation begins usually the section, resting in tectonic contact upon deposits of Pica Pica Formation or the melange of Valle de Pons unit; over a limited area it is also underlaid by Jagua Formation of Quemado unit. In its turn, Guasasa Formation is overlaid by Ancón and Pica Pica Formations. The sequence ends with tectonic melange rocks of fairly small thickness (as compared to the melange of Valle de Pons unit).

Infierno unit overlies usually directly the highest members of Valle de Pons unit (Fig. 8B). This is the case of Pons and Pica Pica Valleys. However, in the Sierra Quemado, Infierno unit is underlaid by the unit of Quemado. In the environs of Viñales and in the Sierra Pesquero, there are at the base of Infierno units some remnants of San Cayetano, Jagua, and Guasasa Formations (Figs 9—10), while they are lacking west to Santo Tomás, except of the upper part of Guasasa Formation. Then one may conclude that aside of a general décollement at the boundary between San Cayetano and Jagua Formations, a partial décollement has also taken place at the boundary between massive and bedded limestones of Guasasa Formation at the time of the initial nappe formation. Infierno unit is overthrust and, in part, sheared by Celadas (Danilewski *in*: Pszczółkowski & *al.* 1975) and Viñales units. In the south, Infierno unit is covered with nappe units of the Alturas de Pizarras del Sur.

Infierno unit can be characterized by its variable structural thickness and the décollement within Guasasa Formation. The maximum thickness approximates 400 m (Sierra del Infierno, Sierra de Cabezas) but it is commonly reduced down to 30—60 m. The base parts of the section are often squeezed out; there are also both décollements of the base and shears of the top parts of the unit (Fig. 11), the latter caused by overthrusts of higher tectonic units. Internal shears and dé-

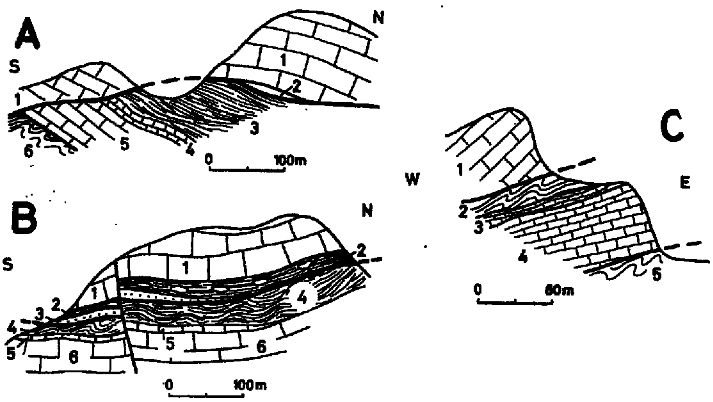


Fig. 9

A — Section of the western slope of the Pica Pica Valley

Viñales unit: *1* Guasasa Formation, *2* Jagua Formation; Infierno unit: *3* Pica Pica Formation, *4* Ancón Formation, *5* Guasasa Formation; Valle de Pons unit: *6* Pica Pica Formation

B — Section across the mogote El Toro in the Pons Valley

Viñales unit: *1* Guasasa Formation, *2* Jagua Formation, *3* fragments of San Cayetano Formation; Infierno unit: *4* Pica Pica Formation with the melange zone at the top, *5* Ancón Formation, *6* Guasasa Formation

C — Section across the eastern slope of the Luis Lazo Valley

Viñales unit: *1* Guasasa Formation; Infierno unit: *2* Pica Pica Formation, *3* Ancón Formation, *4* Guasasa Formation; Valle de Pons unit: *5* Pica Pica Formation

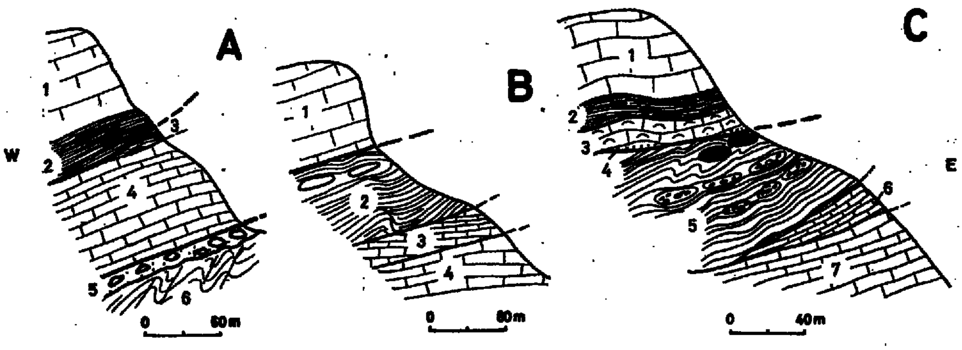


Fig. 10. Sections across Sierra de Cabezas
A — Vinales unit: *1* Guasasa Formation, *2* Jagua Formation; Infierno unit: *3* Ancón Formation, *4* Guasasa Formation; Valle de Pons unit: *5* melange zone, *6* Pica Pica Formation
B — Vinales unit: *1* Guasasa Formation; Infierno unit: *2* Pica Pica Formation with the melange zone at the top, *3* Ancón Formation, *4* Guasasa Formation
C — Vinales unit: *1* Guasasa Formation, *2—3* Jagua Formation, *4* San Cayetano Formation; Infierno unit: *5* Pica Pica Formation, *6* Ancón Formation, *7* Guasasa Formation

collements did also result in thinning the unit owing to differential movements in local tension areas. This is the case of Pons elevation. According to Danilewski (*in*: Pszczółkowski & *al.* 1975), the bedded limestones thrust northwards have been additionally split into two sets one of which forms now Celadas unit.

There are many reverse faults (inclined at 30—40°) of shear origin in Infierno unit. Along some of the fault planes, small overthrusts have taken place. The orientation of these fault planes and the inferred strains agree well with the general

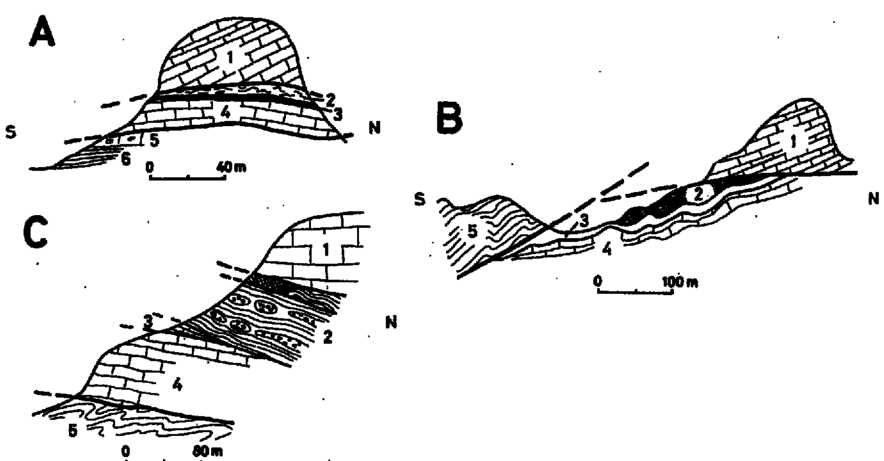


Fig. 11. Sections across Sierra Quemado (*A*, *B*) and Sierra de Cabezas (*C*)
A — Vinales unit: *1* Guasasa Formation; Infierno unit: *2* Pica Pica Formation, *3* Ancón Formation, *4* Guasasa Formation; Quemado unit, Jagua Formation: *5* bedded limestones with concretions, *6* coquinas
B — Vinales unit: *1* Guasasa Formation; Infierno unit: *2* Pica Pica Formation, *3* Ancón Formation, *4* Guasasa Formation; *5* Alturas de Pizarras del Sur units
C — Vinales unit: *1* Guasasa Formation; Infierno unit: *2* Pica Pica Formation (including the melange zone at the top), *3* Ancón Formation, *4* Guasasa Formation; Valle de Pons unit: *5* Pica Pica Formation and the melange

transport direction of Sierra de los Organos structures. Most probably, this shear system was related to either the overthrust of Infierno unit itself or the strains resulting from subsequent overthrusts of the higher units. In fact, quite different deformations occur in Valle de Pons unit. Due to its considerable mechanical uniformity (prevalence of bedded limestones), Infierno unit displays an exceptionally high deformation homogeneity.

CELADAS UNIT

This unit has been distinguished by Danilewski (*in:* Pszczółkowski & *al.* 1975). Its areal extent is very limited and it has been derived from Infierno unit.

VINALES UNIT

Viñales unit is among the largest ones in the mogote belt. It can be traced from Caiguanabo in the east up to Mogote San Carlos in the southwest. Most mogote tops are built of massive limestones of Viñales unit (Fig. 12). Hence, the unit is

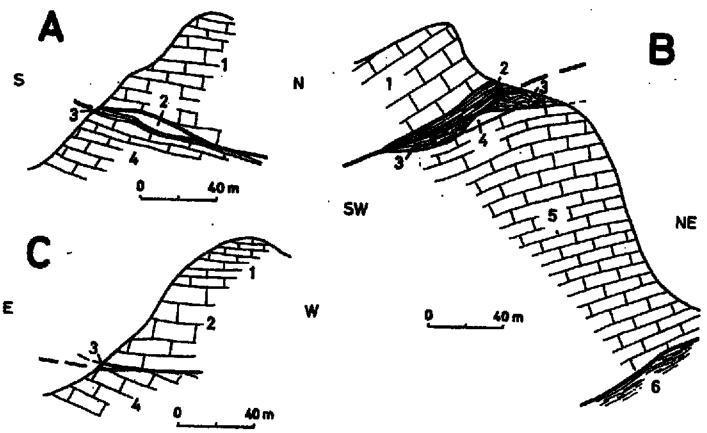


Fig. 12. Sections across the eastern slope of the Pica Pica Valley (*A*), Resolladero from the Luis Lazo Valley (*B*), and Resolladero from the Pica Pica Valley (*C*)

A — Vinales unit: *1* Guasasa Formation; Infierno unit: *2* Pica Pica Formation, *3* Ancón Formation, *4* Guasasa Formation

B — Vinales unit: *1* Guasasa Formation, *2* Jagua Formation; Infierno unit: *3* Pica Pica Formation, *4* Ancón Formation, *5* Guasasa Formation; *6* Valle de Pons unit

C — Vinales unit: *1—2* Guasasa Formation (*1* bedded limestones, *2* massive limestones), *3* Jagua Formation; Infierno unit: *4* Guasasa Formation

easily recognizeable in the field. In a structural depression between the Sierra Celadas and San Andres, beds of Viñales unit dip rather steeply northwards which results in a more or less continuous exposure belt. Further to the west, in the area of Pons elevation, the dips become more gentle. In that area, Viñales unit forms frequently tectonic caps superposed on either Infierno and Celadas unit or Valle de Pons unit. In a depression by Mogote San Carlos, Viñales unit is usually well developed. According to Grodzicki (*in:* Pszczółkowski & *al.* 1975), it flatly shears Sierra de Guane unit from the south, while in the north it overlies Infierno unit. From the west, it has been sheared by one of the units of Alturas de Pizarras del Norte.

In general, Viñales unit is thrust over Infierno or Celadas units, the latter ones being sometimes considerably reduced. In places (*e.g.* in the mogote of Gramales), it rests on Valle de Pons unit because Infierno and Celadas units are reduced entirely (Fig. 13).

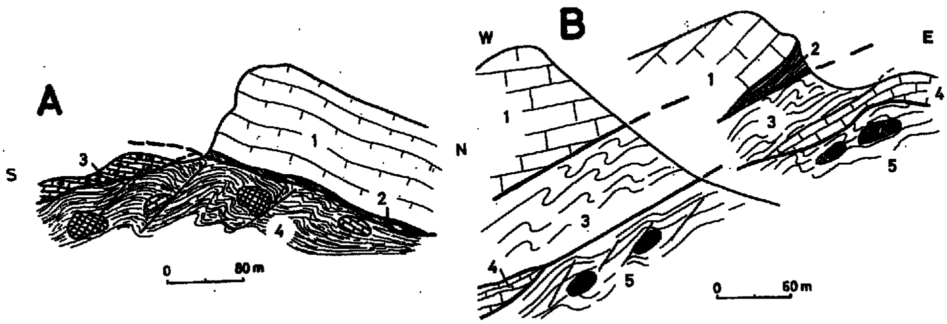


Fig. 13. Sections across Sierra Gramales in the Pons (*A*) and the Pica Pica (*B*) Valleys
A — Vinales unit: *1* Guasasa Formation, *2* Jagua Formation; Infierno unit: *3* bedded limestones of Guasasa Formation; Valle de Pons unit: *4* Pica Pica Formation with the melange zone at the top
B — Vinales unit: *1* Guasasa Formation, *2* Jagua Formation; Infierno unit: *3* Pica Pica Formation with the melange zone at the top, *4* Guasasa Formation with fragments of Ancón Formation; Valle de Pons unit: *5* melange

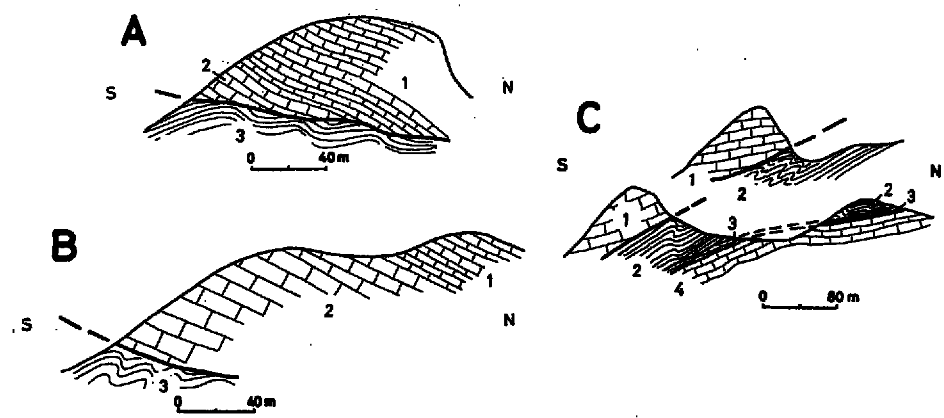


Fig. 14. Sections across Sierra de Cabezas, in the southern part of the Pica Pica Valley (*A*), northern part of the Pica Pica Valley (*B*), and Sierra Quemado (*C*)
A, B — Vinales unit: *1* bedded limestones of Guasasa Formation, *2* massive limestones of Guasasa Formation; *3* Infierno unit
C — *1* Vinales unit; Infierno unit: *2* Pica Pica Formation, *3* Ancón Formation, *4* Guasasa Formation

Viñales unit comprises the uppermost San Cayetano, Jagua, Guasasa, Ancón, and Pica Pica Formations, and the melange rocks. Certainly, in no place all the lithostratigraphic units are present (Fig. 14). The section begins commonly with deposits of either Jagua or Guasasa Formations. The top parts of the section have also been taken off in places, because of a tectonic squeeze. Complete sections are to be found where the overlying units are preserved, *i.e.* in Mogote Pancho Luis-Pico Simon and San Carlos depressions.

In the eastern Sierra de los Organos, Viñales unit is overthrust by Ancón unit. In the Pons elevation and San Carlos depression, Viñales unit represents actually the highest one observed. In fact, structural unit of the Alturas de Pizarras had undoubtedly been higher but they have been subsequently eroded in the structure axial zone. East to Viñales, the investigated unit is hidden under some nappe units of the Alturas de Pizarras del Sur, Ancón unit of the mogote belt, and units of the Sierra del Rosario. In that area, massive limestones of Guasasa Formation and bedded, concretion-bearing limestones of Jagua Formation crop out in some tectonic windows; these deposits may also be attributed to Viñales unit.

The tectonics of Viñales unit appears quite unique. The unit is less uniform than Infierno one, just to mention the presence of massive limestones of Guasasa Formation (San Vicente Member). Those limestones of considerable thickness occur between well-bedded limestones intercalated with shales of Jagua Formation and bedded limestones of the upper part of Guasasa Formation. This lithology must have decisively controlled the deformations of the whole unit. Disturbances at the boundary of Jagua and Guasasa Formations are expressed by slight folding, intrastratal glides, and local breccias in the highest beds of Jagua Formation. The overlying massive limestones reacted as rigid bodies subject to disjunctive deformations. Glides, shears, and décollements occur also frequently in the passage zone between the massive limestones of San Vicente Member of Guasasa Formation and the overlying bedded limestones. In the Sierra de Cabezas, a décollement resulting in a discrepancy of some 10—15° occurs at the latter boundary.

SIERRA DE LA GÜIRA UNIT

This unit has been distinguished by Piotrowski (*in*: Pszczółkowski & *al.* 1975). It stretches from San Diego de los Baños in the east to San Andres in the west. It comprises San Cayetano (in part), Jagua, Guasasa (San Vicente Member), Ancón, and Pica Pica Formations. It is overthrust by Los Bermejales and Loma Colorada units (Pszczółkowski & *al.* 1975) of the Sierra del Rosario. The overthrust plane is weakly tilted but in places, it becomes steeper up to 45°. Beds of the unit dip northwards at some 30—50°. In the east, Sierra de la Güira unit is thrust over units of the Alturas de Pizarras del Sur. Westwards, however, the latter units are superposed over the former one. This is due to a small, reverse overthrust that followed the main phase of tectonic transport (Piotrowski *in*: Pszczółkowski & *al.* 1975).

ANCÓN UNIT

Ancón unit is exposed east to Pons elevation, eastern Sierra de los Organos. This is the highest tectonic unit of the mogote belt (Danilewski *in*: Pszczółkowski & *al.* 1975).

Ancón unit comprises all lithostratigraphic units from the San Cayetano up to Pica Pica Formations but there are commonly décollements and tectonic reductions at both the base and top of the latter formation (Danilewski *in*: Pszczółkowski & *al.* 1975). Ancón unit is overthrust by La Paloma unit of the Sierra del Rosario. Danilewski (*in*: Pszczółkowski & *al.* 1975) claimed that the latter unit had been thrust from the north. However, the present author is of the opinion that it was thrust from the south, as it is the case with all other nappe-scale units (Piotrowska 1975, *in*: Pszczółkowski & *al.* 1975).

NAPPE-SCALE UNITS OF THE ALTURAS DE PIZARRAS DEL SUR

These units have been recognized by Piotrowska (1975) south and southeast to the mogote belt. They comprise mostly rocks attributed to San Cayetano Formation, forming several nappes or scales. The nappe-scale units are but hardly separable one from another due to the lack of paleontological data and high lithological homogeneity of San Cayetano Formation. They are exposed between San Diego de los Baños and Guane environs where they are transgressively covered with the Miocene sediments (Paso Real Formation).

The northern boundary of Alturas de Pizarras del Sur units coincides with the morphologic one between the sandstone-shaly hills and the limestone mogotes. Along this boundary, one can observe Alturas de Pizarras del Sur units thrust over the calcareous units. The overthrust plane is horizontal as a rule, or slightly dipping southwards. Steeper dips have been recorded but in a few cases. There are some displacements along the vertical strike-slip faults within the contact zone, *e.g.* between the localities Sumidero and Luis Lazo (Fig. 15*A-B*). In that area, the fault zones are quite distinct, displaying many almost vertical tectonic mirrors at the limestone planes. There are many generations of slip grooves, the vertical one prevailing. There is also a horizon displaying small drag folds of horizontal axes and 1.5—2 cm in amplitude. Their asymmetry demonstrates the southern side of the fault to have moved down, *i.e.* that one built by the units of Alturas de Pizarras del Sur. Presumably, the fault runs eastwards up to Sumidero, and westwards up to Mogote San Carlos. The amplitude is rather small and variable. Actually, this is either a hinge fault or a fault zone that was activated many times and showed differential displacement directions; horizontal shifts cannot be excluded either. Dr. Lilienberg (*pers. comm.*) assessed that there are also differential recent vertical movements. In fact, the Alturas de Pizarras del Sur are actually subject to a slight uplift, whereas the mogote belt north to the line Sumidero-Luis Lazo shows considerable positive movements at a rate higher than the average in the Cordillera de Guaniguanico. Hence, some disjunctive zones must occur concordant with the structure of Sierra de los Organos which have accentuated the structural elevation nature of the mogote belt, even despite the Alturas de Pizarras del Sur nappe units being thrust over the calcareous ones.

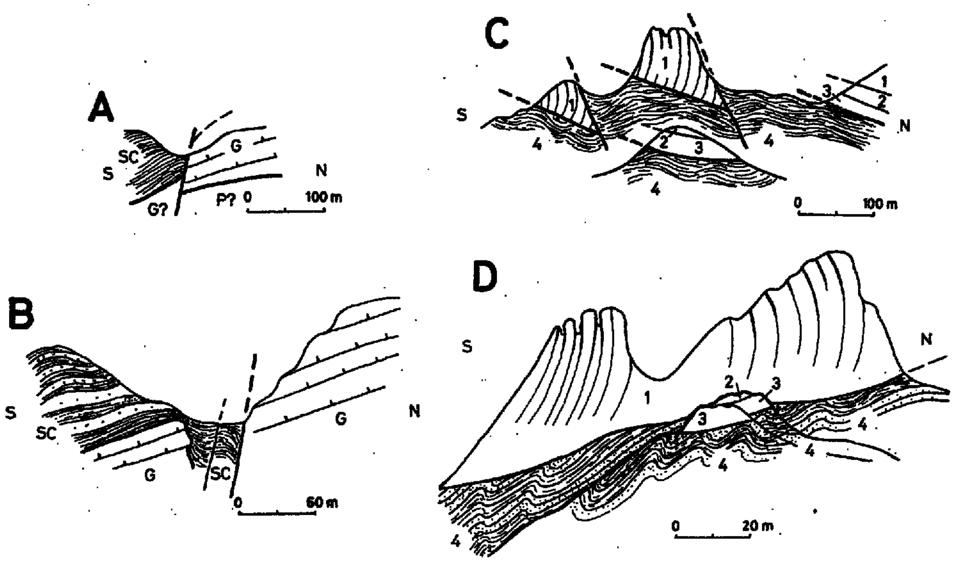


Fig. 15

A, B — Sections across the fault zone near Mogote Sumidero

Sc San Cayetano Formation, *G* Guassa Formation, *P* Pica Pica Formation

C, D — Sections across Sierra Quemado

1 Guasasa Formation, *2—3* Jagua Formation, *4* San Cayetano Formation

The overthrust of nappe units of Alturas de Pizarras del Sur onto the calcareous ones is to be commonly observed within the contact zone. In many tectonic halfwindows representing structural depressions (*e.g.* south to Cabezas), one may see sediments of Jagua, Guasasa, Ancón, and Pica Pica Formations or the melange rocks attributed to Infierno and Viñales units, overlaid by sandstones and shales of San Cayetano Formation of the units of Alturas de Pizarras del Sur. The nappe units of Alturas de Pizarras del Sur border gently upon the calcareous ones. This contact may be disturbed in some areas due to a phase younger than the main one which has resulted in minor reverse overthrusts. This is the case in the Sierra de la Güira.

In the Sierra Quemado, north to Isabel Maria, bedded limestones of Infierno unit dipping gently northwards crop out in mogote walls rising up from a depression. They are cut along a plane tilted southwards by rocks of San Cayetano Formation attributed to the nappe units of Alturas de Pizarras del Sur. They form something like a tectonic wedge pressed inbetween two calcareous units, namely Infierno and Viñales units (Fig. 15C-D). Fragments of the latter unit tectonically contact San Cayetano Formation under the form of two small cliffs. The beds exposed in those cliffs are almost vertically bent northwestwards thus, pointing to the transport from the southeast. The contact plane between Viñales and Alturas de Pizarras del Sur units dips southeastwards, that is just as do the beds of San Cayetano Formation (Fig. 16). Then, it appears quite possible that a reverse glide of the cliffs of Viñales unit is taking place. The structure is about 150 m long and it can be traced over some 500 m. All the above examples demonstrate that the present-day northern boundary of the nappe units of Alturas de Pizarras del Sur is often highly complex owing to disjunctive deformations variously oriented. A lineament along which tectonic windows appear north to the Cerro Cabras should also be regarded as such a contact zone.

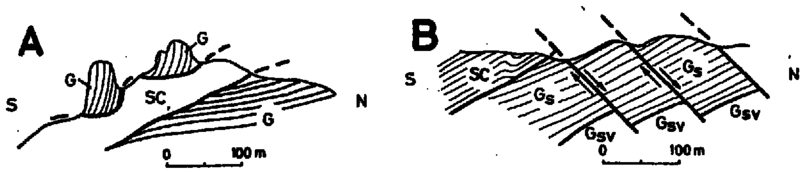


Fig. 16. Sections (*A*, *B*) across Sierra Quemado
G Guasasa Formation: *Gsv* non-bedded massive limestones, *Gs* bedded limestones; *SC* San Cayetano Formation

The nappe units of Alturas de Pizarras del Sur are thrust over various units of the mogote belt. In the east, they contact the underlying units of Sierra de la Güira, Ancón, and Viñales. By the locality Viñales, they override Viñales unit. Further to the southwest, up to the mogote of Sumidero, Infierno unit emerges from under the Alturas de Pizarras del Sur overthrust. In Sumidero and San Carlos Mogotes, the units of Alturas de Pizarras del Sur contact Viñales unit again. The latter disappears by Guane, giving way to the lower units such as Sierra de Guane and Paso Real ones.

This replacement sequence of the underlying calcareous units may support the reality of transversal undulations as claimed above, because the higher calcareous units are tectonically reduced or do not occur at all in the elevation areas. Thus, it appears quite possible that the transversal undulations have originated due to a relatively early phase of the tectonic transport.

From the south and southeast, the nappe units of Alturas de Pizarras del Sur are limited by the superposed metamorphosed units. The contact zone is complex and hardly traceable in places. It is generally concordant with the structural direction of Sierra de los Organos, although there are also local discrepancies. In Cerro Cabras area, the nappe units of Alturas de Pizarras del Sur are covered with a tectonic cap of considerable size, the disconformity being of but a few degrees. This structure has been recognized for a distinct metamorphosed nappe unit, *viz.* Cerro Cabras one (Piotrowska 1972, 1975).

Piotrowski (*in:* Pszczókowski & *al.* 1975) has attempted to subdivide the nappe units of the eastern Alturas de Pizarras del Sur into smaller structural elements. Apart from distinct overthrust planes, the main criterion was a concordance in the structural directions. On this basis, several units of nappe-scale nature have been recognized, separated during the tectonic transport. By the localities Isabel Maria and Cayo San Felipe, an unit occurs with strikes close to meridional over a large area, that is almost perpendicular to the directions prevailing in the lower units of Alturas de Pizarras del Sur. Possibly, a rotation or rather a twist of the transported unit took place in that area due to a change in the local strain field. The adjacent units do not show any deformations different from those recorded commonly in the nappe units of Alturas de Pizarras del Sur.

The scaled units of Alturas de Pizarras del Sur display unique deformation features developed during the main tectonic phase or some subsequent tectonic movements. Completely preserved folds of some tens to several hundred meters in amplitude occur but sporadically. In most cases, only fold fragments are preserved. Normal limbs of scaled anticlines and synclines occur most frequently. Broad bends associated with shears or small overthrusts are also very frequent. Folds of 0.5 to 8 m in amplitude occur commonly. Concentric folds prevail among these structures, exhibiting frequently both décollements at the bed boundaries and internal shears. No disharmonic folds have been recorded. In fact, San Cayetano rock complexes comprising fairly thin and compatible sandstone and shale beds are rather uniformly resistant to tectonic deformations. Disharmonic deformations have usually taken place at the boundaries of thicker sandstone and shaly sets. In such cases, there are commonly décollements and shears of differential displacement; drag folds or other early-phase folds have also developed. The developing folds underwent shearing process passing rapidly into scale formation, which was due to mechanical heterogeneity of the involved rock complexes. Concentric folds occur commonly, their outer parts comprising sandstone layers, and the internal parts composed of disharmonically folded shales. As a rule, internal shaly parts are more intensely deformed than the outer ones. There are also reverse structures with sandstones in the core and shales in the outer part. The sandstone cores have usually pierced the surrounding shales; then, there is no deformation in the shales but just an increase in density of drag folds. Such phenomena are typical of both broad and narrow folds as well as of small bends.

Some strongly deformed zones exhibit many various structures, whereas others, mostly shaly ones are hardly touched by tectonic deformations. This is related primarily to the lithology of San Cayetano Formation. Bent sandstone-shaly sets attributed to the scale units of Alturas de Pizarras del Sur are frequently wedged between planes of criss-crossing faults of various origin. As judged from the tilt of folds and scales as well as from the bends near fault planes, there are northerly or northwesterly displacements.

Intensity of tectonic deformations appears particularly variable in boudinage structures. The boudinage trends are generally concordant with the fold-axes trends thus, pointing to the general structural direction. Peculiar boudinage structures have developed within the zones of local tension.

Disjunctive structures range from fine cleavage up to great fault zones. The cleavage appears quite easily recognizeable in the field, as elongated parallelepipeds of rhomboidal, rectangular, or square bases occur commonly among debris of San

Cayetano deposits. Generally speaking, these are pencil structures; their origin is explained further on in the text. Cleavage associated with fault zones appears very common in the Alturas de Pizarras del Sur. Nevertheless, it appears useless for the analysis of general structural problems. Numerous fault zones are described further on in the text.

The units of Alturas de Pizarras del Sur are exposed in a shallow longitudinal depression. Tectonic windows of San Felipe and Caliente reflect probably a subordinate elevation. Structural direction of the latter zone has been imposed by disjunctive tectonics. By the way, it is also concordant with the main structural trend found in the Sierra de los Organos.

NAPPE-SCALE UNITS OF THE ALTURAS DE PIZARRAS DEL NORTE

North and northwest to the mogote belt, there is a broad belt of outcrops of the nappe-scale units of Alturas de Pizarras del Norte comprising mainly deposists of San Cayetano Formation. The outcrops stretch from Río Malas Aguas up to Guane and Mantua where they become covered with the Quaternary sediments of coastal zone. In the east, this belt is only 12 km broad but it gradually broadens southwestwards to attain by Guane some 25 km in width.

In the northwest, the units of Alturas de Pizarras del Norte are thrust over La Esperanza facies-structural zone. The overthrust is of a complex fault-overthrust nature and it is hardly traceable in places. By Santa Lucia, it is obscured by a system of vertical and steep faults with which the polymetallic ores of Santa Lucia--Castellano are associated. The overthrust inclination is highly variable in that area. In fact, the plane is almost horizontal in places, while it may also be considerably steeper due to block rotations or fault disturbances. In contrast, the overthrust plane dips rather gently southwest to Baja. Moreover, disjunctive tectonics has much less affected the overthrust in the latter area. In places, rocks of La Esperanza zone are thrust over the units of Alturas de Pizarras del Norte due probably to some reverse movements (Danilewski 1972, Piotrowska 1972). In most cases, however, the units of Alturas de Pizarras del Norte superpose La Esperanza facies-structural zone, as demonstrated by the boreholes situated by Santa Lucia where melange rocks underlaid by greywacke sandstones of La Esperanza zone are tectonically overlaid by strata of San Cayetano Formation. In fact, limestones and sandstones of La Esperanza zone emerge from below San Cayetano Formation by Dimas.

In the south and southeast, the nappe-scale units of Alturas de Pizarras del Norte superpose various units of the mogote belt. The overthrust planes are usually weakly inclined or horizontal. In the contact zones, considerable tectonic reductions occur in the underlying structural units. For example, in Arroyo La Mina river bed, Pons Valley, sandstones and shales of San Cayetano Formation are underlaid by some 2 meters thick zone comprising elongate fragments of beds (up to 0.8 m in length) of Alturas de Pizarras del Norte unit, along with lense-like blocks of Ancón Formation of Valle de Pons unit. All but a few blocks display tectonic mirrors and slip grooves. The thickness of Ancón Formation of Valle de Pons unit appears reduced down to but a meter, and the rocks show directional orientation of their components and strong recrystallization.

Northwestern boundary of the nappe units of Alturas de Pizarras del Norte is hardly traceable. In fact, because of the same lithology and consistent structural trends, the boundary separating Loma del Muerto and La Paloma units of the Sierra del Rosario (Pszczółkowski & *al.* 1975) from Alturas de Pizarras del Norte ones can be but approximately marked (Figs 2—3). According to Danilewski (*in*: Pszczółkowski & *al.* 1975), all the deposits of San Cayetano Formation exposed along a belt between La Palma and Río Malas Aguas are to be attributed to Sierra del Rosario units. Nevertheless, San Cayetano deposits exposed southwest to Minas de Matahambre seem to resemble more closely those of the Sierra de los Organos than those of the Sierra del Rosario. Moreover, Haczewski (*in:* Pszczółkowski & *al.* 1975) observed by Mantua, Alturas de Pizarras del Norte, a sedimentary transition from San Cayetano to Jagua Formations, the latter formation recorded only in the Sierra de los Organos. There are also in the considered deposits some coquinas up to 14 m thick (by La Manaja) reported from a belt between Mantua and El Jobo, southwest to Minas de Matahambre. Coquina beds of a comparable thickness have been insofar unknown in San Cayetano Formation of the Sierra del Rosario (Pszczółkowski & *al.* 1975). Sedimentological characteristics of San Cayetano Formation deposits exposed in the Alturas de Pizarras del Norte does also appear significantly different from that typical of the Sierra del Rosario, especially of La Paloma and Cinco Pesos units (Haczewski 1976). Possibly, some of the units forming the hills of Alturas de Pizarras del Norte (Alturas de Pizarras del Norte, Loma del Muerto, Coralillo, Cayetano, and La Llave units are exposed in that area) represent a structural complex derived from a transitory area between the facies typical of Sierra de los Organos and Sierra del Rosario (Piotrowska *in:* Pszczółkowski & *al.* 1975). To solve this problem, further investigations are needed in the area between Río Malas Aguas and La Palma.

The units of Alturas de Pizarras del Norte are exposed in a longitudinal structural depression. There are some subordinate elevations within that depression, such as Cayo de las Damas, Limonar, La Manaja, and Mantua, reflected by tectonic windows with fragments of calcareous units cropping out. The linear pattern of these windows points to a close relation of the elevations to disjunctive tectonics. Furthermore, serpentinite rocks occur in Cabeza de Horacio tectonic window, north to La Manaja-Mantua elevation, overlaid by the units of Alturas de Pizarras del Norte. In this sense, one may also speak about the elevation of Cabeza de Horacio.

In Matahambre depression (Piotrowska 1972, 1974, 1975), north to Cayo de las Damas-Limonar elevation, the tectonic units dip rapidly northwestwards along the northern slope of the depression. One may suppose that this rapid decline of the base plane of the nappe units of Alturas de Pizarras del Norte results from a fault or flexure. In fact, this base plane occurs at the surface in Cayo de las Damas--Limonar tectonic windows, while it attains a depth of over 1400 m some hundred meters away, in Matahambre mine. One may claim that a disjunctive tectonic zone was active in that area during the overthrust and therefore, the nappe units had to fill up the depression. Thereafter, the units of Alturas de Pizarras del Norte have been considerably condensed and secondarily scaled in Matahambre depression, displaying often southerly vergencies. The northwestern boundary of Matahambre depression is marked by the boundary between the units of Alturas de Pizarras del Norte and La Esperanza facies-structural zone. The northeastern and southwestern extents of Matahambre depression are hardly determined.

An elevation occurs by Mantua as a prolongation of the longitudinal elevations of Cayo de las Damas, Limonar, and La Manaja. The outcrops of the lower tectonic units become considerably wider in Mantua window thus, indicating that this is a dome-like elevation different from those in the east displaying a linear pattern. Mantua elevation is also marked in the mogote belt. Thus, one may conclude that this transversal elevation is marked in the whole structure of the Sierra de los Organos. In contrast, in the area of Pons and Matahambre, central Sierra de los Organos, prominent Pons elevation of the mogote belt borders upon distinct Matahambre depression.

The present author (Piotrowska 1974) tried to recognize minor tectonic units in the Alturas de Pizarras del Norte. Some subdivisions have also been done in the environs of Matahambre mine (Laveroy & *al.* 1967). Furthermore, Hatten (1957) has distinguished two nappe units by the locality San Cayetano, their boundary traced at the prolongation of Limonar-Cayo de las Damas tectonic window. However, all these units have been attributed by Danilewski & Pszczółkowski (*in:* Pszczółkowski & *al.* 1975) to the Sierra del Rosario. In the area of Guane and Mantua, Grodzicki (*in:* Pszczółkowski & *al.* 1975) has also distinguished two structural units within the Alturas de Pizarras del Norte. Correlation of the considered units has not been so far accomplished over the whole area of Alturas de Pizarras del Norte.

At the contact with the mogote belt, the tectonic units of Alturas de Pizarras del Norte are usually much more deformed than the units of Alturas de Pizarras del Sur. The intensity of deformations decreases distinctly northwards. The strongest deformations occur in a unit exposed between the mogote belt and Cayo de las Damas and Limonar tectonic windows. They are to be observed along the road between Pons and Matahambre where both fold (true folds, cleavage folds, boudinage structures, bends, etc.) and disjunctive deformations (cleavage, mostly joint one, pencil structures, numerous small and large faults, shears and wedging of rock portions) occur. In that section, the beds change frequently both their strikes and dips, while the overthrust plane is almost horizontal. The deformation type is almost uniform all over the considered tectonic unit. In contrast, a unit exposed by Minas de Matahambre exhibits rather constant strikes along the NW—SE axis and northerly dips of 50—80°. One may claim that the beds dip monoclinally northwestwards at least in some areas. Boudinage, gentle bends, intrastratal décollements and shears, and locally dislocation-related cleavage appear as the most typical deformations in that unit. Further to the north, the deformations are quite similar to those observed in the nappe-scale units of Alturas de Pizarras del Sur.

In particular units of the Alturas de Pizarras del Norte, the bed dips decrease northwards. They are steep near steep northerly oriented fault planes but they become more gentle further on, behind synclinal or anticlinal hinges. Structures of that type may be called scales regardless of their variable size. The northern nappe units of Alturas de Pizarras del Norte are less complex. Both the geometry and frequency of fine tectonic structures indicate the main northwesterly and weak southerly displacements. The latter transport direction may be related to the main phase of northward movements: it may represent a local disturbance of the strain field caused *e.g.* by a resistance mass.

LIMONAR-CAYO DE LAS DAMAS TECTONIC WINDOW

This element covers a narrow area in the hills of Alturas de Pizarras del Norte where deposits of Guasasa, Ancón, and Pica Pica Formations and the melange rocks are exposed, overlaid by San Cayetano sediments. The beds dip but gently in the eastern part of the window, whereas the dips become highly variable in the west. The rocks emerging in the window are to be attributed to a calcareous unit of the Sierra de los Organos. Limonar-Cayo de las Damas tectonic window reflects a subordinate longitudinal elevation within a larger depression of the Alturas de Pizarras del Norte. Locally, strong tectonic disturbances occur in that zone. These are mostly folds developed under conditions of high rock plasticity. Their axes are vertical which points to horizontal shifts during their development. In places, tectonic disturbances caused by transcurrent movements do also occur in the window.

Limonar-Cayo de las Damas zone has been variously interpreted. According to Hatten (1957), there are two tectonic units plunging northwards; the northern unit consists entirely of San Cayetano Formation and has been thrust over the other one comprising both San Cayetano and calcareous sediments. Other authors accept the existence of a deep fracture with considerable vertical slip (Malinovsky & Carassou 1967, 1972, 1974).

Recent field observations deny all these concepts. The calcareous formations do not show sedimentary continuity with San Cayetano Formation; in contrast, they are separated from the latter by an overthrust plane. Then, they are to be assigned to distinct tectonic units. One may conclude that Limonar-Cayo de las Damas zone represents an elongate tectonic window.

CABEZA DE HORACIO TECTONIC WINDOW

Serpentinized ultrabasic rocks and gabbros are exposed in the area of Cabeza de Horacio, south to Dimas. The lense-like outcrop area is 5.5 km long and 2 km broad. The considered rocks are covered with overthrust units of the Alturas de Pizarras del Norte. According to Haczewski (*in*: Pszczółkowski & *al.* 1975), one deals here with two flat units each consisting of serpentinized ultrabasic rocks that are strongly folded but with primary structures preserved; upwards, these rocks pass into gabbros. If so, the igneous rocks must have occurred in Cabeza de Horacio area prior to the overthrust of the nappe-scale units of Alturas de Pizarras del Norte. In other words, one cannot regard the ultrabasic rocks as an intrusion that pierced the surrounding rocks of San Cayetano Formation. In fact, there are no thermal contacts with the latter sediments (Skupiński & Haczewski *in*: Pszczółkowski & *al.* 1975). The contacts are, on the contrary, discrepant. Small tectonic caps of San Cayetano Formation superpose the ultrabasic rocks.

Presumably, the rocks exposed in Cabeza de Horacio window represent a structural zone different from the Alturas de Pizarras del Norte. One may claim that they should be assigned to La Esperanza facies-structural zone.

METAMORPHOSED UNITS

Three metamorphosed units have been insofar recognized, *viz.* Mestanza, Pino Solo, and Cerro Cabras ones (Piotrowska 1972, 1975; Piotrowski & Piotrowska *in*: Pszczółkowski & *al.* 1975). Mestanza and Pino Solo units contact and in places pass into each other, Cerro Cabras unit occurs under the form of a tectonic cap resting on the nappe-scale units of Alturas de Pizarras del Sur (Piotrowska 1972, 1975, *in*: Pszczółkowski & *al.* 1975).

MESTANZA UNIT

This unit forms a narrow belt in the southeastern Sierra de los Organos, between Las Puntas and La Güira by Cerro Cabras where it plunges under Pino Solo unit. It contains rocks varying in metamorphism intensity which have originated mostly from Jagua and Guasasa Formation. Mestanza unit is thrust over the nappe units of Alturas de Pizarras del Sur (Fig. 17) along a steep plane inclined southeast-

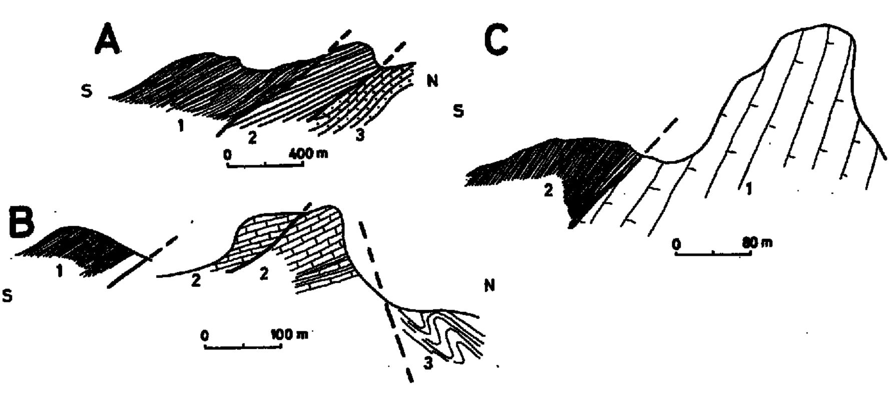
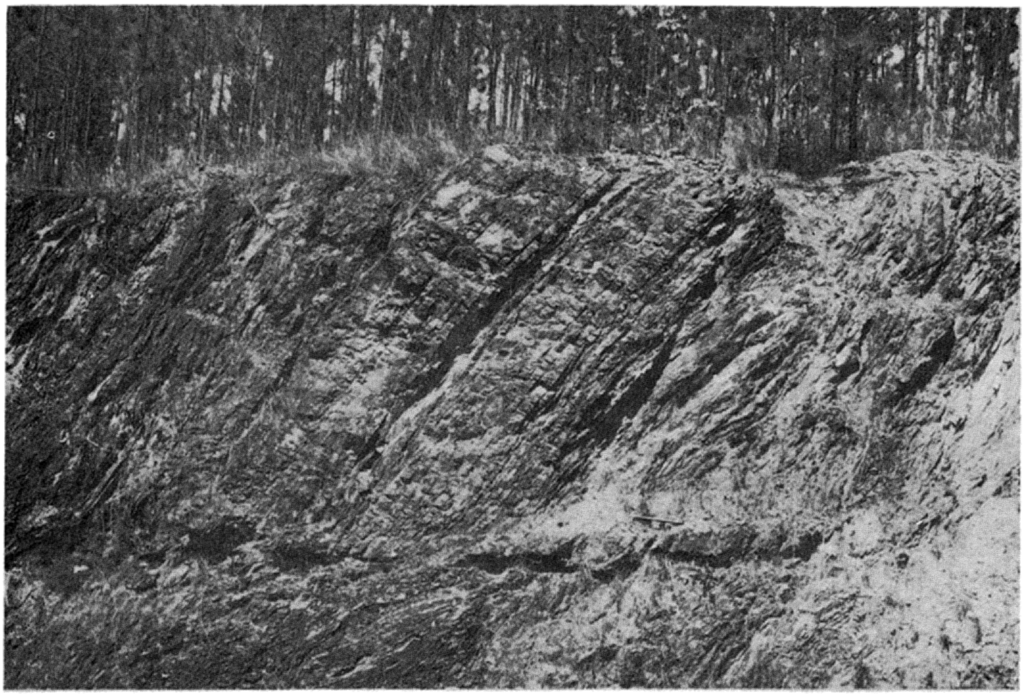
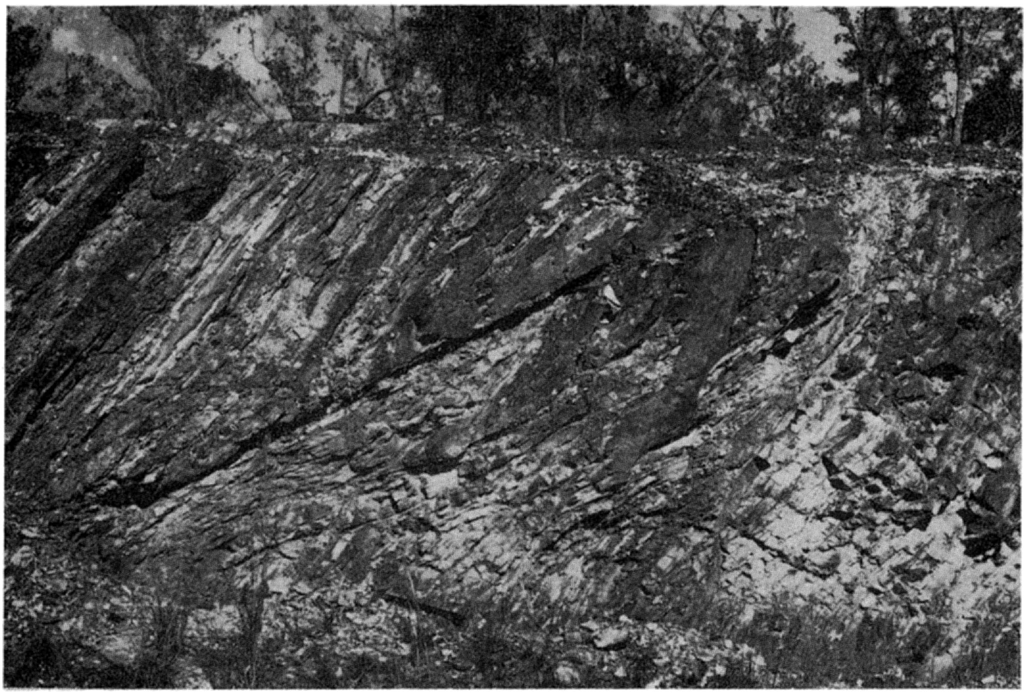


Fig. 17. Sections across the metamorphic units near Mestanza
A, B — *1* Pino Solo unit, *2* Mestanza unit, *3* Alturas de Pizarras del Sur units
C — Mestanza unit: *1* recrystallized limestones, *2* graphitic schists

Small-scale, cleavaged folds in the metamorphic unit near Rio Galafre





Fold deformations in the San Cayetano Formation in Alturas de Pizarras del Norte near Minas de Matahambre wards. The beds show southerly dips. The formations present in this unit are usually strongly reduced with numerous shears and décollements both within and inbetween them. There is no section with particular members of Mestanza unit passing one into another. In places (*e.g.* by Loma La Mina), however, Mestanza unit makes a whole along with Pino Solo unit. One may claim that these units are separated by an overthrust of variable amplitude.

PINO SOLO UNIT

Pino Solo and Cerro Cabras units make the highest overthrust unit known in the Sierra de los Organos. The former unit occurs between San Diego de los Baños in the east and Sábalo in the southwest. In the east, it forms a narrow belt broadening westwards to attain by Sábalo 5.5 km in width. In the north, it superposes the units of Alturas de Pizarras del Sur, while it is limited by Pinar fault in the south.

Three lineation directions occur in Pino Solo unit (Millán 1972, Piotrowska 1972). The oldest one is expressed by recrystallization-textural orientation and gouffrage. Another lineation crossing the former at angles of 20—30°, appears related to the unit transport. It has been noted in folds of various type, mostly similar to shear--zigzag folds (Pl. 4). The youngest lineation is represented by broad bends and marginal lineations. It may be related to a subsequent phase of deformation. Shears and plastic bends occur very commonly in the whole complex One may claim that this unit has been deformed in a more uniform manner than all the other units of the Sierra de los Organos. Undoubtedly, the metamorphism and directional recrystallization have decreased the original variability in reaction to strain among particular lithological members.

Initially, Pino Solo unit made probably a single nappe along with Mestanza and Cerro Cabras units. The differentation has taken place during the last phase of the tectonic transport, *i.e.* later than in the non-metamorphosed nappe units. This is indicated by a sedimentary continuity existing probably by La Mina between Arroyo Cangre Formation of Pino Solo unit and Jagua Formation of Mestanza unit. The discontinuity between the above units may be of scissor nature, the overthrust amplitude of Pino Solo unit onto Mestanza one increasing probably northeastwards. The lithological sequences observed in both the units demonstrate that one deals here with overturned series (Piotrowska 1972, Piotrowski 1973).

CERRO CABRAS UNIT

This unit forms a tectonic cap. It comprises quartzites with small amounts of phyllitic shales, superposing sandstones and shales of San Cayetano Formation of the units of Alturas de Pizarras del Sur. The rocks of Cerro Cabras unit dip monoclinally southwards. At the base, the unit is limited by an overthrust plane shearing Cerro Cabras unit as well as the units of Alturas de Pizarras del Sur. Textural lineations, fine chevron and drag folds, and joint cleavage are the most common deformations in Cerro Cabras unit. There are no broad bends associated in other units with a younger phase of deformations, due probably to a considerable resistance of the thick-bedded quartzites.

MESOSTRUCTURES OF THE SIERRA DE LOS ORGANOS

Complex tectonic processes in the Sierra de los Organos and diverse lithologies involved have ultimately resulted in development of various fine tectonic structures. The term "mesostructures" as meant in this paper does not refer precisely to fine tectonic structures; nor is it defined by means of measurable parameters. The investigated mesostructures comprise mostly folds, boudinage, cleavage, textural and marginal lineations, and minor overthrusts.

SMALL FOLDS

Fold type depends on lithology as well as on tectonic deformation type and intensity in a given tectonic unit of the Sierra de los Organos.

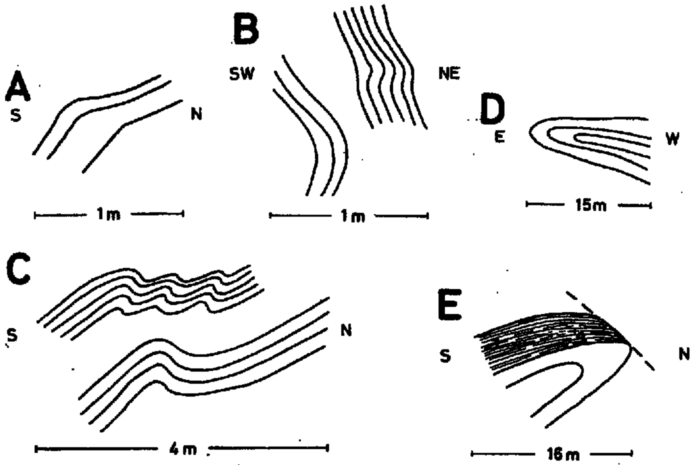


Fig. 18. Bend of beds (*ABC*) and similar folds (*DE*) in sandstones and shales of San Cayetano Formation

Flexure folds are the simplest continuous tectonic structures. However, they cannot be regarded as true folds (Fig. 18 *A*—*C*). In fact, they are usually broad with a radius of several tens centimeters up to a dozen meters in length and radius to amplitude ratio of 3 : 1. The layer thickness does generally not change (Fig. 18 *B*—*C*) and hence, the considered flexure folds may represent incipient concentric folds. Flexure folds of radius to amplitude ratio of 2 : 1 occur but in a few layers (Fig. 18 *A*—*C*). Under a stronger or long-lasting stress, the latter bends might have changed into intrastratal folds by developing disruption planes at both the base and top of a bend. Most bends reflect the direction of *B* lineation, the only difficulty being to directly measure flexure-fold hinges. The flexure folds occur in all but a few tectonic units and lithologic members of the Sierra de los Organos. A separate group is represented by flexure folds developed near fault zones or small overthrusts.

Folds resulting from bending occur rather commonly, represented mainly by concentric and similar folds. Concentric folds are usually obscured by subordinate deformations such as internal décollements (Fig. 19*A*), fine foldings of limb fragments (Fig. 19*B*), or partly bounding by discontinuity surfaces (Fig. 19*C*). The latter case represents probably a concentric intrastratal fold. Similar folds (Fig. 18 *D*—*E*) show usually a slight increase in layer thickness in the hinge. Fold cores built of incompetent beds have often reacted in a different way than did the competent outer layers. In such cases, the folding was much more intense (Fig. 20*A*); boudinage structures (Fig. 20*B*) or small overthrusts (Fig. 19*A*) developed in the cores of folds resulting from bending. Folds with elongate hinge are very common (Figs 20*C*—*D*, 21*A*—*B*), showing sometimes competent core parts under the form

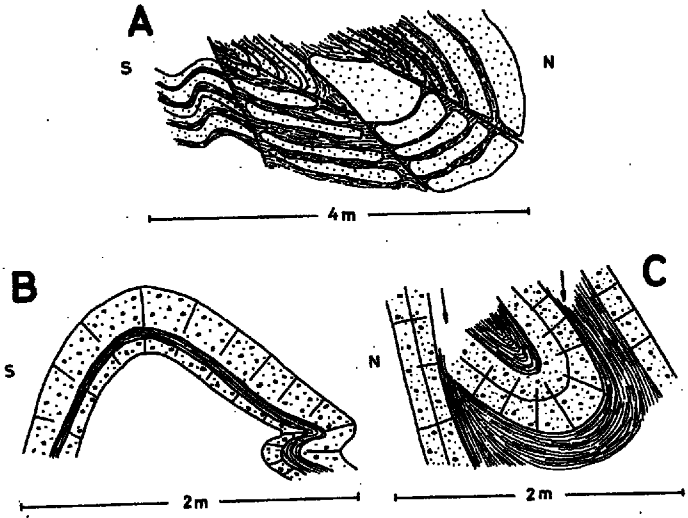


Fig. 19. Concentric folds in sandstones and shales of San Cayetano Formation

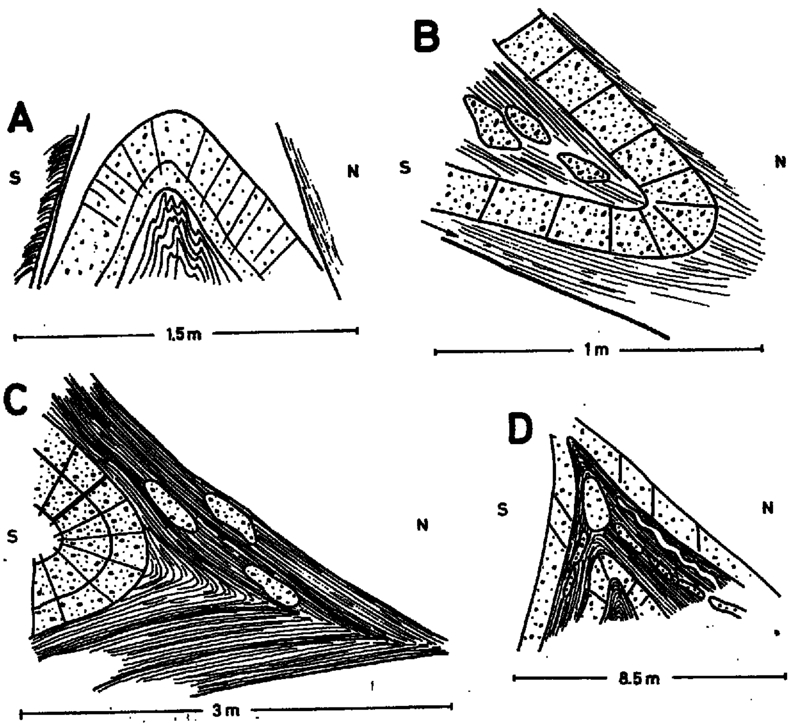


Fig. 20. Folds resulting from bending of cylindrical (*AB*) and elongate (*CD*) hinges in sandstones and shales of San Cayetano Formation

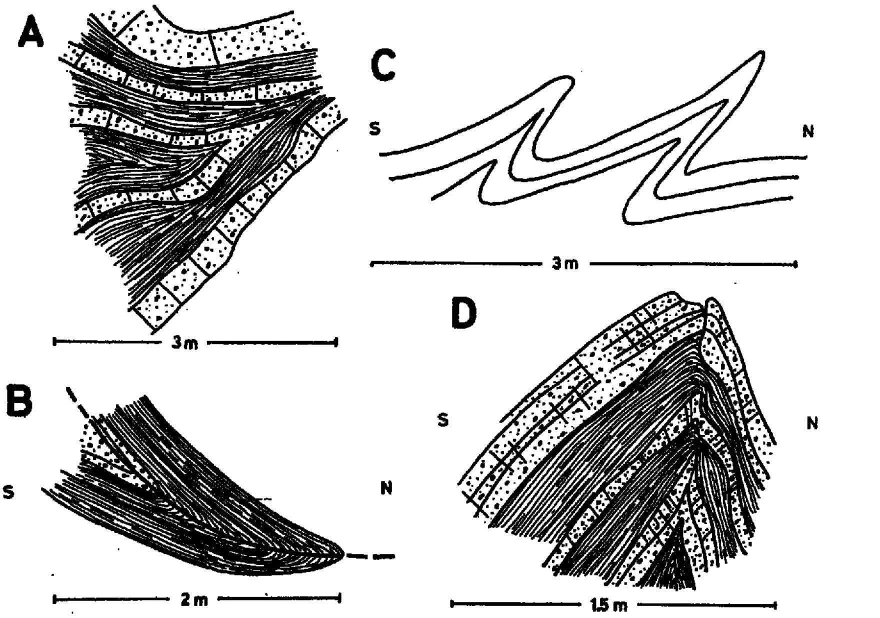


Fig. 21. Folds resulting from bending of zigzag and crest-like hinges in sandstones and shales of San Cayetano Formation

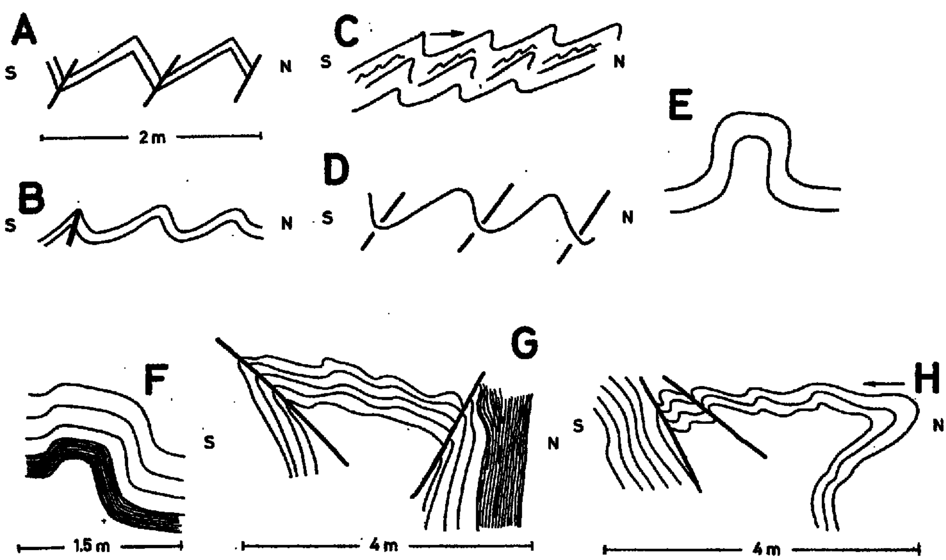


Fig. 22. Most common types of folds (sections perpendicular to the fold axis)

of a concentric fold (Fig. 20C). Many folds display a zigzag (Figs 20C, 21A, D, 22A) or crested shape (Figs 21C, 22B—C). There are also hyperbolic (Fig. 22D) and box folds (Fig. 22E—F) among the folds resulting from bending. Fan folds do also occur but they are usually rather complex (Fig. 22G—H). Most folds resulting from bending are asymmetric. Zigzag folds contact sometimes crest-like ones (Fig. 22B). Crest-like folds may also comprise subordinate drag-folds (Fig. 22C). Hyperbolic folds (Fig. 22D) appear commonly hardly distinguishable from parabolic ones; it seems, however, that the former ones prevail definitely. Box folds (Fig. 22E—F) are most frequently represented by small structures comprised within limbs of large anticlines. One may claim that the box folds constituted initial developmental phase of more complex, frequently disharmonic fan folds. In some box folds, the limbs are distinctly isoclinal (Fig. 22E).

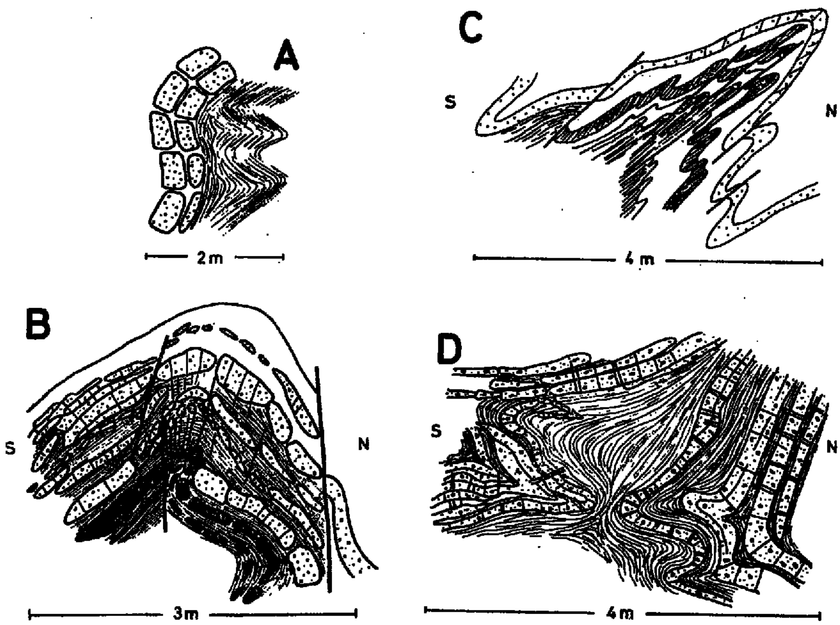


Fig. 23. Disharmonic folds (Pica Pica Formation; sandstones and cherts)

Some features of disharmonic folds are already displayed by the above examples of concentric and similar folds. True disharmonic folds occur even in the simplest bends (Fig. 23A). Disharmonic folds may also result from bend folding (Fig. 23B). In the investigated fold, the competent beds have been almost completely boudinaged; the core appears much more folded than the outer parts; small displacements have taken place along the cleavage planes. Another disharmonic fold comprises a lot of drag folds within its internal portion (Fig. 23C). The axial cleavage planes are distinctly concordant with the axial planes of the drag folds which may suggest that this particular fold resulted from both bending and shearing processes. Some disharmonic folds developed under the conditions of relatively strong plastic deformations (Fig. 23D).

Folds resulting from shearing occur mostly in the metamorphosed units of Sierra de los Organos, *viz.* in Pino Solo, Mestanza, and Cerro Cabras units. Phyllitic schists of the metamorphosed units of Pino Solo and Cerra Cabras appear especially prone to such deformations. Nevertheless, one may hardly say that the investigated structures (Fig. 24) result entirely from a displacement of microlithons along slide surfaces (cf. Ramsay 1962, de Sitter 1964). One may rather claim that they have been formed due to both shearing and bending processes (cf. Bankwitz 1965). Some of these structures (Fig. 24*B*, *D*, *E*) may represent forms assigned by

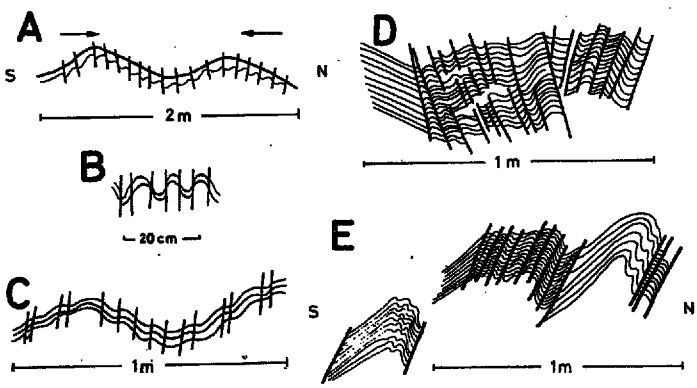


Fig. 24. Small folds developed during bending and shearing in the metamorphic unit

de Sitter (1964) to crenulation cleavage, the latter category including cleavage folding with a contribution by bending process. Small zigzag folds observed commonly in the metamorphosed units exhibit the axial planes accentuated by cleavage surfaces (Fig. 22*A*—*B*). At least some of these zigzag folds may be considered as knee folds or accordion folds (de Sitter 1958). The considered structures are usually less than 40 cm in amplitude, and most commonly less than 20 cm.

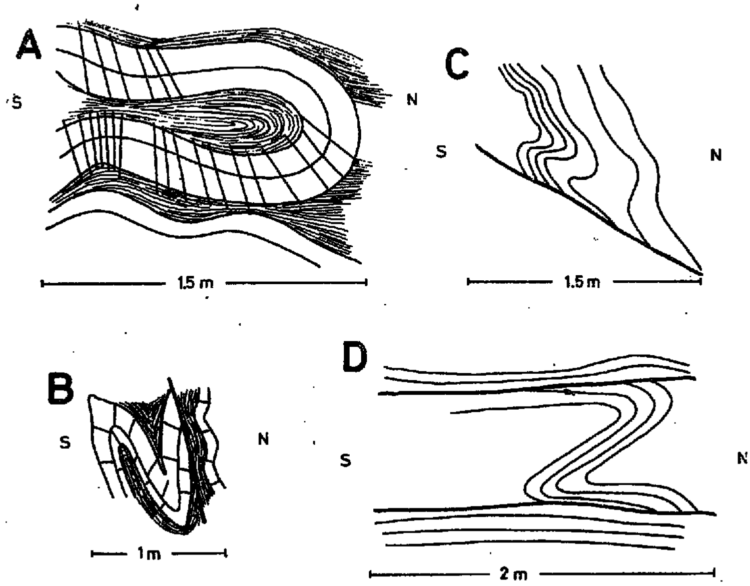


Fig. 25. Folds resulting from considerable viscosity? of rocks (San Cayetano Formation: sandstones and shales; Pica Pica Formation: cherts, sandstones, shales and limestones)

There are also some folds originated under the conditions of somewhat plastic (viscous?) flow (Fig. 25). Such folds are most frequently related to fault zones or overthrust planes (Fig. 25*B*—*D*). Their relative scarcity indicates that plastic-flow conditions were not typical of the structural development of the Sierra de los Organos.

All the above-presented simple fold types occur quite rarely in the Sierra de los Organos, which is due to the complex tectonic history of the nappe-scale units and the repeated partitioning of particular transported rock masses. Fold structures appear most frequent in the zones of high deformation intensity. They contact one another along discontinuity surfaces. Intrastratal folds occur commonly (Fig. 25*D*). In many cases there are no true folds but rather twists or their fragments. Some folds are deformed by secondary displacements (Figs 26*A*—*D*, 27*A*). Smaller folds may also be scaled (Figs 26*C*—*D*, 27*A*—*B*).

A scaled fold of 0.5 up to 3 meters in amplitude appears as the most typical mesostructure in the nappe-scale units of Sierra de los Organos. Such deformations may result from displacements along discontinuity surfaces the strike of which is parallel to the fold axes (Figs 27*D*—*F*, 28*A*—*C*). Such a scaling occurs but in a few folds, whereas the adjacent folds remain undeformed and pass gradually into gentle bends. Anticlinal hinges are commonly cut by steep glide surfaces and contact strongly folded beds that constituted previously the anticline shorter limbs (Fig. 27*D*). There are scales with the shearing planes almost parallel to the bedding planes in limbs (Fig. 28*D*—*E*) as well as ones with the glide planes oblique to the bedding in limbs (Fig. 28*F*—*G*). In a few cases (cf. Figs 27*E* and 28*E*) it is possible that the discussed structures were originally independent, and these subsequently contacted along a tectonic surface. Some folds (Fig. 29*A*—*B*) may have originated from slightly bent layers deformed subsequently by a set of reverse faults, displacements along those faults leading to a more substantial bending of layers and giving them finally the shape of scales. Such structures may also represent

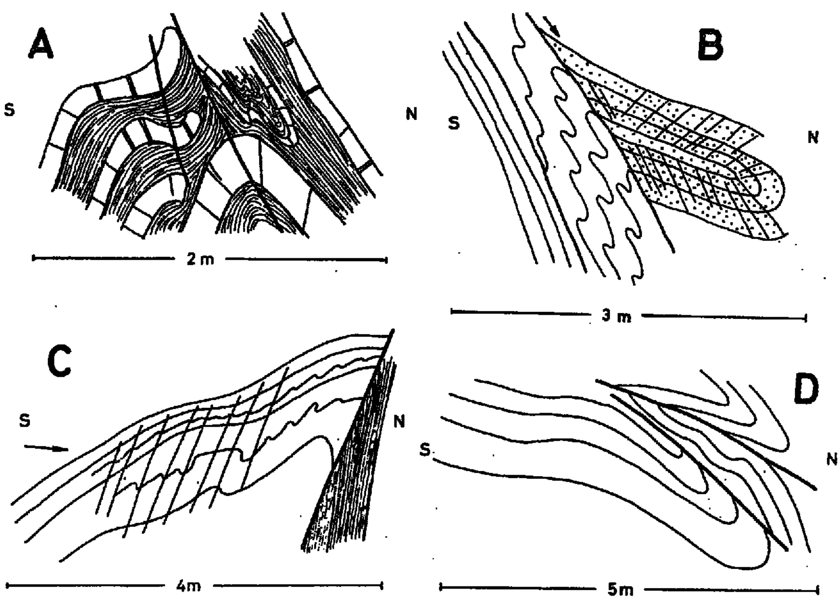


Fig. 26. Folds deformed by secondary displacements (San Cayetano Formation: sandstones and shales)

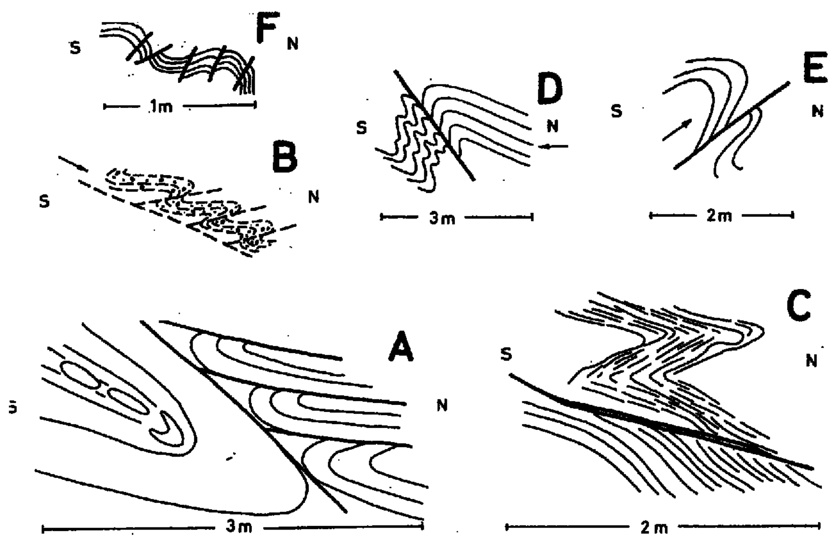


Fig. 27. Examples of scaled folds (San Cayetano Formation: sandstones and shales)

well-developed folds scaled and, in part, reduced tectonically. The latter hypothesis appears, however, implausible. Deformations leading to scale development stop sometimes at the moment of the formation of discontinuity surfaces in a shorter fold limb (Fig. 29C). Be the gliding planes steep, particular scales may vary in both the size and deformation intensity (Fig. 29*D*, *F*); furthermore, almost horizontal layers may pass gradually into almost vertical ones (Fig. 29*E*). Both the variability

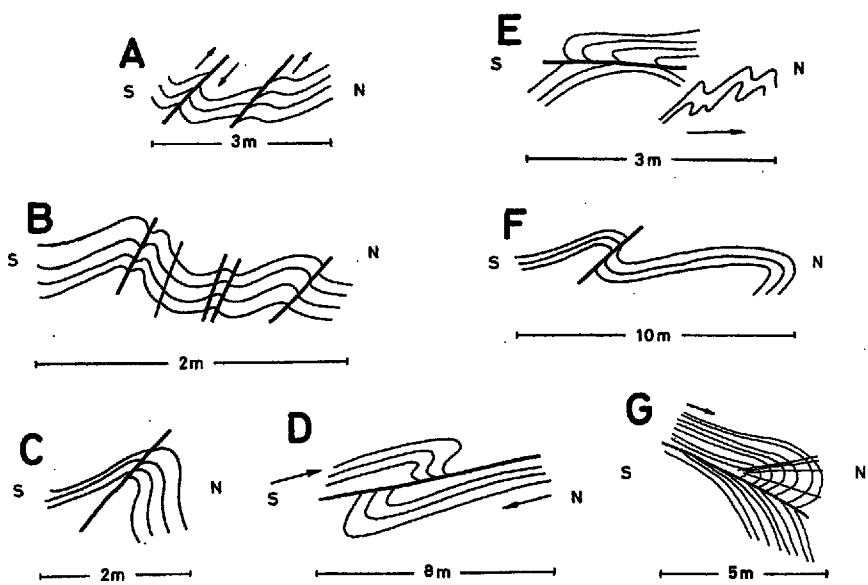


Fig. 28. Thrust slicing and small overthrusts in folds (San Cayetano Formation: sandstones and shales)

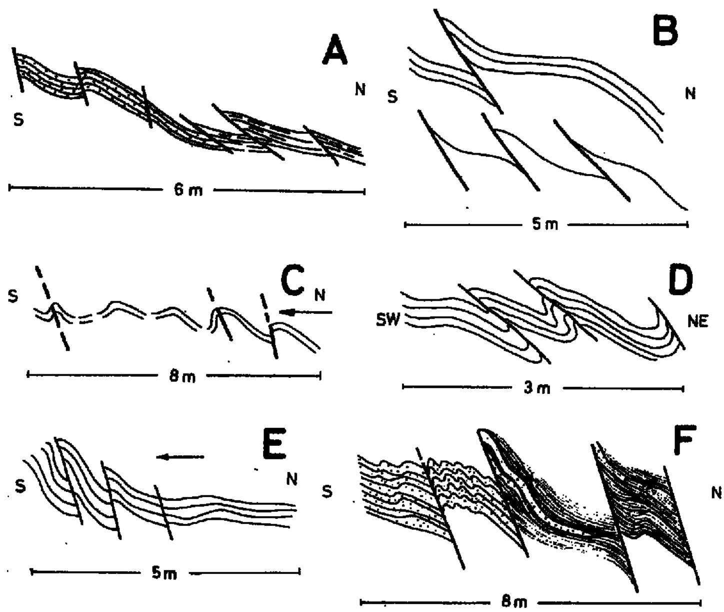


Fig. 29. Thrust slicing and small overthrusts in folds (San Cayetano Formation: sandstones and shales)

(Fig. 30*A*) and position of scales (Fig. 30*B*) may be quite difficult to explain. In the latter case, one may suppose that aside of the scaling, an additional piling up of drag folds has also taken place; it cannot be also excluded that these are the sedimentary structures subsequently tectonically deformed.

Small drag folds subordinate to the above-described fold structures do obviously vary in their origin. Some drag folds (Fig. 31*A*—*B*) could develop owing to a couple of forces acting in the fold limbs. A simple compression acting at the beginning within a bedding plane may also result in development of drag folds (Fig. 31*C*). In the investigated case, such a compression has led to the cleavage development in shales and folding of thin sandstone layers. A slightly thicker sandstone layer has been slightly bent at the top and glided a little at the contact with shales. The forces may have started to act after the folding and cleavaging of internal layers thus, causing their asymmetry. Hence, it appears disputable whether the investigated structures are true drag folds even although their shape corresponds to the latter structures.

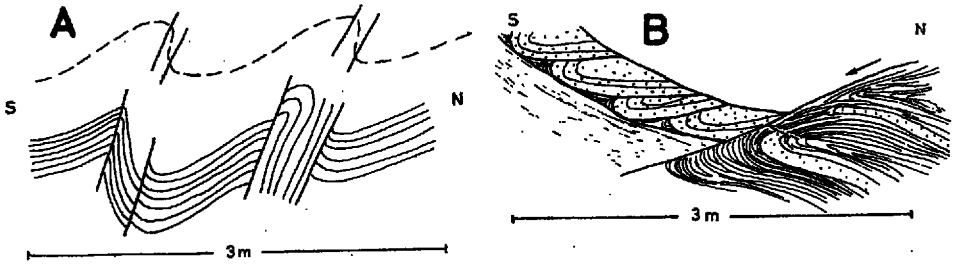


Fig. 30. Deformations in folds leading to the formations of scales (San Cayetano Formation: sandstones and shales)

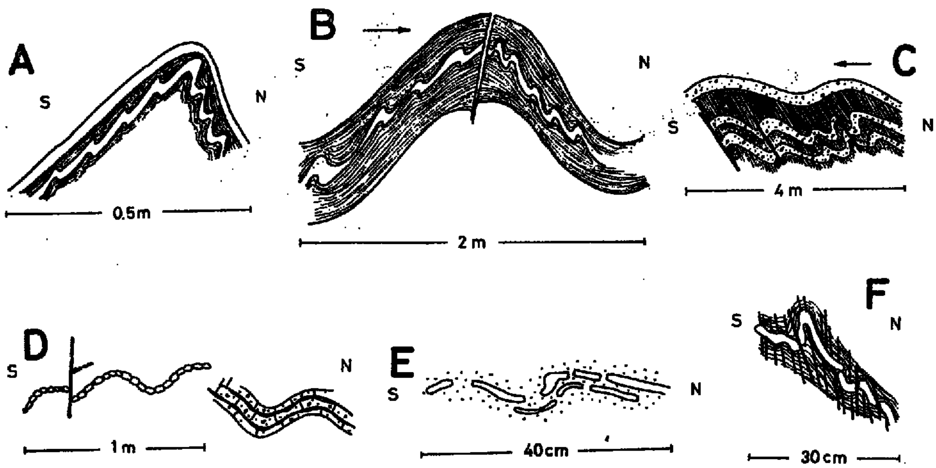


Fig. 31. Small drag-folds (*A*—*C*), and folded quartz veins (*D*—*F*); San Cayetano Formation: sandstones and shales

Folded quartz veins occur frequently in strata of San Cayetano Formation. Undoubtedly, there are several generations of veins, as crystallization sequences may be observed at their crossing points. The relation of the quartz veins to other fold structures remains insofar unknown. They occur at various discontinuity surfaces such as intrastratal planes, joint and cleavage fissures, and fault planes. Some folded quartz veins (Fig. 31*D*) developed probably within previously formed folds, infilling the intrastratal fissures. Others (Fig. 31*E*) were folded and simultaneously dilatated, as demonstrated by the occurrence of isolated quartz fragments. Some small folds (Fig. 31*F*) may be due to crystallization and increase in volume of a quartz vein; the strains thus formed were thereafter released in disturbances of both the quartz vein itself and surrounding shales.

BOUDINAGE

Boudinage structures occur in most bedded rock complexes with lithologic differences at the layer interfaces. They are almost frequent in San Cayetano, Arroyo Cangre, and Pica Pica Formations, and in the melange rocks. In most cases, their origin appears associated with the early phase of folding, as there is a concordance between the longest axes of boudinage structures and the axes of mesofolds. This is especially the case of San Cayetano Formation. On the other hand, the boudinage of melange zones can hardly be attributed to a given phase, as those zones are very strongly deformed tectonically.

The boudinage structures have developed mostly within sandstone layers contacting shales. They represent either single structures separated from the rest of a bed (Fig. 32*A*—*C*) or sets of structures associated with previous bedding Fig. 32*D*—*H*). Intrastratal folds formed between two sandstone layers display commonly boudinage structures (Fig. 32*D*). In places, sandstone beds have locally become thinner resulting in a segmentation. This demonstrates that under the conditions of a considerable distension, discontinuity planes perpendicular to the bedding are not needed to form boudinage structures. In some cases (Fig. 32E),

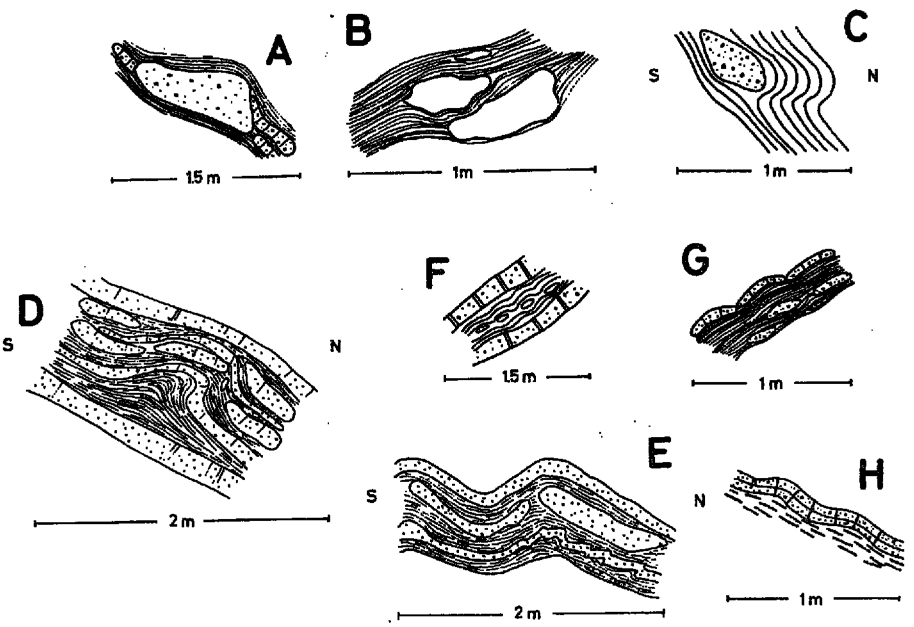


Fig. 32. Examples of boudinage (San Cayetano Formation: sandstones and shales)

complex tectonic events could be involved even despite an apparent simplicity of the structure. The investigated fold displays a slight southerly asymmetry. The top sandstone layer is continuously bent without any change in thickness nor any joint or cleavage surfaces. A sandstone layer in the core has been already boudinaged although this is but an incipient form of boudinage. Thus, distension conditions must have existed in that part of the fold. The lowermost sandstone layer shows small, northerly asymmetrical drag folds indicating a considerable plasticity. In fact, these fine drag folds may be the oldest elements of the whole structure. The conditions necessary to boudinage the central sandstone layer appeared when a pair of forces had begun to act in the main fold limbs.

Boudinage structures occur commonly within strongly disturbed scale-fault zones (Fig. 33*A*—*C*) younger than the boudinage process itself. In fact, most boudinage structures were related to a phase of fold development associated with the main tectonic transport to the north. Locally, conditions allowing a boudinage development could also exist during some subsequent deformation phases, but the younger boudinage structures are nowhere dominant.

CLEAVAGE

Dense network of cleavage appears typical of clastic sediments of San Cayetano Formation. Together with the bedding planes, it produces the so-called "pencil structures" that disintegrate easily. The latter structures are usually elongate parallelepipeds of rhomboidal, rectangular, or square

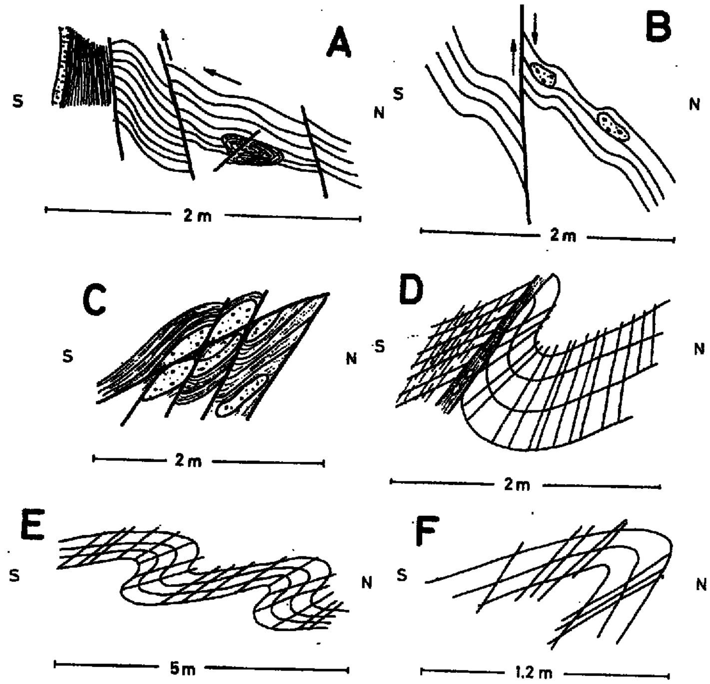


Fig. 33. Boudinage structures in zones of discontinuous deformations (*A*—*C*) and axial cleavage in folds (*D*—*F*); San Cayetano Formation: sandstones and shales

base. They develop in thin- or medium-bedded rocks crossed by a system of cleavage or cleavage combined with joint where one of the cleavage systems is concordant with the *b* axis. Most frequently, an axial cleavage is involved (Figs 33*D*—*F*, 34*A*—*B*, 35*A*—*D*). When crossing a stratification plane, the surfaces of axial cleavage delineate a ledge. This ledge is concordant with the *b* axis. It represents also a lineation type called here the ledge lineation.

Typically, the axial cleavage appears like a fan oriented towards the external hinges and converging to the internal parts of an anticline or syncline (Fig. 33*D*—*F*).

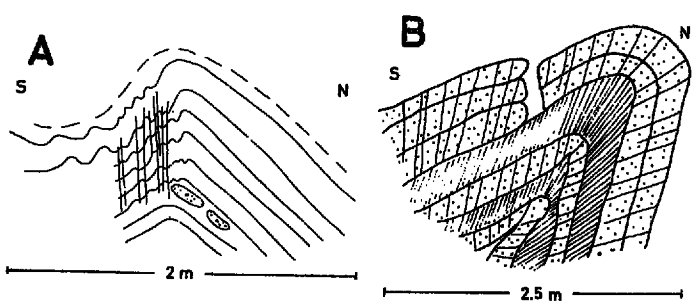


Fig. 34. Cleavage in folds (San Cayetano Formation: sandstones and shales)

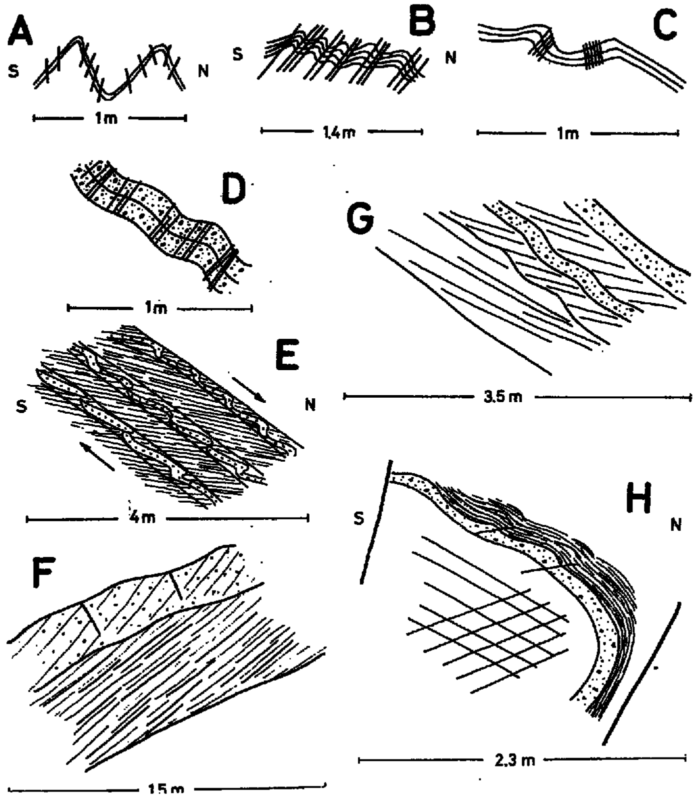


Fig. 35. Cleavage in folds (San Cayetano Formation: sandstones and shales)

In an asymmetrical fold, axial cleavage may develop combined with fine folds due to the rapid shortening of a limb (Fig. 34*A*). In folds resulting from bending, axial cleavage may exhibit a characteristic variability in angle among particular layers of variable lithology (Fig. 34*B*). Sometimes, cleavage surfaces are somewhat clustered. Their density may increase within synclinal zones of folds (Fig. 35*B*), shorter limbs of opposite-pointing asymmetric folds (Fig. 35*C*), or synclinal hinges and limbs of broad, fine bends (Fig. 35*D*). Crenulation cleavage (Sitter 1964) is closely associated with fine folds (Fig. 24*D*—*E*) in the metamorphosed units. In fact, it is related in origin to the fold formation just as it is the case with zigzag and knee folds. Fine cleavage and drag fold structures may allow to restore a larger fold structure (Fig. 35*E*). When cleavage developes in a sandstone-shaly complex, it may occur either in both the sandstones and shales (Fig. 35*F*), or exclusively in the shales (Fig. 35*G*). In the former case, an angular difference occurs between the cleavage planes developed in differential lithologies.

In general, only axial cleavage can be used to reconstruct larger fold structures. This is chiefly due to its role in the origin of ledge lineations and pencil structures. Fissure cleavage accompanies usually fault zones but it has not been quantitatively studied. It may indicate but an intensity of deformation process.

Shear cleavage in form of plane systems crossing each other at a small angle (Fig. 35*H*) appears quite distinct in non-bedded rocks (*e.g.* massive limestones of the lower part of Guasasa Formation) or in thick sandstone beds of San Cayetano Formation. Shear cleavage systems with simultaneous or subsequent displacements along the shear planes occur in serpentinite bodies sticking within the melange as well as in kataclastic matrix of the melange zones. In most cases, the orientation of these systems (*cf.* also Fig. 35*H*) points to a horizontal strain, as the ledge lineation is horizontal. The systems are rather easily recognizeable even although their distribution is non-uniform. Fisssures parallel to the shear cleavage planes are frequently infilled with quartz.

TEXTURAL LINEATION

Textural lineations occur first of all in thick complexes of phyllitic quartz schists and quartzites of the metamorphosed units of Pino Solo and Cerro Cabras. They resulted from a directional recrystallization under strain conditions. Gouffrage shows the same orientation in the metamorphosed units.

The textural lineation has been recognized for the B_1 lineation, as it is the oldest one in the Sierra de los Organos (Millán 1972). Most probably, it was formed at an early stage of the main orogenic phase, prior to the main transport phase of the units towards the north. This is, indeed, suggested by the superposition of younger fold deformations (lineation B_2) onto the B_1 lineation. The angular difference is about 30° between B_1 and B_2. The B_1 lineation displays similar orientation and structural characteristics in both the metamorphosed and other tectonic units (however, lithological variability between and within particular units has also to be taken into account). The B_2 lineation has been insofar ascertained only in the metamorphosed units and in a small rock complex of unclear tectonic position southwest to Minas de Matahambre. One may claim that the latter complex represents a remnant of the metamorphosed units overlying the units of Alturas de Pizarras del Norte. Then, the original extent of the metamorphosed units should be shifted much to the north, relative to their present-day boundary. However, both the existence of such remnants of the metamorphosed units and B_1 lineation may be also explained by local conditions of stronger stress in the considered units of Alturas de Pizarras del Norte.

In the units of Alturas de Pizarras and in clastic formations of the calcareous units of the mogote belt, a linear orientation of particles occurs in places resulting from an action of some strains (Cloos 1947). However, no directional recrystallization of minerals has been evidenced in those structures.

LEDGE LINEATION AND PENCIL STRUCTURES

The term "ledge lineation" is here meant to denote such lineations that result from two crossing *S*-surfaces and mark the *B* lineation. A ledge formed by an intersection of stratification planes in a fold with axial or any other cleavage system developed in the same strain field may be the simplest example here. Also an intersection of two cleavage surfaces, *e.g.* axial and recrystallization ones, shall produce a ledge marking the *B* lineation.

Ledge lineations are typical of the units of Alturas de Pizarras comprising clastic sediments of San Cayetano Formation. They occur also in sediments of Pica Pica Formation, the melange zones of the mogote belt, and some rock complexes of the metamorphosed units (where the metamorphism is not very strong). In general, the ledge lineations are associated with thin-bedded clastic sediments.

Some textural lineations occur in thin-bedded rock complexes criss-crossed by a dense cleavage network (axial as a rule) concordant with the *b* axis. A ledge thus formed is usually concordant with the fold axis, *i.e.* with the B_2 lineation. In the case of a cleavaged fold cut additionally by a joint or cleavage system oriented at an angle to the fold axis, one deals with the pencil structures. In some areas built by San Cayetano Formation, there are vast fields covered with scree composed of elongate parallelepipeds of rhomboidal, rectangular, or square base, called here pencil structures. Their size and shape vary depending on the bed thickness, cleavage density, and angular orientation of cleavage systems versus the structural coordinates. Theoretically, pencil structures can develop when a pair of forces acts in clastic thin-bedded rocks. The longer edges of the pencil structures delineate the B_2 lineation within the nappe-scale units of Sierra de los Organos and hence, they may be useful in a spatial reconstruction of large structures.

SMALL FAULTS AND OVERTHRUSTS

There are tremendous quantities of displacement surfaces in the nappe-scale units of Sierra de los Organos, systematic study of which needs detailed work exceeding the scope of the present paper. Only a preliminary classification can be accomplished here.

Undoubtedly, the oldest small displacements took place at the early stages of the tectonic transport, *i.e.* simultaneously with the first fold deformations. The disconformity and displacement surfaces initiated at that time were then active during all the phases of the structure partitioning, and have finally led to small scaling, wedging, and other displacements of entire folded complexes or their parts (Figs 36*A*—*B*, 37*A*—*C*) usually along disconformity surfaces dipping at 30—60°. In less folded parts of the nappe-scale units, small reverse faults have been formed at that time (Fig. 37*D*—*G*), sometimes with curved displacement surfaces (Fig. 37*F*). These faults were followed by horizontal displacement surfaces developed still during the transport phase. Small displacements have taken place along the latter surfaces (Fig. 38*A*—*C*). The horizontal displacement surfaces influenced greatly development of increased deformation-density zones that are so typical of the Sierra de los Organos. There are also some disjunctive deformations (Figs 38*D*—*F*, 39*A*—*B*) related probably to the final phase of the tectonic transport.

The phase of southward displacements followed the main phase of the nappe transport to the north. It is reflected mostly by a system of reverse faults of northerly dips.

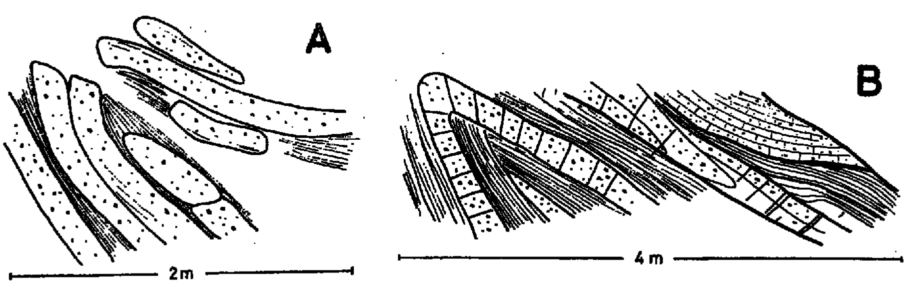


Fig. 36. Discontinuous deformations in folds (San Cayetano Formation: sandstones and shales)

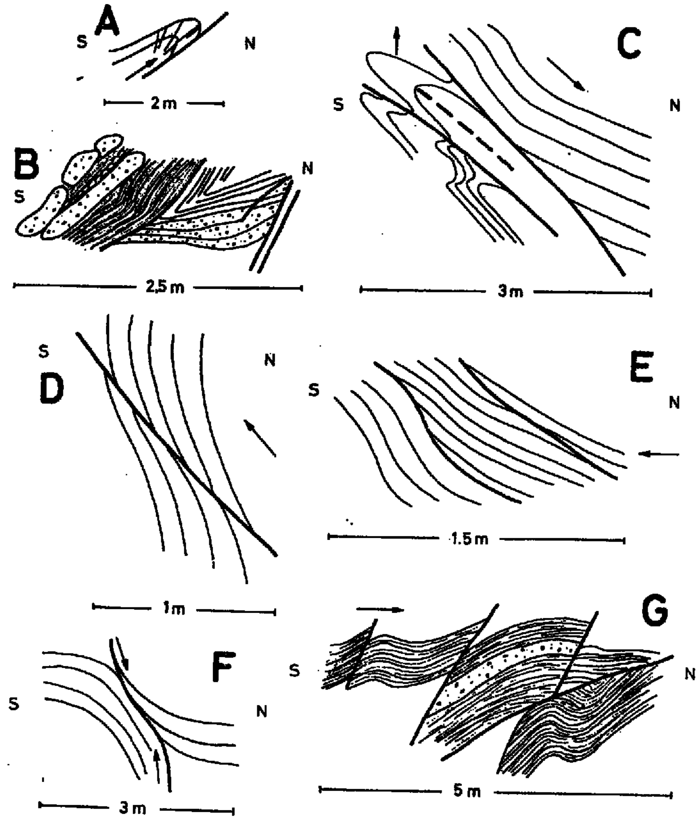


Fig. 37. Discontinuous deformations associated with the main phase of the tectonic transport (San Cayetano Formation: sandstones and shales)

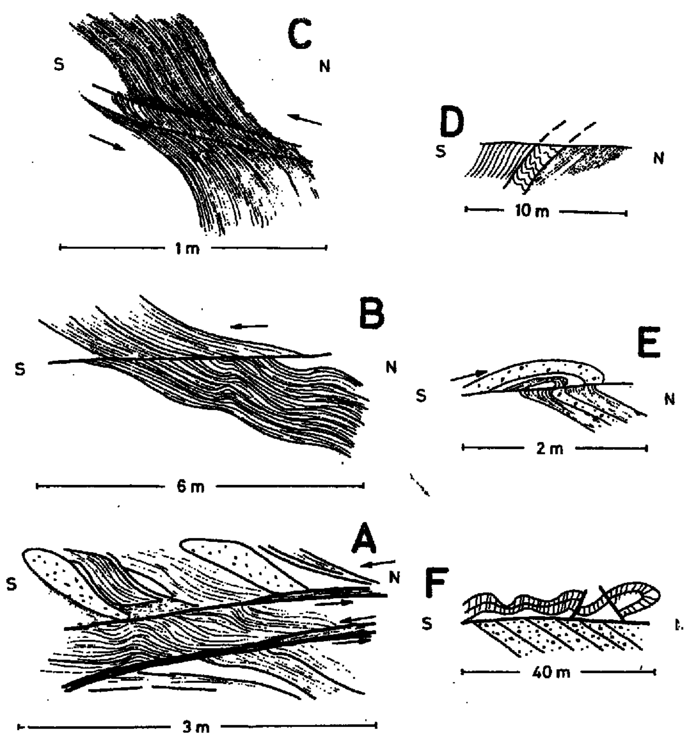


Fig. 38. Small displacements associated with the main phase of the tectonic transport (San Cayetano Formation: sandstones and shales)

Disjunctive deformations developed after the tectonic transport are represented mainly by wrench, strike-slip, and normal faults related to a phase of vertical post-orogenic movements (Fig. 39C).

Slip grooves have not been studied in detail, as they are mostly destroyed by rapidly progressing weathering processes.

LINEATION DIAGRAMS

Linear mesostructures have been measured all over the Sierra de los Organos. Altogether, ca 3,000 textural, ledge, fold axes, gouffrage, and boudinage lineations have been measured and projected onto the upper hemisphere of a net (Fig. 40). A large number of diagrams are concerned with the metamorphosed units comprising a lot of well-preserved small tectonic structures. Lineations are also frequent in the units of Alturas de Pizarras, while they are usually associated with definite lithological levels in the calcareous units of the mogote belt. One diagram is concerned with La Esperanza facies-structural zone.

There is a distinct maximum represented by horizontal or almost horizontal (in the mogote belt) lineations of 50—70° in direction (lineation B_2). The maximum is stretched along the NW-SE axis, which results from a rotation of particular, usually small segments of the Sierra de los Organos limited by fault systems oblique and perpendicular to the structure axis. Longitudinal faults and differential horizontal displacements along their surfaces could also result in rotation of some structural fragments of the Sierra de los Organos. The B_2 lineation (Fig. 40) appears concordant with the axes of larger folds and bed strikes (Fig. 3), except possibly of the metamorphosed units since their mesostructures display directions of 50—70°, whereas the axes of larger structures as observed in aerial photographs (Fig. 4) display azimuths of 40—60°. The lineation of 50—70° in direction gives the strongest maxima and hence, should be regarded as the main one. It appears related to the main tectonic phase, namely the nappe transport.

Less distinct maximum is represented by lineations of 170° in direction (lineation B_3). In some cases, these lineations join the fields located in diagram centers. As it comes from field observations, these directions are most commonly exhibited by broad bends and folds associated with a displacement phase subsequent to the main orogenic phase. The folds showing vertical axes may have originated from horizontal displacements along surfaces of vertical faults; while the horizontal lineations of 170° in direction must have been related to a local compression of particular structural segments of the Sierra de los Organos along the SW-NE axis, *i.e.* perpendicular to the main structural trends. Such a compression may have been generated by displacements along Pinar fault.

The oldest lineation expressed by linear directional textures (B_1) is to be found in the metamorphosed units. There is no distinct maximum represented by those lineations because of too few measurements. Nevertheless, one may claim that it is 80—90° in direction as de-

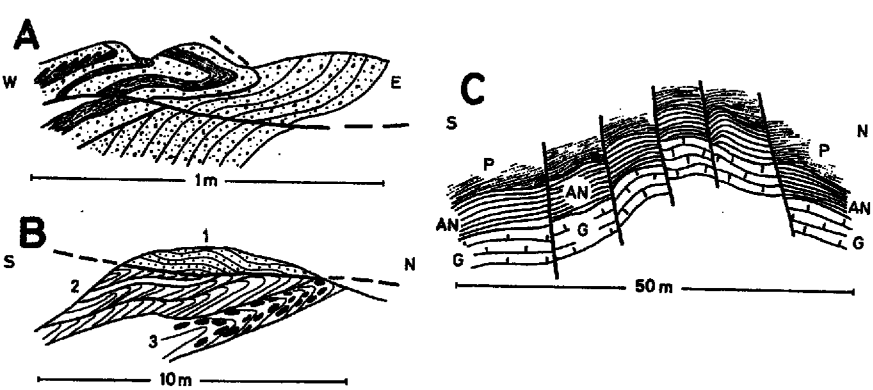


Fig. 39. Small overthrusts developed during the final phase of the tectonic transport (*A*, *B*) and faults developed after the main tectonic phase (*C*)

A — San Cayetano Formation: *1* sandstones, *2* shales

B — *1* sandstones of San Cayetano Formation, *2* sandstones and shales of Pica Pica Formation, *3* cherts of Pica Pica Formation

C — *P* Pica Pica Formation, *AN* Ancón Formation, *G* Guasasa Formation

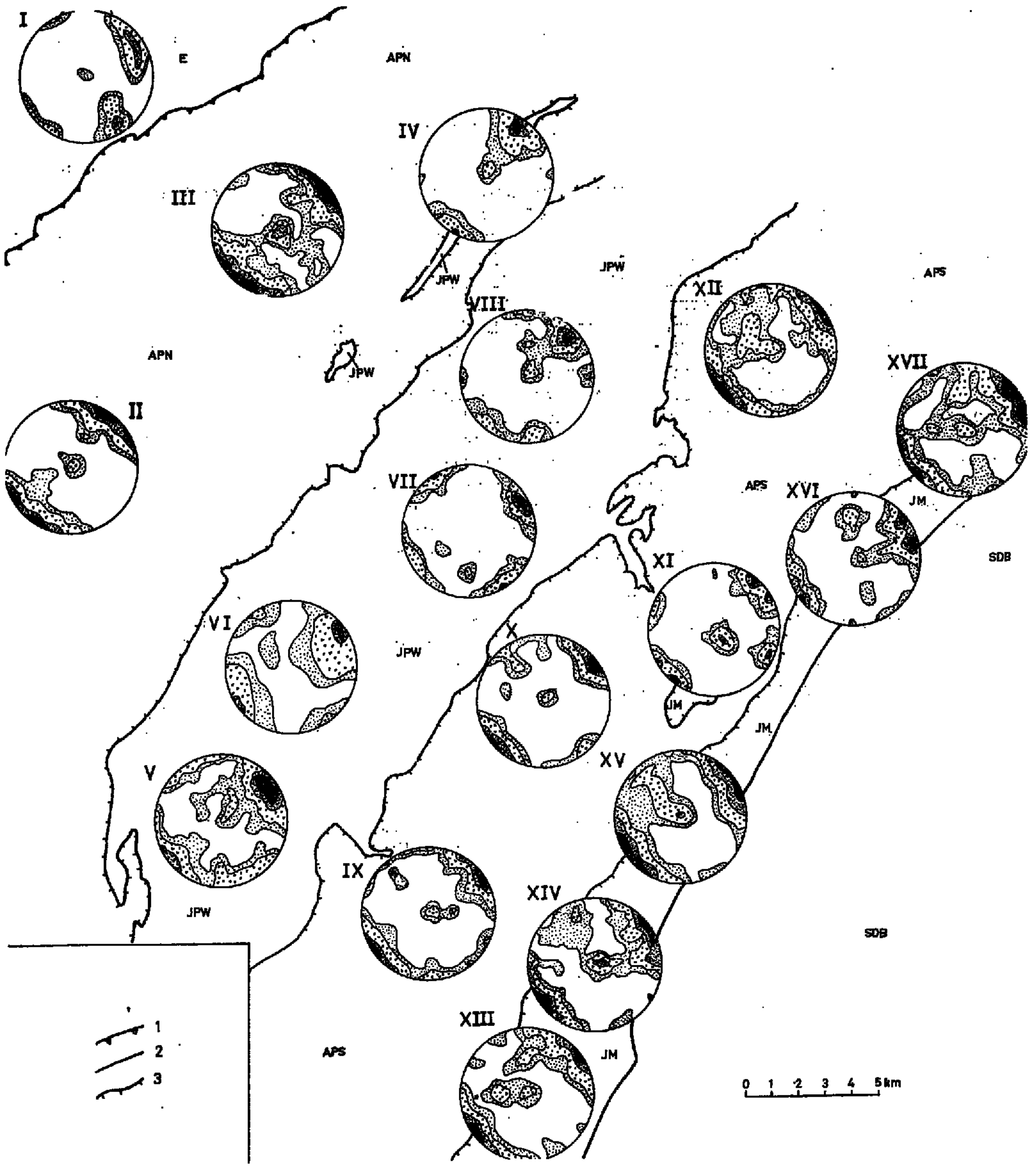


Fig. 40. Tectonic sketch-map of the central part of Sierra de los Organos (with lineation diagrams)

E La Esperanza facies-tectonic zone, *SDP* San Diego de los Banos facies-tectonic zone Guaniguanico facies-tectonic zone, Sierra de los Organos region: *JPW* nappe units of the mogote belt, *APS* Alturas de Pizarras del Sur units, *APN* Alturas de Pizarras del Norte units, *JM* metamorphic units

1 overthrust of the units of Sierra de los Organos onto La Esperanza facies-tectonic zone, *2* Pinar fault, *3* boundaries of the overthrusts of the main groups of units monstrated by some diagrams and the angle relative to the B_2 lineation (25—35°). The B_1 lineation co-occurs usually with the main B_2 lineation.

One may conclude that there are three lineation types in the Sierra de los Organos, *viz.* the oldest lineation (B_1) noted only in the metamorphosed units, represented by textural lineations and gouffrage; the main lineation (B_2) found in all the structural units, expressed by folds, ledge lineations, pencil structures, and boudinage; and the youngest one (B_3) related to displacements and local strain fields following the main orogenic phase, marked first of all in broad bends.

DISJUNCTIVE TECTONICS

The entire structure of Sierra de los Organos is cut by a system of faults (Fig. 41) out of which only some can be attributed to a definite stage of the orogenic phase or to the post-orogenic stage (Pl. 5). Photointerpretation and fieldwork have made possible to plot the fault directions (Fig. 42). However, the diagrams are not clear enough to allow to recognize the origin of particular fault sets.

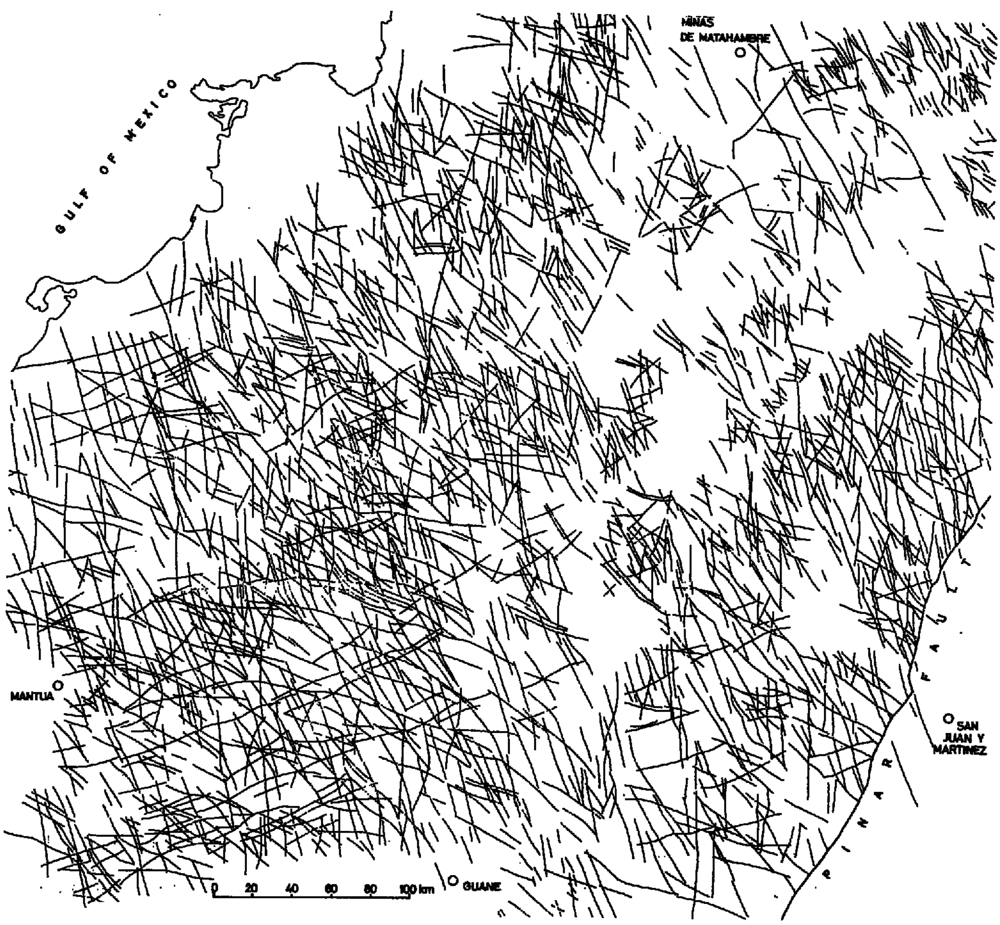


Fig. 41. Network of faults in Sierra de los Organos; the map drawn on the basis of interpretation of aerial photographs

The prevalence of the 150—170° direction results from a superposition of two fault sets. With the azimuth of 60° accepted for the mean value for the structural axes (Fig. 40), one may interpret the faults of some 150° in direction as perpendicular ones concordant with the main direction of the tectonic transport (in *a—c* plane of structural coordinates). These faults appear to be related closely to an overthrust phase, probably the latest one. Displacements along these faults caused rotations of some portions of the nappe-scale units, reflected in differential shifts

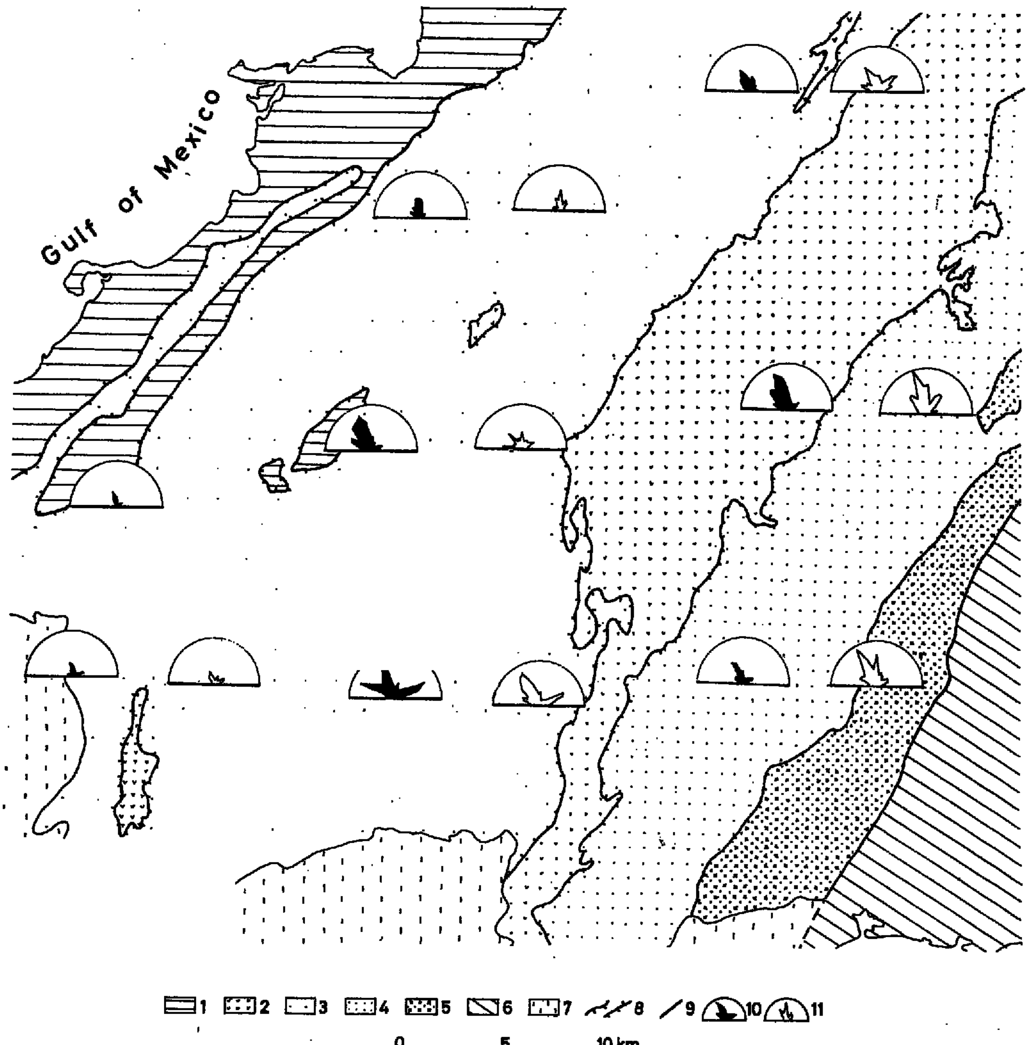


Fig. 42. Tectonic sketch-map of the central and western parts of Sierra de los Organos (with diagrams of faults)

1 La Esperanza facies-tectonic zone, *2* calcareous units of the mogote belt, *3* Alturas de Pizarras del Norte units, *4* Alturas de Pizarras del Sur units, *5* metamorphic units, *6* San Diego de Los Banos facies-tectonic zone, *7* Neogene-Quaternary, *8* boundaries of the facies-tectonic zones and between the groups of units, *9* Pinar fault, *10* diagrams of faults observed in aerial photographs, *11* diagrams of faults observed in the field of the segments. The Sierra Quemado may serve as an example here. In fact, there are distinct local deviations from the mean azimuth of the structure axes, caused by the massif rotation resulting from differential shifts among the eastern (quicker shift) and western parts (slower shift).

Another well-developed system is represented by shear faults of vertical *b* axes. These faults are probably related to a strain field generated during the tectonic transport (diagonal faults) although it might also develop after the final repose of structural units. This system comprises two fault sets, one set of the strike of some 170° and the other of some 130° in direction, the latter being much less distinct. Both the sets criss-cross at a dihedral angle of 40—60°. Their orientation varies but not greatly among particular parts of the Sierra de los Organos.

The third system consists of faults associated with lineaments parallel to the structure axis which at the same time are frequently longitudinal elevations (Limonar-Cayo de las Damas, La Manaja, and Calientes-Cayo San Felipe zones, lineament of Mestanza-Sábalo zone). It has probably developed when the nappes reached the area of present-day Cordillera de Guaniguanico. The origin of those longitudinal elevations is partly due to discontinuity surfaces along which even considerable vertical displacements may have taken place; however, such displacements are not traceable in the field. Displacement amplitudes may increase downwards, as it seems that the longitudinal elevations are compensated near the surface by the overthrust units. In the mogote belt, there are also several longitudinal lineaments with distinct horizontal or vertical displacements. In fact, recent vertical movements take place by the mogotes of San Carlos and Sumidero (Dr. Lilienberg, *pers. comm.*). Presumably, the considered system of disjunctions had already existed in the substrate when the nappe units have been overthrust, being but reactivated at that tectonic phase. In proximity of Pinar fault, some horizontal shifts might have taken place along these zones during the phase following the main orogenic paroxysm. Such fault zones parallel to the structural axes have been presented by Beneš & Hanuš (1967). Nevertheless, their very pattern seems to be more complex than that claimed by these authors. Moreover, a hydrothermal mineralization may be equally or even more closely associated with perpendicular (in the *a*—*c* plane of structural coordinates) or oblique faults (diagonal due to the shearing) than with the faults parallel to the structural axes.

The considered longitudinal elements have been frequently regarded as vertical faults of considerable throws thus, allowing to interpret the entire tectonics of Sierra de los Organos in terms of steep fault displacements (Abakumov & *al.* 1968, Khudoley *in*: Khudoley & Meyerhoff 1971, Cherepanov & *al.* 1971, Malinovsky & Carassou 1974), while disregarding a possibility of nappe overthrusts.

However, the investigated faults (Figs 41—42) may suggest that the curvature of Cordillera de Guaniguanico hardly influences the main fault zones (except of the longitudinal disjunctions gradually changing their orientation according to the change in the structure axis trend), as it is the case with the lineations (Fig. 40). In fact, this arc may be too little curved to cause a reorientation of the systems of faults and lineations. Such an interdependence should, however, be marked in the field. Be the pattern of the cordillera arc related directly to the nappe transport, one should presume that the systems of shear and perpendicular faults have originated during the last overthrust phase or slightly later, due to a strain field constant all over the Sierra de los Organos. The observed pattern of linear structures may suggest that the curvature has resulted from subsequent strike-slip movements that did not induce any change in the original structural orientation. Such movements might represent simple shifts (without any rotation) of particular segments of the Cordillera de Guaniguanico separated by disjunction zones.

In places, there is a system of shear faults displaying vertical slip faces. It can be interpreted as developed under compression along the W—E axis, *i.e.* during a change in the strain field in the area. The system occurs but locally.

A dislocation system along the N—S axis occurs in some zones. The displacements appear rather insignificant and hence, the system can be regarded as fracture zones. Possibly, one deals here with but surficial signs of deep fractures.

Slips horizontal or oblique to steep faults appear as the most common displacements in the Cordillera de Guaniguanico. Vertical shifts occur but in a few cases. The horizontal shifts are sinistral as a rule.

Any strike-slip fault separating the Sierra de los Organos from Sierra del Rosario (*cf.* Rigassi-Studer 1963) has not been ascertained (Pszczółkowski & *al.* 1975). The units of Sierra del Rosario overlap those of the Sierra de los Organos without any fault zone shifting one region relative to the other (Pszczółkowski 1972, 1974).

The deep fault of Consolation del Norte claimed by Furrazola-Bermúdez & *al.* (1964) to separate Guaniguanico facies-structural zone from Bahía Honda one does also appear to be of but subordinate importance. In fact, there are vertical faults along the northern boundary of Guaniguanico zone (D. Danilewski, *pers. comm.*) but their significance is much less than it was previously assumed.

PINAR FAULT

Pinar fault appears unique among the disjunctive structures in Cuba. According to Furrazola-Bermúdez & *al.* (1964), this is a deep fracture 160 km long and down to 3,000 m deep with its slip surface steeply tilted southeastwards (*cf.* Truitt & Brönnimann 1956, Hatten 1957). In the opinion of Meyerhoff (*in:* Khudoley & Meyerhoff 1971), Pinar fault is of strike-slip type and has still remained active (*cf.* MacGillavry 1970). Meyerhoff & Hatten (1974) claimed that it does continue northeastwards up to the Florida Straits. Rigassi-Studer (1963) on the other hand, ignored Pinar fault entirely.

Pinar fault separates two zones different in both the facies and tectonics (Pszczółkowski & *al.* 1975). With the age of the youngest Guaniguanico formations taken into account, the fault can be regarded as not older than of the Middle Eocene age. Hence, it is younger than or in its initial stage coeval with the main orogenic phase. Thus, Pinar fault cannot be regarded as one of those dislocations along which the activity of geosynclinal movements was consequently ceasing eastwards since Late Cretaceous time, as postulated by Malfait & Dinkelman (1972). The Neogene facies distribution in San Diego de los Baños facies-structural zone and at the western margin of Guaniguanico zone may suggest that the main displacements along Pinar fault had taken place prior to the Miocene transgression (Paso Real Formation), although the fault has remained active even after the Neogene.

The hypothesis about Pinar fault nature presented by Meyerhoff (*in:* Khudoley & Meyerhoff 1971) explains in a way the Upper Cretaceous and Lower Paleogene facies diversity at both the sides of the fault and hence, it appears rather plausible. This concept does, however, not explain the occurrences of similar or even indentical formations south to Guaniguanico zone (San Diego de los Baños zone) and north and east to the Cordillera (La Esperanza and Bahía Honda zones). Taking for granted strike-slip or wrench displacements, an analogous horizontal shift along the northern boundary of Guaniguanico zone might also be expected, while it has not been insofar found. There are no larger strike-slip faults within the Paleogene sediments of Capdevila and Universidad Formations in the area between Cayajabos and Cabanas, north to the Sierra del Rosario (Pszczółkowski *in:* Pszczółkowski & *al.* 1975).

The available data do not allow to recognize precisely the nature of displacements along Pinar fault. Pszczółkowski (*in:* Pszczółkowski & al. 1975) assessed that oblique slip scratches have been observed at vertical tectonic mirrors south to Soroa. This suggests a throw-slip nature of the fault at least at some developmental stages. According to Pszczółkowski (*in:* Pszczółkowski & *al.* 1975), there are no structures associated with the major strike-slip dislocations; however, the present author is of the opinion that at least some fault sets reaching Pinar fault obliquely at the angles of 40—50° north to San Juan and Martinez may have been associated with displacement along Pinar fault.

Following the main assumptions of Meyerhoff (*in*: Khudoley & Meyerhoff 1971), a hypothesis has been put forth by Pszczółkowski & Piotrowska (*in*: Pszczółkowski & *al.* 1975) concerning the evolution of Pinar fault in the light of strike-slip or throw-strike-slip concept (Fig. 43). The discontinuity surface developed during or

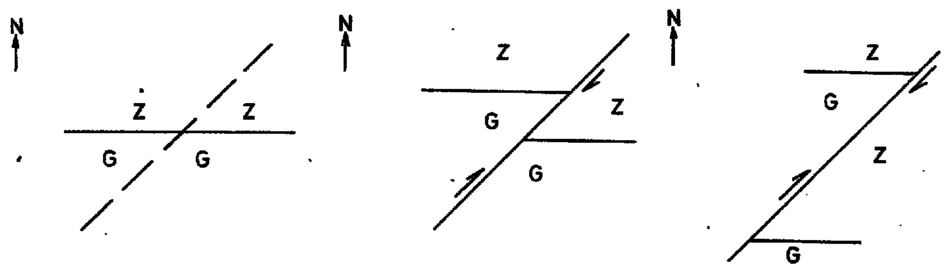


Fig. 43. Interpretation of displacements along the Pinar fault (according to Piotrowska & Pszczółkowski *in*: Pszczółkowski & *al.* 1975)
Z Zaza facies-tectonic zone, G Guaniguanico facies-tectonic zone

following the final phase of the overthrusts in Guaniguanico zone. At the Early Eocene decline, an area occurred north to that zone which should have embraced the present-day zones of La Esperanza, Bahía Honda, and San Diego de los Baños, that is the eastern counterparts of Zaza zone of Central Cuba. The initial shears of Pinar fault were probably oriented at an acute angle relative to the boundary between Guaniguanico and Zaza zones. Thus, a fault had been formed along which the northwestern limb has been shifted northeastwards. In other words, this was a dextral fault. Such shifts appear uncommon in the Caribbean; nevertheless, some dextral displacements have been already evidenced (Mattson 1966, 1973; MacGillavry 1970; Malfait & Dinkelman 1972). The total shift was at least 160—180 km, as the Cordillera de Guaniguanico when drawn back to such a distance along Pinar fault, puts fragments of Zaza zone in their presumed initial position. At late Early Eocene time, *i.e.* at the beginning of the overthrust movements, the southwestern Guaniguanico zone contacted along Pinar fault directly the zone of San Diego de los Baños. It was the time when the deposition of Loma Candela Formation began. This formation contains abundant rock material derived from Guaniguanico zone (Pszczółkowski & *al.* 1975). On the other hand, conglomerates of Loma Candela Formation exposed south and southwest to San Diego de los Baños lack material typical of the Sierra de los Organos, which is explained by Pszczółkowski & *al.* (1975) by either a coverage by the units of Sierra del Rosario, or a remoteness of the Sierra de los Organos from Loma Candela depocenter. The shallow Middle Eocene basin received exclusively material derived from the Sierra del Rosario and San Diego de los Baños zone. At Late Eocene to Oligocene time, the presumed shifts were accompanied by a vertical and/or oblique throw along Pinar fault. This throw can also be observed in the Miocene and the throw distance may have attained 150—200 m (Pszczółkowski *in:* Pszczółkowski & *al.* 1975).

TECTONIC STYLE OF THE SIERRA DE LOS ORGANOS

The Sierra de los Organos appear as a typical example of Alpine tectonics; they show, however, some peculiarities making them different from other orogenic systems. The complexity of tectonic processes was partly controlled by the variable lithology. Subsequent décollements have taken place in the transported rock masses. These décollements and differential movements of the various partial nappes imposed the tectonic style on the Sierra de los Organos. The structural inversion (diverticulation) as expressed by the superposition of the calcareous units of the mogote belt by the nappe-scale units of Alturas de Pizarras, results just from these décollements and differential movements.

Most tectonic units display a normal position of their beds. Taking for granted that the initial nappe was transported as a "board" and the main décollement during the transport has taken place at a single horizon dividing the nappe into two "boards", one may conclude that the lack of large units of reversed sequences (except of the metamorphosed units) must have resulted in the absence of any structures developed from refolding.

The calcareous units of the mogote belt comprise mainly Jagua, Guasasa, Ancón, and Pica Pica Formations and the melange rocks while the units of Alturas de Pizarras comprise San Cayetano Formation. This characteristic distribution is clearly explained by a décollement at the boundary between San Cayetano and Jagua Formations.

The structural units are limited at both the top and base by décollement surfaces (at a single horizon) and shear planes (cutting various horizons), resulting in variability in structural thickness of all the nappe-scale units.

There are also subordinate décollements and shears within the tectonic units as mentioned already by Knipper & Puig-Rifa (1967). The décollements are almost invariably associated with predisposed lithologic boundaries, that is planes separating formations of different mechanic properties (*e.g.* Ancón and Pica Pica Formations boundary, or Jagua and Guasasa Formations boundary).

The tectonic units vary in their typical deformations. In general, the structural trends appear concordant among the units (a slight difference occurs, however, between the units of the mogote belt and Alturas de Pizarras) but locally, there are differences in both the deformation type and distribution within larger units. As the matter of fact, this seems obvious when relatively early individualisation of the nappe-scale units during the tectonic transport is taken into account. Although dependent always upon the general strain field, all the units have been deformed in a unique way depending also upon the local conditions of tectonic transport. The lithologies played also an important role in determining the deformations. More intense plastic deformations are to be expected in units built of well--stratified sequences as a bedding releases somewhat strains by means of an intrastratal gliding. In massive complexes, strains are released by shears. Local differences in deformation style resulting from a minor variability in lithology occur within the units of Alturas de Pizarras.

Large folds appear uncommon in the nappe-scale units of Sierra de los Organos. This is due to the very nature of the tectonic transport with gradual décollements and loose, rather horizontal displacements of the rock masses. The transport conditions did not favour development of large fold structures such as *e.g.* those shown by Hatten (1957). The units of Sierra de los Organos have glided one over another which process was made feasible by the occurrence of shale patches in some formations. In fact, large folds are rare even in such incompetent rocks as some portions of San Cayetano Formation. Some units may have been overthrust under the conditions of either a weak compression or the strains released first of all along surfaces of mechanic discontinuity.

The scarcity of large fold structures in the Sierra de los Organos co-occurs with the abundance of fold mesostructures developed under the conditions of plastic deformation. This may indicate that the deformation forces were insufficient to fold the whole units and hence, the accumulated strains were released in stronger deformations clustered in some specific rock portions or along earlier surfaces of mechanic inhomogeneity or fault planes. Décollements and glides resulting in differential shift velocities among the rock masses played an important role in this process. In some cases, a part of shifted unit was subject to a stronger compression due to a differential displacement. In effect, deformations associated with the tectonic transport may be clustered not only near the main overthrust planes but also in some other zones. It occurs commonly that a rock complex appears considerably deformed with many small folds, shears, and boudinage structures, while it passes laterally into but slightly bent layers. Such a zonal pattern of tectonic deformations is typical of all the units of Sierra de los Organos although it appears to be the most distinct in the nappe-scale units of Alturas de Pizarras.

The above-described structural features of the Sierra de los Organos result from the very nature of the displacements that can be briefly determined as differential movements due to décollements. These differential movements have led to the formation of nappe-scale units (Piotrowska *in:* Pszczółkowski & *al.* 1975), the latter term being intended to stress both their derivation from a single initial nappe and subsequent individualisation.

Behavior of the rock masses during the tectonic transport may suggest that processes related to a prevalence of gravitational component played an important role at the first stage of the structural development of Sierra de los Organos. In fact, gravitational displacements have been reported from the Caribbean by Hess (1966, 1968), Mattson (1966, 1973), and others. Nevertheless, one can hardly accept this component as the main motive power of the tectonic processes in the Sierra de los Organos.

DEVELOPMENT OF THE NAPPE STRUCTURES OF THE SIERRA DE LOS ORGANOS

The present-day tectonic structure of the Sierra de los Organos is largely determined by the sedimentary environment and strain conditions in the Cuban geosyncline during the period preceding the nappe overthrusts. A quiet carbonate sedimentation prevailed at the Late Jurassic to Early Cretaceous time in all the structural units except of Valle de Pons one (however, volcanic activity has also been reflected in Jagua Formation; Piotrowski 1973). Thereafter, the sedimentary environment changed rapidly due to a change in the basin bathymetry at the Late Cretaceous to Paleogene time. This is, indeed, indicated by erosional gaps (possibly, sedimentary gaps, too) at the boundary of Guasasa and Ancón Formations. The vertical movements that took place at that time represented an echo of the Subhercynnian phase or introduced the approaching Laramide phase. They were then hampered during the Paleocene when monotonous sediments of Ancón Formation have been deposited. At the Early Eocene time, bathymetric changes were very rapid. Cherts have been deposited in some parts of the basin (the present-day Valle de Pons unit), replaced subsequently by clastic shallow-water sediments, *viz.* breccias and conglomerates alternated with volcanics-bearing greywacke sandstones. There are also some limestone and shale intercalations. Aside of the bathymetric changes, the source areas must have changed as well. In fact, large ultramaphic rock bodies embedded in a strongly tectonized sandstone-shaly complex appear at that time.

The latter complex has been called Vieja Wild Flysch by Hatten (1957). According to Hatten (1957), cordilleras were formed at the Eocene time supplying sedimentary materials to the basin. At the same time, alien material such as ultramaphic rocks (serpentinite, gabbro, basalt blocks, and smaller pieces of eclogites) has been supplied as olistolites due to gravitational glides. Vertical uplift of the cordilleras caused synsedimentary tectonic disturbances.

However, entirely sedimentary nature claimed by Hatten (1957) for the Vieja Wild Flysch may not be the case, as in places the rocks appear simply as a megakataclasite. The term "melange" seems relevant here (*cf.* Hsü 1968, Piotrowski 1973, Pszczółkowski & *al.* 1975). Nevertheless, the notion of melange zones as resulting from remobilization and protrusion of ultramaphic rocks at the bottom of steep and deep overthrusts (Knipper & Puig-Rifa 1967, MacGillavry 1970) requires some modification if it is to be applied to the Vieja Wild Flysch of Hatten (1957). In fact, the melange zones of the Sierra de los Organos occur at the top of structural units instead of their base parts. Moreover, overthrust planes that separate the units have been formed due to either almost horizontal décollements or slightly tilted shears, and one can hardly accept their deep penetration down to the upper part of the mantle.

Despite the above-mentioned characteristics, the present author is of the opinion that the considered rock complex can be justifiably regarded as melange. As the matter of fact, the considered rock complex is tectonized more or less uniformly, much more intensely than elsewhere in the Sierra de los Organos. This phenomenon cannot be explained by the zonal pattern of deformations since one deals here with a complex of considerable thickness and definite lithostratigraphic position; while the zones of increased deformation density are usually less thick and pass laterally into weakly deformed strata. The melange zones occur in a definite lithostratigraphic position, at the top of structural units. They appear over Pica Pica Formation (Pinos Formation *sensu* Herrera 1961) in a tectonic contact; no melange has been noted in units built up of San Cayetano Formation. Then, one may conclude that the melange rocks are limited in their distribution to the units containing the Upper Jurassic to Paleogene formations, that is to the calcareous units of the mogote belt constituting the top part of the initial nappe.

The melange rocks consist mostly of large blocks of ultramaphic rocks and small blocks of acid igneous and metamorphic rocks; the matrix is formed by kataclased clastic sediments, derived probably mainly from Pica Pica Formation. Then, most of the melange components appear alien to Guaniguanico facies--structural zone. The melange rocks are largely analogous to the rocks of Zaza zone broadly meant and its counterparts in Pinar del Río Province, *viz.* San Diego de los Baños, Bahía Honda, and La Esperanza zones. As the matter of fact. the melange zone attains its maximum thickness in the lowest structural units, *i.e.* in those ones that occupied the northernmost positions in the basin and were closest to Zaza eugeosynclinal zone.

Thus, one may agree with Hatten (1957) that the melange material was accumulated in Sierra de los Organos basin prior to the main tectonic transport of the nappes. However, both the source area and transport way of the melange material remain unclear. The melange rocks have been deposited in Guaniguanico basin previously to the main Eocene orogenic phase. Hence, the ultramaphic rocks should have originally occurred in Zaza zone, Central Cuba, rather than in the Cordillera de Guaniguanico. If the ultramaphic rocks were brought into Zaza zone in result of their remobilization and cold protrusions (Knipper & Puig-Rifa 1967, MacGillavry 1970), then their appearance in Guaniguanico facies-structural zone would be the third stage in their geological history. Such an idea agrees well with the age claimed for the main tectonic deformations in the Caribbean (Subhercynnian and Laramide phases according to Knipper & Cabrera 1974; Pirenean phase, too, according to the present author). Hatten (1957) claimed that the Vieja Wild Flysch had been deposited simultaneously with gravity glidings from the uplifting cordilleras. Some alien blocks have been regarded by Hatten (1957) as olistolites. However, the gravity glides appear to have been of a regional rather than local character. Presumably, most ultramaphic rocks have glided down the basin slope into the western part of Guaniguanico zone, *i.e.* the depocenter of Sierra de los Organos, together with other rocks taken along their way. The glided masses have become considerably tectonized and deposited onto incompetent beds of Pica Pica Formation, causing their partial refolding or tectonic reduction. Hence, a considerable tectonic transport took place during an early phase of the main orogenic paroxysm.

Disregarding the cause and derivation of the impulses that had initiated the Eocene overthrusts, one may note that they generated strains resulting in the nappe transport northwards. The units of Sierra de los Organos were probably transported under the form of a nappe "board" (*sensu* Tollmann 1973); the décollement plane is unknown but the lithologic sequence has remained undisturbed despite the tectonic transport. This nappe board represented the initial nappe (Piotrowska 1975). Its base part comprised San Cayetano Formation, while the top parts were formed by the calcareous units terminated with the melange zones. The whole subsequent deformation history of the Sierra de los Organos was controlled mostly by a décollement within the transported initial nappe (Fig. 44), developed at the boundary between clastic sediments of San Cayetano Formation and limestones of Jagua Formation. It does not necessarily mean that the décollement has occurred at a single horizon. Some units derived from the calcareous nappe comprise at the base fragments of the upper part of San Cayetano Formation, while the units of Alturas de Pizarras may contain fragments of the calcareous formations. The main décollement was probably disturbed by shear systems resulting from local strains. It initiated a quicker and independent motion of the whole upper part of the initial nappe comprising the calcareous formations, Pica Pica Formation, and the melange rocks. By this way, the initial nappe has been split into two partial nappes moving northwards at differential velocities. The higher nappe, namely calcareous one (Piotrowska 1972, 1974, 1975) was transported more quickly than the lower nappe of Alturas de Pizarras consisting of clastic rocks of San Cayetano Formation. The moving nappes have been subject to further deformations expressed by above-described mesostructures and scaling of the whole calcareous nappe. Presumably, the scaling resulted notasmuch from folding and stretching the shorter limbs as from displacements along shear planes developed due to strains within the transported rock masses. The shears have been subsequently transformed into reverse faults due to a force acting parallel to the transport direction of the whole nappe. The subordinate, newly formed scales continued to move at differential rates. Quemado and Infierno units may serve as an example here, as they lack some lithostratigraphic units in places. Thus, the tectonic transport of both the calcareous nappe and the subordinate nappe-scale units appears to have been highly variable which influenced the mode of scaling as well as the scale distribution. This variability was the highest at the last transport stage when the nappe-scale units have encroached finally the present-day Cordillera.

At that time, the substrate may have shown a diversified morphology controlling the tectonic transport velocity. Spatial relations between the particular units vary among the eastern, central, and western parts of the Sierra de los Organos, due to the presence of distinct elevations and depressions within the whole structure. In the area of the mogotes of Pico Simon and Pancho Luis, nappe-scale units are considerably packed together and the bed dips are much steeper than elsewhere in the Cordillera de Guaniguanico. Within Pons elevation, nappe-scale units lie almost horizontally, under the form of overlapping "board-like" slabs with numerous shears, displacements, and squeezes more or less parallel to

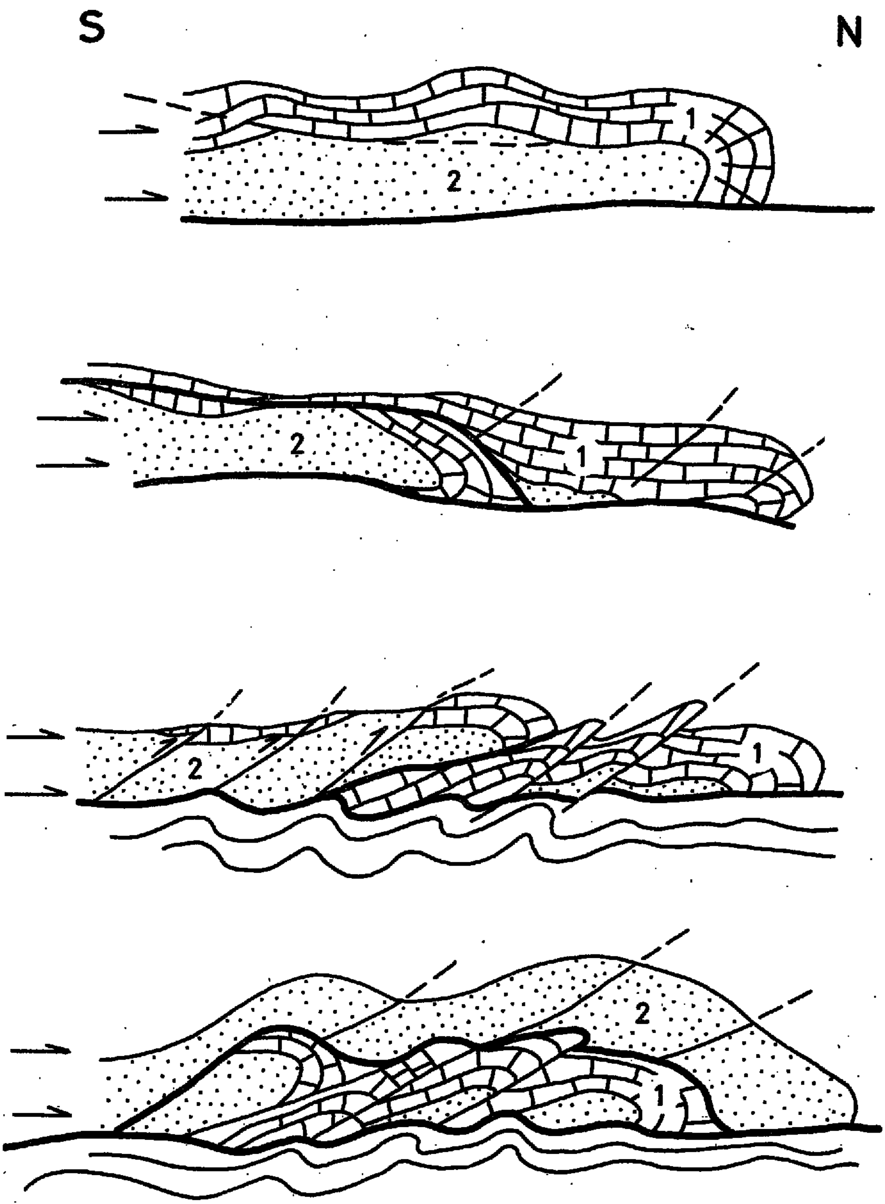


Fig. 44. Phases of the tectonic transport of the nappe-scale of the mogote-forming units and Alturas de Pizarras units
1 carbonate deposits of the Jagua up to Pica Pica Formations (including the melange zone at the top), 2 San Cayetano Formation (units of the Alturas de Pizarras)

the main overthrust surface. San Carlos depression does also display a considerable packing of rock masses. Thus, the calcareous nappe split into smaller nappe-scale units has reached the present-day area of Guaniguanico cordillera. The nappe-scale calcareous units of the mogote belt comprise strata of San Cayetano Formation but sporadically, as the latter formation moving more slowly has remained in the back. When resting already in their present-day area, the nappe-scale units of the calcareous nappe have been subsequently overthrust by the great nappe of Alturas de Pizarras split also into smaller scale elements. By this way, a peculiar structural inversion (diverticulation) has been attained with units making originally the lower part of the initial nappe superposing today units of originally higher structural position; Rigassi-Studer (1963) has called this feature of the Sierra de los Organos the "superposition inversion". When entering the Cordillera area covered already with the calcareous nappe-scale units, the nappe units of Alturas de Pizarras faced a diversified topography. However, this topography appears difficult to decipher because of subsequent vertical movements and horizontal displacements along fault planes. One may but claim that the particular calcareous units varied in their areal distribution. Some units have occurred within the presumed depressions (*e.g.* Sierra de Guane, Paso Real, Quemado, Sierra de Celadas, and Sierra de la Güira units). Their limited extent appears demonstrated by the lack of their remains beyond their occurrence areas, whereas units of greater extent (*e.g.* Infierno unit) have been split into smaller fragments aside of their main mass and despite their tectonic reduction. This is also suggested by the successive disappearance of the structural units when approaching the culmination of Pons elevation, covered only with Valle de Pons, Infierno (partly), and Viñales units. In places, such a successive disappearance of the calcareous units can also be noted in sections perpendicular to the structure axis. This structurally complex area has been thereafter invaded by the overthrust units of Alturas de Pizarras. The average difference in structural direction approximates 10—15°, depending upon a clockwise twist of the calcareous units. That twist cannot be discerned in the diagrams of mesostructure directions and hence, one cannot ascertain that this deviation was already marked during the overthrust of the units of Alturas de Pizarras even although such a claim appears quite plausible. One can hardly explain this slight disconformity by subsequent longitudinal shifts of "wrench" type, as the latter deformations should have embraced the whole set of structural units as found along the section.

The overthrust calcareous and Alturas de Pizarras structural units show almost entirely normal stratigraphic sequence. The local overturns appear related to deformations younger than the main orogenic phase. The superposition of the nappe-scale units of Alturas de Pizarras as resulting from the initial nappe being split into smaller structural elements does not appear obvious and in fact, some authors tried to explain the structure of the Sierra de los Organos without any share of nappe tectonics; however, such explanations can hardly be accepted.

The metamorphosed units occupy the highest position in the Sierra de los Organos. They overlie the nappe-scale units of Alturas de Pizarras del Sur. In the west, Pino Solo and Mestanza units make in places a whole split by a hinge overthrust of the amplitude increasing eastwards. These units show reverse sequences thus, making an exception in the whole Sierra de los Organos. The depocenter distant from the center of Sierra de los Organos basin and the displacement history of these metamorphosed units appear different from those of the non-metamorphosed units; they are different in the facies as well (Piotrowski *in:* Pszczółkowski & *al.* 1975). According to Piotrowski (*in:* Pszczółkowski & *al.* 1975), their depocenter was probably situated within an initial eugeosynclinal zone which is indicated by the occurrence of magmatic rocks (diabases, lamprophyres, gabbros), and tuffs, in sections of Arroyo Cangre Formation as well as by the intercalations of strongly metamorphosed eruptive basic rocks and tuffites in Jagua Formation. The non-metamorphosed units developed probably in a more geanticlinal part of the Cuban geosyncline. The resemblance of metamorphosed units to metamorphic complexes of the Isla de Pinos and Trinidad zone, Central Cuba, may suggest a regional nature of the metamorphism and some relationships with the southernmost parts of the Cuban geosyncline. The metamorphic process might have been related to an early stage of the main orogenic phase or to an early Late Cretaceous(?) phase. One may also suppose that it was synchronous with the first large displacements within the investigated orogene. At that time, a large portion of the Cuban geosyncline from which derive the present-day metamorphosed units of Sierra de los Organos, went down into deeper parts of the lithosphere to be subject to metamorphism under high stress conditions (recrystallization lineations); Piotrowski (*in*: Pszczółkowski & *al.* 1975) claimed that the metamorphic conditions had corresponded to the greenschist mineral facies. Later on, the metamorphosed units have been transported northwards and finally, overthrust onto the nappe-scale units of Alturas de Pizarras. Their original extent appears difficult to decipher. One may, however, claim that they reached the present-day mogote belt or its vicinity. In fact, this might be indicated by the occurrence of small metamorphosed patches corresponding lithologically to the southern metamorphosed units, while situated north to the mogote belt; these patches superpose the units of Alturas de Pizarras del Norte by Minas de Matahambre. However, the considered patches may also represent somewhat more dynamometamorphosed portions of San Cayetano Formation. In the northeast, the metamorphosed units adhere discrepantly to Pinar fault. They stretch far southwestwards, as they have been found directly under the Neogene in the boreholes at Guanahacabibes peninsula.

After the tectonic transport or even at its final phase, strains were generated in the newly formed structure expressed by southerly oriented deformations and displacements (Danilewski 1972; Piotrowska 1972, 1975). The origin of these forces acting opposite to the main transport direction can be variously interpreted. Southward displacements may be plausibly explained by a derivative of the resistance of Florida-Bahama plate and Zaza zone situated at its southern margin, to the overthrusting nappes. Such a resistance appears, indeed, evidenced by a barrier formed previously to the deformation of Zaza zone itself. There are also some local overthrusts of La Esperanza facies-structural zone (Danilewski *in*: Pszczółkowski & *al.* 1975) and Cajalbana massif of Bahía Honda zone (Skupiński & Pszczółkowski *in*: Pszczółkowski & *al.* 1975) as counterparts of Zaza zone, onto the units of the Sierra de los Organos and Sierra del Rosario. Thus, Pirenean phase has terminated in the investigated area. It involved nappe displacements from the moment of their very initiation within the old depocenter till the last episodes in the area of present-day Cordillera de Guaniguanico.

Nevertheless, the tectonic activity did not stop. In fact, subsequent displacements have taken place along fault planes; at least some faults could continue earlier disjunctions developed during the transport or even prior to its initiation.

SIERRA DE LOS ORGANOS AND THE CARIBBEAN REGION

Many geological aspects of both the whole Caribbean and Cordillera de Guaniguanico remain unrecognized. For the moment, nobody knows the present-day substrate of the tectonic units of Sierra de los Organos or the underground of those sequences before they began to shift northwards.

The allochthonous units of Sierra de los Organos may be underlaid by an eugeosynclinal sequence (Zaza zone). There is also some evidence (*e.g.* from the tectonic window of Cabeza de Horacio) that La Esperanza facies-structural zone may occur under the units of Sierra de los Organos. According to Pardo (1975), the rocks exposed in Cabeza de Horacio window represent Bahía Honda zone. It seems, however, that Bahía Honda zone does not continue over any large distance under the tectonic units of Cordillera de Guaniguanico even although the latter zone superposed originally the former one; and the assumption of La Esperanza zone underlying Guaniguanico units appears much more plausible. Then, La Esperanza zone may be regarded as the main substrate unit in the northern Pinar del Río Province. Bahía Honda zone has been partly overthrust by the tectonic units of Guaniguanico zone and thereafter (Pszczółkowski & *al.* 1975) pushed southwards, its southernmost part overriding Guaniguanico units. In fact, one can hardly accept the idea of Hatten (1957) supported also by MacGillavry (1970) claiming that Cajalbana massif making part of Bahía Honda zone has been thrust northwards onto Guaniguanico units.

The tectonic pattern of Pinar del Río Province appears additionally obscured by Pinar fault although displacements along this fault as claimed in the present paper may explain the present-day position of Guaniguanico units. As the matter of fact, dextral shifts in the Caribbean have been recognized by Mattson (1966, 1973) who tried also to relate them to the rotation of Greater Antilles. However, when assuming such displacements along Pinar fault, the problem of original interrelations between Guaniguanico and Zaza zones arises. The metamorphosed units of Guaniguanico zone appear to resemble rocks of the Sierra de Escambray and Isla de Pinos (Millán 1972; Somin & Millán 1972, 1974; Millán & Somin 1976). More and more commonly, all these strata are assigned to the Mesozoic (Millán 1972; Somin & Millán 1972, 1974; Piotrowski *in*: Pszczółkowski & *al.* 1975; Piotrowski 1976) rather than to the Paleozoic as it was previously assumed (Furrazola-Bermúdez & *al.* 1964, Pushcharovski & *al.* 1967, Uchupi 1973). The Jurassic eruptive activity recorded by Piotrowski (1973, 1976) in Arroyo Cangre Formation in the metamorphosed units of Sierra de los Organos may point to some relationships to an eugeosynclinal zone. On the other hand, the sedimentary basin of the units of Sierra de los Organos and possibly also Sierra del Rosario occurred probably south to the miogeosyncline. It might constitute a shallower part of the geosyncline at least at some stages of its development. The depocenter of Guaniguanico zone occurred probably south to Zaza eugeosynclinal zone (Piotrowska *in*: Pszczółkowski & *al.* 1975). Thus, the roots of Sierra de los Organos nappes should be located in an area south to the Cuban coasts. However, Zaza zone itself is not autochthonous (Knipper & Cabrera 1974) and the original location of the eugeosyncline has been contrastingly interpreted (Furrazola-Bermúdez & *al.* 1964; Meyerhoff 1964, 1967; Pardo 1966, 1975; Meyerhoff & Hatten 1968; Judoley & Furrazola-Bermúdez 1971; Khudoley & Meyerhoff 1971; Knipper & Cabrera 1974). Both the deep drillings in Florida (Furrazola-Bermúdez & *al.* 1964) and gravimetric studies (Soloviev & *al.* 1964) have demonstrated that at the southern margin of Florida-Bahama plate, the northernmost sediments of the Cuban geosynclinal system overlie the Paleozoic metamorphic rocks. Those northernmost Cuban geosynclinal sediments represent a miogeosyncline and comprise mostly shallow-water limestones and evaporites; the miogeosyncline originated probably at Late Jurassic time (Meyerhoff 1964; Pardo 1966, 1975; Meyerhoff & Khudoley 1971; Knipper & Cabrera 1974). The considered sediments continue southwards, up to Remedios and Camajuani zones, Northcentral Cuba (Hatten & *al.* 1958; Ducloz & Vuagnat 1962; Meyerhoff 1964; Pardo 1966, 1975; Judoley & Furrazola-Bermúdez 1971; Meyerhoff & Khudoley 1971; Knipper & Cabrera 1974). South to the miogeosyncline, a deep trough was formed at the Jurassic and Cretaceous boundary and persisted up to Cenomanian time (Las Villas sub-zone of Camajuani zone), characterized by the deposition of thin-bedded limestones and siliceous rocks (Knipper & Cabrera 1974). This area was called either "Cifuentes, Placetas, Las Villas, and Jatibonico belt" (Brönnimann *fide* Furrazola-Bermúdez & *al.* 1964, Brönnimann & Pardo 1956), "Placetas and Camajuani zone" (Ducloz & Vuagnat 1962, Meyerhoff & Hatten 1968), "Las Villas facies-structural zone" (Solsona & Judoley 1964, Khudoley 1967, *in*: Khudoley & Meyerhoff 1971), or "leptogeosyncline" (Knipper & Cabrera 1974). Only the northern part comprising deep-water calcareous sediments has been regarded by Meyerhoff (*in*: Khudoley & Meyerhoff 1971) as a leptogeosyncline; while the southern part transitory in facies to the eugeosyncline has been called median welt. According to Knipper & Cabrera (1974), a barrier (Jatibonico sub-zone) was formed along the southern border of the miogeosyncline at Middle Cretaceous time. At the Cenomanian decline, the sedimentation rapidly ceased in the leptogeosyncline and the erosion surface is covered with Maastrichtian sequence.

The eugeosyncline occurred south to the leptogeosyncline. The problem of its substrate remains unsolved. Furrazola-Bermúdez & *al.* (1964) claim that the eugeosynclinal sequence is underlaid by metamorphic rocks of Trinidad (Sierra de Escambray) and Isla de Pinos type, the latter formations being ascribed to the Paleozoic (*cf.* also Pushcharovski & *al.* 1967). Nevertheless, Ducloz & Vuagnat (1962) and Pardo (1966) are of the opinion that the eugeosynclinal volcanic sequence overlies Paleozoic metamorphic rocks different from those of Trinidad Formation and Isla de Pinos. Meyerhoff (1964, *in:* Khudoley & Meyerhoff 1971) does also assume the Paleozoic substrate of continental type under the Cuban eugeosyncline. Some other authors claim that the Cuban geosyncline developed on an oceanic plate (Adamovich & Chejovich 1964; Dietz 1964; Markov & *al.* 1964; Mattson 1966, 1973; Molnar & Sykes 1969; Dietz & *al.* 1970a, b; MacGillavry 1970; Edgar & *al.* 1971; Malfait & Dinkelman 1972; Donnelly 1975; Fox & Heezen 1975; Pinet 1975). Intermediate concepts accepting both continental and oceanic crust in the Caribbean have been put forth by Uchupi (1973) and Iturralde-Vinent (1975).

When assuming that all geosynclines initiate on an oceanic crust (*cf.* Dietz & Holden 1970, Dietz & *al.* 1970), one may claim that such a crust must have existed under the southern part of Cuban geosyncline. In fact, the seismic-refraction data (Ewing & *al.* 1960) suggest that there are fragments of basaltic, oceanic substrate exposed in Yucatán Basin (Dietz & *al.* 1970a, b; Malfait & Dinkelman 1972; Uchupi 1973; Arden 1975; Donnelly 1975; Fox & Heezen 1975). Possible alien fragments of the original substrate of Guaniguanico sequences are unknown as yet. According to Donnelly (1975), Paleozoic complexes of the Caribbean have disappeared in subduction zone which may explain the problem of San Cayetano Formation substrate.

Volcanic activity appeared in the western part of Cuban geosyncline at Early(?) to Middle Jurassic time (Piotrowski *in:* Pszczółkowski & *al.* 1975, Piotrowski 1976). Volcanic phenomena may also have occurred during the Late Jurassic (Wassall 1956, Meyerhoff & Hatten 1968). Thereafter, the tectonic activity increased in intensity during the Middle to Late Cretaceous (Fig. 45). At that time, the Subhercynnian (pre--Maastrichtian) orogenic phase began as reflected by serpentinite overthrusts resulting in the intense folding in Oriente Province (Kozary 1956, 1968; Knipper & Cabrera 1974). The Subhercynnian folding movements decreased in intensity westwards (Knipper & Cabrera 1974). This interpretation agrees with the observations by Mattson (1960, 1973) who found that in Puerto Rico the first gravitational glides had taken place at Albian time.

At Late Cretaceous time, considerable vertical movements occurred probably in the western parts of Cuban geosyncline; possibly, there were also some horizontal displacements in the eugeosynclinal Zaza zone. In fact, volcanic activity and reactivation of serpentinites can undoubtedly be related to that period (Knipper & Puig-Rifa 1967, Bonis 1968, MacGillavry 1970). The Late Cretaceous tectonic activity is also reflected in Guaniguanico zone; particular portions of the basin became vertically differentiated, as marked by sedimentary gaps, erosional gaps, and breccia horizons in some tectonic units of the Sierra de los Organos.

Thus, one may claim that at Late Cretaceous time, the activization of serpentinites began in the northern part of eugeosyncline (Zaza zone = La Esperanza and Bahía Honda zones), and some parts of the eugeosyncline (*e.g.* Bahía Honda zone) were folded. In the southern area (Guaniguanico zone), the tectonic activity resulted in a depth differentiation of the basin. Earlier, a charriage of the serpentinite masses northwards had taken place in the eastern part of geosyncline (Oriente Province), folding the pre-Maastrichtian sediments. In La Habana Province, the first major deformations took place during the Maastrichtian (Pardo 1966). Intense nappe movements persisting since Albian through Maastrichtian time have been reported from Puerto Rico (Glover & Mattson 1960, Mattson 1973). Hence, one may assess that the Late Cretaceous activity (Middle Cretaceous in places) embraced the whole

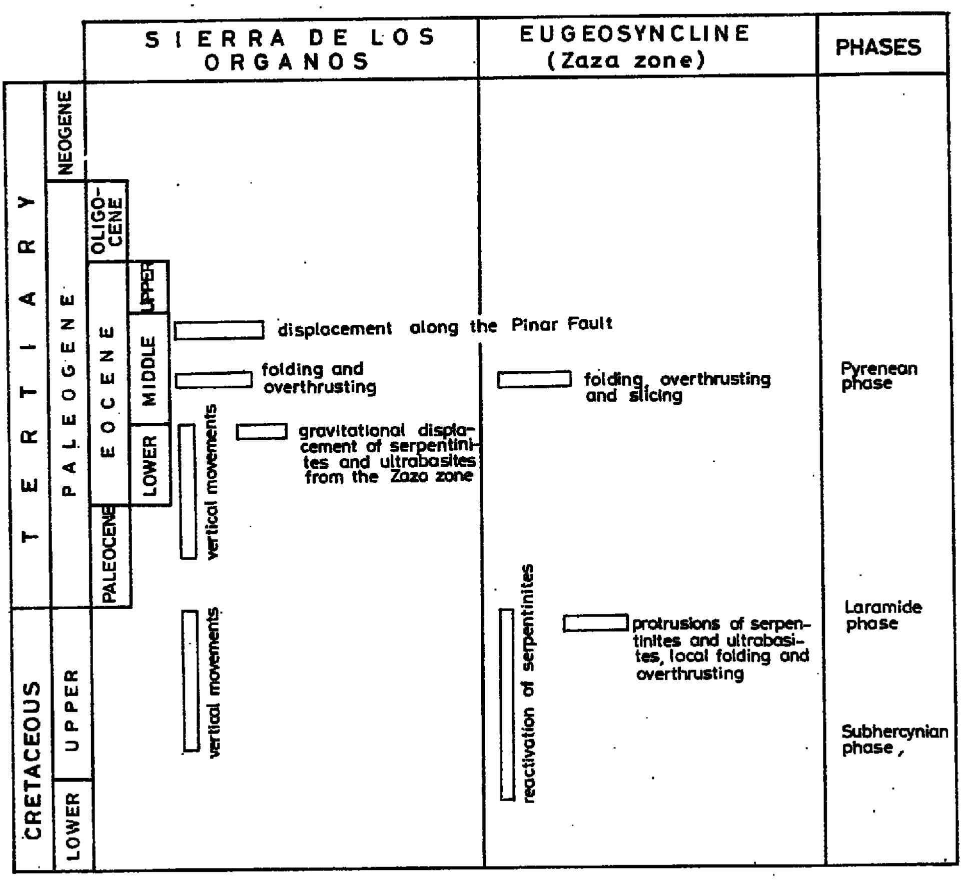


Fig. 45. Sequence of tectonic movements in the Alpine geocycle of the Pinar del Rio Province

Cuban eugeosyncline although with varying intensity. In the north, some folding movements occurred related to the penetration of serpentinites into surficial strata (Knipper & Puig-Rifa 1967). That part of the geosyncline was gradually uplifted. The deposition continued in some areas of Guaniguanico zone, whereas in others it was interrupted from time to time. The uniformity in facies among all the units was attained at the Late Paleogene (Ancón Formation). Later on, cherts (eroded in some units) and wild-flysch sediments have been deposited, the latter composed of material derived from partly folded Zaza zone. During that time (late Early Eocene to early Middle Eocene), the serpentinite-ultrabasic rock masses have glided down the uplifted Zaza zone to form the melange series of Guaniguanico zone. During the Tertiary, the eugeosyncline zone shifted gradually northwards in Central Cuba (Knipper & Cabrera 1974). It was finally thrust over the miogeosyncline moving northwards but more slowly which resulted in a superposition of the eugeosynclinal tectonic units. There are no miogeosynclinal units in Pinar del Río Province. Hence, La Esperanza zone appears as the lowest one even although it makes part of Zaza zone. Another geosynclinal zone, namely Bahía Honda one, has been thrust from the south over La Esperanza zone at the Cretaceous decline or the Paleocene beginnings. At early Middle Eocene time (Pyrenean phase), the main tectonic transport of Guaniguanico nappe units began. Guaniguanico units have been thrust over the partly folded and dislocated Zaza zone. At the end of the Eocene orogenic phase, a minor reverse transport, *i.e.* southwards, occurred at differential rate and distance. It resulted in a part of Bahía Honda and La Esperanza zones being thrust over Guaniguanico units. The Eocene dextral shift of some 160—200 km along Pinar fault has ultimately shaped the main structural features of Pinar del Río Province.

Geological history of the Caribbean has to be always considered within a framework of continental plates, namely the North- and South American ones, between which the Antilles are situated.

At Triassic time, the Caribbean region could not be larger than one fourth of its present-day size (Carey 1958, Bullard & *al.* 1965, Freeland & Dietz 1971, Le Pichon & Fox 1971, Fox & Heezen 1975).

During the Late Triassic to Early Jurassic, *i.e.* at the time when North America began to depart from Africa and South America, the oceanic part of the Caribbean shows evolution similar to that of the North Atlantic (Fox & Heezen 1975). The separation of the Caribbean plate (Yucatán and a part of Central America) from the coasts of North America resulted from a rift and clockwise rotation during the early Mesozoic (Carey 1958, Freeland & Dietz 1971, Helwing 1975). The opening of the Gulf of Mexico resulted from the same processes. Walper & Rowett (1972) claim that this opening took place during the Triassic through separation of the northwestern South America from Ouachita system.

The beginnings of the Caribbean region are unknown (Donnelly 1975) but may have been coeval with the beginnings of the North Atlantic (early Mesozoic). In fact, Donnelly (1975) claims that the Caribbean basin was formed between the North and South Americas in the position of the present-day Venezuela and Columbia basins; then, the Greater Antilles would make a barrier separating the North America from Africa and South America. In this concept, the eastern Antilles separated from the African coasts would have joined the northern coast of South America, while the western termination of the Greater Antilles should have developed as a rift and subsident continental margin modified thereafter by subduction.

During the Early Cretaceous opening of the South Atlantic (Le Pichon & Hayes 1971), a clockwise movement of the eastern part of the Greater Antilles took probably place (Donnelly 1964, 1975). This seems to be indicated by paleomagnetic observations on the Middle Cretaceous lavas from Puerto Rico (Fink & Harrison 1972). The Early Cretaceous opening of the Atlantic Ocean has also been postulated by Fox & Heezen (1975). Since that time, the oceanic crust in the Caribbean has been wedged inbetween the North and South Americas shifting at variable rates (Fox & Heezen 1975).

Malfait & Dinkelman (1972) interpret the Caribbean block as a fragment of primary Pacific plate situated between the North and South Americas. In this concept, the Caribbean made part of a drifting continent detached from the Pacific plate at Late Mesozoic time; and till Eocene time, its geological history was the same as that of the eastern part of the Pacific plate preserved in the Central America. Also MacGillavry (1970) regards the Caribbean as an old oceanic plate situated between the North and South American continents and the sialic block of Central America. He claims that at Cretaceous time, the Caribbean plate detached from the metamorphic block of Central America along a giant fracture and shifted southwards.

Since the Late Cretaceous through Eocene, Cuba and Hispaniola were thrust under the North American plate (Malfait & Dinkelman 1972), this northeasterly movement of Caribbean plate being caused by the approaching North and South Americas (Dietz & Holden 1970a, b). The Cretaceous compression resulted at Late Cretaceous time in development of a subduction furrow (with the Eocene maximum) along the rim of the Caribbean (Edgar & *al.* 1971, Freeland & Dietz 1971, Mattson 1973, Knipper & Cabrera 1974, Fox & Heezen 1975). The initial compression phase has been reflected in tectonic displacements and glides of the oceanic crust along the Antilles axis as well as in mobilization of the serpentinites and metamorphism. On the other hand, the partial sinking of continental crust into oceanic one initiated the Middle Cretaceous calcium-alkaline volcanism in the Greater Antilles (Bowin 1966, 1975;

Donnelly 1966; Mattson 1966; Nagle 1972) and granodioritic plutonism (Hamilton 1969, MacGillavry 1970, Larson & Pitman 1972).

Since Middle Cretaceous through Eocene time, fold deformations and nappe overthrusts have developed in various parts of the Caribbean. At the beginning of the Tertiary, the movement of Caribbean plate has become more easterly and this change in direction resulted in splitting the Caribbean block along Montagua fault and Cayman trough (Malfait & Dinkelman 1972). However, Meyerhoff (1966) claims that Cayman trough has already developed during the Middle Cretaceous. Malfait & Dinkelman (1972) are of the opinion that Cayman trough has cut across Cuban trough at Late Eocene to Early Oligocene time thus, terminating the thrusting of Cuba and Hispaniola under Florida-Bahama plate; whereas the overthrust movements in Puerto Rico trench have continued resulting in the later volcanic activity.

To summarize the above discussion, one may claim that most structural and developmental characteristics of the Caribbean can be explained by seafloor spreading (Dietz 1961, Vine & Matthews 1963) and plate tectonics (Morgan 1968). This has been, indeed, demonstrated by Donnelly (1964, 1975), Mattson (1966, 1973), Dengo (1969), Molnar & Sykes (1969), MacGillavry (1970), Edgar & *al.* (1971), Freeland & Dietz (1971), Le Pichon & Fox (1971), Malfait & Dinkelman (1972), Uchupi (1973, 1975), Knipper & Cabrera (1974), and Khain (1975).

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STRUKTURY PŁASZCZOWINOWE SIERRA DE LOS ORGANOS W ZACHODNIEJ KUBIE

(Streszczenie)

Przedmiotem pracy jest charakterystyka stylu tektonicznego oraz rozmieszczenie przestrzenne i rekonstrukcja transportu tektonicznego jednostek strukturalnych Sierra de los Organos, położonych w zachodniej części kordyliery Guaniguanico w prowincji Pinar del Río w zachodniej Kubie. Rozważane jednostki tektoniczne zostały ukształtowane w trzeciorzędzie, a główna faza orogeniczna miała miejsce w środkowym eocenie. Na obszarze tym wyróżnione zostały (*patrz* fig. 1—2) cztery strefy tektoniczno-facjalne (Pszczółkowski & *al.* 1975): Guaniguanico, San Diego de los Baños, Bahía Honda, La Esperanza, spośród których trzy ostatnie są odpowiednikami eugeosynklinalnej strefy Zaza (*por.* Hatten & *al.* 1958) z centralnej części Kuby. Strefa tektoniczno-facjalna Guaniguanico (w której wyróżnia się region Sierra de los Organos i region Sierra del Rosario), charakteryzująca się znacznymi nasunięciami (fig. 3), różni się od pozostałych stref nie tylko stylem tektonicznym, ale także wykształceniem facjalnym. W budowie jednostek łuskowo-płaszczowinowych tej strefy biorą udział formacje od jury dolnej(?)-środkowej do dolnego eocenu.

W regionie Sierra de los Organos autorka wyróżniła cztery grupy jednostek łuskowo-płaszczowinowych (*patrz* fig. 3—5 oraz pl. 1—3): jednostki wapienne pasma

mogotowego, jednostki Alturas de Pizarras del Norte, jednostki Alturas de Pizarras del Sur i jednostki zmetamorfizowane. Szczegółowe obserwacje jednostek tektonicznych centralnej części Sierra de los Organos (fig. 7—17) potwierdziły złożony charakter przemieszczeń w czasie transportu z południa ku północy. Badania mezostrukturalne objęły: drobne fałdy, fleksury, budinaż, kliważ, lineacje teksturalne i krawędziowe, oraz drobne nasunięcia i uskoki (fig. 18—40 oraz pl. 4—5). Przeprowadzona została analiza uskoków (fig. 41—42), a także podany został schemat przemieszczeń wzdłuż uskoku Pinar (fig. 43). Najistotniejszymi cechami stylu tektonicznego Sierra de los Organos są: dyferencjalne przemieszczenia mas skalnych w czasie transportu, prowadzące do utworzenia płaszczowin cząstkowych, inwersja strukturalna (diwertykulacja) obecnych jednostek względem pierwotnej pozycji transportowanych mas skalnych, strefowość deformacji. Jednostki płaszczowinowe Sierra de los Organos wykazują cechy struktur grawitacyjnych. W obrębie rozważanych struktur stwierdzono trzy generacje lineacji. Lineacja najstarsza, występująca w jednostkach zmetamorfizowanych, związana jest zapewne z procesami metamorfizmu, do których doszło przed rozpoczęciem szariażu płaszczowin. Lineacja główna występująca we wszystkich jednostkach tektonicznych utworzyła się w czasie transportu ku północy podczas głównej fazy orogenicznej, zaś lineacja najmłodsza powstała po tej ostatniej fazie. Asymetria drobnych fałdów wykazuje zdecydowaną przewagę przemieszczeń ku północy, chociaż w obrębie Alturas de Pizarras del Norte obserwuje się także drobne fałdy wskazujące na przemieszczenia ku południowi, które najprawdopodobniej zachodziły pod koniec głównej fazy orogenicznej. Na podstawie rozmieszczenia jednostek płaszczowinowych i analizy mezostruktur, autorka przeprowadziła rekonstrukcję procesów tektonicznych w obrębie Sierra de los Organos. W końcowym etapie sedymentacji wild-fliszu, do zbiornika sedymentacyjnego zostały dostarczone serpentynity i ultramafity jako masa skalna zsunięta grawitacyjnie z innej strefy tektoniczno-facjalnej.

W dolnym eocenie środkowym, gdy rozpoczął się transport płaszczowin ku północy, płaszczowina inicjalna przesuwana była w postaci „deski płaszczowinowej", w obrębie której istniało normalne następstwo warstw (por. Piotrowska 1972, 1975). W przemieszczanej płaszczowinie inicjalnej doszło do zasadniczego odkłucia (fig. 44) na granicy klastycznej formacji San Cayetano i wapiennej formacji Jagua. Odkłucie to zapoczątkowało samodzielny ruch całej wyższej części płaszczowiny inicjalnej, która to część — zbudowana przede wszystkim z formacji wapiennych — przesuwana była szybciej niż część leżąca niżej, a zbudowana z formacji San Cayetano. W wyniku tych zróżnicowanych szybkości przemieszczeń (ruchy dyferencjalne), płaszczowina wyższa dotarła wcześniej na obszar Sierra de los Organos, niż płaszczowina dolna. W czasie transportu obie płaszczowiny uległy dalszemu zróżnicowaniu, co doprowadziło do powstania jednostek łuskowo-płaszczowinowych. W ostatniej fazie transportu (*patrz* fig. 45) lub po jego zakończeniu rozpoczęły się przemieszczenia wzdłuż uskoku Pinar. Wygięcie łuku kordyliery Guaniguanico spowodowane zostało procesami młodszymi od głównej fazy orogenicznej.

Basen sedymentacyjny Sierra de los Organos położony był w południowej części ortogeosynkliny kubańskiej, na południe od eugeosynklinalnej strefy Zaza. W czasie głównej fazy orogenicznej jednostki tektoniczne Sierra de los Organos nasunęły się na jednostki tektoniczne strefy Zaza, która została sfałdowana bądź w kredzie górnej, bądź na przełomie kredy i paleogenu (fig. 45). Rotacje i przemieszczenia wzdłuż uskoków na badanym obszarze, podobnie jak i w innych częściach Kuby oraz w całym regionie karaibskim, są pochodną nierównej szybkości przemieszczania ku zachodowi dwóch kier kontynentalnych, północno- oraz południowoamerykańskiej.

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LAS ESTRUCTURAS DE LOS SOBRECORIMIENTOS EN SIERRA DE LOS ORGANOS (CUBA OCCIDENTAL)

(Resumén)

Las unidades tectonicas de la provincia Pinar del Río (fig. 1) se formaron en el Terciario y la principal fase orogénica ocurrió en el Eocene Medio. En la provincia Pinar del Rio se distinguen cuatro zonas estructuro-faciales (fig. 1—2; Pszczółkowski & *al.* 1975), estas son: Guaniguanico, San Diego de los Baños, Bahia Honda, La Esperanza. Las tres últimas zonas corresponden a la zona eugeosynclinal de la Zaza (Hatten & *al.* 1958) en la parte central de Cuba. La zona estructuro-facial de Guaniguanico se caracteriza por la presencia de cabalgamientos considerables (fig. 3) y se diferencia de otras zonas por su desarrollo facial y estilo tectónico. En la estructura de las unidades tectónicas del tipo de escamas-napes toman parte las formaciones del Jurasico Inferior(?) hasta el Eoceno Inferior.

La region de la Sierra de los Organos está ubicada en la parte occidental de la Cordillera de Guaniguanico, mientras que la Sierra del Rosario forma la porción oriental de la misma cordillera. En la Sierra de los Organos han sido distinguidos cuatro grupos de unidades de escamas-napes (fig. 3—5, 7—17; lám. 1—3) las cuales son: unidades calcáreas de la faja de mogotes, unidades de las Alturas de Pizarras del Sur, unidades de las Alturas de Pizarras del Norte, las unidades metamorfizadas. Las observaciones mesoestructurales contienen: los pliegues menores, curvaturas, boudinage, clivaje, lineaciones texturales y bordales, asi como las pequeñas fallas y corrimientos (fig. 18—40; lám. 4—5). Se han ejectuado análisis de las fallas (fig. 41—42), asi como ha presentado la esquema del desplazamiento a lo largo de la fallo Pinar (fig. 43).

Los rasgos mas importantes del estilo tectónico de la Sierra de los Organos son como sigue: los desplazamientos diferenciales de las rocas durante el transporte tectónico, los cuales resultaron en la formación de los napes fraccionadas, inversion estructural de las unidades tectónicas presentes en comparacion con la superposición original de las secuencias rocosas transportadas, la zonación de las deformaciones.

Los napes, o sea las escemas de nape tienen los rasgos de las estructuras gravitacionales.

En base de los estudios efectuados de las mesoestructuras han sido determinados tres tipos de lineación, que representan distintas etapas de las deformaciones. La lineación más vieja existente en las unidades metamorizadas, esta vinculada probablemente con los procesos del metamorfizmo antecedente con respecto al desplazamiento de los napes. La lineación principal ocurre en todos las unidades tectónicas. Esta lineación se ha formado en la fase principal orogénica como resultado del sobrecorrimiento dirigido al norte. La lineación más joven se formo más tarde, después de la principal fase orogénica. El análisis de asimetria de los pliegues menores demostró el predominio decisivo de los desplazamientos tectónicos hacia al norte, aunque en el área de las Alturas de Pizarras del Norte se observa también los pliegues menores que indican los desplazamientos hacia al sur. Estos últimos ocurrieron más probablemente al final de la principal fase orogénica.

Las primeras manifestaciones de la actividad tectónica en forma de movimientos verticales ocurrieron en el Cretasico Superior. Estos movimientos precedieron la fase orogénica la cual se aproximaba. En la última etapa de la deposición en la cuenca sedimentaria se deslizaron por el medio de gravitación las masas rocosas compuestas ante todo por las serpentinitas y rocas ultramaficas. En la parte inferior

del Eoceno Medio empezó el transporte de los napes hacia al norte. La nape inicial se desplaza hacia al norte en la forma de „nape de tabla", en la cual existía la normal superposicion de los estratos. En la nape inicial desplazado al norte occurió el principal despegue entre los depósitos clásticos de la Formación San Cayetano y las calizas de la Formación Jagua (fig. 44). Despegue empezó el movimiento autónomo de toda la parte superior del nape inicial, la cual fue compuesta ante todo de las formaciones calcáreas, desplazada más rápidamente que la parte inferior del nape constituída por las rocas de la Formación San Cayetano. Como resultado de estos movimientos con diferente rapidez, el nape superior (de calizas) ha llegado más temprano alárea de la Sierra de los Organos que el nape inferior (de Alturas de Pizarras). Durante el transporte las ambas napes se dividieron en las unidades secundarias de tipo de escamas-napes. En la última fase del transporte tectónico, o inmediatamente después, empezó el desplazamiento a lo largo de la falla Pinar (fig. 45).

La cuenca sedimentaria de la Sierra de los Organos se encontraba en la parte meridional del ortogeosinclinal cubano, al sur de la zona de la Zaza. Durante la principal faze orogénica las unidades tectónicas de la Sierra de los Organos sobrecorrían las de la zona de la Zaza, la cual, como lo indican algunos datos, fue plegada ya en el Cretasico Superior o a principios del Paleógeno, por lo menos en algunos partes (fig. 45).

Las rotaciones y los desplazamientos a lo largo de las fallas en Cuba y en la región del Caribe se derivan de la desigual rapidez del desplazamiento hacia al oeste de las placas continentales de America del Norte y del Sur